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POROSITY CHANGE BY RESIN IMPREGNATION IN STRUCTURES OBTAINED 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 (bronze infiltration) has an important influence over the mechanical properties of the resulted SLS metallic matrix. In order to reduce the porosity, a new post-processing method has been developed as compared to the classical one, consisting in a supplementary resin impregnation after the bronze infiltrating process. This new stage will have a significant influence not only onto the resulted porosity within the material structure, but also onto the chemical composition of the material. In consequence, the mechanical behaviour of the final parts will be significantly influenced.

Keywords: *selective laser sintering, post-processing, porosity, epoxy resin.*

INTRODUCTION

Within the Selective Laser Sintering (SLS) process, there are a number of input parameters that can be controlled and modified in order to get different characteristics of the sintered parts [1]. Some of this input factors pertain to the laser beam (e.g. laser power, laser scan spacing, etc.), while others refers to the metallic powder properties (e.g. particle size, percentage composition of the constituent materials, etc.) or to the sintering parameters (e.g. layer thickness, scanning speed, etc.) (Figure 1) Output parameters of interest might be hardness, density, strength, porosity, etc. [2].

A considerable amount of work has been done and reported in this field, some of them mentioned bellow. Miler et al have carried out factorial

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experiments to express the strength of a sintered sample as a function of laser power, scanning speed and fill scan spacing and their respective interaction terms. The model developed takes into account the variation of small and large beam spot sizes and effect of heat loss on strength of sintered samples [3].

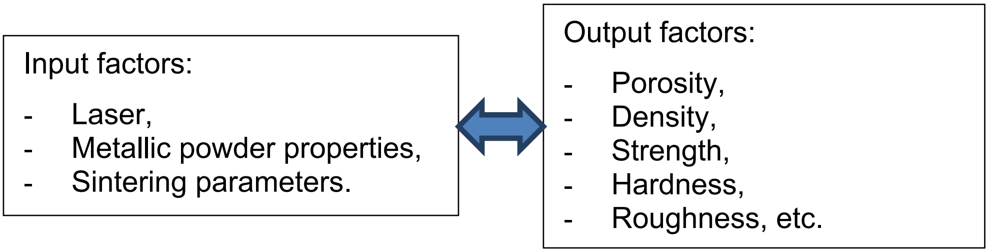


Figure 1. Input and output factors in selective laser sintering

The Song paper states the influence of laser parameters like laser beam power and experimental parameters like scanning speed on various properties of a laser sintered bronze product. It is reported that density increases while material porosity decreases with scanning speed decrease [4].

Hardro et al determined the optimal process parameters for SLS of an elastomeric polymer using an experimental design approach. Laser power, laser scan spacing and part bed temperature were the factors under consideration, while dimensional accuracy and material strength of the sintered samples were the response characteristics. It was concluded that all the factors as well as their interactions are statistically significant [5].

There are also other researches done by the authors with the aim of controlling better the selective laser sintering process in order to obtain a fully dense metal part at the end [6 – 10].

But, in order to turn the SLS process into a production technique for real components, some conditions still have to be fulfilled. Firstly, the process must guarantee consistency on the entire product life cycle [11]. Secondly, process accuracy, surface roughness and the possibility to fabricate geometrical features like overhanging surfaces and internal structures become very important for manufacturing [12]. Finally, the breakthrough of SLS process will depend on reliability, performance and economical aspects like production time and cost [13 – 15].

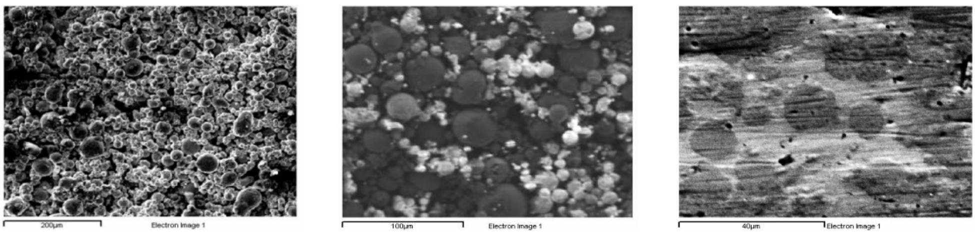
The current paper was not focused on the process control possibilities, but mainly on the metallic material porosity decreasing after the selective laser sintering process is completed. The influence of chemical elements of the metallic matrix and their influence onto the mechanical behaviour of the SLS injection moulding tools are also being analysed.

RESULTS AND DISCUSSION

The alloy elements that are present within the material structure of the metallic parts manufactured by SLS consist basically on two types of alloy elements – iron and cooper (see Figure 2). The percent of iron within the material structure on the pre-processing process is 53%, as carbon is present in the material structure in a percentage of 35%, while the part is in the “green stage”. After the post-processing process, when bronze it is infiltrated into the parts, the matrix will be based mainly on iron (approximately 50%) and cooper (approximately 30%). There are other alloy elements in the matrix structure, such tin, chromium or carbon, having a significant influence as well.

Actually, the combination of iron and cooper is interesting due to the fact that it is not forming any intermediary stage. The cooper can be easily substituted within the iron-based matrix to a temperature of approximately 1500 °C.

The cooper it is known as having excellent diffusion properties within the matrixes that are based mainly on iron material. The easiness of breaking through the material structure, while being in a liquid state makes this type of material to be placed within the preferred material, in the case of matrixes based on iron material. The increased mechanical strength of this type of material it is also a very important analysis criteria, especially in the case when the resulted matrix it is mechanically stressed as it is the case of injection molding tools made by selective laser sintering technology. The thermal conductivity of the iron-cooper matrix is also very important, not only within the infiltrating process, but the injection molding process, as well.



1) 2) 3)

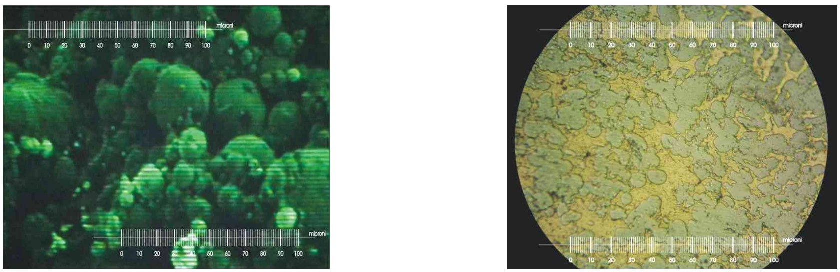
Figure 2. SEM-EDX analysis of the SLS manufactured samples:
1) green stage; 2) after bronze infiltration; 3) after resin impregnation

As related to the other chemical components that are present within the matrix structure (chromium, tin), one of their consequence is the one of decreasing the solubility of cooper material.

Meanwhile, there are also positive aspects that could be mentioned, such as the increasing of corrosion resistance, the hardness or fracture strength of the resulted matrix. All these characteristics are very important in the case of injection moulding tools made by selective laser sintering.

The presence of aluminum and silicium in the matrix after the impregnating process in small quantities is not having a high impact on the overall characteristics of the matrix, even if there are few positive aspects that could be mentioned as advantages, such as the oxidation resistance.

Beside the chemical composition of the metallic matrix, by analyzing the SEM images, it was possible to do some estimations regarding the grains spread onto the material structure, in all three phases of analysis: in green stage, after infiltrating with bronze and after resin impregnation (see Figure 3 and Table 1). This analysis was made based on the images taken from the JEOL JSM - 5600 LV from the Technical University of Cluj-Napoca. As it is possible to observe by analyzing the results presented in Table 1, there is a non-uniform distribution of pores on all three stages. \the possibility to obtain a uniform structure still remains in consequence a difficult task to be solved. It is difficult also to make appreciations on the materials porosity, based on these selected SEM images. That is why it was necessary to do some suplementary calculus, by using formula 1. The results of the made calculus based on this formula proved that it is possible to speak about a porosity decrease from a value of approximately 34 % in the case of sample infiltrated with bronze to a value of approximately 25 % in the case of epoxy resin impregnation (see Table 2), but there are still many other aspects to be analyzed in the future, such as the study of the impregnation procedure in accordance with the size and the shape of the metallic part to be impregnated with resin and type of epoxy resin to be used within the impregnation process.



1) 2)

Figure 3. SEM images of the sample:
1) in green stage; 2) after bronze infiltration process

Table 1. Grains distribution of samples

Sample in green stage			Sample infiltrated with bronze			Sample impregnated with epoxy resin		
Diam. [μm]	No.	Spread [%]	Diam. [μm]	No.	Spread [%]	Diam. [μm]	No.	Spread [%]
1	10	17.2	1	-	-	1	-	-
5	19	32.7	5	20	30.7	5	8	21.6
10	15	25.8	10	22	33.8	10	16	43.2
20	7	12	20	15	23.07	20	8	21.6
30	4	6.8	30	6	9.2	30	3	8.1
40	2	3.4	40	2	3.07	40	1	2.7
50	1	1.7	50	-	-	50	1	2.7
Total	58	99.6	Total	65	99.84	Total	37	99.9

Table 2. Aparent density and calculated porosity

	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	29.00	34.07	34.58	25.5

CONCLUSIONS

Researches that were made regarding post-processing stage of injection moulding tools by selective laser sintering (SLS) technology revealed that resin impregnation is a reliable alternative when speaking about decreasing the porosity of these type of tools made by Laserform St-100 metallic powder material. In the case when Ropoxid R510 epoxy resin material has been used as impregnating material, the porosity was decreased from 34% to a value up to 25%, with positive consequences over the mechanical behaviour of such active elements used within the injection moulding process. Meanwhile, the chemical analysis that has been made proved the fact that the metallic matrix is based on the iron-cooper alloyed material, with positive consequences not only for the selective laser sintering process (cooper being easiness to be braked through the material structure), but also for the injection moulding process, due to the thermal conductivity of the material. Still, there are many other aspects to be analyzed in the future, such as the study of the impregnation procedure in accordance with the size and the shape of the metallic part to be impregnated with resin and the type of epoxy resin to be used within the impregnation process, but as demonstrated, the solution of supplementary epoxy resin impregnation process could be an alternative in the case when the porosity of a metallic part manufactured by selective laser sintering process still have to be decreased afterwards.

EXPERIMENTAL SECTION

The LaserForm St-100 material, which is used for manufacturing metallic parts by using the selective laser sintering technology is a stainless steel powder mixed with an epoxy resin for binding the grains. The part is manufactured based on the layer-by-layer manufacturing technique, every slice being scanned by a CO_2 laser with a maximum power up to 50 W. The polymer that is surrounding the grains is melted and welded together, so as the part in “green stage” it will be obtained. In order to obtain a fully dense metal part, a second stage is obligatory needed in the oven, when, at 1070 ˚C, the binder is burned out and under the capillarity effect, bronze is infiltrated. While post processing in the oven, the metallic part follows the next steps:

- Melting (burning out) the polymer (at 450 °C – 650 °C), which was surrounding the metal grains

- Get fully sintered metal parts, while increasing the temperature to about 700°C

- Infiltrating with bronze, at about 1050 °C – 1070 °C

- Cooling down the parts (natural / slow cooling).

The selective laser sintering process seems well controlled, but in fact there are some limitations, such as the possibility of porosity control. The level of porosity, the shape, the size and the non-uniform porosity distribution into the porous material structure have an important influence over the mechanical and technological characteristics of the metallic parts that are manufactured. If the possibilities of controlling the porosity are limited, the possibilities of decreasing the level of porosity after the selective laser sintering process are not limited.

In order to study the possibility of decreasing the porosity within the material structure, the schematic method presented in Figure 4 has been used, consisting basically in vacuum impregnation equipment.

A sintered die for the lid button of a grass cutting machine has been manufactured using the Sinterstation 2000 equipment from the National Center of Rapid Prototyping – Technical University of Cluj-Napoca, being then split into four pieces by using a side mill. Every sample has been weighted in air and water before on every stage of the manufacturing. For the impregnation process, the epoxy resin ROPOXID R510 has been successfully used. The aim of resin impregnation under the vacuum is to fill all the existing blanks in the model structure. Half litter of resin has been used with 5% hardener in order to reduce the polymerization process of the resins (see Table 3). The resin and the hardener were mixed until the air was completely sucked by the vacuum. After 8 minutes under the vacuum a boiling phenomenon appears. Total time of maintaining under the vacuum was 56 minutes. After taking out from the vacuum impregnation equipment, the samples were introduced into the oven, as illustrated in Table 3. The samples were dried in the oven for 72 hours.

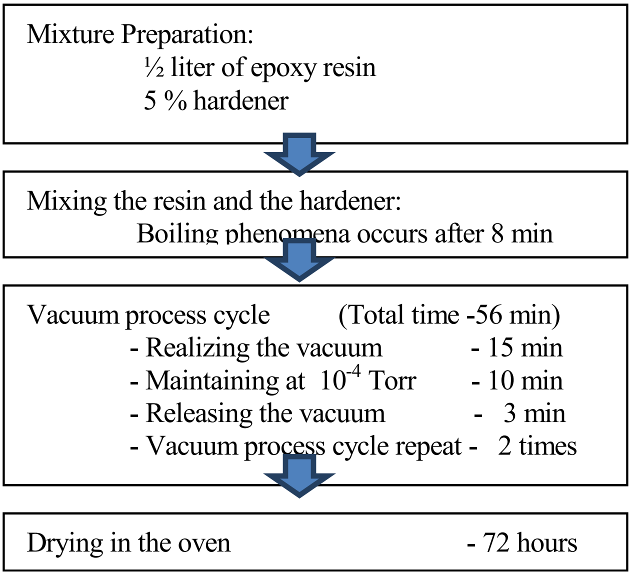


Figure 4. Process Flow for Resin impregnation

The porosity of the material was calculated using the following formula:

$$P_d = \frac{(m_2 - m_1) \cdot \rho_w}{(m_2 - m_3) \cdot \rho_L} \cdot 100 \quad (1)$$

where: 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 (g/cm^3), ρ_L is the resin density (g/cm^3).

At the end of the experiment, some estimation were made regarding the chemical structure and porosity of the sintered die in all stages: in “green stage”, after infiltration with bronze and after resin impregnation, based on the SEM images analyzed with the TESLA BS-300 and JEOL JSM - 5600 LV microscope from the Technical University of Cluj-Napoca.

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