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To cite this article: L Markoviová and V Zatkalíková 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **465** 012004

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The effect of UV aging on structural polymers

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Abstract. Polymer composites, their composition, and their properties are the major causes of their application as a construction material. Last century composites with polymer matrix were considered as the most perspective constructional material. Previous researches have only focused on mechanical characteristics of polymer composites but it is also important to observe their mechanical properties before and after UV radiation [1, 2]. The aim of this study is to analyse the change in mechanical properties which are influenced by UV radiation. It was decided that the optimal method for this investigation was to accelerate ageing in UV box. The test samples were evaluated by the selected mechanical parameters - tensile strength, three-point bend, hardness, Vicat temperature. The same parameters were assessed before and after 500 hours UV radiation. These results extend our knowledge of polymer composites and their behaviour before and after UV radiation. This work shown UV radiation has significant influence on the change of selective mechanical properties. Current polymer composites are sensitive to UV radiation which minimize their mechanical properties which change due to partial cross-linking of the matrix and crack at the interface of the matrix and reinforcement.

1. Introduction

Polymeric construction materials are currently developing tremendously and are used in almost all industries. Due to their price, properties, production and processing technologies, more and more classic materials (metals, wood, ceramics, glass, etc.) are replaced. Despite the fact that the use of plastics in various industries is beneficial in terms of energy (their production is less energy-consuming, saving energy resources), environmental (reducing the amount of air pollutants) and economic (saving the raw material resources) we not forget the fact that also polymeric materials become significant waste [3]. Many of them, in degradation processes, release low-molecular compounds that can be harmful to health or endanger the environment. It is therefore important to know the properties of plastics in various degradation environments. In this case we are talking about aging plastics [4].

Polymer aging is the sum of the irreversible changes in the polymer properties of light, sun, ambient air, oxygen, radiation, and heat. Often, many agents act together and the overall effect of aging is more pronounced. Aging is manifested by permanent changes in some properties, in particular loss of ductility, impact strength, sometimes by decreasing strength and loss of polymer mass. In Table 1, there are the basic definitions of terms in the field of aging of polymers [5-6].



Table 1. Selected definitions of the aging of polymers.

Natural aging	Aging of polymers through the environment when stored or in use
Artificial aging	Aging of polymers in artificially created conditions
Climate aging	Aging of polymers due to climatic conditions of a given earth band
Biological aging	Aging of polymers through the action of living organisms that are in contact with them
Mechanical aging	Aging of polymers due to long-term static or dynamic loads
Thermal aging	Aging of polymers through heat
Thermo-oxidative aging	Aging of polymers by the effect of heat in the presence of oxygen
Oxidation aging	Aging of Polymers by Oxygen
Ozone aging	Aging of polymers by ozone
Light aging	Aging of polymers through the visible and ultraviolet portion of the light spectrum
Photooxidation aging	Aging of polymers by the effect of visible and ultraviolet light spectrum in the presence of oxygen
Chemical aging	Aging of polymers by chemically aggressive substances

If polymers are exposed to weathering, we can observe changes in appearance and changes in physical properties after a while. This aging is a result of the relatively long-lasting effect of solar radiation, temperature, oxygen, humidity, ozone, atmospheric impurities. Photochemical destruction and photochemically activated oxidation of macromolecules are considered the main cause of the change. However, the experimental results obtained are very dependent on the climate from which the samples are subjected, the slope of the sample to the sun, the color and the quality of the substrate material on which the samples are laid, the sample preparation conditions, so it is rather difficult to choose a unit to compare the measurement results in samples exposed to weather conditions. A comprehensive approach to solving the problem is to monitor the effect of all factors that are considered in the atmospheric environment to change the physical properties of the polymers individually but also their combinations [7-8].

2. Experimental material and methods

The choice of materials was focused on thermoplastics, which are widely used mainly in the automotive industry. These are in particular composites based on polyamides with filler. As the experimental material on the matrix polyamide 66 (PA 66) was added with polyimide addition. The PA 66 business designation Durethan is intended for injection molding. It is a partially crystalline polymer, characterized by a combination of properties particularly suited for technical applications. High mechanical strength and stiffness is combined with good electro-insulating properties, high thermal and chemical resistance, good weathering and low friction. It dampens shock and noise well. Test samples with the designation PA 66 GF 10, PA 66 GF 20, PA 66 GF 30 differed in glass fiber (GF) content (10 %, 20 % and 30% GF, % = vol. %). The glass fibers coded GF 672 with diameter 10 µm and length 4 mm. The composites are estimated for interior and exterior details of cars, then it is expected their UV stability. The matrix includes also UV stabilizer. The structures of the tested composites were observed by light microscope. We monitored homogeneity of the composite and the manner of distribution of glass fibres in the polymer matrix. The filler content of 10 %, the structure more evenly - glass fibers are evenly distributed in the polymer matrix. Fiber size was also about the same. To 20 % filler content sites began to appear smaller clusters of glass fibers and emptier place in the matrix. Size fiberglass was also maintained at the approximate size. At 30 % filler content the structure of the least uniform. Fiberglass seats were piled on each other. Processing technology will brake the fibers into smaller pieces, so the material was located fibers of different sizes. Different size glass fiber in a polymer matrix was dependent on its percentage (Figure 1) [9].

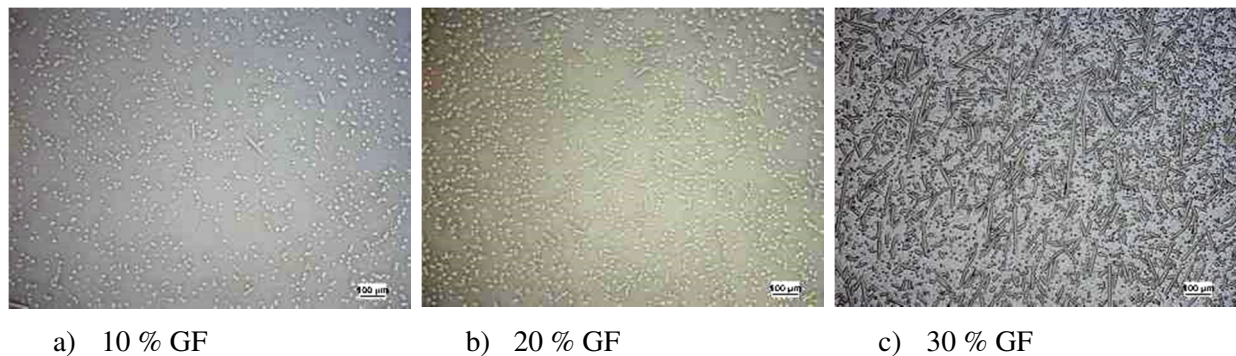


Figure 1. Structure of composite.

Testing degradation of polymeric materials is one of the most important tests to the lifetime of polymer product. Ageing tests can be either in real conditions of use of the polymer in a particular application, or using artificial accelerated ageing conditions. Accelerated ageing methods provide test results significantly faster natural aging tests. Testing is based on exposing test bars to man-made climate. After a fixed interval of exposure changes are detected in end points (aesthetic, physical, electrical, etc.). The apparatus for man-made weather ageing ensure continued maintaining of artificial climatic conditions (day and night cycles, changing humidity, drought and wet, etc.). The apparatus SolarBox 1500e (Figure 2) which was used in the experiment has the following characteristics: a source of light radiation guarantees a radiant flux of radiation intensity 550 W.m^{-2} . The source of light is a xenon arc lamp, but other sources of radiation are allowed too. The device must be equipped with a thermometer built into the black panel, which senses the temperature of the black panel. The black panel temperature of exposure time was selected at 100°C the liquid phase lasted for 102 minutes and the wet phase for 18 minutes. If it necessary wetting by distilled or deionised water can be applied. Test runs continued for a period fixed in the testing program. The duration of the test was 500 hours [10].



Figure 2. SolarBox 1500e.

The test samples were evaluated by the selected mechanical parameters (tensile strength, bending strength - three-point bend, hardness - Brinell, Vicat temperature) before and after UV radiation. The parameters were assessed after 1 run, 500 hours of UV radiation acting on the sample.

3. Experimental results and discussion

A tensile test was performed using the device WDW 20. The speed of a moving jaw was set at $1 \text{ mm} \cdot \text{min}^{-1}$. The sample was pinned to the jaw and force was exercised in the longitudinal axis until the sample break. We measured the maximum force required to break the test samples. Figure 3 shows that the highest tensile strength of the composite is reached with 30 % glass fiber content on the other hand the smallest tensile strength composite with a filler content of 10 %. It follows that the strength characteristics of the composite depends mainly on the content and distribution of the glass fibers in the polymer matrix. UV radiation is the strength values did not change significantly. Since a partially crystalline PA, stroke causes the chains straighten it, undergoing its subsequent solidification.

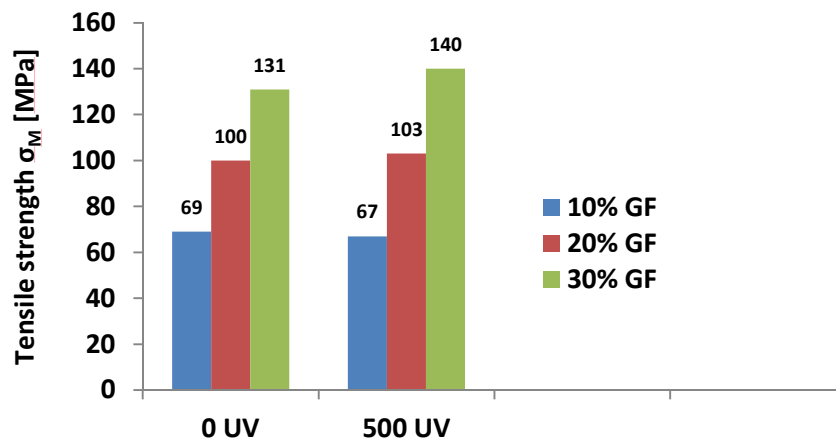


Figure 3. Effect of UV radiation on the change of tensile strength.

A bend test was also performed using the device WDW 20 with the aid of three-point bending. The sample is put on two supports placed, 40 mm away from each other. Burden was applied in the middle of the sample bar to exercise some force. Print speed was also one arm $1 \text{ mm} \cdot \text{min}^{-1}$. Peak force was recorded during the test. The test results are indicated in Figure 4.

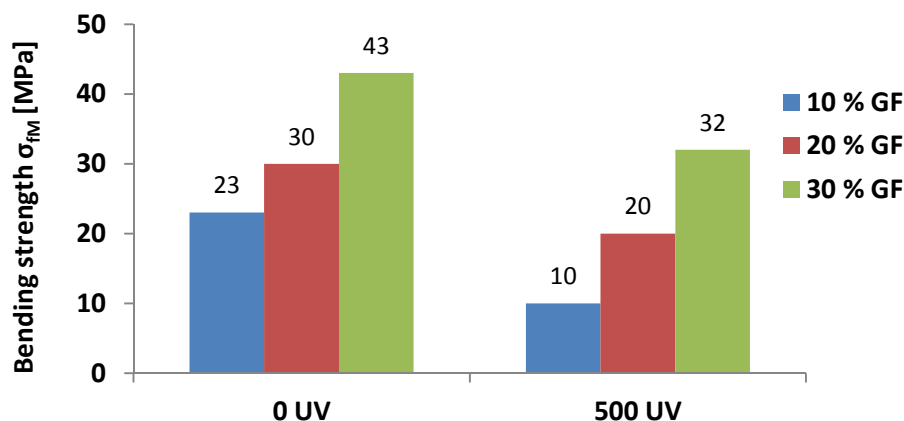


Figure 4. Effect of UV radiation on the change of bending strength.

The highest bending strength of the composite is reached with 30 % glass fiber content on the other hand the smallest bending strength composite with a filler content of 10 %. It follows that the strength characteristics of the composite depends mainly on the content and distribution of the glass fibers in the polymer matrix. Composite specimens showed a significant decrease in the values of the bending strength after 500 hours of UV irradiation. The bending strength decreased by more than 50 % compared to the bending strength that was measured in samples without UV irradiation. Composites are becoming significantly fragile.

Hardness (HBW) test was conducted durometer CV-3000 LDB. Loading force was set to 250 kp, injection time was 10 seconds and the indentation diameter balls of 5 mm. Each sample was made 5 measurements. The final hardness is shown in Figure 5.

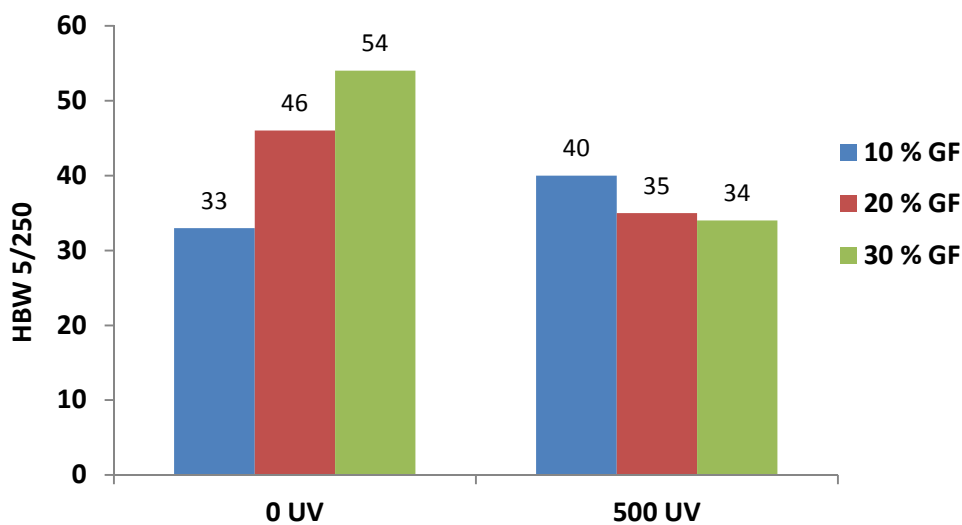


Figure 5 Effect of UV radiation on the change of Brinell hardness

The Vicat softening temperature is the temperature at which a flat-ended needle penetrates the specimen to the depth of 1 mm under a specific load. The temperature reflects the point of softening to be expected when a material is used in an elevated temperature application. The test specimen must be between 3 and 6.5 mm thick and at least 10 mm in width and length. Of each sample were made three measurements and are determined by the final arithmetic value (Table 2).

Table 2. Vicat temperature

Filler content	Vicat temperature [°C]	
	0 UV	500 UV
10 %	231	234
20 %	240	241
30 %	242	243

4. Conclusions

Based on the experiments performed on composite PA 66 with different content of the filler (GF) we can conclude:

- UV radiation has negligible influence on tensile strength values. Tensile strengths have only slightly decreased after exposure to UV radiation (500 hours).
- The bending strength of the composite depends mainly on the content and distribution of the glass fibers in the polymer matrix. Composite specimens showed a significant decrease

in the values of the bending strength after the 500 hours of UV irradiation. The bending strength decreased by more than 50 % compared to the bending strength that was measured in samples without UV irradiation. Composites are becoming significantly fragile.

- By measuring the Brinell hardness of the material is confirmed that the increasing volume of glass fibers increases the hardness, the UV light had almost no effect on its value.
- The softening point of the composite increases with the content of glass fibers. UV radiation has had no significant impact on softening point, there was only a slight change in the material properties. The biggest change in the softening point was the composite containing 10 % filler wherein the temperature is increased from 231 °C to 243 °C. This may be caused by changes in the structure.
- Materials selected to test mechanical properties are characterized by properties such as stiffness, tensile strength, bending strength, and toughness. Under the influence of the degradation environment, the properties under consideration have changed only minimally, and their use in the consumer and automotive industries has little effect on their utility value.

Acknowledgement

The research was supported partially by Slovak Academy of Science grant KEGA No. 049ŽU-4/2017.

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