TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics and Mechanics
Vol. 56, Issue I, March, 2013

INNOVATIVE SOLUTION TO DECREASE THE POROSITY OF INJECTION MOULDING TOOLS MADE BY SELECTIVE LASER SINTERING TECHNOLOGY

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Abstract: *The manufacturing of the injection moulding tools is one of the most important industrial applications of Selective Laser Sintering (SLS) technology. The resulted porosity after post-processing stage in the oven has an important influence on the mechanical properties of the SLS metallic parts. In order to reduce the porosity, a new post-processing method has been developed as compared to the classical one. The paper presents the new method and some results obtained by the authors.*
Key words: *Selective Laser Sintering, Additive Manufacturing, Rapid Tooling, Injection Moulding.*

1. INTRODUCTION

Over the last decade, the selective laser sintering (SLS) process has gained a wide acceptance as Rapid Prototyping (RP) technique [1], [2], [3], [4]. Due to technical improvements, better process control and the possibility to process all kind of metals, a shift to firstly Rapid Tooling (RT) and secondly Rapid Manufacturing (RM) came up in recent years [5, 6]. Many applications could take advantage of this evolution by using the SLS technology, not only for visual concept models and onetime functional prototypes, but also for tooling moulds, tooling inserts and end-use functional parts with long-term consistency [7], [8]. To turn the SLS process into production techniques for real components, some conditions have to be fulfilled. Firstly, manufacturing applications increase the requirements on material and mechanical properties [9], [10]. The process must guarantee consistency on the entire product life cycle. Secondly, process accuracy, surface roughness and the possibility to fabricate geometrical features like overhanging surfaces and internal structures become very important for manufacturing. Finally, the breakthrough of SLS process as RM techniques will depend on reliability, performance and economical aspects like production time and cost [11], [12].

The presented work investigates if the SLS process fulfills these requirements, focusing mainly on mechanical properties, by analyzing the porosity issue. Theoretical and experimental methods for estimating the porosity of the SLS injection moulding tools made by Laserform St-100 metallic powder are revealed. The solution that has been developed and applied by the authors at the Technical University of Cluj-Napoca, in order to decrease the porosity of the SLS metallic parts (after post-processing stage in the oven) is presented also in this paper

2. INDUSTRIAL CASE STUDY DEVELOPED AT TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

Powder material always contains a considerable amount of air inside it in between the particles. The non-uniform porosity distribution of the porous material surface has an important influence over its mechanical and technological characteristics. After the post-processing stage in the oven, when the bronze is being infiltrated into the parts, the remaining porosity is around 30 %. In order to decrease the porosity, and increase the mechanical and technological characteristics accordingly, a new post-processing method (different as compared to the classical one) has been developed at the Technical University of Cluj-Napoca (TUCN) by the authors, consisting in a supplementary epoxy resin impregnation of the tools after the post-processing stage in the oven.

By the theoretical point of view, the porosity of the material can be calculated very simple using the formula presented below:

$$P = P_1 + P_2 + P_3 = \frac{(m_2 - m_1)\cdot \rho_w}{(m_2 - m_3)\cdot \rho_L} \qquad (1)$$

where:

- P – is the part porosity
- m_1 – is the sample mass, weighted in air before resin impregnation;
- m_2 – is the sample mass, weighted in air after the impregnation
- m_3 – is the sample mass weighted in water
- ρ_W is the water density
- ρ_L is the resin density (g/cm^3).

By the experimental point of view, in order to do the calculation and compare the obtained porosity, before infiltration with bronze, after infiltration and after the supplementary epoxy resin impregnation, few samples manufactured by Selective Laser Sintering technology were needed.

For this purpose, one case study has been developed within a project work, jointly at the Technical University of Cluj-Napoca and Plastor Industrial Company from Oradea. Two sets of active elements – punch and die – for a lid button of a grass-cutting machine, were manufactured by using the Sinterstation 2000 equipment from the Technical University of Cluj-Napoca (Fig. 1).

One set has been post-processed in classical way by infiltrating with bronze at 1070°C in the oven, the other set being supplementary impregnated with different types of resins in vacuum, using the impregnation equipment and dry-oven presented in Figure 2.

Fig. 1. Active tools manufactured using the Sinterstation 2000 equipment (TUCN)

Fig. 2. Vacuum impregnation equipment and dry-oven

The aim of resin impregnation under the vacuum was to fill all the existing blanks in the model structure. Several steps were followed, as illustrated in Table 1.

Table 1

Resin impregnation under vacuum

Mixture Preparation: ½ liter of epoxy resin 5 % hardener
Mixing the resin and the hardener: Boiling phenomena occurs after 8 min
Vacuum process cycle (Total time -56 min) - Realizing the vacuum - 15 min - Maintaining at 10^{-4} Torr - 10 min - Releasing the vacuum - 3 min - Vacuum process cycle repeat - 2 times
Drying in the oven - 72 hours

The test samples were obtained by splitting the sintered die in four parts using a side mill, each of them being weighted afterwards in air before and after the impregnation and in water before impregnation, as illustrated in Figure 3.

Fig. 3. SLS split samples, weighted in air and water

3. OBTAINED RESULTS

After finishing the experiment, some theoretical calculus could be made according to formula (1). The obtained results are presented in Table 2.

Table 2

The obtained results

	Sample 1			Sample 2		
	Green stage	**After bronze infiltration**	**After resin impregnation**	**Green stage**	**After bronze infiltration**	**After resin impregnation**
Apparent density ρ [g/cm^3]	4.84	4.80	5.34	5.07	5.03	5.6
Porosity P [%]	37.05	34.62	29.0	34.07	34.58	25.5

Finally, by using an electronic microscope from TUCN, some comparisons could be made with the results obtained by calculus in all stages: before infiltration, after infiltration with bronze and after resin impregnation.

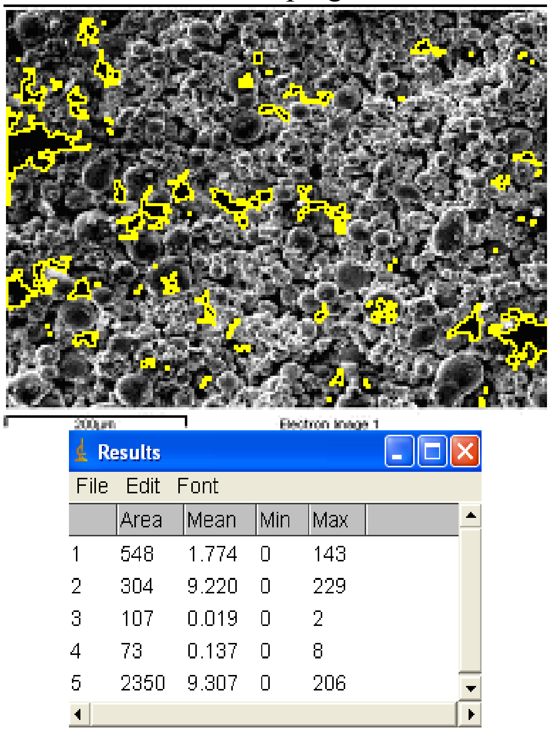

Fig. 4. ImageJ software analyzer

ImageJ software was used to analyze the images (Figure 4). The porosity in this case was calculated by using the following formula:

$$p = \frac{\sum Ai}{Atot} \qquad (2)$$

where - A_i represents each granule area and A_{tot} is the entire image area.

Obtained results are comparable with the theoretical ones in all stages.

The resin impregnation solution has proved to be reliable in order to decrease the porosity of the SLS metal parts.

As compared to the classical solution (infiltrating with bronze at 1070 ˚C), the supplementary epoxy resin impregnation of the metallic parts in vacuum decreased their porosity from 30 % to less than 26 %.

4. INJECTION MOULDING TEST

The practical tests for injection moulding by using the SLS tools, supplementary impregnated with epoxy resins were made successfully within the industrial company that we cooperated with.

There were some dimensional contractions during the SLS process and post processing. That is why, it was necessary to do some finishing operations to the punch and die.

These finishing operations were performed at Plastor Company from Oradea, using some hand tools for finishing, in order to obtaining a perfect close of the active elements and positioning into plates, as presented in Figure 5.

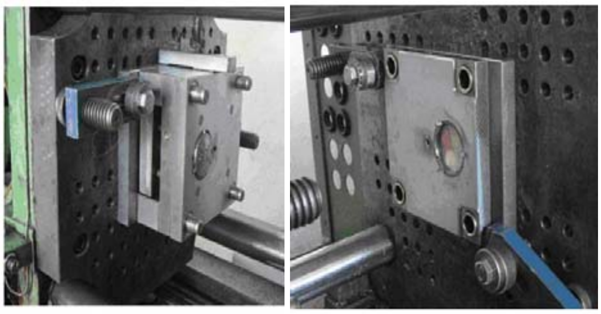

Fig. 5. **Positioning the active elements into plates**

The tests of the SLS tools behavior were made at Plastor Company, using a Krauss Maffei 90/340 A injection moulding machine. The injection moulding tests were made using the ABS Terluran 867 M material. Injected parts obtained at Plastor Oradea using the active elements made by SLS at TUCN are presented in Figure 6.

Fig. 6. Injected parts using SLS tools on Krauss Maffei 90/340 A machine

5. CONCLUSIONS

The resin impregnation solution has proved to be reliable in order to decrease the porosity of the SLS metal parts.

As compared to the classical solution of post-processing the SLS tools (infiltrating with bronze at 1070 ˚C), the supplementary epoxy resin impregnation of the metallic parts in vacuum decreased their porosity from 30 % to less than 26 %.

Future research needs to be done in order to decrease the porosity of the parts to less then 20 % by adjusting the mixing epoxy resin and the hardener percent or by increasing the total time of maintaining the parts under vacuum.

The made research is the first one made in Romania at the Technical University of Cluj-Napoca (UTCN), in cooperation with an industrial company, proving the applicability and opportunity of these new modern methods of moulds manufactured by selective laser sintering technology, at the industrial level.

Meantime, some important research needs to be done in the future regarding the strength of sintered materials (such as fracture strength or endurance strength) and also regarding the thermal stability and durability of these injection moulding SLS tools.

6. ACKNOWLEDGEMENTS

This paper was supported by the project "Development and support of multidisciplinary postdoctoral programmes in major technical areas of national strategy of Research Development - Innovation" 4D-POSTDOC, contract no. POSDRU/89/1.5/S/52603, project co-funded by the European Social Fund through Sectorial Operational Programme Human Resources Development 2007-2013".

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O soluție inovativă pentru reducerea porozității elementelor active de matriță fabricate prin tehnologia sinterizării selective cu laser

Rezumat: În cadrul acestei lucrări este prezentată o soluție inovativă care a fost aplicată cu succes la Universitatea Tehnică din Cluj-Napoca în vederea reducerii porozității elementelor active de matriță fabricate din material pulverulent de tipul Laserform T-100, cu ajutorul tehnologiei de sinterizare selectivă cu laser (Selective Laser Sintering - SLS). Metoda impregnării suplimentare cu rășină epoxidică în etapa de post-procesare a acestor elemente active s-a dovedit a fi o soluție viabilă, după cum s-a putut observa acest aspect atât în urma analizei microstructurii pieselor metalice fabricate prin sinterizare selectivă cu laser, analizate ulterior cu ajutorul microscopului electronic la Universitatea Tehnică din Cluj-Napoca, cât şi în urma testelor efectuate în etapa de injectare materiale plastice în cadrul firmei Plastor SA din Oradea, etapă în care, elementele active ale unei matrițe pentru injectat capacul butonului de reglaj la o maşină de tuns iarba, fabricate prin SLS şi impregnate ulterior cu rășină eproxidică la Universitatea Tehnică din Cluj-Napoca au fost testate cu succes în cadrul firmei Plastor SA din Oradea la injectarea pieselor din material plastic de tipul ABS Terluran 867 M în serii de câteva mii de bucăți de piese injectate.

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