PLANNING AND MANUFACTURING A MOULD FOR RESIN TRANSFER MOULDING

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ABSTRACT

This study deals with the planning and the manufacturing of a low-cost modular mould to be used in the resin transfer moulding (RTM) and it analyzes the costs and benefits of the suggested innovative solution.

A production chain allows the manufacturing of this cheap mould, with high mechanical performances and fit for mass production and uses technologies generally employed in other production process such as step milling and electrodeposition.

The steps of this production chain are the following:

- definition of the mathematics of the object to be obtained;
- step milling to make the negative of the object, that is the mould model;
- copying process of the negative;
- deposition of a metallic layer on the copy of the mould model;
- application of a reinforcing on the metallic layer.

An evaluation of the production chain has then been made analyzing the dimensional tolerances reached on the mould model and on the copy and the times of fabrication.

Keywords: Resin Transfer Moulding, Step Milling, Electrodeposition, Rapid tooling

1. INTRODUCTION

The choice of modern composite manufacturing methods is made considering costs, quality, health and safety and fitness [1]. Since the complexity of the parts and the requirements for long production runs increase, tooling has become an expensive process requiring long lead times for manufacturing and high costs [2].

This study deals with the planning and the manufacturing of a low-cost modular mould to be used in the resin transfer moulding (RTM) and analyzes the costs and benefits of the suggested innovative solution.

Resin transfer moulding is a promising manufacturing method at low and medium volume, high-performance polymer composite structures because of its slightly low equipment and tooling costs, short cycle times and improved design flexibility [3].

Although RTM technique is still in a development stage, it has considerable potentiality to provide consistently superior components. Further, the advantages of RTM over more traditional composites manufacturing processes are significant. These advantages include the possibility to acquire excellent control over the mechanical properties of the finished part, shorter cycle time compared with other similar processes, low tooling cost and lead time and the possibility to make complex parts.

In RTM process (Fig. 1) a catalysed resin is injected into a closed mould cavity which has a pre-placed fiber stack, called the preform, at room temperature [4]. After the resin has completely permeated the preform, the mould walls are subject to high temperatures in order to initiate complex crosslinking chemical reactions called cure. Cure leads to an increase in the viscosity of the resin and eventually the resin gels to form a structurally hard composite product.

A wide range of resin systems can be used including polyester, vinylester, epoxy, phenolic and methyl methacylates etc, combined with pigments and fillers including aluminium trihydrates and calcium carbonates if required. The fibre pack can be either glass, carbon, arimid or a combination of all [5].

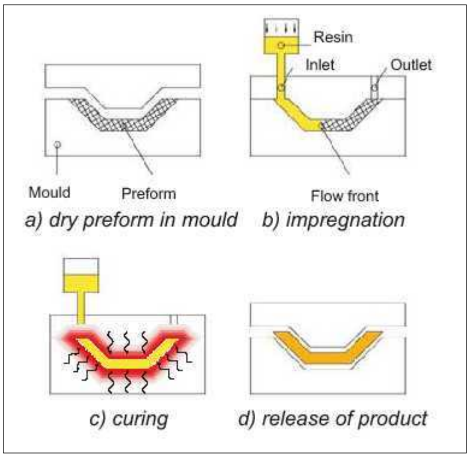

Fig.1. RTM Process

In order to get a cheap mould with high mechanical performances, a production chain is used and it employs technologies generally utilized in other production process such as electrodeposition and step milling; this chain includes the following step:

- definition of the mathematics of the object to be obtained;
- step milling to make the negative of the object that is the mould model;
- copying process of the negative;
- deposition of a metallic layer on the copy of the mould model;
- application of a reinforcing on the metallic layer.

The suggested chain has been evaluated on the benchmark shown in Fig. 2 introducing various and different geometric complexities typical of the composite material articles.

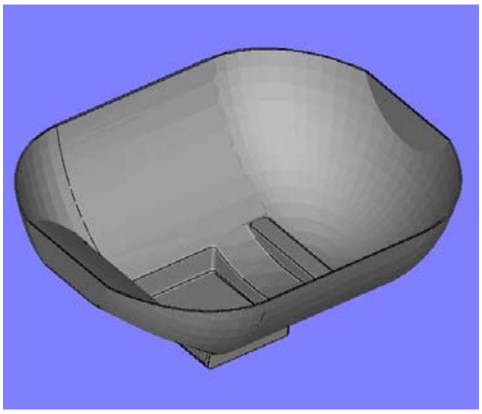

Fig. 2. 3D CAD model of the benchmark (470x391x180 mm)

2 EXPERIMENTAL TESTS

2.1 REALIZATION OF THE MOULD MODEL

The mathematical mould model (Fig. 3) has been obtained by a subtractive operation of the benchmark from a rectangular block, while its construction has been performed with a step milling operation.

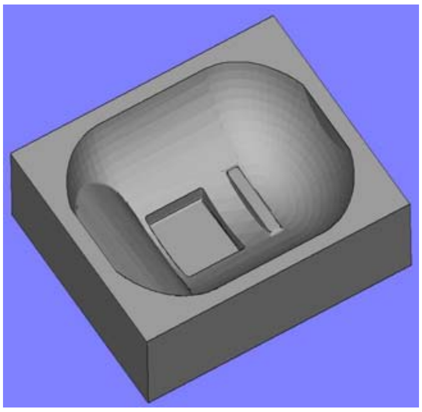

Fig. 3. 3D CAD mould model (477 x 405 x 180 mm)

In order to manufacture our sections to work one by one with the step milling process, we have decided to slice the mould model having dimensions equal to 405 x 477 x 180 mm and in format STL with plans perpendicular to the Z axis, distant 45 mm from each other (Fig. 4).

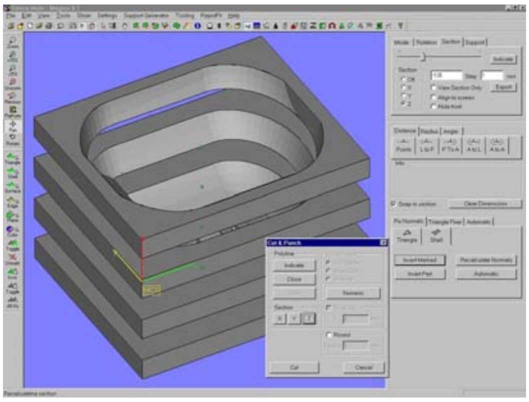

Fig. 4. Execution of the slicing on the STL mould model

Then each section, exported as a STL file, has been imported into a 3D CAD-CAM software to produce the tool path which will form the part program, setting the most appropriate tool operations; in our specific case three operations have been used:

- a rough operation, increasing step by step the pass along Z axis to remove the greatest part of material in the centre of the shape;
- a finishing operation to finish up carefully the surfaces parallel to the Z axis;
- a further finishing operation following parallel plans to finish with precision and without any residual material the surface on the low part of the mould.

Referring to the tools chosen, we used a flat end mill, with 20 mm diameter [8] for the rough operations on every section, while for both finishing operations we used a ball end mill, with 10 mm diameter [9, 10].

The manufacturing operations of each mould section have been performed using an epoxy resin with a density of 750 Kg/m^3.

After the rough and finishing operations on each single section, it was necessary to fix on them some reference points, in order to assembly the four sections in a correct way and obtain the mould.

In Fig. 5 the mould model completely assembled is shown.

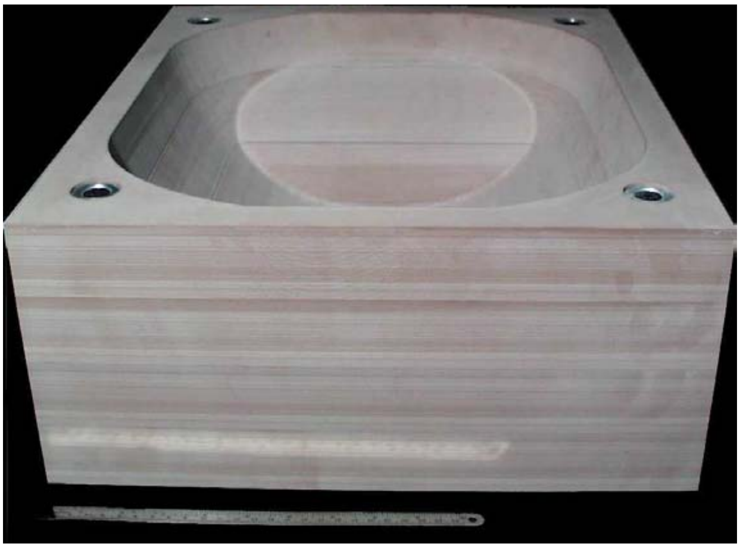

Fig. 5. The mould model, after the assembling operation

After the assembling operation, the mould model shows some light defects placed on the junction surfaces among the various sections (Fig. 6), due first of all to the elastic instability of the resin, once it has been fixed on the tool machine and solicited by the tool itself during the cutting process.

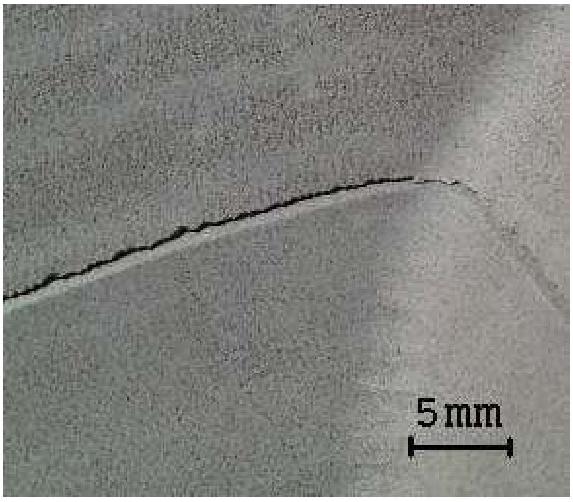

Fig. 6. Discontinuity among the sections

Therefore, in order to get the copy of the mould model, the mould model has been manually finished with a sanding operation, applying, where necessary, a thin layer of filler resin. Then a specific detaching varnish has been applied into the whole mould model, so to avoid that the resin used to get the copy could infiltrate the model mould itself. After this finishing operation, the mould model is shown in Fig. 7.

Fig. 7. The finished mould model

2.2 REALIZATION OF THE COPY OF THE MOULD MODEL

The copy of the mould model was obtained using epoxy resin, which better than the other tested resins, satisfied the following conditions:

- not high polymerization time at room temperature, stable within the electrodeposition temperature;
- temperature degree during the polymerization so that will not damage the prototype;
- resistance to the chemical corrosion of the deposition bath.

The epoxy resin was easily poured and characterized by a good copying of the particulars; its curing time was about 8-10 hours and its temperature during the polymerization was 60°C. The cured resin is stable at thermal stress with heating rate of 10°C/min up to about 180°C. Since the polymerization reaction is exothermal and can reach such temperatures to damage the model and there is the need to reduce the use of such resin, pouring was made on a support previously prepared and inserted into the mould model in such a way to fill the space between the support and the surface of the mould to copy.
In Fig. 8 the copy of the mould model is shown.

Fig. 8. Copy of the mould model

2.3 MANUFACTURING OF THE METALLIC MOULD

The metallic mould has been made with a Nickel electrodeposited shell on the copy of the mould model and with the consolidation of the same shell with a filler.

Before making the Nickel electrodeposition, it is necessary to get the conductivity of the surface of the copy. For this purpose we have made a metalization by Silver chemical deposition which requires a constant control of the bath because the concentration of Silver elements during the bath decreases when the treatment goes on. The chemical deposition usually needs an initial phase of mordening of the surfaces but that is not required in our case [11, 12, 13].

Nickel deposition has been a process used and tested for a long time and its fundamental principles are well-known but its application in a new field, as in our case, requires the exact definition of some aspects that are not present in the previous application. Among the many nickeling baths for electroforming, we have tried to find one suitable to satisfy the need to obtain a deposit with high deposition speed, absence internal stress, hardness of about 200 ÷ 300 HV, good penetration capability. Some tests on sulfamate and fluoborate baths have been made using different process parameters. At the end of the test, we have decided to make the mould with electrodeposition with nickel fluoborate baths, a deposition temperature of 50°C, a currenty density up 3 A/dm^2 [11]. The least layer of Nickel was over 5 mm, the deposition time was of 144 hours.

Micropores and microscopic irregularities of the surface can trap gas blisters obtained during the deposition step; if these irregularities are particularly spread, they can bring a detachment of the metallic layer during the first step of deposition with a further loss of shape of the metal. For these reasons the surfaces of the copy has undergone a quality control with the use of the microscopy: no porosities have been noticed preventing the following deposition.

The surface of the mould when coming out of the bath and without any finishing operation is shown in Fig. 9. Some dull areas have been noticed on the surfaces and they are due to the first layer chemically deposited but they do not influence the surface morphology because of their very limited thickness (less than 0.05 mm).

Fig. 9. Detail of the surface of the metallic shell

When the mould is taken out of the bath, we have made a pouring of epoxy resin to reinforce the shell and to allow the extraction of the copy. The Fig. 10 shows the finished mould.

Fig. 10. Finished nickel mould

3 EVALUATION OF MANUFACTURING CHAIN

3.1 ANALYSIS OF THE DIMENSIONAL TOLERANCES

Step milling process of the chain has been evaluated on the basis of dimensional tolerances. Regarding dimensional tolerances, some dimensional measurements on the mould model (before and after manual finishing operation) and on its copy have been made with a co-ordinate measure machine.

In order to describe the dimensional accuracy of the part, the measured geometric entities have been the following (Fig. 11):

- sphere diameter;
- cylinder diameter;
- planes planarity;
- rake angles.

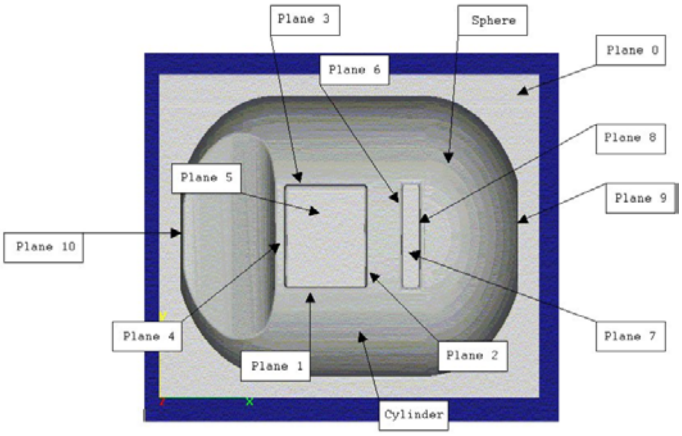

Fig. 11. Geometric entities measured on the mould model

Each measurement has been compared with nominal dimensions. The graphics in Fig. 12 indicate how the manual finishing operation on the mould model has certainly caused some dimensional changes on the model itself. These changes are more relevant for the sphere diameter but less for the cylinder.

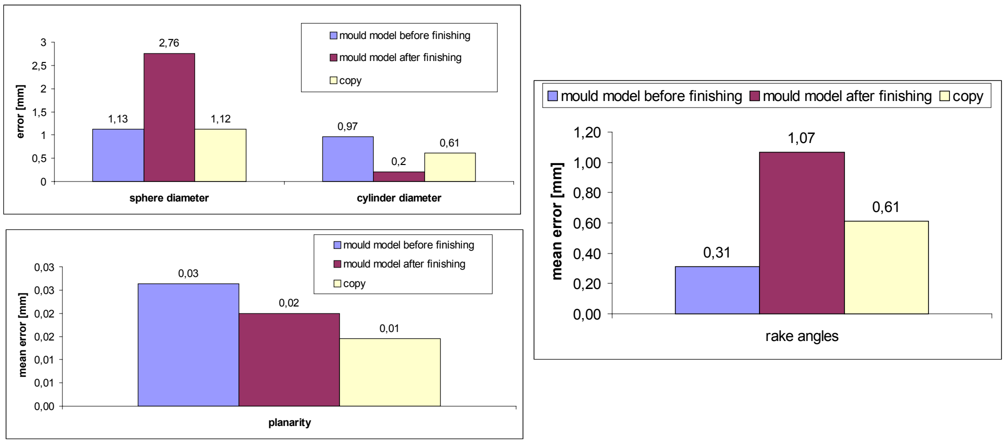

Fig. 12. Comparison between the measurements

We must stress that the analysis of the dimensional tolerances has not been made on the metallic mould because the nickeling, that is an atomic process, does not modify the tolerances of the starting master.

3.2 TIMES AND COSTS ANALYSIS

In the evaluation of the manufacturing of this mould, it is necessary to notice that curing times of the epoxy resin both for the copy and for the reinforcing of the shell are dead times because they do not imply labour costs and so they do not influence the cost of production. The deposition time does not need any labour control while the step of preparation, pouring, milling, extraction of the mould are manual steps.

Table 1 lists the total times for the mould manufacturing.

Therefore in terms of optimisation times, it is very convenient to get the copy using the model of the mould rather than obtaining it by step milling; in fact the time of this operation is less than half than the one traditional milling would take.

Table 1. Total times of the manufacturing of the mould

PROCESS STEPS	Time
Manufacturing of the negative of the benchmark with step milling (slicing, tool path, milling, assembly, finishing)	54 h
Manufacturing of the copy (application of the resin, curing, finishing)	23 h
Manufacturing of the metallic shell (deposition time)	144 h
Finishing of the nickel mould	18 h
Total	239h

The cost of step milling and copy manufacturing has been about 2000 €, the cost of mould manufacturing has been 2400 € and the full cost of the process has been 4400€.

4 CONCLUSIONS

The step milling process employed in the manufacturing chain described in this paper, is founded on the traditional milling process and belongs to the rapid tooling technologies [13, 14, 15]. It is important to point out the advantages of this technique:

- no limit to the dimensions of pieces to be produced;
- reduction of the amount of tools;
- better control of the tool path that is section by section and not on the whole piece;
- use of a wide range of materials, in particular all the ones commonly used in the traditional cutting processes, such as steel, a great variety of light alloys and also resins for models.

In the definition of production chain, we have faced and solved some problems about the ways to get a suitable copy, to obtain the conductivity of the surface of the copy, to find out the best bath for geometries with complex curves and to reinforce the obtained metallic shell.

In order to obtain the metallic shell, the utilization of the Nickel electroforming has to fulfil these conditions:

- in order to allow the possibility of reproducing the process, Nickel deposition is made on the copy of the mould obtained by step milling and not on the master made directly with this technique;
- it is necessary to act on the produced copies to get the conductivity of the surfaces without deteriorating the surfaces characteristics;
- when the mould is taken out of the deposition bath, it must undergone machining operations to eliminate the material in excess.

The chain described represents a valid alternative to the conventional manufacturing processes to produce moulds for resin transfer moulding (RTM) because it allows to reduce times and development costs and at the same time gives good dimensional tolerances similar to those ones obtained by the traditional process.

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