MANUFACTURING METHOD OF CARBON/EPOXY COMPOSITE BENT TUBES WITH VARIABLE SECTION

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ABSTRACT: This paper presents a new manufacturing technology of bent tubular parts with variable section made of reinforced fibre composite materials. The authors propose a study regarding a mountain bike handlebar made from carbon/epoxy materials. The mechanical characteristic of the materials are determinate by tensile tests.
KEY WORDS: Composite materials, carbon fibre, pipes

1 INTRODUCTION

Composite materials (CM) belong to a class of materials with specials characteristics. They have various applications due to their multiple properties and features. The fibre reinforced composite (FRP) came successfully in our day by day life after a stage done in the top domains of the global technology. Used in medical, military, performance sports, spatial domains or race cars building, these materials get to be used in our everyday life. These are the reasons why the authors included this segment of modern and extremely dynamic engineering materials into the study, which produced significant developments regarding the usage of these materials in different fields.

From the point of view of tubes obtaining from FRP, the most existent technologies, mentioned in the scientific literature, is the filament winding or pultrusion (Barbero, 1999), (Gay, D. et al, 2003), (Vasiliev, V.V.& Morozov, E.V.,2001).

The reinforced structures with fibres got to a lot of mechanical characteristics that differ when measurements are done on different directions of the application. In this way it was necessary the accomplishment of a homogenization study for these materials, study that can allow the usage of some material constants in dimensioning procedure.

The homogenization method supposes determination of the material constants for a homogeneous material, the equivalent of the composite material (Angioni, M. et.al, 2011), (Lukkassen, D et.al, 2010), (Andrianov, I.V. et.al, 2008), (Bakhvalov, N.S.,& Panasenko, G.P., 1989), (Greco, F.,& Luciano, R.,2011), (Georgiades, A.V., et.al, 2006), (Jasiuk, I.,& Kouider, M.W., 1993), (Hollister, S.J.& Kikuchi, N., 1992), (Wang, W.-X., et.al, 2006).

The design of tubular parts has to rely on material constants of the test specimen that are obtained on the same geometric shape as for the structure.

Jin-Chee Lui and Wu (Lui, J-C & Wu H.-C., 2010) proposed three testing method for bicycle frame. They studied stresses produced by torsion, frontal and vertical loadings using the finite element (FE) analysis. The fibre direction and stacking sequence design for the bicycle frame made for the carbon/epoxy laminates composites were proposed.

In the case complex structure to determinate the constants of FRP is not too easy and not all the time the theoretical researches are validate by practical results.

Different authors proposed some rapid manufacturing technologies to obtain a prototype (Leordean, V.D, et.al. 2011), (Coman, A, et.al., 2013), (Sabau, E, et.al, 2010), (Panc N., et.al, 2011), (Chhabra, M.a & Singh, R.b.2011), (Kumar, S.a & Kruth, J.-P 2010), (Singh R, 2013), (Udroiu, R, et.al. 2011).

The authors proposed to manufacture and to determine the materials constants of tubular bent carbon fibre material with variable cross-section. They propose a study regarding a mountain-bike handlebar. They start with a simple and innovative method to manufacture the bent tubular pipe. It was used modern technologies to design and to obtain the prototype. The proposed method for obtaining bent tubular and variables section parts, offers a simple solution for obtaining models that are not require complex equipments or machineries Tubular

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pieces were manufactured in closed mould using an internal pressure.

2 METHODS AND MATERIALS

2.1 Design

Considering the observations of certain experts were designed a new model of tubular part. We keep the same standard for the middle and the ends of the diameter dimension.

The virtual prototype was made using the 3D CAD SolidWorks software. The 3D prototype is submitted to selective laser sintering (SLS) machine. Through this process, in short time, a prototype from plastic material (polyamide - PA) was obtained. We manufactured the prototype on the SLS "Sinter station 2000" machine. The plastic prototype was verifying on bicycle. The next step was produced the mould to obtain the piece from composite material.

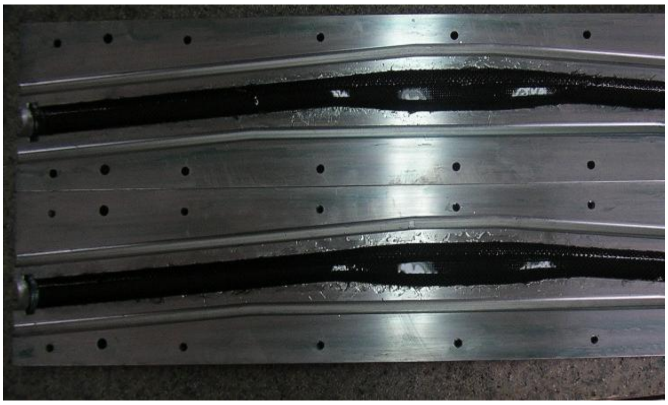

Figure 1. The metallic mould

Proposed technology requires manufacturing of a metallic mould with a CNC processing centre. Based on the virtual CAD model (CATIA software) the mould is designed in 3D to the corresponding dimensions of the prototype.

To manufacture the mould, specific software to program the CNC machine, it must be run in Solid CAM. The program is submitted to the process centre, which executes the milling. In this case we used a CNC type Fadal VMC 4020.

The mould (Fig.1) was manufactured from aluminium alloy type 7075-T6. Due to three-dimensional complex shape of mould concavity its roughness has to be reduced after milling.

2.2 Manufacturing method

The process consists in forming tubular parts of composite materials with closed mould, the mandrel, being removed. Its place is taken by an elastic tubular element on which an internal pressure it is applied. The composite material, in non-polymerization state, is deposited on the elastic element and inserted in the mould. An internal pressure is applied on the elastic element. Its volume increased. So a pressing of composite material to mould's wall is realized. The mould is heated trough its own plant or in heating room. After polymerization, the elastic element is removed and the composite material tube is released of the mould.

Figure 2 presents the main scheme of the facility production of bent and variable section tubes made from reinforced fibre composite materials. In the semi mould concavity 1 is placed the elastic element 3 on which is applied the composite material fabric.

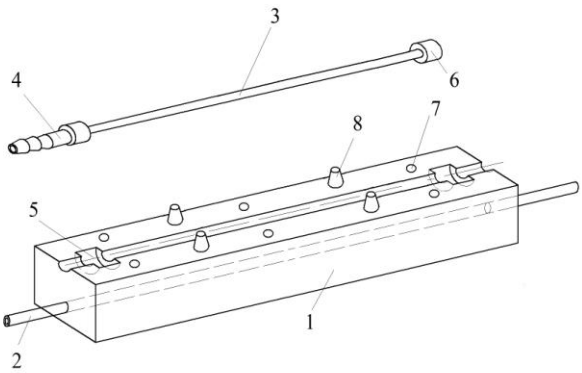

Figure 2. Main scheme of tubes facility production

After closing the matrix with connection coupling 4, a pressure is applied to the elastic element this changing its volume.

The connection coupling to pressure source 4 and the elastic element stopper is placed in channel guide 5 for not being pushed out from the mould. The semi moulds are centred with the help of centring pins 8. Setting the two semi moulds is possible using screws on setting holes 7. The mould has its own heating facility 2 or can be placed in a heating chamber for the polymerization of composite material. By removing the internal mandrel, we have the possibility to obtain composite materials tubes with variable wall thickness according to the reinforced composite material thickness.

The process eliminates the released problems of composite tube on the mandrel after the composite materials polymerization. Through this technology it is allowed to obtain reinforced fibre composite materials, bent and having variable sections. Using traditional processes, the mandrel, which is used for manufacturing the tube, would be impossible to be removed after material polymerization. Its centre section is bigger than end sections.

2.3 Composite materials design. Methods of analysis

Were used carbon fibre plain fabric (200g/m2, 3K), UD longitudinal elastic carbon fibre hose extensible from 20 to 50 mm (HT carbon fibre 9K, 10 ends/cm, flat width, welt 3 ends/cm black double), carbon fibre hose ±450, to 12-40 mm diameter (96 threads Toray 3K, Weave double-braid), in epoxy resin type L285 and 286 the hardener from Hexion manufacturer. The mixing ratio is 100:40 parts by weight. It was respected the work condition according to the prescription of the resin producer. During the manufacturing process the internal pressure in the mould was 0.6 MPa along the polymerization time. Easy machining is required in the separation plane area. This removes the excess of the material from the surface (Figure 3). The configuration laminate of the tube is: [0º-90ºf/0º/±45º].

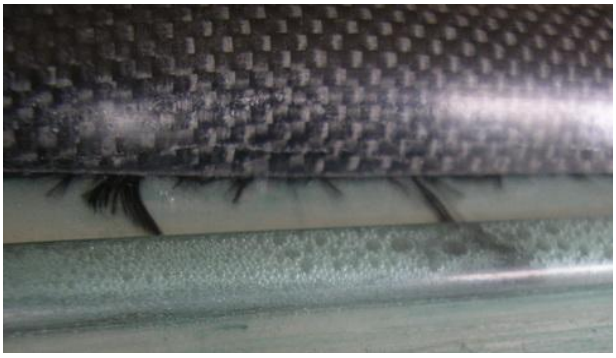

Figure 3. The excess of the resin after polymerization

Knowing the real material parameters plays a key role in a reliable FE simulation of the composite handlebar. The manufactured material is an unsymmetrical (unbalanced) orthotropic laminate. Experimental identification of mechanical properties being a complicated reverse engineering problem entailing several tests specifically designed. For determining given elastic constant tests should be run always serially in order to reliably determine the value of that elastic constant on a statistical basis. Because of anisotropy, non-homogeneity and internal defects of the material, different testing procedures may even result in significantly different values of the same elastic constant (Genovese K. et.al, 2004), (Kosa G, et.al, 2011), (Kollar L, & Springer GS. 2003). Analytical models and numerical techniques are much simpler than experimental techniques. They are often based on highly idealized conditions. That may be openly in contrast with the real behaviour of the material. In the FE simulations the composite laminate has been considered a single-layer equivalent model with orthotropic behaviour characterized by a set of nine engineering constants.

Calculation of the material constants was done using a theory based on classical laminated plate theory software, for performing simple calculations, called the Laminator ver. 3.7.. Based on single ply material proprieties and layup (stacking sequence) the software calculates the apparent laminate stiffness properties, Poisson ratios, shear coupling coefficients and A, B, D stiffness matrices of the laminate.

Table 1 shows the input data materials properties of individual plies according to the producer. Bi-directional ply was considered for calculation as two uni-directional layers having the half of thickness and orientation +45° and -45° respectively

Table 1. Designed ply material properties of carbon/epoxy composite

Layer	Material	E_1 [GPa]	E_2 [GPa]	E_{12} [GPa]	ν_{12}
1	Weave 2x2 Twill	53.6	55.2	2.85	0.042
2	UD	181	10.3	7.17	0.28
3	UD	181	10.3	7.17	0.28
3	UD	181	10.3	7.17	0.28

Apparent values of the material constants corresponding to the single-layer equivalent model obtained using the above presented stacking sequence is listed in Table 2. In this table the subscript 1 denotes the fibre axes of the second ply.

Table 2. Designed material constants of the single-layer equivalent model

$\mathbf{E_1}$ [GPa]	$\mathbf{E_2}$ [GPa]	$\mathbf{E_3}$ [GPa]
67.7	24.61	24.61
ν_{12}	ν_{13}	ν_{23}
0.657	0.239	0.239
$\mathbf{G_{12}}$ [GPa]	G_{13} [GPa]	$\mathbf{G_{23}}$ [GPa]
11.32	9.93	9.93

2.4 Manufacturing of tensile test specimens

To determine the mechanical characteristic of the carbon/epoxy laminates, plates were manufactured from the same materials as for the handlebars. Layers distribution was kept the same and reinforcement degree. For obtaining the plates were used vacuum forming technology. With this technology it is possible to manufacture compact composite plates.

The reinforcing material resin wet applied on the plate mould, was covered by a perforated foil, and after, by an absorbent felt. The whole assembly was introduced in a special foil bag afterwards. After closed, the bag was coupled to a vacuum pump, and the bag was vacuumed. During this time the atmospheric pressure will work on the mould a uniform packing not dependant of the plate complexity. The purpose of the vacuuming is the eliminations of the air bubbles and the volatile compounds which are retained in the felt layer.

The mould was introduced in a heating chamber and kept at 60 ºC for 3 hours for a more uniform and faster polymerization. During all this time, the pump was vacuuming

Five specimens were made from each plate and subjected to uniaxial tensile tests on a INSTRON 8862 testing machine. The samples dimensions were compliant standards EN ISO 527-4 and ISO 527-5. The ends of the specimens were reinforced with a 2 mm thick, 20 X 35 mm TAB in order to avoid the slippage and breakage of specimens at clamping. The TABs were made from glass woven fabric reinforced epoxy resin, and were fixed on the specimens with a structural epoxy glue of type Scotch-Weld DP9323 A-B.

3 RESULTS AND DISCUSSION

The fibber volume fraction determined was 67.33% and the final weight of the handlebar was 150 g at 680 mm length.

The result of proposed innovative technology is shown in Figure 5, which represents a bent tube with variable section made from carbon fibre in epoxy matrix.

Through the innovative solutions adopted, this technology allows us to produce tubular parts calibrated on the outside of mould used. The reinforced material can be preferentially oriented on request direction, keeping its architecture after polymerization. It is obtained a well compressed composite material with a uniform structure, with a high reinforcement degree, which has high mechanical characteristics.

Figure 4. The carbon fibre/epoxy handlebar

The main disadvantage of this process is the necessity of using a mould, which conditions the tube sizes. Using this process, for production of tubes with larger diameters (> 1000 mm) it is necessary that mould to be consolidated. Due to internal pressure applied to elastic tap holder, the resulting forces on mould have significant value. The consolidation of the matrix leads to increasing its weight.

Table 3. Experimental results

E_1 [GPa]	E_2 [GPa]	ν_{12}	N_{23}	σ_{u1}	σ_{u2}
63.1	20.91	0.659	0.261	456.4	99.5

The experimentally obtained results (mean values) are presented in Table 3 and it can be noticed the good agreement with the above presented theoretical ones. Experimental mean values results of tensile testing indicate a value of the ultimate stress of this material, in one direction, comparable to that of steel.

4 CONCLUSIONS

Traditional materials of the bicycle handlebar are the steel or aluminium alloy. For the purpose of reducing weight, the carbon/epoxy composite materials are now widely used to make the bicycle handlebar.

This paper presents a specific manufacturing technology of bent tubular parts with variable section made of reinforced fibre composite materials.

By removing the internal mandrel we have the possibility of obtaining composite materials tubes with variable wall thickness according to reinforced composite material thickness. The process eliminates the release issues of composite tube on the mandrel after the composite material's polymerization. This technology allows obtaining reinforced fibre composite materials, bent and variable sections and tubular parts of small diameters. Using traditional processes, the mandrel, on which this tube could form, would be impossible to be removed after material polymerization. Its centre section is bigger than end section.

The resulting parts have superior mechanical characteristics than common materials having a 7 times low density comparing to steel.

Using this manufacturing method was obtaining the weight of the handlebar of 150 g at 680 mm length. The weight of aluminium alloy handlebar at the same dimension is 250 g and for steel 720 g.

With carbon /epoxy handlebar we reduce the weight by 60% in aluminium alloy case and for steel 480%.

The vacuum bag process for obtaining the composite materials has a big advantage. With this process we obtained the same fibber volume fraction like in handlebar case. This allows obtaining the same mechanical characteristic for the carbon composite materials plates like pipes material.

Experimental values of the material constants are agreed with the theoretical ones.

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