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An Influence of UV Ageing Process on Tensile Strength and Young's Modulus of Polymeric Fiber Composite Materials

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Abstract. The aim of this study was to estimate the influence of the UV ageing process of the polymer matrix composites (PMC). Samples were prepared using 2 types of prepregs in the form of: (1) fabrics and (2) unidirectional fibers. The samples were aged in an accelerated weathering chamber for various times. Then the uniaxial tension tests were conducted using the DIC (digital image correlation) method to monitor deformation process of the PMC in time. Changes of the tensile strength and the Young modulus were experimentally estimated and compared to reference samples without ageing.

1. Introduction

The PMC, apart from static, dynamic and thermal loads [10-11] are also exposed to the natural environment.

The UV radiation for epoxy matrix composites without any coatings e.g. in the form of paint, is destructive by erosion. During the UV radiation the polymer chains may break down and CO, CO_2 and H_2 may be released. This ensures that the matrix becomes more brittle especially at low temperatures [1].

The PMC are often used for the production of wind turbine blades, building structures, ship hulls that are exposed both to: (a) the UV radiation and (b) moisture penetration. With the simultaneous influence of both factors, [6], a significant increase of the Young modulus was obtained for the composite with the isophthalic polyester matrix and fiberglass reinforcement. This is related to combination of water and the formation of longer chains of the polyester matrix.

The PMCs are also used in aerospace. In this case, ageing can be carried out as synergy of:

(1) high vacuum,
(2) the UV radiation,
(3) cyclic changes of temperature,
(4) atomic oxygen occurring in the atmosphere.

These are factors occurring on a low Earth's orbit, and research requires a special laboratory chamber, which was used in [9].

Natural fibers with polymer matrixes are increasingly used currently. In [2] the authors investigated composite based on natural fibers of flax. The tests were carried out both using UV radiation and water spray. Samples were aged for the following times: 500 h, 1000 h and 1500 h. The strength reduction after 1500 h was 29.9% and the Young's modulus reduction was 34.9%. However, it should be mentioned, that the samples were made by hand lay up method, which could have a significant impact on the results. In the paper [8] the bio-epoxy jute-basalt hybrid composite material was investigated. The ageing tests were carried out for the following steps: 14, 28, 56 and 84 days. Addition of basalt fiber layers allowed for more that 2-fold increase of the Young's modulus and bending strength. Generally, it can be concluded that composites with natural fibers such as flax, hemp, jute and sisal are more sensitive to aging.

Among the analyzed works, uniaxial tensile tests [4], three point bending tests [8] and Charpy impact tests [12] are most often used. However, there is no reports in the literature concerning the strain fields distributions in the analyzed aged samples. Therefore, the aim of this paper is to fill this gap.

2. Samples ageing

The tests were carried out using the QUV LU-8047-TM chamber. It allows to restore atmospheric conditions:

(1) solar radiation,
(2) water condensation,
(3) rain-induced erosion.

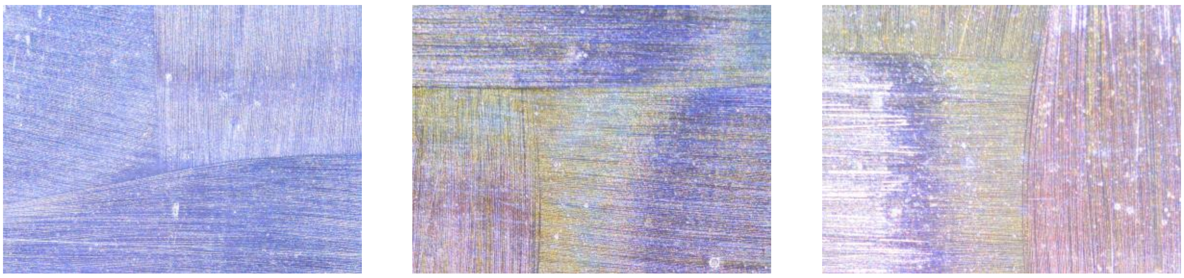
In this study only the UV radiation system was used. Ageing was carried out using UVA-340 lamps, which provide the best possible simulation of sunlight in the critical short wavelength region from 365 nm down to the solar cutoff of 295 nm. Its peak emission was at 340 nm. The radiation power was 0.89 W/m^2 and this was the value consistent with ASTM G154. The temperature that the samples reached was 50°C.

The tests were carried out for two types of PMC composites reinforced by:

- a fabric - Gurit prepreg EP121-C20-45, 0.23mm thick elementary layer,
- unidirectional fibers - Gurit prepreg EP137-CR527_100-35, having 0.1mm thick elementary layer.

For samples with the EP121 material, layering system 0_4 was used, and for material the EP137 it was $[0,90]_4$. Aging tests were carried out for 4 times: 144 h, 288 h, 432 h and 576 h. In the middle of each cycle (every 72 h), the chamber was opened and the samples were rotated to the other side, so that the ageing process was uniformly done for both sides. Each series consisted of 3 samples, and the reference samples were not subjected to the UV radiation. A total of 30 samples were tested (15 for EP121 and 15 for EP137).

Just after the first ageing cycle, yellow discolorations appeared on the surface. Therefore, after ageing tests, samples were subjected to microscopic observations (figure 1).



a) b) c)

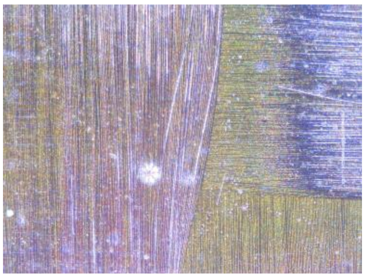
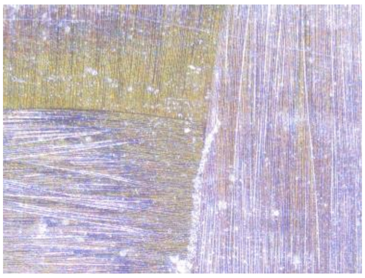
d)  e) 

Figure 1. Microscopic observations: a) 0 h, b) 144 h, c) 288 h, d) 432 h, e) 576 h.

For the subsequent ageing cycles, the intensity of discoloration did not change, however, after wiping the sample surface with a white and wet fabric, the fabric became colored. This demonstrates the chemical destruction of the PMC matrix outer layer and the formation of microparticles [3]. Therefore, degradation may be accelerated if there will be a movement of the microparticles caused by water flow under gravity, which happens when condensation or rain occurs.

In [7] in addition to yellow discolorations, the authors also observed crack formations for the PMC materials with reinforcement by fibers made of nylon and polypropylene. Tests were carried out both for: (1) the UV radiation and (2) the moisture absorption. Photo degradation of the PMCs causes formation of ester, aldehyde, formate and propyl end groups. The UV exposure may bring positive or negative changes concerning the values of elastic modulus and strength.

3. Laboratory tests

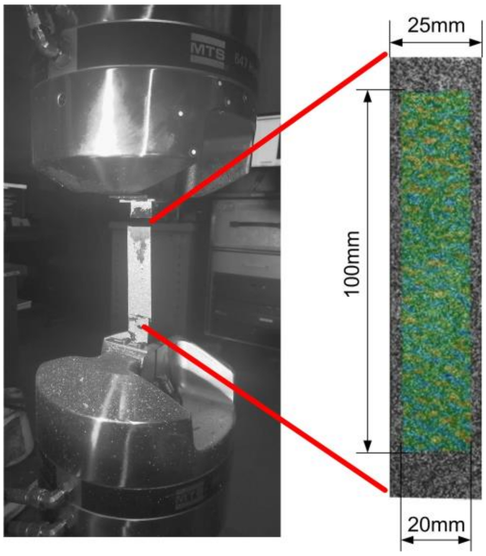


Figure 2. View of the sample central part after test and DIC observation areas

Laboratory tests were carried out for samples in accordance with the ASTM-D3039. The dimensions of the samples were 25 x 250 mm. The thickness for the EP121 material was 0.96 mm and for the EP137 0.84 mm. Both the wide and thickness of individual samples were measured with a micrometer with an accuracy of 0.001 mm.

Uniaxial tensile tests were carried out using the MTS 100 kN testing machine (figure 2) at a speed of 2 mm/min. The DIC system ARAMIS was coupled with testing machine, what allowed to determine displacement fields in the samples and further calculation of the elastic properties and strains of the considered PMC materials. The images were saved with frequency equal to 0.5 s.

4. Analysis of experimental results

The analysed PMCs behave as linearly elastic materials and their basic parameters like: the Young's modulus (E), the Poisson ratio (ν), tensile strengths ($\sigma_{\mathrm{yy}}^{\mathrm{f}}$), strains at failure ($\varepsilon_{\mathrm{yy}}^{\mathrm{f}}$) were collected in table 1.

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Table 1. Results summary

	E [MPa]		ν [-]		σ_{yy}^{f} [MPa]		ε_{yy}^{f} [%]	
	EP121	EP137	EP121	EP137	EP121	EP137	EP121	EP137
0 h	52733	74807	0.050	0.035	732	1288	1.36	1.64
144 h	51232	74104	0.055	0.036	766	1343	1.43	1.72
288 h	53971	74871	0.054	0.035	800	1424	1.43	1.81
432 h	52761	74265	0.059	0.038	765	1307	1.41	1.66
576 h	53996	74378	0.066	0.039	748	1358	1.35	1.72

On the side edges of the samples we observed free fibers that did not carry load or they were deformed in an accidental directions. Therefore, we limited the measurements area to the central part of the sample, i.e. to the field 20 mm x 100 mm to omit introduction of errors (figure 2).

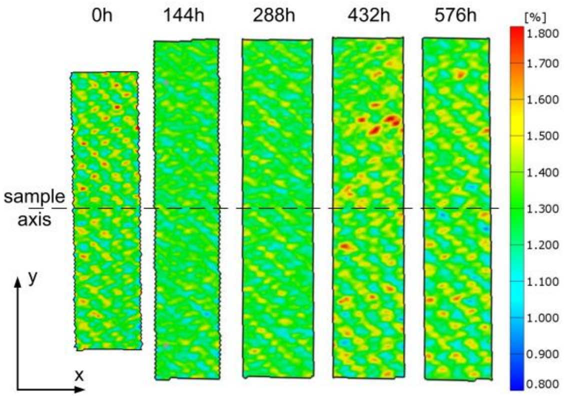

Figure 3. ε_{yy} strains in the EP121 for the axial force equal to 18,050 N

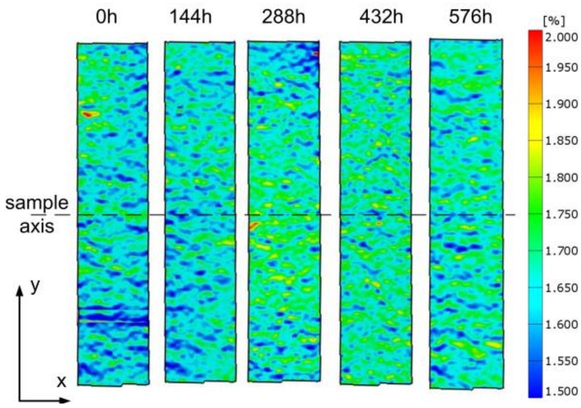

Figure 4. ε_{yy} strains in the EP137 for the axial force equal to 27,500 N

Figure 3. shows the normal strain fields ε_{yy} for the PMC reinforced by the EP121 for all ageing periods and the load level 18,050 N. For a better comparison, the scales of strain fields were unified to the range of 0.8% - 1.8%. Due to the fact, that reinforcement material is a twill fabric, we obtained characteristic strands at an angle 45°. Uniform values along the strands are distorted in particular for the 432 h sample. For the sample aged 576 h, the lowest strain value was observed. This indicates a disturbance during load transfer between the fibers and the matrix.

Figure 4 shows the normal strain fields ε_{yy} for the EP137 reinforcement at the load equal to 27,500 N. This force corresponds to the maximum effort in samples. The legend for each sample was unified to the range of 1.5% - 2%. The EP137 prepreg is in the form of unidirectional fibers, hence the deformation strands are arranged perpendicular to the sample axis. Only for the 288 h sample increased strain values can be observed close to the sample axis and equal to 2%.

5. Conclusions

In this paper, the results of UV ageing tests were presented for the two types of PMCs with reinforcements in the form of fabric and unidirectional fibers. The DIC system ARAMIS was used to observe in details changes of elastic properties during uniaxial tensile tests. The following conclusions can be formulated:

- just after the first ageing cycle in the EP121 material, discolorations appeared at strands interlacing area, i.e. in places rich in resin,

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- discoloration are the results of matrix UV decomposition and are easy to remove. Therefore, if the additional condensation or rain-induced erosion occurs, subsequent layers of the matrix would be exposed and the ageing effect would be more visible. The occurrence of above mentioned phenomena will be included in next studies.
- taking into account the σ_{yy}^{f} tensile strength for both EP121 and EP137, there is an increase of 9.2% and 10.5%, respectively for 288 h, while for the 576 h the increase of strength is smaller and is around of 5.4% for both materials. As compared to the reference samples, strain at failure are also increased.
- it should be noted, that there is no UV influence when analyzing values of the Young's modulus for both materials and all ageing times.
- during the tensile tests for aged samples, characteristic cracking sound was heard much earlier than for reference samples. This indicates that such tests should be carried out using acoustic emission.

The paper will be extended to include degradation processes during deformation and formulation of analytical or numerical models. One can apply a continuum damage approach as it was done for example in [12-18]. Other manner of degradation description is multiscale modeling, e.g. [19-34].

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