

Lightweight magnetic composites for aircraft applications

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Carbon fibers/polymer matrix composites tend to be used more widely instead of aluminum structures in the aircraft and aerospace industry. There are many reasons that explain the increasing interest for this class of composites due to the lightweight, high strength, high stiffness, good fatigue life, excellent corrosion resistance and low cost manufacturing. Moreover, a considerable effort is paid to improve the thermal/electrical conductivity and the electromagnetic shielding effectiveness of lightweight composites. It is well known that in operation, the engines of the aircraft generate a large amount of electrical current during start up. This electrical current is undesirable and must be conducted away. Otherwise, the electronic components need to be protected against electromagnetic waves produced by other sources placed inside or outside the aircraft. This paper concerns the state-of-the-art of the lightweight composites and deals with discussing solutions, new material recipes and testing results. This approach refers to the possible use of coated carbon fibers, carbon nanotubes and ferrite additive.

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1. Introduction

Due to their lightweight, exceptionally high strength and modulus, high stiffness, good fatigue life, and excellent corrosion resistance, carbon fiber/organic 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. Because of their low density, superior physical and mechanical properties and low cost manufacturing, these materials have replaced metals, such as aluminum alloys, in many applications [1]. Passenger aircraft Boeing 747 and 767 have composite parts, such as doors, rudders, elevators, ailerons, spoilers, flaps, fairings, to lower the weight, increase the payload and the fuel efficiency [2].

As regards thermal and electrical behaviour of lightweight composites, different demands can occur, with respect of the application type. In the case of aircraft and spacecraft it is possible to use composites with zero thermal conductivity or with a very good thermal and electrical conductivity. Moreover, there are situations when a good electro-magnetic shielding effectiveness is needed. Carbon fiber, coated carbon fiber, bromine intercalate, carbon nanotube, filler, iron fiber and ferrite powder are some components used in order to obtain advanced lightweight composites.

Carbon fiber is engineered for strength and stiffness, but there are variations in electrical conductivity, thermal and chemical properties. The primary factors governing the physical properties are the degree of carbonization, the orientation of the layered carbon planes, and the degree of

crystallization [3]. Carbon fiber has a higher modulus parallel to the fiber axis than perpendicular to the fiber axis. Similarly, the electrical and thermal conductivities are higher along the fiber axis, and the coefficient of thermal expansion is lower along the fiber axis [4].

The enhancement of the electrical and thermal conductivity, as well as the shielding effectiveness of the organic matrix composites, is possible by using epoxy resin reinforced with nickel coated carbon fibers [5].

The carbon nanotube considered the ultimate carbon fiber has been shown to possess exceptional stiffness and strength, extraordinary resilience, remarkable thermal and electrical properties, and low density [6]. Because of these properties, carbon nanotubes can be used for aerospace applications, as follows: high-strength lightweight composites, membranes, heat-exchangers, coatings, radiation shielding, antistatic applications, supercapacitors and sensors. The presence of the nanofillers can provide more toughness, good conductivity, and UV absorption [3].

Electro-magnetic and microwave absorbing lightweight composites was obtained from epoxy resin filled with iron fibers.

In such a combination, the magnetic iron fibers may be useful in producing thin and lightweight radar absorbing materials [7]. The enhancement of the interface fitness in the case of organic matrix composites is possible by introducing ferrite particles in the polymer. The ferrite particles that are introduced into the composite structure induce magnetic properties and increase the load transfer capacity of the interface [8].

2. Ferrite additive for lightweight magnetic composites

The class of lightweight magnetic composites that is interesting for the aerospace technology is based on combining organic matrix, reinforcing glass fibers and magnetic powders [8,9]. Generally, the quality and the 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 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 [10].

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

2.1. Interaction between ferrite particles and oxygen molecules

In the mechano-quantic theory of the chemical bonds, the paramagnetism of the oxygen molecules is pointed out by means of the molecular orbital method (MOM). As one may notice from Fig. 2, there are two unbound electrons in the antibonding orbitals π_{2px}^* and π_{2py}^* explaining the paramagnetic behavior of the molecules O_2 , in the presence of the external magnetic field. As stipulated by the 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 the spinel ferrite, the magnetic structures of hematite type compound and the garnet [11].

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.

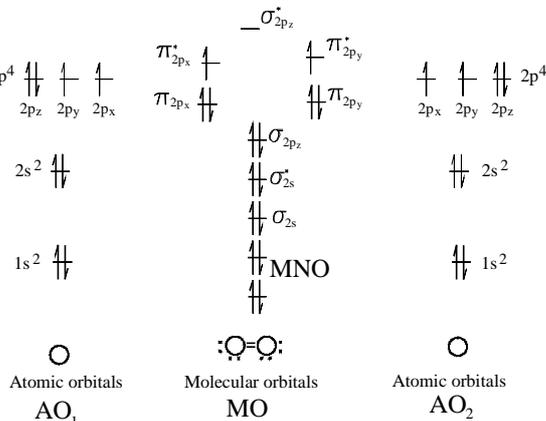


Fig. 2. Schematic representation of chemical bonds in O_2 molecule, using MOM.

The basic cell of cubical crystalline lattice contains eight molecules of PQ_2X_4 type. The bigger ions, X^{-2} , are paced in a face centered cubic lattice (O_h). There are two positions for this kind of lattice: tetrahedral which is surrounded by four X^{-2} ions, and octahedral, surrounded by six X^{-2} ions. An ion that is 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. In the elementary cell of spinel type structure, the metallic ions are placed in eight tetrahedral positions marked with A, and six octahedral positions marked with B.

It has been proved a normal and an inverse spinel structure, which represent extreme situations. Usually, the arrangement of the cations complies with the following relation: $[Me_x^{2+}Fe_{1-x}^{3+}]_O \times [Me_{1-x}^{2+}Fe_{1+x}^{3+}]_T O_4$, where O and T indexes correspond to the octahedral and tetrahedral positions, respectively. The magnetic properties of the ferrite are determined by the positions occupied by metallic ions in the spinel structure.

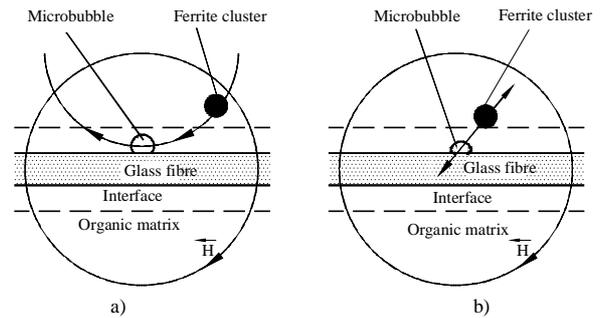


Fig. 3. Interaction between micro bubbles and ferrite particles a) In the initial stage, throughout the fluid matrix; b) In the advanced stage of precursor jellification.

The interaction between oxygen molecules and ferrite particles was studied on a composite with polyester matrix and reinforced with glass fibers, produced by means of two different technologies [9]. The first was a common one but for the second the composite was obtained in the presence of an external vibrating magnetic field. The movement of the ferrite particles under the influence of the magnetic field experience two stages, taking into account the time-dependent viscosity of the resin precursor (Fig. 3). It is certain that the time interval between the initial moment of introducing the catalyst and the total jellification time (Δt , the time necessary for polyester resin jellification) there are two types of movement for the ferrite particles within the polyester mass. In the initial stage of the embedding the reinforcing material into the polymeric matrix, the ferrite particles are moving along the lines of the external magnetic field, also making moving the air micro bubbles.

In the second stage, when the increase of precursor viscosity does not allow the flow of ferrite particles, the movement is reduced to a vibration of the particles situated near the interface, resulting a spreading of the air micro bubbles in the polyester matrix (Fig. 3). For both

stages, the result is the interface enhancement by the mechanism of micro bubbles displacement from the interface toward the mass of the matrix.

2.2. Structural characterization by SEM analysis

Two groups of composite samples were manufactured and examined, the first one obtained in normal condition

and the second one in the presence of an external vibrating magnetic field. The structural characterization of the studied composites was performed by scanning electron microscopy. The samples obtained from a polyester matrix with 5% ferrite, having the symbol $B_0(P_4)$, were investigated on surface and on cross section (Fig. 4).

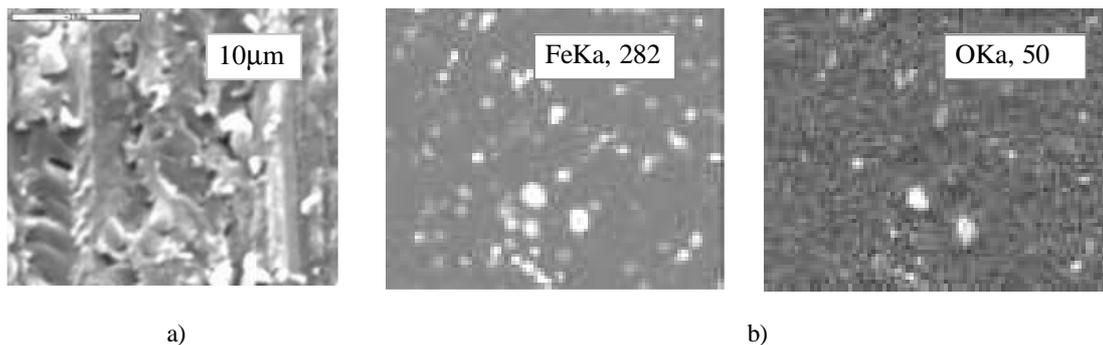


Fig. 4. SEM analysis of the composite $B_0(P_4)$: a) On the surface; b) On a cross section

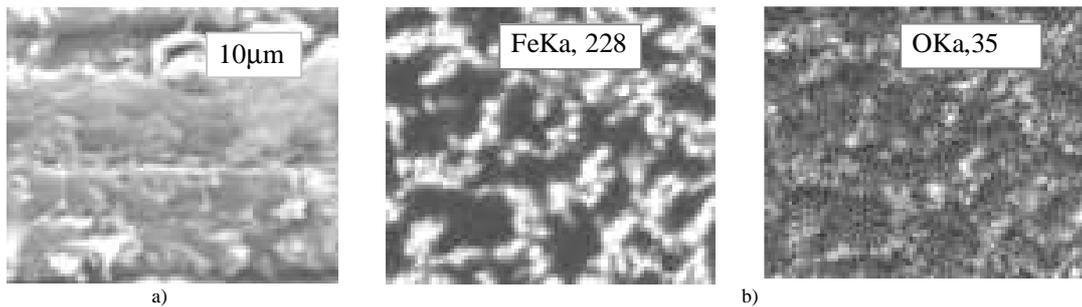


Fig. 5. SEM analysis of the composite $C_0(P_2)$: a) On the surface; b) On a cross section.

There was pointed out the structure of the material obtained from organic precursor and ferrite particles, after usual manufacture, and also Fe and molecular oxygen distribution.

The composite samples with a polyester matrix and 5% ferrite, obtained when applying an external vibrating magnetic field, were noted $C_0(P_2)$, and they were also investigated on the surface and in cross section, as it is shown in Fig. 5. The investigation objective is to compare the samples $B_0(P_4)$ to samples $C_0(P_2)$ and to underline morphological aspects of the polyester matrix and ferrite particles for both the composite obtained under usual condition and by applying an external vibrating magnetic field. When applying a vibrating magnetic field, the particles Fe_3O_4 generate clusters that include in their chain the matrix of the composite and air micro bubbles.

2.3. Experimental assessment

A large test plan has been sketched in order to obtain a complete description of lightweight magnetic composite for further standard information and possible patent

specification. A special emphasis has been put on the mechanical test, which is more relevant for the estimation of the material behavior. The comparative study considered the magnetic composite samples versus standard glass fibers reinforced composite with polyester matrix.

Tensile test

The ISO 527 states the specimen geometry as ISO type III sample. Another solution, corresponding to the ASTM D 3039-95, which is more suitable, was chosen [12]. The test speed was $v \leq 5$ mm/min for usual test, and $v \leq 2$ mm/min when needed the deformation and the tensile modulus of elasticity determination [13].

The tensile test was performed on AGL Slow machine using a HBM50 axial extensometer, a Sandner transversal extensometer, and 2 N pretension load and 2mm/min test speed. It has been found that lightweight magnetic composite proves better tensile strength than standard material (Fig. 6). There was no significant difference concerning elastic modulus and decreasing values were

recorded with temperature increase, for both materials tested. The second material that contains ferrite additive seems to be stronger than the material without additive.

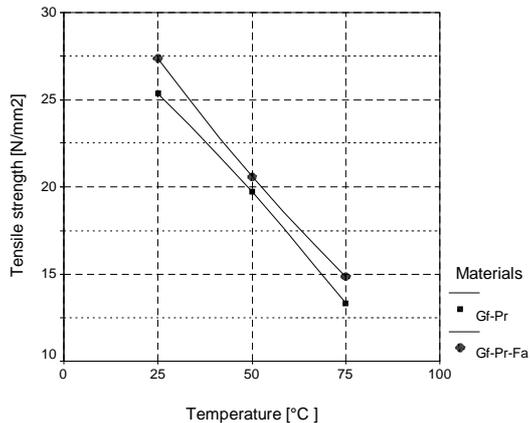


Fig. 6. Influence of temperature on the tensile strength. The acronym Gf-Pr means “glass fiber – polyester resin”, while Gf-Pr-Fa means “glass fiber – polyester resin – ferrite additive”.

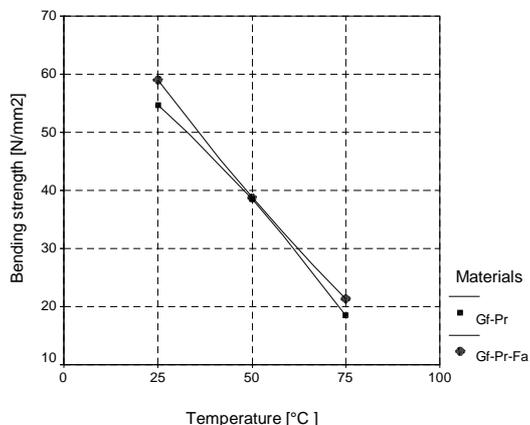


Fig. 7. Effect of the temperature on the bending strength.

Bending test

For the bending test, the 3-points method has been used. The loading speed has to be limited in order to get a bending deflection lower than 10 mm/min. Strain gauge type of measurement was used during the bending test. The shape and dimensions of the samples were found in the EN63 standard. Two types of materials were tested for three values of the temperature, using a Biege deflection gauge, a 3 N pretension load and 2 mm/min test speed. The maximum load, the bending strength, flexural elastic modulus, the stress at 0.2 % offset and the strain at flexural strength have been recorded. As a general tendency, mechanical parameters of the two materials tested decrease with higher work temperature. Bending

strength gets better values in case of magnetic composite (Fig. 7). The point is that the second material proves better elastic properties than the first material. This could be explained by the presence of the ferrite particles in the mass of the organic matrix.

Interlaminar shear strength test

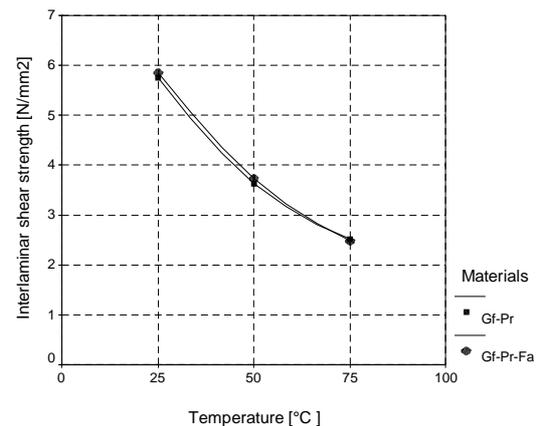


Fig. 8. Influence of the temperature on the interlaminar shear strength.

The interlaminar shear strength was measured for two types of materials and three values of the temperature. Only the maximum load has been considered and on its basis the interlaminar shear strength has been calculated (Fig. 8). As it can be seen in the figure there is no significant difference between the values of the interlaminar shear strength proved by both tested materials. A high level of the interlaminar shear stress can determine the rise of delamination and the damage of the interfacial layers of the composite. While there is no difference between these values the risk of delamination is the same.

3. Discussion

In terms of the obtained results, the testing program demonstrated clearly the increase of the mechanical properties of the new composite after introducing the ferrite particles in its organic matrix. It was easy to see that the tensile strength, the bending strength, the compression strength and even the interlaminar shear strength proved better values in the case of magnetic composite than standard one. It was possible to observe that for increasing value of temperature the ferrite additive strengthen the elastic behavior of the material over the whole range. It can also be seen that over 50 °C the magnetic composite proves higher values of the strain at bending strength than the first one without ferrite.

As it was expected the increase of work temperature generally causes a diminishing of the strength of all the studied materials. An overview of the results reveals an

optimum concentration of the ferrite at 2.5 % Fe_3O_4 . The most important point of the study is perhaps the elucidation of the effect of the magnetic field on the mechanical behavior of the composite. It has been found that the presence of the vibrating magnetic field when processing the material induces the scattering of the air micro bubbles from the interface to the mass of the organic matrix. It results an enhancement of the composite interface with a desired effect on the mechanical parameters.

4. Conclusions

During the last decade, a considerable effort has been spent with finding solutions for obtaining lightweight and ultra-lightweight composites to be used in aerospace applications. The quality of the resin matrix can be improved with additives such as carbon filler, carbon whiskers, carbon nanotubes and ferrite powder. The most promising component for ultra-light and high strength advanced composites seems to be the ultimate carbon fiber, the carbon nanotube, due to its exceptional chemical, mechanical and electrical properties. As regards the ferrite additive, a few works were reported due to the limited application of this type of composite. From a mechanical point of view the presence of Fe_3O_4 additive particles in the mass of the composite determines the improvement of the material properties.

Even if the testing program did not answer all the questions assumed in the initial objectives, the obtained results are encouraging for continuing the experimental approach. The lightweight material and the magnetic properties recommend this new class of magnetic composite with organic matrix to be used in space technology and avionics, for aircraft-type instruments, as well as in electronic and chemical industries.

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