Effect of UV Radiation to Change the Properties of the Composite PA+GF

Lenka Markovičová, Viera Zatkalíková, Tomasz Garbacz

Abstract—The development of composite materials and the related design and manufacturing technologies is one of the most important advances in the history of materials. Composites are multifunctional materials having unprecedented mechanical and physical properties that can be tailored to meet the requirements of a particular application. Some composites also exhibit great resistance to high-temperature corrosion, oxidation, and wear. Polymers are widely used indoors and outdoors, therefore they are exposed to a chemical environment which may include atmospheric oxygen, acidic fumes, acidic rain, moisture heat and thermal shock, ultra-violet light, high energy radiation, etc. Different polymers are affected differently by these factors even though the amorphous polymers are more sensitive. Ageing is also important and it is defined as the process of deterioration of engineering materials resulting from the combined effects of atmospheric radiation, heat, oxygen, water, micro-organisms and other atmospheric factors.

Keywords—Composites with glass fibres, mechanical properties, polyamides, UV degradation.

I. INTRODUCTION

A composite material is a macroscopic combination of two or more distinct materials, having a recognizable interface between them. Composites are used not only for their structural properties, but also for electrical, thermal, tribological, and environmental applications. Modern composite materials are usually optimized to achieve a particular balance of properties for a given range of applications.

Composites are commonly classified at two distinct levels. The first level of classification is usually made with respect to the matrix constituent. The major composites classes include organic-matrix composites (OMCs), metal-matrix composites (MMCs), and ceramic-matrix composites (CMCs). The term organic-matrix composite is generally assumed to include two classes of composites: polymer-matrix composites (PMCs) and carbon-matrix composites (commonly referred to as carbon-carbon composites). Carbon-matrix composites are typically formed from PMCs by including the extra steps of carbonising and densifying the original polymer matrix.

The second level of classification refers to the reinforcement form-particulate reinforcements, whisker reinforcements, continuous fibre laminated composites, and

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woven composites (braided and knitted fibre architectures are included in this category), as depicted in Fig. 1.
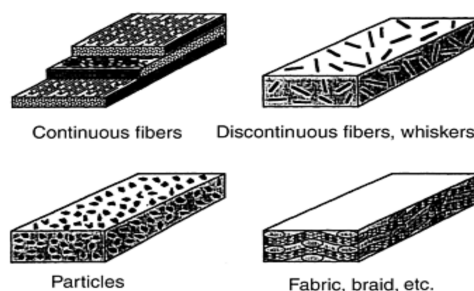

Fig. 1 Common forms of fibre reinforcement

The purpose of the matrix is to bind the reinforcement together by virtue of its cohesive and adhesive characteristic, to transfer load to and between reinforcements, and to protect the reinforcements from environments and handling. The matrix also provides a solid form to the composite, which aids handling during manufacture and is typically required in a finished part. This is particularly necessary in discontinuously reinforced composites, because the reinforcements are not of sufficient length to provide a handleable form. Because the reinforcements are typically stronger and stiffer, the matrix is often the weak link in the composite, from a structural perspective [1].

Organic matrices for commercial applications include thermoplastics (PP, PA, PAI, PEI, etc.) thermosets (PES, vinyl ester resins, epoxy resins, etc.). Polyamide (PA) is generally known as nylon. This is a collection of polymers, which differ in chain structure, and which are, according to the numbers of consecutive C-atoms in the chain, designated as PA-6, PA-6,6, PA-11, PA-4,6 and PA-12. Polyamides are crystalline polymers with relatively high melting points (200-300°C). They possess a good impact strength due to the fact that they absorb several per cents of water from the atmosphere. Moreover, a good abrasion resistance and a low friction make them suitable for the technical use, such as in bearings and gear wheels. Polyamides are quite often reinforced with short glass fibres to improve their stiffness [2].

The principal purpose of the reinforcements is to provide superior levels of strength and stiffness to the composite. In a continuous fibre - reinforced composite, the fibres provide virtually all of the strength and stiffness. Even in particle-reinforced composites, significant improvements are obtained. The most commonly used reinforcing fibres are: glass fibres, boron fibres, carbon fibres aramid fibres, other organic fibres, silicon carbide monofilaments [3].

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Glass fibres are among the most versatile industrial materials known today. They are readily produced from raw materials, which are available in virtually unlimited supply [4]. All glass fibres are derived from compositions containing silica. They exhibit useful bulk properties such as hardness, transparency, resistance to chemical attack, stability, and inertness, as well as desirable fibre properties such as strength, flexibility, and stiffness [5]. Glass fibres are used in the manufacture of structural composites, printed circuit boards and a wide range of special-purpose products [6]. Glass fibres fall into two categories, low-cost general-purpose fibres and premium special-purpose products. Over 90% of all glass fibres are general-purpose products. These fibres are known by the designation E-glass and are subjected to ASTM specification [7]. The remaining glass fibres are premium special - purpose products. Many, like E-glass, have letter designations implying special properties [8], [9]. Some have trade names, but not all are subject to ASTM specifications. Table I presents the designation of selected glass fibres

TABLE I
DESIGNATION OF GLASS FIBRES

Letter designation	Property or characteristic
E, electrical	Low electrical conductivity
S, strength	High strength
C, chemical	High chemical durability
M, modulus	High stiffness
A, alkali	High alkali or soda lime glass
D, dielectric	Low dielectric constant

II. MATERIALS AND METHODS

A. Experimental Material

As experimental material was used composite formed polymer matrix (PA) and filler – glass fibres. Glass fibre has a production label GF 672, fibre diameter is 10 μm and fibre length is 4 mm. The test composite contains 10% glass fibre (lable PA+10GF). This is a modern material that will be used in automobile interior and exterior. The composition should be resistant to UV radiation due to the addition of UV stabilisers. All test specimens were prepared by injection moulding technology.

B. UV Degradation

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 (Fig. 2) ensure continued maintaining of artificial climatic conditions (day and night cycles, changing humidity, drought and wet, etc.)

Fig. 2 SolarBox 1500 E with flooding

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 65°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. The numbers of man-made climate factors that simultaneously affect the test bars is selected by the test program. Test runs continued for a period fixed in the testing program. The duration of the test was 500, 750 and 1000 hours.

C. Evaluation of Mechanical Properties and Structure

The test samples were evaluated by the selected mechanical parameters (tensile strength and flexural strength) regarding the effects of UV radiation. The same parameters were assessed after 3 runs (500, 750 and 1000 hours) of UV radiation acting on the sample. The test also included evaluation of the structure and changes in the structure before and after UV irradiation.

Samples for the structure test were embedded in Bakelite in the first step and then cut and polished. Grinding of the samples was carried out using the device Struers Tegra Pol-15 under a program designed for polyamides. SiC abrasive paper with grain size 500, 1 200 and 4 000 was used for grinding. Each grit sandpaper was used to grind the sample for 1 minute. Grinding was followed by polishing using Mol plate for 3 minutes. This was followed by 2 minute polishing with Nap-B, and finally polishing was finalized using wet disc and Chem-OP-S (diamond slurry) for 1 minute. The samples prepared in the above-mentioned way were evaluated for structure changes by light microscope Neophot 32.

III. RESULTS AND DISCUSSION

The effect of UV radiation on the sample of the composite was evaluated by visual inspection of the changes in the surface quality of the samples before and after UV irradiation. Table II shows changes in the colour-fastness of the samples after UV irradiation.

UV radiation causes a change in the colour-fastness of the material. Examples of his change were assessed by a visual inspection. We did not determine the degree of discolouration

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the sample continued to be used for testing its mechanical properties. Photograps show that the most significant discolouration occurred after 1000 hours of UV irradiation.

TABLE II
DISCOLOURATION OF THE SAMPLES AFTER UV IRRADIATION

PA+10GF	
Without UV radiation	
After UV ageing for 500 hours	
After UV ageing for 750 hours	
After UV ageing for 1000 hours	

A tensile test was performed using the device WDW 20. The speed of a moving jaw was set at 1 mm.min^{-1} with. 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. From the acquired data, we calculated the tensile strength, σ_M (Fig. 3).
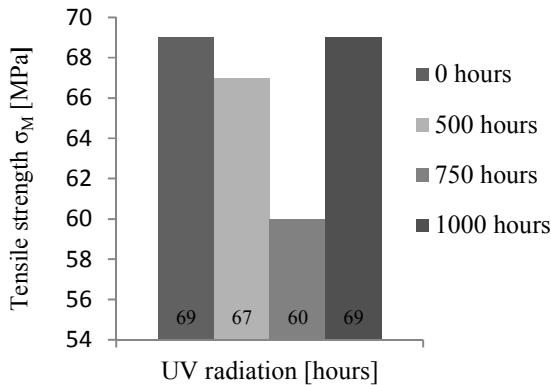

Fig. 3 Effect of UV radiation on the change in tensile strength

Fig. 4 shows that UV radiation slightly decreased the tensile strength. The most significant decrease in the observed values was recorded at the 750 –hour exposure to UV radiation. on values obtained at testing a specimen exposed 750 hours to UV radiation. After 1000 hours of exposure to UV radiation the tensile strength slightly increased again, which was probably due to partial cross-linking of the polymer matrix.

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 mm.min^{-1}. Peak force was recorded during the test. The test results are indicated in Fig. 4.

Composite specimens PC+10GF showed a significant decrease in the values of the flexural strength after the shortest-minimum period of UV irradiation (500 hours). The f flexural strength decreased by more than 50 % compared to the flexural strength that was measured in samples without UV irradiation. Composites are becoming significantly fragile. Changes in the flexural strength were considerably extensive

after the longer periods (750 to 1000 hours) exposure to UV irradiation.
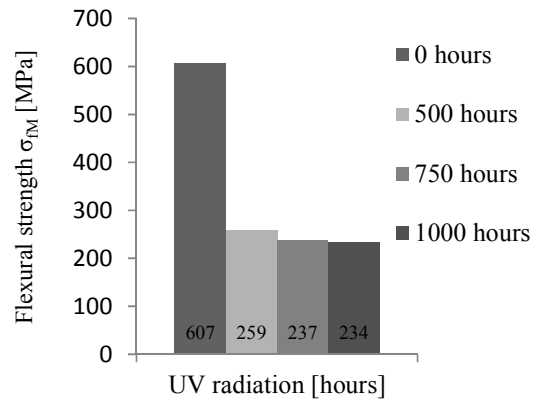

Fig. 4 Effect of UV radiation on the change in flexural strength

The experiment also included evaluation of the structure of the composite PA+10GF before and after UV irradiation by a light microscope. We monitored homogeneity of the composite, the manner of distribution of glass fibres in the polymer matrix, and cracking caused by UV radiation.

Based on the structural analysis, we can conclude that the distribution of the in the matrix is uniform in the filler content of 10% (Fig. 5).

(a) without UV

(b) 500 hours UV

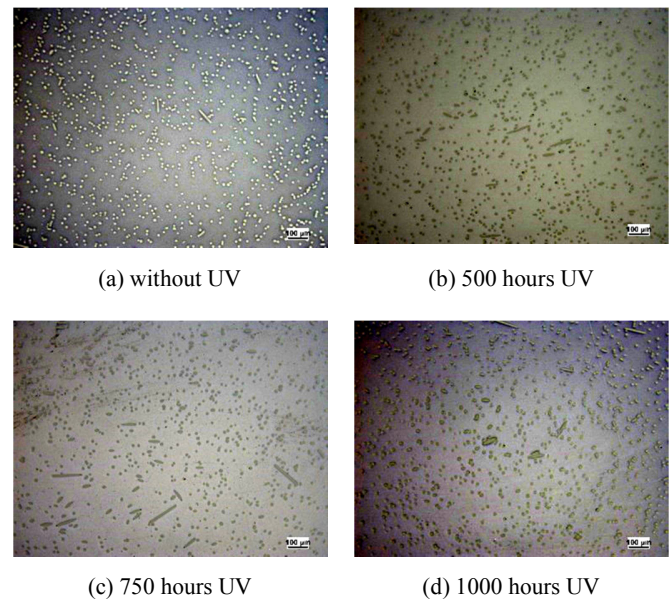(c) 750 hours UV

(d) 1000 hours UV

Fig. 5 Distribution of the filler in the polymer matrix-middle, 100x

Uniform distribution of the filler in the matrix was observed in the central portion of the sample. Towards the periphery of the sample the filler was unevenly distributed, and we observed increased density of the filler (Fig. 6).
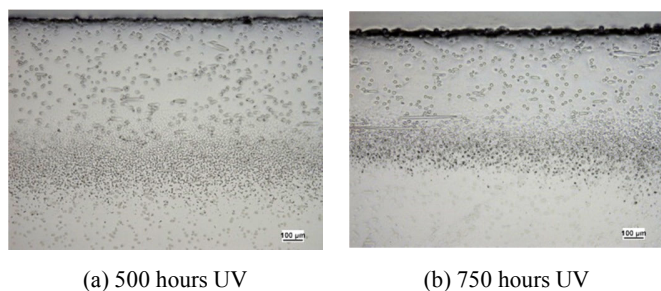
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[3] A. Swiatek et al., Distribution and geometric characteristic of pores and the strength properties of extrudates obtained by the twin-screw extrusion, *in Material science*, 2014, vol. 49, p. 812-818.
[4] High Performance Composites Source Book 2001, Ray Publishing.
[5] K. L. Loewenstein, The Manufacturing Technology of Continuous Glass Fibers, 3rd revised ed., Elsevier, 1993.
[6] F. T. Wallenberger, Structural Silicate and Silica Glass Fibers, in *Advanced Inorganic Fibers Processes, Structures, Properties, Applications,* F.T. Wallenberger, Ed., Kluwer Academic Publishers, 1999, p 129–168.
[7] F. T. Wallenberger, Melt Viscosity and Modulus of Bulk Glasses and Fibers: Challenges for the Next Decade, in *Present State and Future Prospects of Glass Science and Technology*, Proc. of the Norbert Kreidl Symposium (Triesenberg, Liechtenstein), 1994, p 63–78.
[8] "Standard Specification for Glass Fiber Strands", D 578-98, *Annual Book of ASTM Standards*, ASTM.
[9] P. K. Gupta, Glass Fibers for Composite Materials, *Fibre Reinforcements for Composite Materials*, A.R. Bunsell Ed., Elsevier Publishers, 1988, p 19–72.

(a) 500 hours UV   (b) 750 hours UV

Fig. 6 Distribution of the filler in the polymer matrix-edge, 100x

(a) without UV   (b) 500 hrs UV
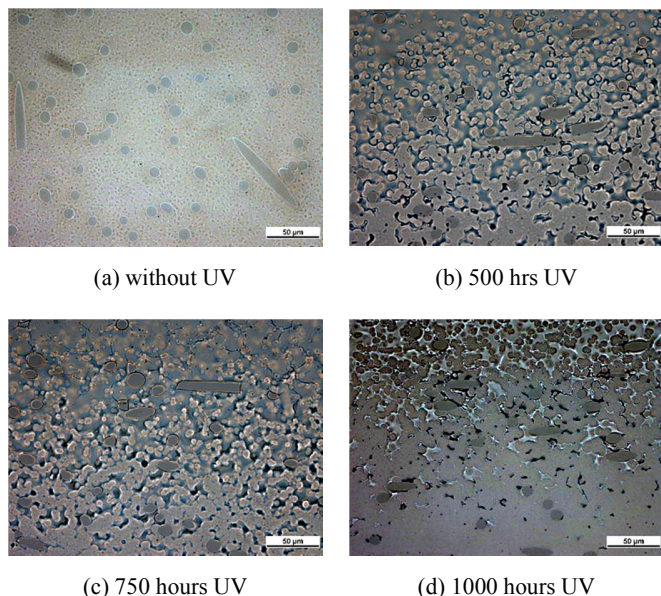
(c) 750 hours UV   (d) 1000 hours UV

Fig. 7 The change in the matrix and the presence of cracks after UV irradiation, 500x

UV radiation is an intense degradation factors affecting the change in the structure of polymers. As can be seen in Fig. 7 even a minimum duration of UV irradiation significantly changes the nature of the observed sample areas. The polymer matrix begins to degrade by UV radiation gradually. The polymer matrix is separated from the glass fiber. The polymer matrix-fibre interface exhibits low adhesion, which is needed in the future to support the addition of the adhesive. UV radiation created cracks in the composite, which is spread in the direction of the glass fibre in the polymer matrix.

ACKNOWLEDGMENT

REFERENCES

[1] C. Zweben, Mechanical Engineer's Handbook, Composite Materials and Mechanical, 2nd ed., John Wiley & Sons, Inc., New York, 1998.
[2] A. K. van der Vegt: From polymers to plastics, DUP Blue Print 2002, p. 240.