MANUFACTURE METHODS COMPARISON AND CHARACTERIZATION OF CONDUCTIVE GLASS REINFORCED PLASTICS BY ADDING CARBON NANOFIBRES

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ABSTRACT

In this work, carbon nanofibre (CNF)/glass fibre/polyester resin laminated composites have been prepared in order to use this kind of composites in transport applications. Laminates were made by two different manufacturing methods, such as Hand Lay-up method and vacuum bag technique in order to compare the influence of the used method in the final properties of the composite. Both kinds of laminates were prepared with two different glass fibre layouts: four Chopped Strand Mats (CSM) layers and three CSM layers with two woven roving layers between them. Every kind of laminate was loaded with CNF between 0 and 2wt% with regard to the resin. It is found that the presence of CNF has supposed a reinforcement of the composites in both flexural and tensile strength. On the other hand, composites prepared by the vacuum bag technique showed an important increase in their mechanical properties due to the preparation method. Finally, it was found electrical conductivity through the composites with only 0.5 wt% CNF loading.

1. INTRODUCTION

The use of composite materials grows more and more everyday in several applications, especially in transport applications, such as automotive and aeronautics industry. Fibre Reinforced Polymers (FRP), and specifically reinforced with glass fibres (GRP) are widely used [1]. This kind of composites is use because of its high specific strength and stiffness [2]. In addition, these composites can easily get complicated shapes and they show high chemical and environmental resistance.

In the same way, during last decades, carbon fibres as reinforcement have been used widely in polymer matrix composites, especially unsaturated polyester [3] due to an increase of the mechanical and electrical properties. As a result of the success of this kind of reinforcements, during the last 15 years it has been developed a great technology around carbon nanotubes (CNT), which were discovered in 1991 [4]. CNTs show exceptionally high electrical and mechanical properties, and therefore these properties will be transmitted to the composites in which they are put into [5]. However, CNTs are too expensive to be used in industrial applications where a large-scale is needed.

The problem of the cost can be solved by the use of carbon nanofibres (CNF). Due to their relatively low cost, CNFs are perfect candidates to partially substitute traditional carbon fibres and CNTs, especially in polymer matrix composites [6].

Therefore, owing to the price and excellent properties, CNF are an ideal reinforcement for GRPs to increase the strength of the composites. In the same way, CNFs give composites the possibility of electrical conduction. There are several applications such as static discharge, electrostatic painting or EMI shielding in which composites can be used if they are conductive. These applications could be very important in the automotive industry to produce lighter vehicles [7-9]. This paper studies how CNFs work as reinforcement in this kind of composites and the influence of the manufacturing method in the mechanical and electrical, with the aim of a future application in the automotive industry.

2. EXPERIMENTS

The matrix of the laminated composites was an isoftalic polyester resin recommended for use in high performance applications. Laminated composites were cured during 24 hours at room temperature and then post-cured for 16 hours at 40ºC according to supplier's recommendations.

Carbon nanofibres have been used as reinforcement are Grupo Antolín NanoFibres (GANF) and present diameters between 20 and 40 nm with a highly graphitic (~70%).

Two different types of glass fibre reinforcement have been used. Chopped Strand Mat (CSM) was 300g/m^2 E-glass and it was made from 50 mm long glass filaments with a styrene soluble emulsion binder. It was also used a bidirectional 500 g/m^2 E-glass woven roving (WR).

In order to compare obtained results two different manufacturing method were used: Hand lay-up method and vacuum bag technique. Hand lay-up is the simplest open moulding method of the composite fabrication processes. Reinforcing mat or woven roving was positioned manually in the open mould, and resin was brushed over and into the glass plies. Entrapped air was removed manually with rollers to complete the laminates structure. For a high quality part surface, a plane glass was used as the mould surface (Figure 1a). On the other hand, vacuum bag moulding is a refinement of hand lay-up that uses vacuum to eliminate entrapped air and excess resin. After the lay-up was fabricated, a nonadhering film of nylon was placed over the lay-up and sealed at the mould flange. Vacuum was drawn on the bag formed by the film while the composite cure at room temperatures (Figure 1b).

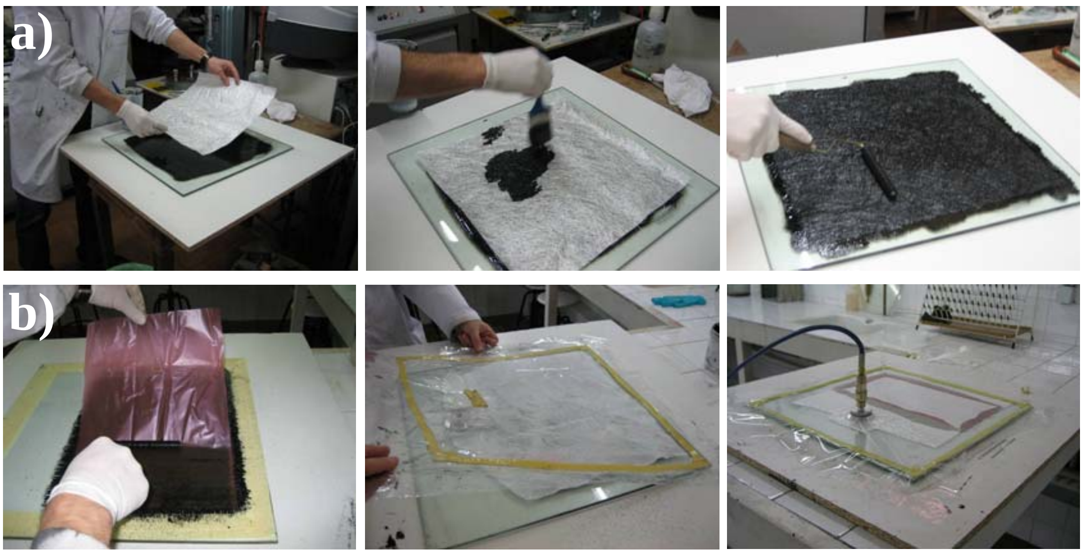

Figure 1. a) Hand lay-up method steps and b) vacuum bag method extra steps.

Two different glass fibres layouts were prepared for both methods: four 300 g/m^2 CSM layers and three CSM layers with two 500 g/m^2 WR layers inserted between the CSM layers. The resin used in these composites was previously loaded by mechanical mixing with CNF before laminating, in the range between 0 and 2 wt%.

Laminated composites were cut with a diamond blade saw to get test specimens according to ASTM Standards for flexural (ASTM D 790-00) [10] and tensile testing (ASTM D 3039M-95a) [11]. Volume electrical resistivity was also measured.

3. EXPERIMENTAL RESULTS

3.1 3-Point bending test

3-point bending tests were carried out for every composition of the prepared laminated composites. Obtained results are shown in Figures 2 and 3.

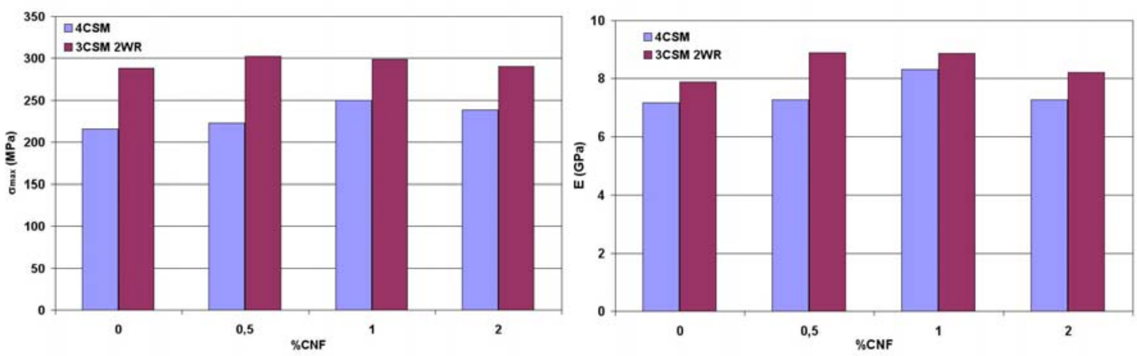

Figure 2. Flexural strength (σ_{max}) and modulus of elasticity in bending (E) obtained results for composites prepared by the Hand Lay-up method.

As it can be seen in Figure 2, the addition of CNF to the composites produces an increase in the flexural strength and modulus of elasticity in bending for every composition. Composites containing 0.5 and 1 %CNF show the best results. Even though the increase of the flexural strength with regard to the composite without CNF is not so large, it must be taken in account that the real CNF percentage in the whole composite is lower. It should also be noted that there is an important increase of the flexural strength when woven roving is incorporated to the glass fibre layout due to the higher amount of glass fibre in the composite.

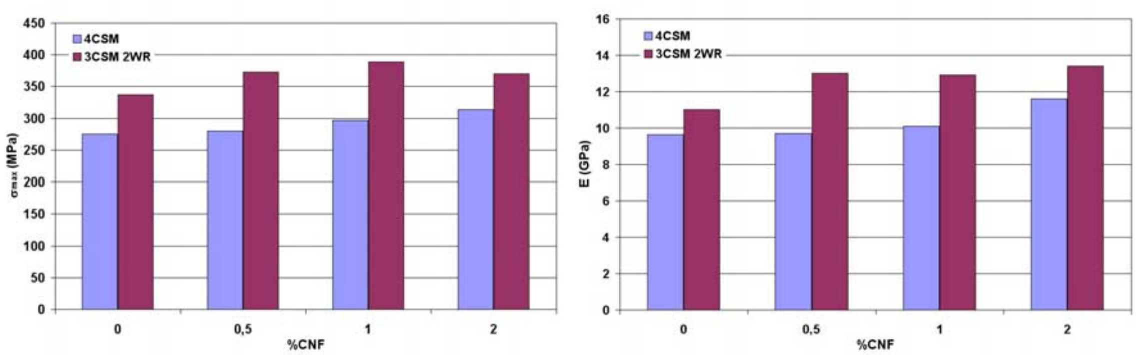

Figure 3. Flexural strength (σ_{max}) and modulus of elasticity in bending (E) obtained results for composites prepared by the Vacuum Bag method.

In the case of the laminated composites prepared by the Vacuum Bag technique (Figure 3), it can be seen a similar behaviour than in the case of hand lay-up composites. The laminates are weakly reinforced by the presence of CNF and the composites with 3 CSM and 2 WR layers in their structure show the highest strength.
Comparing the obtained results for the two manufacturing methods, it must be noted that the Vacuum Bag technique produces stronger composites with the same

composition. The increase of the strength is mainly due to a better adhesion between fibres (glass and CNF) and matrix as a result of use of vacuum. The pressure that the film produces over the composite allows a stronger adhesion.

3.2 Tensile test

Tensile tests were also carried out for every composition of the prepared laminated composites. Obtained results are shown in Figures 4 and 5.

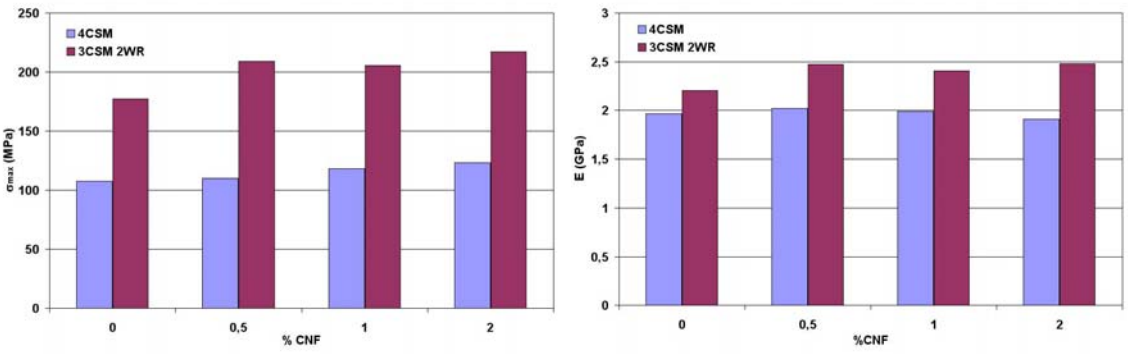

Figure 4. Ultimate Tensile Strength (σ_{max}) and Young's modulus (E) obtained results for composites prepared by the Hand Lay-up method.

In the case of the tensile test we found the same behaviour as in the bending test commented before. The presence of CNF in the matrix improves the ultimate tensile strength (UTS) of every composite prepared by the hand lay-up method. However, there is an important aspect in these results in contrast to bending tests' ones. The difference between the tensile strengths of both glass fibre layouts is much higher in the tensile test. This difference can be explained because of the type of stress produced over the specimens during the test. The presence of the WR layers produces in the laminated composites a better reinforcement when the stress is uniaxial (case of tensile test) than in the bending test (tensile and compressive stress).

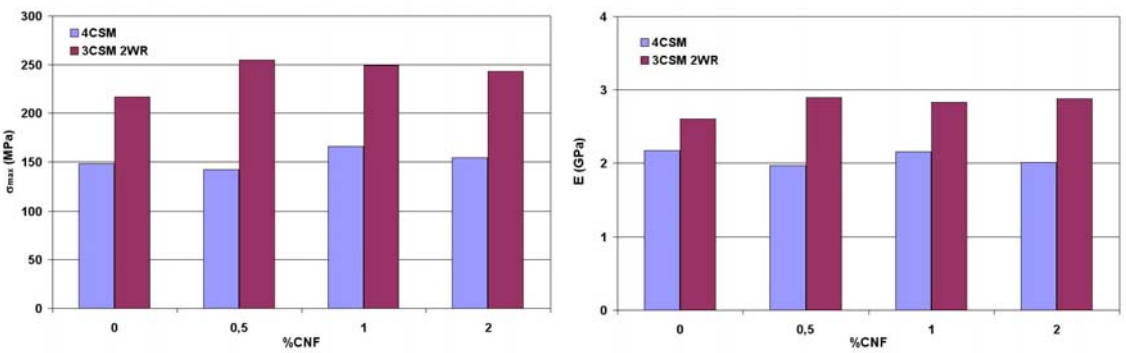

Figure 5. Ultimate Tensile Strength (σ_{max}) and Young's modulus (E) obtained results for composites prepared by the Vacuum Bag method.

Vacuum bag laminated composites results obtained in the tensile tests (Figure 5) corroborate the explanations given before. The UTS of the composites prepared by this method are higher than the hand lay-up ones for every composition. There is also higher difference between the mechanical results of the two glass fibre layouts as in the previous case. And finally, it is also found the reinforcing role of the CNF when they are added to the composite compared with the composites without CNF.

3.3 Electrical measurements

Finally, electrical resistivity (ρ) was calculated from the measured electrical resistance for every composition and the obtained results can be seen in Figure 6.

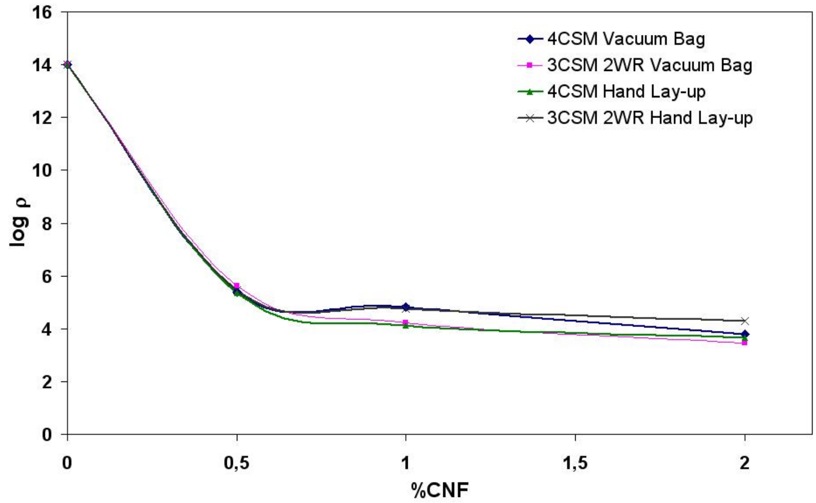

Figure 6. Log ρ (Ω·cm) as a function of the %CNF in the matrix of the composites.

As it can be seen in Figure 6, the addition of CNF produces an important decrease of the electrical resistivity in all the composites, regardless of the manufacturing method. With only 0.5 %CNF in the matrix, the composites can be considered "conductive". According to these results, it can be assumed that the manufacturing method is not the main factor to achieve electrical conduction. Therefore, it is only necessary adding enough %CNF to create a "conduction network" through the composite.

This electrical resistivity values allow the use of these composite in static discharge or electrostatic painting applications (Figure 7).

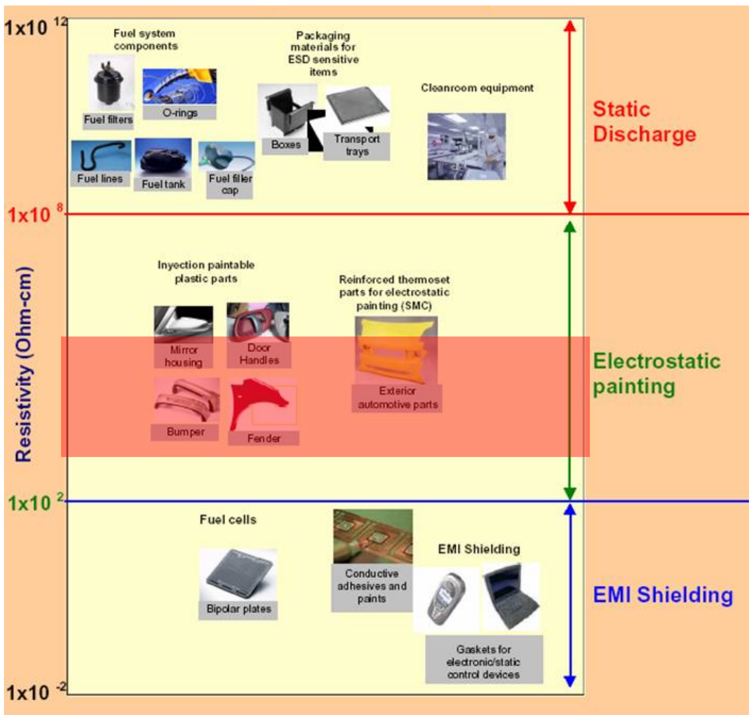

Figure 7. Composites application as a function of their electrical resistivity and the range of the studied composites values (marked in red).

4. CONCLUSION

This work has shown up the possibilities of carbon nanofibres as reinforcement to be used in industrial or semi-industrial composite materials. By adding only 0.5 or 1%CNF with regard to the polymer matrix mechanical properties were found improved in both flexural and tensile tests. It has also be found electrical resistivities, in the range between 10^5 and 10^3 $\Omega\cdot$cm. These values are low enough to use these composites materials in applications where polymer matrix composites could not be used because of their high resistivity, e.g. static discharge, electrostatic painting.

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[11] ASTM D3039M-95a. "*Standard Test Method for Tensile Properties Matrix Composite Materials*"