RAPID MANUFACTURING METHODS FOR OBTAINING BENT TUBULAR PARTS MADE OF CARBON/EPOXY COMPOSITE

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Abstract: *This paper presents a research regarding a new method to obtain bent tubular parts made of reinforced composite materials. Using modern rapid manufacturing methods and based on competitive prototyping, this paper presents a comparative study of two modern mould manufacturing methods. This paper is also presenting an innovative modern technology for manufacturing bent tubular parts with a variable section made of carbon/epoxy composite materials.*
Key words*: tubes, composite materials, Rapid Prototyping, CAD, CAM*

1. INTRODUCTION

Composite materials entered our daily life after a short period of time in the areas of world technology. It is a priority to obtain composite materials by using simple technologies with minimum investment. The development of the composite materials (CM) in a sustained rate, especially in the last four decades, has led to research which reveal both properties and deficiencies of this materials (Iancău H., et al, 2002), (Vasiliev V.,et al, 2001). Current research of CM area is developed in a sustained rate incorporating advanced technologies of Rapid Prototyping or Computer-aided design (CAD) systems and Computer-aided manufacturing (CAM). All these are done in order to obtain CM parts faster, cheaper and more accessible (Bâlc N., et al, 2000), (Berce P., et al, 2000). The migration of CM of high performance areas to daily areas is in a continuous and sustained rate.
The physical-mechanical properties of these materials require the use of CM more frequently. Composite materials successfully replace the traditional metallic materials.
The paper presents the computed design of a tubular model, using 3D CAD SolidWorks software. The 3D model is submitted to selective laser sintering machine, (SLS). A prototype from plastic material (polyamide -PA), is obtained through this process (Dimitrov K., et al, 2006),(Upcraft S., et al, 2005). The steps of manufacturing the composite material mould, the advantages and disadvantages of this method.
Simultaneously, starting from marker design using the virtual model, it is presented another modern method of manufacturing moulds for composite materials. Both advantages and disadvantages of using this rapid mould manufacturing method are presented in papers (Bere P, 2009).
This paper continues presenting a manufacturing technology of bent tubular parts with variable section made of reinforced fibre composite materials. The new technology uses a mould and a flexible mandrel to witch an internal pressure is applied.

2. METHOD AND MATERIALS

2.1. Prototype Manufacturing Method

In order to obtain a tubular part it is necessary to manufacture a prototype. This could be made by traditional handmade processes or by Rapid Prototyping, due to the complexity of the shape that has a shape with variable sections.
It was preferred the faster and more accurate option – to manufacture the prototype part using the SLS machine. The virtual prototype was made using the 3D CAD SolidWorks software (Fig. 1). The designed part is a mountain bike handlebar. The final purpose of this research is to manufacture the handlebar from a composite material made of carbon fibres in an epoxy matrix. The purpose was to reduce the weight and to increase the mechanical characteristics of the handlebar.

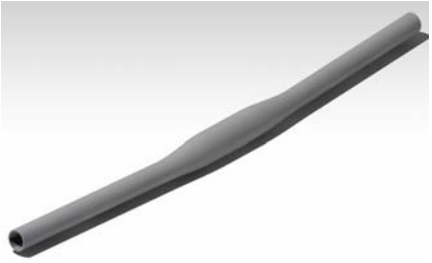

Fig.1. The virtual model made with 3D CAD SolidWorks software.

Considering the observations of the experts in bicycles, a new model of the tubular part was designed. (Fig.1)
The 3D prototype is submitted to a SLS machine type „Sinterstation 2000". A prototype from plastic material (polyamide - PA), is obtained through this process. The machine uses a polyamide powder type DURAFORM. Onto the polymeric surface an epoxy resin is applied. A 5 watts Lasser beam heats the powder on the prototype outline surface. The part is formed by depositing successive layers of about 0.1 mm.
Because the prototype model is too long and doesn't fit in the work area of the SLS machine, it was split in three segments (Fig. 2).
After all the prototype parts were obtained, they were glued together and the model was realised. Because of its high surface roughness (25 μm) obtained in the SLS process, the models surface was processed by applying a filler layer and a mechanical processing with sandpaper and polish.
The surface of the prototype must be polished as much as possible in order to offer an easy released interface. The prototype (Fig. 3) is used to manufacture a mould from composite materials. It is necessary for manufacturing the reinforced fibres composite materials tubular part.
The manufacturing time for this part was 14 hours from which 12 hours only on the SLS machine.

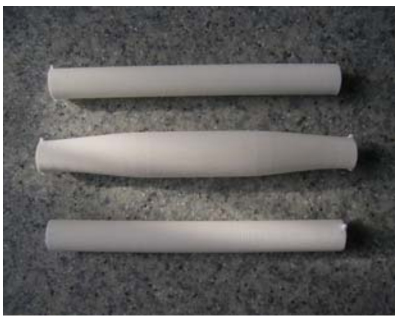

Fig.2. Plastic material prototype

Fig.3. Assembled and processed prototype

2.2. Composite Material Mould Manufacturing

To obtain a tubular part, a composite material mould can be used. The mould is made from two semi-moulds closed with terminal screws.
The mould is manufactured from glass fibre reinforced composite materials impregnated with epoxy resin. An epoxy resin L 235 produced by Lange-Ritter Germany was used. It has a low contraction coefficient (1–2%) compared with polyester matrix (6–15%). This provides a good dimensional precision of the matrix. The epoxy matrix has also a good behaviour at high temperature after a heat treatment at high temperature, higher than the mould's working temperature. The manufacture time was 70 hours. The weight of the mould is 5 kg and the estimated value is 350 Euro.
The advantages of using a composite material mould are: a quick manufacturing, the reduced weight (easy handling of the mould), relatively low costs, very good precision, the active surface is easy to work with, the degraded parts can be easily repaired.
The disadvantages of using a composite material mould are: a low thermal stability over 90° C, a limited number of uses (approximately 200), the active surface of the mould can be easily degraded.

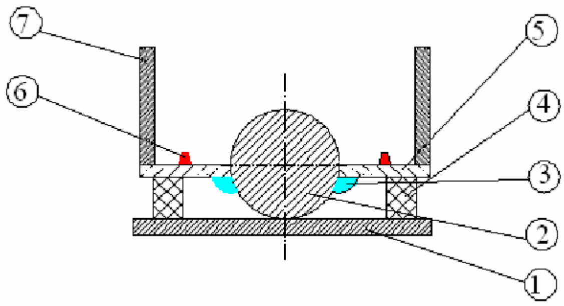

Fig.4. Main scheme for manufacturing a composite material mould 1 – base plate, 2 – model part, 3 – glue (plastic polyethylene material), 4 – distance piece, 5 – separation plane, 6 – fixed mandrel, 7 – perimeter box.

2.3. Metallic Mould Manufacturing

The metallic mould was manufactured with CNC processing equipment. It was designed in 3D by using a CAD CATIA system.

To manufacture the mould, the required software which programs the CNC machine in Solid CAM must run. The program is submitted to the processing equipment, which executes the milling. In this case we used a CNC type Fadal VMC 4020.

The moulds material is aluminium alloy type 7075-T6. It has the strength which is comparable to many steels, and has good fatigue strength. The moulds manufacturing starts with cutting the aluminium alloy plate, the external milling, processing the division planes, heavy-duty milling and shear milling. Because of the three-dimensional complex shape of the mould and its roughness after milling, in the end it was hand processed by grinding with sandpaper with a grain size starting from 180 to 1000 after which a polishing has been made (Fig. 5).

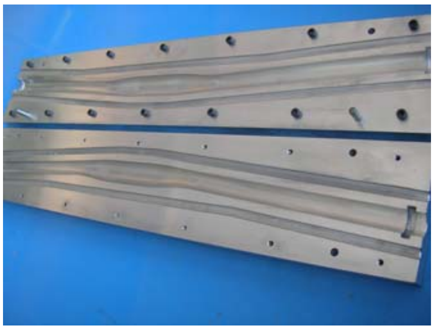

Fig.5. The metallic mould

The total time for manufacturing the mould was 20 hours. The mould weight is 16 kg and its estimated value is 850 Euro.

The advantages using the metallic mould are: the use of rapid manufacturing resources, short manufacturing time, high dimensional precision, high thermal stability, high fatigue strength (manufacture over 1000 parts).

The disadvantages are: high price, highly qualified workers, modern instruments, high weight which creates difficulties in handling.

3. MANUFACTURING METHOD.

The process consists in forming the tubular parts of composite materials by using a closed mould, with the mandrel being replaced 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 inside the elastic element and its volume increases. In this way the composite material is pressed to mould's wall that is heated trough its own plant or in a heating room. After polymerization, the elastic element is removed and the composite material tube is released of the mould.

By removing the internal mandrel, we have the possibility to obtain composite materials tubes with variable wall thickness. The process eliminates the problem of the mandrel extraction from the composite tube. Trough this new technology it is possible to obtain reinforced fibre composite materials, with a bent shape and variable sections, tubular parts of small diameters (< 20 mm), medium (20 – 200 mm) and big diameters (> 200 mm). Trough traditional processes, the mandrel, which can be used for manufacture the tube, would be impossible to remove after material polymerization as its middle section is bigger than the edges.

Figure 6 presents the main scheme for 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. After closing the mould with connection coupling 4, a pressure is applied to the elastic element and this changes its volume. A compression of composite material to mould's wall is achieved. 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 pins 8. Setting the two semi moulds is possible using screws on setting holes 7. The mould has its own heating facility 2 for the polymerization of the composite material.

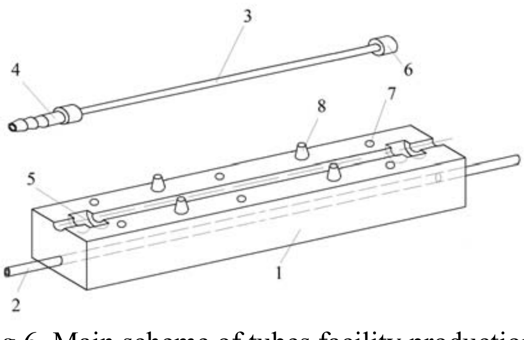

Fig.6. Main scheme of tubes facility production

Trough the innovative solutions adopted, this technology allows us to produce tubular parts calibrated onto the interior of the mould. The reinforced material can be preferentially oriented on requested directions, 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.

During the manufacturing process, the internal pressure in the mould was kept at 6 bar (0.6 MPa) during the polymerization time. Manufacturing technologies of the composite materials usually use vacuum forming at a pressure of -0.9 bars. The proposed manufacturing method use a 6 bars pressure that is almost 6.6 times bigger.

The main disadvantage of this process is the necessity of using a mould, which imposes the tube size. For tubes with large diameters (> 1000 mm) it is necessary to strengthen the mould. Due to the internal pressure applied to the elastic tap holder, the load onto the moulds walls is significantly high. The consolidation of the mould leads to increasing its weight.

Fig.7. The handlebars form carbon fibre

a bent tube with variable section made from carbon fibre in epoxy matrix made with the proposed innovative technology is shown in figure 7. Easy machining is required in the separation plan area to remove the excess of resin from the surface. The fibre volume fraction is 67.33% and the final weight is 95g at 680mm length. The weight reduction in comparison with an aluminium alloy handlebar with similar dimensions is about 2.6 times and 7.8 times for the case of steel handlebar. The result of the proposed innovative technology is the handlebar shown in Fig. 1, which actually represents a bent shape tube with variable cross-section made from carbon fibre in epoxy matrix.

4. CONCLUSIONS

The paper presents the implementation of the modern rapid manufacturing technologies in the field of reinforced fibre composite materials. The phases are: the rapid manufacturing of the SLS prototype, the mould manufacturing by using CAD and CAM system and in the end, with the use of the new technology proposed, the manufacturing of the complex composite materials parts.

Manufacturing the prototype using the SLS system leads to time reduction. The dimensional precision is also superior to hand processed prototype or combined manufacturing technologies.

A comparative study between two modern manufacturing methods is made for moulds manufacture. Both methods offer advantages and disadvantages. Lots of factors that influence a decision must be analyzed, factors like: the dimensional precision, the life time, the work temperature of the mould, the weight, the cost price, the manufacturing time, human resources or the instruments that are used.

This paper also presents a new manufacturing technology of bent tubular parts with variable section made of reinforced fibre composite materials. The resulting parts have superior mechanical characteristics than common materials and a 7 times lower density comparing to steel. Some applications of these parts are: orthopedic prostheses, performing bicycles, robotic arms, motor-sport etc.

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