Effect of Ferrite Particles on Mechanical Behaviour of Glass Fibers Reinforced Polymer Composite

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Due to their lightweight, exceptionally high strength and modulus, high stiffness, good fatigue life, and excellent corrosion resistance, polymer matrix composites are increasingly being used in the aircraft and spacecraft industry. Nowadays, a significant amount of advanced polymer composites is used for military and commercial aircraft and satellite components. Due of their low density, higher physical and mechanical properties and low manufacturing cost, these materials have replaced metals, such as aluminum alloys, in many applications. This paper deals with the class of polymer composites, new material recipes and testing results. This approach refers to the possible use of ferrite additive to improve mechanical and magnetic properties of polymer composites.

Keywords: lightweight, polymer, composite, ferrite

Lightweight composites, based on polymer matrix and high-performance fibers, are increasingly used in aerospace and aircraft industry. New commercial aircraft contain more composites than their predecessors. Passenger aircraft have composite parts, such as doors, rudders, elevators, ailerons, spoilers, flaps, fairings, as they reduce weight, increase payload and provide efficient fuel consumption [1]. In the future, passenger planes will be more than 50% polymer composites, while nowadays a recently built aircraft consists of 25% composite material. Lighter and stronger composites are designed to feature exceptional mechanical strength, high stiffness, good fatigue life, high temperature and corrosion resistance, much better than conventional materials in various commercial and military applications. Very light vehicles, which are faster than standard ones, yachts and boats that are resistant to corrosive seawater, or lightweight blades for turbines that work more efficiently, are all made of polymer composites.

The properties of the composite materials depend not only on the fiber reinforcements, but also on the polymer matrix, the characteristics of the fiber and matrix interface, and the manufacturing process [2].

The use of polymer composites in designing complex applications implies a deep understanding of the structure-property-function relationship. The capacity of determining the filler-matrix interaction and the interface effect on the macroscopic properties are the key points of the composite properties control [3]. The present-day literature is quite abundant in information on conventional composites which is an excellent starting point in understanding the behaviour of polymer composites [4]. Moreover, composite properties prediction models can be identified (module, thermal conductivity) [5].

At micro-mechanic level, shape, aspect and interface shearing stress are meaningful parameters. It is often assessed that carbon nanotubes should feature the highest capacity of enhancing the composite material [6]. Important information about size influence is taken from thin film physics where a quantitative correlation between film thickness and particles inter-space inside the composites is suggested [7].

Also the glass-transition temperature of a polymer can be modified by adding nanoparticles which may have attraction or rejection behavior to the matrix [8]. The control of nanoparticles dispersion into the polymer matrix is a crucial issue in developing high-performance polymer composites [9]. Theoretical and experimental strategies are investigated to find chemical and physical methods of controlling nanoparticles dispersion into the polymer matrix. Analysis of the interaction between particles of different shapes, usually spherical, cylindrical and flat, in vacuum , reveals the dependence of the interaction energy on nanoparticles shape and aspect [10].

Polymer composites with ferrite additive

The class of lightweight magnetic composites which is interesting for the aerospace technology is based on combining organic matrix, reinforcing glass fibers and magnetic powders [11]. Generally, the quality and behaviour of a composite are influenced by the interface fitness, which has a direct contribution to the effort transfer from the exterior to the strength structure, through the organic matrix. In the case of the composites with polyester matrix, the interface is significantly affected by the presence of the atmospheric air, which is physically and chemically adsorbed at the reinforcing fibers surface [12].

The paramagnetic properties of the oxygen molecules can control the spreading of the air micro bubbles emerging on the interface. The ferrite particles interacting with the oxygen molecules, play the role of a "vacuum cleaner" absorbing the bubbles situated at the interface level. Moreover, if while producing the composite, an external vibrating magnetic field is active, it is possible that the microbubbles scatter into the mass of the organic matrix. Therefore, an enhancement of the interface fitness is expected [13].

During manufacturing, when contact between matrix and reinforcing fibers occurs, microbubbles are incorporated and then noticed in solid phase. The ferrite particles used as additive confer the magnetic properties to the composite and they can also be used to control the microbubbles scattering into the mass of the material.

Control of oxygen molecules by ferrite particles

In the mechanic-quantum theory of chemical bonds, the paramagnetism of the oxygen molecules is revealed by means of the molecular orbital method (MOM). It is

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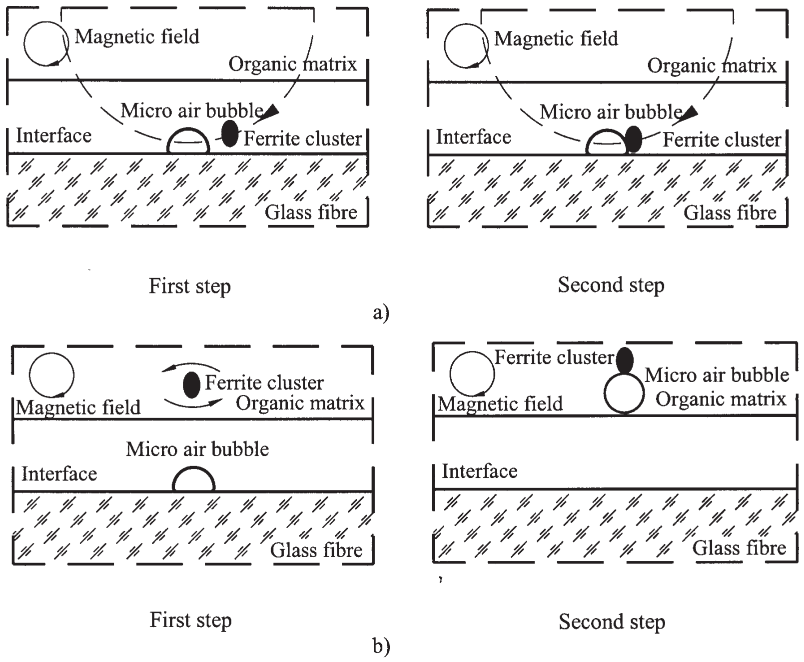


Fig. 1. Interaction between micro bubbles and ferrite particles
a) In the initial stage, throughout the fluid matrix; b) In the advanced stage of precursor jellification

well known that there are two unbound electrons in the antibonding orbitals π^*_{2px} and π^*_{2py} accounting for the paramagnetic behavior of the molecules O_2, in the presence of an external magnetic field. According to Hund's law, antibonding orbitals π^*_{2px} and π^*_{2py}, having the same energy, are successively populated by one electron. Among representative magnetic materials there are spinel ferrite, magnetic structures of hematite type compound and garnet [14].

The spinel structure is given by the general formula PQ_2X_4, where X is one of O^{2-}, S^{2-}, Se^{2-} ions, and P and Q are metallic ions. As regards common ferrites, P is one of Mn^{2+}, Fe^{2+}, Ni^{2+}, Co^{2+}, Zn^{2+} or Mg^{2+} divalent ions, and Q is one of Mn^{3+}, Fe^{3+}, Co^{3+}, Al^{3+}, Ga^{3+} trivalent ions.

The basic cell of cubical crystalline lattice contains eight molecules of PQ_2X_4 type. The bigger ions, X^{-2}, are placed in a face centered cubic lattice (O_h^7). There are two positions with this type of lattice: tetrahedral which is surrounded by four X^{-2} ions, and octahedral, surrounded by six X^{-2} ions. An ion placed in tetrahedral position has a cubic crystalline symmetry. The symmetry of metallic ions that surround an octahedral position is lower than the cubic one.

The interaction between oxygen molecules and ferrite particles was studied on a composite with polyester matrix reinforced with glass fibers, produced by means of two different technologies. The former was a common one but, for the latter, the composite was obtained in the presence of an external vibrating magnetic field. The movement of the ferrite particles under the influence of magnetic field experiences two stages, taking into account the time-dependent viscosity of the resin precursor. During the first stage, the ferrite particles are moving along the lines of the external magnetic field, also causing the microbubbles to move (fig.1).

In the second stage, when the increase in the precursor viscosity prevents the ferrite particles from flowing, the movement is reduced to a vibration of the particles situated near the interface, causing the microbubbles to spread into the polyester matrix.

SEM investigation

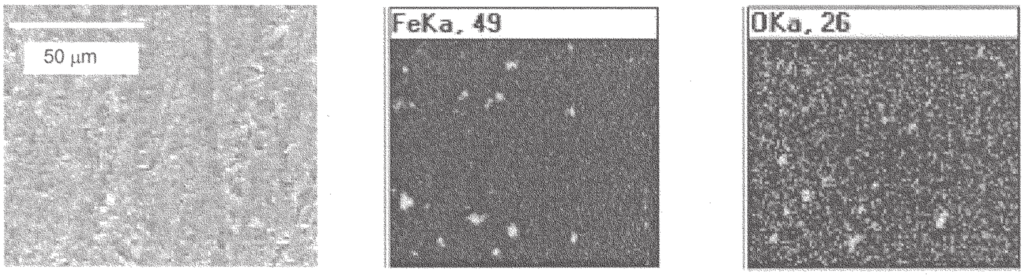
Four types of composite samples were manufactured and examined: the first, called PG, based on polyester resin and glass fibers, the second, PGFe-1, made of polyester resin, glass fibers and 2,5% Fe_3O_4, the third one, PFe-1 containing polyester resin and 2,5% Fe_3O_4, and the fourth one, PFe-2, with 5% Fe_3O_4, made under vibrating magnetic field. The structural characterization of the above materials was possible by scanning electron microscopy.

The composite samples with polyester matrix, 2.5% ferrite and glass fibers, noted with PGFe-1, were investigated on the surface and in cross section, as shown in figure 2. The images of the composite structure were captured at 50 μm and 10 μm scales. SEM images of the PFe-1 composite are shown in figure 3. It was thus revealed the structure of the material obtained from organic precursor and ferrite particles, and also Fe and molecular oxygen distribution. The composite samples with polyester matrix and 5% ferrite, obtained when applying an external vibrating magnetic field, were noted PFe-2, and they were also investigated on the surface and in cross section (fig.4). When applying a vibrating magnetic field, the particles Fe_3O_4 generate clusters that include both the composite matrix and the microbubbles to their chain. The movement of the ferrite clusters near the interface, by the above-mentioned interaction, produces structural homogenization, and allows the detaching and scattering of the microbubbles from the fibers proximity towards the polyester matrix mass [15]. The purpose of the investigation is to compare the samples PFe-1 with samples PFe-2 and to highlight the morphological aspects of the polyester matrix and ferrite particles for the two polymer matrices obtained under normal condition and when applying an external vibrating magnetic field. Also, an experimental study of the polyester composite reinforced by glass fibers, PG, relative to the composite with ferrite additive, PGFe-1, was performed in order to assess the influence of Fe_3O_4 particles on the mechanical behaviour.

Experimental assessment of mechanical behaviour

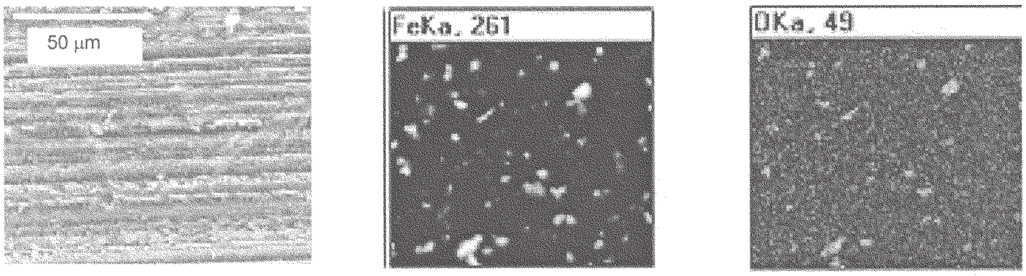
The mechanical behaviour of the fibers reinforced polymer composites can be assessed by means of different uniaxial tests such as: tensile, compression, bending, and interlaminar shear strength [11]. A relevant test for layered fiber reinforced polymer composites is the biaxial test which is performed in a limited number of laboratories because of its complexity and high costs involved [16-18].

The comparative study considered polymer composite samples with ferrite additive, called PGFe-1, as usual glass



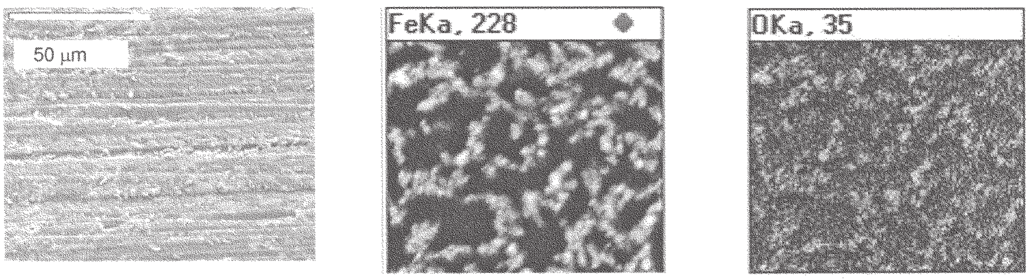
a) b)

Fig. 2. SEM graphs of the polyester matrix with glass fibres and 2,5 % Fe_3O_4 - PGFe-1
a)On surface; b) On cross section



a) b)

Fig. 3. SEM graphs of the polyester matrix with 2,5 % Fe_3O_4 - PFe-1
a)On surface; b) On cross section



a) b)

Fig. 4. SEM graphs of the polyester matrix with 5 % Fe_3O_4, magnetic field – PFe-2
a)On surface; b) On cross section

fibers reinforced composite with polyester matrix, PG. The tensile test was performed on AGL Slow machine using a HBM50 axial extensometer, a Sandner transversal extensometer, 2 N pretension load and 2mm/min test speed [11]. It has been found that PGFe-1 composite features better tensile strength than PG material (fig. 5). There was a sensible difference concerning elastic modulus; decreasing values were recorded with temperature increase, for both of the tested materials (fig.6). The second material containing ferrite additive seems to be stronger than the additive-free material.

In the case of compression strength, four types of polymer composite were tested for three temperature values, in order to estimate the compressive stress. The first material (PG) does not contain ferrite additive, while the second one (PGFe-1) has 2.5% Fe_3O_4. The third and the fourth material (PGFe-2 and PGFe-3) contain 2.5% Fe_3O_4 and 5% Fe_3O_4 respectively, and have been made under the influence of a vibrating magnetic field working in the target side of the sample. The tests have been performed using a 2 N pretension load and 1 mm/min test speed. The graphs in figures 7 and 8 show that in all cases the compression strength decreases with the increased temperature. It can also be seen that all the materials containing Fe_3O_4 have a better strength than first material which does not contain ferrite particles. Moreover, the 3rd material seems to have the best behaviour. It means that 2.5 % Fe_3O_4 rate is the optimum concentration of the oxide for the composite obtained in a vibrating magnetic field. The increase in the concentration rate leads to a decreased compression strength with the materials made under the action of the magnetic field. Two tendencies were noticed: one regarding the increase in the compression strength in the case of magnetic composite and one concerning the improved of the mechanical properties in the case of material obtained under the influence of a magnetic field. This result confirms the assumption described before in this paper regarding the mechanism of microbubbles scattering during the manufacture process of the composite.

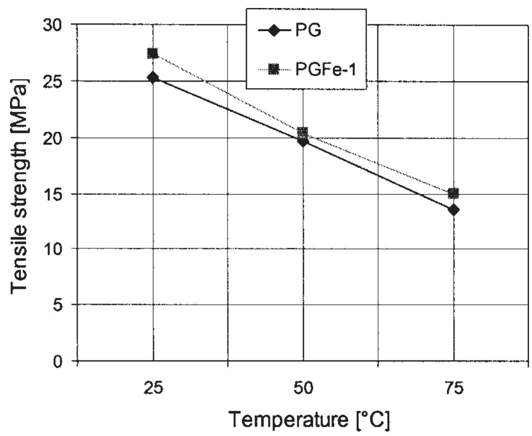


Fig. 5. Tensile strength.PG - polyester resin + glass fiber; PGFe-1 - polyester resin + glass fiber + 2.5% ferrite additive

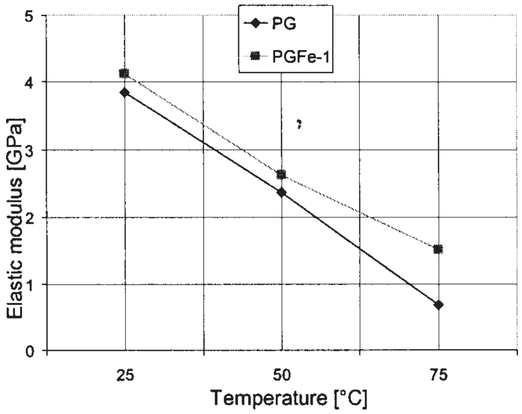


Fig. 6. Elastic modulus. PG - polyester resin + glass fiber; PGFe-1 - polyester resin + glass fiber + 2.5% ferrite additive

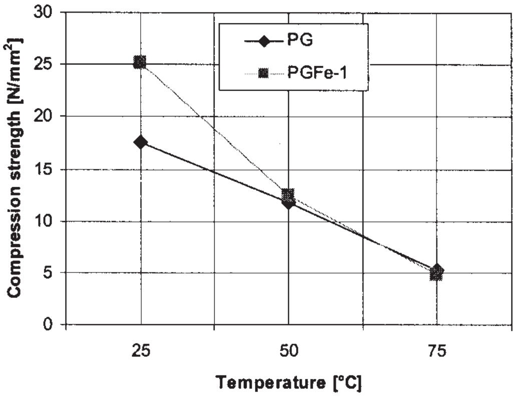


Fig. 7. Compression strength. PG - polyester resin + glass fiber; PGFe-1 - polyester resin + glass fiber + 2.5% ferrite additive

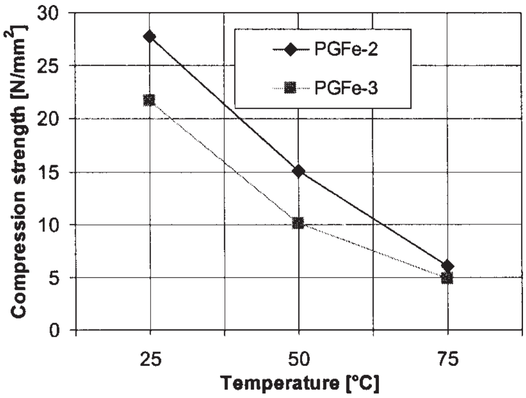


Fig. 8. Compression strength. PGFe-2 - polyester resin + glass fiber + 2.5% ferrite additive under magnetic field PGFe-3- polyester resin + glass fiber + 5% ferrite additive under magnetic field

Results and discussions

In the light of results obtained, the testing program clearly demonstrated the improvement of the composite mechanical properties after introducing the ferrite particles into its organic matrix. It was easy to see that the tensile strength, the bending strength, the compression strength and even the interlaminar shear strength reached better values in the case of the magnetic composite than the standard one. It was possible to notice that, with increased temperature values, the ferrite additive improves the elastic behaviour of the material over the whole range.

As expected, a higher working temperature generally causes the strength of all samples studied to diminish. An overview of the results reveals an optimum concentration of the ferrite at 2.5 %. The most important point of the study is the elucidation of the effect of magnetic field on the mechanical behavior of the composite. It has been found that the presence of a vibrating magnetic field, when processing the material, induces the scattering of the air micro bubbles from the interface into the mass of the organic matrix. It results in an enhancement of the composite interface with a favorable effects on the mechanical properties.

Conclusions

The quality of the resin matrix can be improved with additives such as ferrite powder. From a mechanical point of view the presence of Fe_3O_4 particles in the mass of the composite determines the improvement of the material properties. Interaction between ferrite particles and oxygen molecules was discussed relative to SEM investigation and mechanical tests. It has been found that the presence of ferrite powder in the polymer matrix has a favorable effect on the interface fitness as well as on the mechanical performance. The promising results are accounted for the interaction of ferrite particles and oxygen molecules and by the presence of the vibrating magnetic field. The mechanical and magnetic properties recommend the use of the new class of lightweight polymer composite in aerospace technology, aircraft-type instruments, and shipbuilding industry.

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