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A COMPARATIVE STUDY ON THE POLYMERIC MULTIPHASE COMPOSITE FAILURE IN 3-POINTS BENDING TESTS

Dana I. Luca Motoc[1], Nicolae Dădîrlat[2], Horatiu Teodorescu Drăghicescu[1]
[1] Transilvania University of Brasov, Brasov, ROMANIA, danaluca@unitbv.ro
[2] Arplama Group, ROMANIA

Abstract: *The paper aims to approach the failure mechanisms during the 3-point bending tests used as an experimental procedure for polymeric multiphase composite characterization. The multiphase polymeric composites were manufactured using a self-developed technology, having a 5 layers architecture, each of them containing dilute particles embedded into different volume fraction into a polymeric matrix along with long, random glass fibers. A micromechanical based approach will be used during the modeling step to size the stress and strains on the outer layers of the particle (e.g. ceramic, different volume fraction) and long, random glass fibers reinforced polymeric multiphase composite materials under the study. A comparison will be made with the experimental data retrieved from 3-points bending tests to aid the sample analysis.*
Keywords: *multiphase, polymer, composite, 3-point bending, environment conditioning*

1. INTRODUCTION

Heterogeneous materials are the most surprisingly type of materials in nature or engineered based on design or experience. Hence, the developing and characterization of newly composite structures are not a simple task to handle being well acknowledged the endless efforts on encompassing internal structure parameters, configuration or interaction as well as environmental conditioning as influencing factor on material overall properties.
Estimation of the effective heterogeneous material properties such are the mechanical (e.g. longitudinal, shear or bulk moduli, Poisson ratio, etc), thermal (e.g. thermal conductivity or thermal expansion, etc.) or electrical (e.g. electrical conductivity, etc.) in terms of the phase properties and microstructure is a lastingly standing issue. A micromechanical based approach will be used in the present paper to predict the multiphase polymeric composite structures developed and manufactured using a lay-up manufacturing technology [1]-[3]. The predicted data will be next compared with two sets of experimental data retrieved after conditioning the composite sample to different environmental conditioning.
Multiphase polymeric composites have found a niche into engineering applications that involve extreme environmental conditions, such as high and low temperatures or fluctuations between these, including different hygroscopic parameters. These engineered and engineering applications include electronic packaging and substrates, sensors and actuators, drive shafts, cylinders and brake rotors, pistons, bearings to name only few of them.
In order to design a suitable multiphase polymeric composite structure for the previous mentioned engineering applications several material properties has to be predicted and/or experimentally retrieved. Following this objective, an attempt has been made to analyze the behavior of a particle-fiber type multiphase polymeric composite material subjected to 3-point bending conditions.
Fiber reinforced composite materials are very sensitive to the mechanical loads, either tension, compression or bending. This is the reason for which such tests are conducted carefully [4]-[5]. Furthermore, if subjected to environmental extreme conditioning these composite samples add a supplementary influencing factor to the evolution of their material properties.
Based on the previous mentioned ones this paper will focus on the mechanisms of elastic properties degradation for a multiphase polymeric class of composite materials due to both environmental conditioning as well as phase related characteristics (e.g. volume fraction, etc.).

2. EXPERIMENTAL RESEARCH

The multiphase composite samples were manufactured as having three phases – random fibers and particles - embedded in different volume fraction into a polymeric matrix. The matrix material is commercially known as SYNOLITE 8388 P2 from DSM Composite Resins (Switzerland), a polyester resin type.
The particle inclusions considered were ceramic materials (with a high content of Al_2O_3), made from a natural stone, characterized as having a relatively high purity and provided by Alpha Calcite, Germany under the Alfrimal registered trade-mark, mixed within the polyester resin mass in 5% and 10% volume fraction, respectively.
The 3rd phase chosen were E-glass type random fibers, commercially available under MultiStratTM Mat ES 33-0-25 trade name, from Johns Manville, SUA, mixed as having a 65% volume fraction in the overall composite volume. The reference sample was made without any particle content and used for comparison purpose.
The samples were conditioned within a temperature controlled oven to an extreme environmental regime – a normal summer desert day, 7 days long, 24 hours/day, at temperature range from -10^{0}C (during the night) to 40^{0}C (during the midday). The humidity levels, temperatures and hours corresponding to a single day thermal cycle, used as input data for the oven programming, are given in the Table 1.

Table 1: Thermal cycle characteristics simulating a desert environment

Temperature [^{0}C]	Relative humidity level [%]	Time [h]
-10	45	8
0	50	1
10	50	1
20	55	1
30	60	1
40	65	8

The measurements were performed using a LR5K plus 3-point bending device from Lloyd Ltd. Company, at a speed of 1 mm/min for rectangular shaped composite samples positioned on two supporting beds. A computer program was used to analyze the experimental curves and to provide the corresponding statistics on each representative composite class under investigation. Experimental data were next subjected to further comparison by the aid of Microsoft Excel, as a common and graphical/statistics environment.

3. RESULTS AND DISCUSSION

Figure 1 is being shown the experimental configuration and sample positioning within whereas in Figure 2 is being shown several multiphase composite samples after being subjected to cumulative environmental conditioning and 3-point bending tests.

Figure 1: Experimental 3-point bending configuration and composite sample positioning

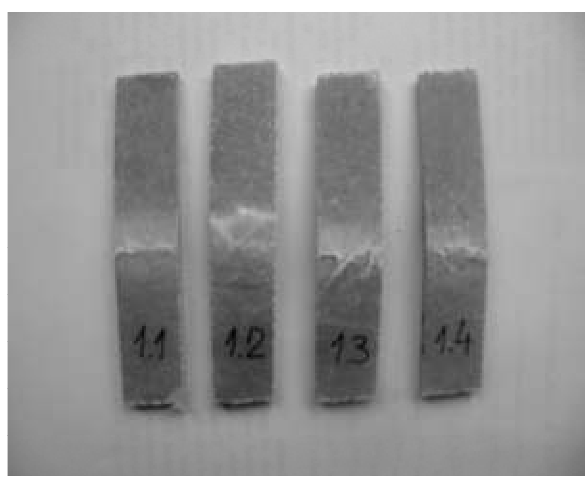

Figure 2: Representative multiphase composite samples subjected to extreme environmental conditions

In Figure 3 is being represented the experimentally retrieved Young's modulus of bending for the multiphase polymeric composite samples subjected to 3-point bending, with or without extreme environmental conditioning. As it can be seen, the environmental conditioning acts as a supplementary influencing factor on the elastic property on discussion by diminishing the overall modulus. This degradation can be regarded to the surface' structural morphology modification.

With respect to the theoretical elastic modulus of each multiphase composite class under discussion a micromechanical based approach was used based on the well known and most employed theoretical model of Mori-Tanaka. For the particle-fiber multiphase combination the overall elastic modulus was retrieved by using a two step homogenization scheme, actually applying successively the former theoretical scheme. The expressions of the elastic moduli, such as Young, shear or bulk modulus can be found in composite materials related literature. As a remark, the overall elastic properties depends on each constitutive through their individual material property as well as on their volume fraction. The latter has influence on the overall longitudinal elastic modulus by leading to a decrease as the particle content is increasing.

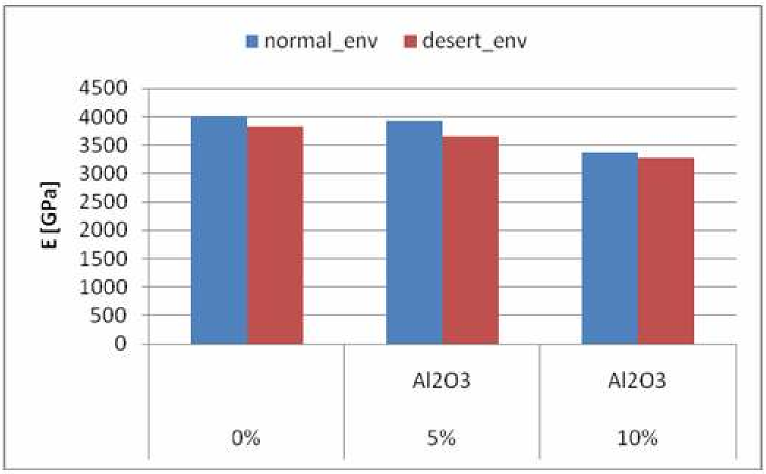

Figure 3: Experimentally retrieved Young modulus of bending for the multiphase composite samples, with/without environmental conditioning

In Figure 4 is being plotted the relative differences among the theoretically predicted and experimentally retrieved elastic modulus of bending for the multiphase polymeric composite classes under discussion subjected or not to extreme environmental conditions. These differences are revealing the degree of influence of the supplementary desert look like environmental conditioning on the overall mechanical property analyzed.

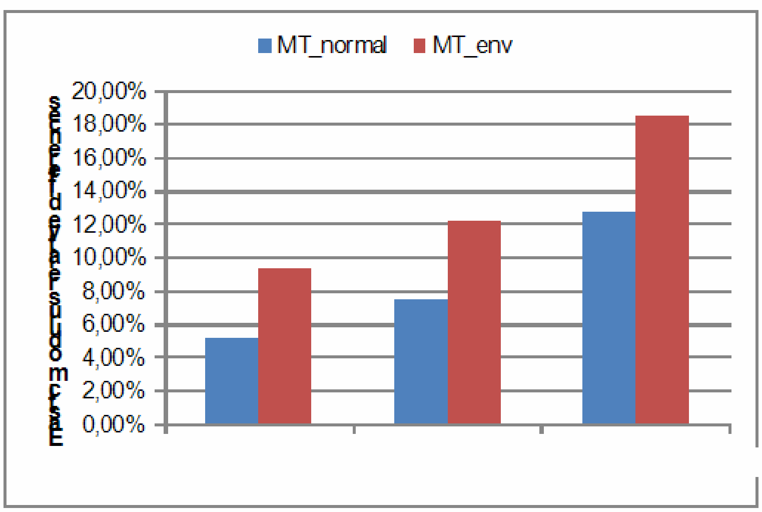

Figure 4: Relative differences between the theoretical predicted (Mori-Tanaka) and experimentally retrieved values for the multiphase polymeric composite samples with/without exposed to extreme environmental conditions

4. CONCLUSIONS

The environmental extreme conditioning as well as the structure related parameters such is the phase volume fractions acts as main influencing factors on the elastic modulus degradation for the multiphase polymeric classes analyzed herein. The micromechanical based theoretical models approaches better the overall elastic properties of the composite materials no matter their morphology, type of materials or phase number but always seem to lead to higher values comparatively to the experimental ones. This observation is normal and reality related due to the fact that the theoretical models such is the one used in this work do not encompass information with respect to the interaction of phases or morphology related modification as these heterogeneous materials are experiencing environmental changes.

The subject of herein paper is opening a niche with respect to the needs of modifying the micromechanically based theoretical model in order to encompass these types of environmental related changes. Moreover, it leads to the possibility of approaching both theoretically and experimentally other multiphase composite structures such as fiber-fiber or particle-particle as well as other types of environmental regimes.

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