IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: M H Malik *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **507** 012001

IOP Conf. Series: Materials Science and Engineering **507** (2019) 012001 doi:10.1088/1757-899X/507/1/012001

Comparison of cut-resistance performance of gloves made from virgin and recycled Para-Aramid fibres

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Abstract. Application areas of high performance fibres are increasing day by day due to their superior physical, thermal and chemical properties. Para-aramid is one of these high-tech fibres which is extensively used for making technical textiles like cut-resistant gloves, cut-protective seat covers, and puncture-resistant fabrics, etc. As the use of this fibre has increased manifold, an attempt has been made to assess the performance of recycled fibres in comparison with the virgin fibres, by opening the para-aramid knitted fabric rags into fibrous state and convert the reclaimed fibres into yarn for making cut-resistant cost effective gloves. Four yarns, each of 70 tex, were spun on a DREF 3000 friction spinning machine. Two yarns were made from 100% virgin para-aramid fibres, the first one was the core-wrapped yarn consisting of a 50 micrometer steel wire in its core and the second one without it. The other two yarns were spun from a blend of 50% virgin and 50% recycled para-aramid fibres, one yarn with a 50 micrometer steel core while the other without it. The test results on the manufactured gloves from these yarns showed that the cut-resistance performance of the gloves made from 50:50 blend of virgin and recycled para-aramid fibres was comparable with the gloves made from virgin para-aramid fibres.

1. Introduction

Injuries at workplace can be caused by accidents, a growing number of which are due to improper or insufficient protection for workers. Industrial injuries can be caused by many reasons including mechanical failure, electronic failure, hazardous environmental conditions, faulty design of equipment, human failure, defective material, and poor working conditions [1]. Researchers have found that hands and fingers were most likely to get injured among body parts [2, 3]. Hands of workers are exposed to different types of dangers in various occupational fields like gardening, textiles, steel manufacturing, and glass furnaces, etc. Such dangers include burning, cutting, and rubbing, etc. of body parts. Majority of these hand injuries include puncture and cutting type lacerations [4]. Such injuries can be avoided if protective gloves are used [5]. Cut resistant protective gloves are used to protect the wearer's hands from cuts while working with sharp tools or edges in workplaces such as edible meat processing units, glass producing and processing works, and metal sheet processing plants, etc. [6]. Such gloves should have good grip ability and dexterity in addition to desired properties of tear strength and cut as well as abrasion resistance [7, 8]. The resistance to cutting is measured by cut resistance performance which has been classified into 5 categories by International Standards Organization [9]. Cut resistant gloves are made from different types of materials which are selected in different combinations to achieve certain level of cut resistance. Material selection cannot be done merely on the basis of tensile properties of materials which essentially show material's resilience towards pulling in lateral direction [10]. High strength materials, showing excellent properties against tensile loads, showed reduced strengths under traverse loads when loaders with sharpened contact edges were used [11]. Gloves made from latex give the lowest level of cut resistance whereas gloves made from metal mesh provide the best cut-resistant performance, but such gloves of metal mesh become heavy, uncomfortable, and possess poor dexterity. Therefore, attempts are made to make lighter and more comfortable gloves with better cut resistance performance. Recently, this objective has been achieved by using high performance materials such as para-aramids whose high strength to weight ratios resulted into strong yet light and comfortable gloves [12]. Para-aramids are about five times stronger than steel and gloves made from para-aramids give exceptional cut-resistance [12]. Para-aramids can also be used with reinforcement by steel wire or glass filaments. E-glass reinforced para-aramid gloves were found to be effective for cut protection under EN308:2003 [13].

Cut resistance is the material's ability of resisting damage or failure when an attempt to cut it is made by a moving sharp-edged object. Cutting, which involves sliding movement of a sharp edge against the subject material, is affected by friction between the two. Greater the work required to deform the material in transverse compression, higher will be the energy dissipated showing better cut resistance performance of the material [14]. Any increase in the coefficient of friction of the yarn changes the cut resistance of the material, depending on the thickness and the microstructure of the material to be cut [15]. Cut resistance can be improved by increasing areal density, or by using high-performance materials and composite yarns made with varying combination of materials [16, 17]. These methods can be used separately, or in combination, to improve cut resistance of textile materials.

Cut resistance performance of gloves and clothing can be measured by using two testing methods- EN388 applicable for European Union whereas ANSI/ISEA 105-2016 for American markets [18]. ASTM F1790 is based on the ANSI/ISEA procedure which uses TDM 100 machine in which straight edges with three different loads are slid against the fabric specimen to cut the specimen within 2-inch distance of movement, and then load for cutting at standard reference length of 25.4 mm (1 inch) is calculated by regression [19]. In EN388:2003 blade cut resistance method based on Coup Test, a circular blade with fixed 5N load is used to cut the glove specimen by moving back and forth on it. The number of cycles of blade to cut the fabric are noted; the higher the number of cycles, greater the cutting resistance. EN388 was revised in 2016 by combining both "Coup Test" and the "TDM-100 Test". The objective was to increase the accuracy of the testing instrument. In the new test a maximum limit of 60 cycles is fixed for coup test. If specimen is cut within this limit, TDM-100 test is skipped and result of Coup test is given mentioning skipping of the other test. On the other hand, if specimen does not cut within 60 cycles, then TDM-100 test becomes necessary and results are given accordingly. A two-year time allowance (up to 2018) was given to glove manufacturers selling in Europe to comply with the new EN388:2016 standard. The standard was revised to accommodate for the error induced by fabrics made of high performance yarns containing glass and steel which resulted into dulling of cutting edge.

Weight of the material, and different coatings applied to the outer surface, can also affect the performance characteristics. Lighter weight gloves are found to be more flexible, having better dexterity and result in less hand fatigue, whereas the heavier gloves generally provide better cut protection. Different materials have been used to improve cut resistance of the gloves. Nowadays, cut resistant gloves are made from different types of high performance composite yarns with various core and sheath combinations which give different levels of cut resistance performance. This study was done to evaluate the cut resistance performance of gloves made from virgin and recycled para-aramid fibres, and core-spun yarns made from stainless steel monofilament wire core. In addition, a comparison of gloves made from virgin and recycled para-aramid fibres was also made to evaluate the suitability of using recycled materials in order to address environmental aspects of using these materials.

The tensile properties and regularity of spun-yarns are influenced by length, strength, fineness and length uniformity of the constituent fibres [20-23]. To obtain the consistent quality of spun yarns, it is essential to have the minimum variation in the properties of the constituent fibres [24-26]. Two drawing frame passages are given to improve the regularity and uniformity of the material.

The production and use of plastics leaves bad impact on environment firstly because these are not easily biodegradable, and secondly because they consume about 8% of world oil and gas during production [27]. These impacts can be reduced by recycling of materials. Further, use of recycled materials also results into reduction in carbon dioxide emissions due to less need for new materials. Recycled materials have been in use for decades to cut down the costs in addition to protection of environment. Literature on use of recycled polymers for making cut-resistant gloves is scarce. In such a study use of recycled PPTA fibres with and without steel core gave better cut-resistant properties than virgin PPTA fibres probably due to higher coefficient of friction because of fibrillation during recycling process [28]. The present study was aimed at studying the possibilities of cost reduction by using blends of virgin and recycled para-aramid fibers and their effect on cut-resistance properties.

2. Materials and methods

In this study four types of yarns were made- yarns of virgin para-aramid (poly-p-phenylene terephthalamide or PPTA) fibres with and without steel core, and yarns of recycled para-aramid fibres of the same type mixed with virgin para-aramid fibres in the 50:50 ratios, with and without steel core. The core of stainless steel monofilament of 50 micrometer (micron) diameter was used for the study. All the yarns were spun on DREF 3000 friction spinning system. The recycled fibres for this study had been reclaimed by gently opening the knitted fabric rags using a textile recycling machine.

2.1. Raw material properties

The linear density, breaking strength, elongation at break and tenacity of stainless steel wire of thickness 50 microns were 139 deniers, 150 cN, 18.1% and 9.72 cN/tex respectively. The length, fineness, strength and elongation of virgin and recycled PPTA fibres were measured in the standard atmosphere in accordance with ISO 139:2005 following the test standards ISO 6989:1981, ISO 1973:1995 and ISO 5079:1995 respectively [29-32]. Physical properties of the fibres are summarized in table 1.

Table 1. Physical properties of para-aramid fibres.

Properties	Virgin PPTA Fibre	Recycled PPTA Fibre
Mean fibre length (mm)	46.05	35.50
Maximum fibre length (mm)	47.00	46.00
Minimum fibre length (mm)	43.00	16.00
CV %	2.34	27.05
Fibre fineness (tex)	0.25	0.25
Mean breaking force (cN)	35.74	21.94
Maximum breaking force (cN)	39.73	30.94
Minimum breaking force (cN)	31.91	15.22
CV %	6.69	20.03
Elongation at break (%)	17.68	11.96
Mean tenacity (cN/tex)	144.3	90.3
Maximum tenacity (cN/tex)	158.9	123.7
Minimum tenacity (cN/tex)	127.6	60.9
CV %	6.84	19.56

2.2. Pre-spinning processing

Virgin and recycled PPTA were processed separately in the blow room, carding section and drawing section of a textile spinning mill. The virgin PPTA was opened manually and fed to the blow-room line, which consisted of a bale-breaker, a transport fan, a fine opener, a metal detector, a transport fan and a chute feed system for feeding the smaller opened tufts in the form of a batt to the carding machines.

However, the recycled PPTA was first sprayed with antistatic oil in the ratio of 1.5% by weight of input material, and then thoroughly mixed by hand before feeding to the blow-room line. The virgin PPTA batt was carded at a rate of 24.25 kg/h, and sliver of 4.25 g/m (60 grain/yard) linear density was produced at a delivery rate of 100 m/min. On the other hand, recycled PPTA batt was carded at a rate of 16.95 kg/h and sliver of 4.25 g/m (60 grains/yard) linear density was produced at the delivery rate of 70 m/min. The carded slivers of virgin PPTA fibres were fed to the breaker drawing machine with a doubling of six slivers to obtain the breaker drawn sliver of 3.56 g/m (55 grain/yard) at the delivery speed of 335 m/min. The drawn slivers of virgin PPTA fibres were then fed to the finisher drawing machine with a doubling of six slivers to obtain the finisher drawn sliver of 2.91 g/m (45 grains/yard) at the delivery speed of 350 m/min. The blending of virgin and recycled PPTA fibres in 50:50 ratios was carried out on the breaker drawing machine having doubling of six slivers. The drawn sliver of linear density 3.56 g/m (55 grains/yard) was delivered at a speed of 335 m/min. A second passage of finisher drawing with doubling of six slivers was used to improve the blending and regularity within the material. The sliver of linear density 2.91 g/m (45 grains/yard) was drawn from finisher frame at a speed of 350 m/min.

2.3. Yarn spinning

Yarns from virgin PPTA and blend of virgin and recycled PPTA drawn slivers were spun with and without stainless steel monofilament core on DREF 3000 friction spinning machine. The linear density of each yarn was 70 tex (Ne 8.4). The first two types of yarns were made by using three finisher drawn slivers of virgin PPTA fibres as sheath, while the remaining two types of yarns were made by using three finisher drawn slivers of virgin and recycled PPTA fibres in 50:50 ratios. Each set of yarn types were further divided into two types based on existence or absence of monofilament stainless steel cores in addition to one sliver of same material as in sheath. The physical properties of the spun yarn were measured as per ISO 2062:2009 and ASTM D 3108-01 test methods and are given in table 2 [33, 34].

Table 2. Physical properties of yarns.

Material Composition	Physical Properties				
	Breaking Strength (cN)	**CV (%)**	**Elongation (%)**	**Tenacity (cN/tex)**	**Coefficient of Friction**
VPA[a]	998	8.69	6.06	14.26	0.233
RPA/VPA[b]	641	24.26	5.92	9.16	0.263
VPA+SC[c]	524	4.22	10.98	7.49	0.237
RPA/VPA+SC	417	12.76	5.85	5.96	0.277

[a] VPA = Virgin para-aramid
[b] RPA = Recycled para-aramid fibre
[c] SC = Steel core

2.4. Gloves manufacturing

Five pieces of gloves were made from each composite yarn on a 7-guage Shima Seiki gloves knitting machine. In each case the yarn feed rate and courses per unit length were kept constant to achieve the areal density of 285 g/m^2. Each glove had the size of 240mm x 100mm.

The methodology of the study can be expressed pictorially as below in 'figure 1'.

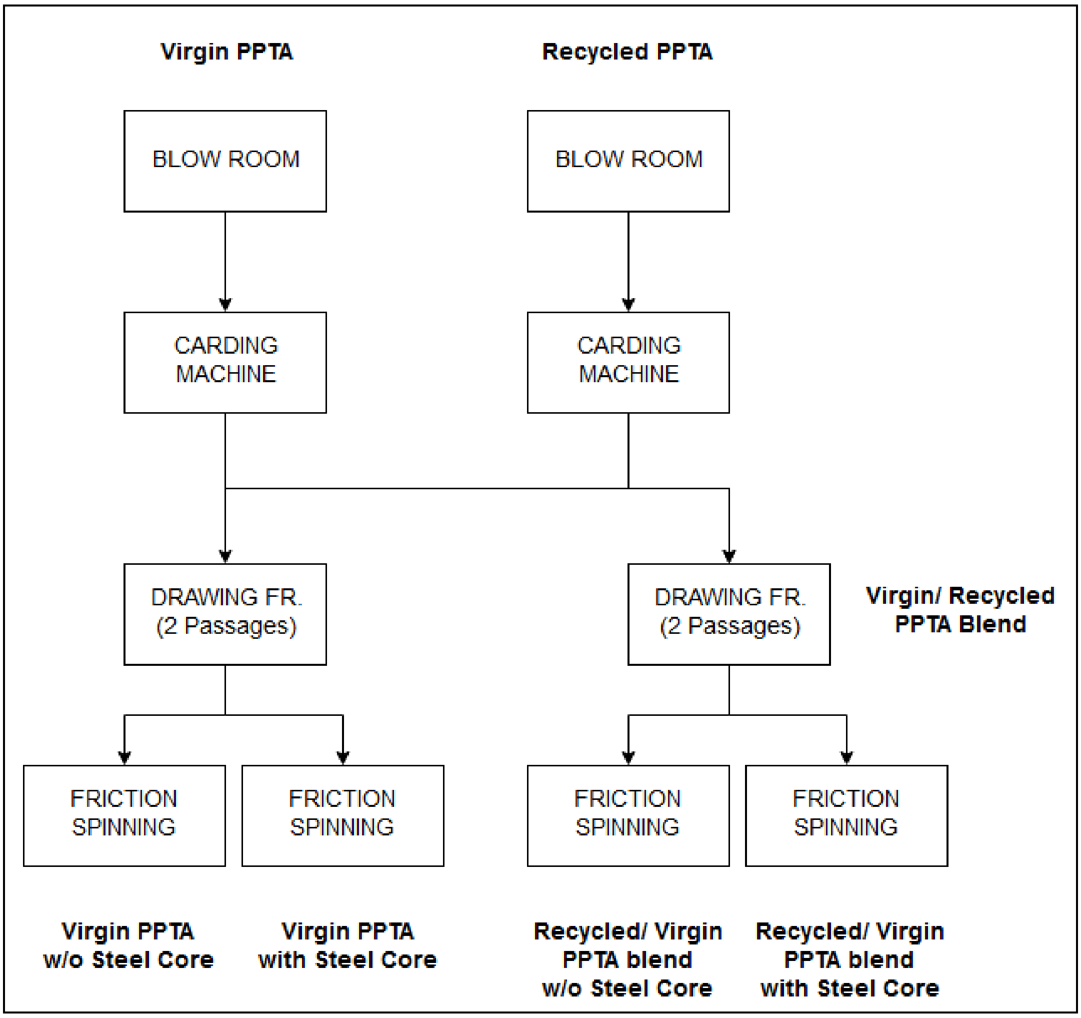

Figure 1. Flowchart of the study

3. Results and discussion

3.1. Physical properties of fibres and yarns

Physical properties of virgin and recycled materials were measured and compared for both fibre and yarn states. The physical properties of recycled fibres were poor as compared to virgin fibres (table 1), although maximum care had been taken during opening of knitted fabric rags on a textile recycling machine to avoid fibre breakage and loss of strength. In order to avoid fibre damage due to fibre lapping to rollers, anti-static oil was sprayed and atmosphere of the recycling department was controlled. Para-aramid fibres exhibited good fibre-to-fibre and fibre-to metal resistance. Nevertheless, the recycling process created fibrillation on the surface of reclaimed fibres (figure 2), compared to clear surface of virgin PPTA fibres shown in figure 3. The linear density remained unchanged in both cases.

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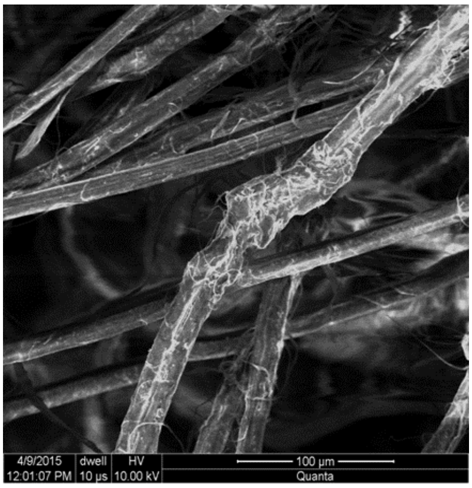

Figure 2. SEM image of recycled para-aramid fibre.

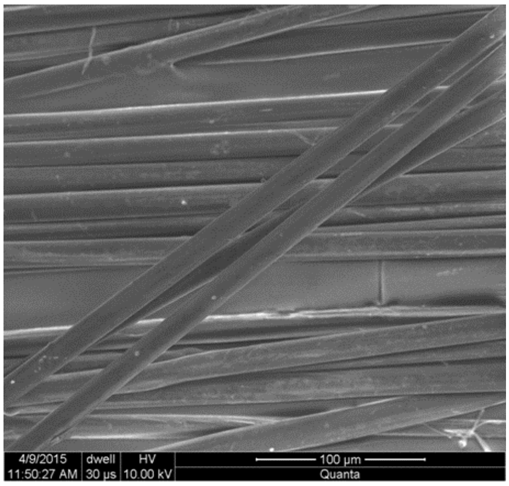

Figure 3. SEM image of virgin para-aramid fibre.

Tensile properties of yarns made from blend of recycled and virgin PPTA fibres in 50:50 ratios were considerably poor as compared to yarns made from virgin PPTA fibres due to inferior properties of recycled PPTA fibres. That showed the direct linear relationship between tensile properties of yarns and fibre length and tensile properties of their constituent fibres.

When a steel wire of 50 microns was used as a core of 70 tex yarns spun from a blend of recycled/virgin and virgin fibres, the tensile properties of composite yarns deteriorated as compared to the yarns of the same composition but without steel core due to low tenacity (9.72 cN) of steel wire in comparison with high tenacities of virgin and recycled PPTA fibres. Another factor for this decrease was use of 22% w/w of steel wire in the composite yarn. The coefficient of friction of yarns made from partly recycled fibres was higher due to presence of fibrils on the surface of these fibres. The protruding fibrils offered higher friction to metal during testing (table 2).

3.2. Glove cut resistance

In this research work, EN 388:2003 test method was used to measure the cut resistance performance of gloves as it was still valid and condition of the cutting blade was taken special care of. Another care was to ensure proper cutting of gloves fabric having yarns with stainless steel cores. In this method a circular blade with fixed load of 500g/5N was moved to and fro to cut the material. The number of cycles to cut the material is counted. The sharpness of the blade is checked before and after every test by using a standard reference fabric of cotton. The test is repeated five times to get the highest value of cut resistance index “I” which is calculated using equation (1).

$$I = \frac{(C + T)}{C} \tag{1}$$

Where “C” is the cut resistance of reference fabric and “T” is the cut resistance of testing specimen. Higher index values show better cut resistance performance of the material. Cut performance level ranging from 0 to 5 is then calculated based on average cut resistance index value as shown in table 3.

Table 3. Cut Performance Level

Cut Resistance Index	Cut Performance Level
20.0	5
10.0	4
5.0	3
2.5	2
1.2	1
<1.2	0

Higher cut performance level shows more resistance to cutting, which is desirable for protective gloves.

Further studies using updated testing method are expected by researchers in future. Mean values of cut indices and performance level of each sample are given in table 4.

Table 4. Cut performance of gloves.

Material Composition	Cut Index (lengthwise)	CV (%)	Cut Performance Level	Cut Index (Widthwise)	CV (%)	Cut Performance Level
VPA	2.78	2.27	2	3.53	6.28	2
RPA/VPA	3.07	2.18	2	4.02	3.73	2
VPA+SC	2.82	2.62	2	3.79	7.94	2
RPA/VPA+SC	3.47	5.28	2	5.90	7.79	3

The mean cut index values along the length and width of glove samples were in the range of 2.78-3.47 and 3.53 – 5.90 respectively. The cut performance of all samples in length and width directions was of level 2 except one, where the glove made from recycled/virgin fibres with steel wire core showed a mean cut index of 5.9 along the width corresponding to cut performance level 3.

High level of coefficient of variation of cut indices in both directions for yarns using stainless steel cores, perhaps, showed the insignificance of using that core, may be due to slippage between core and wrapping fibres.

In general, the performance of all glove samples made from virgin or recycled/virgin fibres either with or without steel core in yarns fall in the cut performance level 2, which shows that cost effective cut-resistance gloves of same performance level can successfully be made from recycled para-aramid fibres instead of expensive virgin para-aramid fibres. This result is also not against a recent study conducted by Awais et al. [28]. Moreover, the usage of steel core could not result into any significant improvement in blade cut resistance of gloves. Higher cut performance levels can be achieved either by increasing the weight of gloves using coarser yarns or placing glass yarn in the core of yarn instead of steel wire.

4. Conclusion

Cost effective cut-resistant gloves can be manufactured by using friction-spun yarns consisting of recycled para-aramid fibres. However, recycling process should be gentle to avoid fibre length breakage which reduces the tensile properties of the yarns and may cause lower efficiency in the knitting process. The recycled process created fibrils on the surface of fibres which seem to be favorable to the cutting resistance of the knitted gloves. The movement of the fibrils with the moving blade dissipates a part of the cutting energy in friction resulting in enhanced cut index. Further the mobility of fibres and yarn improves the cut performance level of knitted structures. The use of steel core in making the yarns could not show justification due to high levels of variation within readings probably due to slippage between core and sheath materials. In fact, the use of monofilament core becomes questionable as a result of this study.

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