

Bending and Compressive Properties of Fabric Reinforced Composites

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Among the reinforced composites the ones with fabric reinforcements are studied due to of their excellent properties. This type of materials allows the control of properties due to the placement of fabrics in the reinforcement structure. This study is carried out to identify the effect of reinforcement sheets orientation on the mechanical properties of composites with epoxy matrix and the effect of modified matrix on the same properties. Four types of fabrics had been used as reinforcements for materials each material being reinforced with a single type of fabric excepting the medial sheet which is the same for all the materials. Both three point bending tests and compressive tests were performed perpendicular on the reinforcement plane.

Keywords: epoxy resin, modified epoxy, fabrics, bending tests, compressive tests

The fabric reinforced thermoset polymers are of large interest in composite industry due to their cheap forming technique and their spectacular properties [1]. The fabrics are allowing the regulate distributions of fibres inside the materials and this is leading to very good mechanical properties. Of course from industrial point of view there are technologies to produce pre-pregs which are orthotropic systems with all the fibres aligned in one direction [2, 3]. These pre-pregs are designed such as the composites manufacturers to use them as elementary units to form laminates by bonding together a number of them. Generally the bonding process is involving high values of pressure and temperature sometimes completed by the use of an adhesive. In such type of materials one very important problem is the one of bond resistance and the materials designers have to take into account this issue when they are designing a material for a certain application [4]. In this case, as the theory claims, they have to design the material to resist to higher loadings than the ones required by the application.

The thermoset polymers are solid substances that are obtained by initiating a polymerization reaction through mixing two liquid substances one is called resin the other one is called the hardener [5, 6]. After the mixture is realized its viscosity increases till the solution becomes a solid and from this moment the polymer is formed and any intervention is impossible. Varying the mixing ratios it is possible to obtain fast polymers (with a very short time gel period) and polymers with a gel time long enough to allow manufacturing manoeuvres. That is way reinforced composite materials with thermoset polymer matrix are more attractive for manufacturers than the ones with thermoplastic polymer matrix [7]. The most common method to form reinforced thermoset polymers is the one

called lay-up or wet lay-up that consists of alternate depositions of polymer and reinforcement layers to obtain a certain shape [8]. In the automotive industry, for instance, this method is used especially to tune some parts of the car body but in this case only glass fibres are used (due their low price) and the fibres are not regularly distributed [9]. It is difficult to obtain a fibre reinforced composite with arranged fibres because all the known fibres (glass, carbon, aramid) do not present lateral filaments and they are easily gliding one on each other destroying the regular distribution when the polymer layer is spread [10, 11].

A solution to obtain fibres reinforced composites with regularly distributed fibres is to use fibre fabrics instead of rovings or individual fibres. The fibres manufacturers are offering a very large diversity of fabrics for various applications. For this study simple type fabric of carbon fibres, glass fibres and aramid fibres were chosen. A special type of fabric was used as medial sheet of reinforcement while the other types of fabric are symmetrically distributed related to medial sheet. The special type of fabric is a handmade transformation of a mixed fabric made of carbon and aramid fibres on a fraction of 2:1 in the warp while in perpendicular direction the sequence carbon:aramid is 1:2. On this direction (perpendicular on the warp) of fabric each second yarn of aramid fibres was replaced with a yarn of glass fibres in which a tinned wire of cooper was inserted. The cooper wires 0.2 mm diameter were inserted in order to increase the electromagnetic shielding of material and to investigate the possibility to get loading information by means of cooper wire electric resistance.

All the three fabrics (fig. 1) were prepared to ensure a high quality of the interphase fibre-matrix and their stability during cutting and moulding. The forming technique is a

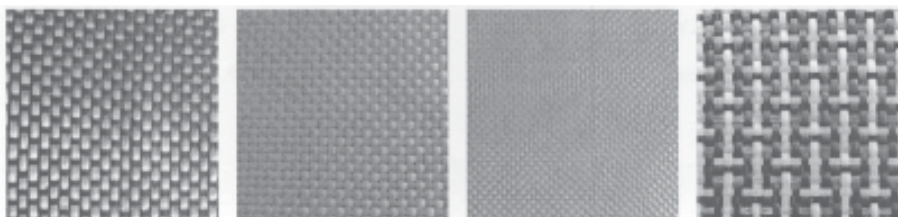


Fig. 1. The fabrics used to reinforce the materials. From left to right: carbon fibres, aramid fibres, glass fibres and hybrid fabric

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modification of wet lay-up method with the pre-polymer imbued sheets of fabrics placed into a mould. Using this technique is possible to set various orientations of reinforcement sheets only by cutting them on desired directions from the fabric [12, 13].

There are several studies regarding the mechanical properties of fabric reinforced polymer matrix composites [14, 15] and also the laminate theory is offering some mathematical description of these materials by using an approximation for mechanical constants of fabric reinforced lamina [16, 17]. This study is made to point out the type of fibres, orientation of reinforcement sheets, and modified matrix effects on mechanical properties of formed materials.

Experimental part

Materials and methods

The epoxy system Epiphen RE4020-DE4020 (Bostik) was chosen as matrix for materials. This is 45 min gel time system which allows 30 min of manoeuvring before becoming too viscous. Also the system allow modifications by mixing the RE-4020 component with various powders and then realising the pre-polymer mixture (between RE – 402 and DE – 4020). For this study three classes of fabric reinforced composites had been formed. All the materials are reinforced with 17 layers of fabrics and these layers are mirror distributed relative to medial layer (which consists on the above mentioned special hybrid fabric). Each material is reinforced with the same type of fabric in all its layers the differences between classes being made by orientations of layers (for class C1) and type of matrix (class C2). The three materials in C0 class are reinforced with all the fabrics oriented at 0° meaning that for all the reinforcement layers (excepting the medial one) the yarns of warp and fill are reciprocal parallel and parallel with the mould edge. The matrix of C0 class is made of epoxy resin. In each class the material named Cx.1 is reinforced with carbon fibre fabric, Cx.2 is reinforced with aramid fibre fabric and the last one, Cx.3 is reinforced with glass fibre fabric. For the classes C1 and C2 the layers orientations of carbon and aramid (C1.1, C1.2, C2.1, C2.2) fabrics are $0^\circ/45^\circ/0^\circ/30^\circ/15^\circ/30^\circ/0^\circ/30^\circ/H90^\circ/30^\circ/0^\circ/30^\circ/15^\circ/30^\circ/0^\circ/45^\circ/0^\circ$ with the angles measured from warp direction, while for the glass fibre fabric reinforced materials (C1.3 and C2.3) the layers orientation is $45^\circ/30^\circ/15^\circ/30^\circ/45^\circ/30^\circ/15^\circ/45^\circ/H90^\circ/45^\circ/15^\circ/30^\circ/45^\circ/30^\circ/15^\circ/30^\circ/45^\circ$. The difference between materials in class C2 and the ones in class C3 is made by the matrix. Class C2 materials have epoxy resin matrix while for the materials in class C3 the matrix is made of epoxy resin with 10% starch, 10% aramid powder

and 10% carbon black (in weight ratios) for layers 1 to 5 and 13 to 17 while for the layers 6-12 epoxy resin with 10% starch, 10 carbon black and 10% ferrite (also weight ratios). Realization of such type of matrix is made possible by the forming technique and by the versatility of the polymer. The mentioned additives are seen as modifiers of basic properties of epoxy resin excepting the starch which is firstly dispersed into the main component of epoxy system to prevent aggregation of the other powders [18, 19].

After their formation all the materials were thermally cured according the epoxy producer recommendations to achieve best properties of polymer. The samples for three point bending and compressive tests were extracted by cut on a water jet machine avoiding the thermal depreciation of material edges. In figure 2 (middle column) all the materials are looking as mats because the aramid fibre is difficult to cut due its high shear modulus. The left column presents cross-sectional microscopic images of carbon reinforced materials and the right columns contains images of glass reinforced materials. The white spots in the lateral columns represent the cooper wires.

Results and discussions

From each material five samples were extracted for three point bending tests. Their dimensions had been computed according ISO 178 because the thickness of the materials is not the same. Other five samples were extracted for compressive tests, according to ASTM D – 695 – 02 A. All the samples were cut out from the original plate only along the warp yarns. All the tests were performed of perpendicular direction on reinforcement plane such as the neutral plane is the medial plane reinforced with the hybrid fabric which was cut parallel with the fill and that is why when the configuration of reinforcement was described above the middle layer was marked $H90^\circ$. All the materials kept their integrity at loads of about 10kN so no plastic deformations were noticed. All tests were performed on an Instron 8874 machine at a speed of 2mm/min.

The results are presented, for bending elastic modulus in figures 3 and 4. The comparison between the materials in first two classes shows that the materials with different orientations of layers have smaller bending elastic modulus then their homologues with the same orientation of fibres with a maxim value for the carbon fibre fabric reinforced composites inside each of two classes. Taking into account the way the samples were extracted all the samples in first class (C0) were loaded on the most resistant geometry the one with the highest number of long fibres and that is explaining their behaviour.

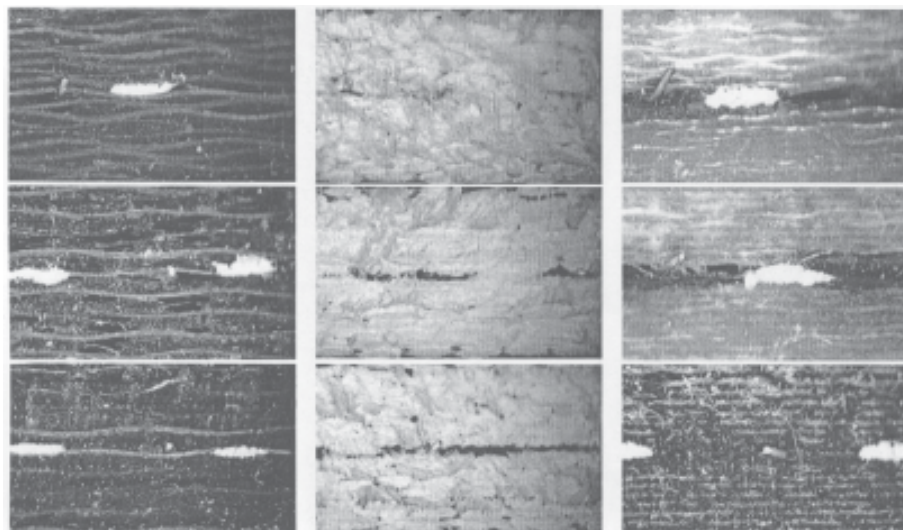


Fig. 2. Cross-sectional microscopic images of materials. Left, carbon reinforced materials. Middle, aramid reinforced materials. Right, glass reinforced materials

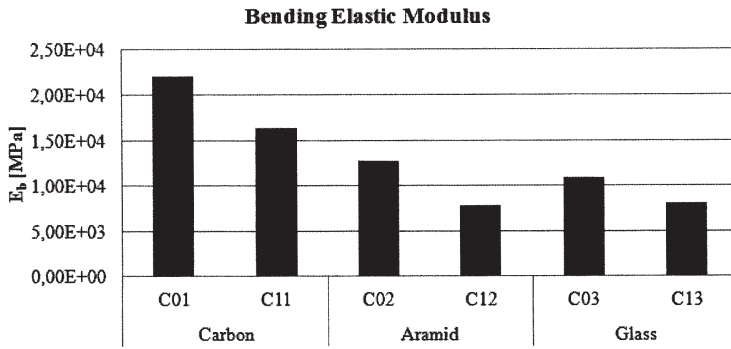


Fig. 3. Bending elastic modulus for materials in first two classes

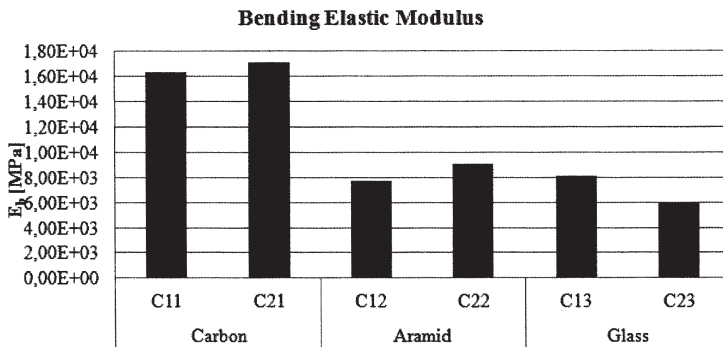


Fig. 4. Bending elastic modulus for materials in last two classes

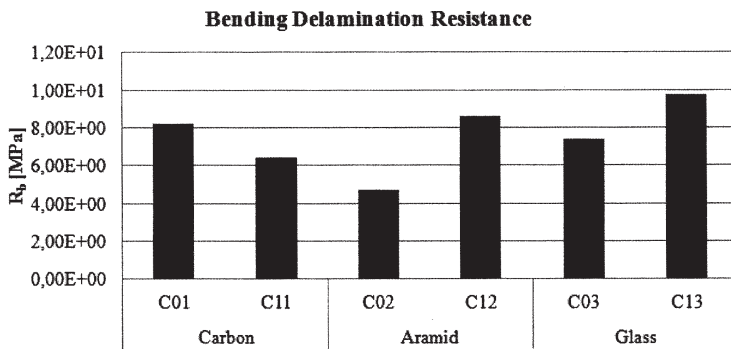


Fig. 5. Delamination resistance for materials of classes C0 and C1

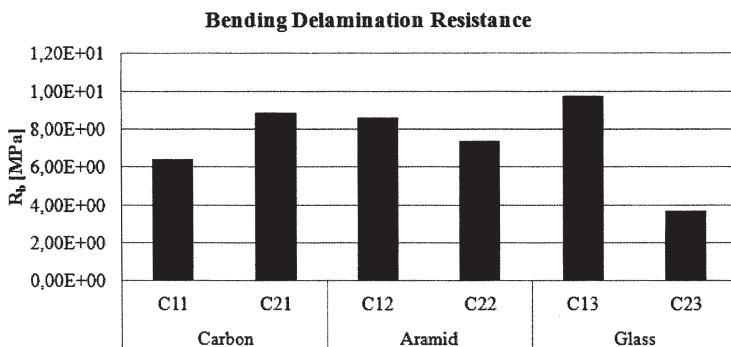


Fig. 6. Delamination resistance for materials of classes C1 and C2

Comparing the same parameter for the last two classes it might be easily seen that the materials with modified matrix show higher values of bending elastic modulus and the matrix is reducing the effect of fibres orientation due to the fact that this modified matrix is more rigid (because of the powders used). In the case of glass reinforced materials the bending modulus is reaching its smallest value both because the shortness of the fibres and of the matrix rigidity. In the case of carbon fibre and aramid fibre reinforced materials there still are long yarns in samples.

Another interesting parameter which always is studied for laminates is the delamination resistance evaluated through bending tests [20]. For studied materials the values of this parameter are presented, also by comparison, in figure 5 for C0 and C1 classes and in figure 6 for C1 and C2 classes.

For the first two classes can be noticed the fact that for aramid and glass reinforced materials the values of delamination resistance are higher for the materials in C1 than the ones of the same parameter and same materials in class C0 while in the case of carbon reinforced materials the situation is opposite. An explanation could reside in the fact that the carbon fibre reinforcement are allowing lower quality interphases with the epoxy resin. The best interphase corresponds to glass reinforced materials intermediate values of the parameter – corresponding to intermediate quality of interphase – characterize the aramid reinforced materials. In figure 6 it can be seen that the delamination resistance of fabric reinforced material with modified matrix is higher than the one of the same material but with epoxy matrix because the lower quality of interphase is compensated by the increasing of the specific area. The other two materials in class C2 show lower values of the

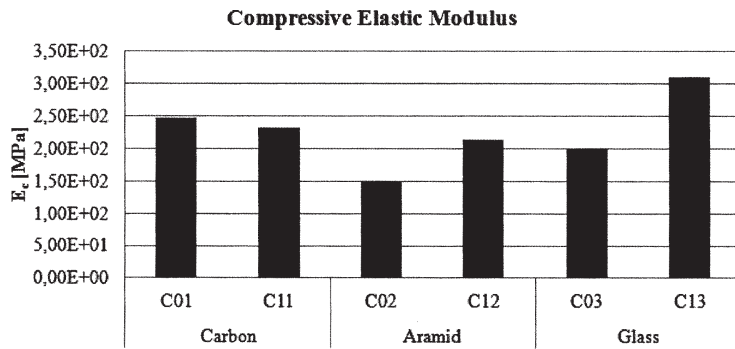


Fig. 7. Compressive elastic modulus – materials in classes C0 and C1

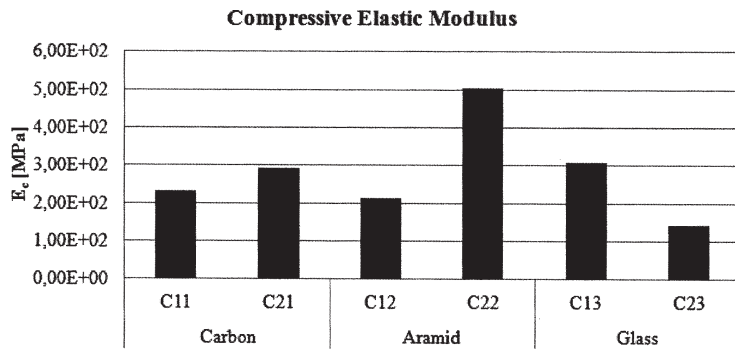


Fig. 8. Compressive elastic modulus – materials in classes C0 and C1

delamination resistance than their homologues in class C1 due to the matrix.

The compressive elastic modulus was evaluated and the values are showed in figure 7 and figure 8 once again by comparison between first two classes and last two classes. High values of the parameter had been recorded for the materials with different orientations of reinforcement layers for aramid and glass reinforcement due to their high transverse elasticity and the fact that being differently oriented the fibres have enough room around them to pack themselves during compression. Comparing results in figure 8 the modified matrix is increasing more than twice the value of compressive elastic modulus for the same reinforcement but with epoxy matrix and five times relative to aramid reinforced material in class C0. The value of the parameter for carbon reinforced material in class C2 (C21) is a little higher than the one of the material in class C1 (C11) meaning that matrix is correcting the defects introduced through different orientation of fibres. The weakest material is the one reinforced with glass fibres and modified matrix due to the fact that glass fibres are acting one on each other during the external loads producing their reciprocal fracture.

Conclusions

Three classes of materials had been designed and formed in order to identify the effect of fibres orientation and the effect of modifying the matrix over the bending and compressive properties of materials. All the materials are fabric reinforced materials with the same type of fabric in entire volume of material, excepting the medial layer which is made of one special type of fabric.

The modified matrix is also divided into external parts (layers from 1 to 5 and 13 to 17) and internal part (6 to 12). For the external parts the epoxy resin was modified by adding 10% starch, 10% aramid powder and 10% carbon black all of them in weight ratios. The starch was used to avoid the other two components aggregation. The carbon black is meant to change the electric conductivity of materials while the aramid powder is meant to increase the shock resistance of materials. The internal part is modified by adding 10% starch, 10% carbon black and 10%

ferrite, the last one meant to change the magnetic properties of materials.

Bending tests showed that the best performances regarding bending elastic modulus are reached in the case of materials with all the reinforcement layers oriented in the same direction due to the presence of long fibres in the samples and with a maxim value for carbon reinforced materials. Changing the orientation of some layers the bending elastic modulus decreases for all the samples but this situation may be corrected by using the modified matrix. The exception is the glass reinforced material the one in which there are not any long fibres.

The delamination resistance is higher for the materials with differently oriented layers excepting the carbon reinforced material due to the poor quality of interphase between carbon fibres and matrix but the situation is partially solved by using the modified matrix. In the case of aramid reinforced material the use of modified matrix is decreasing the value of delamination resistance. In the case of glass fibre reinforced materials the use of modified matrix is reducing the delamination resistance at half of its value for the same reinforcement with epoxy resin.

The compressive tests showed that the most valuable materials are the ones with aramid fibres fabric reinforcements. The aramid reinforced modified matrix material has a compressive modulus five times higher than the one of the material with the same reinforcement but with all the layers oriented in the same direction and epoxy resin as matrix. Poor results are noticeable for glass fibres fabric reinforced materials, especially the one with modified matrix due to the interaction between fibres and between fibres and ferrite particles that produce fracture of the fibres.

Other studies might be leaded with various fabrics used to reinforce the same material – in order to reduce the anisotropy, and with other formulae for matrix modifications. Of course such a study cannot be completed without tensile tests and thermal and electric tests to characterize the materials. More than that the tensile tests results might be compared with the estimation of elastic constants made on the basis of laminate theory.

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