EXPERIMENTAL RESEARCHE REGARDING BY USING RAPID TOOLING TECHNOLOGIES IN MANUFACTURING COMPLEX PARTS

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ABSTRACT: This paper has described an indirect method of rapid tooling technique, using for made the mould to manufacturing a representative part with complex geometry shape, by injection. The different changes in the market requirements entail the necessity of a flexible and efficient manufacturing process. The flexible moulds are made of low - hardness materials, such as silicone rubber, epoxy resin, low - melting point alloys etc., using new techniques like Vacuum Casting and Metal Spraying. The metal spraying techniques is one of the most common procedures used in flexible tools manufacturing. The mould manufacturing by metal spraying was made in the laboratory of Innovative Technologies, at Technical University of Cluj-Napoca, as result of the theoretical and experimental research work of the author, in the framework of doctoral studies in the field of industrial engineering.
KEY WORDS: mould, metal spraying, molten metal, master model, part

1. INTRODUCTION

Under present conditions the development and economic growth are important factors for economic and social progress. An important role in the process of developing it has concurrent engineering. This is a strategy in engineering, generated by the competition for survival of companies and industrial companies that advertised on the one hand reduce the cycle time from conception to the placing on the market, reducing costs for assimilation and to manufacture of new products, improvement of products characteristics as accuracy, quality, reliability, as the degree of satisfaction of customers needs and desires [5]. Tools and moulds manufacturing by spraying with molten metal are successfully used in many applications, including deformations cold plastics, injection, die-casting, casting patterns easily fusible [1]. Such parts can be manufactured from a wide variety of materials, such as polypropylene, ABS, polyamide, and materials that are considered sensitive, such as composite materials. The process of a model RP by spraying molten metal is one of the most used methods of manufacture of flexible tools. Application of metal layer is done with a thickness of about 2 mm further back-formed crust is filled with epoxy resin [1], [3]. During the spray operation with molten metal it is important that the temperature of the RP to maintain as low. If the resistance is exceeded of thermal transfer model RP, precision tool that you will get will be badly affected. The most commonly used techniques for spraying of molten metal alloys using low melting points, such as those based on tin and lead. For spraying molten metal is using a spray gun similar to the one used in the painting. Metallic material used shall be in the wire form, which is powered by the gun where it is melted by the electrical arc. The gun is introduced inside a compressed gas, through a hose from a compressor, which spraying molten metal it over the RP (Rapid Prototyping) model. The melting temperature of the metal used is higher, the more difficult to maintain the RP, at low temperature. For this reason, it is more difficult to apply than the model RP alloys with high melting points, such as zinc or alloys based on aluminium. Method of deposit of metallic spray is often used to gauge models that have complex curved surfaces. The durability of tools coated with metal sprayed depends on several factors, namely:

- Tool or mould is more complex and has more fine detail, the sustainability will be lower. Can be used the inserts of aluminium and bronze, where the part have deep channels or fine detail. It increases the durability of spray-coated metal blanks, thereby ensuring a better quality of parts to be manufactured with these tools;
- Low temperature and viscosity of injected material will increase the sustainability of those blanks. Manufacturing series that can be obtained with a set of moulds covered with metallic spray can be very varied. May be deducted by 25 ... 250 for polypropylene, or lifted, 1800 ...2500 for ABS.

2. STAGES OF MANUFACTURING THE MOULDS BY SPRAYING MOLTEN METAL

According to literature of the speciality, stages of manufacturing the moulds by spraying molten metal are [1]: Is manufacturing the model RP having angles of inclination necessary to account for the tolerance of the factory by injection;

1. Finish the surfaces of the master model to get an accuracy and roughness better expected and what parts will be manufactured by injection moulding of plastics, bearing in mind that the resulting mold will be a faithful replica of the master;
2. The model is positioned at the level of a separation plan, so as to be able to deposit metallic spray for the first half of the mould;
3. Model and plane of separation shall be covered with a thin layer of polyvinyl alcohol (PVA) in order to facilitate later retrieval of the model RP which could subsequently lead to peeling them;
4. The extractor rods will position before spraying metallic spray. These rods extractors are the role to facilitate the evacuation of upcoming castings or injected, but they are useful in the manufacture of blanks for the evacuation model RP;
5. Continue to apply by spraying a metallic layer of approximately 2 mm thick, in one work session so as not to appear between the oxidation layer, which could subsequently lead to peeling them;
6. To confer this resistance of metallic thin crusts, on the back of it shall be lodged a support material, generally an epoxy resin. At first the resin shall be submitted through the coating to ensure complete filling of the cavities, then pour the resin until the required thickness. Sometimes it uses aluminum or another metal powder, not so for the resin reinforcement especially for increasing the thermal conductivity of the future mould. Provision may be made at this stage and a network of thin tubes or channels for cooling with water;
7. Once it has been poured behind the mould, it is processed through the milling to ensure great flatness. In steps 1-8, only a half-mould is formed, for the second half-mould method and steps of the analog thing. It rotate the model with 180° (degrees) and positioned on the flat surface and remove the previous milled board you delineate the separation plan of the two half mould;
8. Repeat steps 4-8 to form the other half of the mould;
9. Removed the RP model is the most difficult part of the method. If you are not working with the maximum attention, it may be that some portions of the metallic layer applied to fall off along with the RP. The extractor rods can be very useful at this stage.

3. EXPERIMENTAL RESEARCHE FOR MOULD MANUFACTURING BY METAL SPRAYING TECHNIQUES

Experimental research concerning to manufacturing the mould by spraying molten metal, and manufacturing the part by injection moulding have been achieved at the National Centre of Rapid Prototyping within the Technical University of Cluj-Napoca. Mould manufacture has been carried out in accordance with the steps listed in section 2 (Stages of manufacturing the moulds by spraying molten metal). The construction of the sample part RP, model SLS was made using the Sinter Station 2000 machine, at the National Centre of Rapid Prototyping within the Technical University of Cluj-Napoca. During the SLS technique, Dura Form PA polyamide powder was used to create the prototype part. The master model is shown in figure1. I do mention that master model presented has been used by the author, from another experiment, in which it was used for the manufacturing of a silicone rubber mould [5].

Figure 1. The SLS model, obtained by selective laser sintering process

For the manufacturing of the mould has been used the master SLS model, manufactured through the process of selective laser sintering, which was spray molten metal. Master SLS model was hand-finished surfaces with abrasive paper, to get an accurate and a better quality of surfaces, considering that the mould will be a faithful replica of the master model used. After finishing the master model, was covered with varnish, to fill the pores (RP sintered models are porous) in order to obtain the best quality of the surfaces.

Still, after drying of the lake was covered with a thin layer of polyvinyl alcohol (PVA), in order to facilitate the extraction model of mould, thus avoiding sticking metal shell model which will form, sticking that could cause exfoliation the cover to extract the model from the mould. The model has been positioned and secured with clay on a wooden plate with dimensions of 160x110 mm, the separation plan, so as to be able to deposit metallic spray for the first half of the mould. For spray gun we used metal rods, which were melted at a temperature of 287° C. During the process of SLS model with molten metal, the spraying was done about 30 seconds, during which lowers the melting temperature of the 287° C at 277 ° C. After consuming a rod, the gun was fed with a different rod, the process continuing until the coverage of the whole surface model. It was molten metal sprayed about 30 minutes and it was consuming five metallic rods. Further to confer strength metallic shell formed, on the back of it has been made a support material, having in the basic composition, epoxy resin and other components in different amounts which are presented in table 1.

Table 1. Component materials used to made the mould support

Nr. crt.	Component materials	Quantity [g]
1.	MCP 1 - casting resin component 1	61
2.	MCP 2 – casting resin component 2	122
3.	Metallic powder	183
4.	Hardener	5
5.	Aluminium balls	The amount contained in the mixture formed of the components 1 ...4

The components were mixed in a container, then the mixture was poured over the model positioned in the wooden box (the box dimensions has 160x110x77 mm) and it was left for 24 hours to solidify. After the solidification of the material support, behind the mould was machined by milling, to ensure the planarity of the surface. At this stage it was only half mould. Further of the process for the second half mould have travelled the same stages except for the finishing and coating with polyvinyl alcohol (PVA). At the end after opening the mould and removing the master model, they result two half mould shown in figure 2. This mould is used to produce plastic parts by injection moulding.

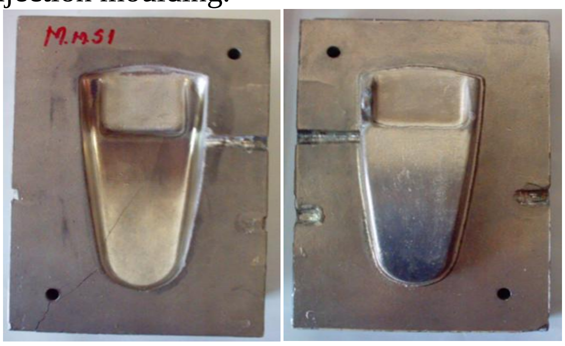

Figure 2. Mould made by Metal Spraying

Still the two half mould were assembled for manufacturing the plastic part by injection the polypropylene material using the injection moulding machine MCP 100KSA shown in figure 3, from the laboratory of Innovative Technology, at the National Centre of Rapid Prototyping within the Technical University of Cluj-Napoca.

Figure 3. Injection moulding machine MCP 100KSA from the laboratory of Innovative Technology, at the National Centre of Rapid Prototyping Manufacturing within Technical University of Cluj-Napoca

The sustainability of the metal spraying mould can be improved by avoiding thermal shock of them. To do this, the mould used for injection of polypropylene was heated slowly up to the temperature thing (for polypropylene temperature recommended is 40 ... 60 ° C).

For the injection of the part, were made several attempts to complete filling of the mould cavity by using different injection parameters (shown in the following table) that have been set manually. For protect these soft tools, different injection pressure has been used, to test which is the optimal, because much pressure may produce fissures or cracks in the mould.

Table 2. Injection parameters

Nr.crt.	Temperature [°C]	Pressure [Bari]	Time [sec]	Observation
1.	225	2,5	15	
2.	225	2,5	15	
3.	230	4	10	
4.	225	3	10	
5.	225	3	15	
6.	225	3	15	
7.	235	3,5	10	Complete filling of the mould

To manufacture by injection of the representative part using the mould made by spraying of molten metal, the plastic material used was polypropylene in the form of granules. After the cooling time of the mould, the mould has been opened to extract the injected part, shown in figure 4.

Figure 4. Removed the injection part from the mould made through the process of spraying molten metal

After extracting the part from mould, after removing brush peens burr and rod formed into the injection hole the part achieved is shown in figure 5.

Figure 5. The polypropylene part made by injection into the mould obtained by spraying molten metal

4. COMPARATIVE STUDY REGARDING THE MANUFACTURING ACCURACY OF THE SAMPLE PART

The manufacturing accuracy for the Rapid prototyping and Rapid Tooling technologies is influenced by many factors. Knowledge of the influence factors enables the manufacturing of parts with high accuracy. The notion of accuracy in case of parts obtained by RT and RP technologies, involve surface characteristics in terms of continuity properties between different surfaces, as well as the smoothing properties that define geometric accuracy. The geometrical accuracy shows the importance in the field of aesthetic for visualization and design. By comparative study, this section presents the manufacturing accuracy of the sample parts made by SLS, and by injection in metal spraying mould.

The Rapid Prototyping and rapid Tooling manufacturing accuracy depends on several factors. A good knowledge of these influences ensures high accuracy manufacturing of parts.

The manufacturing accuracy analysis of the sample part obtain by SLS process and the injection part in the metal spraying mould was realized using the graphics results obtained after measuring the parts on the Coordinate Measuring Machine ZEISS ECLIPSE 500, at the Technical University of Cluj-Napoca.

4.1 The accuracy of the prototype part manufacturing by SLS.

Measurement of prototype part on machine ZEISS ECLIPSE 500**.** Measurement strategy was determined according to the geometric characteristics of the part. To measure the workpiece (figure 6 and 7) was determined by a system of coordinates, presented on the computer screen, depending on which will be assessed points measured.

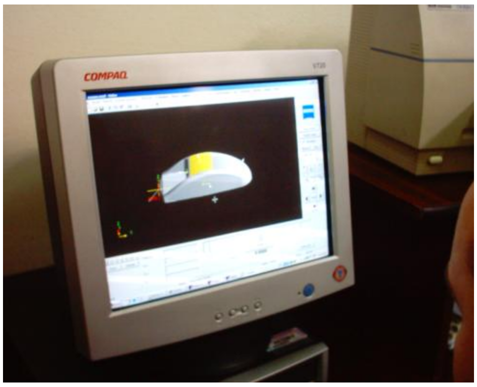

Figure 6. The allocation of the reference coordinate system of the mode SLS through the geometric model

Figure 7. Sequence performed during the measurement of the SLS part on the machine prototype ZEISS ECLIPSE 500

The results obtained by measuring the prototype part manufacturing by process of selective laser sintering at different points on the complex surface, have been represented on the computer screen shown in figure 8.

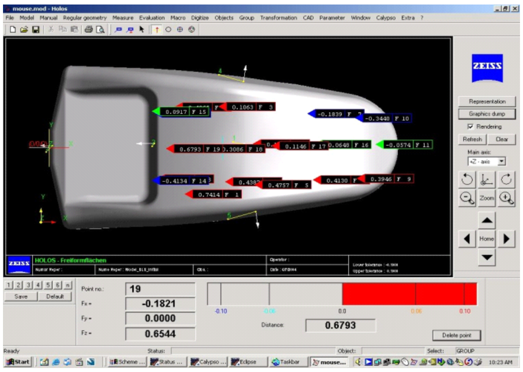

Figure 8. Graphic representation of results obtained by measurement of part manufacturing by SLS process

On the basis of measurements and results obtained by calculating the average value of deviations using the MS-Excel, the precision of prototype part manufacturing by selective laser sintering is ± 0.3 mm. Several important factors influencing the accuracy of manufacturing of the SLS are:

- STL model orientation in the work area of the Rapid Prototyping machine;
- The accuracy of the STL model;
- The thickness of the powder material used in the construction of layers of model.

The orientation of the model in the work area of the RP machine is an important factor, because during the process of construction of the model, through an optimal orientation will be reduced by the effect of scale on the surfaces of interest.

The quality of the representation of 3D geometric model in STL file format has influence on the accuracy of part, because a poor quality of it will lead to an inadequate RP model.

The thickness of the polypropylene powder used during construction of the layers, affect the accuracy of execution of the SLS model, due to the occurrence of the effect of scale. If the layer of material is lower, the quality of the STL model is high such a SLS model will be adequate. Precision parts made by SLS process using powder material (Duraform) is ± 0.12 mm / section.

4.2 The accuracy of the part manufacturing using the mould obtained by spraying molten metal.

To measure the part manufacturing by using the mould obtained by spraying molten metal, We used the same strategy of measurement as previously presented and the results of the measurements obtained by graphic representation of geometrical deviations on the computer screen, are shown in figure 9.

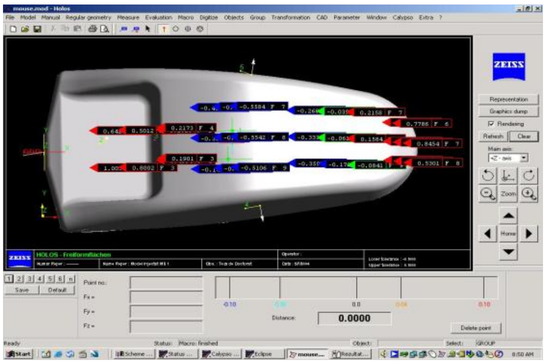

Figure 9. Graphic representation of results obtained by measurement of part manufacturing by using the mould obtained by spaying molten metal

By calculating the average of the deviations by using the MS Excel program, the accuracy of part manufacturing by injection using the mould obtained by spraying molten metal, is ± 0.39 mm. The precision is lower than the SLS model and the part obtained by casting in silicone rubber mould [5]. This can be explained by the size and contractions sense of sprayed material on the surfaces of model’s in cooling process. Factors that influencing the accuracy of the part manufacturing by using the mould obtained by spraying molten metal (MS):

Precision of the shape rendering in half-mould, which depends on the precision of master model used in the forming of the mould made by spraying molten metal;

Technological parameters of manufacturing of material (the type of material sprayed, spraying speed, transport medium of material, the thickness of a layer, the number of layers sprayed, the time between two successive spraying);

Material contractions used to manufacturing of part.

From the comparative study regarding the accuracy of the part, manufacturing by the three methods (SLS, casting in silicon rubber mould ang injection in metal sptaying mould), there are the following conclusions:

Rapid Prototyping and Rapid Tooling technologies, does not imply high precision accuracy, precizion being reported at ± 0,1000 ÷ ±0,2000 mm;

the influence of the materials contractions used in the manufacturing of the silicone rubber mould and the mould obtained by spraying molten metal, on the accuracy of the parts manufacturing using these moulds is small;

epoxy resins are materials used to manufacturing of moulds, because these materials make contractions under 0.1%;

As a result from the comparativ study regarding the accuracy of representative part and conclusions detached, in order to obtain an accuracy more forthcoming to the precision required for parts manufacturing using Rapid Prototyping and Rapid Tooling in order to obtain an accuracy as close to the precision required parts manufactured using Rapid Prototyping technologies and Rapid Tooling, the recommended solution is to achieve of geometric corrections of 3D CAD model, so they take into account both the contractions are produced in the process of obtaining the metal spraying mould, especially at the parts obtained by vacuum castings in silicone rubber mould.

5. CONCLUSIONS:

Compared to classical technologies, Rapid Tooling technologies employment for manufacturing the mould by Metal Spraying process, presents the following advantages:

- Able to get smaller radius than through the milling operation. In the cases of milling operation, the radiuses that can be obtained depend from the vertex radius of the cutting tool;
- Through this process the geometric shapes of the master model used are copied with fidelity and the accuracy of the model shape in the half - mould, depends on the level of the master model finishing used;
- Metal spraying is a flexible process and can be used to manufacture a wide range of material;
- Low manufacturing costs compared with conventional tooling technologies. On the basis of calculation, the economic impact of the cost of production for the moulds made using RT technologies and processing through CNC, the cost of fabrication is approximately with 50 percent lower for metal spraying mould [5];
- Other main advantage of the spray metal tooling is that can produce large tools quickly;
- Short time of product development and low development cost;

Within the process may be highlighted some disadvantages:

- One of the disadvantages is the control process. The process is interdependent of many variables and it has proved difficult to predict the shape, porosity or metal deposition rate. The process depends on the operator`s experience;
- Secondly the materials with low melting point have limited the durability of mould.

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