Evaluation of mechanical properties of glass fibers chopped strands mat composite subjected to UV degradation

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Abstract. The paper focuses on the evaluation of physical and mechanical features of ageing glass fibers chopped strands reinforced polymeric composite, denoted MAT300. First, the samples were analyzed with chroma meter in order to determine the coefficients of color change. Then, the control samples were subjected to three points bending since the other samples were exposed to ultraviolet radiation UV-A radiation for 216 hours. After ageing, the color parameters were measured and the bending test was performed in the laboratory of the Department of Mechanical Engineering at the Transylvania University of Brașov, on the LS100 Lloyd’s Instruments type test machine. Results showed the characteristic curves of the fibers glass chopped strands MAT samples, the values of the modulus of longitudinal elasticity, the strain and the breaking stress. Also, the color parameters (lightness, greenness and yellowness scale) were measured, both before and after test, in the rupture zone, considering that the sample break is accompanied by the delamination of the fiber and matrix layers.

1. Introduction

The advantage of glass fiber reinforced plastic in comparison with other materials, are the specific strength (the strength to weight ratio σ/ρ), specific stiffness or specific modulus (the stiffness to weight ratio E/ρ) and tailored material [1]. But, during life conditions, the composite structures are subjected to environmental factors: variations in humidity, temperature, UV radiations, chemical and biological agents which lead to mechanical properties modification of them. Exposure to ultraviolet radiations triggers changes in the chemical structure on the surface of the composite, a phenomenon known as photolysis. Similarly, free radicals are formed in the polymer by the dissociation of the C-H ties in the polymer chains [2, 3]. These chemical reactions lead to a material fragility and micro-cracking of its matrix at the interface with the fibers [4]. From a mechanical point of view, the exposure to UV radiation can produce, on the one hand, the change in elastic characteristics, and on the other hand the appearance of stress concentrators on the surface of the polymeric material (which can lead to its premature failure) [5]. Concomitant exposure to UV radiation and to temperature changes accelerates the degradation processes which occur in GFRP, such as oxidation, chemical attack, degradation of the morphological characteristics of the surface, cutting down on mechanical properties and reducing the occurrence of the creep [6, 7]. In previous studies, the authors investigated the mechanical properties of glass fibers chopped strand mat composites subjected to tensile and bending [8, 9]. This study deals
with evaluation of mechanical and physical properties of glass fibers chopped strand mat subjected to UVA radiation (365 nm), for 216 hours.

2. Experimental set-up

2.1. Experimental method
The experimental investigation consists of bending tests of control samples and UV exposed samples. The mechanical tests were performed on universal testing machine LS100 Lloyd’s Instrument belonging to the Mechanical Engineering Department of Transylvania University of Brasov. The specimens were loading with a constant speed of 1 mm/min until breaking. For data acquisition, the Nexygen Plus software was used.

A part of samples were used as control samples and the other part were used for ageing by UV-A radiation (wavelength $\lambda = 365$ nm) exposed for 216 hours. Also, the color changes (in terms of lightness $L$; redness $a^*$ and yellowness $b^*$) was measured before and after ageing, and also before and after mechanical tests with aim to emphasize the surface modification of composites in different stage of degradation (physical/mechanical). The used device for color changes was Chroma Meter CR-400. The CIE $L^*a^*b^*$ color scale (Commission International de l’Eclairage, 1976) was used to quantify the changes on color produced by UV radiation of glass fibers chopped strand mat composite. The overall color change of composite surface was calculated using the relation (1), where $E^*$ represent the overall color change; index 0 – the values of control samples; UV – the values after ageing [9]:

$$
\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}
$$

2.2. Materials
The composite material analyzed in this study consists of six layers of glass fibers chopped strands Mat 300 g/m$^2$ reinforcement and polyester resin of the APROPOL M 105 TA. The mechanical properties of resin are presented in table 1. For bending test, the samples were performed according to ISO 178: 2003 (figure 1, a and b). The geometrical characteristics of tested samples are shown in tables 2. The samples were obtained from the same plate of glass fibers chopped strands mat composite, being divided in two sets: one of them is for control, being subjected to bending, the other, was exposed to ultraviolet radiation and after 216 hours, the color change and the mechanical properties were measured.

Figure 1. The glass fibers chopped strand MAT samples: a) control samples for bending; b) UV samples for bending test.
Table 1. The mechanical properties of polyester resin as matrix of E-fiber glass chopped strand Mat composites

| Properties                                      | Values |
|------------------------------------------------|--------|
| Density [kg/dm³]                                | 1.1    |
| Cure temperature[°C]                            | 66     |
| Bending strength [MPa]                          | 90     |
| Shear modulus [MPa]                             | 4100   |
| Tensile strength [MPa]                          | 55     |
| Longitudinal elasticity modulus [MPa]           | 3600   |
| Strain                                          | 2 %    |
| Water absorption in 24 h (sample of 50x50x4 [mm³]) [mg/sample] | 19     |
| Water absorption in 28 days (samples of 50x50x4 [mm³]) [mg/sample] | 92     |

Table 2. The physical features of samples for bending test

| Bending test | MAT01-B | MAT02-B | MAT03-B | MAT04_B | Media | STDEV |
|--------------|---------|---------|---------|---------|-------|-------|
| Length [mm]  | 80      | 80      | 80      | 80      | 80    | 0     |
| Width [mm]   | 9.89    | 9.92    | 9.97    | 9.93    | 9.928 | 0.033 |
| Thickness [mm] | 4.19  | 4.06    | 4.49    | 4.15    | 4.223 | 0.186 |
| Mass [g]     | 4.436   | 4.346   | 4.855   | 4.455   | 4.523 | 0.226 |

| Sample before UV | MAT1B-B_UV | MAT2B-UV | MAT3B_UV | MAT4B_UV | Media | STDEV |
|-------------------|------------|----------|----------|----------|-------|-------|
| Length [mm]       | 80         | 80       | 80       | 80       | 80    | 0     |
| Width [mm]        | 9.89       | 9.92     | 9.97     | 9.93     | 9.928 | 0.033 |
| Thickness [mm]    | 4.19       | 4.06     | 4.49     | 4.15     | 4.223 | 0.186 |
| Mass [g]          | 4.436      | 4.346    | 4.855    | 4.455    | 4.523 | 0.226 |

3. Results and discussions

3.1. Bending test
The mechanical behavior of MAT samples is presented in figure 2, where can be noticed the characteristic curves load – deflection (figure 2, a) and stress – strain (figure 2, b). From both figures, it can be observed that samples have similar behavior during bending test. But, analyzing the values of Young modulus to bending, the MAT samples subjected to UV radiation recorded an increasing of modulus with almost 95% (figure 3, b) and an increasing of bending stress with almost 80% (figure 3, d). The stiffness decreases after UV radiation with 72% and the maximum load also decreased with 90%.
So, it can be concluded that the exposure at UV radiation affects the mechanical characteristics of composite structure. The increasing of some mechanical features of glass fibers chopped strands MAT composite it can be due the acceleration process of polymerization-condensation of matrix by means of ultraviolet radiation. For a long period of exposure to UV, at the matrix surface some reticular process will appear which will lead to decreasing the mechanical properties of composite [10 – 12].

Figure 2. a) Load vs deflection graph; b) Stress vs strain graph

Figure 3. Comparison of average values of different features of MAT control samples (MAT-CS) and MAT samples exposed to UV radiation (MAT-UV): (a) stiffness; (b) Young modulus; (c) Maximum Load; Maximum Stress

3.2. Color change
The novelty of this study consists of evaluation of color changes in case of UV radiation. So, the chroma test was applied on control sample before and after bending test and on samples exposed to
Both mechanical bending test and UV exposure, the lightness ($L^*$) increases: with 3.5% in case of UV exposure and with almost 30% in case of breaking to bending, in comparison with control samples lightness (figure 4, a). Because of composite structure, the samples recorded a green scale (negative values of $a^*$ coefficient, according to CIE) which decreasing with 14% for MAT-UV (figure 4, b). The scale of yellow increased with 4.25% after ageing and decreased with 18% when the samples broken (figure 4, c). Applying the relation (1), the overall change color represented in figure 4, d, is more obviously in case of mechanical stressed samples and UV exposure.

![Graphs showing changes in lightness, greenishness, yellowness, and overall color change](image)

**Figure 4.** The average values of color changes parameters: (a) the lightness $L^*$; (b) the greenish $a^*$; (c) the yellowness $b^*$; (d) the overall color change $E^*$

### 4. Conclusion

The paper presents the experimental study on ageing of fibers glass chopped strands materials for short time exposure. The following remarks can be mentioned:

- For short time exposure to UV-A radiation, the Young modulus of bending recording an increase with 95%, which is explained by accelerating chemical reaction of matrix (polymerization) and matrix curing;
- The bending strength increases after UV radiation with almost 80%;
- The lightness of MAT samples exposed to UV increased with 3.5% in comparison with control sample, the greenish decreased with 14% and the yellowness increased with 4.25%.

As future research, the authors will continue to analyze the ageing and weathering of glass fibers chopped strands mat composite, exposing the samples for a longer period.
5. References

[1] Aramide FO, Atanda PO and Olorunniwo OO 2012 Mechanical Properties of a Polyester Fiber Glass Composite *International Journal of Composite Materials* 2(6) pp 147-151

[2] Stanciu MD, Harapu A, Teodorescu Drăghicescu H, Curtu I and Savin A 2016 Comparison between viscous elastic plastic behavior of the composites reinforced with plain glass fabric and chopped strand mat *7th International Conference on Advanced Concepts in Mechanical Engineering, Materials Science and Engineering* 147 012097 doi:10.1088/1757-899X/147/1/012097

[3] Matuana LM, Kamdem DP 2002 Accelerated ultraviolet weathering of PVC/wood fiber composites *Polym. Eng. Sci*. 42:1657–66

[4] Darie R N, Bercea M, Kozłowski M and Spiridon I 2011 Evaluation of properties of LDPE/oak wood composites exposed to artificial ageing *Cellulose Chem. Technol*. 45:127-135

[5] Bodîrlău R, Teaca C A and Spiridon I 2009 Preparation and characterization of composites comprising modified hardwood and wood polymers/poly (vinyl chloride) *Bio Resources* 4(4):1285-1304

[6] Teacă C A, Roșu D, Bodîrlău R and Roșu L 2013 Structural changes in wood under artificial UV light irradiation determined by FTIR spectroscopy and colour measurements – a brief review *Bio Resources* 8(1):1478-1507

[7] Maxwell A S, Broughton W R, Dean G and Sims G D 2005 Review of accelerated ageing methods and lifetime prediction techniques for polymeric materials *NPL Report DEPC MPR 016* Queen’s Printer of Scotland

[8] Stanciu MD, Bucur V, Valcea CS, Savin A and Sturm R 2018 Oak particles size effects on viscous-elastic properties of wood polyester resin composite submitted to ultraviolet radiation *Wood Sci Technol* 52 (2): 365-382 [https://link.springer.com/article/10.1007/s00226-017-0971-0](https://link.springer.com/article/10.1007/s00226-017-0971-0)

[9] Stanciu MD, Șova D, Savin A, Ilias N and Gorbacheva G 2020 Physical and Mechanical Properties of Ammonia-Treated Black Locust Wood *Polymers* 12 377 doi:10.3390/polym12020377

[10] Shokrieh MM and Bayat A 2007 Effects of Ultraviolet Radiation on Mechanical Properties of Glass/Polyester Composites *J. Comp. Mat* 41 (20) pp 2443-2455

[11] Ramli J, Jeeferie AR and Mahat MM 2011 Effects of UV curing exposure time to the mechanical and physical properties of the epoxy and vinyl ester fiber glass laminates composites *ARPN Journal of Engineering and Applied Sciences* 6(4) pp 104-109

[12] Heinrick M, Crawford B and Milani AS 2017 Degradation of fiberglass composites under natural weathering conditions *MOJ Poly Sci*. 2017 I(1) pp18–24 DOI: 10.15406/mojps.2017.01.00004