

Abstract

ANDRAE, NATHALIE. Durable and Environmentally Friendly Flame Retardants for Synthetics. (Under the direction of Dr. C. Brent Smith and Dr. Peter J. Hauser.)

Flame retardants are critical to textiles by impeding and suppressing flame resulting in protection to both life and property. However, over the years the environmental and health concerns surrounding the use of halogenated flame retardants has increased. The resulting legislation and debates have made it important to look for alternatives. The main objective of the research was to find suitable substitutions for brominated flame retardants on synthetic textiles. The effectiveness of the treatment to reduce char length and the effect of the treatments on the physical properties (i.e. stiffness, tear strength) of the substrates were analyzed.

The research focuses on the application of non-halogenated flame retardants applied to four synthetic substrates: a polyester woven, a polyester/nylon nonwoven, a nylon knit, and an acrylic woven. Ten commercially available, alternative flame retardants, nine of which were phosphorus based, were padded onto the substrates. A vertical burn test was applied, and the resulting char lengths were used to identify the most promising flame retardants. The selected flame retardants were reapplied and the samples underwent 10 and 25 wash cycles. The vertical burn test was used to determine the effectiveness and durability of the flame retardants after the various wash intervals. The ICP analysis method was used to establish the amount of phosphorus available in the flame retardant chemicals and on the treated substrates.

The research found that several phosphorus based treatments were effective for the polyester substrate and that one treatment was effective on nylon. Statistical analysis

demonstrated that the brominated flame retardant used to treat the polyester statistically worked better than several of the non-halogenated treatments at the low wash cycles but not at the high wash cycles. The non-halogenated flame retardants padded on the acrylic and nonwoven substrates were unsuccessful in reducing the char length.

Durable and Environmentally Friendly Flame Retardants for Synthetics

by
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1. Introduction

The use of durable and environmentally friendly flame retardants is of growing importance in several industries including textiles and plastics. With the increasing environmental and health concerns surrounding the use of halogenated flame retardants, the push to find alternatives due to current and pending legislation is rising. While some substitutes have been found to be effective in suppressing flame, there are concerns surrounding other properties, such as the durability and cost of these materials.

1.1 Background

The primary purpose of flame retardants is to protect lives and property. Multiple risk-benefit analyses conducted over the last decade show that flame retardants have helped lessen the number of severe injuries and deaths caused by fires. Legislation has become more stringent especially in the United Kingdom and in California. This has led to not only tighter fire standards but also to studies on the environmental and health impact of flame retardants ³.

Flame retardant textiles are found in a variety of textile products ranging from clothing, to automotive textiles, to home furnishings. Legislation has continuously been passed since the 1950s which enforces flame retardant standards. After the 1920s, several Flammable Fabrics Acts (FFAs) were passed in order to regulate the manufacturing of flammable clothing. Certain apparel items such as children's sleepwear, cowboy chaps, and brushed rayon sweaters were consumer safety concerns. The Flammable Fabrics Act was amended in 1967 in order to incorporate other areas such as plastic, foam, and interior furnishings. In 1972, the U.S. Consumer Product Safety Commission (CPSC) became

responsible for the FFA regulations. The coverage of the legislation includes apparel, children's sleepwear, carpets, mattress, and other items ⁵.

Halogenated flame retardants, for example bromodiphenyl ethers, are causing rising concerns among certain environmental and legislative groups, yet this class of flame retardants has shown over time to be an economical and effective treatment for the suppression of flame. While some alternatives have been found to be effective in suppressing flame of a textile, there are other concerns such as the durability of these products since many textiles, such as apparel, are routinely laundered. There are also concerns surrounding the degree of performance and costs of these alternatives.

Currently, legislation is being considered and passed both in Europe and the U.S. banning certain brominated flame retardants. Both the European Union and California have banned the production and/or use of both penta and octa bromodiphenyl ethers ⁶. Debate whether deca diphenyl ethers and other brominated flame retardants should be banned as well are pending.

With this research, ten non-halogenated flame retardants were applied to four synthetic substrates in the Pilot Plant. The synthetic fabrics tested consisted of two woven, one knit, and one nonwoven material. Based on initial vertical burn test results, the most promising flame retardants for each substrate were kept for further testing and evaluation. In order to have a comparison, a brominated treatment was applied to both the polyester woven and the nylon knit. Therefore, the non-halogenated treatments were analyzed in terms of their effectiveness on the substrates and their effectiveness compared to that of a brominated treatment.

1.2 Specific Research Objectives

The primary goal of this research is to identify and evaluate the performance, feasibility, durability, as well as other properties of ten non-halogenated flame retardants which are commercially available for synthetic materials.

The focus of this research will also include the identification of novel approaches to flame retardancy such as nanocomposite/nanoclay systems. This research will identify a list of the commercially available flame retardants which fall into the environmentally friendly and durable category.

The specific goals were:

- To identify the commercially available, non-halogenated, durable flame retardants
- To test and evaluate approximately five of the most promising finishes from the review on synthetic textiles
- Compare the effectiveness of the most promising finishes to a brominated treatment
- To identify and test (time permitting) novel approaches to flame retardant finishing, such as nanocomposites of fibers and clay

The research will serve the Textile Industry in identifying promising alternatives to halogenated systems prior to the enforcement of U.S. wide regulations. Becoming a market leader and leading the industry in the search for alternatives to halogenated flame retardants can be advantageous. With pending changes in legislation and consumer interests, it will be valuable to demonstrate the involvement in the innovation of such products.

2 Literature Review

The growing environmental and health related concerns surrounding halogenated flame retardants, has multiple industries including the textiles and plastics searching for alternatives. The primary focus of this research will be to evaluate flame retardants which are categorized as environmentally friendly and durable for synthetic textiles. Topics such as legislation, mechanisms of flames, mechanisms of flame retardancy, and proposed commercial products will be discussed in this review. The review will also contain a list of the commercially available flame retardants which fall within the above categories.

2.1 Legislation

In the early 1950s, deaths surrounding flammable fabrics became a public concern and resulted in the Flammable Fabrics Act. This act resulted in regulations which affected the flammability of textiles purchased by consumers. Soon other legislative acts were put into place including the Amended Flammable Fabrics Act of 1967 in the U.S. This allowed the government to set standards and allowed for cause of deaths to be investigated and for research to be conducted. In 1972, the 0-6X Children Sleepwear Standard DOC FF-3-71 and in 1975 the 7-12 Children's Sleepwear DOC PFF-5-13 came into effect. With both these regulations, the vertical strip testing for flammability and the durability testing of 50 wash and dry cycles was standardized ⁷.

The concern surrounding chemicals used for flame retardants has focused on various groups over the years. For example, in 1977, the U.S. Consumer Product Safety Commission (CPSC) banned Tris (2, 3 dibromopropyl) phosphate flame retardant which was often used for children's garments. The chemical structure for Tris can be seen in Figure 2-1.

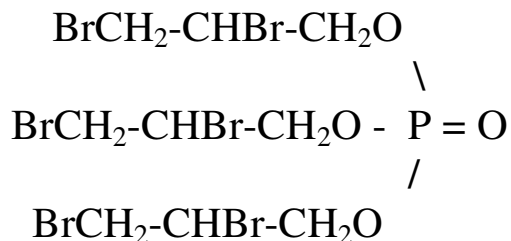


Figure 2-1 Chemical Structure of Tris (2,3 dibromopropyl) phosphate

The ban not only included the chemical but all fibers, yarns, and fabrics containing Tris ⁸. In the United Kingdom, Tris was found to leach out of garments when wet (e.g. from urine) which was a concern especially since children's sleepwear was often treated with this chemical. Further studies found that the substance was a possible carcinogen and so this flame retardant was banned ⁹.

2.1.1 The Debate Surrounding Halogenated Flame Retardants

Pending and current legislation is causing some halogenated flame retardant producers to search for non-halogenated product lines. The growing concerns surrounding halogenated flame retardants both from an environmental and health point of view are making the need for alternatives more critical.

How do products get categorized as a risk? In Europe, a group called "Risk Assessment" or RA investigates individual chemicals on their impact on both human and environmental health. Then, the government decides how to proceed. Politicians may decide that further investigation is necessary, that there is not a risk and no action needs to be taken, or that there is a risk and measures are necessary. Both penta and octa-BDEs (brominated diphenyl ethers) were determined to be a risk, though the risk for octa was not as apparent. There have been over 588 studies conducted on deca-BDEs and currently no risks have been acknowledged. Yet, more studies involving human health such as on neurobehavior and

environmental studies are being planned ¹⁰. A few of the independent organizations who have researched deca-BDEs and have determined that there was no risk involved with the use of such chemicals include: U.K. Department of Trade and Industry, Voluntary Children's Chemical Exposure Program (VCCEP), U.S. Consumer Product Safety Commission, and the U.S. National Academy of Science Review ¹⁰.

In the United States, California, Illinois, Maine, Michigan, New York, Maryland, Oregon, and Hawaii have banned penta and octa-BDEs (brominated diphenyl ethers). Many of these states attempted to ban deca-BDEs as well, but the legislation was postponed until deca-BDES were removed from the lists. In Montana, a resolution to ban PBDEs (polybrominated diphenyl ethers) failed and Massachusetts recently removed PBDEs from a list of targeted chemicals to study. Rhode Island has decided not to move forward with legislation proposing the banning of brominated flame retardants at this time.

In August of 2006, Sweden passed a ban on deca-BDEs and is now pushing the European Union to do the same. Certain goods such as electronics and automobiles were exempt from the ban which was to go into effect January 1, 2007 ¹¹.

Some feel that no chemical risk to humans or the environment should be tolerated while others feel that banning flame retardant products that work is worse as it creates a fire risk. Halogenated flame retardants have been proven to be effective and economical. They save lives, and some feel sacrificing this for either substandard products or no flame retardant chemistry is not worth the risks. They believe that banning all species of PBDEs (polybrominated diphenyl ethers) is a mistake until more risk assessments are conducted ^{10, 12}. Brominated flame retardants have been proven to save lives. Some are wary of using

alternatives since brominated treatments have existed on the market for so many years and have proven to be effective ³. The debate is ongoing both in Europe and in the United States.

Table 2-1 below lists the estimated number of lives in the United States saved by brominated flame retardants used in textile applications every year. These brominated flame retardants are also used in the plastics industry and have resulted in lives being saved from fires involving electronics and other plastic products ⁴.

Table 2-1 Estimated Lives Saved in US Annually by Brominated Flame Retardants for Textile Applications ⁴

Product flame retarded by brominated FRs	Total lives saved	Maximum potential lives saved
Fabric back coating	144	160
Cushioning	216	216

Phosphorus chemistry appears to be the route that many chemical manufacturers are going towards. The use of intumescent systems, where a foam layer is formed to protect the substrate, in backcoatings is also another likely alternative.

2.2 Mechanisms of Flames with Respect to Fabrics

2.2.1 Ignition, Pyrolysis, and Combustion

In the discussion of flame retardants, it is critical to understand how fires begin. First, an ignition source is needed. There are two types of ignition: autoignition which occurs spontaneously and flash ignition which occurs due to an external source such as a flame. The temperature, amount of oxygen available, and both the physical and chemical properties of a polymer affects ignition. Polymers, natural and synthetic, when exposed to enough heat may degrade or pyrolyse. Pyrolysis is the decomposition due to nonoxidative heating which

is initially endothermic and becomes exothermic ^{1, 7}. During this process, volatiles may be released which when combined with air and a high enough temperature may ignite ¹.

Combustion follows pyrolysis and is an exothermic reaction which involves both fuel and an oxidizer ⁷. During combustion, the energy equal to the heat of combustion is released. The polymer combustion cycle is self-sustaining. In other words, the heat released due to burning (exothermic) helps to sustain the pyrolysis of the polymer which in turns releases more flammable gases which when heated and mixed with the air result in more flames ¹.

Thermoplastics often begin to melt and drip but, with additional heat, they pyrolyze and produce volatile molecules ¹. Next, combustible materials ignite and as the fire heats up flammable gases are released ¹³. The polymer further decomposes when the flammable gases burn, releasing additional heat ¹⁴. This cycle continues until there is either no longer any combustible material available or a lack of oxygen exists ¹³.

Figure 2-2 shows a simplified polymer combustion cycle and Figure 2-3 shows a more detailed cycle for a fiber.

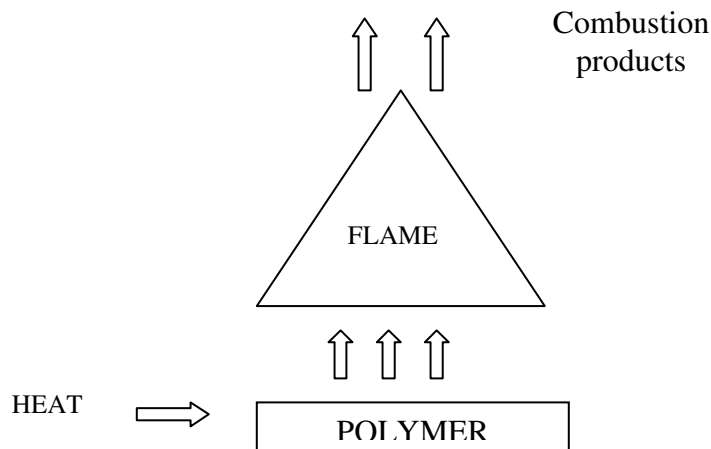


Figure 2-2 Polymer Self-Sustaining Combustion Processes ¹

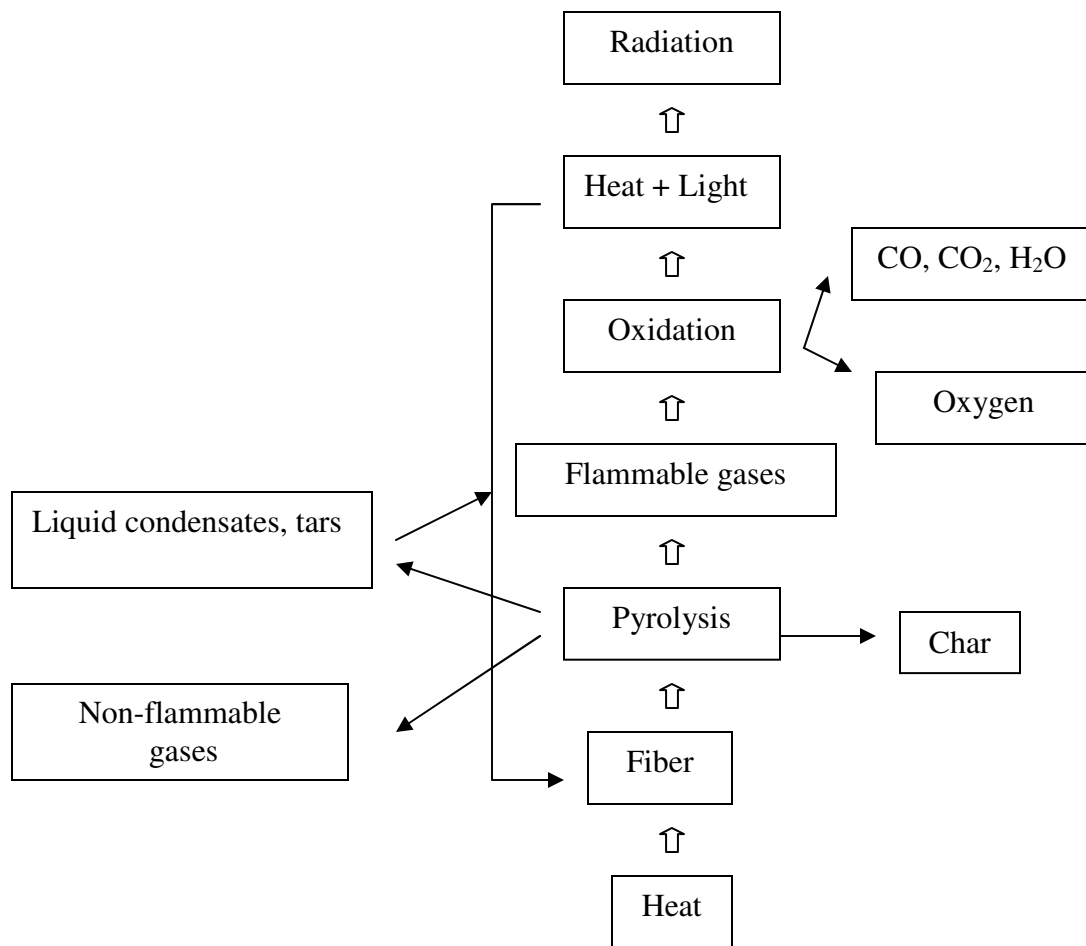


Figure 2-3 Combustion with Flame Retardant Actions ²

2.2.2 Fiber Composition and Fabric Construction

The burn tendencies and burn properties of textiles are critical to understand. Not all textiles (natural, synthetics) or textile constructions (yarn, fabric, garment) react the same way under heat. Natural fibers such as cotton and silk burn relatively easily in comparison to synthetics which have a greater tendency to resist ignition ¹³. Synthetic fibers such as polyester, polypropylene, and polyamides shrink away when exposed to a flame. Yet, this action does not result in the fabric being classified as flame retardant. The resulting melt drip

can result in severe burns and injuries ^{3,13}. In the case of synthetics, another issue that arises is that though the fiber shrinks away from the ignition source, a secondary ignition may occur. Both these concerns result in the need for flame retardants on synthetics. The flame retardants used for synthetics often act by increasing the tendency of the fabric to melt and shrink away from the flame source. Others function by promoting the extinction of flaming droplets ².

The construction of the textile also affects the likelihood of burning. The yarn geometry is important. Yarns which are spun tighter are more likely to resist ignition than a loosely spun yarn. Horrocks references research conducted by Garvey et al ¹⁵ which studied hybrid viscose blended yarns to determine which spinning type (ring or rotor spun) better resisted ignition. The testing showed that the results varied depending on the blend percentages and further testing was planned. However, research has shown that the yarn structure does affect the burn tendency of a fabric ².

The density and structure of a fabric are critical. For example, a dense fabric composed of several layers is less likely to burn than a low density fabric with an open structure ². In other words, a tightly woven fabric is less likely to ignite than a loosely woven fabric ¹³.

2.2.3 Heat Release

Multiple properties of a material relate to its fire hazard including how easily ignitable the material is and the rate and amount of heat that is released. The way the flame spreads and the amount and toxicity of the smoke released are all critical ¹. The heat release is what determines the rate at which a fire will spread and therefore dictates the burning

hazard ². The use of a cone calorimeter may be used to measure heat release on a small scale
1.

The Limiting Oxygen Index (LOI) is a value which indicates the burning tendency of a material. ASTM D 2863- 06a is the standard test method for measuring the minimum oxygen concentration to support candle-like combustion of plastics. Within this test method, a test specimen is held up vertically by a mixture of oxygen and nitrogen which are moving upwards through a chimney. The upper end of the specimen is ignited. The burning behavior is observed and sequential tests are run where the amount of oxygen is changed in order to determine the minimum level of oxygen needed for ignition ¹⁶. Any fiber with a LOI value of 21% or lower will effortlessly ignite and burn in the presence of air. LOI values of 26-28 are indicative of fibers which are flame retardant. These fibers will pass the majority of the vertical and horizontal flame tests. The heat of combustion (ΔH_C) is important because it indicates how quickly a fire will spread ². Table 2-2 lists the glass transition, melting, and pyrolysis temperatures as well as the LOI% and ΔH_C values for several synthetics.

Table 2-2 Synthetic Temperature and LOI Values ²

Fiber	Tg deg C (softens)	Tm deg C (melts)	Tp deg C (pyrolysis)	Tc deg C (ignition)	LOI %	ΔH_C kJ/g
Nylon 6	50	215	431	450	20-21.5	39
Nylon 6,6	50	265	403	530	20-21.5	32
Polyester	80-90	255	420-447	480	20-21	24
Acrylic	100	>220	290	>250	18.2	32

2.3 Purpose of a Flame Retardant

The first job of a flame retardant is to reduce the possibility of ignition, but should the material ignite, flame retardants are designed to interrupt the combustion process ^{1, 13}. In

order to hinder combustion, flame retardants interfere with the fuel, oxygen, and/or heat cycles needed to maintain combustion ¹⁴.

2.4 Mechanisms of Flame Retardancy

As shown by Figure 2-3, combustion is a feedback mechanism. Different types of flame retardants will impede combustion by various mechanisms and at various stages of combustion ¹⁷. Below is a list of flame retardancy mechanisms and examples of flame retardants which work within that mechanism.

The various flame retardancy mechanisms include:

- Reducing the evolved heat to below what is needed to sustain combustion
 - Inorganic and organic phosphorus-containing agents, aluminum hydroxide
- Improving the decomposition temperature
 - Inherently flame resistant fibers (e.g. aramids)
- Modifying pyrolysis process to promote char formation (barrier between flame and polymer) and decrease flammable volatiles
 - Phosphorus and nitrogen containing flame retardants
- Interfering with flame chemistry
 - Halogenated flame retardants often in synergy with antimony
- Isolating the flame from the oxygen supply
 - Halogenated flame retardants by releasing hydrogen halide
 - Hydrated flame retardants by releasing water ^{1, 2}

The gas (vapor) phase and condensed phase are the two best known mechanisms for flame retardancy, though not the only systems ^{7, 18}. These work by interfering with the combustion process via a chemical or mechanical mechanism. New methods for flame retardancy are developing which are based on physical principles.

2.4.1 Gas Phase (Vapor Phase) Mechanism

Halogen based flame retardants work via the gas phase. This phase works by interfering with the combustion process of the substrate by inhibiting the chain branching reactions ^{7, 17, 18}. The phase can be identified by the decrease in the amount of fuel

combusted by atmospheric oxygen and by looking at the heat to combustible fuel ratio. The amount of combustible fuel will remain unchanged. In other words, the pyrolytic process should not change unlike the combustion mode ⁷.

The flame retardant moiety must be volatile so that it can be in the gas phase in order to interfere with the combustion reactions in the flame. Polymers under pyrolysis can react with air resulting in chain branching reactions which advance the combustion. The halogenated flame retardants interfere with the chain reaction by preventing hydroxide and hydrogen free radicals from reacting with oxygen and carbon monoxide. Radicals are captured therefore disturbing the exothermic oxidative flame chemical processes resulting in the hindrance of combustion ^{7, 18}. Figure 2-4 shows the vapor phase mechanism.

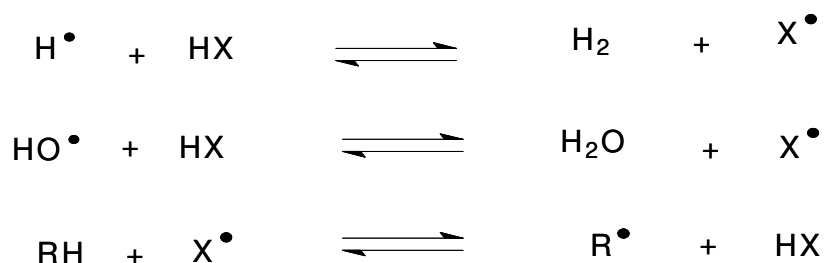


Figure 2-4 Vapor Phase Mechanism

2.4.2 Condensed Phase

Flame retardant chemicals in the condensed phase cause a reduction in the amount of gaseous combustibles produced by altering the pyrolytic path. Instead, carbonaceous char, water, and carbon dioxide are often produced ^{7, 18}. The inert insulating material (e.g. char) serves to reduce the gases. The char forms a heat and mass flow barrier which serves to protect the fiber. Carbon is stabilized and prevented from turning into combustible gases ¹.

Dehydration and cross linking are two significant processes that play a role in flame retardants which act via the condensed phase mechanism. These are both recognized to

occur in cellulose and synthetics. How effective the applied flame retardant will be depends on the predisposition of the polymer to dehydrate and form char^{3, 4, 7, 14, 18}. The degree of cross linking can have an effect on the reduction of the flammability of the polymer^{7, 18}.

Phosphorus based flame retardants have been found highly effective in oxygen containing textiles such as cellulose, nylon, and polyester¹⁴. They work by cross linking and promoting carbon char as shown in Figure 2-5. During thermal decomposition, the phosphorus compounds are converted to phosphoric acid. The phosphoric acid then extracts water from the burning substrate resulting in the formation of char. Some phosphorus compounds have been found to act in the gas phase, but the majority work via the condensed phase¹⁹.

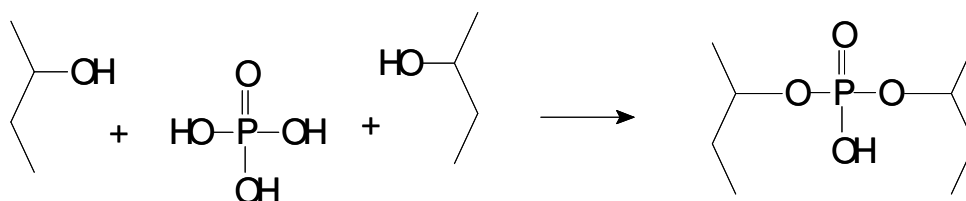


Figure 2-5 Cross linking of Phosphorus-based Flame Retardant

2.4.2.1 Char Formation

Char formation impedes flame by forming a barrier (controlling mass and heat transfer) which acts to protect the polymer surface from degrading. In other words, char helps retard flame by reducing the amount of fuel available to the flame^{1, 7, 18}. The degree to which the char protects the substrate from degradation depends on how quickly it forms compared to other degradation mechanisms such as the formation of combustible gases¹.

The release of water, which aids in the dilution of combustible vapors, may occur during the

char formation¹⁸. The amount and chemical and physical structure of the char are critical to the effectiveness of the flame retardant^{1, 18}. A structure with channels and cracks would not be ideal¹⁸. The char structure should have closed cells with pockets of gas maintaining the polymer below its decomposition temperature and preventing volatile substances from reaching the flame¹. Figure 2-6 below shows an ideal and a poor char structure. The ideal figure is composed of closed pockets while the poor has channels.

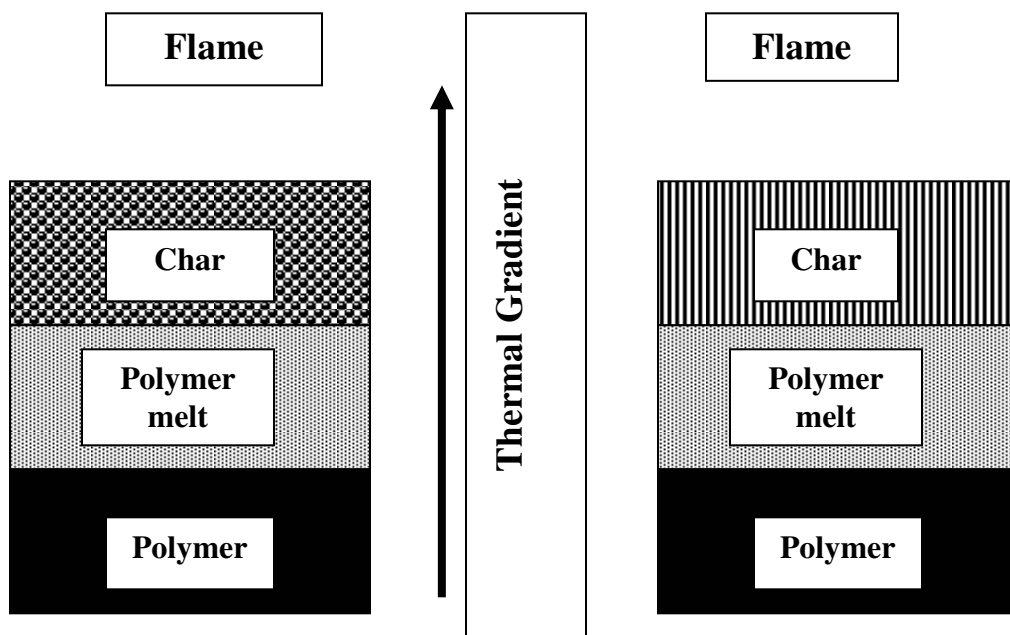


Figure 2-6 a. Ideal Char Structure b. Poor Char Structure¹

2.4.3 Third Flame Retardant Mechanism

A third mechanism, called the physical effect, is a combination of the condensed phase and vapor phase. Inorganic flame retardants are the main category of flame retardants that can work using this method and amounts up to 60% by weight in the polymer are needed. The primary effect can be the formation of a non-combustible layer or the dilution of combustible material^{3, 7}. In the coating effect, a protective layer of glass or char impedes

the combustible gases and forms an insulating barrier for the substrate. Boron derivatives on cotton work using this mechanism. The dehydration occurs as shown in Figure 2-7.

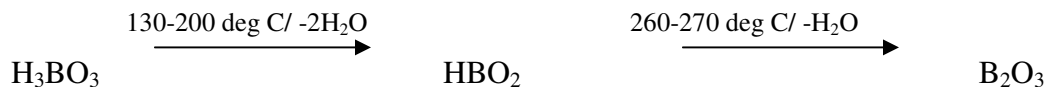


Figure 2-7 Dehydration of Boric Acid

The dilution physical effect is carried out by filling the amorphous regions and pores of the polymer. This will result in more heat being needed in order to reach the pyrolysis temperature. The amount of combustible gases available will be lowered, resulting in less heat being available for pyrolysis, therefore resulting in the flame retardancy of the polymer. Alumina, clay, zinc oxide are just a few examples of fillers that work using this mechanism.

2.5 Fire Safety and Standards

Fire test methods exist to determine the fire risks of products used for a variety of applications. These were developed to help determine the risks to both humans and property

¹³. Some critical tests for textiles are found in Table 2-3 below.

Table 2-3 Textile Fire Standards

Application	Fire Standards
Mattress ticking	BS 6807- 1/2, EN 597- 1/2
Upholstery	BS 5852p1
Protective clothing	EN 533, NF P92 503 (M1), BS 7175 Crib 5
Carpet	DIN 4102(B1), FAR25-853
Non Woven	NF P92 503
Curtains	NF P92 503

The tests give specifications as to the type and size of a sample, source of the flame, duration of the application of the flame to the substrate, and more importantly help determine the effectiveness of a flame retardant. Depending on the end use of a product, different standards are required to be met.

2.6 Health and Environmental Concerns

There are concerns surrounding the toxicity of flame retardants since the combustion products are released into the environment. More specifically, the concern is focused on toxic combustion products coming from brominated and chlorinated dioxins and dibenzofurans halogenated flame retardants⁹. Figure 2- 8 and Figure 2- 9 show the chemical structures for dioxin and dibenzofurans.

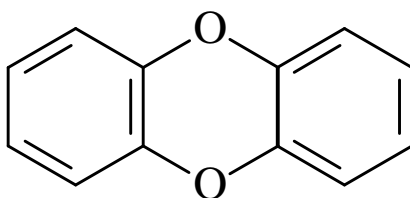


Figure 2-8 Dioxin Chemical Structure

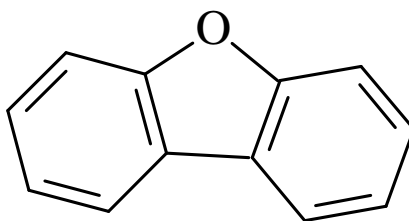


Figure 2-9 Dibenzofuran Chemical Structure

Multiple studies have indicated that serious health concerns can be connected with exposure to dioxin-like compounds. Dioxins have been found to cause acute and chronic toxicity^{17, 20}. Dibenzofurans and dibenzodioxins are just two carcinogens which are adsorbed by smoke particles resulting in an environmental health hazard¹.

The fear of toxic products being released into the environment has resulted in regulation restrictions in Europe and in the United States. Other concerns encompass both the processing and recycling of flame retardant treated materials⁹. The toxic hazard to the environment is determined by the rate of decomposition of materials and the amounts of

toxic products released. On the other hand, the toxic risk depends on the probability of a particular fire scenario and the toxic hazards that would result ⁹. Current research dictates that the main toxicity effects of most flame retardants alone is not the primary concern. Instead, the toxic effects from long term exposure due to the persistence and bioaccumulation of these substances are worrisome ⁹.

There are both risks and benefits surrounding brominated flame retardants. The risks include the fact that some species have been found to bioaccumulate and that they are persistent. In other words, once in the environment or in the body the levels do not appear to decrease. Substances classified as bioaccumulates remain stable in the body. Bioaccumulation can occur if a substance is relatively insoluble in water but is easily soluble in fats. If a substance is water soluble the body can rid itself of it lessening the concern of bioaccumulation ¹³. Currently, researchers do not know or understand what the long term risks of having traces of these chemicals in the body or environment are.

2.6.1 Polybrominated diphenyl ethers

Polybrominated diphenyl ethers (PBDEs) are among the most stable brominated flame retardants, but the fact that they accumulate is a concern and has recently led to legislation in Europe and the United States ¹⁹. The chemical structure for PBDEs is seen in Figure 2-10 below where x and y vary resulting in the penta, octa, and deca forms.

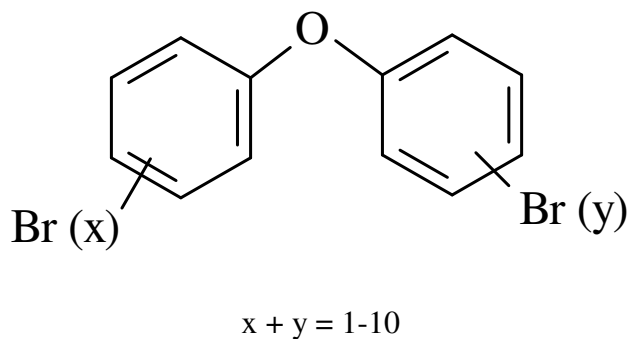


Figure 2-10 Polybrominated Diphenyl Ether Chemical Structure

This halogenated flame retardant class which has been under much scrutiny over the last few years comes in three forms, penta, octa, and deca. Deca-BDEs are additive versus reactive flame retardants. In other words, this flame retardant physically not chemically binds to the material whether textiles or plastics³. PBDEs therefore leach out into the surrounding areas²¹. Deca-BDE is produced in the greatest quantity where 10% is used in the textile industry and the remaining 90% in the plastics industry³. In Europe, especially the United Kingdom, brominated flame retardants played a major role in the back coating of upholstery fabrics. Pentabromodiphenyl ether (penta-BDE) was the main flame retardant used in polyurethane foam for upholstery^{6, 12}. The concern surrounding the foam is that upon burning it releases a large amount of heat as well as toxic fumes¹². Bans have been put into place, but they did not stop with the penta- BDEs but also included both octa and deca BDEs. Currently, both the European Union and California have banned the production and/or use of both penta and octa bromodiphenyl ethers. A significant new use rule (SNUR) has been proposed for both these products by the EPA⁶. SNUR requires notification to the EPA before either of the PBDEs mentioned above is manufactured or imported for significant new use. The goal is to force chemical manufacturers to find safer alternatives. While the EPA recognizes there are concerns due to the exposure and accumulation of the

chemicals, the agency has not deemed that these chemicals pose a risk to either human health or the environment ²¹.

Research in Sweden showed that over a 25 year period, the level of polybrominated ethers in human breast milk had increased over 50 times. The same research showed that workers who were in contact with brominated flame retardants had blood levels that were 50 times higher ⁹.

In Germany, a lab study in the mid eighties working with brominated diphenyl oxide discovered the release of brominated dioxins and furans during pyrolysis. This led to concern surrounding certain flame retardants throughout parts of Europe ¹⁷. Several other studies have shown similar results adding to the concern. However, while studies are showing the persistence and bioaccumulation of these products, some researchers feel there is no concrete evidence of health or environmental risks from these substances ^{17, 22}.

2.6.2 Halogenated Flame Retardant Manufacturers

With the potential of regulations banning all types of brominated flame retardants, halogenated suppliers are beginning to expand into the non-halogenated sector ^{3,4}. In 2003, the five main chemical players for brominated flame retardants in the United States were Great Lakes, Albemarle, Occidental (OxyChem), Dead Sea Bromine, and Akzo Nobel. Great Lakes which was the primary brominated company acquired FMC Process Additives and Anzon and thereby was able to add phosphorus and antimony products to their product line ⁴.

In 2003, Great Lakes Chemical Corp. agreed to phase out the production of penta- and octa-polybrominated diphenyl ether (PBDE) by December of 2004. Great Lakes was the only U.S. producer of penta-PBDE. The agreement was the result of discussions with the

Environmental Protection Agency (EPA) who had planned to prevent new uses of these two brominated flame retardants in the market. The reasons for the agreement stemmed from the fact that both penta- and octa-PBDE were detected in samples of human breast milk, tissue, and blood. The Environmental Working Group discovered levels of PBDEs in breast milk that were 75 times higher in 20 first time mothers compared to mothers in Europe ²².

The EPA is helping companies to find alternatives for brominated flame retardants such as Firemaster 550 to replace penta-PBDE which is used in the flame retardant of foams ²². Table 2-4 lists the main suppliers of brominated flame retardants.

Table 2-4 World Brominated Flame Retardant Suppliers ⁴

Flame retardant type	Suppliers
Brominated	Albemarle Corporation, Dead Sea Bromine Group,
	Great Lakes Chemical, Atofina, Ferro, Clariant, Toso

2.6.3 Halogenated Flame Retardant World Market Share

Halogenated flame retardants are extensively used world wide. While there is some discrepancy as to the 1998 global percentage that brominated flame retardants accounted for, sources do agree on the reach that this flame retardant class had. One source stated that bromine accounted for 39% of the flame retardant global market ¹² and another stated 23% market penetration ³. A reference from 1999 had brominated flame retardants making up approximately 25% of the world market ¹⁹.

2.7 Types of Flame Retardants

There are four main chemical groupings of flame retardants. These are inorganics (e.g. aluminum trioxide and magnesium hydroxide), nitrogen-based organic, organophosphorus (e.g. phosphate esters), and halogenated flame retardants ¹⁷. Flame

retardants are further divided based on durability. Depending on their fastness to laundering, flame retardants can be classified as non-durable, semi-durable, or durable¹³.

2.7.1 Halogen Based

Halogenated flame retardants are believed to work through the gas phase mechanism as described in section 2.4.1. They hinder the combustion of the substrate by encumbering chain branching^{17, 18}.

The mass and density of the halogen and the strength of the carbon-halogen bonds are some of the reasons why bromine is a more effective flame retardant than chlorine^{7, 18}. The structure of the compound can affect the performance of the flame retardant. For example, aromatic brominated retardants are found to be effective at high temperatures and more temperature resistant than aliphatic brominated compounds¹⁷.

2.7.1.1 Synergism Between Halogenated Flame Retardants and Antimony

Synergism occurs when the effectiveness of the combination of compounds is greater than the sum of the individual effects. Halogenated flame retardants such as bromine and chlorine are often found in synergistic systems with antimony since their flame retardancy is increased with the addition of antimony. This was found to be true for several polymers including nylon, polyester, and polyolefins¹⁸. With this synergism, both the gas phase and condensed phase mechanisms are believed to contribute, though the antimony oxide such as Sb_2O_3 or Sb_4O_6 is most effective in the gas phase. The antimony halide is believed to form a barrier over the substrate surface thereby protecting it^{7, 18}.

2.7.2 Phosphorus Based Flame Retardants

Phosphines, red phosphorus, phosphates, phosphine oxides, and phosphonates are just some of the phosphorus compounds that may be used to retard flame²³.

Phosphorus containing flame retardant materials often work in the condensed phase by promoting char formation ^{7, 17, 18}. Polyurethane foams are one area where phosphorus flame retardants are often used due to their effectiveness ²³. Some studies have shown that a substantial quantity of the phosphorus remains in the char resulting in a more effective barrier ⁷. While acting in the condensed phase, phosphoric or polyphosphoric acids can be released from phosphorus flame retardants. These acids act as dehydration catalysts forming char especially with cellulose ⁴.

A common type of phosphorus based flame retardant which is durable for synthetics is based on the cyclic phosphonate ester (CPEs) group. These are useful for both polyester and nylon. They are applied using the pad-dry-cure-rinse process. During the curing stage, the fibers swell open (especially polyester) allowing a percentage of the flame retardant to enter. During the cooling phase, 25-50 percent of the flame retardant is trapped within the fibers. Next, the remaining flame retardant is rinsed from the surface ¹⁴.

While the majority of phosphorus compounds work via the condensed phase, there are some which can act in the gas phase ¹⁷. Polyurethane is one such polymer where some of the gas phase action occurs in addition to the condensed phase ⁷. Red phosphorus is one phosphorus system believed to work in both phases ²³.

Nitrogen derivatives often enhance the ability of phosphorus to hinder flame ^{7, 23}. Yet, the nitrogen compound used and the polymer substrate affect the degree to which the phosphorus effect is enhanced ²³. Nitrogen helps improve the attachment of phosphorus to the substrate ¹³. Past research studies have proposed various theories as to why nitrogen improves the flame retardancy of phosphorus. One theory is that the P-N intermediates are better phosphorylating agents. Another theory is that nitrogen enhances the oxidation of

phosphorus releasing inert gases such as ammonia. A third theory is that nitrogen aids in slowing the volatility loss of phosphorus from the condensed phase ¹⁸.

Red phosphorus is one system that appears to be effective without the aid of nitrogen. This system has several potentially attractive features such as the need of small amounts, stability during processing, and the effects on the substrates mechanical and electrical properties are insignificant. However, there are some potentially critical disadvantages of using red phosphorus which includes the reddish-brown color that it imparts. The particulate form may also result in problems during spinning ²³.

2.7.2.1 Phosphorus Manufacturers

By purchasing FMC Corporation's Polymers Additive Division in 1999, a large portion of Great Lake's business now comes from phosphorus flame retardants. Clariant obtained Albright & Wilson's red phosphorus business and Akzo acquired Courtaulds' phosphorus flame retardant business. A year later, Albright & Wilson sold the phosphorus business to Rhodia. This resulted in Rhodia becoming the dominant player in the specialty phosphate chemical arena ⁴.

Table 2-5 Phosphorus Flame Retardant Suppliers⁴

Flame retardant type	Suppliers
Phosphorus	Albright & Wilson (part of Rhodia), Akzo, Clariant, FMC Corporation (subsidiary of Great Lakes),
	Olin, Bayer, Italmatch Chemicals, Solutia, Unitex Chemical, Nordmann, Rassmann

2.7.2.2 Phosphorus As an Alternative

The next important question is why should phosphorus be considered as an alternative? Phosphorus flame retardants have been used for over 150 years. In terms of textiles, they have been found to be successful for a large range of fiber types. Furthermore,

they are compatible with other processing chemicals and are easy to use. Very importantly, especially in the face of legislation, they are found to be safe from both a toxicological and environmental standpoint ¹⁴.

However, like any substance there are both advantages and disadvantages of using phosphorus based flame retardants.

Table 2-6 Advantages and Disadvantages of Phosphorus Containing Flame Retardants⁴

Advantages	Disadvantages
Effective at low concentration- organic types	Lack of permanency and hygroscopicity of inorganics
Easy incorporation and processing	Potential health hazard during processing organics
Little detrimental effect of physical properties	Release of toxic combustion products from organics
Good UV stability	
Low to moderate price	

In terms of substitutes for penta-BDEs in polyurethane foam, Tris(chloropropyl) phosphate ($C_9H_{18}Cl_3O_4P$) or TCPP has been proposed. This product is a mixture of various isomers. The concerns surrounding this group is that there are some structurally related compounds which are carcinogenic and that limited toxicity data exist for this product. Aromatic phosphates are another flame retardant which are currently used in polyurethane foam found in home furnishings. However, there is the concern of exposure to aromatic phosphates ⁶.

2.7.3 Nanocomposite Flame Retardants

In 1961, the first polymer-clay nanocomposites were reported by Blumstein ²³. In the 1980s, the Toyota Central Research Laboratories began researching nanocomposites ^{24, 25}. Toyota found that certain properties such tensile strength and modulus could be increased ²⁵.

Yet, it was not until the mid nineties that the thermal stabilities of clay nanocomposites were studied. Since the late nineties, there has been an increase in the number of studies on the flammability properties of various polymer-clay nanocomposites. One main advantage of such flame retardant systems is that they may be effective at concentrations of 5% w/w or less^{23, 24}. Some studies have shown that polymer nanocomposites improve the barrier properties, mechanical properties, and help to reduce the flammability of textiles²⁶.

Nanocomposites exist in two main forms, the intercalated form and the exfoliated form. In the intercalated form, the layers preserve interlaminar contact while in the exfoliated form the layers are delaminated and therefore scattered due to incoming material²³.

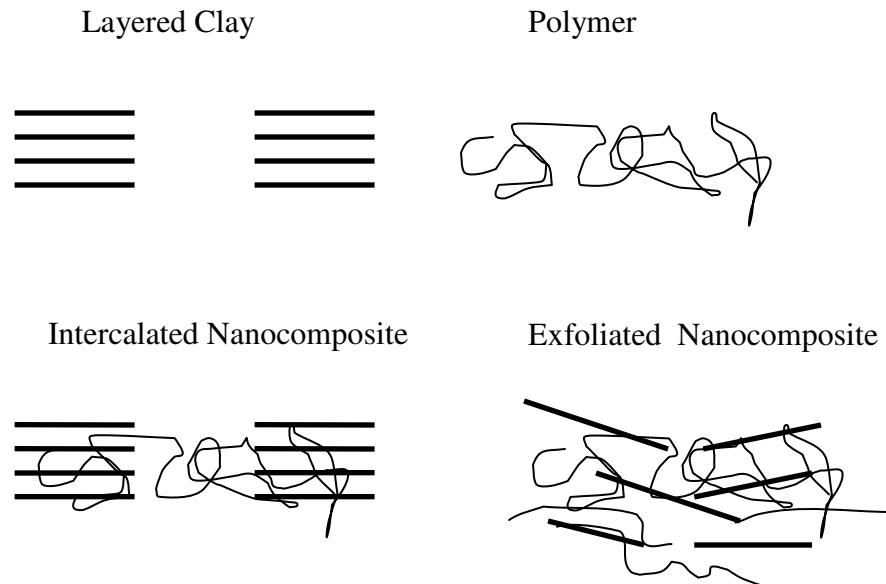


Figure 2-11 Nanocomposite forms: Intercalated and Exfoliated

The research is ongoing in this field and several mechanisms have been proposed to describe how polymer-clay nanocomposites work to impede flame. One theory is that the heat release rate is reduced due to the formation of a protective layer composed of clay

platelets and char. Another is that radical trapping can occur by paramagnetic iron in the clay²⁷.

The flame retardancy of polypropylene is enhanced with the use of various nanocompounds such as montmorillonites and boroxsiloxanes. There is still research to be conducted in this area. With some polymers, such as polypropylene, nanoclay appears to hinder the burning and help with char formation. Yet, the ignition tendency and the after-flaming properties of the substrate are not diminished. Currently, nanocomposites in polypropylene have an exfoliated structure²³.

Multiple polymer-clay nanocomposite studies have been conducted in the last seven years. Serge Bourbigot and his team studied the flammability of polyamide-6/clay hybrid nanocomposite textiles. They were trying to find a mechanism to flame retard a textile that would then have an effective laundry resistance. The research was approved in 2001 and the polyamide-6/clay nanocomposite was formed through melt blending and had an exfoliated structure. The multifilaments were then knitted into a fabric. The sample's heat release was then compared to a pure polyamide-6 using a cone calorimeter at 35 kW/m². The heat released on the nanocomposite treated sample was 40% less than the untreated polyamide-6 sample²⁴.

In 2002, Serge Bourbigot et al. presented research where two approaches were used to produce a flame retarded textile using nanocomposites: nanocomposite yarn and a nanocomposite coating. A polyamide-6 (PA-6)/clay hybrid with an exfoliated structure was used to manufacture multifilaments yarns via melt spinning. A nanocomposite coating was synthesized using montmorillonite clay and an organic-inorganic hybrid material to form a polyurethane (PU) nanocomposite²⁶.

Horrocks, Kandola, and Padbury²⁵ conducted research incorporating nanoclays with conventional flame retardants. This was done in hopes of being able to reduce the amount of flame retardant used and to help overcome some of the shortcomings of nanoclays such as ignition resistance and ability to self extinguish. It was hypothesized that it would help improve the manufacturing and processing of the polymers since less of the traditional flame retardant would be in the melt. The research specifically studied the influence of nanodispersed montmorillonite clays on polyamide fibers. The results showed that strength and tensile strength improved significantly. In terms of flame retardancy, more work was required, but initial results demonstrated that lower amounts of conventional flame retardants were needed in the presence of the nanoclay structure.

2.7.4 Intumescent Systems

Intumescent systems and phosphorus based flame retardants are two of the most promising candidates to replace brominated flame retardants in backcoatings³. Intumescent systems are composed of three parts: the acid source, the carbon source, and the gas source. It is believed that as the carbon source degrades, the acid acts as a catalyst. Carbon foam is formed when the carbon source composed of polyols are dehydrated. This foam with the correct thickness and density serves to impede the spread of the flame³. The foam then serves as an obstruction between the substrate and the fire¹⁹. The gases given off are not combustible, and therefore do not contribute to the burn cycle. The gases for example may consist of ammonia, water, or hydrochloric acid³.

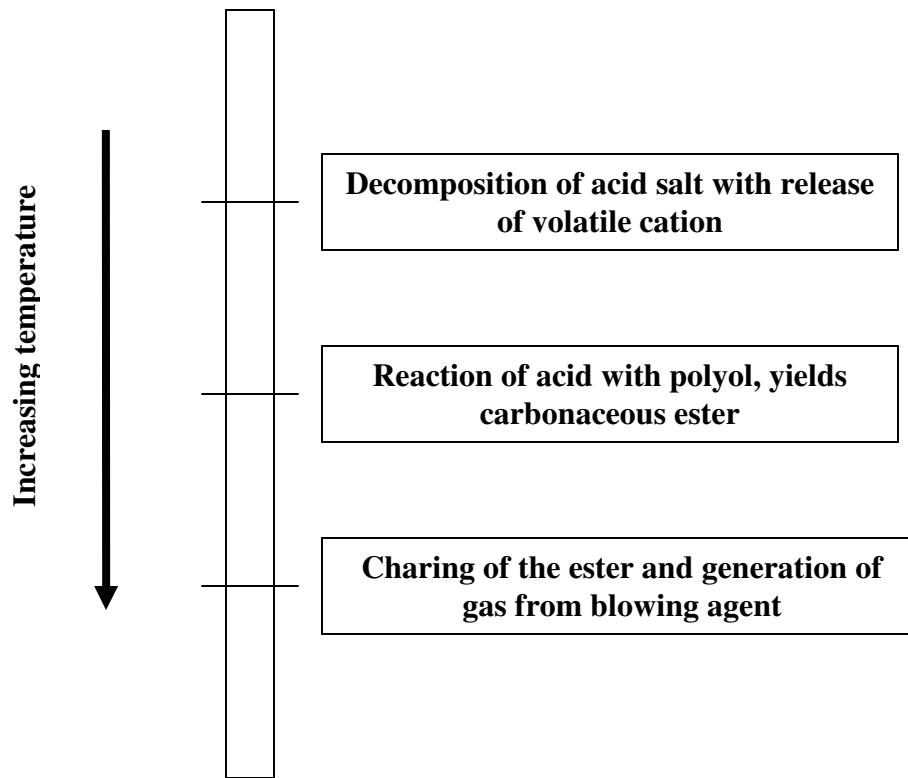


Figure 2-12 Fire Process Connected with Intumescence³

Intumescent systems are favored due to the low environmental concerns surrounding their use. While very effective, a large concern with intumescent systems is the need for special handling during the application process so that the systems work properly³. Other concerns include water solubility and cost¹⁹.

2.8 Durability

Flame retardants fall into three categories: durable, semi-durable, and nondurable. Durable finishes can withstand multiple launderings and are the most complicated to apply. A nondurable finish does not withstand laundering and must be reapplied. Semi-durable treatments fall in between nondurable and durable. Depending on the end use of the product, the durability of the treatment is important. For example, clothes need to have a durable

flame retardant treatment since they are laundered regularly while upholstery fabric would not.

2.9 Testing Methods

There are many test standards available to test the flammability of various products. Table 2-3 in section 2.5 lists several. These tests are important in gauging the safety of a product in terms of both life and property. Depending on the product, the type of flame source, and duration of the exposure to the flame will differ. When exposed to an ignition source, cellulosic, and protein fibers will form char which help to reduce the spread of the flame. Thermoplastic fibers, such as olefin, polyester, and nylon will shrink away from, melt and/or drip when in contact with an ignition source ²⁸.

Many properties are evaluated during burn testing including char length, after-flame and afterglow times, and melt drip. ASTM D 6413-99 defines char length as the distance of visible fiber damage beginning at the bottom edge where the flame was applied. After-flame time is a measurement of how long a substance continues to flame once the ignition source is removed and afterglow is how long a substance glows after the ignition source is removed. Self-extinguishment is defined as when the glowing or flaming of a specimen goes away after the flame source is removed ²⁸.

In the vertical flame test, the specimen is placed in a U-shaped metal frame and is ignited from the bottom. Char length, after-flame, afterglow, and melt drip are all evaluated. Figure 2-12 below shows the set up for a vertical flame test: flame cabinet, vertically mounted fabric sample, and flame source centered at the bottom vertical edge. A horizontal burn test would be set up similarly but with the sample placed horizontally. The flame source is placed at the center of one of the short sided edges.

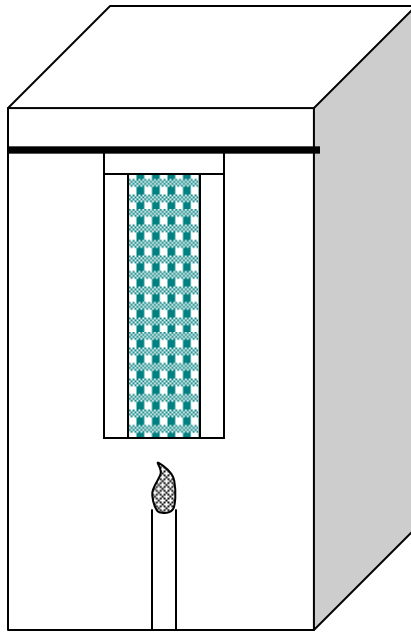


Figure 2-13 Vertical Flame Test Set Up

3 Experimental Design

3.1 Flame Retardant Vendors, Chemicals, Substrates, and Application Methods

Ten non-halogenated and two halogenated flame retardants were obtained from seven vendors. Table 3-1 lists the flame retardant vendors, flame retardant samples, and fabric applications for the nonhalogenated flame retardants. Table 3-2 contains the same information for the brominated flame retardants.

Table 3-1 Non-halogenated Flame Retardant Vendors, Samples, and Fabric Application

Company	Sample	Fabric Application
Apexical, Inc	Flameproof 1528	PET, Nylon, Nonwoven
Glo-tex	Glo-tard NY-22M	Nylon
Glo-tex	Glo-tard NTB	PET
TechTex	Interrupt 4T	PET
TechTex	Ulterion N1000	PET
Amitech, Inc	Pyrozyl M-73	PET
Amitech, Inc	Pyrozyl GOMB	Acrylic/ Other synthetics
Emerald	Pyrosan@SYN	PET/ Acrylic
Nicca USA, Inc	FiNone P-205	PET/Other synthetics
Rhodia	Amgard CT™	PET

Table 3-2 Brominated Flame Retardant Vendors, Samples, and Fabric Application

Company	Sample	Fabric Application
Amitech, Inc	Pyrozyl DTE	Nylon
Apexical, Inc	Flameproof 1506	PET

Table 3-3 and Table 3-4 list the composition of the flame retardants and the application method.

Table 3-3 Non-halogenated Flame Retardant Composition and Application Method

Sample	Composition	Application
Flameproof 1528	Phosphate esters	Pad dry thermosol
Glo-tard NY-22M	Urea Methylol Condensate	Spray/padded
Glo-tard NTB	Phosphonate Ester/ Organophosphate	Spray/padded
Interrupt 4T	Cyclic Phosphonate Esters (Dialkyl alkyl phosphonates)	Pad/dry thermo
Ultrion N1000	Cyclic Phosphonate Ester	Pad dry thermo; latex
Pyrozyl M-73	Phosphorus	Pad dry cure
Pyrozyl GOMB	Phosphoric acid, aqua ammonia	Pad
Pyrosan SYN	Phosphorus	Pad/thermosol
FiNone P-205	Phosphoric acid derivative	Pad dry
Amgard CT	Organic phosphonates, cyclic phosphonate 19.8%	Pad dry thermosol

Table 3-4 Brominated Flame Retardants Sample, Composition, and Application Method

Sample	Composition	Application
Pyrozyl DTE	Cyclic brominated polymer	Exhaust dyeing/Pad application
Flameproof 1506	Polyhalogenated organic phosphate	Exhaust

3.1.1 Percent Solids

The percent solids of each flame retardant were calculated. First, an empty weighing boat was weighed and tared. Next, approximately one gram of each flame retardant was added. The weighing boat was then placed into an oven and dried at 105 °C. The weighing boat was then removed, allowed to cool to room temperature, and weighed. The percent solids was calculated using the following equation:

Equation 1 Percent Solids

Mass of dry FR = (Mass of weighing boat + dry FR) – Mass of weighing boat

% Solids = (Mass of dry FR / Mass of FR added to weighing boat) x 100

Table 3-5 Percent Solids

Flame Retardant	Weighing Boat (g)	FR (g)	Weighing boat + dry FR (g)	Dry FR (g)	% Solids
Amgard CT	1.7	1.1	2.7	1.0	92.3
FiNone P-205	1.7	1.0	2.2	0.5	49.0
Flameproof 1528	1.8	1.0	2.5	0.8	74.4
Pyrosan SYN	1.8	1.1	2.7	1.0	92.2
Pyrozyl GOMB	1.7	1.0	2.2	0.5	44.0
Pyrozyl M-73	1.7	1.0	2.2	0.4	40.5
Ulterion N1000	1.7	1.0	2.7	0.9	91.6
Flameproof 1506	1.7	1.1	2.5	0.7	68.1
Pyrozyl DTE	1.8	1.1	2.4	0.6	57.4

The data in Tables 3-6 and 3-7 were obtained from the vendor Material Safety Data Sheets.

Table 3-6 Percent Actives in FRs

Flame Retardant	% Actives
Amgard CT	> 90
Flameproof 1528	Not Provided
Pyrosan SYN	93.0
Pyrozyl GOMB	Not Provided
Pyrozyl M-73	Not Provided
Ulterion N1000	93.0
Pyrozyl DTE	Not Provided

Table 3-7 Percent Volatiles in FRs

Flame Retardant	% Volatiles
FiNone P-205	9.0
Flameproof 1528	Not Provided
Pyrosan SYN	2.0 – 7.0
Pyrozyl GOMB	Not Provided
Pyrozyl M-73	Not Provided
Flameproof 1506	36-37
Pyrozyl DTE	Not Provided

3.1.2 Substrate Specifications

3.1.2.1 Polyester

Alice Manufacturing Company, Inc. donated 127 yards of unprepared and undyed polyester. The weight of the woven was 4 oz/sq. yard. The weave was 74 PPI by 108 EPI composed of multi filament yarns. The polyester was 72 inches wide in roll form and was cut into 18 inch wide segments using a band saw so that the NCSU padder could be used to apply the flame retardants.

3.1.2.2 Nylon

A nylon/lycra knit was donated to the research by Sara Lee. The nylon knit was 7.5 oz/sq. yard and 60 inches wide in roll form. The construction was a jersey knit with 74 WPI and 100 CPI. The nylon was cut down into 18 inch wide segments by hand. The reason for 18 inch segments was so that the NCSU padder could be used to apply the flame retardants.

3.1.2.3 Acrylic

Glen Raven donated the solution dyed navy blue acrylic. The acrylic woven was 8.6 oz/sq. yard. The weave was 33 PPI by 53 EPI composed of 2 ply spun yarns. The acrylic was 63 inches wide in roll form and 186 yards in length. The roll was cut down into 18 inch wide segments so that the NCSU padder could be used to apply the flame retardants.

3.1.2.4 Nonwoven

The unprepared and undyed nonwoven was donated by Freudenberg. The nonwoven was a 70/30 polyester/nylon hydroentangled blend with a weight of 100 grams per square meter. The nonwoven was 67 inches wide in roll form and was cut down into 18 inch wide segments so that the NCSU padder could be used to apply the flame retardants.

3.2 Testing Methods- Prior to Paddings

3.2.1 Spot Test for Identification of Warp Sizes on Fabrics

The spot test²⁹ consists of placing drops of up to eight solutions onto the textile substrate. A flow chart is used to determine which drops to place in order to identify the presence of PVA, starch, CMC, or another size.

3.2.2 AATCC Test Method 81-2001, pH of the Water-Extract from Wet Processed Textiles

This method was used to test whether or not the fabric had been properly prepared prior to beginning flame retardant treatments. A 10 (+/- 0.1) gram sample of the fabric was cut and placed into 250 mL of distilled water that had been boiling for ten minutes. Once the sample was added and immersed, a watch glass was placed over the beaker. The water was left to boil for an additional ten minutes. Next, the beaker and its contents were cooled to room temperature. The specimen was removed and the excess liquid squeezed into the beaker. A pH meter was used to read the pH of the extract³⁰. If the pH did not fall within a specified pH range, the fabric was sent through the preparation process a second time. pH values ranging from 6-9 were considered acceptable for all substrates in this research.

3.3 NCSU Pilot Plant Padding Applications- Equipment

All the non-halogenated flame retardants were applied in the NCSU Pilot Plant using the W. Mathis AG padder and dried using the W. Mathis AG dryer, as seen in Figure 3-1 and Figure 3-2.



Figure 3-1 NCSU Werner Mathis AG Padder- Rolls Vertical and Flushed



Figure 3-2 NCSU Werner Mathis AG Dryer

3.4 NCSU Pilot Plant Padding Applications- Bath and Equipment Parameters

3.4.1 Padding Bath Parameters

Some of the flame retardant products were recommended to be used only on (a) particular substrate(s). Other products stated that they were recommended for (a) particular synthetic(s) and could possibly be used for others. In these cases, the treatments were applied to all four synthetics (acrylic, polyester, nonwoven, and nylon).

For all treatment baths, the highest recommended amount of flame retardant whether based on weight of bath (owb) or on weight of fabric (owf) was used. The purpose of the research was to find which commercially available flame retardants worked, not the optimization of the chemicals.

Based on initial trials, it was determined necessary to add a wetting agent to some of the treatment baths to ensure adequate wet pick up. In these cases, the wetting agent added was Clariant's Sodyeco Penetrant EH at 2 g/L.

Equation 2 and Equation 3 were used to determine the amount of flame retardant needed either on weight of bath (owb) or on weight of fabric (owf).

Equation 2 Amount of Flame Retardant owb

$(\% \text{ owb}/100) * \text{bath size (mL)} = \text{no. of g of flame retardant needed}$

For example, if 7.5% owb is needed for a 200 mL bath, the result would be 15 g of flame retardant.

$(7.5/100) * 200 \text{ mL} = 15 \text{ g of flame retardant}$

Equation 3 Amount of Flame Retardant owf

$(\% \text{ owf}/100) * \text{fabric weight (g)} = \text{no. of g of flame retardant needed}$

Equation 4 was used to calculate the wet pick up (wpu). Initial wpu checks indicated that it was necessary to add a wetting agent to some of the treatment baths.

Equation 4 Wet Pick Up

$$\text{wpu} = [((\text{Weight of treated sample}) - (\text{weight of untreated sample})) / (\text{weight of untreated sample})] * 100$$

Equation 5 was used to determine if the correct amount of flame retardant was padded on for one of the treatments.

Equation 5 Dry Add-on Calculation

$$\% \text{ dry add on} = (\% \text{ conc in bath} \times \% \text{wpu}) / 100$$

3.4.2 Padder and Dryer Parameters

The paddings were conducted in three rounds. In the first round, the ten available flame retardant treatments were applied to the appropriate substrate(s). The treated samples underwent one and three wash cycles and then vertical burn testing in order to determine which flame retardant/substrate combinations to eliminate. The most promising flame retardants were applied to the appropriate substrate(s) during the second round paddings. After laundering the second round paddings 10 and 25 times, it was concluded that some treated but unwashed samples were needed for physical testing. Therefore, the treatments padded during the second round, were reapplied using the same procedures during the third round paddings.

3.4.2.1 First Round Paddings

The rolls on the padder were set up horizontally and flush with each other in order to form a trough for the bath. The padding and drying were conducted in a batch set up. In the first round of paddings, two 18 x 23 inches samples, were padded for each treatment. Each sample passed through the padder and wpu checks were taken. The padded sample was then placed on tenter frames and placed into the dryer. Treatments needing curing were then

passed through the dryer a second time at the recommended curing temperature and dwell time.

Trough formed due to horizontal placement of padder rolls.

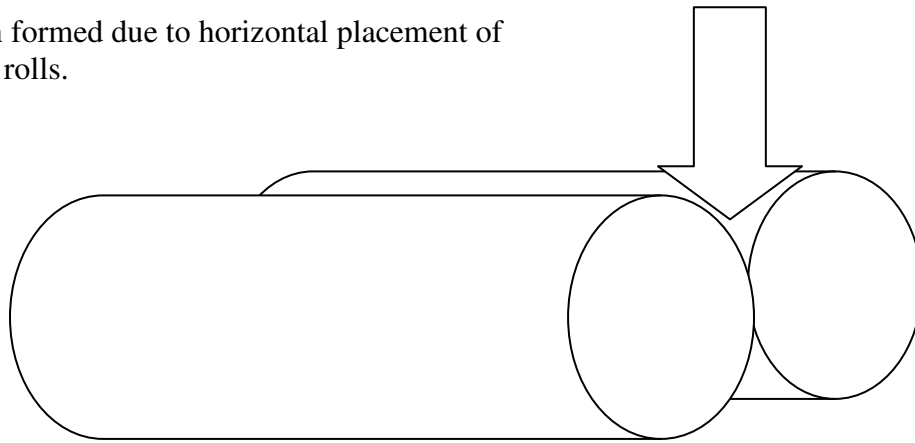


Figure 3-3 Padder Rolls Horizontal and Flush – Batch Process

3.4.2.2 Second and Third Round Paddings

During the second and third round paddings, the rolls were set up vertically and the fabric was drawn through the padder directly into the dryer in a continuous set up.

Treatments needing curing were then passed through the dryer a second time at the recommended curing temperature and dwell time. The second round paddings were conducted on 4-5 yard samples. The third round paddings were approximately 1.5 yards long.

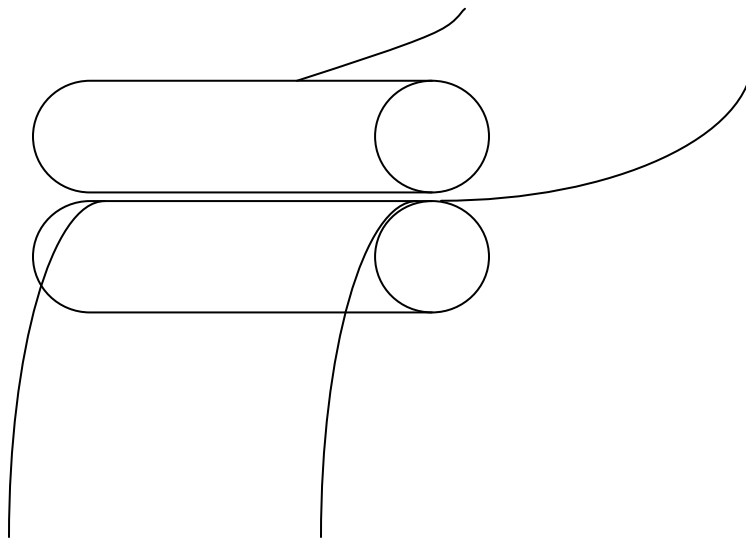


Figure 3-4 Padder Rolls Vertical - Continuous Process

3.4.3 Washer and Dryer Parameters- Durability

A Kenmore washer and dryer were used for the durability portion of the research. The amount of AATCC Standard Reference Detergent without brightener and the temperature of the wash bath were recorded for all wash sets. The temperature was recorded using an Omega Microprocessor thermometer.

AATCC Test Method 130-2000 Soil Release: Oily Stain Release Method³¹ and AATCC Standardization of Home Laundry Test Conditions³² were used to conduct the wash trials in order to determine the durability of the flame retardant treatments. The washers were filled to a medium water level and 100 (+/- 1) grams of AATCC Standard Reference Detergent was added. The wash water temperature was set to warm, 41 +/- 3 °C, though in reality the temperatures ranged from 34 to 47 °C. The wash cycle was set to 12 minutes at a normal setting. Each load was 4.00 (+/- 0.15) pounds (1.80 +/- 0.07 kg) with fewer than 30 treatment samples. Ballast could be added for additional load weight if necessary. For the synthetics, the dryer was set to the normal setting for 20 minutes.

3.5 Testing Methods- After Paddings

3.5.1 Vertical Flame Test - ASTM D 6413-99

ASTM D 6413-99 standard test method for flame resistance of textiles (vertical test) was used to conduct the burn tests. A Tirrill burner with a 99% purity methane gas source was used to apply the flame to a 12"x 3" specimen. The sample was mounted in a sample holder and hung vertically in the flame cabinet. The flame was placed 0.75 inches below the center bottom vertical of the sample and applied for 12 +/- 0.2 seconds. A solenoid valve controller was used to apply the flame for 12 seconds. Afterflame time, melt drip, and char

length were observed, measured, and recorded³³. The flame testing was conducted on untreated samples and both first and second round padding treatments.

3.5.2 Stiffness Testing ASTM D 4032-94 Standard Test Method for Stiffness of Fabric by the Circular Bend Procedure

Two (4 x 8 inch) samples of both untreated and treated substrates were tested at 0 and 25 wash cycles. The treated samples were from the second and third round paddings. The 4 x 8 inch samples were folded in half with the creased side facing the same direction and were placed into the tester. The tester was set for maximum compression. The average of the two specimens was calculated and the stiffness value in pounds was recorded for each sample set

34 .

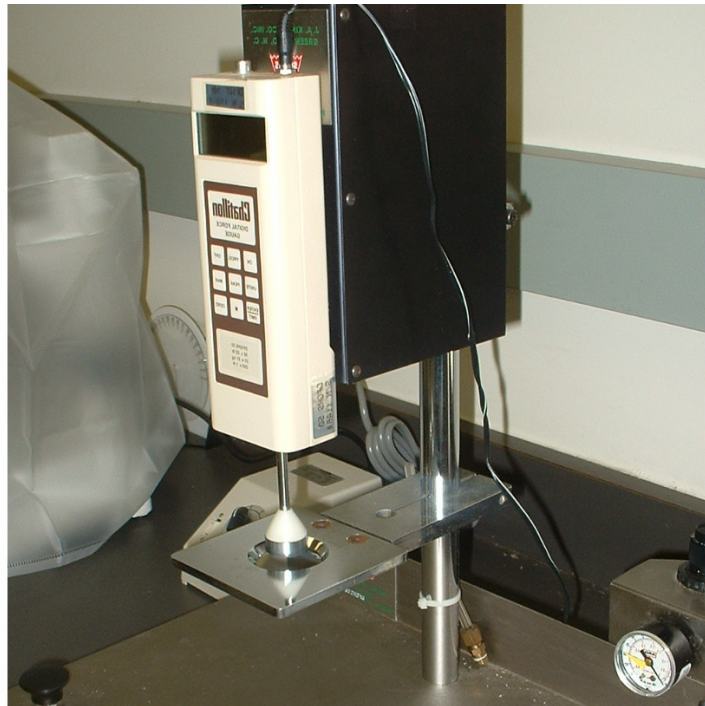


Figure 3-5 Stiffness Tester

3.5.3 Tear Strength Testing – ASTM-D 2261 Tearing of Woven Fabrics by the Tongue (single rip) Method

This test was conducted on the polyester woven and polyester/nylon nonwoven fabrics. Three (3 x 8 inch) samples in both the machine direction and the cross-machine direction were torn using a 1000 lb load³⁵. The tear strength was calculated as the average of the five highest peaks over 3 inches (80 mm) of tear. Untreated and treated samples at 0 and 25 wash cycles were tested. The treated samples were from the second and third round paddings.



Figure 3-6 Sintech Tear Tester

3.5.4 Burst Strength Testing- ASTM D 3786-06

ASTM D3786-06 Standard Test Method for Hydraulic Bursting Strength of Textile Fabrics- Diaphragm Bursting Strength Tester Method was used to test the nylon knit³⁶.

Untreated and treated samples at 0 and 25 washes were tested. The treated samples were from the second and third round paddings. Due to the extensibility of the knit, the fabric was pre-stretched and 3 readings were taken for each sample set. Figure 3-7 shows the equipment used to conduct the burst testing.



Figure 3-7 Mullen Burst Tester

3.5.5 Whiteness Index Testing: AATCC Test Method 110-2000

This test was conducted on the polyester, nonwoven, and nylon fabrics. A spectrophotometer was used to look at the whiteness index of both untreated and treated samples at 0 and 25 washes. The treated samples were from the second and third round paddings. The settings were a 10 degree standard observer using D65 lighting³⁷. Two samples from each sample set were read four times each. After each reading, the fabric samples were turned 90 degrees. The machine was set up with a R/T mode of reflectance where specular was excluded. A 30 mm aperture plate was used.

ΔL^* , Δa^* , Δb^* , and ΔE_{cmc} were obtained from the spectrophotometer readings. A negative ΔL^* value would indicate that the treatment was darker than the standard and a positive value would indicate that a treatment was lighter than the standard. A positive Δa^* value indicates a sample which is redder than the standard and a negative value one which is greener than the standard. A negative Δb^* value indicates a sample is bluer than the standard and a positive value indicates it is yellower. ΔE_{cmc} is a measure of the overall color change. A ΔE_{cmc} value greater than 1 is considered noticeable in the textile industry.

3.5.6 Microwave Digestion and Inductively Coupled Plasma (ICP) Testing

The CEM Corporations Mars 5 Microwave Accelerated Reaction System was used to digest both flame retardant chemicals and flame retardant treated fabrics in preparation for ICP analysis. Depending on the number of samples per run, the wattage applied differed. One to two vessels were digested with 300 watts, three to five vessels were digested at 600 watts, and six or more vessels were digested with 1200 watts.

3.5.6.1 Microwave Digestion and ICP Testing – Flame Retardant Chemicals

Digestion and ICP analysis were conducted to determine the amount of phosphorus in each of the flame retardant chemicals. The vessels for microwave digestion were prepared by measuring two samples less than 0.5 grams of each flame retardant in a weighing boat. The flame retardant was then carefully transferred into a digestion Teflon vessel and rinsed with a few milliliters of HPLC grade deionized water. Next, 10 mL of Nitric acid (69% concentration) was added to each vessel. The vessels were carefully prepared and mounted according to procedure and placed in the microwave. The program was set to ramp to a temperature of 180 °C for 10 minutes. The pressure was set to 800 psi. The temperature was held for 25 minutes and then cooled down.

After digestion, the samples were carefully transferred into 100 mL volumetric flasks with a funnel. The vessel body and cap were carefully rinsed with the HPLC grade deionized water. The volumetric flasks were then filled to the 100 mL mark with HPLC grade deionized water. A 1000 ppm, 500 ppm, and a blank were used as the standards.

3.5.6.2 Microwave Digestion and ICP Testing – Flame Retardant Treated Fabric

3.5.6.2.1 Polyester Woven and Polyester/Nylon Nonwoven

Fabric samples were prepared by cutting less than 0.5 grams of fabric into small strips. The strips were placed into the microwave digestion Teflon vessels. A 2:1 Nitric acid (69% concentration) to Sulfuric acid (98% concentration) bath was prepared. Twenty milliliters of the solution was pipetted into the Teflon vessels. The vessels were then properly mounted and placed into the microwave. The program was set to ramp for 10 minutes to 160 °C where it was held for 30 minutes. The pressure was set to 800 psi. This was followed by a cool down period.

The vessels were dismounted and the digested solution carefully poured using a funnel into either a 50 or 100 mL volumetric flask. The cap and body of the vessel were rinsed with the 2:1 Nitric/Sulfuric solution. The flask was then filled to the 50 or 100 mL mark with the acid solution. A 1000 ppm standard, a 100 ppm standard, and a blank were used as references on the ICP machine.

3.5.6.2.2 Nylon Knit

Fabric samples were prepared by cutting less than 0.5 grams of fabric into small strips. The strips were placed into the microwave digestion Teflon vessels. Ten milliliters of HPLC grade water followed by 10 mL of Nitric Acid (69% concentration) was pipetted into each of the vessels.

Each vessel was then properly mounted and placed into the microwave. The program was set to ramp for 10 minutes to 100 °C where the temperature was held for 30 minutes. The pressure was set to 800 psi. This was followed by a cool down period. The vessels were dismounted and the digested solution carefully placed into either a 50 or 100 mL volumetric

flask. The cap and body of the vessel were rinsed with the 1:1 HPLC water and Nitric acid solution. The flask was then filled to the 50 or 100 mL mark with the acid/water solution depending on the volume of the volumetric flask. A 1000 ppm standard, a 100 ppm standard, and a blank were used as references on the ICP machine.

3.6 Polyester Woven

3.6.1 Preparation of Polyester

3.6.1.1 Identification of Warp Size

The polyester woven underwent spot tests for identification of warp sizes on fabrics as described in section 3.2.1. The polyester was found to have PVA size.

3.6.1.2 Desizing and Scouring Procedure

The polyester was desized and scoured using the NCSU Theis Jet Dye machine. A nonionic surfactant, Kieralon N-F by BASF and defoamer Burst 2000 by Ciba were added to the bath in addition to soda ash. The dwell time for the treatment was thirty minutes at 180 °F. Approximately, fifty-five pounds of fabric were prepared. A defoamer was added to the polyester bath since the fabric was floating on top of the bath. Table 3-8 below shows the preparation bath recipe used for the polyester woven.

Table 3-8 Preparation Recipe for Polyester

Substrate	Liquor Ratio	Temperature (°F)	Na₂CO₃ (g)	Nonionic Surfactant (mL)	Defoamer (g)
Polyester woven	10:1	180	500	200	50

The fabric was then dried on the tenter frame in the Pilot Plant.

3.6.2 AATCC TM 81 – Fabric Water Extract Testing

Prior to treating the polyester with flame retardants, AATCC Test Method 81-2001, pH of the Water-Extract from Wet Processed Textiles, was used to determine that the fabric had been properly prepared as described in section 3.2.2.

3.6.3 NCSU Pilot Plant Padding Applications- First Round

The polyester samples were treated using the padder and dryer as described in section 3.4.2.1. Table 3-9 lists the flame retardant treatments applied to the polyester.

Table 3-9 Flame Retardants for Polyester

Flame Retardant Chemicals
Amgard CT
FiNone P-205
Flameproof 1528
Glo-tard NTB
Interrupt 4T
Pyrozyl M-73
Pyrosan SYN
Pyrozyl GOMB
Ultrion N1000

The first round of paddings consisted of 200 mL baths and the padding and drying of two 18 x 23 inch samples for each treatment. Tables 3-10, 3-11, 3-12, 3-13, and 3-14 below show the specifications for the owb, owf, dry add on treatments as well as the drying and curing parameters. Equations 2, 3, and 5 in section 3.4.1 were used to calculate the amount of flame retardant needed in each treatment. Wet pick up checks, using Equation 4 in section 3.4.1, were calculated for each treatment.

Table 3-10 Polyester owb Treatments

Fabric	Chemical	Bath size (mL)	% owb	Amount of FR (g)	Amount of Wetting Agent (g)	WPU %
Polyester	FiNone P-205	200	30	76.2	0.4	72.22
Polyester	Flameproof 1528	200	15	36.6	0.4	91.89
Polyester	Pyrosan SYN	200	7.5	19.2	0.4	101.0
Polyester	Pyrozyl GOMB	200	40	108	0.4	88.57
Polyester	Pyrozyl M-73	200	15	33.0	0.4	82.40

Table 3-11 Polyester owf Treatments

Fabric	Chemical	Bath size (mL)	% owf	Amount of FR (g)	Amount of Wetting Agent (g)	WPU %
Polyester	Amgard CT	200	6	2.23	0.4	92.10
Polyester	Interrupt 4T	200	3	1.10	0.4	82.85
Polyester	Ulterion N1000	200	6	2.20	0.4	82.85

Table 3-12 Polyester Dry Add On Treatment

Fabric	Chemical	Bath size (mL)	% Dry add on	Amount of FR (g)	Amount of Wetting Agent (g)	WPU %
Polyester	Glottard NTB	200	1.52	2.99	0.4	91.67

For the Rhodia Amgard CT treatment on polyester, the pH of the bath needed to be 6.5 and the vendor recommended 1.5 g/L of soda ash. Initially, 0.3 grams of soda ash was added to the 200 mL bath however the pH went to 10. A second bath was made and 0.1 grams of soda ash was added to the 200 mL bath resulting in a pH of 6.5. The samples were passed through the oven twice to ensure they were properly dried prior to curing.

Table 3-13 Polyester Padder and Dryer Specifications

Fabric	Chemical	Padder pressure (psi)	Drying Temperature (Celsius)	Drying Oven Speed (m/min)	Dryer Dwell Time (mins)
Polyester	FiNone P-205	0.6	121	1.8	1
Polyester	Flameproof 1528	0.6	121	1.8	1
Polyester	Pyrosan SYN	0.6	121	1.8	1
Polyester	Pyrozyl GOMB	0.6	121	1.8	1
Polyester	Pyrozyl M-73	0.6	121	1.8	1
Polyester	Amgard CT	0.6	121	1.8	1
Polyester	Interrupt 4T	0.6	121	1.8	1
Polyester	Ulterion N1000	0.6	121	1.8	1
Polyester	Glottard NTB	0.6	121	1.8	1

Table 3-14 Polyester Curing Parameters

Fabric	Chemical	Curing Temperature (Celsius)	Curing Time (minutes)	Curing Dryer Speed (m/min)
Polyester	FiNone P-205	N/A	N/A	N/A
Polyester	Flameproof 1528	190	0.75	2.5
Polyester	Pyrosan SYN	188	1.5	1.24
Polyester	Pyrozyl GOMB	N/A	N/A	N/A
Polyester	Pyrozyl M-73	188	0.75	2.5
Polyester	Amgard CT	N/A	N/A	N/A
Polyester	Interrupt 4T	196	0.75	2.5
Polyester	Ulterion N1000	196	0.75	2.5
Polyester	Glottard NTB	N/A	N/A	N/A

3.6.3.1 Rinsing After Treatment

The samples treated with Tech Tex Interrupt 4T, Tech Tex Ulterion N1000, Apexical Flameproof 1528, and Rhodia Amgard CT were all rinsed by hand in a 10L bucket with cold

water. The purpose of this was to remove any remaining flame retardant from the substrate surface that was not cured into the fibers. This was recommended by the vendors of the above treatments to improve the hand of the fabrics.

3.6.4 Durability Testing- Wash Trials for 1 and 3 Washes

AATCC Test Method 130-2000 Soil Release as described in section 3.4.3 was used to conduct the wash tests.

Table 3-15 below shows the wash parameters for the elimination of flame retardants based on 1 and 3 washes. The wash load comprised of all treatments conducted on the polyester woven, nylon knit, acrylic woven, and the polyester/nylon nonwoven.

Table 3-15 Wash Parameters for 1 and 3 Washes

Weight of Set (kg)	No. of Launderings	Amount of detergent (g)	Wash Temperature (°C)
1.52	1	100.0	32.0
	2	100.1	30.6
	3	100.0	27.6

3.6.5 Vertical Flame Testing – Elimination of Flame Retardants based on Burn Tests at 1 and 3 Washes

Vertical flame testing was conducted as described in section 3.5.1. Burn tests were conducted after 1 and 3 washes. Any failures at 1 wash would not be burnt at 3 washes since an early failure would be indicative of later failures. Three washes were conducted for an initial determination of the durability of the treatment. One machine direction and one cross-machine direction burns were done for each treatment at 1 wash and three burns in each direction were done at 3 washes. The data for all the treatment combinations were compared. Flame retardants that had char lengths greater than 8 inches were eliminated. Samples that had char lengths greater than 6 inches and after flame times greater than 18 seconds were

flagged. For polyester some flame retardants that fell in the flagged category were eliminated in order to have only five treatments to test in future rounds. The most promising flame retardants for each synthetic substrate were selected for further testing.

3.6.6 NCSU Pilot Plant Padding Applications- Second Round

The padder and dryer specifications were set up as explained in section 3.4.2.2. For polyester five of the nine flame retardants from the first round paddings were continued in the second round. The bath sizes were increased to 800 – 1200 mL since the sample sizes were increased as explained in section 3.4.2.2. Only the most promising flame retardant treatments based on the burn test results at 1 and 3 washes were padded on during the second round. Table 3-16, 3-17, 3-18, and 3-19 below show the bath treatments and padder, dryer, and curing parameters conducted for the second round paddings on polyester.

Table 3-16 Polyester owb Treatment- 2nd Round

Fabric	Chemical	Bath size (mL)	% owb	Amount of FR (g)	Amount of Wetting Agent (g)	WPU %
Polyester	Flameproof 1528	800	15	146	1.6	81.39
Polyester	Pyrosan SYN	800	7.5	76.8	1.6	73.30
Polyester	Pyrozyl M-73	1200	15	132	1.6	81.25

Table 3-17 Polyester owf Treatment- 2nd Round

Fabric	Chemical	Bath size (mL)	% owf	Amount of FR (g)	Amount of Wetting Agent (g)	WPU %
Polyester	Amgard CT	800	4.5	18.0	1.6	78.90
Polyester	Ultrion N1000	1200	4.1	18.1	2.4	80.64

Table 3-18 Polyester Padder and Dryer Specifications – 2nd Round

Fabric	Chemical	Padder pressure (psi)	Drying Temperature (Celsius)	Drying Oven Speed (m/min)
Polyester	Flameproof 1528	0.7	130	0.9
Polyester	Pyrosan SYN	0.7	130	0.9
Polyester	Pyrozyl M-73	0.7	130	0.9
Polyester	Amgard CT	0.7	130	0.9
Polyester	Ulterion N1000	0.7	130	0.9

Table 3-19 Polyester Curing Specifications- 2nd Round

Fabric	Chemical	Curing Temperature (Celsius)	Curing Time (minutes)	Curing Oven Speed (m/min)
Polyester	Flameproof 1528	200	0.75	2.50
Polyester	Pyrosan SYN	200	3.02	0.67
Polyester	Pyrozyl M-73	200	1.5	1.57
Polyester	Amgard CT	200	1.5	1.57
Polyester	Ulterion N1000	200	3.02	0.67

3.6.7 Polyester Exhausted with a Brominated Flame Retardant

In order to have a comparison, a brominated sample was exhausted onto the polyester. The goal was to be able to compare the durability and effectiveness of a brominated sample with the phosphorus based treated samples.

Table 3-20 below shows the bath recipe used to for the polyester bromine treatment.

Table 3-20 Brominated Flame Retardant Bath Parameters for Polyester

Fabric	Chemical	Bath size (mL)	% owf	Amount of FR (g)	Acetic Acid (Glacial) (g)	Defoamer (g)
Polyester	Flameproof 1506	6000	9	23	1.5	6

The defoamer used was Burst 1000. The flame retardant was exhausted on using the Werner Mathis AG Lab Jumbo Jet JFO machine. The temperature was raised to 180 °F and

held for 10 minutes. It was then raised to 265 °F and held for 45 minutes and cooled back down to 180 °F. The pH of the solution was 4.

3.6.8 Durability Testing- Wash Trials for 10 and 25 Washes

The washer and dryer settings were set as described in section 3.4.3. Set one comprised samples of polyester treated with Ulterion N1000, Amgard CT, Pyrosan SYN, and Pyrozyl M-73. Set two comprised one sample of each of the nonwoven, polyester, and nylon all treated with Flameproof 1528 and one sample of the nonwoven treated with FiNone P-205. The wash parameters can be seen in Table E1 in Appendix E. As samples were taken out after 10 washes, wash sets were combined. Additional ballast was added in order to maintain the proper weight of the load.

3.6.9 Vertical Flame Testing – Elimination of Flame Retardants based on Burn Tests at 10 and 25 Washes

ASTM D 6413-99 standard test method for flame resistance of textiles as described in section 3.5.1 (vertical test) was used to conduct the burn tests. Afterflame time, melt drip, and char length were observed, measured, and recorded. This testing was done for three machine and cross-machine direction samples at 10 and 25 washes.

3.6.10 NCSU Pilot Plant Padding Applications- Third Round

A third round of paddings was deemed necessary in order to be able to conduct physical testing on before and after treatment samples. Since all previously padded samples were washed at least once, it was necessary to repad the flame retardants from the second round. The padder and dryer set up was as described in section 3.4.2.2. Table 3-21, Table 3-22, Table 3-23, and Table 3-24 below list the padder, drying, and curing parameters for the third round treatments.

Table 3-21 Polyester owb Treatment- 3rd round

Fabric	Chemical	Bath size (mL)	% owb	Amount of FR (g)	Amount of Wetting Agent (g)	WPU %
Polyester	Flameproof 1528	400	15	73.2	0.8	127.6
Polyester	Pyrosan SYN	400	7.5	38.4	0.8	118.2
Polyester	Pyrozyl M-73	400	15	66.0	0.8	120.7

Table 3-22 Polyester owf Treatment- 3rd round

Fabric	Chemical	Bath size (mL)	% owf	Amount of FR (g)	Amount of Wetting Agent (g)	WPU %	Soda Ash (g)
Polyester	Amgard CT	400	6	5.4	0.8	128.1	0.1
Polyester	Ulterion N1000	400	6	5.4	0.8	114.8	N/A

Table 3-23 Polyester Padder and Dryer Specifications- 3rd round

Fabric	Chemical	Padder pressure (psi)	Drying Temperature (Celsius)	Drying Oven Speed (m/min)
Polyester	Flameproof 1528	0.7	121	0.76
Polyester	Pyrosan SYN	0.7	121	0.76
Polyester	Pyrozyl M-73	0.7	121	0.76
Polyester	Amgard CT	0.7	121	0.76
Polyester	Ulterion N1000	0.7	121	0.76

Table 3-24 Polyester Curing Specifications - 3rd round

Fabric	Chemical	Curing Temperature (Celsius)	Curing Time (minutes)	Curing Oven Speed (m/min)
Polyester	Flameproof 1528	200	0.75	2.50
Polyester	Pyrosan SYN	200	0.67	3.02
Polyester	Pyrozyl M-73	200	1.50	1.57
Polyester	Amgard CT	200	1.50	1.57
Polyester	Ultrion N1000	200	0.67	3.02

3.6.11 Physical Testing

3.6.11.1 Stiffness Testing

Stiffness testing as described in section 3.5.2 was used to test the before and after treatment samples and the 25 wash cycle treated samples.

3.6.11.2 Tear Strength Testing – ASTM-D2261 Tearing of Woven Fabrics by the Tongue (single rip) Method

The Tear Strength testing as described in section 3.5.3 was used to test the before and after treatment samples and the 25 wash cycle treated samples.

3.6.11.3 Whiteness Index Testing

The Whiteness Index testing as described in section 3.5.5 was used to test the before and after treatment samples and the 25 wash cycle treated samples.

3.6.12 Microwave Digestion and ICP analysis

3.6.12.1 Digestion and ICP analysis of Flame Retardant Chemicals used on Polyester

The flame retardants which were not eliminated during the first round of burn testing at 1 and 3 washes were digested and analyzed using ICP. The digestion of the flame retardant chemicals used to treat polyester were conducted as described in sections 3.5.6 and

3.5.6.1. Table 3-25 below shows the flame retardant chemicals and the amounts which were tested using ICP.

Table 3-25 Microwave Digestion of FRs on Polyester

Samples	Grams of FR for Digestion
Flameproof 1528	0.4919
Flameproof 1528	0.4744
Pyrozyl M73	0.4878
Pyrozyl M73	0.4407
Ulterion N1000	0.4600
Ulterion N1000	0.4862
Pyrosan SYN	0.4435
Pyrosan SYN	0.4720
Amgard CT	0.4710
Amgard CT	0.4888

Once microwave digestion was completed, each sample was carefully poured into a 100 mL volumetric flask. Next, the cap and body of the vessel were carefully rinsed with HPLC grade deionized water. This was done meticulously in order to not lose any trace of the sample digestion. Next, ICP testing was conducted to determine the ppm of phosphorus in each of the flame retardants. A 1000 ppm standard, a 500 ppm standard, and a blank were used as references.

3.6.12.2 Digestion and ICP Analysis of Flame Retardant Treated Polyester

Untreated and treated unwashed and 25 wash cycle fabric samples were digested for ICP analysis. The digestion and ICP analysis of the treated polyester fabric occurred as described in section 3.5.6.2.1.

3.7 Nylon Woven

3.7.1 Scouring Procedure

Since it was a knit, the nylon was scoured only. The scouring took place using the Theis Jet and Table 3-26 below shows the specifications used in preparing the fabric. The nonionic surfactant used was Kieralon N-F by BASF. The dwell time for the treatment was thirty minutes. Fifty-two pounds of nylon were prepared.

Table 3-26 Nylon Preparation Recipe

Substrate	Liquor Ratio	Temperature (°F)	Na₂CO₃ (g)	Nonionic Surfactant (mL)
Nylon knit	10:1	180	500	200

The nylon was dried on the tenter frame in the Pilot Plant.

3.7.2 AATCC TM 81 – Fabric Water Extract Testing

AATCC Test Method 81-2001, pH of the Water-Extract from Wet Processed Textiles was used to ensure the fabric had properly been prepared as explained in section 3.2.2.

3.7.3 NCSU Pilot Plant Padding Applications- First Round

The nylon samples were treated using the padder and dryer as described in section 3.4.2.1. Table 3-27 below lists the flame retardant treatments applied to the nylon.

Table 3-27 Flame Retardants for Nylon Knit

Flame Retardants
FiNone P-205
Flameproof 1528
Glo-tard NY22M
Pyrozyl GOMB

The first round of treatments consisted of 200 to 700 mL baths. Wet pick up checks, using Equation 4 in section 3.4.1, were calculated for each treatment. Equation 2 and Equation 3 in section 3.4.1 were used to make sure the correct amount of each flame retardant was added.

Tables 3-28, 3-29, and 3-30 below show the parameters for the padding, drying, and curing of the nylon treatments. The nylon samples underwent two passes through the oven to ensure they were properly dried prior to curing.

Table 3-28 Nylon owb Treatments

Fabric	Chemical	Bath size (mL)	% owb	Amount of FR (g)	WPU %
Nylon	FiNone P-205	200	30	76.2	72.38
Nylon	Flameproof 1528	200	20	48.8	80.00
Nylon	Glottard NY 22M	200	40	88.8	75.80
Nylon	Pyrozyl GOMB	200	40	108	96.99

Table 3-29 Nylon Padder and Dryer Specifications

Fabric	Chemical	Padder pressure (psi)	Drying Temperature (Celsius)	Drying Oven Speed (m/min)
Nylon	FiNone P-205	0.6	121	1.57
Nylon	Flameproof 1528	0.6	121	1.57
Nylon	Glottard NY 22M	0.8	121	1.57
Nylon	Pyrozyl GOMB	0.7	121	1.57

Table 3-30 Nylon Curing Specifications

Fabric	Chemical	Curing Temperature (Celsius)	Curing Time (minutes)	Curing Oven Speed (m/min)
Nylon	FiNone P-205	N/A	N/A	N/A
Nylon	Flameproof 1528	198.8	1	1.81
Nylon	Glottard NY 22M	162	1.5	1.59
Nylon	Pyrozyl GOMB	N/A	N/A	N/A

3.7.3.1 Rinsing After Treatment

As recommended by the vendor, samples treated with Apexical Flameproof 1528 were rinsed by hand in a 10L bucket with cold water in order to remove any uncured flame retardant from the substrate surface.

3.7.4 Durability Testing- Wash Trials for 1 and 3 Washes

AATCC Test Method 130-2000 Soil Release and AATCC Standardization of Home Laundry Test Conditions were used to conduct the durability testing of the treatments as explained in section 3.4.3. The bath parameters can be seen in Table 3-15 in section 3.6.4.

3.7.5 Vertical Flame Testing – Elimination of Flame Retardants based on Burn Tests at 1 and 3 Washes

ASTM D 6413-99 standard test method for flame resistance of textiles (vertical test) was used to conduct the burn tests as described in section 3.5.1. The elimination of the flame retardants was done as specified in section 3.6.5.

3.7.6 NCSU Pilot Plant Padding Applications- Second Round

The bath sizes were increased to 800 – 1050 mL. Only the most promising flame retardant treatments for each substrate were padded on during the second round. In the case of nylon, Flameproof 1528 was kept even though one of the burns was a failure. This was

done since the remaining five samples passed and in order to have two treatments go through further testing in future rounds. Table 3-31, Table 3-32, and Table 3-33 below contain the treatment, drying, and curing parameters of the second round paddings for nylon.

Table 3-31 Nylon owb Treatment - 2nd Round

Fabric	Chemical	Bath size (mL)	% owb	Amount of FR (g)	Amount of Wetting Agent (g)	WPU %
Nylon	Flameproof 1528	800	20	195	1.6	54.4
Nylon	Pyrozyl GOMB	1050	40	567	0	60.6

Table 3-32 Nylon Padder and Dryer Specifications- 2nd Round

Fabric	Chemical	Padder pressure (psi)	Drying Temperature (Celsius)	Drying Oven Speed (m/min)
Nylon	Flameproof 1528	0.7	130	0.9
Nylon	Pyrozyl GOMB	0.7	130	0.9

Table 3-33 Nylon Curing Specifications- 2nd Round

Fabric	Chemical	Curing Temperature (Celsius)	Curing Time (minutes)	Curing Oven Speed (m/min)
Nylon	Flameproof 1528	200	0.75	2.50
Nylon	Pyrozyl GOMB	N/A	N/A	N/A

3.7.7 Nylon Padded with a Brominated Flame Retardant

A brominated flame retardant was available for padding onto nylon. This was done in order to have a comparison between the effectiveness of brominated versus phosphorus treated flame retardants on nylon. Table 3-34 and Table 3-35 below show the treatment, padder and dryer parameters used for the brominated treatment.

Table 3-34 Nylon Treatment with Brominated Flame Retardant

Fabric	Chemical	Bath size (mL)	% owb	Amount of FR (g)	Amount of Wetting Agent (mL)	WPU %
Nylon	Pyrozyl DTE	1000	15	150	20	83.5

Table 3-35 Nylon Padder and Dryer Specifications

Fabric	Chemical	Padder pressure (psi)	Drying Temperature (Celsius)	Drying Oven Speed (m/min)
Nylon	Pyrozyl DTE	0.7	140	0.9

3.7.8 Durability Testing- Wash Trials for 10 and 25 Washes

Set two comprised of a sample of the nonwoven, polyester, and nylon treated with Flameproof 1528 and a nonwoven treated with FiNone P-205. Set three comprised of both the nonwoven and nylon treated with Pyrozyl GOMB and polyester treated with Flame 1506 and nylon treated with Pyrozyl DTE. The bath parameters can be seen in Table E1 in Appendix E.

3.7.9 Vertical Flame Testing – Elimination of Flame Retardants based on Burn Tests at 10 and 25 Washes

As with polyester, ASTM D 6413-99 standard test method for flame resistance of textiles (vertical test) was used to conduct the burn tests as described in section 3.5.1. The second round of vertical flame testing was conducted as described in section 3.6.9.

3.7.10 NCSU Pilot Plant Padding Applications- Third Round

As described in section 3.6.10 it was necessary to conduct a third round of paddings.

Table 3-36, Table 3-37, and Table 3-38 below lists the padder, drying, and curing parameters for the third round treatments.

Table 3-36 Nylon owb Treatments- 3rd round

Fabric	Chemical	Bath size (mL)	% owb	Amount of FR (g)	Amount of Wetting Agent (g)	WPU %
Nylon	Flameproof 1528	800	20	195	1.6	120.95
Nylon	Pyrozyl GOMB	1050	40	567	2	105.15

Table 3-37 Nylon Padder and Dryer Specifications - 3rd round

Fabric	Chemical	Padder pressure (psi)	Drying Temperature (Celsius)	Drying Oven Speed (m/min)
Nylon	Flameproof 1528	0.7	121	0.76
Nylon	Pyrozyl GOMB	0.7	121	0.76

Table 3-38 Nylon Curing Specifications- 3rd round

Fabric	Chemical	Curing Temperature (Celsius)	Curing Time (minutes)	Curing Oven Speed (m/min)
Nylon	Flameproof 1528	200	0.75	2.50
Nylon	Pyrozyl GOMB	N/A	N/A	N/A

3.7.11 Physical Testing

3.7.11.1 Stiffness Testing

Stiffness testing as described in section 3.5.2 was used to test the before and after treatment samples and the treated with 25 wash cycle samples.

3.7.11.2 Burst Strength Testing

ASTM D3786-06 Standard Test Method for Hydraulic Bursting Strength of Textile Fabrics- Diaphragm Bursting Strength Tester Method was used to test the nylon as described in section 3.5.4.

3.7.11.3 Whiteness Index Testing

The Whiteness Index testing as described in section 3.5.5 was used to test the before and after treatment samples and the treated with 25 wash cycle samples.

3.7.12 Microwave Digestion and ICP analysis

3.7.12.1 Digestion and ICP analysis of Flame Retardant Chemicals used on Nylon

The digestion of the flame retardant chemicals used to treat nylon was conducted as described in section 3.5.6.1.

Table 3-39 below shows the flame retardants which underwent microwave digestion and ICP analysis.

Table 3-39 Microwave Digested FRs on Nylon

Samples	Grams of FR for Digestion
Flameproof 1528	0.4919
Flameproof 1528	0.4744
Pyrozyl GOMB	0.4839
Pyrozyl GOMB	0.4825

Once microwave digestion was completed, the cap and body of the vessel were carefully rinsed with HPLC grade deionized water in order to not lose any trace chemicals. Next, ICP testing was conducted to determine the ppm of phosphorus in each of the flame retardants. A 1000 ppm standard, a 500 ppm standard, and a blank were used as references.

3.7.12.2 Digestion and ICP Analysis of Flame Retardant Treated Nylon

Untreated and 0 and 25 wash cycle treated samples underwent digestion and ICP analysis. The fabric samples for microwave digestion were prepared for ICP analysis as described in section 3.5.6.2.2.

3.7.13 Stretching of Nylon

During the course of the paddings and dryings, it was observed that the nylon was under tension. The calculation of the add-on results for Flameproof 1528 resulted in negative values. After visually inspecting the fabric and counting courses and wales, it was hypothesized that the nylon had stretched and heat set during processing. The following experiment was conducted to determine under which conditions nylon would stretch and remain stretched.

Six samples (18 x 22 inches) were treated according to Table 3-40 below. A 4 x 4 inch square was drawn on each of the samples prior to padding. The Flameproof 1528 treatment bath was prepared as described in sections 3.7.6 and 3.7.10 during the second and third round paddings. The samples treated with water were allowed to soak between ten and fifteen minutes.

Table 3-40 Nylon Stretch Padding Conditions

Treatment	Conditions
Water	Padded, dried at 121°C
Water	Padded, dried at R.T. under tension
Water	Padded , dried at 121°C under tension
Flameproof 1528	Padded, dried at 121°C
Flameproof 1528	Padded, dried at R.T. under tension
Flameproof 1528	Padded , dried at 121°C under tension

The experiment was set up to identify under which drying conditions, at 121 °C or room temperature (R.T.), with or without tension, and padded with water or the Flameproof 1528 would result in stretching. The nylon was put under tension by having the researcher

pull on it as tightly as possible and attaching it to a tenter frame. Therefore, variation in the amount of tension the samples were placed under was expected.

3.8 Acrylic Woven

3.8.1 Preparation of Acrylic

3.8.1.1 Identification of Warp Size

The acrylic woven was scoured and desized in the NCSU Pilot Plant. The acrylic woven underwent spot tests for identification of warp sizes on fabrics as described in section 3.2.1. The acrylic was negative for CMC, PVA, and starch but was identified as having some other size. It was concluded that an acrylic size had been used.

3.8.1.2 Desizing and Scouring Procedure

The acrylic was desized and scoured using the NCSU Theis Jet Dye machine. Table 3-41 below shows the specifications used in preparing the acrylic. The nonionic surfactant used was Kieralon N-F by BASF. A 30 minute dwell time was used for the fifty pounds of acrylic prepared.

Table 3-41 Preparation Recipe for Acrylic

Substrate	Liquor Ratio	Temperature (°F)	Na₂CO₃ (g)	Nonionic Surfactant (mL)
Acrylic woven	10:1	140	500	200

The acrylic ran down the tenter frame to be dried.

3.8.2 AATCC TM 81 – Fabric Water Extract Testing

AATCC Test Method 81-2001, pH of the Water-Extract from Wet Processed Textiles was used to determine that the fabrics had been properly prepared prior to treating them with flame retardant finishes as described in section 3.2.2.

3.8.3 NCSU Pilot Plant Padding Applications- First Round

As described in section 3.4.2.1, the first round paddings were conducted. The first round of treatments consisted of two 18 x 23 inch samples in 300 to 700 mL baths.

The initial acrylic treatment (Pyrozyl GOMB) received 2 g/L of Clariant's Sodyeco Penetrant EH wetting agent. Wet pick up checks, using Equation 4 in section 3.4.1 were calculated for each treatment. It was determined unnecessary to include a wetting agent to the remaining acrylic baths.

Equation 2 and Equation 3 in section 3.4.1 were used to make sure the correct amount of each flame retardant was added. Table 3-42 below shows the flame retardants which were padded onto the acrylic woven.

Table 3-42 Flame Retardants for Acrylic

Flame Retardants
FiNone P-205
Pyrosan SYN
Pyrozyl GOMB

Table 3-43, Table 3-44, and Table 3-45 below show the treatment, padding, drying, and curing specifications for the acrylic paddings.

Table 3-43 Acrylic owb Treatments

Fabric	Chemical	Bath size (mL)	% owb	Amount of FR (g)	Amount of Wetting Agent (g)	WPU %
Acrylic	FiNone P-205	500	30	190.5	0	106
Acrylic	Pyrosan SYN	300	15	57.6	0	103
Acrylic	Pyrozyl GOMB	700	40	378	1.4	136

A joint Pyrozyl GOMB bath was made for the treatment of acrylic and the polyester/nylon nonwoven. Since the wet pick up checks were over 100% for the acrylic treatments, the wetting agent was excluded from the remaining acrylic and nonwoven baths. For the Nicca FiNone P-205 treatment, a joint 500 mL bath was prepared for the acrylic and polyester samples.

Table 3-44 Acrylic Padder and Dryer Specifications

Fabric	Chemical	Padder pressure (psi)	Drying Temperature (Celsius)	Drying Oven Speed (m/min)	Oven Dwell Time (mins)
Acrylic	FiNone P-205	1	121	0.67	3
Acrylic	Pyrosan SYN	1	121	0.67	3
Acrylic	Pyrozyl GOMB	0.6	121	0.67	3

Since the wet pick up of acrylic was over 100%, the padder was set to a psi of 1.0 instead of 0.6 psi for two of the baths to ensure that enough bath solution remained for all treatment samples.

Table 3-45 Acrylic Curing Specifications

Fabric	Chemical	Curing Temperature (Celsius)	Curing Time (minutes)	Curing Oven Speed (m/min)
Acrylic	FiNone P-205	N/A	N/A	N/A
Acrylic	Pyrosan SYN	190	0.75	2.5
Acrylic	Pyrozyl GOMB	N/A	N/A	N/A

3.8.4 Durability Testing- Wash Trials for 1 and 3 Washes

AATCC Test Method 130-2000 Soil Release and AATCC Standardization of Home Laundry Test Conditions were used to conduct the durability testing of the treatments as explained in section 3.4.3. These samples were in bath set one and the parameters can be

seen in Table 3-15 in section 3.6.4.

3.8.5 Vertical Flame Testing – Elimination of Flame Retardants based on Burn Tests at 1 and 3 Washes

ASTM D 6413-99 standard test method for flame resistance of textiles (vertical test) was used to conduct the burn tests as explained in section 3.5.1. The elimination of the flame retardants was conducted as specified in section 3.6.5.

3.9 Polyester/Nylon Nonwoven

3.9.1 NCSU Pilot Plant Padding Applications- First Round

The first round of treatments consisted of 200 to 700 mL baths and the padding and drying of two 18 x 23 inch samples for each of the flame retardants listed in Table 3-46. Treatments were processed as described in section 3.4.2.1.

Wet pick up checks, using Equation 4 in section 3.4.1, were calculated for each treatment. The baths included 2 g/L of Clariant’s Sodyeco Penetrant EH wetting agent.

Equation 2 in section 3.4.1 was used to determine the amount flame retardant needed. Table 3-46 lists the treatments that were applied to the nonwoven.

Table 3-46 Flame Retardants for Nonwoven

Flame Retardants
FiNone P-205
Flameproof 1528
Pyrozyl GOMB

Table 3-47, Table 3-48, and Table 3-49 list the treatment, padding, drying, and curing parameters for the nonwoven treatments during the first round.

Table 3-47 Nonwoven owb Treatments

Fabric	Chemical	Bath size (mL)	% owb	Amount of FR (g)	Amount of Wetting Agent (g)	WPU %
Nonwoven	FiNone P-205	200	30	76.2	0.4	284.6
Nonwoven	Flameproof 1528	200	20	48.8	0.4	214.3
Nonwoven	Pyrozyl GOMB	700	40	378	1.4	208.3

A joint Pyrozyl GOMB bath was made for the treatment of acrylic and the polyester/nylon nonwoven. The wet pick up checks for the Pyrozyl GOMB and Flameproof 1528 treatments indicated that a wetting agent was not necessary for the remaining nonwoven treatments.

Table 3-48 Nonwoven Padder and Dryer Specifications

Fabric	Chemical	Padder pressure (psi)	Drying Temperature (Celsius)	Drying Oven Speed (m/min)
Nonwoven	FiNone P-205	0.6	121	1.8
Nonwoven	Flameproof 1528	0.6	121	1.8
Nonwoven	Pyrozyl GOMB	0.6	121	1.57

Table 3-49 Nonwoven Curing Specifications

Fabric	Chemical	Curing Temperature (Celsius)	Curing Time (minutes)	Curing Oven Speed (m/min)
Nonwoven	FiNone P-205	N/A	N/A	N/A
Nonwoven	Flameproof 1528	190	0.75	2.5
Nonwoven	Pyrozyl GOMB	N/A	N/A	N/A

3.9.2 Durability Testing- Wash Trials for 1 and 3 Washes

AATCC Test Method 130-2000 Soil Release and AATCC Standardization of Home Laundry Test Conditions were used to conduct the durability testing of the treatments as explained in section 3.4.3. The samples were part of bath set number one and the parameters can be seen in Table 3-15 in section 3.6.4.

3.9.3 Vertical Flame Testing – Elimination of Flame Retardants based on Burn Tests at 1 and 3 Washes

ASTM D 6413-99 standard test method for flame resistance of textiles (vertical test) was used to conduct the burn tests as described in section 3.5.1 with the elimination carried out as specified in section 3.6.5.

3.9.3.1 Rinsing After Treatment

As recommended by the vendor, the samples treated with Apexical Flameproof 1528 were rinsed in a 10L bucket with cold water as explained in section 3.6.3.1.

3.9.4 NCSU Pilot Plant Padding Applications- Second Round

The bath sizes were increased to 800 – 1050 mL. Only the most promising flame retardant treatments for each substrate were padded on during the second round. The FiNone P-205 sample was kept since only one sample out of the six failed. The equipment was set up as described in section 3.4.2.2. Table 3-50, Table 3-51, and Table 3-52 below show the treatment, padder, dryer, and curing parameters used to treat the nonwoven during the second round of paddings.

Table 3-50 Nonwoven owb Treatment - 2nd Round

Fabric	Chemical	Bath size (mL)	% owb	Amount of FR (g)	WPU %
Nonwoven	FiNone P-205	800	30	304.8	180.0
Nonwoven	Flameproof 1528	800	20	195.2	168.2
Nonwoven	Pyrozyl GOMB	1050	40	567	208.3

Table 3-51 Nonwoven Padder and Dryer Specifications – 2nd round

Fabric	Chemical	Padder pressure (psi)	Drying Temperature (Celsius)	Drying Oven Speed (m/min)
Nonwoven	FiNone P-205	0.7	130	0.9
Nonwoven	Flameproof 1528	0.7	130	0.9
Nonwoven	Pyrozyl GOMB	0.7	130	0.9

Table 3-52 Nonwoven Curing Specifications- 2nd Round

Fabric	Chemical	Curing Temperature (Celsius)	Curing Time (minutes)	Curing Oven Speed (m/min)
Nonwoven	FiNone P-205	N/A	N/A	N/A
Nonwoven	Flameproof 1528	200	0.75	2.50
Nonwoven	Pyrozyl GOMB	N/A	N/A	N/A

3.9.5 Durability Testing- Wash Trials for 10 and 25 Washes

The washer and dryer settings were set as described in section 3.4.3. Set two contained a sample of the nonwoven treated with Flameproof 1528 and a sample treated with FiNone P-205. Set three contained the nonwoven sample treated with Pyrozyl GOMB.

3.9.6 Vertical Flame Testing – Elimination of Flame Retardants based on Burn Tests at 10 and 25 Washes

ASTM D 6413-99 standard test method for flame resistance of textiles (vertical test)

was used to conduct the burn tests as described in section 3.5.1. The number of burns was the same as in the case of polyester as described in section 3.6.9.

3.9.7 NCSU Pilot Plant Padding Applications- Third Round

A third round of paddings was deemed necessary in order to be able to conduct physical testing of before and after treatment samples since all previously treated samples had undergone at least one laundering.

Table 3-53, Table 3-54, and Table 3-55 below list the padder, drying, and curing parameters for the third round treatments.

Table 3-53 Nonwoven owb Treatments- 3rd round

Fabric	Chemical	Bath size (mL)	% owb	Amount of FR (g)	Amount of Wetting Agent (g)	WPU %
Nonwoven	FiNone P-205	400	30	152	0	331.6
Nonwoven	Flameproof 1528	800	20	195	1.6	330.4
Nonwoven	Pyrozyl GOMB	1050	40	567	2	305.0

Table 3-54 Nonwoven Padder and Dryer Specifications- 3rd round

Fabric	Chemical	Padder pressure (psi)	Drying Temperature (Celsius)	Drying Oven Speed (m/min)
Nonwoven	FiNone P-205	0.7	121	0.76
Nonwoven	Flameproof 1528	0.7	121	0.76
Nonwoven	Pyrozyl GOMB	0.7	121	0.76

Table 3-55 Nonwoven Curing Specifications- 3rd round

Fabric	Chemical	Curing Temperature (Celsius)	Curing Time (minutes)	Curing Oven Speed (m/min)
Nonwoven	FiNone P-205	N/A	N/A	N/A
Nonwoven	Flameproof 1528	200	0.75	2.50
Nonwoven	Pyrozyl GOMB	N/A	N/A	N/A

3.9.8 Physical Testing

3.9.8.1 Stiffness Testing

Stiffness testing as described in section 3.5.2 was used to test the before and after treatment samples and the 25 wash cycle treated samples.

3.9.8.2 Tear Strength Testing – ASTM-D2261 Tearing of Woven Fabrics by the Tongue (single rip) Method

The Tear Strength testing as described in section 3.5.3 was used to test the before and after treatment samples and the 25 wash cycle treated samples.

3.9.8.3 Whiteness Index Testing

The Whiteness Index testing as described in section 3.5.5 was used to test the before and after treatment samples and the 25 wash cycle treated samples.

3.9.9 Microwave Digestion and ICP analysis

3.9.9.1 Digestion and ICP analysis of Flame Retardant Chemicals used on the Nonwoven

The flame retardants which were not eliminated during the first round of burn testing at 1 and 3 washes were digested and analyzed using ICP. The digestions of the flame retardant chemicals used to treat the nonwoven were conducted as described in section

3.5.6.1. Table 3-56 below shows the flame retardant chemicals and the amounts which were tested using ICP.

Table 3-56 Microwave Digested FRs on Nonwoven

Samples	Grams of FR for Digestion
Flameproof 1528	0.4919
Flameproof 1528	0.4744
Pyrozyl GOMB	0.4839
Pyrozyl GOMB	0.4825
Nicca FiNone P-205	0.4774
Nicca FiNone P-205	0.4846

3.9.9.2 Digestion and ICP Analysis of Flame Retardant Treated Nonwoven

Untreated and 0 and 25 wash cycle treated samples were digested and underwent ICP analysis. The fabric samples were treated as described in section 3.5.6.2.1 for microwave digestion in order to undergo ICP testing.

4 Results and Discussion

4.1 Statistical Analysis

Statistical analysis was conducted on the data collected from the burn tests, stiffness tests, tear strength tests, and burst strength tests. The purpose of the analysis was to determine if one or more of the treatments (phosphorus, brominated) differed statistically from the untreated samples and the other treated samples. Furthermore, if there was a statistical difference with the phosphorus treatments, the objective was to determine if the difference was an improvement over the untreated and the brominated treated samples. For the burn data, the char lengths for each treatment type (phosphorus and brominated) were analyzed against one another and against the untreated samples in both the machine (warp) and cross-machine (fill) direction burns. Further analyses, were conducted for selected phosphorus treatments in order to determine which, if any, were the most promising. The burn analysis was conducted at 3, 10, and 25 wash cycles for the polyester, nylon, and nonwoven substrates. The tear strength performances of the polyester and nonwoven substrates in the machine direction (fill yarn) tear and cross-machine (warp yarn) tear of untreated and treated samples (0 and 25 wash cycles) were compared against each other. In the case of the knitted nylon, burst strength testing was conducted instead of tear testing. The results of the stiffness testing were also analyzed for the three substrates for the treated and the untreated samples. The analysis was broken down into unwashed and 25 wash cycle samples.

The analysis was divided into three parts: Normality, Variance, and Means.

Normality: The normality was checked by determining if the residuals from the ANOVA testing were normally distributed. A normal quantile plot, a Goodness of Fit test, and the p-value from the Shapiro-Wilk test were used to determine the distribution

of the data. A p-value greater than 0.05 would indicate that the data were normally distributed.

Variances: Next, the variances were tested to see if they were equal. If the data were normally distributed, the Bartlett p-values were used to determine if the variances were the same. If the data were not normal, the Levene p-value was used. A p-value less than 0.05 would indicate that there was a statistical difference in the variances of the groups of data.

When necessary, a nonparametric method, the Wilcoxon test, was also used. This type of test does not assume that there is a normal distribution and is used to test if the means or medians are the same from group to group. A Chi value less than 0.05 would indicate that there was a statistical difference between the groups.

Means: In ANOVA, the F-test is used to compare two or more groups of data. The diamonds in the plot represent the means where the middle line is the response group mean and the endpoints form the 95% confidence interval for the mean. The F-statistic is a ratio of the Mean Squares (MS) where the ratio is Model MS/Total MS. Mean squares are estimates of variance. A p-value ($\text{prob} > F$) of 0.05 or less indicates that there is a statistical difference in the means of the groups being analyzed.

The Tukey-Kramer analysis method was also used to determine if there was a significant difference. In this analysis, comparison circles are used to determine if differences exist. For example, if someone wants to determine if there is a difference between Treatment A and the remaining treatments they would click on Treatment A's circle resulting in it becoming a highlighted red circle. Any other treatments whose circles also turned red would not be significantly different from the highlighted treatment.

Treatments whose circles turned gray would be significantly different from the red highlighted treatment.

The results from the three parts of the analysis were then used to determine if a significant difference existed overall. Table 4-1 was used to determine which p-value to use for the final determination.

Table 4-1 Statistical Analysis

Normality	Variance	Test used for determining significant differences
Y	N	ANOVA
Y	Y	Welch's ANOVA
N	N	Nonparametric
N	Y	Nonparametric

After plotting the data and looking at the distribution, the following questions were asked:

1. Are the data normally distributed? Y or N (Determined by variance of analysis p-value)
2. Are the variances statistically different? Y or N (Use Levene or Bartlett p-value depending if data are or are not normal)

Based on these responses, the p-value from the appropriate test method would be used to determine overall whether or not there was a statistical difference.

For example, data that had a p-value of 0.08 for distribution would be considered normal. Therefore, the Bartlett p-value would be used to determine if the variances were the same. A Bartlett p-value of 0.12 would be described as not significantly different and

therefore the p-value from the ANOVA (analysis of variance) would be used to determine if a significant difference existed overall.

Since the data sets were small, the ANOVA analysis was not always able to detect a significant difference. Therefore, the burn data for two of the substrates was also analyzed by fitting it to a model since it was hypothesized that a difference existed. By fitting the data to a model, one can determine which effects affect a particular response and allows the data to be grouped into larger sample sets. For example, if one wanted to determine what affected the response of char length, then the effects of wash cycles, burn direction, and treatment could be tested to determine whether they and the interactions between them had a significant effect. By fitting the data to a model, more data is analyzed. For example, when analyzing the cross-machine direction burns, the data set would include the three burns from each of the three wash cycle levels (3, 10, 25). While with the ANOVA analysis, only the three cross-machine direction burns at a particular wash cycle were analyzed together.

4.2 Polyester Woven

4.2.1 AATCC TM 81 – Fabric Water Extract Testing Results

The polyester pH was measured to be 6.33. Since the reading was between 6 and 9, it was considered acceptable, and the substrate did not have to undergo preparation a second time.

4.2.2 Vertical Flame Testing- Elimination of Flame Retardants based on Burn Tests Results at 1 and 3 Washes

Burn tests were conducted in both the machine and cross-machine directions of the fabric. The data from the burns can be seen in Appendix A, Tables A1 – A2.

Initially, treatments with a char length greater than 8 inches were eliminated. However, this resulted in more than five treatments remaining, and therefore treatments which had multiple burns over 7 inches were also eliminated. Based on the vertical burn test results, treatments Amgard CT, Flameproof 1528, Pyrosan SYN, Pyrozyl M-73, and Ulterion N-1000 were selected. ANOVA analysis was conducted on the burn results of the untreated, unwashed polyester and the treated samples that underwent 3 wash cycles. These results can be seen in Table A3 in Appendix A. Since the data were not normally distributed, the nonparametric method (Wilcoxon Test) p-value was used. The analysis shows that there is a statistical difference between the char lengths of the treated and untreated samples in both the machine and cross-machine burn directions. The placement of the ANOVA diamond plots, shows that the phosphorus based treated samples had a reduced char length compared to the untreated in both burn directions. Furthermore, the plots show that the Flameproof 1506 (brominated) treatment had the lowest char length in both burn directions. For example, in the cross-machine burn direction, the untreated samples have a mean burn of 8.15 inches while the phosphorus based samples ranged from 4.23 to 5.23 inches, a 36 – 48% reduction in char length. The brominated flame retardant had the smallest mean burn in the cross-machine direction at 2.21 inches, a 73% reduction.

Further ANOVA analysis, with the addition of the Tukey-Kramer analysis, were used to determine which phosphorus treatments were as effective as the brominated treatment. The results can be seen in Table A4. In the Tukey-Kramer analysis, the char lengths of the phosphorus treated samples were compared to the brominated treatment. The Tukey-Kramer results show that in the cross-machine direction, the brominated

treatment (Flameproof 1506) is significantly different (lower char lengths) from all the phosphorus treatments. However, in the machine direction burns, Flameproof 1528, Pyrosan SYN, and Pyrozyl M-73 are not significantly different from the brominated treatment.

Table 4-2 below shows whether the phosphorus treatments are significantly different from the brominated treatment. In conclusion, not all of the phosphorus based treatments were as effective as the brominated treatment.

Table 4-2 Comparison of Brominated and Phosphorus Treatments in Burn Performance (3 w)

	CMD Significantly Different	CMD Not Significantly Different	MD Significantly Different	MD Not Significantly Different
Amgard CT	X		X	
Flameproof 1528	X			X
Pyrosan SYN	X			X
Pyrozyl M-73	X			X
Ulterion N1000	X		X	

In the analysis comparing the phosphorus treatments to one another, no statistical difference was found in either burn direction as seen in Table A5. However, as mentioned above, there is a statistical difference between some of the phosphorus treatments and the brominated. The overall results found that in terms of the machine direction burns, there were three treatments, Flameproof 1528, Pyrosan SYN, and Pyrozyl M-73 which were as effective as the brominated. However, in the cross-machine

direction burns, none of the treatments were found to be as effective as the brominated treatment.

4.2.3 Vertical Flame Testing –Burn Tests Results at 10 and 25 Washes

The most promising flame retardants, listed in Tables 3-16 and 3-17 in section 3.6.6, were padded during the second and third round paddings. The treatments from the second round paddings underwent 10 and 25 wash cycles and vertical flame testing at these wash cycle intervals. The results for these burns can be seen in Tables A6 and A10 of Appendix A. The data were not normally distributed for both sets, and the nonparametric method (Wilcoxon Test) p-value was used. ANOVA analysis was conducted on the burn results of the untreated, unwashed samples and the 10 and 25 wash cycle treated samples. The analysis considered the number of wash cycles and the burn direction. The analysis for the 10 wash cycle samples is seen in Table A7 in Appendix A. The data showed that there was no significant difference between treated samples at 10 washes and the untreated in the cross-machine direction, but there was a statistical difference in the machine direction. However, even though a significant difference was not found in the cross-machine direction, the phosphorus treatments reduced the char length between 35 – 48% while the brominated treatment reduced it by 65%. A second analysis was conducted at 10 washes where the treated samples were compared to one another as shown by Table A8. The analysis concluded that there was a statistical difference between the treatments at 10 washes where again, the brominated flame retardant had the lowest mean char length in both directions. A significant difference was found between the brominated treatment and Flameproof 1528 and Pyrozyl M-73 in the cross-machine direction burns and between the brominated treatment and Amgard CT

in the machine direction. The results of the comparison of the phosphorus treatments to the brominated treatment can be seen in Table 4-3 below. In conclusion, two flame retardants, Pyrosan SYN and Ulterion N1000, were not significantly different from the brominated treatment in either burn direction.

Table 4-3 Comparison of Brominated and Phosphorus Treatments in Burn Performance (10 w)

	CMD Significantly Different	CMD Not Significantly Different	MD Significantly Different	MD Not Significantly Different
Amgard CT		X	X	
Flameproof 1528	X			X
Pyrosan SYN		X		X
Pyrozyl M-73	X			X
Ulterion N1000		X		X

Further analysis was conducted at 10 wash cycles and found there was no statistical difference among the phosphorus treatments as seen in Table A9.

At 25 washes (treated and untreated), there was a statistical difference in the machine direction burns with the untreated having a much higher char length as seen in Table A 11 in Appendix A. While a significant difference was not found in the cross-machine direction, the phosphorus treatments reduced the char length between 33 – 46% and the brominated by 46%.

Table 4-4 below shows the results of the comparison of the brominated and phosphorus treatments. When the analysis was conducted on the treatments alone, no statistical difference was found. The analysis can be seen in Table A 12 of Appendix A.

Table 4-4 Comparison of Brominated and Phosphorus Treatments in Burn Performance (25 w)

	CMD Significantly Different	CMD Not Significantly Different	MD Significantly Different	MD Not Significantly Different
Amgard CT		X		X
Flameproof 1528		X		X
Pyrosan SYN		X		X
Pyrozyl M-73		X		X
Ulterion N1000		X		X

The results from the 3, 10, and 25 wash cycles indicates that at the lower wash cycles the brominated flame retardant was more effective than some of the phosphorus treatments, but at higher wash cycles, no difference was found between the treatments.

Next, the data was fit to a model since the data indicated that the brominated treatment was not as durable as the phosphorus treatments. This was hypothesized since the percentage by which the brominated treatment reduced char length decreased with increased launderings. The analysis showed that there was a significant decrease in the effectiveness of the brominated treatment to reduce char length when going from 10 to 25 wash cycles but not from 3 to 10 wash cycles. The effectiveness of the phosphorus based treatments was not significantly changed by the number of wash cycles. The results

showed that the durability of the brominated treatment lessened between 10 and 25 launderings. The data can be seen in Table A 13.

4.2.4 Physical Testing

4.2.4.1 Stiffness Testing Results

The stiffness test results can be seen in Table A14 in Appendix A. The p-value from the nonparametric method (Wilcoxon Test) was used and indicated that there was no significant difference between the untreated and treated samples at both 0 and 25 wash cycles. The results of the ANOVA analysis can be seen in Tables A15 – A16. Therefore, the treatments, whether brominated or phosphorus based, statistically did not alter the stiffness of the fabric.

4.2.4.2 Tear Strength Testing Results

The tear strength results can be seen in Tables A17 and A18. In the ANOVA analysis, the analysis of variance p-value was used and showed that for the unwashed untreated and treated samples, there was a statistical difference in the tear strength in both tear directions. This is shown in Table A19. In the case of the fill yarn tears, the brominated flame retardant Flameproof 1506 had a 38% increase in tear strength compared to the untreated and phosphorus based flame retardant treated samples. In the warp yarn tears, the brominated treatment had a lower tear strength. At 25 wash cycles, the data were not normally distributed, and using the p-value from the nonparametric method (Wilcoxon Test), there was a statistical difference in the tear strength of the fill yarns. The untreated sample followed by the brominated treated sample had the highest tear strengths. The data are shown in Table A20. Next, an analysis of only the treated samples was conducted and found that there was a statistical difference between the

treated samples at 25 wash cycles in the filling yarn tears as demonstrated in Table A21. The brominated treatment had higher tear strength for the fill yarns in comparison to the phosphorus treatments. The conclusion from these analyses is that at 0 wash cycles, the treatment of polyester with a phosphorus based flame retardant finish did not statistically alter its tear strength. However, the brominated treatment did significantly increase the tear strength of the fill tears. At 25 wash cycles in the tearing of the fill yarns, the treated samples demonstrated statistically lower tear strength than the untreated. However, it is important to note that the untreated samples were not washed and therefore it cannot be concluded that it was the treatments not the wash cycles which affected the tear strength.

4.2.4.3 Whiteness Index Testing Results

Table 4-5 shows the spectrophotometer results for the unwashed, treated samples in comparison to the untreated sample which was the standard. According to the ΔL^* value, all treatments were darker and the phosphorus treatments yellower than the standard. With the exception of the Flameproof 1528 and Flameproof 1506 treatments, all samples had a ΔE_{cmc} lower than one and therefore were not considered to have a noticeable shade change.

Table 4-5 Polyester Color Indices at 0 Wash Cycles

Name	ΔL^*	Δa^*	Δb^*	ΔE_{cmc}
PET-Amgard CT 0w S1	-0.99 D	0.02	0.36 Y	0.46
PET-Amgard CT 0w S2	-1.09 D	0.08 R	0.29 Y	0.46
PET- Flameproof 1528 0w S1	-1.70 D	-0.58 G	2.05 Y	1.88
PET- Flameproof 1528 0w S2	-1.63 D	-0.44 G	1.46 Y	1.4
PET- M73 0w S1	-1.12 D	-0.28 G	0.55 Y	0.68
PET- M73 0w S2	-0.97 D	-0.26 G	0.58 Y	0.65
PET-Pyrosan 0w S1	-1.47 D	-0.11 G	0.68 Y	0.76
PET-Pyrosan 0w S2	-1.43 D	-0.23 G	0.46 Y	0.68
PET-Ulterion N1000 0w S1	-0.67 D	0.01	0.07 Y	0.24
PET-Ulterion N1000 0w S2	-0.83 D	0.06 R	0.16 Y	0.33
PET- 1506 Br 0w S1	-4.71 D	1.72 R	-1.41 B	2.55
PET- 1506 Br 0w S2	-4.47 D	1.63 R	-1.42 B	2.43

Table 4-6 shows the spectrophotometer results for the 25 wash cycle samples compared to the untreated, unwashed sample which was the standard. The data shows that the phosphorus treatments are all darker and greener than the standard. Some treatments were bluer and others yellower which is a variation from the unwashed readings. According to the ΔE_{cmc} , all treatments had a value less than one with the exception of Flameproof 1506, the brominated treatment.

Table 4-6 Polyester Color Indices at 25 Wash Cycles

Name	ΔL^*	Δa^*	Δb^*	ΔE_{cmc}
PET- Amgard CT 25w S1	-0.54 D	-0.11 G	-0.39 B	0.41
PET- Amgard CT 25w S2	-0.65 D	-0.01	-0.53 B	0.49
PET- Flameproof 1528 25w S1	-0.24 D	-0.41 G	0.17 Y	0.56
PET- Flameproof 1528 25w S2	-0.59 D	-0.34 G	0.17 Y	0.5
PET- M73 25w S1	-0.51 D	-0.25 G	-0.37 B	0.51
PET- M73 25w S2	-0.69 D	-0.22 G	-0.29 B	0.46
PET- Pyrosan SYN 25w S1	-0.26 D	-0.34 G	-0.28 B	0.54
PET- Pyrosan SYN 25w S2	-0.39 D	-0.30 G	-0.41 B	0.57
PET- Ulterion N1000 25w S1	-0.47 D	-0.19 G	-0.45 B	0.5
PET- Ulterion N1000 25w S2	-0.49 D	-0.23 G	-0.34 B	0.47
PET- Flameproof 1506 Br 25w S1	-4.06 D	1.56 R	-1.53 B	2.64
PET- Flameproof 1506 Br 25w S2	-4.31 D	1.60 R	-1.34 B	2.67

Table 4-7 below shows the comparison of the ΔL^* , Δa^* , and Δb^* values for the 0 versus 25 wash cycle treated samples. The table shows that the samples at 25 wash cycles, with the exception of one, were lighter and bluer than the unwashed.

Table 4-7 Polyester Color Differences between 0 and 25 Wash Cycles

Name	ΔL^*	Δa^*	Δb^*
PET-Amgard CT S1	0.46	-0.13	-0.74
PET-Amgard CT S2	0.44	-0.08	-0.81
PET- Flameproof 1528 S1	1.46	0.17	-1.88
PET- Flameproof 1528 S2	1.04	0.11	-1.28
PET- M73 S1	0.6	0.04	-0.93
PET- M73 S2	0.29	0.04	-0.87
PET-Pyrosan S1	1.21	-0.24	-0.97
PET-Pyrosan S2	1.04	-0.06	-0.87
PET-Ulterion N1000 S1	0.19	-0.19	-0.52
PET-Ulterion N1000 S2	0.34	-0.3	-0.5
PET- Flameproof 1506 Br S1	0.67	-0.14	-0.18
PET- Flameproof 1506 Br S2	0.18	0	0.02

4.3 Nylon Knit

4.3.1 AATCC TM 81 – Fabric Water Extract Testing Results

The nylon had a pH of 9.8. This was not in the acceptable range of 6-9 and so the fabric underwent preparation a second time using the same method as before. After the second scouring, the nylon had a pH of 8.5.

4.3.2 Vertical Flame Testing- Elimination of Flame Retardants based on Burn Tests Results at 1 and 3 Washes

Burn tests were conducted in both the machine and cross-machine directions. The data from the burns can be seen in Appendix B in Tables B1 and B2. Based on the data, treatments Flameproof 1528 and Pyrozyl GOMB were selected. Even though Flameproof 1528 had char lengths greater than 8 inches, it was retained due to the limited number of available treatments for nylon and because of its promising results on the other substrates. ANOVA analysis was conducted on the burn results at 3 wash cycles. The p-value from the nonparametric method (Wilcoxon Test) was used and concluded that there was no significant difference between the treated and untreated samples. The results can be seen in Table B3.

4.3.3 Vertical Flame Testing –Burn Tests Results at 10 and 25 Washes

The most promising flame retardants were padded during the second and third round paddings. The second round padded treatments underwent 10 and 25 wash cycles and vertical flame testing at these wash intervals. The analysis considered the number of wash cycles and the burn direction. These results can be seen in Tables B4 and B6. ANOVA analysis was conducted on the burn test char length results of the untreated and the 10 and 25 wash cycle treated samples as shown in Tables B5 and B7. The data were

normally distributed with no statistical difference in the variances. The analysis of variance p-values were used. The data shows that there was not a statistical difference between treated samples at 10 wash cycles and the untreated in either burn direction. At 25 wash cycles there was a significant difference in the performance of Flameproof 1528 in the cross-machine direction. However, the treatment resulted in longer char lengths. The conclusion drawn from the above analyses is that the treatments did not help to reduce the char lengths of the fabric.

While the ANOVA results concluded there was not a statistical difference between Pyrozyl GOMB and the remaining treatments, the mean data for the burns as shown in Tables 4-8, 4-9, and 4-10 below show that Pyrozyl GOMB consistently had a lower char length mean at all the wash intervals. Therefore, the data was fit to a model to determine if there was a difference in the effectiveness of Pyrozyl GOMB.

Table 4-8 Mean Char Length Data at 3 Wash Cycles

CMD- 3 Wash Cycles	Mean	MD- 3 Wash Cycles	Mean
Flameproof 1528	7.8	Flameproof 1528	9.0
Pyrozyl DTE	6.4	Pyrozyl DTE	10.8
Pyrozyl GOMB	4.1	Pyrozyl GOMB	7.7
Untreated- 0 washes	6.9	Untreated- 0 washes	10.7

Table 4-9 Mean Char Length Data at 10 Wash Cycles

CMD- 10 Wash Cycles	Mean	MD- 10 Wash Cycles	Mean
Flameproof 1528	8.8	Flameproof 1528	8.6
Pyrozyl DTE	5.7	Pyrozyl DTE	10.9
Pyrozyl GOMB	4.5	Pyrozyl GOMB	6.9
Untreated- 0 washes	6.9	Untreated- 0 washes	10.7

Table 4-10 Mean Char Length Data at 25 Wash Cycles

CMD- 25 Wash Cycles	Mean	MD- 25 Wash Cycles	Mean
Flameproof 1528	11.1	Flameproof 1528	11.7
Pyrozyl DTE	7.4	Pyrozyl DTE	10.5
Pyrozyl GOMB	3.0	Pyrozyl GOMB	7.2
Untreated- 0 washes	6.9	Untreated- 0 washes	7.0

The data was fit to a model which was used to determine which effects, in this case treatment type, number of wash cycles, and burn direction, affected char length. The interactions between these effects were also analyzed. For example, a two way interaction between the effects included wash cycle + burn direction. The three way interaction between the three effects was also in the model. Fitting the data to a model allows for more data to be analyzed as explained in section 4.1. The analysis seen in Table 4-11 showed that treatment type and burn direction had a significant effect on the char length as indicated by the p-values less than 0.05. The two way interaction of burn direction + treatment type did as well. The analysis showed that the number of wash cycles did not have a significant effect on the char length.

Table 4-11 Interactions

Source	Sum of Squares	F Ratio	Prob > F
Burn Direction	98.3	19.3	<.0001
Treatment	151.9	14.8	<.0001
Wash Cycles	8.60	0.84	0.4372
Burn Direction*Treatment	34.9	3.42	0.0411

The interaction profile in Figure 4-1 shows that Pyrozyl GOMB results in a lower char length. Since the p-value in Table 4-11 shows there is a significant difference in treatment type and the interaction profile shows Pyrozyl GOMB has lower char lengths

than the other two treatments, it can be concluded that this treatment is significantly different. The profile also shows that the burn direction affects the char length with the cross-machine direction burns being lower. This is supported by both the p-value in Table 4-11 and by Figure 4-1.

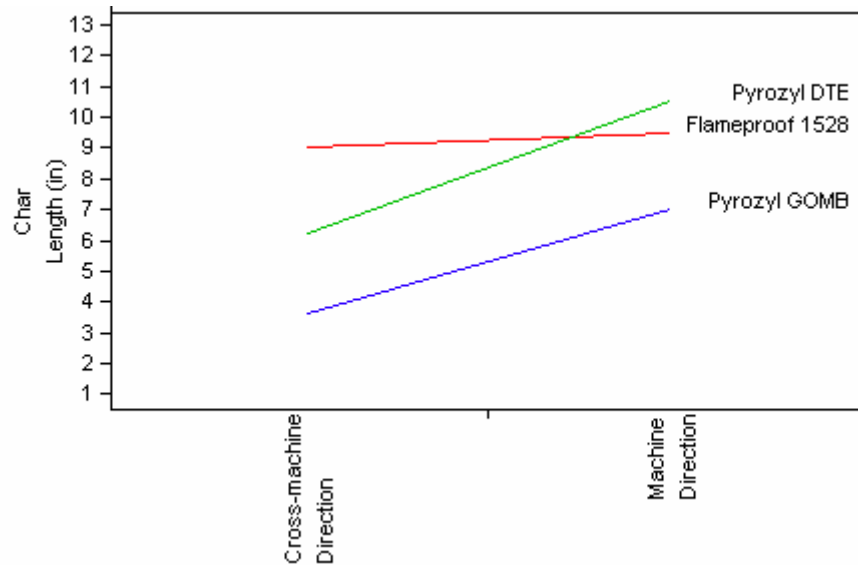


Figure 4-1 Interaction Profile

4.3.4 Physical Testing

4.3.4.1 Stiffness Testing Results

The stiffness test results can be seen in Appendix B in Table B8. The results of the ANOVA analysis can be seen in Tables B9 and B10. The p-value from the analysis of variance was used and a statistical difference in the stiffness of the unwashed samples with treatment Pyrozyl GOMB, where Pyrozyl GOMB was stiffer, was found. At 25 wash cycles, there was no statistical difference in the stiffness of the untreated and treated samples. Therefore, no significant difference in stiffness was found after multiple launderings.

4.3.4.2 Burst Strength Testing Results

Since the nylon was a knit construction, burst strength testing was conducted in place of tear testing. ANOVA analysis of the burst strength results of the untreated and the 0 and 25 wash cycle treated samples was conducted. The data can be seen in Table B11. The data were normally distributed for both the unwashed and 25 wash cycle samples. Tables B12 and B13 depict the ANOVA analyses. The analysis of variance p-values were used. The p-values indicated that there was a statistical difference for the unwashed samples but not the 25 wash cycle samples. The unwashed, treated samples had a lower burst strength than the untreated samples. The mean burst strength for all treated samples increased 3 to 10 percent after 25 washes. Therefore, treating the nylon did affect the burst strength, however the effect was lessened after washing.

4.3.4.3 Whiteness Index Testing Results

Table 4-12 below shows the spectrophotometer results for the unwashed, treated samples versus the untreated sample (standard). The results show that Flameproof 1528 and Pyrozyl GOMB, both phosphorus based, affected the fabric differently. For example, the Flameproof 1528 treatment was darker, redder, and yellower. The ΔE_{cmc} for this sample was greater than one. The Flameproof 1528 samples visually appeared yellower than the other samples. The Pyrozyl GOMB treatment however was lighter and bluer. The ΔE_{cmc} value was also greater than one but by a smaller magnitude than the Flameproof 1528. Visually one could not see a color difference between the Pyrozyl GOMB treated samples and the untreated. The brominated flame retardant Pyrozyl DTE had one sample with a ΔE_{cmc} greater than one.

Table 4-12 Nylon Color Indices at 0 Wash Cycles

Name	ΔL^*	Δa^*	Δb^*	ΔE_{cmc}
Nylon- Flameproof 1528 0w S1	-2.44 D	1.14 R	6.29 Y	6.9
Nylon- Flameproof 1528 0w S2	-3.08 D	1.22 R	7.13 Y	7.81
Nylon- Pyrozyl GOMB 0w S1	1.11 L	0.10 R	-1.41 B	1.55
Nylon- Pyrozyl GOMB 0w S2	1.02 L	-0.01	-1.33 B	1.47
Nylon- Pyrozyl DTE Br 0w S1	-2.4 D	0.08 R	-1.01 B	0.93
Nylon- Pyrozyl DTE Br 0w S2	-2.7 D	0.21 R	-2.63 B	2.51

Table 4-13 below shows the spectrophotometer results for the 25 wash cycle treated samples versus the untreated, unwashed sample (standard). After 25 wash cycles, all the samples were darker than the standard. The ΔE_{cmc} values were still greater than one with the exception of one of the Pyrozyl GOMB samples.

Table 4-13 Nylon Color Indices at 25 Wash Cycles

Name	ΔL^*	Δa^*	Δb^*	ΔE_{cmc}
Nylon- Flameproof 1528 25w S1	-3.48 D	0.38 R	5.68 Y	6.17
Nylon- Flameproof 1528 25w S2	-3.07 D	0.06 R	5.02 Y	5.43
Nylon- Pyrozyl GOMB 25w S1	-1.09 D	-0.05	-1.31 B	1.45
Nylon- Pyrozyl GOMB 25w S2	-1.40 D	-0.05 G	-0.49 B	0.72
Nylon- Pyrozyl DTE Br 25w S1	-2.12 D	-0.15 G	-0.89 B	1.23
Nylon- Pyrozyl DTE Br 25w S2	-1.88 D	-0.14 G	-0.98 B	1.26

Table 4-14 compares the ΔL^* , Δa^* , and Δb^* of the 0 and 25 wash cycle treated samples. The data indicated there were some differences in the samples before and after laundering. Unlike polyester, several of the samples became darker after washing.

Table 4-14 Nylon Color Differences between 0 and 25 Wash Cycles

Name	ΔL^*	Δa^*	Δb^*
Nylon- Flameproof 1528 S1	-1.05	-0.76	-0.62
Nylon- Flameproof 1528 S2	0	-1.16	-2.1
Nylon- Pyrozyl GOMB S1	-2.2	-0.15	0.11
Nylon- Pyrozyl GOMB S2	-2.43	-0.04	0.84
Nylon- Pyrozyl DTE Br 0w S1	-2.4	0.08	-1.01
Nylon- Pyrozyl DTE Br 0w S2	-2.7	0.21	-2.63

4.3.4.4 Nylon Stretching Results

Table 4-15 shows the changes in the dimensions of the 4 x 4 inch square drawn on the nylon.

Table 4-15 Nylon Stretching/Shrinkage Results

Treatment	Conditions	Sq. in Before	Sq. in After	% Change
Water	Padded, dried at 121°C	16	15.73	-1.72
Water	Padded, dried at R.T. under tension	16	16.95	5.96
Water	Padded , dried at 121°C under tension	16	16.40	2.50
Flameproof 1528	Padded, dried at 121°C	16	18.96	18.50
Flameproof 1528	Padded, dried at R.T. under tension	16	20.86	30.35
Flameproof 1528	Padded , dried at 121°C under tension	16	27.13	69.53

In all cases, with the exception of one, stretching of the nylon occurred. Based on the results, the percent change was the most extreme for the Flameproof 1528 treatments. The greatest difference occurred for the Flameproof 1528 sample dried in the oven under tension. These results confirmed that the Flameproof 1528 treatment did result in the nylon heat setting while it was stretched.

4.4 Acrylic Woven

4.4.1 AATCC TM 81 – Fabric Water Extract Testing Results

After scouring and desizing, the acrylic had a pH of 7.26. This was acceptable and the fabric did not need to be prepared a second time.

4.4.2 Vertical Flame Testing- Elimination of Flame Retardants based on Burn Tests Results at 1 and 3 Washes

Burn tests were conducted in both the machine and cross-machine directions. The data from the burns can be seen in Appendix C, Tables C1 and C2. Based on the vertical burn test results, all of the treatments were eliminated. No statistical analysis was

conducted for this substrate. The phosphorus based flame retardants used in this research were unsuccessful in decreasing the flammability of acrylic.

4.5 Polyester/Nylon Nonwoven

4.5.1 Vertical Flame Testing- Elimination of Flame Retardants based on Burn Tests Results at 1 and 3 Washes

Burn tests were conducted in both the machine and cross-machine directions after 1 and 3 wash cycles. The data from the burns can be seen in Appendix D, Tables D1 and D2. Based on the burn test results, none of the treatments were eliminated. FiNone P-205 had one machine direction burn greater than eight inches, but was kept due to the limited number of treatments available for the nonwoven. The average of the two remaining machine direction burns was less than five inches for this treatment. ANOVA analysis was conducted on the burn results for the unwashed, untreated nonwoven and the treated, 3 wash cycle samples. These results can be seen in Table D3. The data were normally distributed and there was no significant difference in the variances in the cross-machine direction. Therefore, the p-value for the analysis of variance was used and indicated there was not a statistical difference between the char lengths of the treated and untreated samples. In the machine direction, there was a statistical difference in the variances and the Welch ANOVA p-value was used. There was no statistical difference between the groups. The results led to the conclusion that the treatments were not successful in reducing the char length of the nonwoven substrate.

4.5.2 Vertical Flame Testing –Burn Tests Results at 10 and 25 Washes

The most promising flame retardants from the first round paddings were padded during the second and third rounds. The second round padded treatments underwent 10

and 25 wash cycles and vertical flame testing was conducted at these wash intervals. The results for these vertical burns can be seen in Tables D4 and D6. ANOVA analysis was conducted on the burn results of the untreated, unwashed and the 10 and 25 wash cycle treated samples. The analysis considered the number of wash cycles and the burn direction. The results can be seen in Tables D5 and D7. The data were normally distributed and there was no statistical difference in the variances for either the 10 or 25 wash cycles in either burn direction. The analysis of variance p-value was used for the four sample sets and only the 10 wash cycle samples in the machine direction were significantly different. In this case, Pyrozyl GOMB samples had a longer char length. The conclusion drawn from these results is that the treatments did not work to suppress flame on the nonwoven substrate.

4.5.3 Physical Testing

4.5.3.1 Stiffness Testing Results

The stiffness test results can be seen in Table D8 in Appendix D. ANOVA analysis was carried out as shown in Tables D9 and D10. For the unwashed samples, there was a statistical difference in the stiffness. FiNone P-205 and Flameproof 1528 had higher stiffness results than Pyrozyl GOMB and the untreated. For the 25 wash cycle samples, the data were normally distributed and there was no statistical difference in the variances. The analysis of variance p-value indicated there was a statistical difference between the groups. The stiffness of the treated samples after 25 wash cycles were lower than the untreated. However, since the untreated was not washed, one cannot conclude that the difference in the stiffness was due to the treatments. The hand of the nonwoven substrate was noticeably softer after multiple washings.

4.5.3.2 Tear Strength Testing Results

The tear strength data can be seen in Table D11 in Appendix D. The data for the unwashed samples were normally distributed and there was no significant difference in the variances of the data. The analysis of variance p-values were used and it was concluded that there was a statistical difference in the samples for the machine tears. The Pyrozyl GOMB samples had higher tear strength for the machine tears. At 25 washes, using the analysis of variance p-values, there was no statistical difference in either the machine or cross-machine tears. The ANOVA analyses can be seen in Tables D12 and D13. The conclusion drawn from the results is that the tear strength with the exception of one unwashed treatment was not affected.

4.5.3.3 Whiteness Index Testing Results

Table 4-16 below shows the spectrophotometer results for the unwashed treated samples versus the untreated sample (standard). All the treatments were yellower than the standard. Flameproof 1528 had ΔE_{cmc} values greater than one and was therefore considered to have a noticeable shade change.

Table 4-16 Nonwoven Color Indices at 0 Wash Cycles

Name	ΔL^*	Δa^*	Δb^*	ΔE_{cmc}
NW- FiNone P-205 0w S1	-0.40 D	-0.12 G	0.16 Y	0.3
NW- FiNone P-205 0w S2	-0.26 D	-0.08 G	0.13 Y	0.23
NW- Flameproof 1528 0w S1	-5.41 D	1.26 R	8.22 Y	11.61
NW- Flameproof 1528 0w S2	-4.34 D	0.69 R	6.43 Y	9.04
NW- Pyrozyl GOMB 0w S1	0.12 L	-0.07 G	0.07 Y	0.15
NW- Pyrozyl GOMB 0w S2	0.07 L	-0.07 G	0.07 Y	0.14

Table 4-17 below shows the spectrophotometer results for the 25 wash cycle treated samples versus the untreated, unwashed samples (standard). The 25 wash cycle

treatments were all darker than the standard. Two of the three treatments appeared bluer after washing. Flameproof 1528 had a noticeable shade change as indicated by the ΔE_{cmc} value.

Table 4-17 Nonwoven Color Indices at 25 Wash Cycles

Name	ΔL^*	Δa^*	Δb^*	ΔE_{cmc}
NW- FiNone P-205 25w S1	-0.14 D	-0.18 G	-0.67 B	0.96
NW- FiNone P-205 25w S2	-0.23 D	-0.15 G	-0.67 B	0.96
NW- Flameproof 1528 25w S1	-1.40 D	-0.68 G	1.41 Y	2.21
NW- Flameproof 1528 25w S2	-1.85 D	-0.75 G	1.19 Y	2.03
NW- Pyrozyl GOMB 25w S1	-0.10 D	0.07 R	-0.19 B	0.29
NW- Pyrozyl GOMB 25w S2	-0.07 D	0.06 R	-0.21 B	0.3

Table 4-18 below compares the ΔL^* , Δa^* , and Δb^* of the 0 and 25 wash cycle treatments. Two of the three treatments became lighter after washing. All the treatments were bluer after 25 wash cycles.

Table 4-18 Nonwoven Color Differences between 0 and 25 Wash Cycles

Name	ΔL^*	Δa^*	Δb^*
NW- FiNone P-205 S1	0.25	-0.07	-0.83
NW- FiNone P-205 S2	0.02	-0.07	-0.81
NW- Flameproof 1528 S1	4.01	-1.94	-6.81
NW- Flameproof 1528 S2	2.49	-1.44	-5.25
NW- Pyrozyl GOMB S1	-0.23	0.14	-0.26
NW- Pyrozyl GOMB S2	-0.14	0.13	-0.27

4.6 Microwave Digestion and ICP analysis

The ICP readings were used to determine the amount of phosphorus in the flame retardant chemicals and the amount on the treated fabrics. The average ICP reading came from the ppm levels detected at wavelengths 213 nm and 214.9 nm. These two wavelengths were the most sensitive in detecting phosphorus amounts at low ppm levels.

Equation 6 below was used to calculate the percentage of phosphorus found in the flame retardant chemicals and on the treated samples from the digestions.

Equation 6 % Phosphorus from Digestions

$$\frac{[(\text{ppm reading}/1,000,000) * \text{flask size (mL)} * \text{density of FR (g/mL)}] / \text{sample size (g)} * 100}{100} = \% \text{ phosphorus from digestion}$$

** where the sample size is either the FR chemical or the fabric sample

Table 4-19 below shows the percentage of phosphorus for each of the flame retardant chemicals.

Table 4-19 % P in Flame Retardants

Treatment	ICP Test Results (ppm)	Flask Size (mL)	Treatment density (g/mL)	Sample (g)	% P in Flame Retardants
Flameproof 1528	774.5	100	1.22	0.483	19.5
Pyrozyl GOMB	130.2	100	1.25	0.483	3.36
FiNone P-205	497.1	100	1.25	0.481	12.9
Pyrozyl M-73	430.3	100	1.24	0.464	11.5
Ulterion N1000	1021	100	1.27	0.473	27.4
Pyrosan SYN	974.4	100	1.28	0.458	27.2
Amgard CT	1010	100	1.25	0.480	26.3

The flame retardants varied in the amount of phosphorus that they contained. Pyrozyl GOMB with 3.36% phosphorus was lower than the remaining treatments which had phosphorus amounts ranging from 11.5 – 27.2%. This can be explained by the fact that Pyrozyl GOMB is a semi-durable flame retardant and the remaining are all durable. Since the phosphorus is what helps to reduce flammability, a durable product would be expected to have a greater concentration of phosphorus. Two of the four treatments, Flameproof 1528 and Pyrosan SYN which had phosphorus percentages at 20% or greater,

were the same treatments which were the most effective in reducing the char length of polyester. Table 4-20 below shows the percent phosphorus detected on polyester.

Table 4-20 % Phosphorus on Polyester

Fabric	Treatment	Wash Cycles	ICP Test Results (ppm)	Flask Size (mL)	FR density (g/mL)	Fabric (g)	% P on Polyester
Polyester	Amgard CT	0	6.165	100	1.25	0.4958	0.15
Polyester	Amgard CT	25	4.827	100	1.25	0.4938	0.12
Polyester	Flameproof 1528	0	218.6	50	1.22	0.4957	2.60
Polyester	Flameproof 1528	25	30.86	100	1.22	0.4902	0.76
Polyester	Pyrosan SYN	0	147.6	50	1.28	0.4971	1.90
Polyester	Pyrosan SYN	25	29.85	100	1.28	0.4950	0.77
Polyester	Pyrozyl M-73	0	66.60	50	1.24	0.4960	0.83
Polyester	Pyrozyl M-73	25	16.77	100	1.24	0.4929	0.42
Polyester	Ulterion N1000	0	17.40	50	1.27	0.4945	0.22
Polyester	Ulterion N1000	25	5.477	100	1.27	0.4973	0.14

All the treatments had a lower amount of phosphorus after 25 wash cycles which can be explained by the fact that any treatment not fully fixed to the fibers would have been removed during the launderings. Flameproof 1528 and Pyrosan SYN which performed well on polyester as discussed in section 4.2, had the greatest amount of phosphorus both unwashed and after 25 wash cycles. The change in the amount of phosphorus before washing and after 25 wash cycles is shown in Table 4-21.

Table 4-21 Difference in %P from Unwashed to 25 Wash Cycles on Polyester

Fabric	Treatment	Difference in %P
Polyester	Amgard CT	21.39
Polyester	Flameproof 1528	71.44
Polyester	Pyrosan SYN	59.37
Polyester	Pyrozyl M-73	49.33
Polyester	Ulterion N1000	37.42

The change in the amount of phosphorus before and after laundering varied from 21.4 – 71.4% depending on the treatment.

The ICP results for nylon can be seen in Table 4-22 below.

Table 4-22 %P on Nylon

Fabric	Treatment	Wash Cycles	ICP Test Results (ppm)	Flask Size (mL)	FR density (g/mL)	Fabric (g)	% P on Nylon
Nylon	Flameproof 1528	0	118.6	100	1.22	0.4919	2.94
Nylon	Flameproof 1528	25	5.026	100	1.22	0.4929	0.12
Nylon	Pyrozyl GOMB	0	55.09	100	1.22	0.496	1.35
Nylon	Pyrozyl GOMB	25	0.4374	100	1.22	0.4922	0.01

Both nylon treatments had phosphorus levels over 1% for the unwashed samples. However, the phosphorus percentage after 25 wash cycles were 95.7-99.2% lower as shown in Table 4-23.

Table 4-23 Difference in %P from Unwashed to 25 Wash Cycles on Nylon

Fabric	Treatment	Difference in %P
Nylon	Flameproof 1528	95.7
Nylon	Pyrozyl GOMB	99.2

Table 4-24 below shows the percent phosphorus detected on the nonwoven substrate through ICP analysis.

Table 4-24 %P on Nonwoven

Fabric	Treatment	Wash Cycles	ICP Test Results (ppm)	Flask Size (mL)	FR density (g/mL)	Fabric (g)	% P on Nonwoven
Nonwoven	FiNone P-205	0	423.8	50	1.27	0.4961	5.42
Nonwoven	FiNone P-205	25	0.154	100	1.27	0.492	0.004
Nonwoven	Flameproof 1528	0	530.5	50	1.22	0.4966	6.51
Nonwoven	Flameproof 1528	25	26.26	100	1.22	0.4939	0.65
Nonwoven	Pyrozyl GOMB	0	133.5	100	1.22	0.4954	3.2
Nonwoven	Pyrozyl GOMB	25	0.1014	100	1.22	0.4942	0.002

All three treatments had between 3 – 6.5% phosphorus on them initially, but none of the burn results showed a significant reduction in char length. Table 4-25 below shows the change in the percent phosphorus after the 25 launderings.

Table 4-25 Difference in %P from Unwashed to 25 Wash Cycles on Nonwoven

Fabric	Treatment	Difference in %P
Nonwoven	FiNone P-205	99.9
Nonwoven	Flameproof 1528	90.0
Nonwoven	Pyrozyl GOMB	99.9

5 Conclusions

5.1 General

The statistical analysis for the following fabrics can be seen in Appendices A-D. Under each ANOVA plot, there is a Means for Oneway Anova data table, which has the mean data for burn, stiffness, and tear strength or burst strength for each treatment-substrate combination. While the p-values were used to determine if a statistical difference existed as described in section 4.1, the means for each treatment data set can be used to obtain an overview of the effects.

5.2 Phosphorus Based Flame Retardants on Polyester

The chemical compositions of the flame retardants used in the research are shown in Tables 3-3 and 3-4. The statistical analysis of the burn test results conducted after 3, 10, and 25 wash cycles led to the conclusion that phosphorus flame retardants are a promising alternative to brominated treatments. The analysis showed that at the lower wash cycles, the char length of the brominated treatment, Flameproof 1506, was significantly different (lower) in both burn directions from several of the phosphorus treatments padded during the second round. Flameproof 1528, Pyrosan SYN, and Pyrozyl M-73 were the three most promising flame retardants after 3 wash cycles since they did not differ significantly from the brominated treatment in the machine direction burns. After 3 wash cycles, the phosphorus treatments reduced the char length of polyester in the cross-machine burn direction between 35.8 - 48.1% and in the machine burn direction between 42.4 - 72.2%. Pyrosan SYN had the best performance out of the phosphorus treatments in both burn directions. The brominated treatment after 3 wash cycles, reduced the char length of polyester by 72.8% in the cross-machine direction and by 80.4% in the machine direction. As the number of wash cycles

increased, the statistical analysis showed that a significant difference existed between fewer of the phosphorus treatments and the brominated. Pyrosan SYN and Ulterior N1000 were the most promising flame retardants at 10 wash cycles since they did not differ significantly from the brominated treatment in either burn direction. Amgard CT, Flameproof 1528, and Pyrozyl M-73 were not statistically different from the brominated treatment in one of the directional burns. At 10 wash cycles, the percent reduction in char length was between 35.0 - 48.3% in the cross-machine direction and 46.7 – 60.3% in the machine direction burns for the phosphorus treatments. Amgard CT performed the best in the cross-machine direction and Pyrosan SYN was the most effective in the machine direction burns. The brominated treatment reduced the char length of the polyester by 64.6% in the cross-machine direction and by 65.9% in the machine direction at 10 wash cycles. At 25 wash cycles, the statistical analysis showed no significant difference between the brominated treatment and any of the phosphorus treatments. During this round of burn testing, the polyester treatments reduced the char length of polyester by 33.7 – 46.4% in the cross-machine direction and between 47.4 – 68.4% in the machine direction. Flameproof 1528 performed the best in the cross-machine burns and Pyrosan SYN performed the best in the machine direction burns. The brominated treatment at 25 wash cycles reduced the char length by 45.6% in the cross-machine direction and 59.1% in the machine direction. The results led to the conclusion that while the brominated treatment was more effective than the majority of the phosphorus treatments at the lower wash cycles, at the higher wash intervals all five phosphorus treatments were as effective.

The percentages by which the phosphorus treatments reduced the char length of the polyester did not alter greatly from the one wash cycle to the next. However, the change in

the effectiveness of the brominated treatment from one wash cycle level to the next appeared more significant. This suggested that the brominated treatment was not as durable as the phosphorus based flame retardants. By fitting the data to a model, it was found that the effectiveness of the brominated treatment declined between 10 and 25 wash cycles. This was not found to be true for the phosphorus based treatments. Therefore, between 10 and 25 wash cycles, the durability of the brominated treatment lessened.

The three most promising treatments, Flameproof 1528, Pyrosan SYN, and Pyrozyl M-73 had between 11.5 - 27.3% phosphorus detected in the flame retardant. Flameproof 1528 and Pyrosan SYN had the highest amounts of phosphorus detected on polyester by the ICP analysis.

None of the treatments statistically altered the stiffness of the substrate. In terms of tear strength, the phosphorus flame retardant treated samples were not significantly different from the untreated while the brominated flame retardant treated samples had a 38.3% increase in the tear strength of the filling yarns. At 25 wash cycles, the brominated and untreated performed significantly different (i.e. higher tear strength) in the fill yarn tears than the phosphorus treated. However, the brominated treatment had a 6.5% reduction in fill yarn tear strength compared to the untreated and the phosphorus treatments had tear strength reductions between 16.7 – 23.0%. Since the untreated samples were not washed, it cannot be concluded that the phosphorus based flame retardants and not the launderings caused the reduction in tear strength.

In terms of the color change ΔE_{cmc} , the brominated treatment had a substantial shade change ($\Delta E_{cmc} > 1$) at both 0 and 25 wash cycles. The unwashed Flameproof 1528 samples also had a shade change.

In conclusion, the phosphorus treatments are a promising alternative to brominated flame retardants on polyester. At the higher wash intervals, none of the five phosphorus based treatments were significantly different from the brominated treatment in terms of char length. For the physical properties of tear, stiffness, and color, the phosphorus treatments overall had little to no effect on the substrate.

5.3 Phosphorus Based Flame Retardants on Nylon

The chemical compositions of the flame retardants used in the research can be seen in Tables 3-3 and 3-4. The statistical analysis led to the conclusion that with the exception of Pyrozyl GOMB, the flame retardant treatments including the brominated treatment, Pyrozyl DTE, did not help to reduce the char length of the substrate.

Pyrozyl DTE did not significantly reduce the char length of the nylon at any of the three wash intervals in either burn direction. Pyrozyl GOMB, which was statistically different from the remaining treatments, reduced the char length by 40.5% at 3 wash cycles, 33.7% at 10 wash cycles, and 56.1% at 25 wash cycles in the cross-machine direction. In the machine direction burns, Pyrozyl GOMB reduced the char length by 27.7, 34.8, and 32.5% respectively at the three wash intervals.

In terms of physical properties, the stiffness was higher for the unwashed treated samples with the exception of Flameproof 1528 which had a 70% decrease. There was no statistical difference in stiffness for any of the treatments at 25 wash cycles. The burst strength was 6.29 – 12.9% lower for the unwashed, treated samples when compared to the untreated. After 25 wash cycles, the burst strength increased between 3 – 10% for all the treatments and no significant difference was found between the treated and untreated samples. All

treatments had ΔE_{cmc} values greater than one. The Flameproof 1528 samples were noticeably yellower than the standard (untreated).

The ICP results indicated that fairly high levels, 1.3% (Pyrozyl GOMB) and 2.9% (Flameproof 1528) phosphorus were found on the nylon. However, the amount of phosphorus detected after 25 wash cycles was greatly reduced. Pyrozyl GOMB was the only promising phosphorus treatment for nylon based on burn tests and physical testing results.

5.4 Phosphorus Based Flame Retardants on Acrylic

The burn test results after the first round of paddings resulted in the elimination of all treatments since the samples had char lengths of 12 inches. Since the research was unsuccessful in finding a non-halogenated based flame retardant for acrylic, it is recommended to look at other alternatives. Possibilities include extruding a flame retardant package with the filaments.

5.5 Phosphorus Based Flame Retardants on Polyester/Nylon Nonwoven

The chemical compositions of the flame retardants used in the research can be seen in Tables 3-3 and 3-4. The statistical analysis of the burn tests led to the conclusion that the flame retardants were unsuccessful in decreasing the char length of the nonwoven substrate. There was no statistical difference in the char lengths of any of the treatments when compared to the untreated at any of the wash cycles. Some of the burn test results showed treated samples having a higher char length than the untreated. For example, at 10 and 25 wash cycles, FiNone P-205 increased the char length of the nonwoven by 10.4 and 8.35% respectively in the cross-machine direction and by 2.72 and 8.78% respectively in the machine direction.

The stiffness results for the unwashed treated and untreated samples were significantly different with a 400% increase for treatments FiNone P-205 and Flameproof 1528. At 25 wash cycles, there was a statistical difference in stiffness with all three treatments having decreases in stiffness between 46.6 – 84.6%. However, it was observed that the hand of the substrate changed with increased washings. Since, the untreated did not undergo any launderings, it cannot be concluded that the change in stiffness came from the treatments and not from the washings. Flameproof 1528 was the only treatment which had a noticeable shade change with a ΔE_{cmc} value greater than one. This same treatment had substantial color changes on the polyester and nylon substrates.

The nonwoven samples had high levels, 3.0 - 6.5% phosphorus on them before any launderings. However, the levels dropped to 0.003 - 0.649% after 25 wash cycles. In conclusion, none of the non-halogenated treatments were successful in flame retarding the polyester/nylon nonwoven.

6 Recommendations for Future Work

The research focused on the application of non-halogenated flame retardants for various synthetic textiles in order to find alternatives for halogenated flame retardants. The results of the research led to the conclusion that several phosphorus based flame retardants were promising in reducing the flammability of polyester and that one treatment, Pyrozyl GOMB, was promising for nylon. In terms of the polyester, it is recommended that Pyrosan SYN, Flameproof 1528, and Pyrozyl M-73 be considered for further research due to their burn performances at 3, 10, and 25 wash cycles. Future work should include Designs of Experiments (DOEs) for each treatment combination in order to optimize the bath concentrations, processing times and temperatures, and the addition of any other processing chemicals. Additionally, larger sample sizes for all the testing conducted; especially burn, tear, burst, and stiffness should be carried out in order to draw a stronger statistical conclusion from the analyses.

No alternatives were found to successfully flame retard the acrylic woven or the polyester/nylon nonwoven. One possible alternative to flame retarding these substrates would be to extrude a flame retardant package with the filaments.

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8 Appendices

Appendix A: Polyester Woven

Table A 1 Polyester Vertical Burn Test - 1 Wash

Fabric	Machine Direction/Cross-machine Direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Polyester	Cross-machine Direction	Untreated	00:43.1	Y	12
Polyester	Cross-machine Direction	Untreated	00:19.1	Y	7.75
Polyester	Cross-machine Direction	Untreated	00:15.2	Y	4.7
Polyester	Machine Direction	Untreated	00:13.8	Y	9.75
Polyester	Machine Direction	Untreated	00:17.5	Y	12
Polyester	Machine Direction	Untreated	00:08.8	Y	12
Polyester	Cross-machine Direction	Pyrozyl M-73	00:00.0	N	4.6
Polyester	Machine Direction	Pyrozyl M-73	00:00.0	N	2.8
Polyester	Cross-machine Direction	Amgard CT	00:00.0	N	4.1
Polyester	Machine Direction	Amgard CT	00:05.9	Y	4.5
Polyester	Machine Direction	Flameproof 1528	00:00.0	Y	4.35
Polyester	Cross-machine Direction	Flameproof 1528	00:00.0	N	3.75
Polyester	Cross-machine Direction	FiNone P-205	00:00.0	N	3.25
Polyester	Machine Direction	FiNone P-205	00:00.0	N	3.8
Polyester	Cross-machine Direction	Glottard NTB	00:10.7	Y	4.34
Polyester	Machine Direction	Glottard NTB	00:44.9	Y	12

Table A 1 Continued

Fabric	Machine Direction/Cross- machine Direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Polyester	Cross-machine Direction	Interrupt 4T	00:00.0	N	3.5
Polyester	Machine Direction	Interrupt 4T	00:05.6	Y	4.4
Polyester	Cross-machine Direction	Pyrozyl GOMB	00:01.2	N	3.8
Polyester	Machine Direction	Pyrozyl GOMB	00:01.4	Y	2.65
Polyester	Cross-machine Direction	Pyrosan SYN	00:00.0	Y	5.1
Polyester	Machine Direction	Pyrosan SYN	00:00.0	Y	4.25
Polyester	Cross-machine Direction	Pyrozyl GOMB	00:00.0	N	3.75
Polyester	Machine Direction	Pyrozyl GOMB	00:00.0	N	3.75
Polyester	Cross-machine Direction	Ultrion N1000	00:00.0	Y	3.75
Polyester	Machine Direction	Ultrion N1000	00:28.0	Y	12

Table A 2 Polyester Vertical Burn Test - 3 Wash Cycles

Fabric	Machine Direction/Cross-machine Direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Polyester	Cross-machine Direction	Pyrozyl M-73	00:00.0	N	4.8
Polyester	Cross-machine Direction	Pyrozyl M-73	00:00.0	N	5.6
Polyester	Cross-machine Direction	Pyrozyl M-73	00:00.0	N	5.3
Polyester	Machine Direction	Pyrozyl M-73	00:00.0	N	4.5
Polyester	Machine Direction	Pyrozyl M-73	00:00.0	Y	4.8
Polyester	Machine Direction	Pyrozyl M-73	00:01.2	Y	4.5
Polyester	Cross-machine Direction	Amgard CT	00:00.0	N	4
Polyester	Cross-machine Direction	Amgard CT	00:00.0	Y	4
Polyester	Cross-machine Direction	Amgard CT	00:05.6	Y	5.5
Polyester	Machine Direction	Amgard CT	00:16.6	Y	5.3
Polyester	Machine Direction	Amgard CT	00:07.2	Y	6.2
Polyester	Machine Direction	Amgard CT	00:00.0	Y	4.7
Polyester	Cross-machine Direction	Flameproof 1528	00:00.0	Y	4.6
Polyester	Cross-machine Direction	Flameproof 1528	00:00.0	Y	4.1
Polyester	Machine Direction	Flameproof 1528	00:00.0	N	4
Polyester	Machine Direction	Flameproof 1528	00:00.0	N	2.8
Polyester	Machine Direction	Flameproof 1528	00:00.8	Y	5.2
Polyester	Cross-machine Direction	Flameproof 1528	00:00.0	Y	4.2

Table A 2 Continued

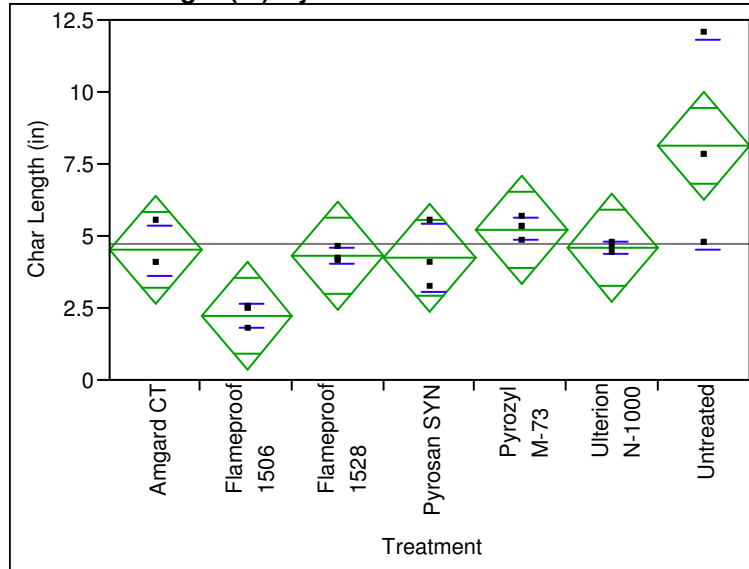
Fabric	Machine Direction/Cross-machine Direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Polyester	Cross-machine Direction	FiNone P-205	00:00.0	N	2.5
Polyester	Cross-machine Direction	FiNone P-205	00:28.4	Y	12
Polyester	Machine Direction	FiNone P-205	00:11.4	Y	9.25
Polyester	Machine Direction	FiNone P-205	00:18.5	Y	9.6
Polyester	Cross-machine Direction	Interrupt 4T	00:01.4	Y	4.25
Polyester	Cross-machine Direction	Interrupt 4T	00:03.1	Y	4
Polyester	Machine Direction	Interrupt 4T	00:06.0	Y	7.5
Polyester	Machine Direction	Interrupt 4T	00:08.4	Y	7.3
Polyester	Cross-machine Direction	Pyrosan SYN	00:00.0	N	5.5
Polyester	Cross-machine Direction	Pyrosan SYN	00:00.0	Y	4
Polyester	Cross-machine Direction	Pyrosan SYN	00:00.0	N	3.2
Polyester	Machine Direction	Pyrosan SYN	00:00.0	Y	3.75
Polyester	Machine Direction	Pyrosan SYN	00:00.0	N	3.4
Polyester	Machine Direction	Pyrosan SYN	00:00.0	N	2.25
Polyester	Cross-machine Direction	Pyrozyl GOMB	01:05.8	Y	12
Polyester	Cross-machine Direction	Pyrozyl GOMB	00:03.7	Y	3.75
Polyester	Machine Direction	Pyrozyl GOMB	00:03.3	N	6.7
Polyester	Machine Direction	Pyrozyl GOMB	10:00.0	Y	8.75
Polyester	Cross-machine Direction	Pyrozyl GOMB	00:00.0	Y	8
Polyester	Machine Direction	Pyrozyl GOMB	00:02.2	Y	6.9
Polyester	Cross-machine Direction	Glottard NTB	00:04.8	Y	4.4
Polyester	Cross-machine Direction	Glottard NTB	00:05.4	N	2.8
Polyester	Machine Direction	Glottard NTB	00:01.2	Y	3.75
Polyester	Machine Direction	Glottard NTB	00:32.4	Y	11.8

Table A 2 Continued

Fabric	Machine Direction/Cross-machine Direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Polyester	Cross-machine Direction	Ultrion N100	00:00.0	Y	4.4
Polyester	Cross-machine Direction	Ultrion N100	00:00.0	Y	4.6
Polyester	Cross-machine Direction	Ultrion N100	00:02.3	Y	4.75
Polyester	Machine Direction	Ultrion N100	00:07.8	Y	7.3
Polyester	Machine Direction	Ultrion N100	00:07.9	Y	7.4
Polyester	Machine Direction	Ultrion N100	07:00.0	Y	4.75
Polyester	Cross-machine Direction	Flameproof 1506	00:00.0	Y	1.75
Polyester	Cross-machine Direction	Flameproof 1506	00:00.0	Y	2.5
Polyester	Cross-machine Direction	Flameproof 1506	00:00.0	Y	2.4
Polyester	Machine Direction	Flameproof 1506	00:00.0	Y	2.5
Polyester	Machine Direction	Flameproof 1506	00:00.0	Y	1.8
Polyester	Machine Direction	Flameproof 1506	00:00.0	Y	2.3

Table A 3 ANOVA Analysis for Polyester Burns at 3 Wash Cycles

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Cross-machine Direction



**Oneway Anova
Summary of Fit**

Rsquare	0.637856
Adj Rsquare	0.482652
Root Mean Square Error	1.511188
Mean of Response	4.745238
Observations (or Sum Wgts)	21

Analysis of Variance

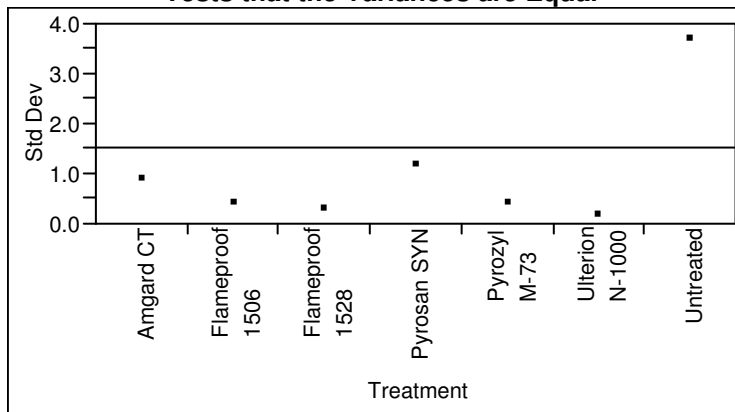
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	6	56.312857	9.38548	4.1098	0.0138
Error	14	31.971667	2.28369		
C. Total	20	88.284524			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	4.50000	0.87249	2.6287	6.371
Flameproof 1506	3	2.21667	0.87249	0.3454	4.088
Flameproof 1528	3	4.30000	0.87249	2.4287	6.171
Pyrosan SYN	3	4.23333	0.87249	2.3620	6.105
Pyrozyl M-73	3	5.23333	0.87249	3.3620	7.105
Ulterion N-1000	3	4.58333	0.87249	2.7120	6.455
Untreated	3	8.15000	0.87249	6.2787	10.021

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.866025	0.666667	0.500000
Flameproof 1506	3	0.407226	0.311111	0.283333
Flameproof 1528	3	0.264575	0.200000	0.200000
Pyrosan SYN	3	1.167619	0.844444	1.033333
Pyrozyl M-73	3	0.404145	0.288889	0.366667
Ulterior N-1000	3	0.175594	0.122222	0.166667
Untreated	3	3.666402	2.566667	3.450000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.6607	6	14	0.2032
Brown-Forsythe	19.0204	6	14	<.0001
Levene	3.8434	6	14	0.0178
Bartlett	3.6140	6	.	0.0014

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
11.2752	6	5.9725	0.0048

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

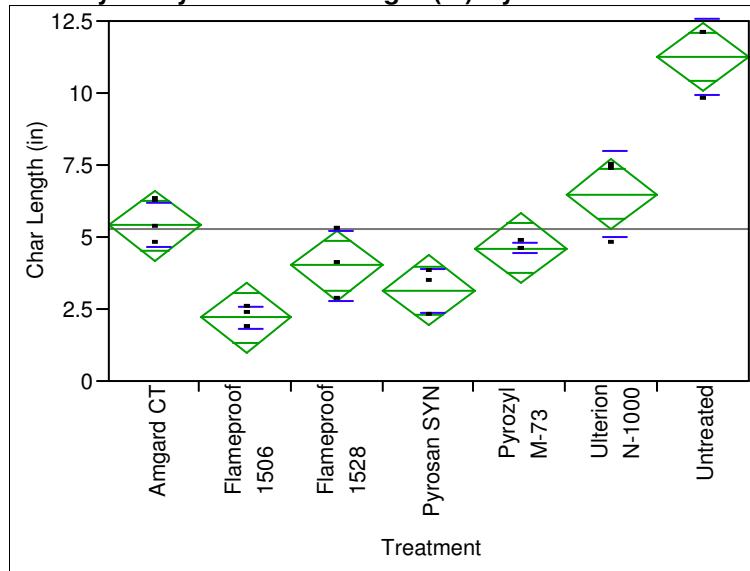
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	29.500	9.8333	-0.302
Flameproof 1506	3	6.000	2.0000	-2.669
Flameproof 1528	3	28.500	9.5000	-0.403
Pyrosan SYN	3	27.500	9.1667	-0.504
Pyrozyl M-73	3	50.000	16.6667	1.662
Ulterior N-1000	3	35.500	11.8333	0.201
Untreated	3	54.000	18.0000	2.064

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
13.2812	6	0.0388

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Machine Direction



Oneway Anova Summary of Fit

Rsquare 0.922363
 Adj Rsquare 0.88909
 Root Mean Square Error 0.980464
 Mean of Response 5.295238
 Observations (or Sum Wgts) 21

Analysis of Variance

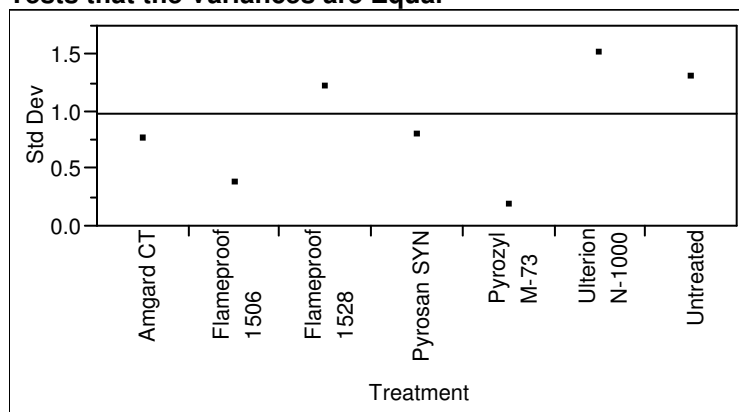
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	6	159.89119	26.6485	27.7211	<.0001
Error	14	13.45833	0.9613		
C. Total	20	173.34952			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	5.4000	0.56607	4.186	6.614
Flameproof 1506	3	2.2000	0.56607	0.986	3.414
Flameproof 1528	3	4.0000	0.56607	2.786	5.214
Pyrosan SYN	3	3.1333	0.56607	1.919	4.347
Pyrozyl M-73	3	4.6000	0.56607	3.386	5.814
Ulterior N-1000	3	6.4833	0.56607	5.269	7.697
Untreated	3	11.2500	0.56607	10.036	12.464

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.754983	0.533333	0.700000
Flameproof 1506	3	0.360555	0.266667	0.300000
Flameproof 1528	3	1.200000	0.800000	1.200000
Pyrosan SYN	3	0.784750	0.588889	0.616667
Pyrozyl M-73	3	0.173205	0.133333	0.100000
Ulterior N-1000	3	1.501943	1.155556	0.916667
Untreated	3	1.299038	1.000000	0.750000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.8239	6	14	0.5700
Brown-Forsythe	0.7120	6	14	0.6460
Levene	2.4525	6	14	0.0782
Bartlett	1.2925	6	.	0.2566

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
22.8143	6	5.7626	0.0009

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	42.000	14.0000	0.855
Flameproof 1506	3	8.000	2.6667	-2.464
Flameproof 1528	3	27.000	9.0000	-0.553
Pyrosan SYN	3	15.000	5.0000	-1.760
Pyrozyl M-73	3	32.000	10.6667	-0.050
Ulterior N-1000	3	47.000	15.6667	1.358
Untreated	3	60.000	20.0000	2.665

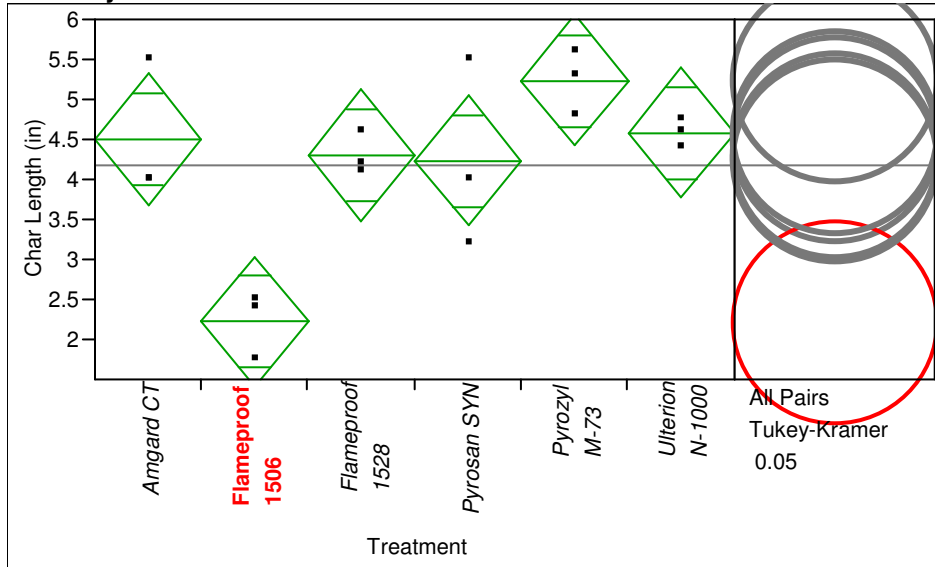
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
17.2692	6	0.0083

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table A 4 ANOVA Analysis for Polyester Burns at 3 Wash Cycles- Excluding Untreated

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Cross-machine Direction, Wash Cycles=3



Oneway Anova Summary of Fit

Rsquare	0.755755
Adj Rsquare	0.653987
Root Mean Square Error	0.651067
Mean of Response	4.177778
Observations (or Sum Wgts)	18

Analysis of Variance

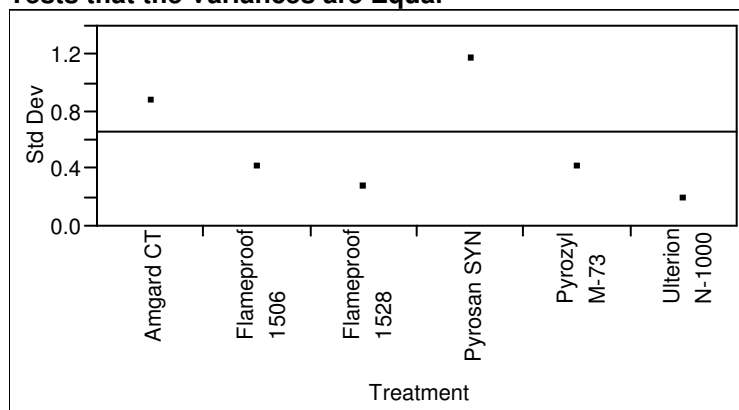
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	15.739444	3.14789	7.4262	0.0022
Error	12	5.086667	0.42389		
C. Total	17	20.826111			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	4.50000	0.37589	3.6810	5.3190
Flameproof 1506	3	2.21667	0.37589	1.3977	3.0357
Flameproof 1528	3	4.30000	0.37589	3.4810	5.1190
Pyrosan SYN	3	4.23333	0.37589	3.4143	5.0523
Pyrozyl M-73	3	5.23333	0.37589	4.4143	6.0523
Ulterior N-1000	3	4.58333	0.37589	3.7643	5.4023

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.866025	0.666667	0.500000
Flameproof 1506	3	0.407226	0.311111	0.283333
Flameproof 1528	3	0.264575	0.200000	0.200000
Pyrosan SYN	3	1.167619	0.844444	1.033333
Pyrozyl M-73	3	0.404145	0.288889	0.366667
Ulterior N-1000	3	0.175594	0.122222	0.166667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.2064	5	12	0.3634
Brown-Forsythe	1.7570	5	12	0.1964
Levene	3.2165	5	12	0.0452
Bartlett	1.5322	5	.	0.1759

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
13.6404	5	5.3532	0.0048

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

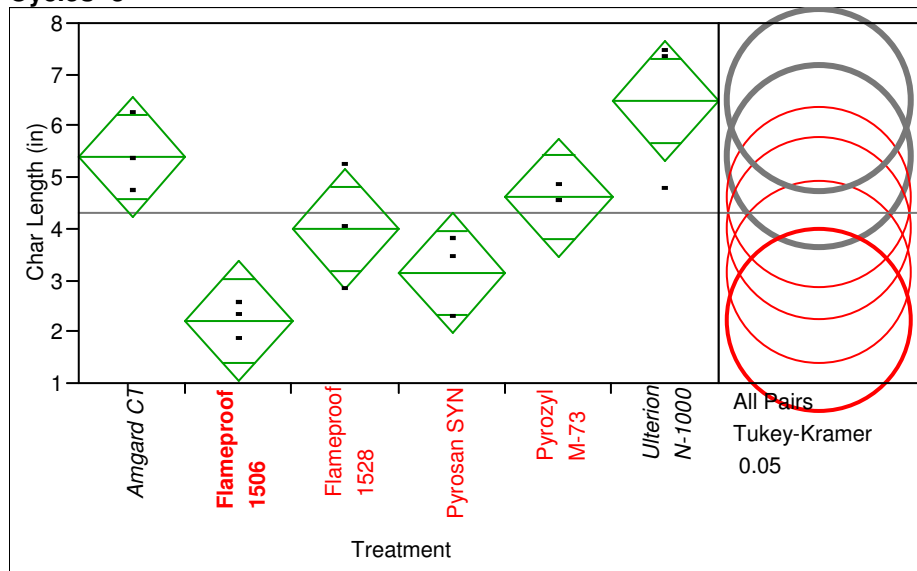
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	28.500	9.5000	0.000
Flameproof 1506	3	6.000	2.0000	-2.614
Flameproof 1528	3	28.500	9.5000	0.000
Pyrosan SYN	3	26.500	8.8333	-0.178
Pyrozyl M-73	3	47.000	15.6667	2.139
Ulterior N-1000	3	34.500	11.5000	0.654

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
10.4566	5	0.0633

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Machine Direction, Wash Cycles=3



Oneway Anova Summary of Fit

Rsquare 0.780163
 Adj Rsquare 0.688565
 Root Mean Square Error 0.916667
 Mean of Response 4.302778
 Observations (or Sum Wgts) 18

Analysis of Variance

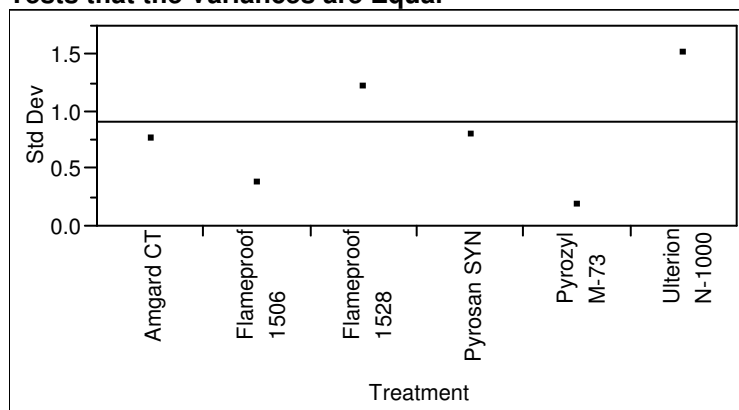
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	35.784028	7.15681	8.5172	0.0012
Error	12	10.083333	0.84028		
C. Total	17	45.867361			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	5.40000	0.52924	4.2469	6.5531
Flameproof 1506	3	2.20000	0.52924	1.0469	3.3531
Flameproof 1528	3	4.00000	0.52924	2.8469	5.1531
Pyrosan SYN	3	3.13333	0.52924	1.9802	4.2864
Pyrozyll M-73	3	4.60000	0.52924	3.4469	5.7531
Ulterior N-1000	3	6.48333	0.52924	5.3302	7.6364

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.754983	0.533333	0.700000
Flameproof 1506	3	0.360555	0.266667	0.300000
Flameproof 1528	3	1.200000	0.800000	1.200000
Pyrosan SYN	3	0.784750	0.588889	0.616667
Pyrozyl M-73	3	0.173205	0.133333	0.100000
Ulterior N-1000	3	1.501943	1.155556	0.916667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.9871	5	12	0.4648
Brown-Forsythe	1.2522	5	12	0.3451
Levene	2.4502	5	12	0.0945
Bartlett	1.4639	5	.	0.1979

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
16.8732	5	5.1087	0.0035

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	42.000	14.0000	1.541
Flameproof 1506	3	8.000	2.6667	-2.371
Flameproof 1528	3	27.000	9.0000	-0.119
Pyrosan SYN	3	15.000	5.0000	-1.541
Pyrozyl M-73	3	32.000	10.6667	0.356
Ulterior N-1000	3	47.000	15.6667	2.134

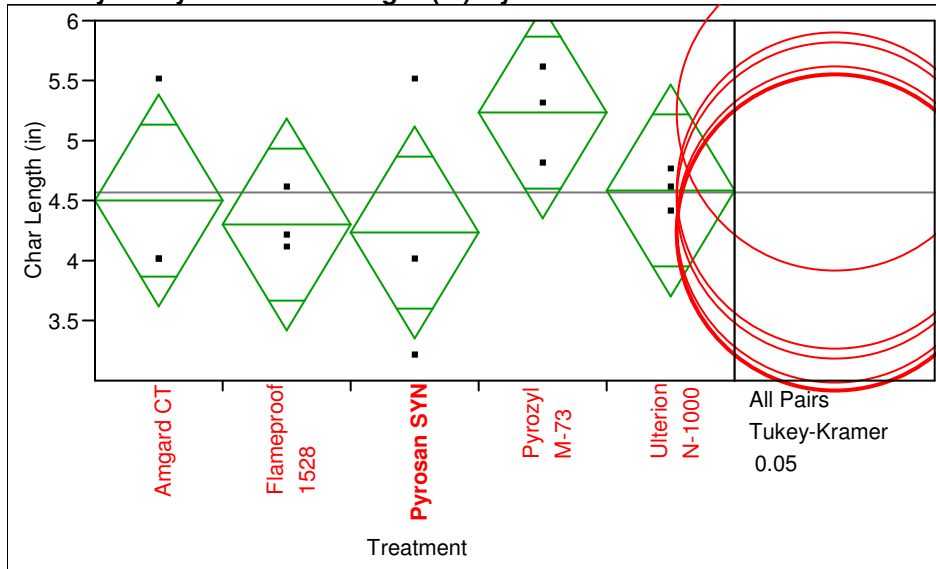
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
13.3647	5	0.0202

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table A 5 ANOVA Analysis for Polyester Burns at 3 Wash Cycles- Excluding Untreated and Flameproof 1506 (Br)

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Cross-machine Direction



Excluded Rows

42

**Oneway Anova
Summary of Fit**

Rsquare	0.284855
Adj Rsquare	-0.0012
Root Mean Square Error	0.689565
Mean of Response	4.57
Observations (or Sum Wgts)	15

Analysis of Variance

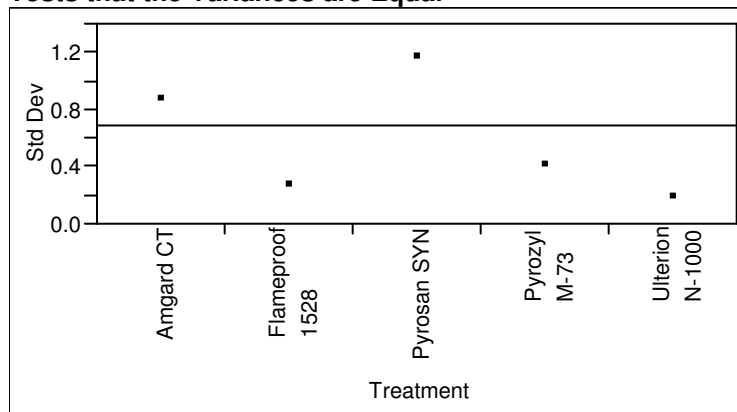
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	4	1.8940000	0.473500	0.9958	0.4535
Error	10	4.7550000	0.475500		
C. Total	14	6.6490000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	4.50000	0.39812	3.6129	5.3871
Flameproof 1528	3	4.30000	0.39812	3.4129	5.1871
Pyrosan SYN	3	4.23333	0.39812	3.3463	5.1204
Pyrozyl M-73	3	5.23333	0.39812	4.3463	6.1204
Ulterior N-1000	3	4.58333	0.39812	3.6963	5.4704

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.866025	0.666667	0.500000
Flameproof 1528	3	0.264575	0.200000	0.200000
Pyrosan SYN	3	1.167619	0.844444	1.033333
Pyrozyl M-73	3	0.404145	0.288889	0.366667
Ulterior N-1000	3	0.175594	0.122222	0.166667

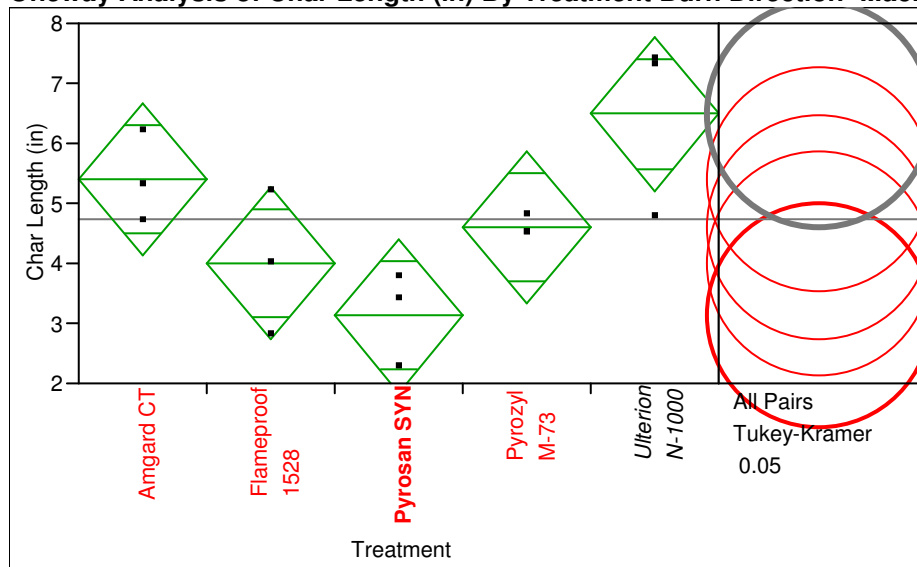
Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.1984	4	10	0.3698
Brown-Forsythe	1.9286	4	10	0.1822
Levene	3.4175	4	10	0.0523
Bartlett	1.7547	4	.	0.1349

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
2.0101	4	4.665	0.2392

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Machine Direction



Excluded Rows
42

Oneway Anova Summary of Fit

Rsquare	0.669129
Adj Rsquare	0.536781
Root Mean Square Error	0.991127
Mean of Response	4.723333
Observations (or Sum Wgts)	15

Analysis of Variance

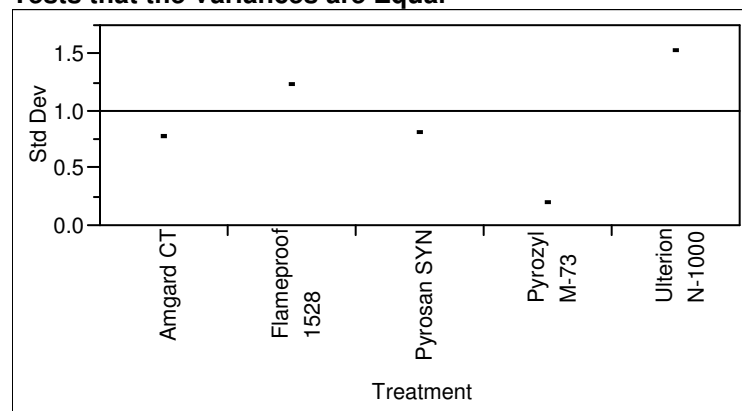
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	4	19.866000	4.96650	5.0558	0.0172
Error	10	9.823333	0.98233		
C. Total	14	29.689333			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	5.40000	0.57223	4.1250	6.6750
Flameproof 1528	3	4.00000	0.57223	2.7250	5.2750
Pyrosan SYN	3	3.13333	0.57223	1.8583	4.4083
Pyrozyl M-73	3	4.60000	0.57223	3.3250	5.8750
Ulterior N-1000	3	6.48333	0.57223	5.2083	7.7583

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.754983	0.533333	0.700000
Flameproof 1528	3	1.200000	0.800000	1.200000
Pyrosan SYN	3	0.784750	0.588889	0.616667
Pyrozyl M-73	3	0.173205	0.133333	0.100000
Ulterior N-1000	3	1.501943	1.155556	0.916667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.8594	4	10	0.5202
Brown-Forsythe	1.0944	4	10	0.4106
Levene	2.1614	4	10	0.1472
Bartlett	1.3692	4	.	0.2418

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

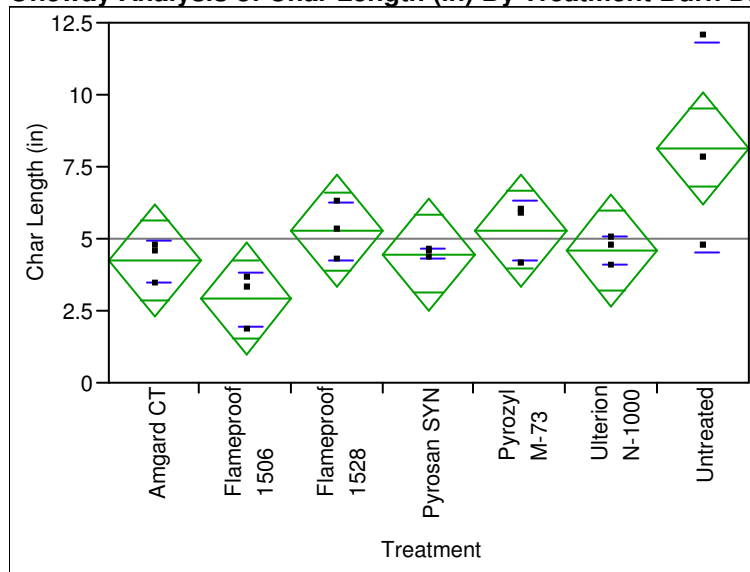
F Ratio	DFNum	DFDen	Prob > F
3.2750	4	4.2327	0.1316

Table A 6 Polyester Vertical Burn Test- 10 Wash Cycles

Fabric	Machine direction/Cross-machine direction	Chemical	After flame time (mins:secs)	Melt Drip	Char length (in)
Polyester	Machine direction	Amgard CT	00:09.4	Y	5
Polyester	Machine direction	Amgard CT	00:08.8	Y	7
Polyester	Machine direction	Amgard CT	00:07.4	Y	6
Polyester	Cross-machine direction	Amgard CT	00:00.0	Y	4.75
Polyester	Cross-machine direction	Amgard CT	00:00.0	Y	3.4
Polyester	Cross-machine direction	Amgard CT	00:00.0	Y	4.5
Polyester	Machine direction	Flameproof 1528	00:00.0	Y	4.5
Polyester	Machine direction	Flameproof 1528	00:00.0	Y	4.8
Polyester	Machine direction	Flameproof 1528	00:00.0	Y	5.3
Polyester	Cross-machine direction	Flameproof 1528	00:00.0	Y	4.25
Polyester	Cross-machine direction	Flameproof 1528	00:00.0	Y	5.25
Polyester	Cross-machine direction	Flameproof 1528	00:00.0	Y	6.25
Polyester	Machine direction	Pyrosan SYN	00:00.0	Y	3.9
Polyester	Machine direction	Pyrosan SYN	00:00.0	Y	5
Polyester	Machine direction	Pyrosan SYN	00:00.0	Y	4.5
Polyester	Cross-machine direction	Pyrosan SYN	00:00.0	Y	4.3
Polyester	Cross-machine direction	Pyrosan SYN	00:00.0	Y	4.5
Polyester	Cross-machine direction	Pyrosan SYN	00:00.0	N	4.6
Polyester	Machine direction	Pyrozyl M-73	00:01.6	N	5.5
Polyester	Machine direction	Pyrozyl M-73	00:00.0	N	4.75
Polyester	Machine direction	Pyrozyl M-73	00:00.0	N	3.75
Polyester	Cross-machine direction	Pyrozyl M-73	00:00.0	Y	4.1
Polyester	Cross-machine direction	Pyrozyl M-73	00:00.0	Y	6
Polyester	Cross-machine direction	Pyrozyl M-73	00:00.0	Y	5.8
Polyester	Machine direction	Ultrion N-1000	00:08.1	Y	6
Polyester	Machine direction	Ultrion N-1000	00:06.3	Y	5.5
Polyester	Machine direction	Ultrion N-1000	00:11.7	Y	6.1
Polyester	Cross-machine direction	Ultrion N-1000	00:00.0	Y	4.75
Polyester	Cross-machine direction	Ultrion N-1000	00:00.0	Y	5
Polyester	Cross-machine direction	Ultrion N-1000	00:05.6	Y	4

Table A 7 ANOVA Analysis for Polyester Burns at 10 Wash Cycles

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Cross-machine Direction



**Oneway Anova
Summary of Fit**

Rsquare	0.57597
Adj Rsquare	0.394243
Root Mean Square Error	1.569956
Mean of Response	4.978571
Observations (or Sum Wgts)	21

Analysis of Variance

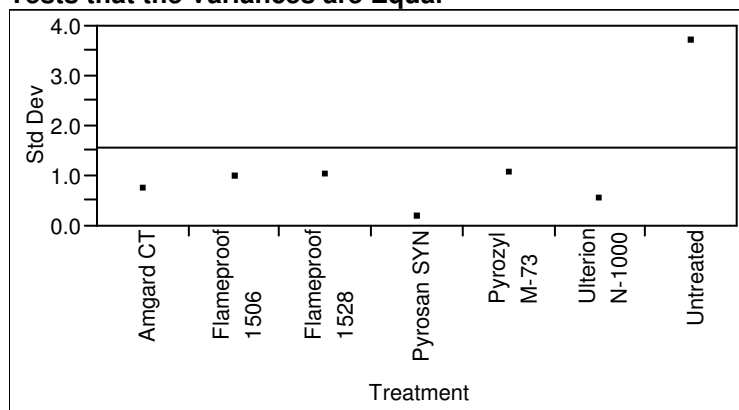
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	6	46.871190	7.81187	3.1694	0.0353
Error	14	34.506667	2.46476		
C. Total	20	81.377857			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	4.21667	0.90641	2.2726	6.161
Flameproof 1506	3	2.88333	0.90641	0.9393	4.827
Flameproof 1528	3	5.25000	0.90641	3.3059	7.194
Pyrosan SYN	3	4.46667	0.90641	2.5226	6.411
Pyrozyl M-73	3	5.30000	0.90641	3.3559	7.244
Ulterior N-1000	3	4.58333	0.90641	2.6393	6.527
Untreated	3	8.15000	0.90641	6.2059	10.094

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.718215	0.544444	0.533333
Flameproof 1506	3	0.954376	0.722222	0.716667
Flameproof 1528	3	1.000000	0.666667	1.000000
Pyrosan SYN	3	0.152753	0.111111	0.133333
Pyrozyl M-73	3	1.044031	0.800000	0.700000
Ulterior N-1000	3	0.520416	0.388889	0.416667
Untreated	3	3.666402	2.566667	3.450000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.5949	6	14	0.2207
Brown-Forsythe	13.3543	6	14	<.0001
Levene	3.1523	6	14	0.0359
Bartlett	2.6459	6	.	0.0144

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
1.6265	6	5.6159	0.2919

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

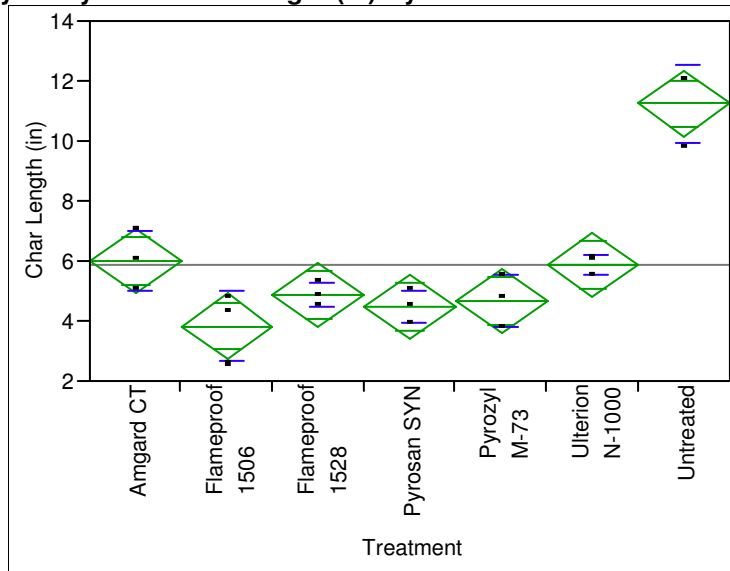
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	26.000	8.6667	-0.654
Flameproof 1506	3	7.000	2.3333	-2.565
Flameproof 1528	3	42.000	14.0000	0.855
Pyrosan SYN	3	28.500	9.5000	-0.402
Pyrozyl M-73	3	41.000	13.6667	0.754
Ulterior N-1000	3	33.500	11.1667	0.000
Untreated	3	53.000	17.6667	1.961

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
11.1877	6	0.0827

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Machine Direction



Oneway Anova Summary of Fit

Rsquare 0.912117
 Adj Rsquare 0.874452
 Root Mean Square Error 0.880273
 Mean of Response 5.85
 Observations (or Sum Wgts) 21

Analysis of Variance

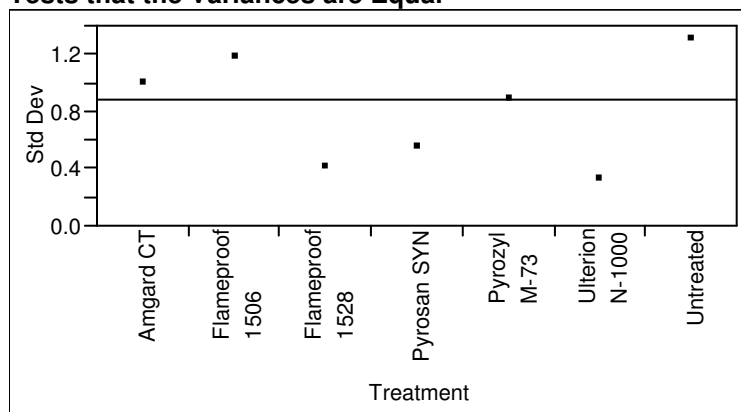
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	6	112.59167	18.7653	24.2170	<.0001
Error	14	10.84833	0.7749		
C. Total	20	123.44000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	6.0000	0.50823	4.910	7.090
Flameproof 1506	3	3.8333	0.50823	2.743	4.923
Flameproof 1528	3	4.8667	0.50823	3.777	5.957
Pyrosan SYN	3	4.4667	0.50823	3.377	5.557
Pyrozyl M-73	3	4.6667	0.50823	3.577	5.757
Ulterior N-1000	3	5.8667	0.50823	4.777	6.957
Untreated	3	11.2500	0.50823	10.160	12.340

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	1.000000	0.666667	1.000000
Flameproof 1506	3	1.181454	0.888889	0.916667
Flameproof 1528	3	0.404145	0.288889	0.366667
Pyrosan SYN	3	0.550757	0.377778	0.533333
Pyrozyl M-73	3	0.877971	0.611111	0.833333
Ulterior N-1000	3	0.321455	0.244444	0.233333
Untreated	3	1.299038	1.000000	0.750000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.7369	6	14	0.6286
Brown-Forsythe	0.7668	6	14	0.6081
Levene	1.6752	6	14	0.1996
Bartlett	0.8100	6	.	0.5619

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
9.6164	6	6.0579	0.0070

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	44.000	14.6667	1.057
Flameproof 1506	3	12.500	4.1667	-2.014
Flameproof 1528	3	26.500	8.8333	-0.604
Pyrosan SYN	3	19.000	6.3333	-1.359
Pyrozyl M-73	3	23.000	7.6667	-0.957
Ulterior N-1000	3	46.000	15.3333	1.259
Untreated	3	60.000	20.0000	2.669

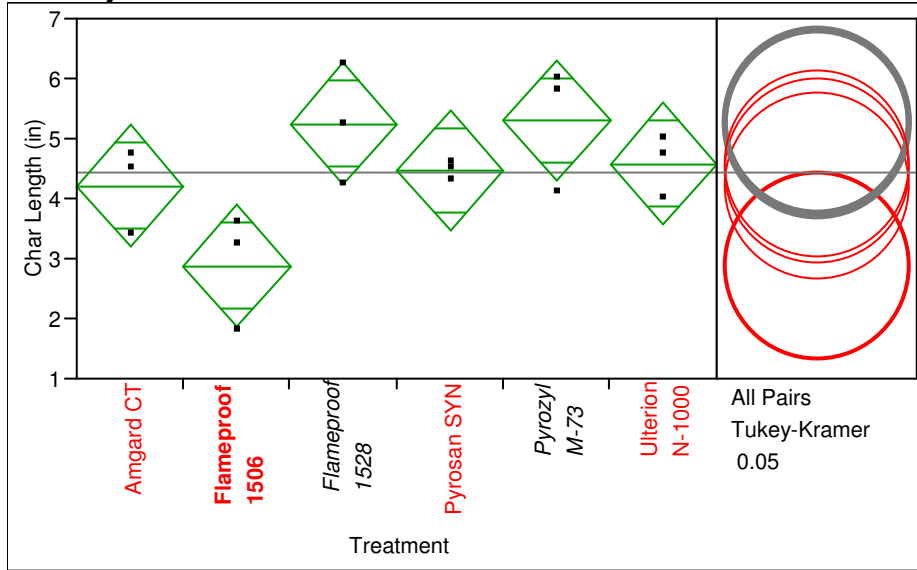
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
15.4498	6	0.0170

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table A 8 ANOVA Analysis for Polyester Burns at 10 Wash Cycles- Excluding Untreated

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Cross-machine Direction, Wash Cycles=10



Oneway Anova Summary of Fit

Rsquare	0.60489
Adj Rsquare	0.440261
Root Mean Square Error	0.796956
Mean of Response	4.45
Observations (or Sum Wgts)	18

Analysis of Variance

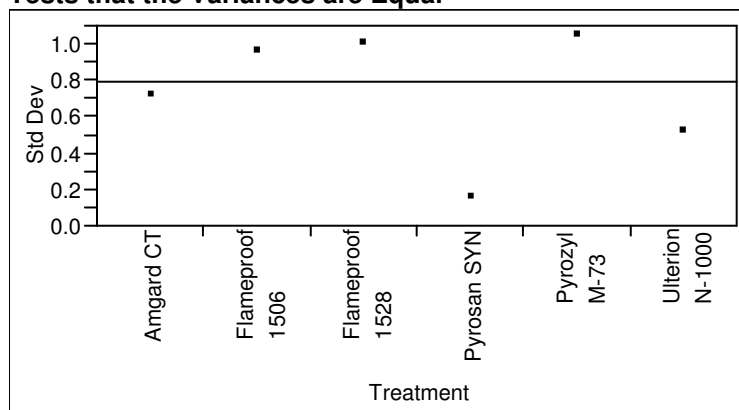
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	11.668333	2.33367	3.6743	0.0301
Error	12	7.621667	0.63514		
C. Total	17	19.290000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	4.21667	0.46012	3.2141	5.2192
Flameproof 1506	3	2.88333	0.46012	1.8808	3.8859
Flameproof 1528	3	5.25000	0.46012	4.2475	6.2525
Pyrosan SYN	3	4.46667	0.46012	3.4641	5.4692
Pyrozy M-73	3	5.30000	0.46012	4.2975	6.3025
Ulterior N-1000	3	4.58333	0.46012	3.5808	5.5859

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.718215	0.5444444	0.533333
Flameproof 1506	3	0.954376	0.7222222	0.716667
Flameproof 1528	3	1.000000	0.6666667	1.000000
Pyrosan SYN	3	0.152753	0.1111111	0.133333
Pyrozyl M-73	3	1.044031	0.8000000	0.700000
Ulterior N-1000	3	0.520416	0.3888889	0.416667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.5955	5	12	0.7044
Brown-Forsythe	1.0643	5	12	0.4264
Levene	1.6369	5	12	0.2242
Bartlett	1.0079	5	.	0.4110

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
1.6290	5	4.9644	0.3035

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

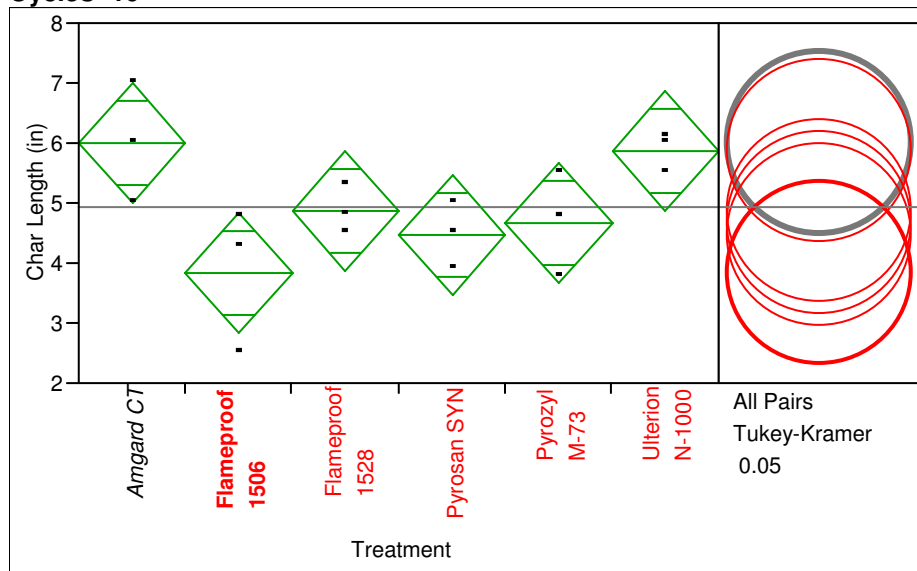
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	25.000	8.3333	-0.356
Flameproof 1506	3	7.000	2.3333	-2.490
Flameproof 1528	3	40.000	13.3333	1.305
Pyrosan SYN	3	28.500	9.5000	0.000
Pyrozyl M-73	3	39.000	13.0000	1.186
Ulterior N-1000	3	31.500	10.5000	0.296

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
8.5088	5	0.1303

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Machine Direction, Wash Cycles=10



Oneway Anova Summary of Fit

Rsquare	0.58493
Adj Rsquare	0.411984
Root Mean Square Error	0.789163
Mean of Response	4.95
Observations (or Sum Wgts)	18

Analysis of Variance

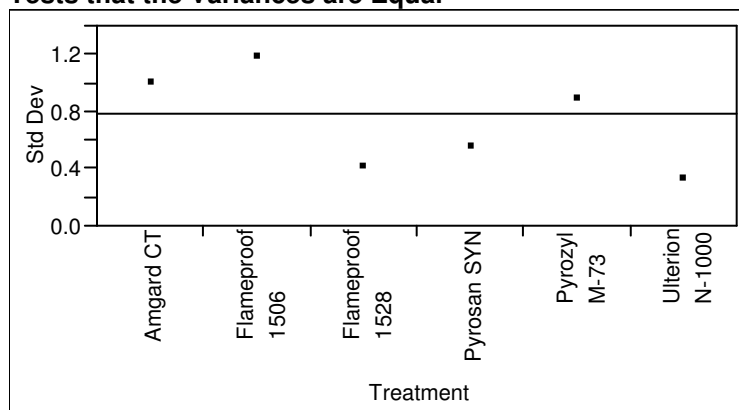
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	10.531667	2.10633	3.3822	0.0389
Error	12	7.473333	0.62278		
C. Total	17	18.005000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	6.00000	0.45562	5.0073	6.9927
Flameproof 1506	3	3.83333	0.45562	2.8406	4.8261
Flameproof 1528	3	4.86667	0.45562	3.8739	5.8594
Pyrosan SYN	3	4.46667	0.45562	3.4739	5.4594
Pyrozyl M-73	3	4.66667	0.45562	3.6739	5.6594
Ulterior N-1000	3	5.86667	0.45562	4.8739	6.8594

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	1.000000	0.666667	1.000000
Flameproof 1506	3	1.181454	0.888889	0.916667
Flameproof 1528	3	0.404145	0.288889	0.366667
Pyrosan SYN	3	0.550757	0.377778	0.533333
Pyrozyl M-73	3	0.877971	0.611111	0.833333
Ulterior N-1000	3	0.321455	0.244444	0.233333

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.7813	5	12	0.5820
Brown-Forsythe	2.9114	5	12	0.0600
Levene	1.2667	5	12	0.3395
Bartlett	0.7904	5	.	0.5564

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
3.6394	5	5.4301	0.0829

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	44.000	14.6667	1.782
Flameproof 1506	3	12.500	4.1667	-1.841
Flameproof 1528	3	26.500	8.8333	-0.178
Pyrosan SYN	3	19.000	6.3333	-1.069
Pyrozyl M-73	3	23.000	7.6667	-0.594
Ulterior N-1000	3	46.000	15.3333	2.019

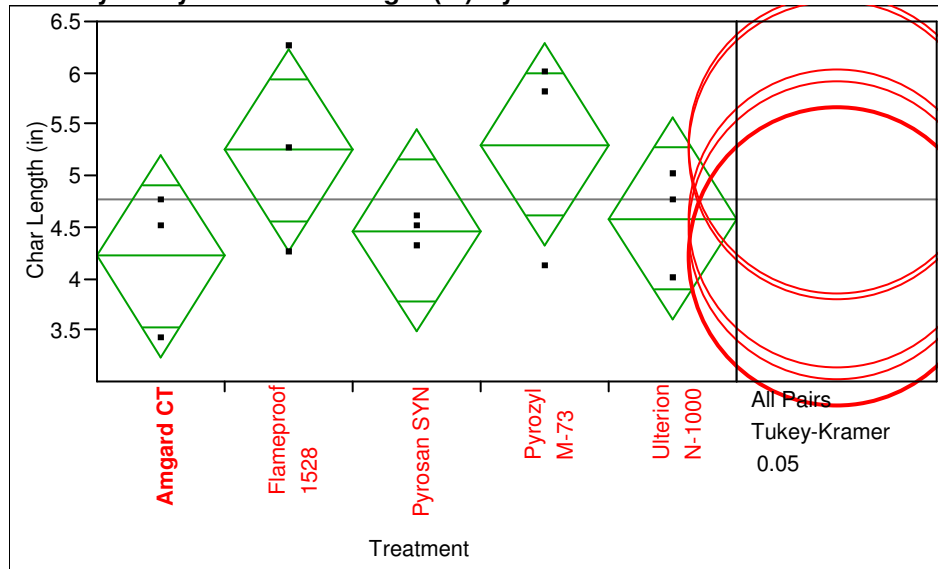
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
10.8983	5	0.0534

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table A 9 ANOVA Analysis for Polyester Burns at 10 Wash Cycles- Excluding Untreated and Flameproof 1506

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Cross-machine Direction



Excluded Rows

6

**Oneway Anova
Summary of Fit**

Rsquare	0.328108
Adj Rsquare	0.059351
Root Mean Square Error	0.761577
Mean of Response	4.763333
Observations (or Sum Wgts)	15

Analysis of Variance

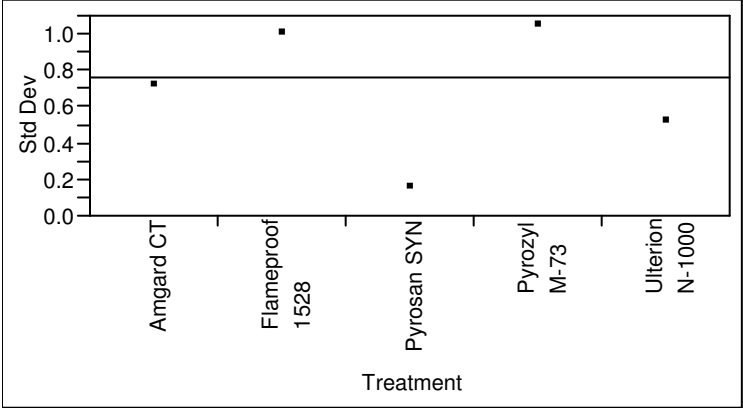
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	4	2.8323333	0.708083	1.2208	0.3616
Error	10	5.800000	0.580000		
C. Total	14	8.6323333			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	4.21667	0.43970	3.2370	5.1964
Flameproof 1528	3	5.25000	0.43970	4.2703	6.2297
Pyrosan SYN	3	4.46667	0.43970	3.4870	5.4464
Pyrozyl M-73	3	5.30000	0.43970	4.3203	6.2797
Ulterior N-1000	3	4.58333	0.43970	3.6036	5.5630

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.718215	0.5444444	0.533333
Flameproof 1528	3	1.000000	0.6666667	1.000000
Pyrosan SYN	3	0.152753	0.1111111	0.133333
Pyrozyl M-73	3	1.044031	0.8000000	0.700000
Ulterior N-1000	3	0.520416	0.3888889	0.416667

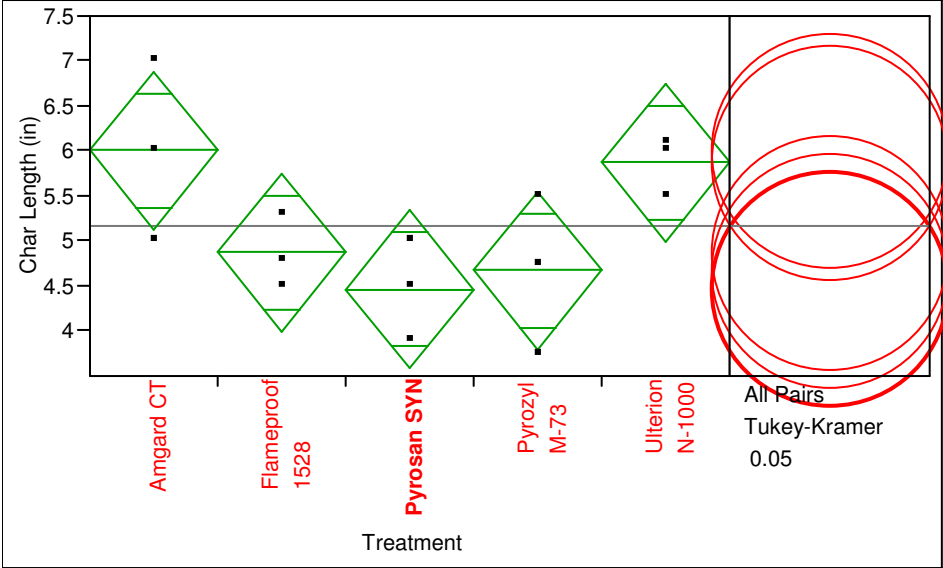
Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.7437	4	10	0.5837
Brown-Forsythe	1.4493	4	10	0.2881
Levene	1.8213	4	10	0.2014
Bartlett	1.2151	4	.	0.3019

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0.7048	4	4.289	0.6263

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Machine Direction



Excluded Rows
6

Oneway Anova Summary of Fit

Rsquare	0.563454
Adj Rsquare	0.388835
Root Mean Square Error	0.684227
Mean of Response	5.173333
Observations (or Sum Wgts)	15

Analysis of Variance

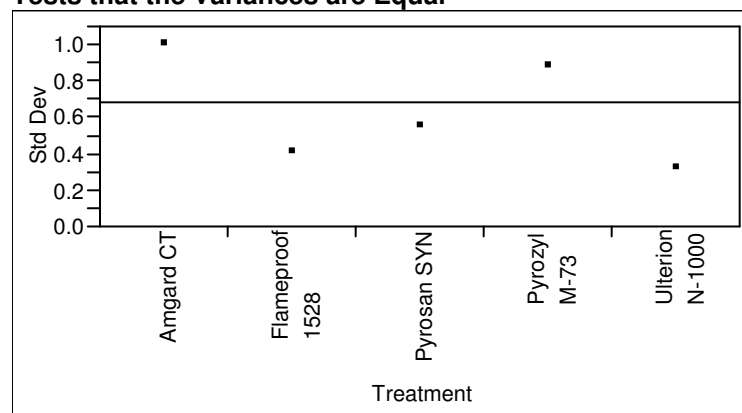
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	4	6.042667	1.51067	3.2268	0.0605
Error	10	4.681667	0.46817		
C. Total	14	10.724333			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	6.00000	0.39504	5.1198	6.8802
Flameproof 1528	3	4.86667	0.39504	3.9865	5.7469
Pyrosan SYN	3	4.46667	0.39504	3.5865	5.3469
Pyrozyl M-73	3	4.66667	0.39504	3.7865	5.5469
Ulterior N-1000	3	5.86667	0.39504	4.9865	6.7469

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	1.000000	0.666667	1.000000
Flameproof 1528	3	0.404145	0.288889	0.366667
Pyrosan SYN	3	0.550757	0.377778	0.533333
Pyrozyl M-73	3	0.877971	0.611111	0.833333
Ulterior N-1000	3	0.321455	0.244444	0.233333

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.8092	4	10	0.5469
Brown-Forsythe	16.8257	4	10	0.0002
Levene	0.7969	4	10	0.5537
Bartlett	0.7251	4	.	0.5746

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

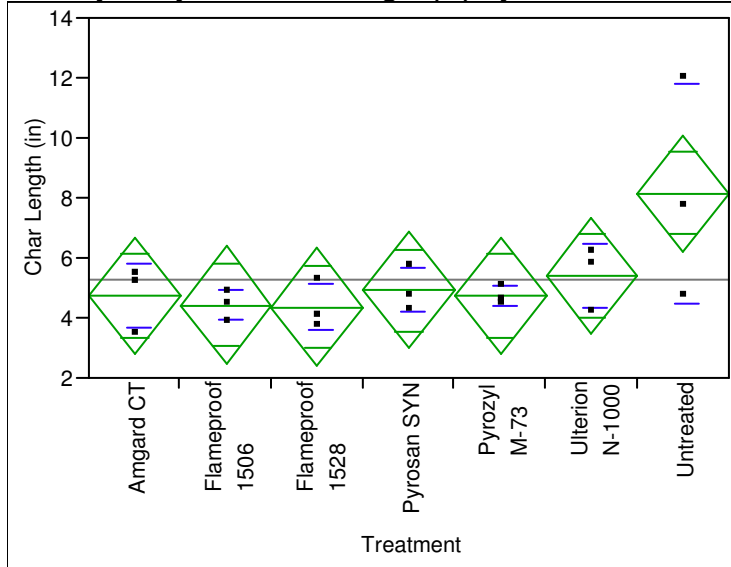
F Ratio	DFNum	DFDen	Prob > F
4.0068	4	4.8249	0.0836

Table A 10 Polyester Vertical Burn Test - 25 Wash Cycles

Fabric	Machine direction /Cross-machine direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Polyester	Machine direction	Amgard CT	00:07.8	Y	6.25
Polyester	Machine direction	Amgard CT	00:08.8	Y	3.4
Polyester	Machine direction	Amgard CT	00:09.5	Y	6.2
Polyester	Cross-machine direction	Amgard CT	00:00.0	Y	5.2
Polyester	Cross-machine direction	Amgard CT	00:01.4	Y	5.5
Polyester	Cross-machine direction	Amgard CT	00:02.3	Y	3.5
Polyester	Machine direction	Flameproof 1528	00:00.0	Y	5.75
Polyester	Machine direction	Flameproof 1528	00:00.0	Y	4.8
Polyester	Machine direction	Flameproof 1528	00:00.0	Y	4
Polyester	Cross-machine direction	Flameproof 1528	00:00.0	Y	5.25
Polyester	Cross-machine direction	Flameproof 1528	00:00.0	Y	4.1
Polyester	Cross-machine direction	Flameproof 1528	00:00.0	Y	3.75
Polyester	Machine direction	Pyrosan SYN	00:00.0	N	3.5
Polyester	Machine direction	Pyrosan SYN	00:00.0	N	3.9
Polyester	Machine direction	Pyrosan SYN	00:00.0	N	3.25
Polyester	Cross-machine direction	Pyrosan SYN	00:00.0	Y	5.75
Polyester	Cross-machine direction	Pyrosan SYN	00:00.0	Y	4.3
Polyester	Cross-machine direction	Pyrosan SYN	00:00.0	Y	4.7
Polyester	Machine direction	Pyrozyl M-73	00:02.7	Y	6.25
Polyester	Machine direction	Pyrozyl M-73	00:00.0	Y	4.8
Polyester	Machine direction	Pyrozyl M-73	00:09.2	Y	5.75
Polyester	Cross-machine direction	Pyrozyl M-73	00:00.0	Y	5.1
Polyester	Cross-machine direction	Pyrozyl M-73	00:00.0	Y	4.5
Polyester	Cross-machine direction	Pyrozyl M-73	00:00.0	Y	4.6
Polyester	Machine direction	Ulterion N-1000	00:08.9	Y	5.75
Polyester	Machine direction	Ulterion N-1000	00:08.1	Y	5.25
Polyester	Machine direction	Ulterion N-1000	00:06.5	Y	6.75
Polyester	Cross-machine direction	Ulterion N-1000	00:00.0	Y	4.2
Polyester	Cross-machine direction	Ulterion N-1000	00:09.0	Y	6.2
Polyester	Cross-machine direction	Ulterion N-1000	00:07.8	Y	5.8

Table A 11 ANOVA Analysis for Polyester Burns at 25 Wash Cycles

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Cross-machine Direction



**Oneway Anova
Summary of Fit**

Rsquare	0.477726
Adj Rsquare	0.253894
Root Mean Square Error	1.570221
Mean of Response	5.247619
Observations (or Sum Wgts)	21

Analysis of Variance

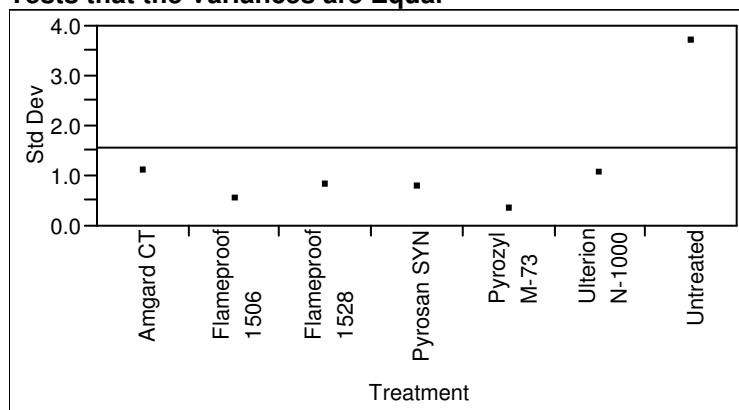
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	6	31.574048	5.26234	2.1343	0.1138
Error	14	34.518333	2.46560		
C. Total	20	66.092381			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	4.73333	0.90657	2.7889	6.678
Flameproof 1506	3	4.43333	0.90657	2.4889	6.378
Flameproof 1528	3	4.36667	0.90657	2.4223	6.311
Pyrosan SYN	3	4.91667	0.90657	2.9723	6.861
Pyrozyl M-73	3	4.73333	0.90657	2.7889	6.678
Ulterior N-1000	3	5.40000	0.90657	3.4556	7.344
Untreated	3	8.15000	0.90657	6.2056	10.094

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	1.078579	0.822222	0.766667
Flameproof 1506	3	0.503322	0.355556	0.466667
Flameproof 1528	3	0.784750	0.588889	0.616667
Pyrosan SYN	3	0.748888	0.555556	0.616667
Pyrozyl M-73	3	0.321455	0.244444	0.233333
Ulterior N-1000	3	1.058301	0.800000	0.800000
Untreated	3	3.666402	2.566667	3.450000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.5946	6	14	0.2207
Brown-Forsythe	12.4962	6	14	<.0001
Levene	3.1410	6	14	0.0364
Bartlett	2.2848	6	.	0.0331

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0.6043	6	6.0062	0.7220

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

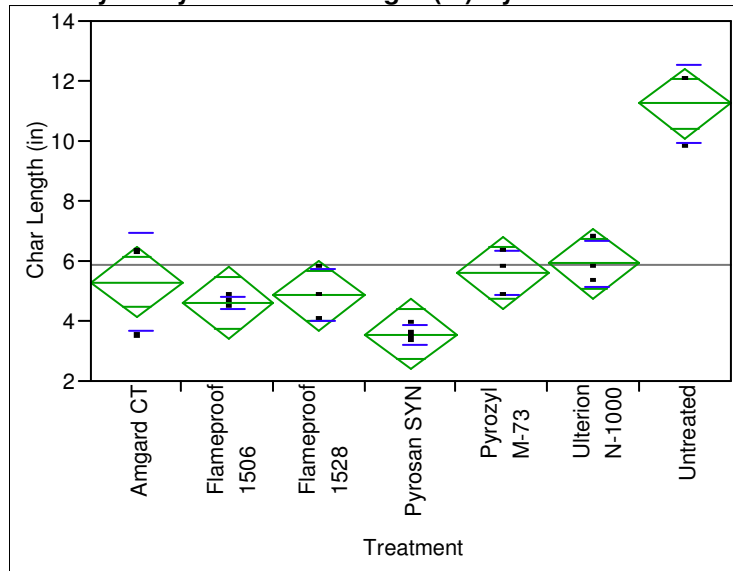
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	31.000	10.3333	-0.151
Flameproof 1506	3	22.500	7.5000	-1.006
Flameproof 1528	3	21.000	7.0000	-1.157
Pyrosan SYN	3	33.500	11.1667	0.000
Pyrozyl M-73	3	29.500	9.8333	-0.302
Ulterior N-1000	3	42.000	14.0000	0.855
Untreated	3	51.500	17.1667	1.810

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.0165	6	0.4213

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Machine Direction



Oneway Anova Summary of Fit

Rsquare 0.897753
Adj Rsquare 0.853934
Root Mean Square Error 0.955373
Mean of Response 5.864286
Observations (or Sum Wgts) 21

Analysis of Variance

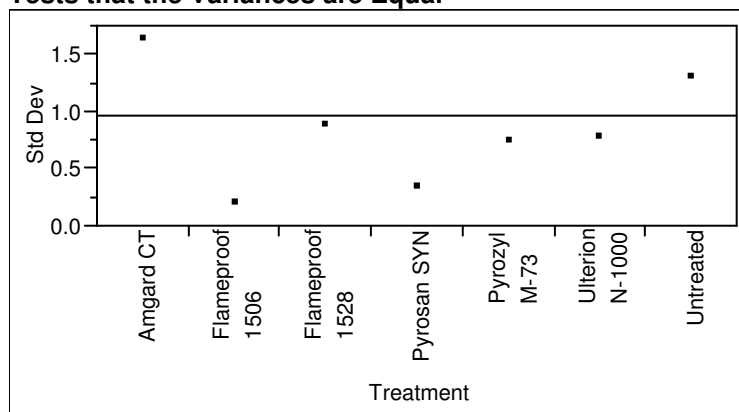
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	6	112.19738	18.6996	20.4873	<.0001
Error	14	12.77833	0.9127		
C. Total	20	124.97571			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	5.2833	0.55159	4.100	6.466
Flameproof 1506	3	4.6000	0.55159	3.417	5.783
Flameproof 1528	3	4.8500	0.55159	3.667	6.033
Pyrosan SYN	3	3.5500	0.55159	2.367	4.733
Pyrozyl M-73	3	5.6000	0.55159	4.417	6.783
Ulterior N-1000	3	5.9167	0.55159	4.734	7.100
Untreated	3	11.2500	0.55159	10.067	12.433

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	1.631206	1.255556	0.966667
Flameproof 1506	3	0.200000	0.133333	0.200000
Flameproof 1528	3	0.876071	0.600000	0.850000
Pyrosan SYN	3	0.327872	0.233333	0.300000
Pyrozyl M-73	3	0.736546	0.533333	0.650000
Ulterior N-1000	3	0.763763	0.555556	0.666667
Untreated	3	1.299038	1.000000	0.750000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.9907	6	14	0.4681
Brown-Forsythe	0.3773	6	14	0.8814
Levene	3.3583	6	14	0.0290
Bartlett	1.3225	6	.	0.2429

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
13.2388	6	5.8747	0.0034

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	33.500	11.1667	0.000
Flameproof 1506	3	22.000	7.3333	-1.059
Flameproof 1528	3	27.000	9.0000	-0.555
Pyrosan SYN	3	8.000	2.6667	-2.470
Pyrozyl M-73	3	38.500	12.8333	0.504
Ulterior N-1000	3	42.000	14.0000	0.857
Untreated	3	60.000	20.0000	2.672

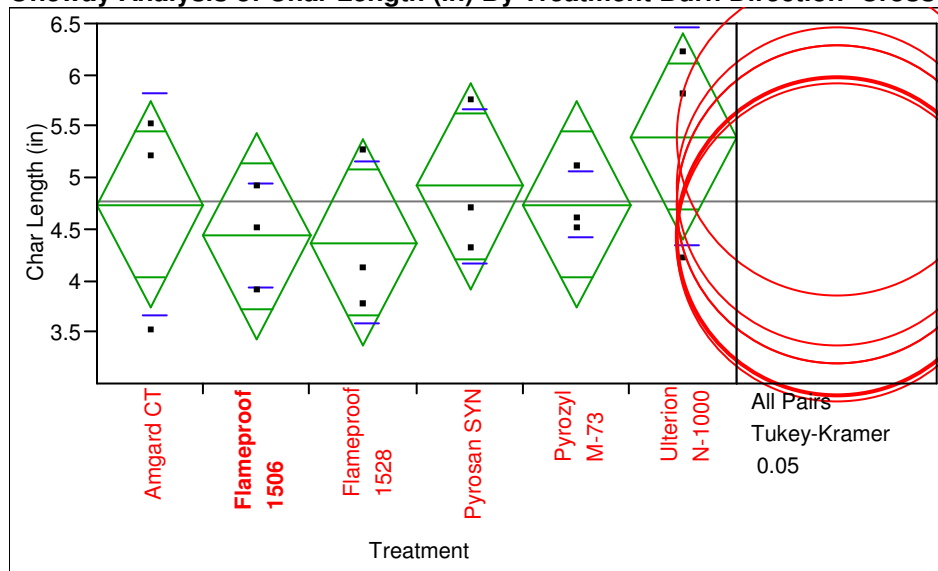
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
14.1394	6	0.0281

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table A 12 ANOVA Analysis for Polyester Burns at 25 Wash Cycles- Excluding Untreated

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Cross-machine Direction



Excluded Rows

3

**Oneway Anova
Summary of Fit**

Rsquare	0.215003
Adj Rsquare	-0.11208
Root Mean Square Error	0.797566
Mean of Response	4.763889
Observations (or Sum Wgts)	18

Analysis of Variance

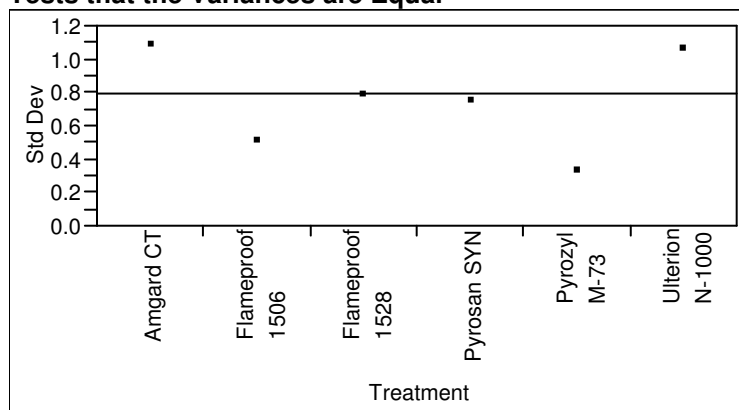
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	2.0906944	0.418139	0.6573	0.6623
Error	12	7.6333333	0.636111		
C. Total	17	9.7240278			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	4.73333	0.46047	3.7300	5.7366
Flameproof 1506	3	4.43333	0.46047	3.4300	5.4366
Flameproof 1528	3	4.36667	0.46047	3.3634	5.3700
Pyrosan SYN	3	4.91667	0.46047	3.9134	5.9200
Pyrozyl M-73	3	4.73333	0.46047	3.7300	5.7366
Ulterior N-1000	3	5.40000	0.46047	4.3967	6.4033

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	1.078579	0.8222222	0.7666667
Flameproof 1506	3	0.503322	0.3555556	0.4666667
Flameproof 1528	3	0.784750	0.5888889	0.6166667
Pyrosan SYN	3	0.748888	0.5555556	0.6166667
Pyrozyl M-73	3	0.321455	0.2444444	0.2333333
Ulterior N-1000	3	1.058301	0.8000000	0.8000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.5993	5	12	0.7017
Brown-Forsythe	0.5070	5	12	0.7659
Levene	1.6665	5	12	0.2170
Bartlett	0.5784	5	.	0.7167

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0.3978	5	5.3882	0.8335

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Comparison for all pairs using Tukey Kramer HSD						
	q*	Alpha				
	3.35886	0.05				
Abs(Dif)-LSD	Ulterior N-1000	Pyrosan SYN	Pyrozyl M-73	Amgard CT	Flameproof 1506	Flameproof 1528
Ulterior N-1000	-2.1873	-1.7040	-1.5207	-1.5207	-1.2207	-1.1540
Pyrosan SYN	-1.7040	-2.1873	-2.0040	-2.0040	-1.7040	-1.6373
Pyrozyl M-73	-1.5207	-2.0040	-2.1873	-2.1873	-1.8873	-1.8207
Amgard CT	-1.5207	-2.0040	-2.1873	-2.1873	-1.8873	-1.8207
Flameproof 1506	-1.2207	-1.7040	-1.8873	-1.8873	-2.1873	-2.1207
Flameproof 1528	-1.1540	-1.6373	-1.8207	-1.8207	-2.1207	-2.1873

Positive values show pairs of means that are significantly different.

Level	Mean
Ulterior N-1000	A 5.4000000
Pyrosan SYN	A 4.9166667
Pyrozyl M-73	A 4.7333333
Amgard CT	A 4.7333333
Flameproof 1506	A 4.4333333
Flameproof 1528	A 4.3666667

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	29.000	9.6667	0.000
Flameproof 1506	3	21.500	7.1667	-0.770
Flameproof 1528	3	20.000	6.6667	-0.948

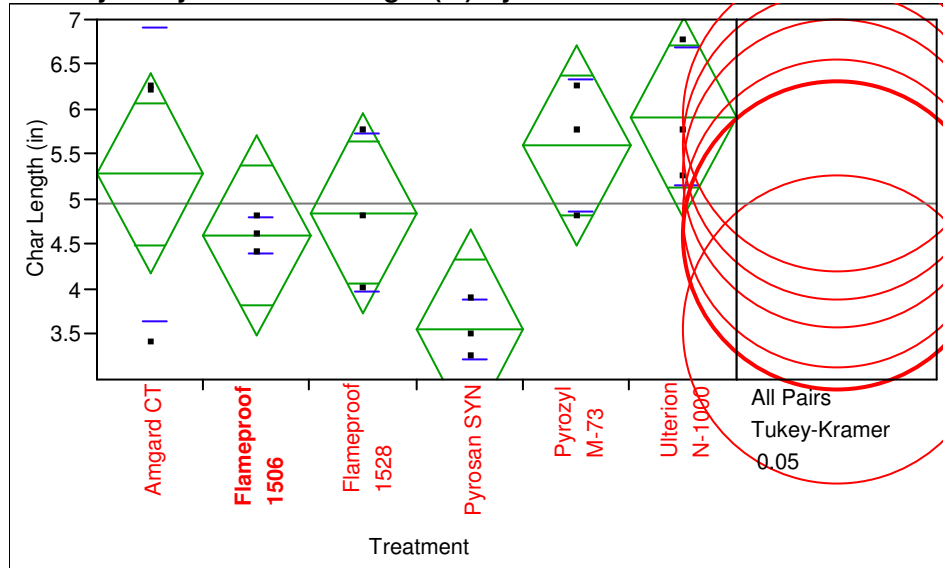
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Pyrosan SYN	3	32.000	10.6667	0.356
Pyrozyl M-73	3	28.500	9.5000	0.000
Ulterior N-1000	3	40.000	13.3333	1.304

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
3.1143	5	0.6824

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Machine Direction



Excluded Rows

3

Oneway Anova Summary of Fit

Rsquare	0.531707
Adj Rsquare	0.336584
Root Mean Square Error	0.885218
Mean of Response	4.966667
Observations (or Sum Wgts)	18

Analysis of Variance

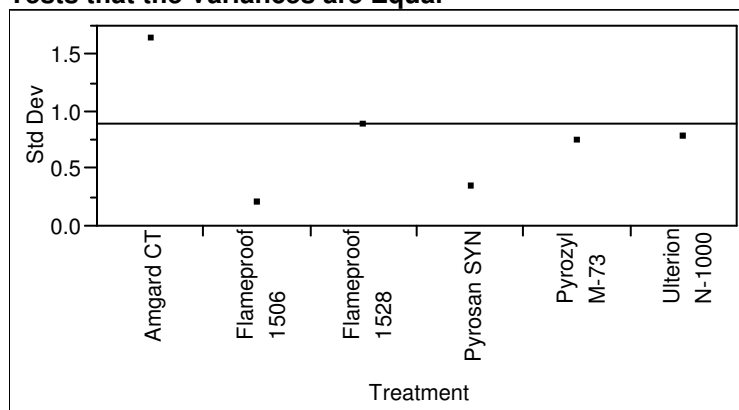
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	10.676667	2.13533	2.7250	0.0719
Error	12	9.403333	0.78361		
C. Total	17	20.080000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	5.28333	0.51108	4.1698	6.3969
Flameproof 1506	3	4.60000	0.51108	3.4865	5.7135
Flameproof 1528	3	4.85000	0.51108	3.7365	5.9635
Pyrosan SYN	3	3.55000	0.51108	2.4365	4.6635
Pyrozyl M-73	3	5.60000	0.51108	4.4865	6.7135
Ulterior N-1000	3	5.91667	0.51108	4.8031	7.0302

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	1.631206	1.255556	0.966667
Flameproof 1506	3	0.200000	0.133333	0.200000
Flameproof 1528	3	0.876071	0.600000	0.850000
Pyrosan SYN	3	0.327872	0.233333	0.300000
Pyrozyl M-73	3	0.736546	0.533333	0.650000
Ulterior N-1000	3	0.763763	0.555556	0.666667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.1883	5	12	0.3709
Brown-Forsythe	0.6079	5	12	0.6958
Levene	3.4892	5	12	0.0353
Bartlett	1.4811	5	.	0.1922

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
5.8317	5	5.2312	0.0347

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Comparisons for all pairs using Tukey Kramer test								
	q*	Alpha						
	3.35886	0.05						
Abs(Dif)-LSD			Ulterior N-1000	Pyrozyl M-73	Amgard CT	Flameproof 1528	Flameproof 1506	Pyrosan SYN
Ulterior N-1000			-2.4277	-2.1110	-1.7944	-1.3610	-1.1110	-0.0610
Pyrozyl M-73			-2.1110	-2.4277	-2.1110	-1.6777	-1.4277	-0.3777
Amgard CT			-1.7944	-2.1110	-2.4277	-1.9944	-1.7444	-0.6944
Flameproof 1528			-1.3610	-1.6777	-1.9944	-2.4277	-2.1777	-1.1277
Flameproof 1506			-1.1110	-1.4277	-1.7444	-2.1777	-2.4277	-1.3777
Pyrosan SYN			-0.0610	-0.3777	-0.6944	-1.1277	-1.3777	-2.4277

Positive values show pairs of means that are significantly different.

Level	Mean
Ulterior N-1000	5.916667
Pyrozyl M-73	5.600000
Amgard CT	5.283333
Flameproof 1528	4.850000
Flameproof 1506	4.600000
Pyrosan SYN	3.550000

Levels not connected by same letter are significantly different.

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
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Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	33.500	11.1667	0.536
Flameproof 1506	3	22.000	7.3333	-0.714
Flameproof 1528	3	27.000	9.0000	-0.119
Pyrosan SYN	3	8.000	2.6667	-2.380
Pyrozyl M-73	3	38.500	12.8333	1.131
Ulterion N-1000	3	42.000	14.0000	1.547

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
9.1139	5	0.1046

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table A 13 Polyester Fit Model – Burn Tests

Term	Std Error	t Ratio	Prob> t
Intercept	0.135089	31.39	<.0001
Burn Direction[Cross-machine Direction]	0.135089	-0.46	0.6450
Treatment[Amgard CT]	0.302069	2.35	0.0215
Treatment[Flameproof 1506]	0.302069	-6.73	<.0001
Treatment[Flameproof 1528]	0.302069	-0.30	0.7659
Treatment[Pyrosan SYN]	0.302069	-1.84	0.0693
Treatment[Pyrozyl M-73]	0.302069	2.24	0.0282
Burn Direction[Cross-machine Direction]*Treatment[Amgard CT]	0.302069	-1.28	0.2037
Burn Direction[Cross-machine Direction]*Treatment[Flameproof 1506]	0.302069	0.23	0.8153
Burn Direction[Cross-machine Direction]*Treatment[Flameproof 1528]	0.302069	0.70	0.4840
Burn Direction[Cross-machine Direction]*Treatment[Pyrosan SYN]	0.302069	2.03	0.0463
Burn Direction[Cross-machine Direction]*Treatment[Pyrozyl M-73]	0.302069	1.26	0.2135
Wash Cycles[10-3]	0.191045	2.41	0.0187
Wash Cycles[25-10]	0.191045	0.87	0.3898
Burn Direction[Cross-machine Direction]*Wash Cycles[10-3]	0.191045	-0.98	0.3297
Burn Direction[Cross-machine Direction]*Wash Cycles[25-10]	0.191045	0.78	0.4392
Treatment[Amgard CT]*Wash Cycles[10-3]	0.42719	-0.71	0.4828
Treatment[Amgard CT]*Wash Cycles[25-10]	0.42719	-0.62	0.5366
Treatment[Flameproof 1506]*Wash Cycles[10-3]	0.42719	1.62	0.1105
Treatment[Flameproof 1506]*Wash Cycles[25-10]	0.42719	2.32	0.0229
Treatment[Flameproof 1528]*Wash Cycles[10-3]	0.42719	1.05	0.2972
Treatment[Flameproof 1528]*Wash Cycles[25-10]	0.42719	-1.44	0.1541
Treatment[Pyrosan SYN]*Wash Cycles[10-3]	0.42719	0.76	0.4512
Treatment[Pyrosan SYN]*Wash Cycles[25-10]	0.42719	-0.93	0.3539
Treatment[Pyrozyl M-73]*Wash Cycles[10-3]	0.42719	-0.92	0.3606
Treatment[Pyrozyl M-73]*Wash Cycles[25-10]	0.42719	0.04	0.9664
Burn Direction[Cross-machine Direction]*Treatment[Amgard CT]*Wash Cycles[10-3]	0.42719	-0.59	0.5537
Burn Direction[Cross-machine Direction]*Treatment[Amgard CT]*Wash Cycles[25-10]	0.42719	1.10	0.2769
Burn Direction[Cross-machine Direction]*Treatment[Flameproof 1506]*Wash Cycles[10-3]	0.42719	-0.69	0.4908
Burn Direction[Cross-machine Direction]*Treatment[Flameproof 1506]*Wash Cycles[25-10]	0.42719	0.57	0.5712

Table A 13 Continued

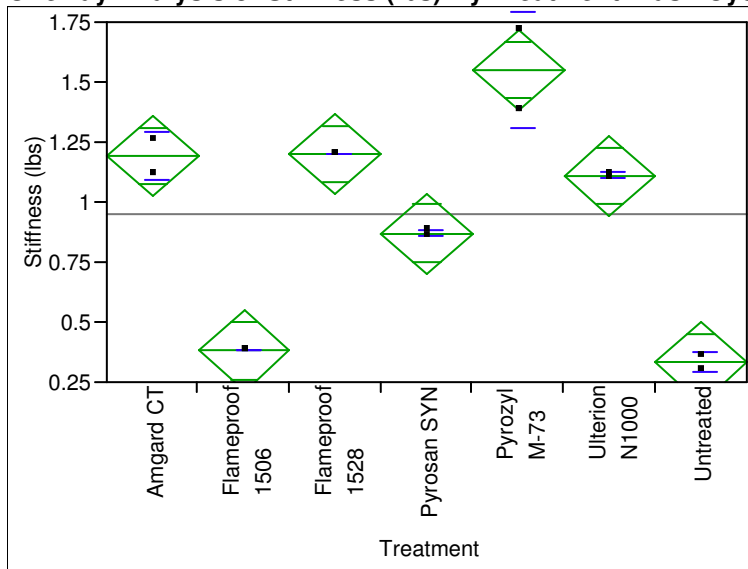
Term	Std Error	t Ratio	Prob> t
Burn Direction[Cross-machine Direction]*Treatment[Flameproof 1528]*Wash Cycles[10-3]	0.42719	0.54	0.5933
Burn Direction[Cross-machine Direction]*Treatment[Flameproof 1528]*Wash Cycles[25-10]	0.42719	-1.36	0.1774
Burn Direction[Cross-machine Direction]*Treatment[Pyrosan SYN]*Wash Cycles[10-3]	0.42719	-0.85	0.3989
Burn Direction[Cross-machine Direction]*Treatment[Pyrosan SYN]*Wash Cycles[25-10]	0.42719	1.25	0.2147
Burn Direction[Cross-machine Direction]*Treatment[Pyrozyl M-73]*Wash Cycles[10-3]	0.42719	0.44	0.6620
Burn Direction[Cross-machine Direction]*Treatment[Pyrozyl M-73]*Wash Cycles[25-10]	0.42719	-2.10	0.0389

Table A 14 Polyester Stiffness Data- 0 and 25 Wash Cycles

Fabric	Treatment	Wash Cycles	Stiffness (lbs)	Wash Cycles	Stiffness (lbs)
Polyester	Untreated	0	0.3	25	N/A
Polyester	Untreated	0	0.36	25	N/A
average			0.33		N/A
Polyester	Amgard CT	0	1.12	25	0.36
Polyester	Amgard CT	0	1.26	25	0.3
average			1.19		0.33
Polyester	Flameproof 1528	0	1.2	25	0.44
Polyester	Flameproof 1528	0	1.2	25	0.36
average			1.2		0.4
Polyester	Pyrozyl M-73	0	1.72	25	0.34
Polyester	Pyrozyl M-73	0	1.38	25	0.38
average			1.55		0.36
Polyester	Pyrosan SYN	0	0.86	25	0.44
Polyester	Pyrosan SYN	0	0.88	25	0.48
average			0.87		0.46
Polyester	Ultrion N1000	0	1.1	25	0.36
Polyester	Ultrion N1000	0	1.12	25	0.3
average			1.11		0.33
Polyester	Flameproof 1506	5	0.38	25	0.32
Polyester	Flameproof 1506	5	0.38	25	0.28
average			0.38		0.3

Table A15 ANOVA Analysis for Polyester Stiffness- 0 Wash

Oneway Analysis of Stiffness (lbs) By Treatment Wash Cycles=0



Oneway Anova Summary of Fit

Rsquare	0.972219
Adj Rsquare	0.948406
Root Mean Square Error	0.099857
Mean of Response	0.947143
Observations (or Sum Wgts)	14

Analysis of Variance

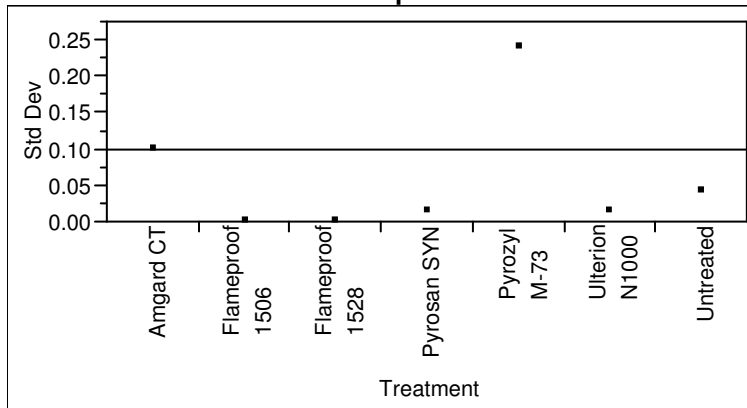
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	6	2.4426857	0.407114	40.8281	<.0001
Error	7	0.0698000	0.009971		
C. Total	13	2.5124857			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	2	1.19000	0.07061	1.0230	1.3570
Flameproof 1506	2	0.38000	0.07061	0.2130	0.5470
Flameproof 1528	2	1.20000	0.07061	1.0330	1.3670
Pyrosan SYN	2	0.87000	0.07061	0.7030	1.0370
Pyrozyl M-73	2	1.55000	0.07061	1.3830	1.7170
Ulterior N1000	2	1.11000	0.07061	0.9430	1.2770
Untreated	2	0.33000	0.07061	0.1630	0.4970

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	2	0.0989949	0.0700000	0.0700000
Flameproof 1506	2	0.0000000	0.0000000	0.0000000
Flameproof 1528	2	0.0000000	0.0000000	0.0000000
Pyrosan SYN	2	0.0141421	0.0100000	0.0100000
Pyrozyl M-73	2	0.2404163	0.1700000	0.1700000
Ulterior N1000	2	0.0141421	0.0100000	0.0100000
Untreated	2	0.0424264	0.0300000	0.0300000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.0000	-1	0	0.0000
Brown-Forsythe	.	6	7	.
Levene	.	6	7	.
Bartlett	.	6	.	.

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
.	6	.	.

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	2	20.500	10.2500	0.916
Flameproof 1506	2	7.000	3.5000	-1.374
Flameproof 1528	2	21.000	10.5000	1.007
Pyrosan SYN	2	11.000	5.5000	-0.641
Pyrozyl M-73	2	27.000	13.5000	2.107
Ulterion N1000	2	15.500	7.7500	0.000
Untreated	2	3.000	1.5000	-2.107

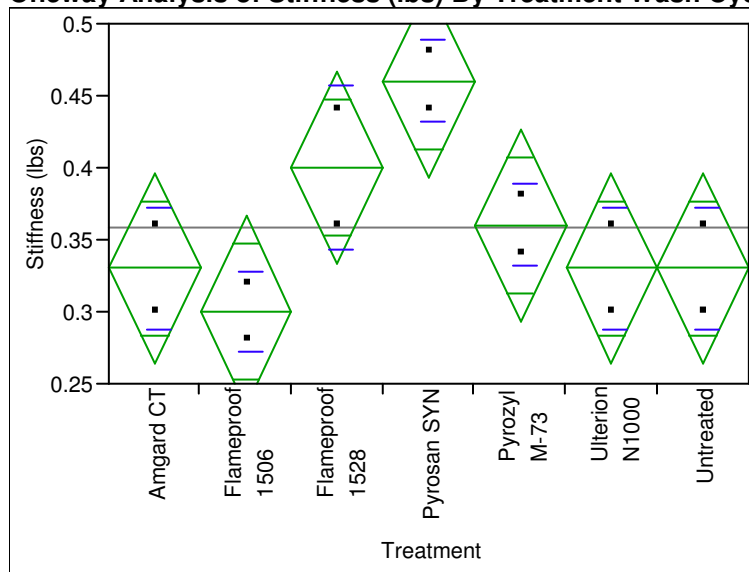
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
12.4967	6	0.0518

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table A 16 ANOVA Analysis for Polyester Stiffness- 25 Wash Cycles

Oneway Analysis of Stiffness (lbs) By Treatment Wash Cycles=25



Oneway Anova Summary of Fit

Rsquare	0.764814
Adj Rsquare	0.563225
Root Mean Square Error	0.039641
Mean of Response	0.358571
Observations (or Sum Wgts)	14

Analysis of Variance

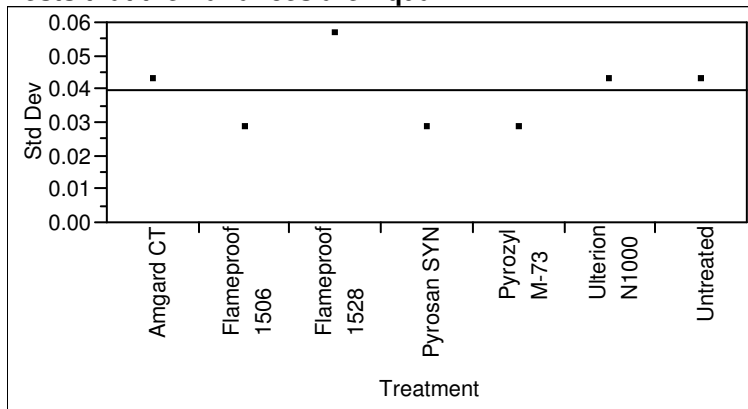
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	6	0.03577143	0.005962	3.7939	0.0523
Error	7	0.01100000	0.001571		
C. Total	13	0.04677143			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	2	0.330000	0.02803	0.26372	0.39628
Flameproof 1506	2	0.300000	0.02803	0.23372	0.36628
Flameproof 1528	2	0.400000	0.02803	0.33372	0.46628
Pyrosan SYN	2	0.460000	0.02803	0.39372	0.52628
Pyrozyl M-73	2	0.360000	0.02803	0.29372	0.42628
Ulterion N1000	2	0.330000	0.02803	0.26372	0.39628
Untreated- Unwashed	2	0.330000	0.02803	0.26372	0.39628

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	2	0.0424264	0.0300000	0.0300000
Flameproof 1506	2	0.0282843	0.0200000	0.0200000
Flameproof 1528	2	0.0565685	0.0400000	0.0400000
Pyrosan SYN	2	0.0282843	0.0200000	0.0200000
Pyrozyl M-73	2	0.0282843	0.0200000	0.0200000
Ulterior N1000	2	0.0424264	0.0300000	0.0300000
Untreated	2	0.0424264	0.0300000	0.0300000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.0000	-1	0	0.0000
Brown-Forsythe	2.46e+15	6	7	<.0001
Levene	2.46e+15	6	7	<.0001
Bartlett	0.1094	6	.	0.9954

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
3.0436	6	3.0924	0.1896

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	2	11.500	5.7500	-0.557
Flameproof 1506	2	6.000	3.0000	-1.578
Flameproof 1528	2	21.000	10.5000	1.021
Pyrosan SYN	2	26.500	13.2500	2.042
Pyrozyl M-73	2	17.000	8.5000	0.278
Ulterior N1000	2	11.500	5.7500	-0.557
Untreated	2	11.500	5.7500	-0.557

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
8.5682	6	0.1994

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table A 17 Polyester Tear Strength at 0 Wash Cycles

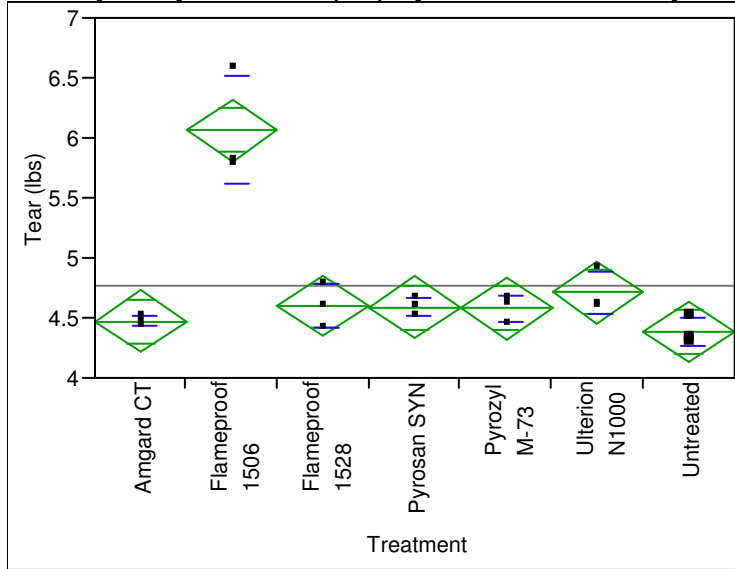
Fabric	Treatment	Washes	Tear Yarns	Ave "N" Peaks (lb)
Polyester	Untreated	0	Fill	4.51
Polyester	Untreated	0	Fill	4.3
Polyester	Untreated	0	Fill	4.34
Polyester	Untreated	0	Warp	5.19
Polyester	Untreated	0	Warp	6.29
Polyester	Untreated	0	Warp	5.49
Polyester	Amgard CT	0	Fill	4.47
Polyester	Amgard CT	0	Fill	4.51
Polyester	Amgard CT	0	Fill	4.43
Polyester	Amgard CT	0	Warp	6.52
Polyester	Amgard CT	0	Warp	6.93
Polyester	Amgard CT	0	Warp	6.02
Polyester	Flameproof 1528	0	Fill	4.41
Polyester	Flameproof 1528	0	Fill	4.6
Polyester	Flameproof 1528	0	Fill	4.79
Polyester	Flameproof 1528	0	Warp	5.99
Polyester	Flameproof 1528	0	Warp	6.69
Polyester	Flameproof 1528	0	Warp	6.82
Polyester	Pyrozyl M-73	0	Fill	4.66
Polyester	Pyrozyl M-73	0	Fill	4.62
Polyester	Pyrozyl M-73	0	Fill	4.45
Polyester	Pyrozyl M-73	0	Warp	6.74
Polyester	Pyrozyl M-73	0	Warp	5.93
Polyester	Pyrozyl M-73	0	Warp	6.88
Polyester	Pyrosan SYN	0	Fill	4.6
Polyester	Pyrosan SYN	0	Fill	4.51
Polyester	Pyrosan SYN	0	Fill	4.66
Polyester	Pyrosan SYN	0	Warp	6.57
Polyester	Pyrosan SYN	0	Warp	6.27
Polyester	Pyrosan SYN	0	Warp	6.76
Polyester	Ultrion N1000	0	Fill	4.62
Polyester	Ultrion N1000	0	Fill	4.6
Polyester	Ultrion N1000	0	Fill	4.91
Polyester	Ultrion N1000	0	Warp	6.16
Polyester	Ultrion N1000	0	Warp	6.88
Polyester	Ultrion N1000	0	Warp	6.86
Polyester	Flameproof 1506	0	Fill	5.82
Polyester	Flameproof 1506	0	Fill	6.58
Polyester	Flameproof 1506	0	Fill	5.78
Polyester	Flameproof 1506	0	Warp	4.83
Polyester	Flameproof 1506	0	Warp	4.79
Polyester	Flameproof 1506	0	Warp	4.83

Table A 18 Polyester Tear Strength at 25 Wash Cycles

Fabric	Treatment	Washes	Tear Direction	Ave "N" Peaks (lb)
Polyester	Amgard CT	25	Fill	3.62
Polyester	Amgard CT	25	Fill	3.6
Polyester	Amgard CT	25	Fill	3.47
Polyester	Amgard CT	25	Warp	4.91
Polyester	Amgard CT	25	Warp	5.42
Polyester	Amgard CT	25	Warp	5.47
Polyester	Flameproof 1528	25	Fill	3.26
Polyester	Flameproof 1528	25	Fill	3.37
Polyester	Flameproof 1528	25	Fill	3.5
Polyester	Flameproof 1528	25	Warp	5.21
Polyester	Flameproof 1528	25	Warp	4.85
Polyester	Flameproof 1528	25	Warp	5.08
Polyester	Pyrozyl M-73	25	Fill	3.46
Polyester	Pyrozyl M-73	25	Fill	3.39
Polyester	Pyrozyl M-73	25	Fill	3.43
Polyester	Pyrozyl M-73	25	Warp	5.36
Polyester	Pyrozyl M-73	25	Warp	5.55
Polyester	Pyrozyl M-73	25	Warp	5.1
Polyester	Pyrosan SYN	25	Fill	3.66
Polyester	Pyrosan SYN	25	Fill	3.6
Polyester	Pyrosan SYN	25	Fill	3.45
Polyester	Pyrosan SYN	25	Warp	4.89
Polyester	Pyrosan SYN	25	Warp	5.27
Polyester	Pyrosan SYN	25	Warp	4.74
Polyester	Ultrion N1000	25	Fill	3.71
Polyester	Ultrion N1000	25	Fill	3.45
Polyester	Ultrion N1000	25	Fill	3.79
Polyester	Ultrion N1000	25	Warp	5.21
Polyester	Ultrion N1000	25	Warp	5.38
Polyester	Ultrion N1000	25	Warp	5.27
Polyester	Flameproof 1506	25	Fill	4.11
Polyester	Flameproof 1506	25	Fill	4.07
Polyester	Flameproof 1506	25	Fill	4.11
Polyester	Flameproof 1506	25	Warp	4.98
Polyester	Flameproof 1506	25	Warp	5.13
Polyester	Flameproof 1506	25	Warp	5.08

Table A 19 ANOVA Analysis for Polyester Tear Strength- 0 Wash Cycles

Oneway Analysis of Tear (lbs) By Treatment Wash Cycles=0, Tear =Fill



**Oneway Anova
Summary of Fit**

Rsquare 0.908903
 Adj Rsquare 0.869862
 Root Mean Square Error 0.20756
 Mean of Response 4.77
 Observations (or Sum Wgts) 21

Analysis of Variance

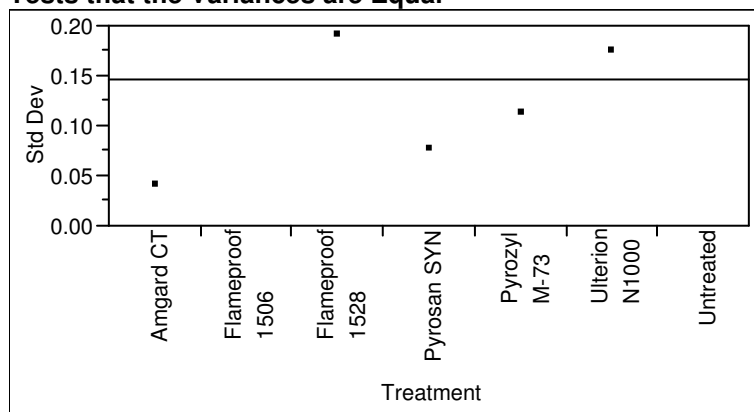
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	6	6.0176667	1.00294	23.2805	<.0001
Error	14	0.6031333	0.04308		
C. Total	20	6.6208000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	4.47000	0.11983	4.2130	4.7270
Flameproof 1506	3	6.06000	0.11983	5.8030	6.3170
Flameproof 1528	3	4.60000	0.11983	4.3430	4.8570
Pyrosan SYN	3	4.59000	0.11983	4.3330	4.8470
Pyrozyl M-73	3	4.57667	0.11983	4.3196	4.8337
Ulterior N1000	3	4.71000	0.11983	4.4530	4.9670
Untreated	3	4.38333	0.11983	4.1263	4.6404

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.0400000	0.0266667	0.0400000
Flameproof 1506	0	.	0.0000000	0.0000000
Flameproof 1528	3	0.1900000	0.1266667	0.1900000
Pyrosan SYN	3	0.0754983	0.0533333	0.0700000
Pyrozyl M-73	3	0.1115049	0.0844444	0.0833333
Ulterior N1000	3	0.1734935	0.1333333	0.1100000
Untreated	0	.	0.0000000	0.0000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.8541	4	10	0.5230
Brown-Forsythe	1.6086	4	10	0.2467
Levene	1.6584	4	10	0.2351
Bartlett	1.0413	4	.	0.3841

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
2.1004	4	4.5918	0.2281

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

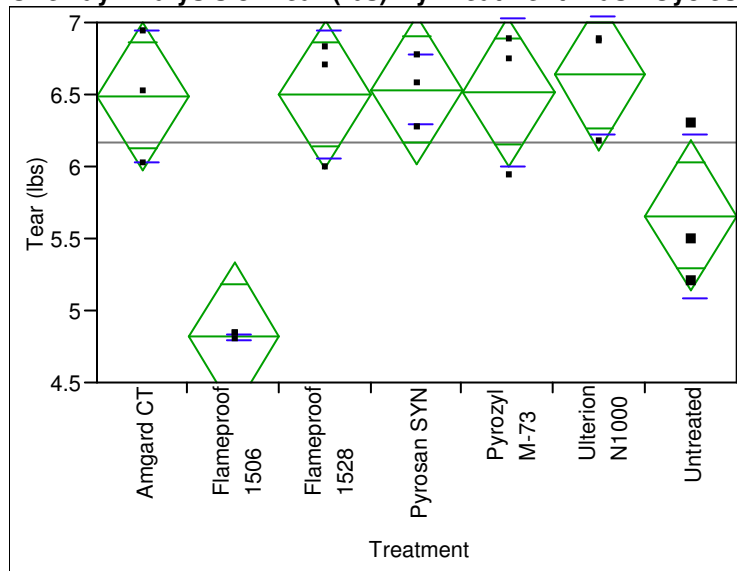
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	11.500	3.8333	-1.743
Flameproof 1506	0	0.000	0.0000	.
Flameproof 1528	3	23.000	7.6667	-0.073
Pyrosan SYN	3	26.000	8.6667	0.218
Pyrozyl M-73	3	26.000	8.6667	0.218
Ulterior N1000	3	33.500	11.1667	1.307
Untreated	0	0.000	0.0000	.

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
4.3122	4	0.3654

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Tear (lbs) By Treatment Wash Cycles=0, Tear =Warp



Oneway Anova Summary of Fit

Rsquare 0.772768
 Adj Rsquare 0.675382
 Root Mean Square Error 0.418
 Mean of Response 6.16381
 Observations (or Sum Wgts) 21

Analysis of Variance

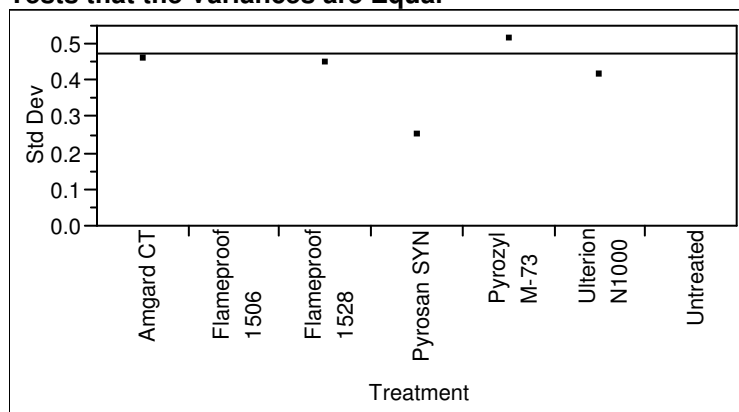
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	6	8.318762	1.38646	7.9352	0.0007
Error	14	2.446133	0.17472		
C. Total	20	10.764895			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	6.49000	0.24133	5.9724	7.0076
Flameproof 1506	3	4.81667	0.24133	4.2991	5.3343
Flameproof 1528	3	6.50000	0.24133	5.9824	7.0176
Pyrosan SYN	3	6.53333	0.24133	6.0157	7.0509
Pyrozyl M-73	3	6.51667	0.24133	5.9991	7.0343
Ulterior N1000	3	6.63333	0.24133	6.1157	7.1509
Untreated	3	5.65667	0.24133	5.1391	6.1743

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.4557412	0.3133333	0.4400000
Flameproof 1506	0	.	0.0000000	0.0000000
Flameproof 1528	3	0.4464303	0.3400000	0.3200000
Pyrosan SYN	3	0.2470493	0.1755556	0.2266667
Pyrozyl M-73	3	0.5128678	0.3911111	0.3633333
Ulterior N1000	3	0.4100406	0.3155556	0.2466667
Untreated	0	.	0.0000000	0.0000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.2696	4	10	0.8909
Brown-Forsythe	0.2719	4	10	0.8895
Levene	0.6243	4	10	0.6558
Bartlett	0.2171	4	.	0.9291

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0.0396	4	4.873	0.9960

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	24.000	8.00000	0.000
Flameproof 1506	0	0.000	0.00000	.
Flameproof 1528	3	21.000	7.00000	-0.361
Pyrosan SYN	3	22.000	7.33333	-0.217
Pyrozyl M-73	3	23.500	7.83333	0.000
Ulterior N1000	3	29.500	9.83333	0.722
Untreated	0	0.000	0.00000	.

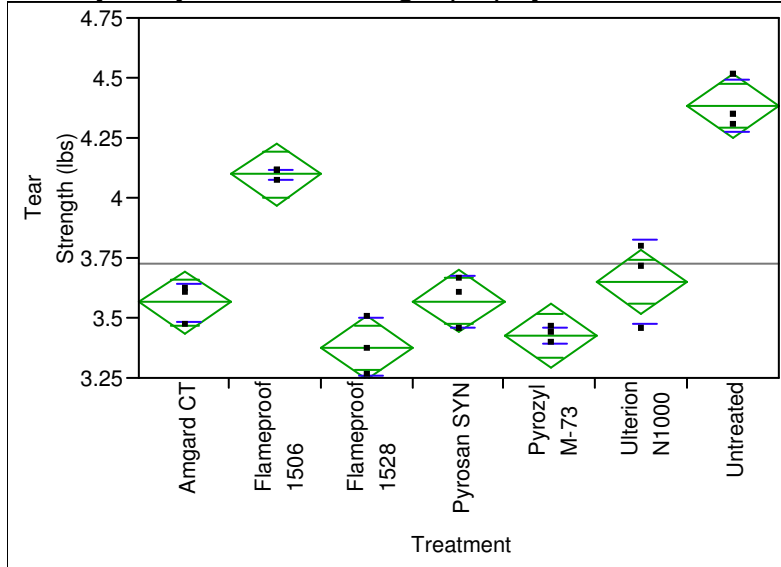
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.7263	4	0.9480

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table A 20 ANOVA Analysis for Polyester Tear Strength- 25 Wash Cycles

Oneway Analysis of Tear Strength (lbs) By Treatment Wash Cycles=25, Tear Direction=Fill



**Oneway Anova
Summary of Fit**

Rsquare 0.941151
 Adj Rsquare 0.91593
 Root Mean Square Error 0.105942
 Mean of Response 3.72381
 Observations (or Sum Wgts) 21

Analysis of Variance

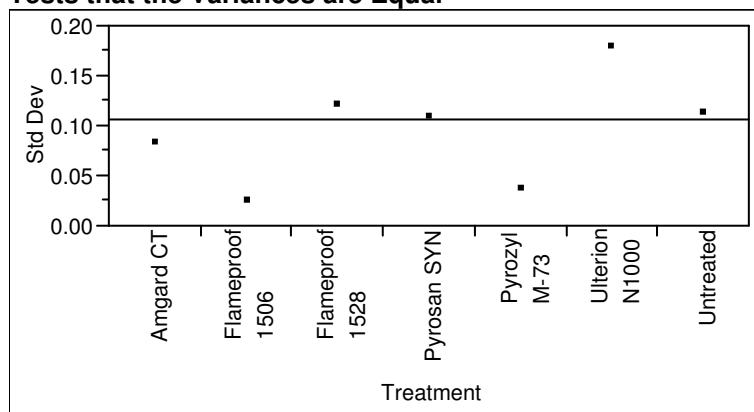
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	6	2.5129619	0.418827	37.3159	<.0001
Error	14	0.1571333	0.011224		
C. Total	20	2.6700952			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	3.56333	0.06117	3.4321	3.6945
Flameproof 1506	3	4.09667	0.06117	3.9655	4.2279
Flameproof 1528	3	3.37667	0.06117	3.2455	3.5079
Pyrosan SYN	3	3.57000	0.06117	3.4388	3.7012
Pyrozyl M-73	3	3.42667	0.06117	3.2955	3.5579
Ulterion N1000	3	3.65000	0.06117	3.5188	3.7812
Untreated- Unwashed	3	4.38333	0.06117	4.2521	4.5145

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.0814453	0.0622222	0.0566667
Flameproof 1506	3	0.0230940	0.0177778	0.0133333
Flameproof 1528	3	0.1201388	0.0822222	0.1166667
Pyrosan SYN	3	0.1081665	0.0800000	0.0900000
Pyrozyl M-73	3	0.0351188	0.0244444	0.0333333
Ulterior N1000	3	0.1777639	0.1333333	0.1400000
Untreated	3	0.1115049	0.0844444	0.0833333

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.8896	6	14	0.5280
Brown-Forsythe	1.7775	6	14	0.1758
Levene	2.2854	6	14	0.0951
Bartlett	1.2181	6	.	0.2932

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
101.2302	6	5.8849	<.0001

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

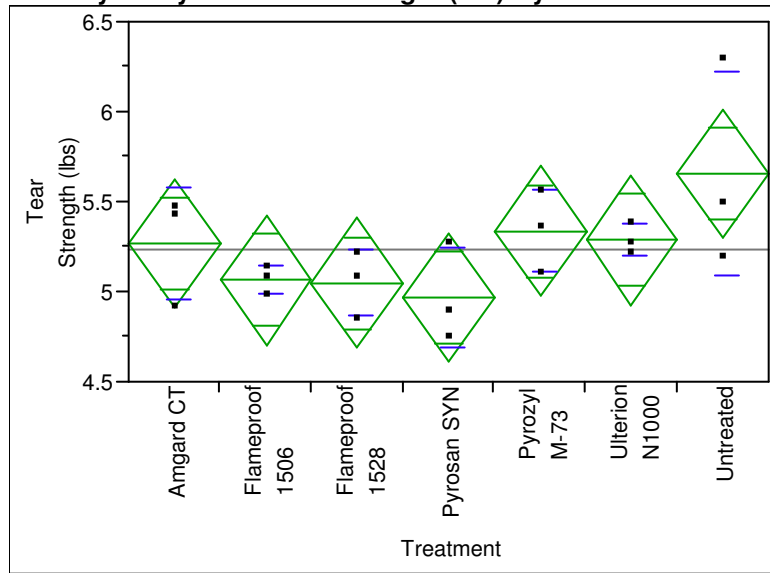
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	30.500	10.1667	-0.201
Flameproof 1506	3	51.000	17.0000	1.761
Flameproof 1528	3	12.000	4.0000	-2.062
Pyrosan SYN	3	29.000	9.6667	-0.352
Pyrozyl M-73	3	14.000	4.6667	-1.861
Ulterior N1000	3	34.500	11.5000	0.101
Untreated	3	60.000	20.0000	2.666

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
16.3045	6	0.0122

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Tear Strength (lbs) By Treatment Wash Cycles=25, Tear Direction=Warp



Oneway Anova Summary of Fit

Rsquare 0.454588
 Adj Rsquare 0.22084
 Root Mean Square Error 0.290697
 Mean of Response 5.231905
 Observations (or Sum Wgts) 21

Analysis of Variance

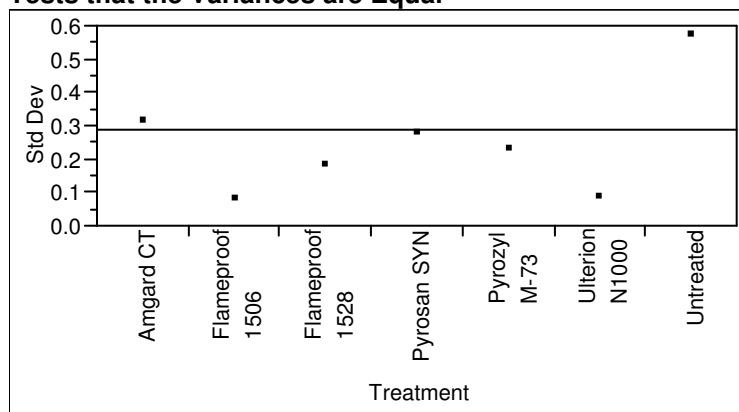
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	6	0.9860571	0.164343	1.9448	0.1431
Error	14	1.1830667	0.084505		
C. Total	20	2.1691238			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	5.26667	0.16783	4.9067	5.6266
Flameproof 1506	3	5.06333	0.16783	4.7034	5.4233
Flameproof 1528	3	5.04667	0.16783	4.6867	5.4066
Pyrosan SYN	3	4.96667	0.16783	4.6067	5.3266
Pyrozyl M-73	3	5.33667	0.16783	4.9767	5.6966
Ulterior N1000	3	5.28667	0.16783	4.9267	5.6466
Untreated- Unwashed	3	5.65667	0.16783	5.2967	6.0166

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.3098925	0.2377778	0.2033333
Flameproof 1506	3	0.0763763	0.0555556	0.0666667
Flameproof 1528	3	0.1823001	0.1311111	0.1633333
Pyrosan SYN	3	0.2731910	0.2022222	0.2266667
Pyrozyl M-73	3	0.2259056	0.1577778	0.2133333
Ulterior N1000	3	0.0862168	0.0622222	0.0766667
Untreated	3	0.5686241	0.4222222	0.4666667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.2321	6	14	0.3477
Brown-Forsythe	2.0887	6	14	0.1202
Levene	3.1755	6	14	0.0351
Bartlett	1.4549	6	.	0.1894

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
1.9732	6	5.9978	0.2144

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	39.000	13.0000	0.553
Flameproof 1506	3	20.500	6.8333	-1.207
Flameproof 1528	3	20.000	6.6667	-1.258
Pyrosan SYN	3	17.500	5.8333	-1.509
Pyrozyl M-73	3	43.000	14.3333	0.956
Ulterior N1000	3	41.000	13.6667	0.755
Untreated	3	50.000	16.6667	1.660

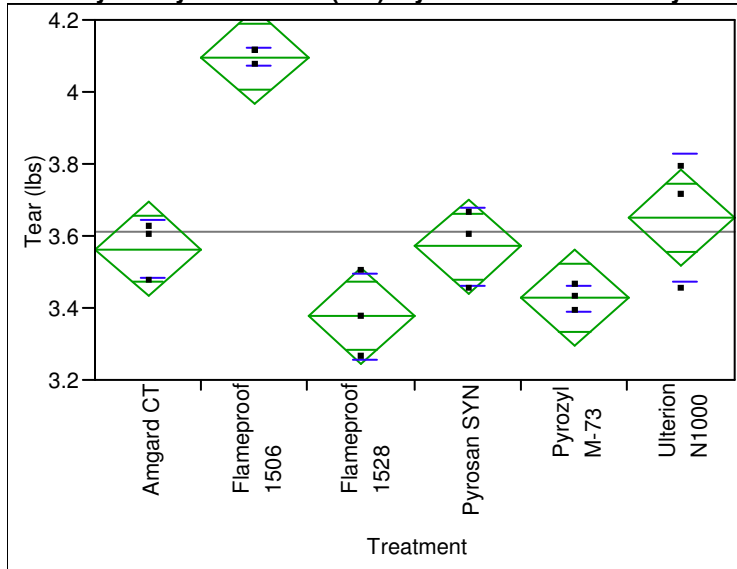
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
9.1477	6	0.1654

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table A 21 ANOVA Analysis for Polyester Tear Strength- 25 Wash Cycles - Excluding Untreated

Oneway Analysis of Tear (lbs) By Treatment Wash Cycles=25, Tear Direction=Fill



**Oneway Anova
Summary of Fit**

Rsquare	0.882202
Adj Rsquare	0.83312
Root Mean Square Error	0.104987
Mean of Response	3.613889
Observations (or Sum Wgts)	18

Analysis of Variance

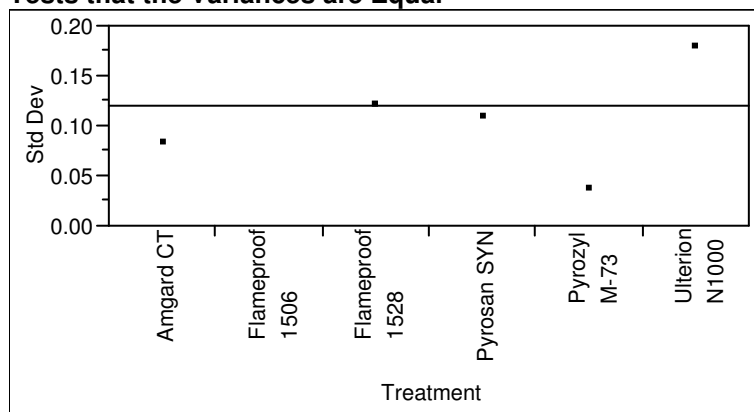
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	0.9905611	0.198112	17.9739	<.0001
Error	12	0.1322667	0.011022		
C. Total	17	1.1228278			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	3.56333	0.06061	3.4313	3.6954
Flameproof 1506	3	4.09667	0.06061	3.9646	4.2287
Flameproof 1528	3	3.37667	0.06061	3.2446	3.5087
Pyrosan SYN	3	3.57000	0.06061	3.4379	3.7021
Pyrozyl M-73	3	3.42667	0.06061	3.2946	3.5587
Ulterior N1000	3	3.65000	0.06061	3.5179	3.7821

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.0814453	0.0622222	0.0566667
Flameproof 1506	0	.	0.0000000	0.0000000
Flameproof 1528	3	0.1201388	0.0822222	0.1166667
Pyrosan SYN	3	0.1081665	0.0800000	0.0900000
Pyrozyl M-73	3	0.0351188	0.0244444	0.0333333
Ulterior N1000	3	0.1777639	0.1333333	0.1400000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.8455	4	10	0.5274
Brown-Forsythe	1.5885	4	10	0.2515
Levene	1.8582	4	10	0.1945
Bartlett	0.9111	4	.	0.4563

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
2.6890	4	4.5376	0.1648

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

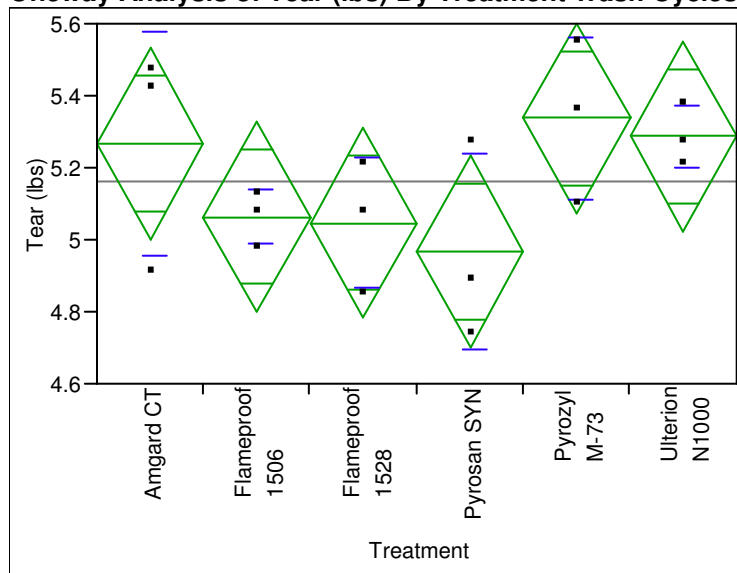
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	30.500	10.1667	0.868
Flameproof 1506	0	0.000	0.0000	.
Flameproof 1528	3	12.000	4.0000	-1.663
Pyrosan SYN	3	29.000	9.6667	0.651
Pyrozyl M-73	3	14.000	4.6667	-1.374
Ulterior N1000	3	34.500	11.5000	1.446

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.0502	4	0.1333

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Tear (lbs) By Treatment Wash Cycles=25, Tear Direction=Warp



Oneway Anova Summary of Fit

Rsquare	0.397965
Adj Rsquare	0.147117
Root Mean Square Error	0.211424
Mean of Response	5.161111
Observations (or Sum Wgts)	18

Analysis of Variance

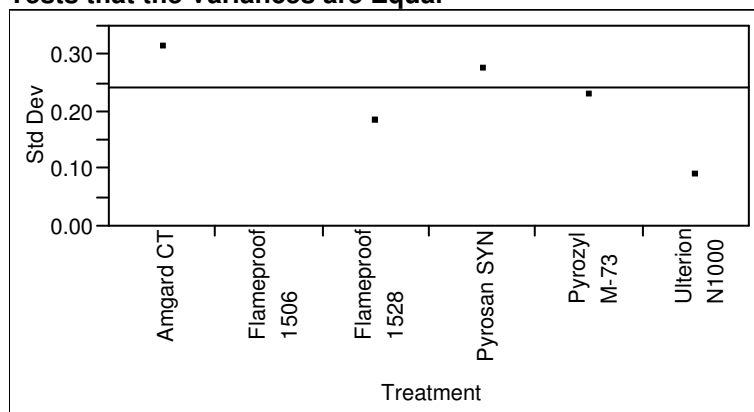
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	0.35457778	0.070916	1.5865	0.2371
Error	12	0.53640000	0.044700		
C. Total	17	0.89097778			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Amgard CT	3	5.26667	0.12207	5.0007	5.5326
Flameproof 1506	3	5.06333	0.12207	4.7974	5.3293
Flameproof 1528	3	5.04667	0.12207	4.7807	5.3126
Pyrosan SYN	3	4.96667	0.12207	4.7007	5.2326
Pyrozy M-73	3	5.33667	0.12207	5.0707	5.6026
Ulterior N1000	3	5.28667	0.12207	5.0207	5.5526

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Amgard CT	3	0.3098925	0.2377778	0.2033333
Flameproof 1506	0	.	0.0000000	0.0000000
Flameproof 1528	3	0.1823001	0.1311111	0.1633333
Pyrosan SYN	3	0.2731910	0.2022222	0.2266667
Pyrozyl M-73	3	0.2259056	0.1577778	0.2133333
Ulterior N1000	3	0.0862168	0.0622222	0.0766667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.5735	4	10	0.6882
Brown-Forsythe	0.5880	4	10	0.6789
Levene	1.4447	4	10	0.2895
Bartlett	0.6176	4	.	0.6499

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
1.3641	4	4.6314	0.3714

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Amgard CT	3	31.000	10.3333	0.940
Flameproof 1506	0	0.000	0.0000	.
Flameproof 1528	3	14.500	4.8333	-1.301
Pyrosan SYN	3	13.500	4.5000	-1.446
Pyrozyl M-73	3	32.000	10.6667	1.084
Ulterior N1000	3	29.000	9.6667	0.651

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.6619	4	0.2259

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Appendix B: Nylon Knit

Table B 1 Nylon Vertical Burn Test - 1 Wash

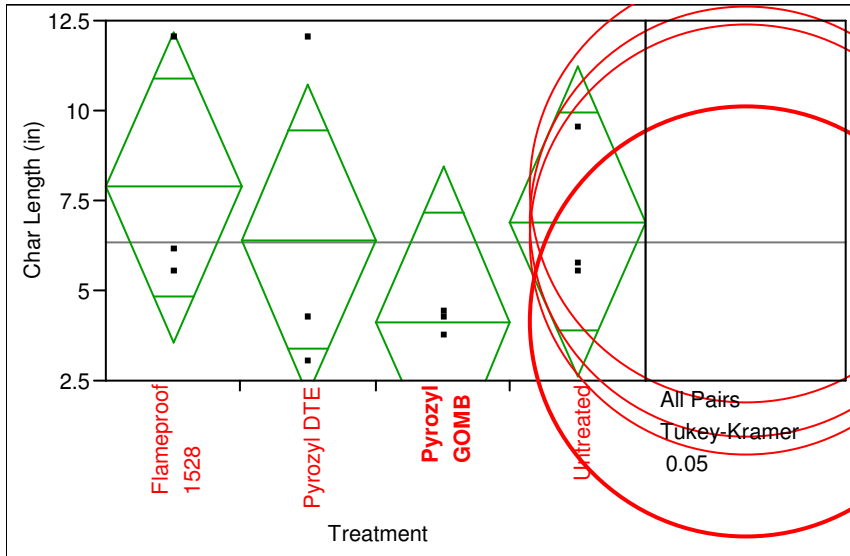
Fabric	Machine Direction/Cross-machine Direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Nylon	Cross-machine Direction	Untreated	00:58.3	Y	9.5
Nylon	Cross-machine Direction	Untreated	00:56.9	Y	5.75
Nylon	Cross-machine Direction	Untreated	00:48.1	Y	5.5
Nylon	Machine Direction	Untreated	00:55.9	Y	8
Nylon	Machine Direction	Untreated	01:13.1	Y	12
Nylon	Machine Direction	Untreated	02:08.3	Y	12
Nylon	Cross-machine Direction	Flameproof 1528	00:00.0	Y	2.25
Nylon	Machine Direction	Flameproof 1528	00:00.0	Y	3.75
Nylon	Cross-machine Direction	FiNone	01:56.9	Y	12
Nylon	Machine Direction	FiNone	00:50.8	Y	12
Nylon	Cross-machine Direction	Glottard NY 22	00:00.0	N	4
Nylon	Machine Direction	Glottard NY 22	01:31.8	Y	12
Nylon	Cross-machine Direction	Pyrozyl GOMB	01:48.5	Y	12
Nylon	Machine Direction	Pyrozyl GOMB	00:02.3	N	3.25

Table B 2 Nylon Vertical Burn Test - 3 Wash Cycles

Fabric	Machine direction/Cross-machine direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Nylon	Cross-machine Direction	Flameproof 1528	00:46.8	Y	5.5
Nylon	Cross-machine Direction	Flameproof 1528	01:57.1	Y	6.1
Nylon	Cross-machine Direction	Flameproof 1528	01:17.3	Y	12
Nylon	Machine Direction	Flameproof 1528	00:38.9	Y	11
Nylon	Machine Direction	Flameproof 1528	00:52.6	Y	8.5
Nylon	Machine Direction	Flameproof 1528	01:10.8	Y	7.5
Nylon	Cross-machine Direction	Glo NY	00:00.0	N	3.5
Nylon	Cross-machine Direction	Glo NY	00:00.0	N	4.4
Nylon	Machine Direction	Glo NY	00:57.1	Y	8.6
Nylon	Machine Direction	Glo NY	1.49.65	Y	12
Nylon	Cross-machine Direction	Pyrozyl GOMB	00:00.0	N	4.4
Nylon	Cross-machine Direction	Pyrozyl GOMB	00:00.0	N	4.2
Nylon	Cross-machine Direction	Pyrozyl GOMB	00:57.4	Y	3.75
Nylon	Machine Direction	Pyrozyl GOMB	00:34.4	Y	11.25
Nylon	Machine Direction	Pyrozyl GOMB	00:45.0	Y	6.3
Nylon	Machine Direction	Pyrozyl GOMB	00:39.5	Y	5.6
Nylon	Cross-machine Direction	Pyrozyl DTE	00:00.7	Y	3
Nylon	Cross-machine Direction	Pyrozyl DTE	00:00.0	Y	4.25
Nylon	Cross-machine Direction	Pyrozyl DTE	57:26.0	Y	12
Nylon	Machine Direction	Pyrozyl DTE	01:55.0	Y	12
Nylon	Machine Direction	Pyrozyl DTE	00:59.8	Y	8.5
Nylon	Machine Direction	Pyrozyl DTE	01:37.8	Y	12

Table B 3 ANOVA Analysis for Nylon Burns at 3 Wash Cycles

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Cross-machine Direction



**Oneway Anova
Summary of Fit**

Rsquare	0.214525
Adj Rsquare	-0.08003
Root Mean Square Error	3.232872
Mean of Response	6.329167
Observations (or Sum Wgts)	12

Analysis of Variance

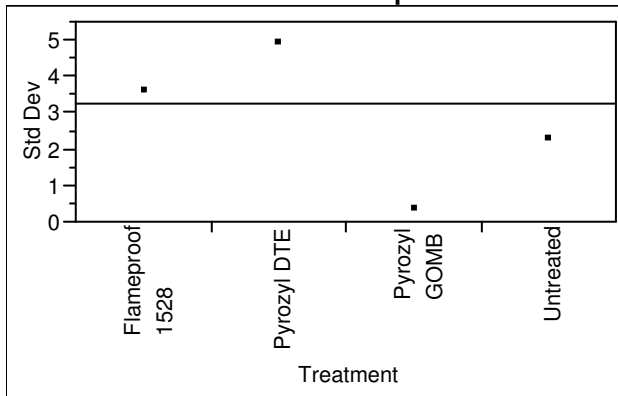
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	22.83563	7.6119	0.7283	0.5633
Error	8	83.61167	10.4515		
C. Total	11	106.44729			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Flameproof 1528	3	7.86667	1.8665	3.563	12.171
Pyrozyl DTE	3	6.41667	1.8665	2.113	10.721
Pyrozyl GOMB	3	4.11667	1.8665	-0.187	8.421
Untreated	3	6.91667	1.8665	2.613	11.221

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Flameproof 1528	3	3.592121	2.755556	2.366667
Pyrozyl DTE	3	4.875534	3.722222	3.416667
Pyrozyl GOMB	3	0.332916	0.244444	0.283333
Untreated	3	2.240722	1.722222	1.416667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.0018	3	8	0.4404
Brown-Forsythe	0.7785	3	8	0.5382
Levene	5.2181	3	8	0.0275
Bartlett	2.3433	3	.	0.0710

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
1.9971	3	3.4089	0.2758

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

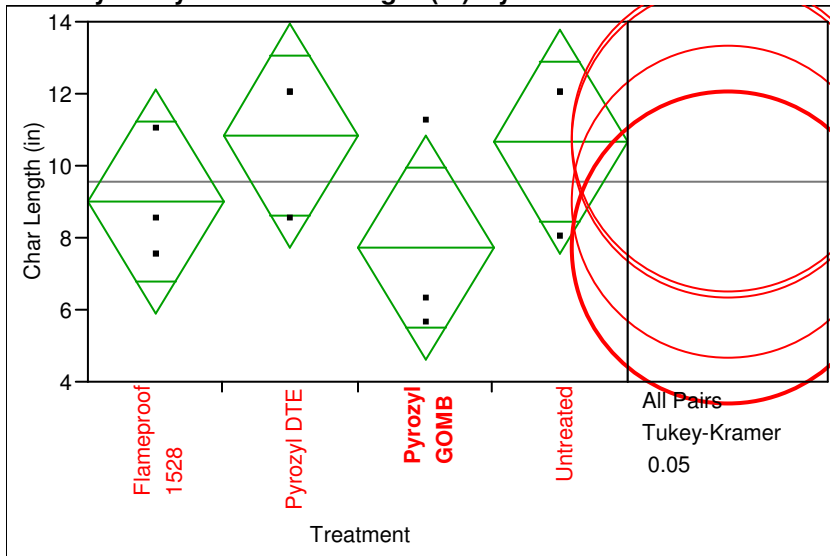
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Flameproof 1528	3	27.000	9.00000	1.299
Pyrozyl DTE	3	16.500	5.50000	-0.464
Pyrozyl GOMB	3	10.000	3.33333	-1.670
Untreated	3	24.500	8.16667	0.835

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
4.6608	3	0.1984

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Machine Direction



Oneway Anova Summary of Fit

Rsquare	0.307489
Adj Rsquare	0.047797
Root Mean Square Error	2.353322
Mean of Response	9.554167
Observations (or Sum Wgts)	12

Analysis of Variance

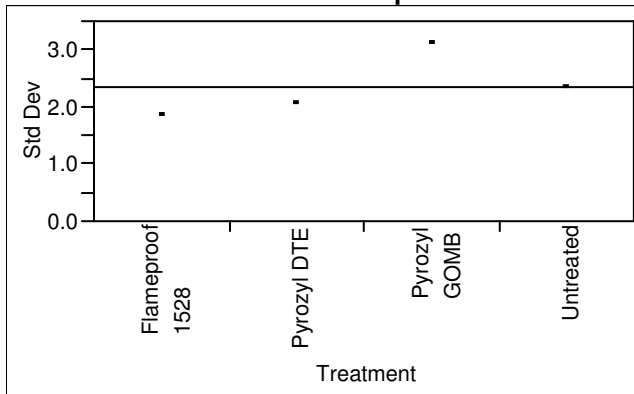
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	19.672292	6.55743	1.1841	0.3752
Error	8	44.305000	5.53812		
C. Total	11	63.977292			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Flameproof 1528	3	9.0000	1.3587	5.8669	12.133
Pyrozyl DTE	3	10.8333	1.3587	7.7002	13.966
Pyrozyl GOMB	3	7.7167	1.3587	4.5835	10.850
Untreated	3	10.6667	1.3587	7.5335	13.800

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level Count Std Dev MeanAbsDif to Mean MeanAbsDif to Median

Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Flameproof 1528	3	1.802776	1.333333	1.500000
Pyrozyl DTE	3	2.020726	1.555556	1.166667
Pyrozyl GOMB	3	3.079908	2.355556	2.116667
Untreated	3	2.309401	1.777778	1.333333

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.3739	3	8	0.7743
Brown-Forsythe	0.1274	3	8	0.9412
Levene	0.8290	3	8	0.5142
Bartlett	0.1861	3	.	0.9059

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0.8081	3	4.3839	0.5472

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Flameproof 1528	3	15.500	5.16667	-0.660
Pyrozyl DTE	3	26.500	8.83333	1.226
Pyrozyl GOMB	3	11.000	3.66667	-1.508
Untreated	3	25.000	8.33333	0.943

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
4.4667	3	0.2153

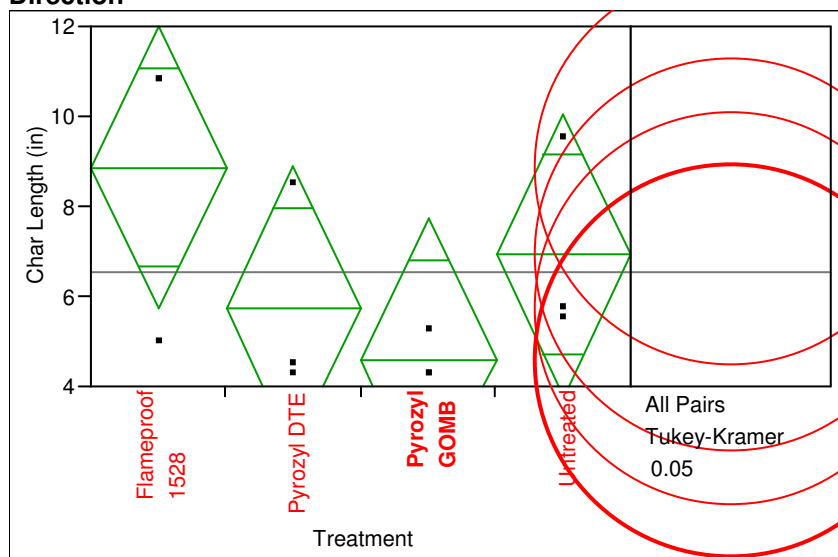
Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table B 4 Nylon Vertical Burns at 10 Wash Cycles

Fabric	Machine direction/Cross-machine direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Nylon	Machine direction	Flameproof 1528	00:57.3	Y	6.5
Nylon	Machine direction	Flameproof 1528	01:03.5	Y	12
Nylon	Machine direction	Flameproof 1528	00:49.6	Y	7.25
Nylon	Cross-machine direction	Flameproof 1528	02:10.6	Y	10.8
Nylon	Cross-machine direction	Flameproof 1528	00:00.0	N	5
Nylon	Cross-machine direction	Flameproof 1528	02:20.7	Y	10.8
Nylon	Machine direction	Pyrozyl GOMB	00:48.3	Y	8.5
Nylon	Machine direction	Pyrozyl GOMB	00:41.7	Y	6.75
Nylon	Machine direction	Pyrozyl GOMB	00:51.3	Y	5.6
Nylon	Cross-machine direction	Pyrozyl GOMB	00:00.0	Y	4.25
Nylon	Cross-machine direction	Pyrozyl GOMB	00:39.0	Y	5.25
Nylon	Cross-machine direction	Pyrozyl GOMB	00:00.0	Y	4.25
Nylon	Machine direction	Pyrozyl DTE	01:39.3	Y	12
Nylon	Machine direction	Pyrozyl DTE	01:25.0	Y	9.9
Nylon	Machine direction	Pyrozyl DTE	01:01.2	Y	11
Nylon	Cross-machine direction	Pyrozyl DTE	00:54.6	Y	4.5
Nylon	Cross-machine direction	Pyrozyl DTE	00:36.3	Y	4.25
Nylon	Cross-machine direction	Pyrozyl DTE	02:22.4	Y	8.5

Table B 5 ANOVA Analysis for Nylon Burns at 10 Wash Cycles

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Cross-machine Direction



**Oneway Anova
Summary of Fit**

Rsquare	0.402809
Adj Rsquare	0.178863
Root Mean Square Error	2.35876
Mean of Response	6.529167
Observations (or Sum Wgts)	12

Analysis of Variance

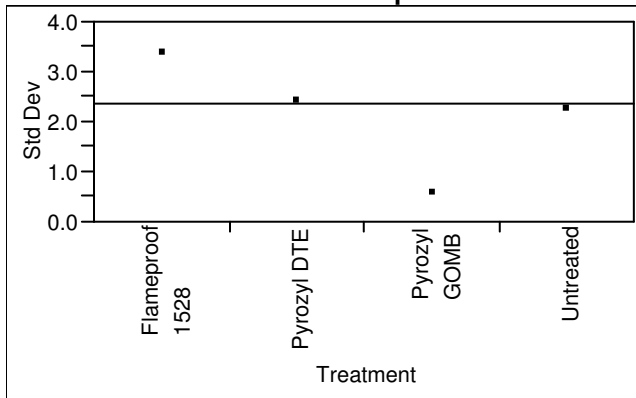
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	30.022292	10.0074	1.7987	0.2253
Error	8	44.510000	5.5638		
C. Total	11	74.532292			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Flameproof 1528	3	8.86667	1.3618	5.7263	12.007
Pyrozyl DTE	3	5.75000	1.3618	2.6096	8.890
Pyrozyl GOMB	3	4.58333	1.3618	1.4429	7.724
Untreated	3	6.91667	1.3618	3.7763	10.057

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Flameproof 1528	3	3.348632	2.577778	1.933333
Pyrozyl DTE	3	2.384848	1.833333	1.500000
Pyrozyl GOMB	3	0.577350	0.444444	0.333333
Untreated	3	2.240722	1.722222	1.416667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.7701	3	8	0.5424
Brown-Forsythe	0.2735	3	8	0.8430
Levene	3.7637	3	8	0.0594
Bartlett	1.2109	3	.	0.3040

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
1.9308	3	3.6278	0.2776

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

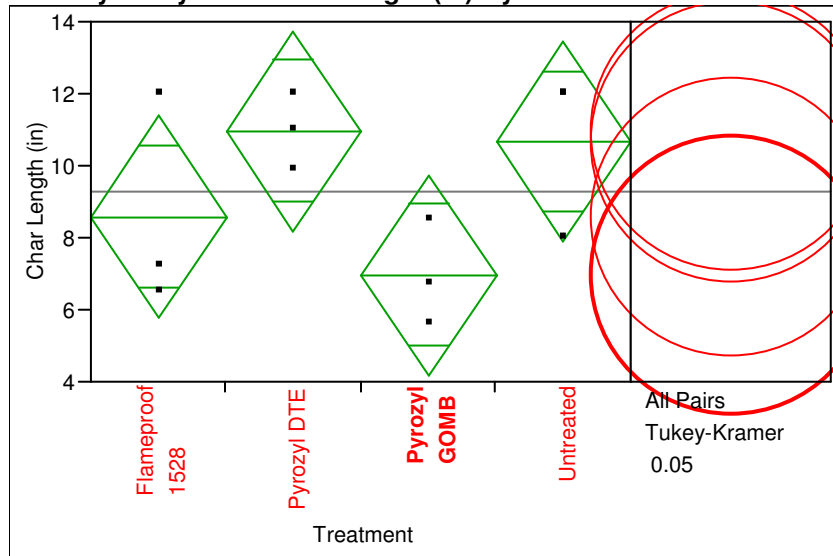
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Flameproof 1528	3	28.000	9.33333	1.492
Pyrozyl DTE	3	15.000	5.00000	-0.746
Pyrozyl GOMB	3	10.000	3.33333	-1.679
Untreated	3	25.000	8.33333	0.933

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.5587	3	0.1352

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Machine Direction



Oneway Anova Summary of Fit

Rsquare 0.478456
Adj Rsquare 0.282876
Root Mean Square Error 2.089557
Mean of Response 9.291667
Observations (or Sum Wgts) 12

Analysis of Variance

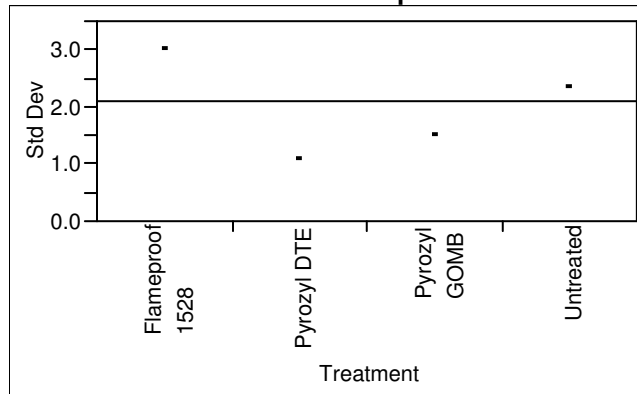
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	32.044167	10.6814	2.4464	0.1386
Error	8	34.930000	4.3663		
C. Total	11	66.974167			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Flameproof 1528	3	8.5833	1.2064	5.8014	11.365
Pyrozyl DTE	3	10.9667	1.2064	8.1847	13.749
Pyrozyl GOMB	3	6.9500	1.2064	4.1680	9.732
Untreated	3	10.6667	1.2064	7.8847	13.449

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level Count Std Dev MeanAbsDif to Mean MeanAbsDif to Median

Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Flameproof 1528	3	2.982588	2.277778	2.083333
Pyrozyl DTE	3	1.050397	0.711111	1.033333
Pyrozyl GOMB	3	1.460308	1.033333	1.350000
Untreated	3	2.309401	1.777778	1.333333

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.7756	3	8	0.5396
Brown-Forsythe	0.2218	3	8	0.8786
Levene	2.3430	3	8	0.1493
Bartlett	0.6513	3	.	0.5820

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
4.0287	3	4.1874	0.1009

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Flameproof 1528	3	16.500	5.50000	-0.471
Pyrozyl DTE	3	25.500	8.50000	1.035
Pyrozyl GOMB	3	10.000	3.33333	-1.694
Untreated	3	26.000	8.66667	1.129

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
4.7162	3	0.1938

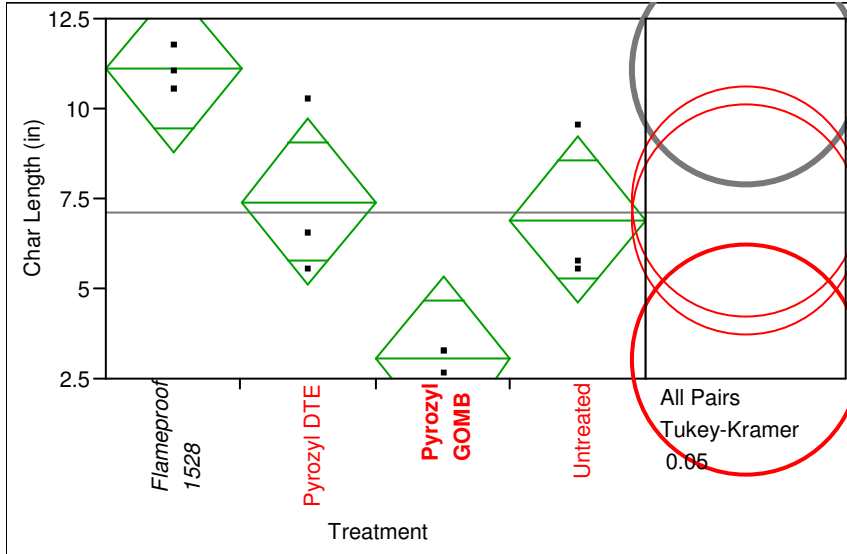
Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table B 6 Nylon Vertical Burns at 25 Wash Cycles

Fabric	Machine direction/Cross-machine direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Nylon	Machine direction	Flameproof 1528	01:01.5	Y	12
Nylon	Machine direction	Flameproof 1528	01:22.7	Y	12
Nylon	Machine direction	Flameproof 1528	01:34.2	Y	11
Nylon	Cross-machine direction	Flameproof 1528	01:33.5	Y	11.75
Nylon	Cross-machine direction	Flameproof 1528	01:17.3	Y	10.5
Nylon	Cross-machine direction	Flameproof 1528	01:11.7	Y	11
Nylon	Machine direction	Pyrozyl GOMB	00:29.1	Y	5
Nylon	Machine direction	Pyrozyl GOMB	00:46.6	Y	8.5
Nylon	Machine direction	Pyrozyl GOMB	00:49.7	Y	8.1
Nylon	Cross-machine direction	Pyrozyl GOMB	00:00.0	N	3.25
Nylon	Cross-machine direction	Pyrozyl GOMB	00:00.0	N	3.25
Nylon	Cross-machine direction	Pyrozyl GOMB	00:00.0	N	2.6
Nylon	Machine direction	Pyrozyl DTE	01:45.5	Y	12
Nylon	Machine direction	Pyrozyl DTE	00:32.3	Y	7.5
Nylon	Machine direction	Pyrozyl DTE	01:47.5	Y	12
Nylon	Cross-machine direction	Pyrozyl DTE	02:04.9	Y	10.25
Nylon	Cross-machine direction	Pyrozyl DTE	00:00.0	N	5.5
Nylon	Cross-machine direction	Pyrozyl DTE	00:39.6	Y	6.5

Table B 7 ANOVA Analysis for Nylon Burns at 25 Wash Cycles

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Cross-machine Direction



**Oneway Anova
Summary of Fit**

Rsquare	0.804927
Adj Rsquare	0.731774
Root Mean Square Error	1.719617
Mean of Response	7.1125
Observations (or Sum Wgts)	12

Analysis of Variance

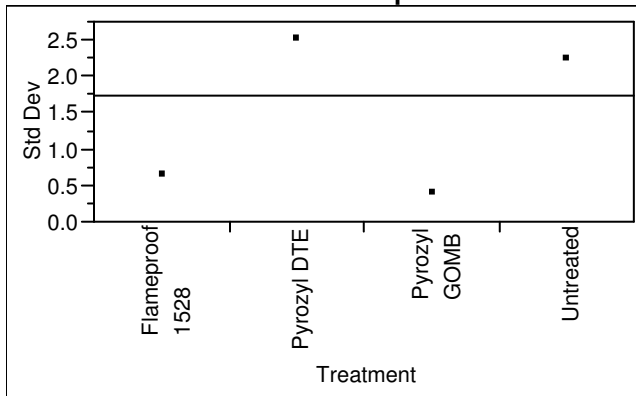
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	97.61396	32.5380	11.0034	0.0033
Error	8	23.65667	2.9571		
C. Total	11	121.27063			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Flameproof 1528	3	11.0833	0.99282	8.7939	13.373
Pyrozyl DTE	3	7.4167	0.99282	5.1272	9.706
Pyrozyl GOMB	3	3.0333	0.99282	0.7439	5.323
Untreated	3	6.9167	0.99282	4.6272	9.206

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Flameproof 1528	3	0.629153	0.444444	0.583333
Pyrozyl DTE	3	2.504163	1.888889	1.916667
Pyrozyl GOMB	3	0.375278	0.288889	0.216667
Untreated	3	2.240722	1.722222	1.416667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.0891	3	8	0.4077
Brown-Forsythe	1.0622	3	8	0.4174
Levene	5.2216	3	8	0.0274
Bartlett	2.0823	3	.	0.1002

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
90.9697	3	3.8906	0.0005

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

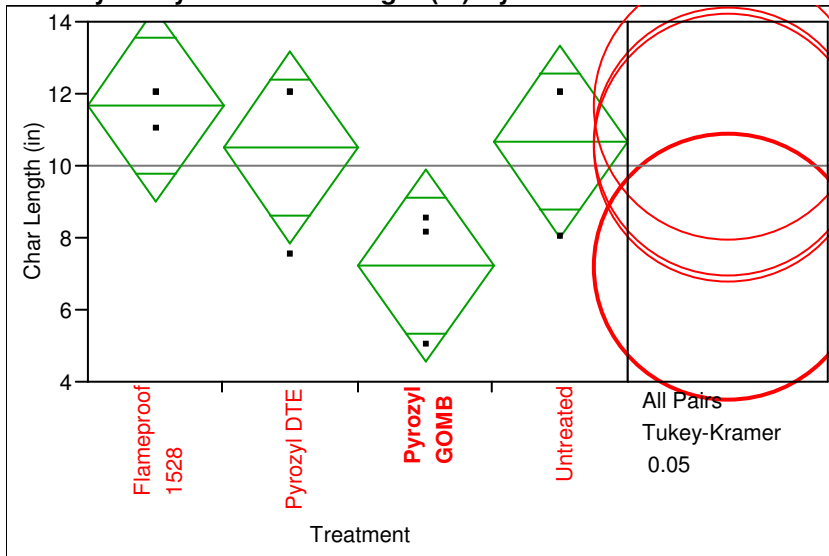
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Flameproof 1528	3	33.000	11.0000	2.412
Pyrozyl DTE	3	20.500	6.8333	0.093
Pyrozyl GOMB	3	6.000	2.0000	-2.412
Untreated	3	18.500	6.1667	-0.093

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
9.4636	3	0.0237

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Char Length (in) By Treatment Burn Direction=Machine Direction



Oneway Anova Summary of Fit

Rsquare	0.51333
Adj Rsquare	0.330829
Root Mean Square Error	2.005409
Mean of Response	10.00833
Observations (or Sum Wgts)	12

Analysis of Variance

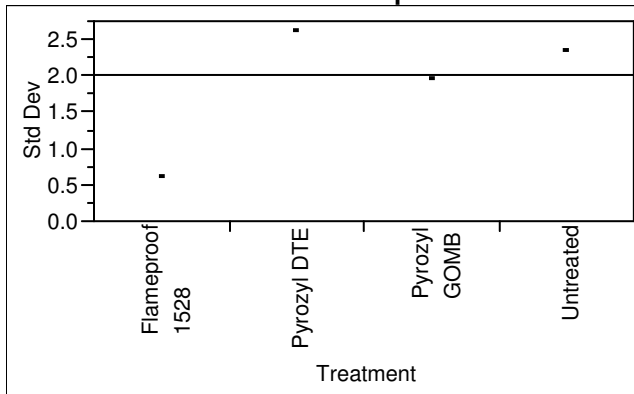
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	33.935833	11.3119	2.8128	0.1077
Error	8	32.173333	4.0217		
C. Total	11	66.109167			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Flameproof 1528	3	11.6667	1.1578	8.9967	14.337
Pyrozyl DTE	3	10.5000	1.1578	7.8301	13.170
Pyrozyl GOMB	3	7.2000	1.1578	4.5301	9.870
Untreated	3	10.6667	1.1578	7.9967	13.337

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level Count Std Dev MeanAbsDif to Mean MeanAbsDif to Median

Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Flameproof 1528	3	0.577350	0.444444	0.333333
Pyrozyl DTE	3	2.598076	2.000000	1.500000
Pyrozyl GOMB	3	1.915724	1.466667	1.300000
Untreated	3	2.309401	1.777778	1.333333

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.6195	3	8	0.6218
Brown-Forsythe	0.2266	3	8	0.8753
Levene	3.1120	3	8	0.0885
Bartlett	0.9830	3	.	0.3996

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
3.7758	3	3.7018	0.1249

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Flameproof 1528	3	25.000	8.33333	0.987
Pyrozyl DTE	3	21.000	7.00000	0.197
Pyrozyl GOMB	3	10.000	3.33333	-1.776
Untreated	3	22.000	7.33333	0.395

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
3.7689	3	0.2875

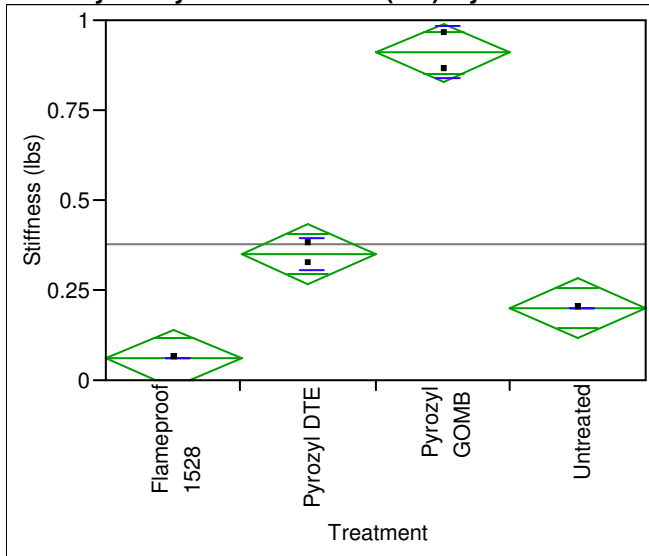
Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table B 8 Nylon Stiffness Data

Fabric	Treatment	Wash Cycles	Stiffness (lbs)
Nylon	Untreated	0	0.2
Nylon	Untreated	0	0.2
average			0.2
Nylon	Flameproof 1528	0	0.06
Nylon	Flameproof 1528	0	0.06
average			0.06
Nylon	Pyrozyl GOMB	0	0.86
Nylon	Pyrozyl GOMB	0	0.96
average			0.91
Nylon	Flameproof 1528	25	0
Nylon	Flameproof 1528	25	0.2
average			0.1
Nylon	Pyrozyl GOMB	25	0.42
Nylon	Pyrozyl GOMB	25	0.38
average			0.38
Nylon	Pyrozyl DTE	0	0.38
Nylon	Pyrozyl DTE	0	0.32
average			0.35
Nylon	Pyrozyl DTE	25	0.32
Nylon	Pyrozyl DTE	25	0.32
average			0.32

Table B 9 ANOVA Analysis for Nylon Stiffness at 0 Wash Cycles

Oneway Analysis of Stiffness (lbs) By Treatment Wash Cycles=0



**Oneway Anova
Summary of Fit**

Rsquare	0.991905
Adj Rsquare	0.985833
Root Mean Square Error	0.041231
Mean of Response	0.38
Observations (or Sum Wgts)	8

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	0.83320000	0.277733	163.3725	0.0001
Error	4	0.00680000	0.001700		
C. Total	7	0.84000000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Flameproof 1528	2	0.060000	0.02915	-0.0209	0.14095
Pyrozyl DTE	2	0.350000	0.02915	0.2691	0.43095
Pyrozyl GOMB	2	0.910000	0.02915	0.8291	0.99095
Untreated	2	0.200000	0.02915	0.1191	0.28095

Std Error uses a pooled estimate of error variance

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

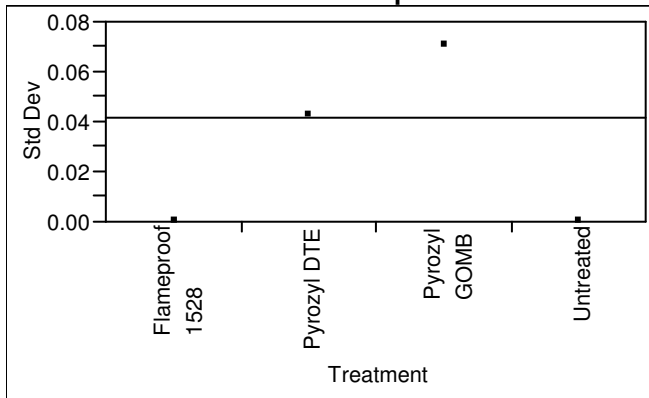
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Flameproof 1528	2	3.000	1.50000	-1.856
Pyrozyl DTE	2	11.000	5.50000	0.506
Pyrozyl GOMB	2	15.000	7.50000	1.856
Untreated	2	7.000	3.50000	-0.506

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.8293	3	0.0775

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Flameproof 1528	2	0.0000000	0.0000000	0.0000000
Pyrozyl DTE	2	0.0424264	0.0300000	0.0300000
Pyrozyl GOMB	2	0.0707107	0.0500000	0.0500000
Untreated	2	0.0000000	0.0000000	0.0000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.0000	-1	0	0.0000
Brown-Forsythe	.	3	4	.
Levene	.	3	4	.
Bartlett	.	3	.	.

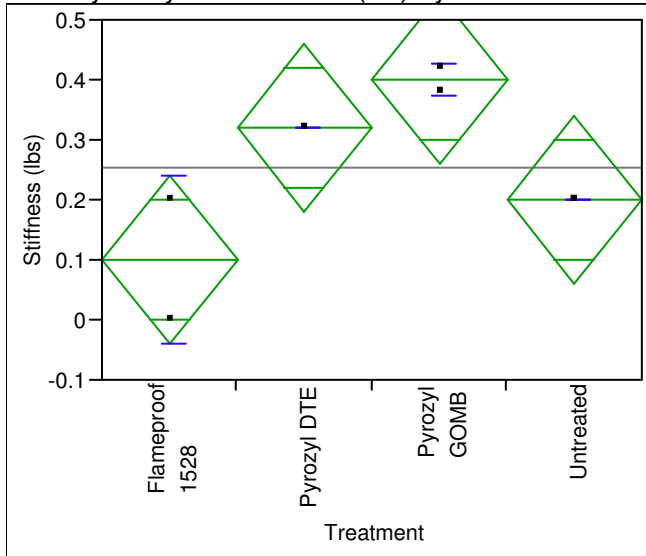
Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
.	3	.	.

Table B 10 ANOVA Analysis for Nylon Stiffness at 25 Wash Cycles

Oneway Analysis of Stiffness (lbs) By Treatment Wash Cycles=25



Oneway Anova Summary of Fit

Rsquare	0.834131
Adj Rsquare	0.709729
Root Mean Square Error	0.072111
Mean of Response	0.255
Observations (or Sum Wgts)	8

Analysis of Variance

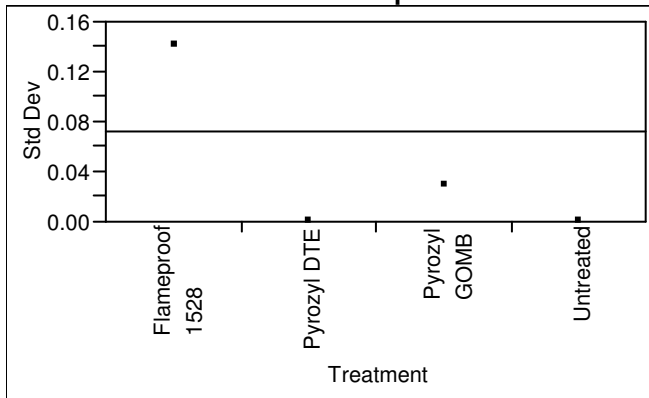
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	0.10460000	0.034867	6.7051	0.0486
Error	4	0.02080000	0.005200		
C. Total	7	0.12540000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Flameproof 1528	2	0.100000	0.05099	-0.0416	0.24157
Pyrozyl DTE	2	0.320000	0.05099	0.1784	0.46157
Pyrozyl GOMB	2	0.400000	0.05099	0.2584	0.54157
Untreated- Unwashed	2	0.200000	0.05099	0.0584	0.34157

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Flameproof 1528	2	0.1414214	0.1000000	0.1000000
Pyrozyl DTE	2	0.0000000	0.0000000	0.0000000
Pyrozyl GOMB	2	0.0282843	0.0200000	0.0200000
Untreated	2	0.0000000	0.0000000	0.0000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.0000	-1	0	0.0000
Brown-Forsythe	1.673e+17	3	4	<.0001
Levene	1.673e+17	3	4	<.0001
Bartlett	.	3	.	.

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
.	3	.	.

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Flameproof 1528	2	4.000	2.00000	-1.547
Pyrozyl DTE	2	11.000	5.50000	0.516
Pyrozyl GOMB	2	15.000	7.50000	1.890
Untreated	2	6.000	3.00000	-0.859

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.5570	3	0.0874

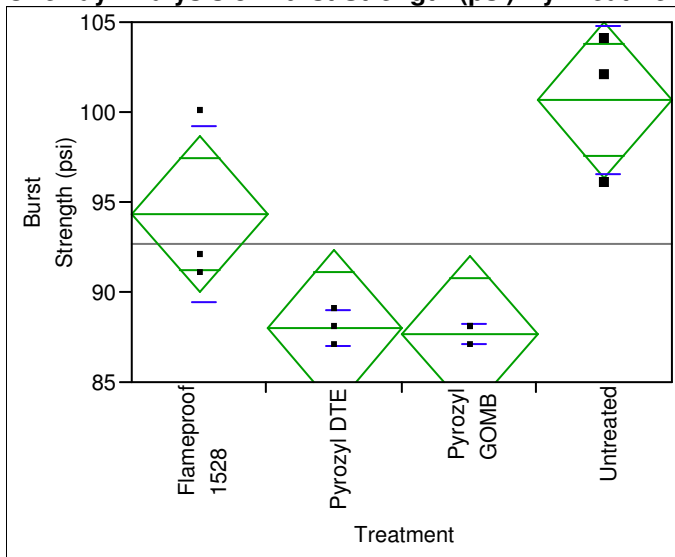
Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table B 11 Nylon Burst Strength Data

Fabric	Chemical	Burst Strength (psi)	Wash
Nylon	Untreated	96	0
Nylon	Untreated	102	0
Nylon	Untreated	104	0
Nylon	Flameproof 1528	91	0
Nylon	Flameproof 1528	100	0
Nylon	Flameproof 1528	92	0
Nylon	Flameproof 1528	100	25
Nylon	Flameproof 1528	96	25
Nylon	Flameproof 1528	96	25
Nylon	Pyrozyl GOMB	88	0
Nylon	Pyrozyl GOMB	88	0
Nylon	Pyrozyl GOMB	87	0
Nylon	Pyrozyl GOMB	97	25
Nylon	Pyrozyl GOMB	97	25
Nylon	Pyrozyl GOMB	100	25
Nylon	Pyrozyl DTE	89	0
Nylon	Pyrozyl DTE	88	0
Nylon	Pyrozyl DTE	87	0
Nylon	Pyrozyl DTE	89	25
Nylon	Pyrozyl DTE	94	25
Nylon	Pyrozyl DTE	95	25

Table B 12 ANOVA Analysis for Nylon Burst Strength at 0 Wash Cycles

Oneway Analysis of Burst Strength (psi) By Treatment Wash Cycles=0



Oneway Anova Summary of Fit

Rsquare	0.798438
Adj Rsquare	0.722852
Root Mean Square Error	3.278719
Mean of Response	92.66667
Observations (or Sum Wgts)	12

Analysis of Variance

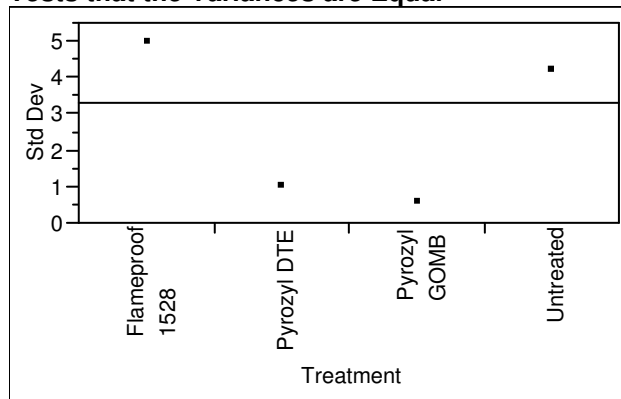
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	340.66667	113.556	10.5633	0.0037
Error	8	86.00000	10.750		
C. Total	11	426.66667			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Flameproof 1528	3	94.333	1.8930	89.968	98.70
Pyrozyl DTE	3	88.000	1.8930	83.635	92.37
Pyrozyl GOMB	3	87.667	1.8930	83.301	92.03
Untreated	3	100.667	1.8930	96.301	105.03

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Flameproof 1528	3	4.932883	3.777778	3.333333
Pyrozyl DTE	3	1.000000	0.666667	1.000000
Pyrozyl GOMB	3	0.577350	0.444444	0.333333
Untreated	3	4.163332	3.111111	3.333333

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.1443	3	8	0.3884
Brown-Forsythe	1.3333	3	8	0.3300
Levene	5.6242	3	8	0.0227
Bartlett	2.5124	3	.	0.0566

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
8.3488	3	3.8528	0.0364

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Flameproof 1528	3	25.000	8.3333	0.933
Pyrozyl DTE	3	11.500	3.8333	-1.399
Pyrozyl GOMB	3	9.500	3.1667	-1.772
Untreated	3	32.000	10.6667	2.238

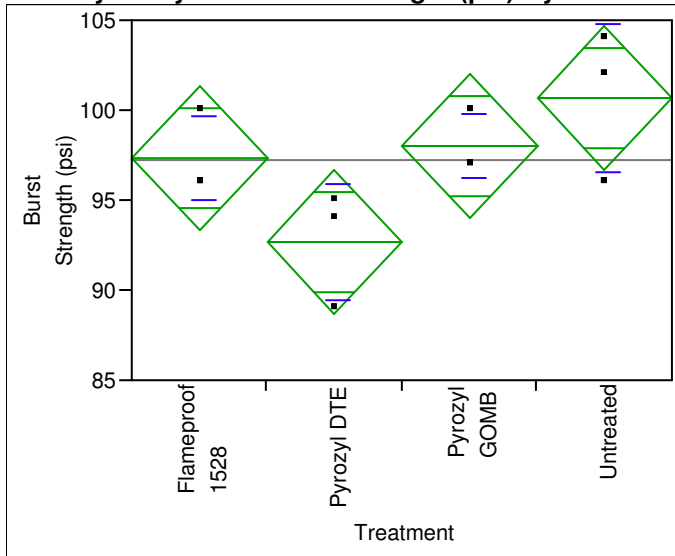
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
9.1471	3	0.0274

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table B 13 ANOVA Analysis for Nylon Burst Strength at 25 Wash Cycles

Oneway Analysis of Burst Strength (psi) By Treatment Wash Cycles=25



**Oneway Anova
Summary of Fit**

Rsquare	0.580583
Adj Rsquare	0.423301
Root Mean Square Error	3
Mean of Response	97.16667
Observations (or Sum Wgts)	12

Analysis of Variance

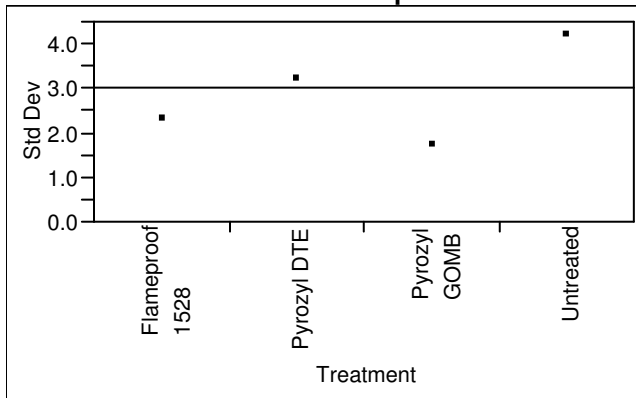
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	99.66667	33.2222	3.6914	0.0620
Error	8	72.00000	9.0000		
C. Total	11	171.66667			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Flameproof 1528	3	97.333	1.7321	93.339	101.33
Pyrozyl DTE	3	92.667	1.7321	88.673	96.66
Pyrozyl GOMB	3	98.000	1.7321	94.006	101.99
Untreated- Unwashed	3	100.667	1.7321	96.673	104.66

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Flameproof 1528	3	2.309401	1.777778	1.333333
Pyrozyl DTE	3	3.214550	2.444444	2.333333
Pyrozyl GOMB	3	1.732051	1.333333	1.000000
Untreated	3	4.163332	3.111111	3.333333

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.6432	3	8	0.6085
Brown-Forsythe	0.7018	3	8	0.5770
Levene	1.4203	3	8	0.3066
Bartlett	0.4570	3	.	0.7123

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
2.2044	3	4.2579	0.2229

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Flameproof 1528	3	19.500	6.50000	0.000
Pyrozyl DTE	3	6.000	2.00000	-2.429
Pyrozyl GOMB	3	24.500	8.16667	0.841
Untreated	3	28.000	9.33333	1.495

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.3202	3	0.0624

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Appendix C: Acrylic Woven

Table C 1 Acrylic Vertical Burn Test- 1 Wash

Fabric	Machine Direction/Cross-machine Direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Acrylic	Cross-machine Direction	Untreated	00:38.4	Y	12
Acrylic	Machine Direction	Untreated	00:21.2	Y	12
Acrylic	Cross-machine Direction	FiNone P-205	01:04.3	N	12
Acrylic	Machine Direction	FiNone P-205	00:52.2	N	12
Acrylic	Cross-machine Direction	Pyrosan SYN	00:16.6	N	6.5
Acrylic	Machine Direction	Pyrosan SYN	00:01.9	N	3.75
Acrylic	Cross-machine Direction	Pyrozyl GOMB	00:00.9	N	1.75
Acrylic	Machine Direction	Pyrozyl GOMB	00:01.5	N	1.25

Table C 2 Acrylic Vertical Burn Test- 3 Wash Cycles

Fabric	Machine direction/Cross-machine direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Acrylic	Cross-machine Direction	Pyrosan SYN	01:24.6	Y	12
Acrylic	Cross-machine Direction	Pyrosan SYN	00:31.9	Y	12
Acrylic	Machine Direction	Pyrosan SYN	00:27.5	Y	12
Acrylic	Machine Direction	Pyrosan SYN	00:23.8	Y	12
Acrylic	Cross-machine Direction	Pyrozyl GOMB	00:30.5	Y	12
Acrylic	Cross-machine Direction	Pyrozyl GOMB	00:35.4	Y	12
Acrylic	Machine Direction	Pyrozyl GOMB	00:25.0	Y	12
Acrylic	Machine Direction	Pyrozyl GOMB	00:20.1	Y	12

Appendix D: Polyester/Nylon Nonwoven

Table D 1 Nonwoven Vertical Burn Test- 1 Wash

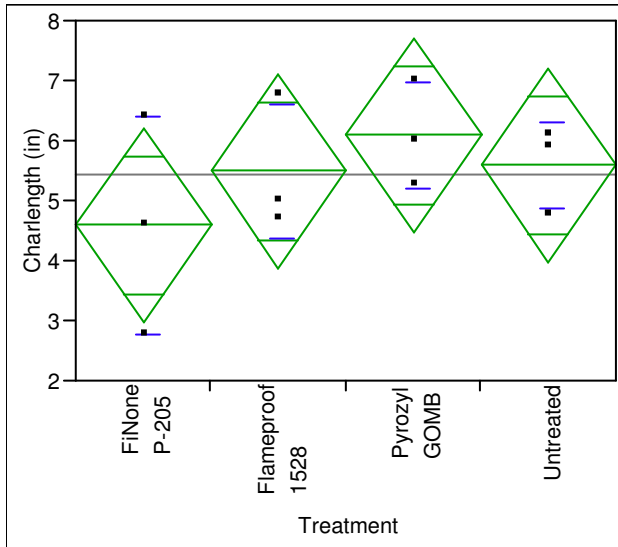
Fabric	Machine direction/Cross-machine direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Nonwoven	Cross-machine Direction	Untreated	00:00.0	Y	4.75
Nonwoven	Cross-machine Direction	Untreated	00:00.0	N	5.9
Nonwoven	Cross-machine Direction	Untreated	00:00.0	Y	6.1
Nonwoven	Machine Direction	Untreated	00:01.1	Y	6
Nonwoven	Machine Direction	Untreated	00:00.0	Y	5.5
Nonwoven	Machine Direction	Untreated	00:00.0	Y	5
Nonwoven	Cross-machine Direction	Flameproof 1528	00:00.0	Y	1.9
Nonwoven	Machine Direction	Flameproof 1528	00:00.0	N	5.8
Nonwoven	Cross-machine Direction	FiNone	00:00.0	N	5.65
Nonwoven	Machine Direction	FiNone	00:00.0	N	5.8
Nonwoven	Cross-machine Direction	Pyrozyl GOMB	00:00.0	Y	3.9
Nonwoven	Machine Direction	Pyrozyl GOMB	00:00.0	N	4.8

Table D 2 Nonwoven Vertical Burn Test - 3 Wash Cycles

Fabric	Machine direction/Cross-machine direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Nonwoven	Cross-machine Direction	Flameproof 1528	00:02.3	Y	4.7
Nonwoven	Cross-machine Direction	Flameproof 1528	00:01.9	Y	5
Nonwoven	Cross-machine Direction	Flameproof 1528	00:00.0	Y	6.75
Nonwoven	Machine Direction	Flameproof 1528	00:12.7	Y	4.25
Nonwoven	Machine Direction	Flameproof 1528	00:00.0	Y	4.5
Nonwoven	Machine Direction	Flameproof 1528	00:00.0	Y	4.5
Nonwoven	Cross-machine Direction	Fi None P-205	00:02.9	N	4.6
Nonwoven	Cross-machine Direction	Fi None P-205	00:02.3	N	2.75
Nonwoven	Cross-machine Direction	Fi None P-205	00:08.9	Y	6.4
Nonwoven	Machine Direction	Fi None P-205	00:14.7	Y	5.8
Nonwoven	Machine Direction	Fi None P-205	00:02.4	N	3.75
Nonwoven	Machine Direction	Fi None P-205	00:20.0	Y	8.4
Nonwoven	Cross-machine Direction	Pyrozyl GOMB	00:04.7	Y	6
Nonwoven	Cross-machine Direction	Pyrozyl GOMB	00:06.1	Y	5.25
Nonwoven	Cross-machine Direction	Pyrozyl GOMB	00:04.6	Y	7
Nonwoven	Machine Direction	Pyrozyl GOMB	00:01.3	Y	6.8
Nonwoven	Machine Direction	Pyrozyl GOMB	00:01.4	N	4.6
Nonwoven	Machine Direction	Pyrozyl GOMB	04:00.0	Y	4.6

Table D 3 ANOVA Analysis for Nonwoven Burn at 3 Wash Cycles

Oneway Analysis of Char length (in) By Treatment Burn Direction=Cross-machine Direction



**Oneway Anova
Summary of Fit**

Rsquare	0.230517
Adj Rsquare	-0.05804
Root Mean Square Error	1.2102
Mean of Response	5.433333
Observations (or Sum Wgts)	12

Analysis of Variance

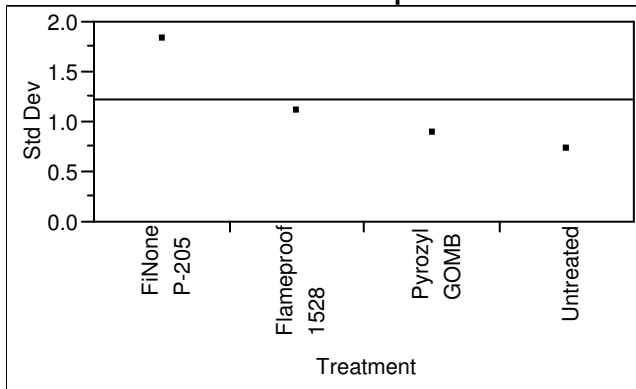
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	3.510000	1.17000	0.7989	0.5284
Error	8	11.716667	1.46458		
C. Total	11	15.226667			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FiNone P-205	3	4.58333	0.69871	2.9721	6.1946
Flameproof 1528	3	5.48333	0.69871	3.8721	7.0946
Pyrozyl GOMB	3	6.08333	0.69871	4.4721	7.6946
Untreated	3	5.58333	0.69871	3.9721	7.1946

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
FiNone P-205	3	1.825057	1.222222	1.816667
Flameproof 1528	3	1.107174	0.844444	0.783333
Pyrozyl GOMB	3	0.877971	0.611111	0.833333
Untreated	3	0.728583	0.555556	0.516667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.8609	3	8	0.4996
Brown-Forsythe	3.8097	3	8	0.0579
Levene	0.7225	3	8	0.5663
Bartlett	0.5589	3	.	0.6421

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0.4704	3	4.3025	0.7181

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

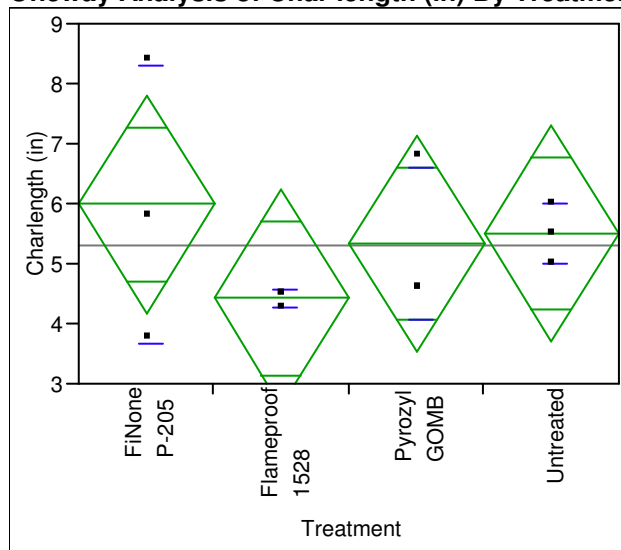
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
FiNone P-205	3	13.000	4.33333	-1.109
Flameproof 1528	3	19.000	6.33333	0.000
Pyrozyl GOMB	3	26.000	8.66667	1.109
Untreated	3	20.000	6.66667	0.000

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.1795	3	0.5360

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Char length (in) By Treatment Burn Direction=Machine Direction



Oneway Anova Summary of Fit

Rsquare	0.20894
Adj Rsquare	-0.08771
Root Mean Square Error	1.352313
Mean of Response	5.308333
Observations (or Sum Wgts)	12

Analysis of Variance

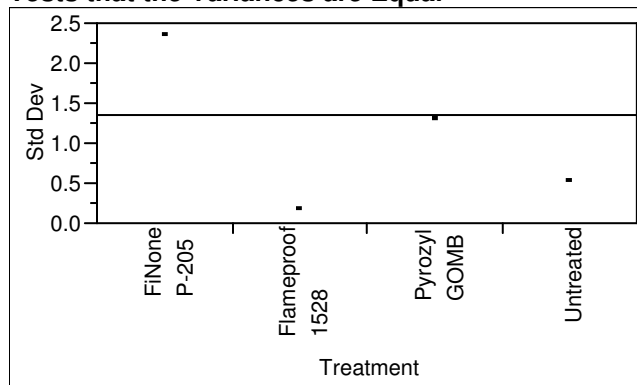
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	3.864167	1.28806	0.7043	0.5757
Error	8	14.630000	1.82875		
C. Total	11	18.494167			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FiNone P-205	3	5.98333	0.78076	4.1829	7.7838
Flameproof 1528	3	4.41667	0.78076	2.6162	6.2171
Pyrozyl GOMB	3	5.33333	0.78076	3.5329	7.1338
Untreated	3	5.50000	0.78076	3.6996	7.3004

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
FiNone P-205	3	2.330415	1.611111	2.233333

Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Flameproof 1528	3	0.144338	0.111111	0.083333
Pyrozyl GOMB	3	1.270171	0.977778	0.733333
Untreated	3	0.500000	0.333333	0.500000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.3844	3	8	0.3160
Brown-Forsythe	6.0677	3	8	0.0186
Levene	3.0516	3	8	0.0920
Bartlett	3.0354	3	.	0.0279

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
3.7435	3	3.5308	0.1321

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
FiNone P-205	3	22.000	7.33333	0.371
Flameproof 1528	3	9.000	3.00000	-1.855
Pyrozyl GOMB	3	22.000	7.33333	0.371
Untreated	3	25.000	8.33333	0.928

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
3.9507	3	0.2668

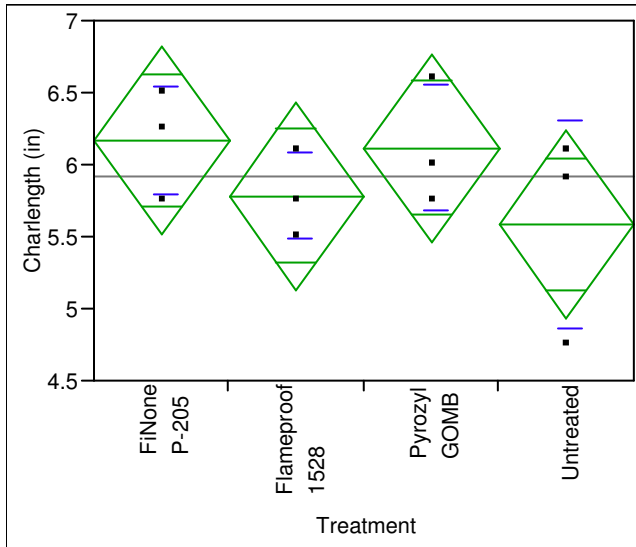
Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table D 4 Nonwoven Burn Test- 10 Wash Cycles

Fabric	Machine direction/Cross-machine direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Nonwoven	Machine direction	FiNone P-205	00:02.5	Y	5.5
Nonwoven	Machine direction	FiNone P-205	00:03.2	Y	5.35
Nonwoven	Machine direction	FiNone P-205	00:01.8	Y	6.1
Nonwoven	Cross-machine direction	FiNone P-205	00:01.2	Y	6.25
Nonwoven	Cross-machine direction	FiNone P-205	00:06.8	Y	5.75
Nonwoven	Cross-machine direction	FiNone P-205	00:03.8	Y	6.5
Nonwoven	Machine direction	Flameproof 1528	00:00.8	Y	5
Nonwoven	Machine direction	Flameproof 1528	00:00.0	Y	5.1
Nonwoven	Machine direction	Flameproof 1528	00:00.0	Y	5.25
Nonwoven	Cross-machine direction	Flameproof 1528	00:01.9	Y	5.5
Nonwoven	Cross-machine direction	Flameproof 1528	00:08.3	Y	6.1
Nonwoven	Cross-machine direction	Flameproof 1528	00:06.4	Y	5.75
Nonwoven	Machine direction	Pyrozyl GOMB	00:07.8	Y	6.25
Nonwoven	Machine direction	Pyrozyl GOMB	00:03.4	Y	6
Nonwoven	Machine direction	Pyrozyl GOMB	00:03.6	Y	6.75
Nonwoven	Cross-machine direction	Pyrozyl GOMB	00:03.2	Y	6
Nonwoven	Cross-machine direction	Pyrozyl GOMB	00:05.0	Y	5.75
Nonwoven	Cross-machine direction	Pyrozyl GOMB	00:03.5	Y	6.6

Table D 5 ANOVA Analysis for Nonwoven Burns at 10 Washes

Oneway Analysis of Char length (in) By Treatment Burn Direction=Cross-machine Direction



**Oneway Anova
Summary of Fit**

Rsquare	0.265821
Adj Rsquare	-0.0095
Root Mean Square Error	0.489473
Mean of Response	5.9125
Observations (or Sum Wgts)	12

Analysis of Variance

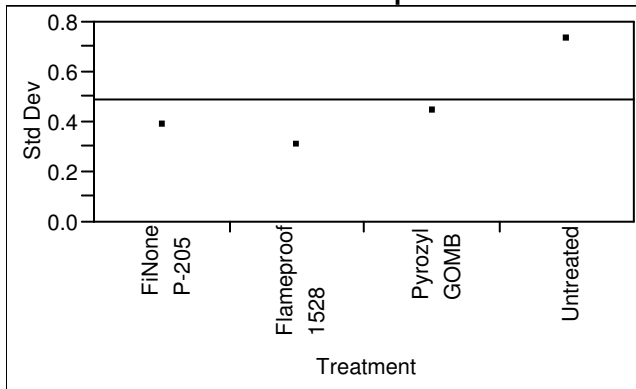
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	0.6939583	0.231319	0.9655	0.4549
Error	8	1.9166667	0.239583		
C. Total	11	2.6106250			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FiNone P-205	3	6.16667	0.28260	5.5150	6.8183
Flameproof 1528	3	5.78333	0.28260	5.1317	6.4350
Pyrozyl GOMB	3	6.11667	0.28260	5.4650	6.7683
Untreated	3	5.58333	0.28260	4.9317	6.2350

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
FiNone P-205	3	0.3818813	0.2777778	0.3333333
Flameproof 1528	3	0.3013857	0.2111111	0.2833333
Pyrozyl GOMB	3	0.4368447	0.3222222	0.3666667
Untreated	3	0.7285831	0.5555556	0.5166667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.8052	3	8	0.5254
Brown-Forsythe	0.3311	3	8	0.8034
Levene	1.7131	3	8	0.2412
Bartlett	0.4956	3	.	0.6853

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0.7833	3	4.3122	0.5587

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

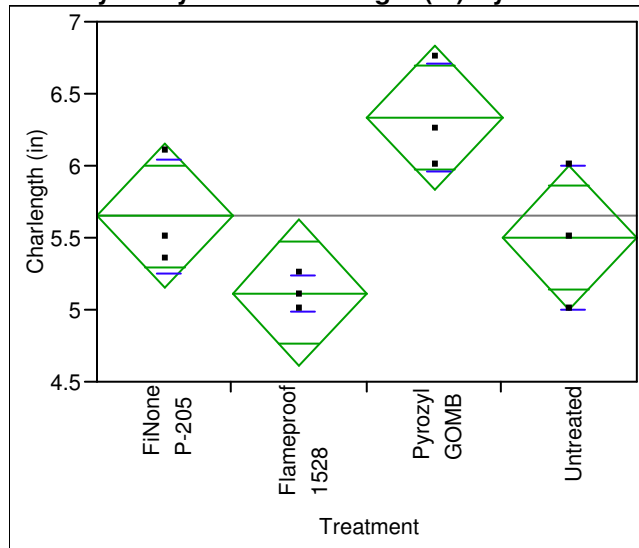
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
FiNone P-205	3	25.000	8.33333	0.933
Flameproof 1528	3	14.500	4.83333	-0.839
Pyrozyl GOMB	3	23.000	7.66667	0.560
Untreated	3	15.500	5.16667	-0.653

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.1791	3	0.5361

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Char length (in) By Treatment Burn Direction=Machine Direction



Oneway Anova Summary of Fit

Rsquare	0.671002
Adj Rsquare	0.547628
Root Mean Square Error	0.377216
Mean of Response	5.65
Observations (or Sum Wgts)	12

Analysis of Variance

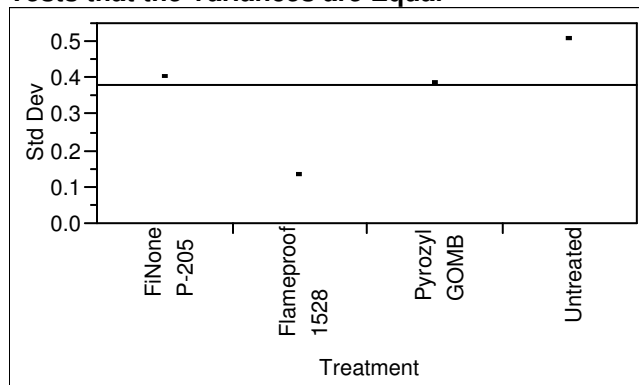
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	2.3216667	0.773889	5.4388	0.0247
Error	8	1.1383333	0.142292		
C. Total	11	3.4600000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FiNone P-205	3	5.65000	0.21779	5.1478	6.1522
Flameproof 1528	3	5.11667	0.21779	4.6145	5.6189
Pyrozyl GOMB	3	6.33333	0.21779	5.8311	6.8355
Untreated	3	5.50000	0.21779	4.9978	6.0022

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
FiNone P-205	3	0.3968627	0.3000000	0.3000000

Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Flameproof 1528	3	0.1258306	0.0888889	0.1166667
Pyrozyl GOMB	3	0.3818813	0.2777778	0.3333333
Untreated	3	0.5000000	0.3333333	0.5000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.6063	3	8	0.6292
Brown-Forsythe	3.3240	3	8	0.0774
Levene	1.0342	3	8	0.4279
Bartlett	0.8309	3	.	0.4766

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
7.6643	3	3.797	0.0429

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
FiNone P-205	3	21.500	7.1667	0.279
Flameproof 1528	3	8.500	2.8333	-1.952
Pyrozyl GOMB	3	31.500	10.5000	2.138
Untreated	3	16.500	5.5000	-0.465

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.2038	3	0.0657

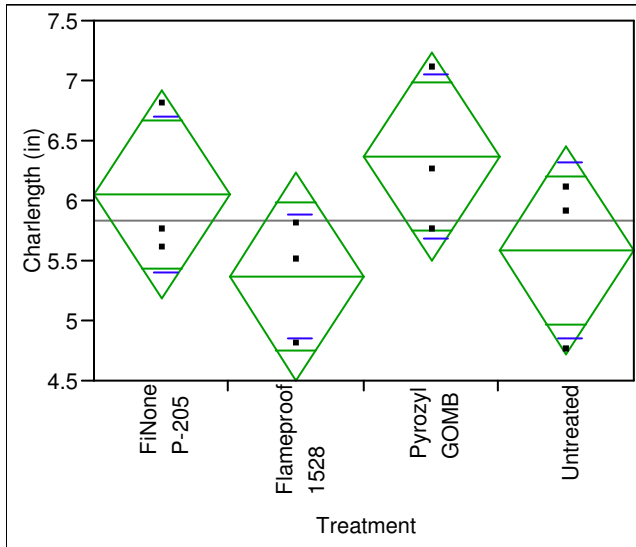
Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table D 6 Nonwoven Vertical Burn Test- 25 Wash Cycles

Fabric	Machine direction/Cross-machine direction	Treatment	After flame time (mins:secs)	Melt Drip	Char length (in)
Nonwoven	Machine direction	FiNone P-205	00:01.8	Y	5.7
Nonwoven	Machine direction	FiNone P-205	00:03.8	Y	6
Nonwoven	Machine direction	FiNone P-205	00:03.8	Y	6.25
Nonwoven	Cross-machine direction	FiNone P-205	00:02.0	Y	5.6
Nonwoven	Cross-machine direction	FiNone P-205	00:00.0	Y	5.75
Nonwoven	Cross-machine direction	FiNone P-205	00:06.2	Y	6.8
Nonwoven	Machine direction	Flameproof 1528	00:00.0	Y	7
Nonwoven	Machine direction	Flameproof 1528	00:00.0	Y	5.25
Nonwoven	Machine direction	Flameproof 1528	00:00.0	Y	6.75
Nonwoven	Cross-machine direction	Flameproof 1528	00:00.0	Y	4.8
Nonwoven	Cross-machine direction	Flameproof 1528	00:07.6	Y	5.8
Nonwoven	Cross-machine direction	Flameproof 1528	00:03.5	Y	5.5
Nonwoven	Machine direction	Pyrozyl GOMB	00:00.9	Y	5.5
Nonwoven	Machine direction	Pyrozyl GOMB	00:06.9	Y	6.3
Nonwoven	Machine direction	Pyrozyl GOMB	00:11.5	Y	6.2
Nonwoven	Cross-machine direction	Pyrozyl GOMB	00:00.0	Y	5.75
Nonwoven	Cross-machine direction	Pyrozyl GOMB	00:04.5	Y	6.25
Nonwoven	Cross-machine direction	Pyrozyl GOMB	00:05.4	Y	7.1

Table D 7 ANOVA Analysis for Nonwoven Burn at 25 Wash Cycles

Oneway Analysis of Char length (in) By Treatment Burn Direction=Cross-machine Direction



**Oneway Anova
Summary of Fit**

Rsquare	0.352104
Adj Rsquare	0.109143
Root Mean Square Error	0.649519
Mean of Response	5.841667
Observations (or Sum Wgts)	12

Analysis of Variance

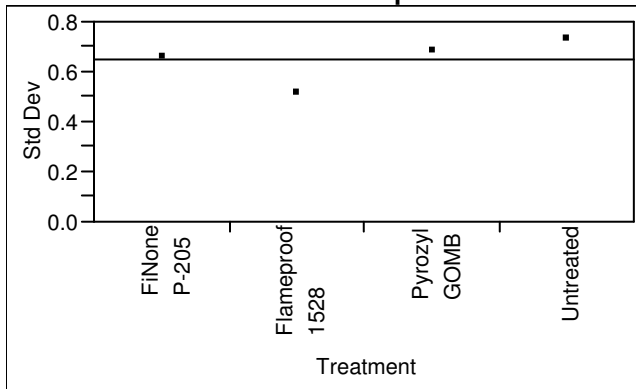
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	1.8341667	0.611389	1.4492	0.2993
Error	8	3.3750000	0.421875		
C. Total	11	5.2091667			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FiNone P-205	3	6.05000	0.37500	5.1852	6.9148
Flameproof 1528	3	5.36667	0.37500	4.5019	6.2314
Pyrozyl GOMB	3	6.36667	0.37500	5.5019	7.2314
Untreated	3	5.58333	0.37500	4.7186	6.4481

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
FiNone P-205	3	0.6538348	0.5000000	0.4500000
Flameproof 1528	3	0.5131601	0.3777778	0.4333333
Pyrozyl GOMB	3	0.6825198	0.4888889	0.6166667
Untreated	3	0.7285831	0.5555556	0.5166667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.1230	3	8	0.9439
Brown-Forsythe	0.1249	3	8	0.9427
Levene	0.2403	3	8	0.8659
Bartlett	0.0713	3	.	0.9753

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
1.2517	3	4.4027	0.3944

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

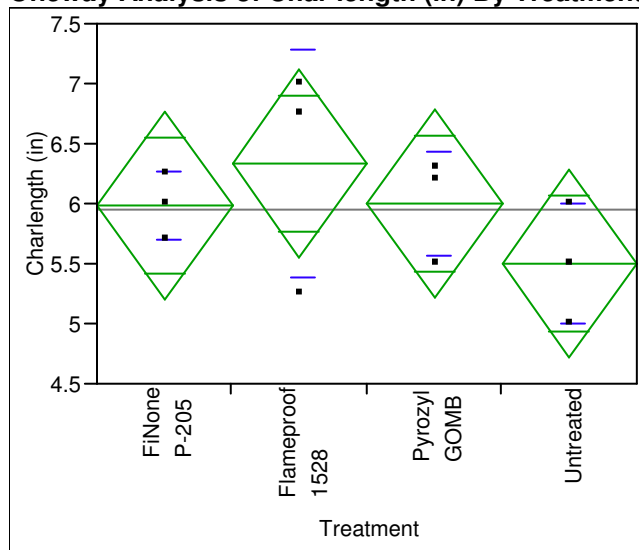
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
FiNone P-205	3	20.500	6.83333	0.093
Flameproof 1528	3	12.000	4.00000	-1.297
Pyrozyl GOMB	3	27.500	9.16667	1.389
Untreated	3	18.000	6.00000	-0.185

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
3.1778	3	0.3650

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Char length (in) By Treatment Burn Direction=Machine Direction



Oneway Anova Summary of Fit

Rsquare	0.272766
Adj Rsquare	5.366e-5
Root Mean Square Error	0.594068
Mean of Response	5.954167
Observations (or Sum Wgts)	12

Analysis of Variance

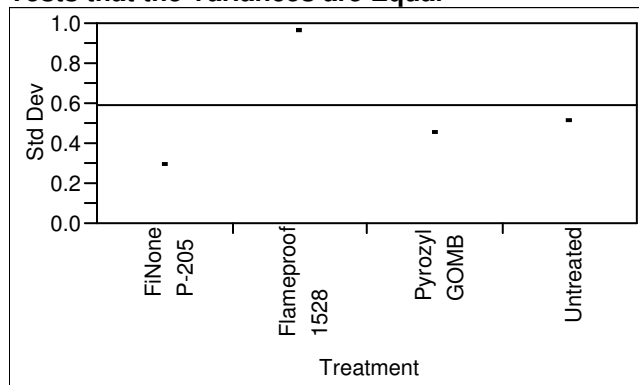
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	1.0589583	0.352986	1.0002	0.4410
Error	8	2.8233333	0.352917		
C. Total	11	3.8822917			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FiNone P-205	3	5.98333	0.34299	5.1924	6.7743
Flameproof 1528	3	6.33333	0.34299	5.5424	7.1243
Pyrozyl GOMB	3	6.00000	0.34299	5.2091	6.7909
Untreated	3	5.50000	0.34299	4.7091	6.2909

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
FiNone P-205	3	0.2753785	0.1888889	0.2666667

Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Flameproof 1528	3	0.9464847	0.7222222	0.6666667
Pyrozyl GOMB	3	0.4358899	0.3333333	0.3000000
Untreated	3	0.5000000	0.3333333	0.5000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.0682	3	8	0.4153
Brown-Forsythe	0.6511	3	8	0.6042
Levene	2.5933	3	8	0.1251
Bartlett	0.8663	3	.	0.4577

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0.7450	3	4.177	0.5770

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
FiNone P-205	3	20.500	6.83333	0.093
Flameproof 1528	3	25.000	8.33333	0.928
Pyrozyl GOMB	3	21.500	7.16667	0.278
Untreated	3	11.000	3.66667	-1.484

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.7758	3	0.4275

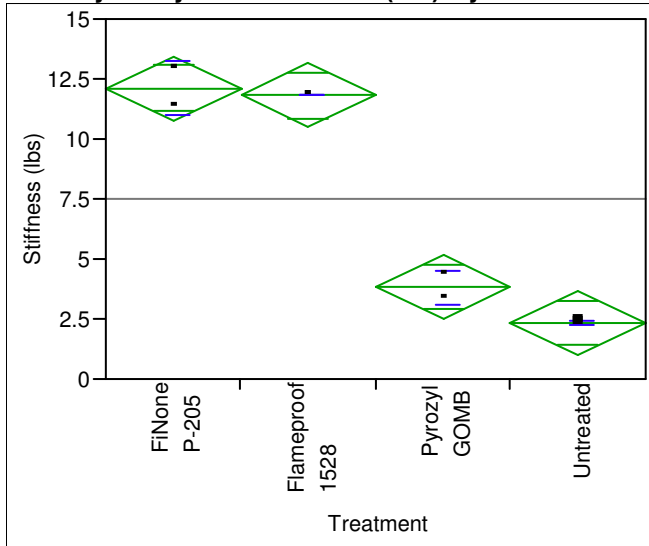
Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table D 8 Nonwoven Stiffness Data

Fabric	Treatment	Wash Cycles	Stiffness (lbs)
Nonwoven	Untreated	0	2.38
Nonwoven	Untreated	0	2.3
average			2.34
Nonwoven	FiNone P-205	0	12.94
Nonwoven	FiNone P-205	0	11.3
average			12.12
Nonwoven	Flameproof 1528	0	11.8
Nonwoven	Flameproof 1528	0	11.8
average			11.8
Nonwoven	Pyrozyl GOMB	0	4.32
Nonwoven	Pyrozyl GOMB	0	3.32
average			3.82
Nonwoven	FiNone P-205	25	0.38
Nonwoven	FiNone P-205	25	0.34
average			0.36
Nonwoven	Flameproof 1528	25	1.48
Nonwoven	Flameproof 1528	25	1.02
average			1.25
Nonwoven	Pyrozyl GOMB	25	0.44
Nonwoven	Pyrozyl GOMB	25	0.34
average			0.39

Table D 9 ANOVA Analysis for Nonwoven Stiffness at 0 Wash Cycles

Oneway Analysis of Stiffness (lbs) By Treatment Wash Cycles=0



**Oneway Anova
Summary of Fit**

Rsquare	0.988582
Adj Rsquare	0.980018
Root Mean Square Error	0.679706
Mean of Response	7.52
Observations (or Sum Wgts)	8

Analysis of Variance

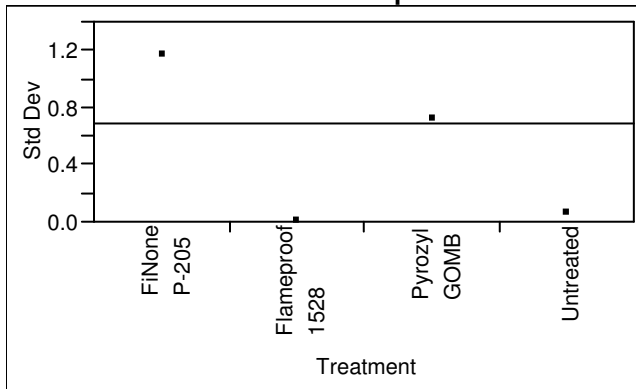
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	160.00160	53.3339	115.4413	0.0002
Error	4	1.84800	0.4620		
C. Total	7	161.84960			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FiNone P-205	2	12.1200	0.48062	10.786	13.454
Flameproof 1528	2	11.8000	0.48062	10.466	13.134
Pyrozyl GOMB	2	3.8200	0.48062	2.486	5.154
Untreated	2	2.3400	0.48062	1.006	3.674

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
FiNone P-205	2	1.159655	0.8200000	0.8200000
Flameproof 1528	2	0.000000	0.0000000	0.0000000
Pyrozyl GOMB	2	0.707107	0.5000000	0.5000000
Untreated	2	0.056569	0.0400000	0.0400000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.0000	-1	0	0.0000
Brown-Forsythe	.	3	4	.
Levene	.	3	4	.
Bartlett	.	3	.	.

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
.	3	.	.

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
FiNone P-205	2	13.000	6.50000	1.174
Flameproof 1528	2	13.000	6.50000	1.174
Pyrozyl GOMB	2	7.000	3.50000	-0.503
Untreated	2	3.000	1.50000	-1.844

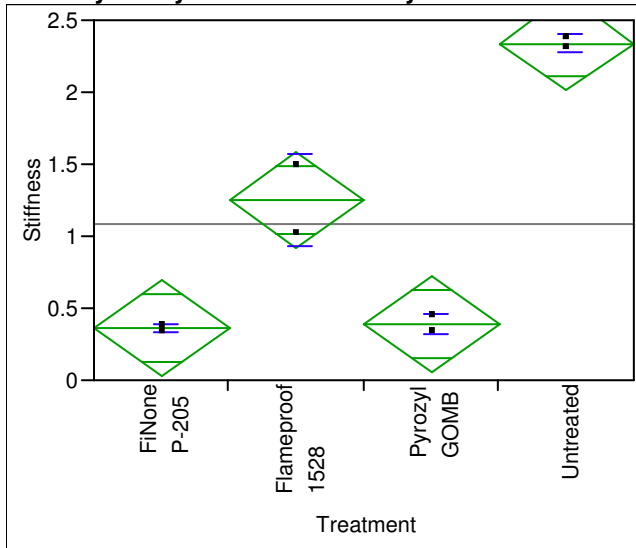
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.0723	3	0.1081

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table D 10 ANOVA Analysis for Nonwoven Stiffness at 25 Wash Cycles

Oneway Analysis of Stiffness By Treatment Wash Cycles=25



**Oneway Anova
Summary of Fit**

Rsquare 0.978488
 Adj Rsquare 0.962354
 Root Mean Square Error 0.169411
 Mean of Response 1.085
 Observations (or Sum Wgts) 8

Analysis of Variance

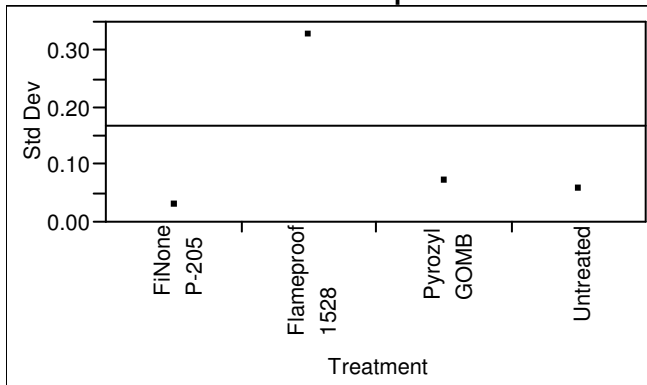
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	5.2218000	1.74060	60.6481	0.0009
Error	4	0.1148000	0.02870		
C. Total	7	5.3366000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FiNone P-205	2	0.36000	0.11979	0.0274	0.6926
Flameproof 1528	2	1.25000	0.11979	0.9174	1.5826
Pyrozyl GOMB	2	0.39000	0.11979	0.0574	0.7226
Untreated	2	2.34000	0.11979	2.0074	2.6726

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
FiNone P-205	2	0.0282843	0.0200000	0.0200000
Flameproof 1528	2	0.3252691	0.2300000	0.2300000
Pyrozyl GOMB	2	0.0707107	0.0500000	0.0500000
Untreated	2	0.0565685	0.0400000	0.0400000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.0000	-1	0	0.0000
Brown-Forsythe	7.01e+17	3	4	<.0001
Levene	7.01e+17	3	4	<.0001
Bartlett	1.4627	3	.	0.2225

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
399.9624	3	1.9673	0.0027

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
FiNone P-205	2	4.500	2.25000	-1.341
Flameproof 1528	2	11.000	5.50000	0.503
Pyrozyl GOMB	2	5.500	2.75000	-1.006
Untreated	2	15.000	7.50000	1.844

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.1145	3	0.1062

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Table D 11 Nonwoven Tear Strength Data

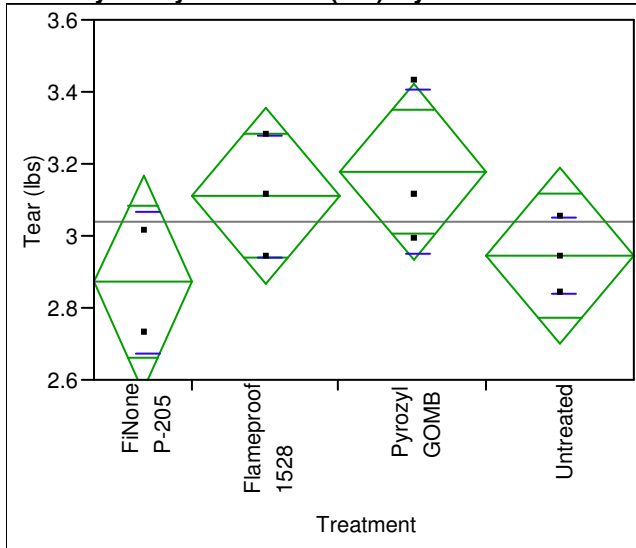
Fabric	Treatment	Wash Cycles	Machine or Cross-machine Tears	Ave "N" Peaks (lb)
Nonwoven	Untreated	0	Cross machine	2.94
Nonwoven	Untreated	0	Cross machine	3.05
Nonwoven	Untreated	0	Cross machine	2.84
Nonwoven	Untreated	0	Machine	2.97
Nonwoven	Untreated	0	Machine	2.97
Nonwoven	Untreated	0	Machine	2.92
Nonwoven	FiNone P-205	0	Cross machine	N/A
Nonwoven	FiNone P-205	0	Cross machine	2.73
Nonwoven	FiNone P-205	0	Cross machine	3.01
Nonwoven	FiNone P-205	0	Machine	2.94
Nonwoven	FiNone P-205	0	Machine	3.01
Nonwoven	FiNone P-205	0	Machine	2.82
Nonwoven	FiNone P-205	25	Cross machine	3.2
Nonwoven	FiNone P-205	25	Cross machine	3.3
Nonwoven	FiNone P-205	25	Cross machine	3.13
Nonwoven	FiNone P-205	25	Machine	3.01
Nonwoven	FiNone P-205	25	Machine	2.94
Nonwoven	FiNone P-205	25	Machine	3.54
Nonwoven	Flameproof 1528	0	Cross machine	2.94
Nonwoven	Flameproof 1528	0	Cross machine	3.28
Nonwoven	Flameproof 1528	0	Cross machine	3.11
Nonwoven	Flameproof 1528	0	Machine	2.92
Nonwoven	Flameproof 1528	0	Machine	3.05
Nonwoven	Flameproof 1528	0	Machine	2.97

Table D 11 Continued

Fabric	Treatment	Wash Cycles	Machine or Cross-machine Tears	Ave "N" Peaks (lb)
Nonwoven	Flameproof 1528	25	Cross machine	N/A
Nonwoven	Flameproof 1528	25	Cross machine	3.11
Nonwoven	Flameproof 1528	25	Cross machine	2.86
Nonwoven	Flameproof 1528	25	Machine	3.37
Nonwoven	Flameproof 1528	25	Machine	3.62
Nonwoven	Flameproof 1528	25	Machine	3.16
Nonwoven	Pyrozyl GOMB	0	Cross machine	3.43
Nonwoven	Pyrozyl GOMB	0	Cross machine	2.99
Nonwoven	Pyrozyl GOMB	0	Cross machine	3.11
Nonwoven	Pyrozyl GOMB	0	Machine	3.2
Nonwoven	Pyrozyl GOMB	0	Machine	3.16
Nonwoven	Pyrozyl GOMB	0	Machine	3.3
Nonwoven	Pyrozyl GOMB	25	Cross machine	3.62
Nonwoven	Pyrozyl GOMB	25	Cross machine	3.01
Nonwoven	Pyrozyl GOMB	25	Cross machine	3.16
Nonwoven	Pyrozyl GOMB	25	Machine	3.09
Nonwoven	Pyrozyl GOMB	25	Machine	3.09
Nonwoven	Pyrozyl GOMB	25	Machine	3.26

Table D 12 ANOVA Analysis for Nonwoven Tear Strength at 0 Wash Cycles

Oneway Analysis of Tear (lbs) By Treatment Wash Cycles=0, Tear =Cross machine



Excluded Rows

1

**Oneway Anova
Summary of Fit**

Rsquare	0.412982
Adj Rsquare	0.161402
Root Mean Square Error	0.178299
Mean of Response	3.039091
Observations (or Sum Wgts)	11

Analysis of Variance

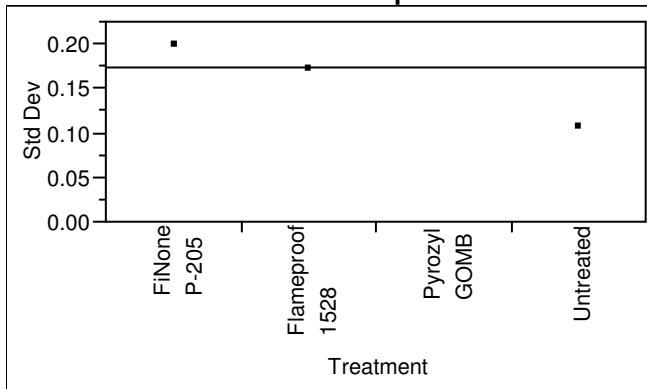
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	0.15655758	0.052186	1.6416	0.2649
Error	7	0.22253333	0.031790		
C. Total	10	0.37909091			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FiNone P-205	2	2.87000	0.12608	2.5719	3.1681
Flameproof 1528	3	3.11000	0.10294	2.8666	3.3534
Pyrozyl GOMB	3	3.17667	0.10294	2.9333	3.4201
Untreated	3	2.94333	0.10294	2.6999	3.1867

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
FiNone P-205	2	0.1979899	0.1400000	0.1400000
Flameproof 1528	3	0.1700000	0.1133333	0.1700000
Pyrozyl GOMB	0	.	0.0000000	0.0000000
Untreated	3	0.1050397	0.0711111	0.1033333

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.5930	1	4	0.4842
Brown-Forsythe	250.6250	2	5	<.0001
Levene	0.5827	2	5	0.5923
Bartlett	0.2512	2	.	0.7779

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
1.0637	2	2.3655	0.4682

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

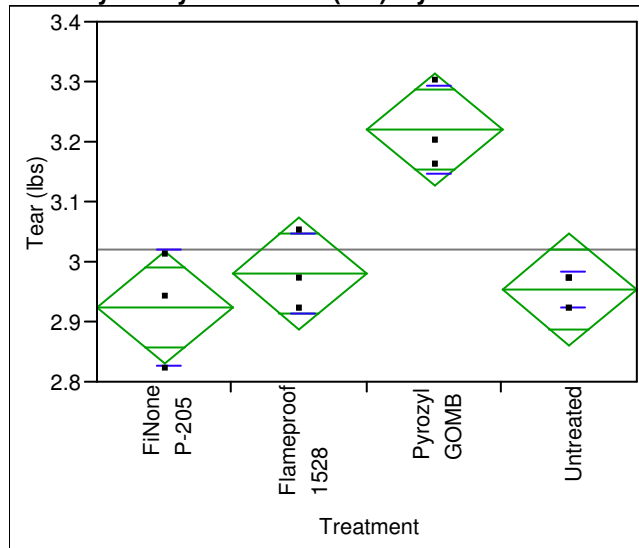
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
FiNone P-205	2	6.000	3.00000	-0.838
Flameproof 1528	3	18.500	6.16667	1.350
Pyrozyl GOMB	0	0.000	0.00000	.
Untreated	3	11.500	3.83333	-0.450

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.3896	2	0.3028

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Tear (lbs) By Treatment Wash Cycles=0, Tear=Machine



Oneway Anova Summary of Fit

Rsquare 0.809377
Adj Rsquare 0.737893
Root Mean Square Error 0.06994
Mean of Response 3.019167
Observations (or Sum Wgts) 12

Analysis of Variance

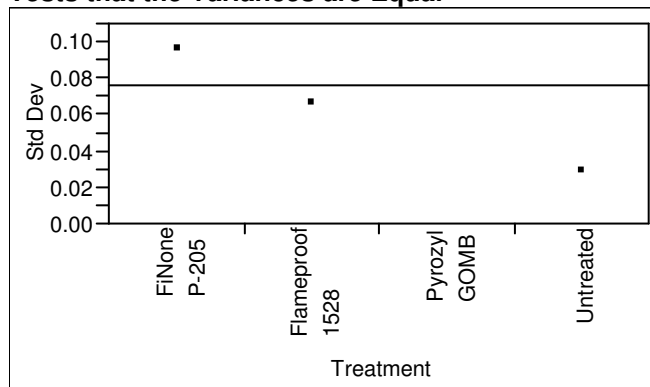
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	0.16615833	0.055386	11.3225	0.0030
Error	8	0.03913333	0.004892		
C. Total	11	0.20529167			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FiNone P-205	3	2.92333	0.04038	2.8302	3.0165
Flameproof 1528	3	2.98000	0.04038	2.8869	3.0731
Pyrozyl GOMB	3	3.22000	0.04038	3.1269	3.3131
Untreated	3	2.95333	0.04038	2.8602	3.0465

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
FiNone P-205	3	0.0960902	0.0688889	0.0866667
Flameproof 1528	3	0.0655744	0.0466667	0.0600000

Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Pyrozyl GOMB	0	.	0.0000000	0.0000000
Untreated	3	0.0288675	0.0222222	0.0166667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.9100	2	6	0.4517
Brown-Forsythe	5.7119	2	6	0.0408
Levene	1.5131	2	6	0.2937
Bartlett	0.9816	2	.	0.3747

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0.3203	2	3.2635	0.7464

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
FiNone P-205	3	13.000	4.33333	-0.396
Flameproof 1528	3	17.500	5.83333	0.528
Pyrozyl GOMB	0	0.000	0.00000	.
Untreated	3	14.500	4.83333	0.000

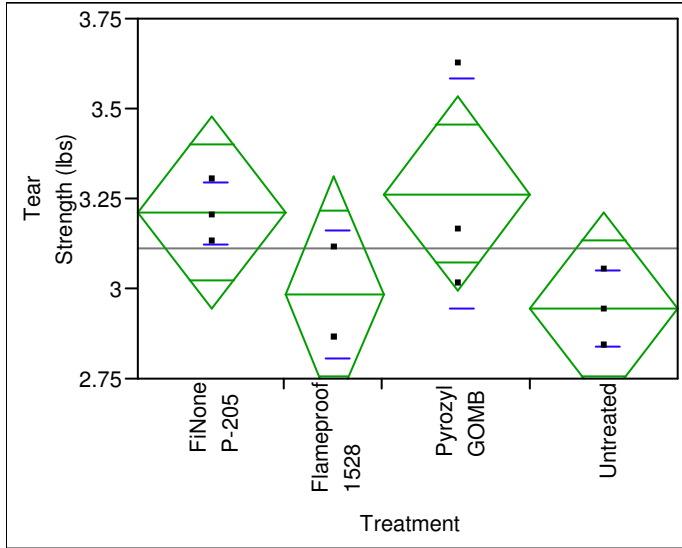
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.4870	2	0.7839

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.
Nonwoven Tear Strength – 25 w with untreated

Table D 13 ANOVA Analysis for Nonwoven Tear Strength at 25 Wash Cycles

Oneway Analysis of Tear Strength (lbs) By Treatment Wash Cycles=25 Tear =Cross machine



Excluded Rows

1

**Oneway Anova
Summary of Fit**

Rsquare	0.443438
Adj Rsquare	0.204911
Root Mean Square Error	0.19639
Mean of Response	3.110909
Observations (or Sum Wgts)	11

Analysis of Variance

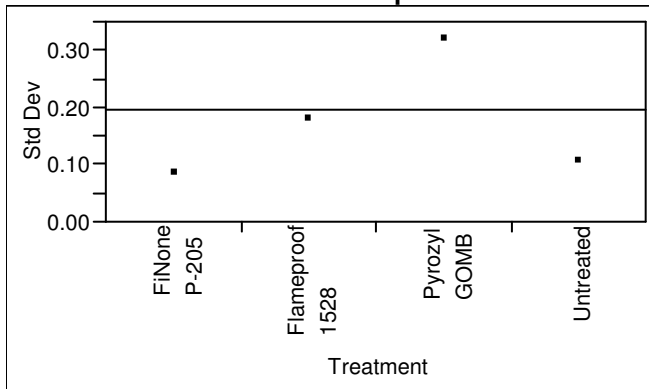
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	0.21510758	0.071703	1.8591	0.2247
Error	7	0.26998333	0.038569		
C. Total	10	0.48509091			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FiNone P-205	3	3.21000	0.11339	2.9419	3.4781
Flameproof 1528	2	2.98500	0.13887	2.6566	3.3134
Pyrozyl GOMB	3	3.26333	0.11339	2.9952	3.5314
Untreated	3	2.94333	0.11339	2.6752	3.2114

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
FiNone P-205	3	0.0854400	0.0600000	0.0800000
Flameproof 1528	2	0.1767767	0.1250000	0.1250000
Pyrozyl GOMB	3	0.3178574	0.2377778	0.2533333
Untreated	3	0.1050397	0.0711111	0.1033333

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.4468	2	6	0.3071
Brown-Forsythe	1.9385	3	7	0.2119
Levene	3.2183	3	7	0.0918
Bartlett	1.0874	3	.	0.3529

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
3.0887	3	3.0742	0.1861

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

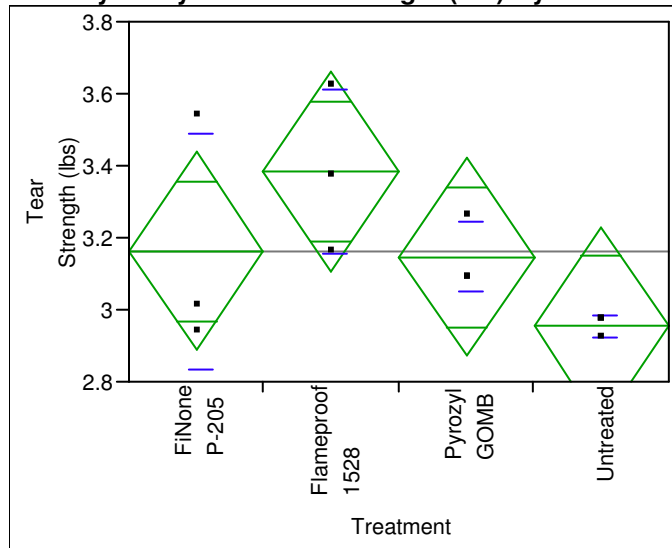
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
FiNone P-205	3	26.000	8.66667	1.531
Flameproof 1528	2	8.000	4.00000	-0.825
Pyrozyl GOMB	3	23.000	7.66667	0.919
Untreated	3	9.000	3.00000	-1.735

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.8788	3	0.1177

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Tear Strength (lbs) By Treatment Wash Cycles=25 Tear =Machine



Oneway Anova Summary of Fit

Rsquare	0.448461
Adj Rsquare	0.241634
Root Mean Square Error	0.206841
Mean of Response	3.161667
Observations (or Sum Wgts)	12

Analysis of Variance

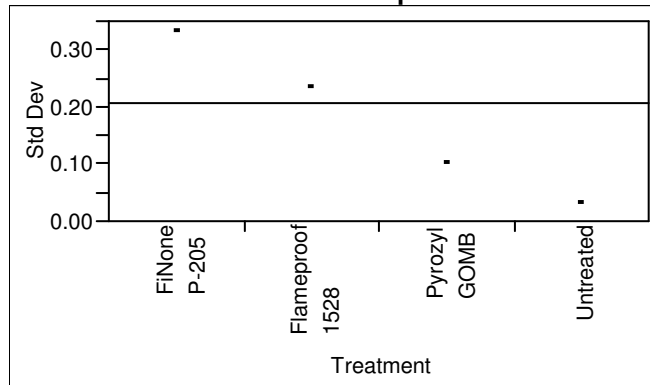
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	0.27830000	0.092767	2.1683	0.1697
Error	8	0.34226667	0.042783		
C. Total	11	0.62056667			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FiNone P-205	3	3.16333	0.11942	2.8880	3.4387
Flameproof 1528	3	3.38333	0.11942	3.1080	3.6587
Pyrozyl GOMB	3	3.14667	0.11942	2.8713	3.4220
Untreated	3	2.95333	0.11942	2.6780	3.2287

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
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Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
FiNone P-205	3	0.3280752	0.2511111	0.2233333
Flameproof 1528	3	0.2302897	0.1577778	0.2233333
Pyrozyl GOMB	3	0.0981495	0.0755556	0.0566667
Untreated	3	0.0288675	0.0222222	0.0166667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.1727	3	8	0.3789
Brown-Forsythe	1.7487	3	8	0.2344
Levene	4.0096	3	8	0.0516
Bartlett	2.3680	3	.	0.0687

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
5.1571	3	3.5486	0.0857

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
FiNone P-205	3	18.000	6.0000	-0.186
Flameproof 1528	3	30.000	10.0000	1.855
Pyrozyl GOMB	3	22.000	7.3333	0.371
Untreated	3	8.000	2.6667	-2.041

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.4812	3	0.0904

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Appendix E

Table E 1 Bath Parameters for 5, 10, 25 Wash Cycles

Set No./ Weight of Set (kg)	No. of Launderings	Amount of detergent (g)	Wash Temperature (°C)
1/ 1.80	1	100.0	31.6
1	2	100.1	20.3
1	3	100.0	43
1	4	100.1	42.7
1	5	100.0	40.1
1	6	100.0	34.6
1	7	100.1	43.8
1	8	100.1	39.7
1	9	100.1	38.4
1	10	100.0	35.7
1	11	100.0	37.2
1	12	100.1	40
1&2/1.74	13	100.0	44
1&2	14	100.0	36.7
1&2	15	100.1	40.3
1&2	16	100.0	43.1
1&2	17	100.0	44.6
1&2	18	100.1	43.2
1&2	19	100.0	35.5
1&2	20	100.1	42.2
1&2	21	100.1	41
1&2	22	100.0	40.2
1&2	23	100.0	N/A
1&2	24	100.0	N/A
1&2	25	100.1	39.4
2/ 1.80	1	100.1	26.1
2	2	100.0	41.9
2	3	100.0	34.2
2	4	100.0	36.3
2	5	100.0	35.7
2	6	100.1	35.6
2	7	100.1	35.2
2	8	100.1	43.7
2	9	100.1	37.8
2	10	100.1	40

Table E 1 Continued

Set No./ Weight of Set (kg)	No. of Launderings	Amount of detergent (g)	Wash Temperature (°C)
1&2/1.74	11	100.0	44
1&2	12	100.0	36.7
1&2	13	100.1	40.3
1&2	14	100.0	43.1
1&2	15	100.0	44.6
1&2	16	100.1	43.2
1&2	17	100.0	35.5
1&2	18	100.1	42.2
1&2	19	100.1	41
1&2	20	100.0	40.2
1&2	21	100.0	N/A
1&2	22	100.0	N/A
1&2	23	100.1	39.4
2/1.76	24	100.1	N/A
2	25	100.0	N/A
3/2.06	1	100.1	41
3	2	100.0	37.8
3	3	100.0	43.7
3	4	100.0	N/A
3	5	100.0	N/A
3	6	100.0	45.6
3	7	100.1	44.3
3	8	100.1	38
3	9	100.0	46.9
3	10	100.0	40.2

Table E 1 Continued

Set No./ Weight of Set (kg)	No. of Launderings	Amount of detergent (g)	Wash Temperature (°C)
3	11	100.2	45
3	12	100.1	43.9
3	13	100.2	41.1
3	14	100.1	43.3
3	15	100.0	43.3
3	16	100.2	43.3
3	17	100.5	43.9
3	18	100.1	42.8
3	19	100.1	41.1
3	20	100.7	43.3
3	21	100.1	41.7
3	22	100.2	43.3
3	23	100.5	42.2
3	24	100.0	43.3
3	25	100.2	41.1