# HEAT TRANSFER BEHAVIOUR OF THE PARTS MANUFACTURED BY SELECTIVE LASER SINTERING (SLS)

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**Abstract**: The variation of temperature in SLS process has a major importance in manufacturing parts from different powders. This experimental study made on a “pump gear” part attends to detect the conditions in which temperature variations are taking place. The study was made referring to DuraformPA and Laserform ST-100 powders and the CosmosWorks analysis can offer the possibility to simulate the heat process in post-sintering oven and can also offer images about the dilatations derived from heat transfer process.

## 1. INTRODUCTION

Sintering temperature is a very important factor, which has a great influence about final consolidation level of the sintered parts. The chamber temperature has a step-variation. There is a warm-up level, when temperature is constantly, then it follows a variation – on build-up time – and finally it comes a cool-down stage, when temperature become constantly again.

The temperature is set-up depending on the material. At metallic powders, for example, warm-up time is reduced comparing to the polymeric powders, to avoid the oxidation of the material. The warm-up stage stabilizes the temperature in the process chamber, part bed, and feed beds. If the temperature is not set correctly there may appear some problems which affect the quality of the manufactured parts.

A problem that Sinterstation 2000 system has encountered was an inconvenient one: the edges of the part rise above the part bed surface and the parts were shrinking along Z axis. This usually occurs when the part temperature dips too low after the feed powder is added. This curl can also occur if the part bed temperature is too low. This curling and shrinkage can be seen in figure 1.1.

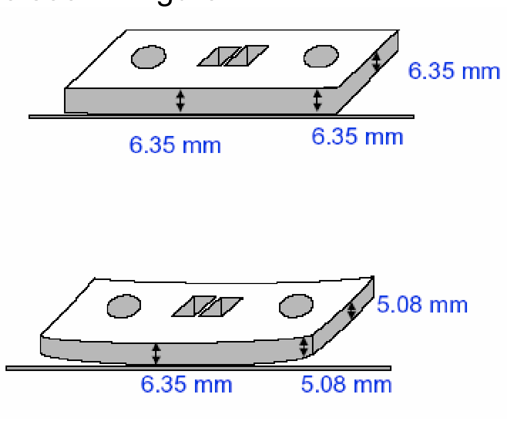


**Fig.1.1. Curling and Z-shrinkage of a part**

Another potential problem that can occur is excessive heating rate or temperature which causes partial melting of powder on the part bed surface. To avoid this phenomenon of appearing cracks on the surface bed is recommended to decrease the temperature with 2 degrees until the powder is uniformly spread (see figure 1.2).

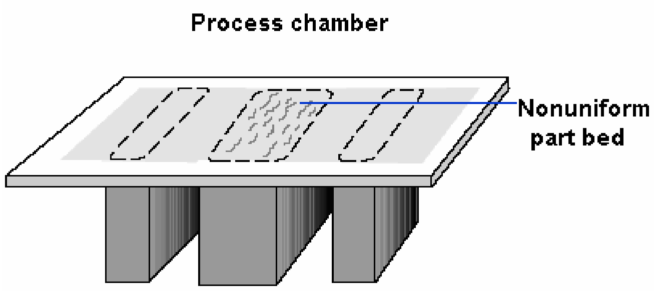


**Fig.1.2. Excessive heating temperature effect**

## 2. CASE STUDY CONCERNING THE SLS MANUFACTURING PROCESS OF A "PUMP GEAR"

In this study we follow to manufacture a part (an oil pump gear) from Duraform powder (see figure 2.1.) and to determine the manufacturing errors that appear during building time and the conditions in which these errors arise. Following the process of manufacturing the part we try to establish the optimum conditions of building, optimum parameters: laser power, temperature, part placement and orientation in chamber room of the system. And because the productivity is an important issue and the system must be used at maximum capacity, the gear in cause, was positioned and manufactured beside another part, a large- sized housing.

The steps that the any part follows in manufacturing process are very important. The part has to be modelled 3D, than this model has to be saved in STL format to be transferred on Sinterstation machine to be build. The SLS system is than prepared with powder; the parts have to be positioned and oriented in their best way possible to obtain a good quality surface. And because this quality of the surface can be different by changing the parts orientation with some small degrees, the placement and positioning of the parts have to be optimized.

The oil pump gear has overall dimensions of 60 mm in diameter and 17 mm on height. Building it beside a large-sized part was insignificant from the amount of powder point of view because the total amount of powder was determined by the height of higher part.

**Fig. 2.1 3D Model of "pump gear"**

After manufacturing the gear it could be remarked that even it was looking upon obtaining a quality surface by orientating the part in its best position, it was neglected an important aspect which carry out of great errors of manufacturing. This aspect was related to mass heat transfer that a large-sized part can produce over neighbouring parts. Figure 2.2 illustrates the shrinkage caused by heat transfer.

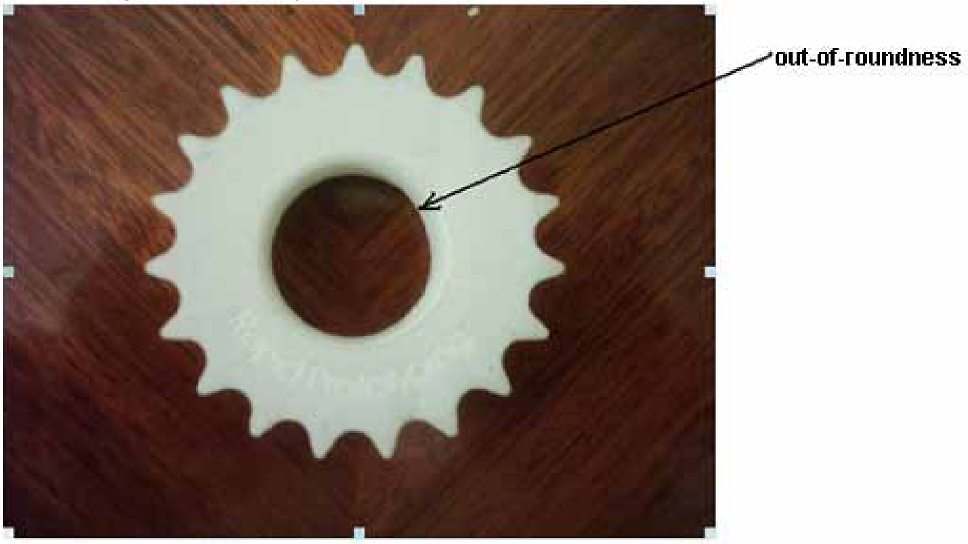


**Fig. 2.2 Shrinkage caused by heat transfer**

To see the deviations of the part profile we optically measured it to get some more information. And because it was necessary to see how big these deviations are we take into account all the measuring methods possible: Best Fit method, Gauss Fit method, Tolerance Fit method, Best Gauss Fit method and Best Tolerance Fit method. The best results were obtained by Best Gauss Fit method, where deviations were: 532,8 µm on inner diameter and 647,9 µm on outer diameter. Figure 2.3 illustrates this profile measure made on a WERTH system.

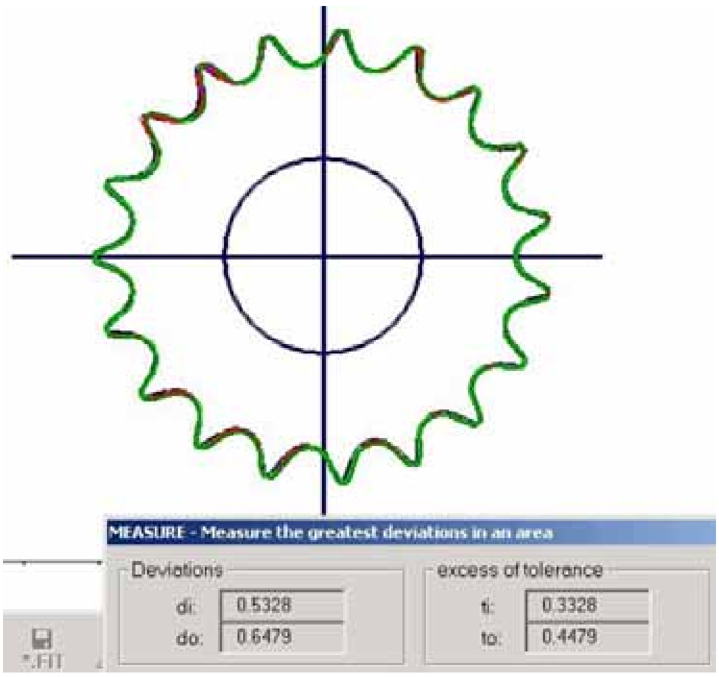


**Fig. 2.3 Profile measuring of the part**

Maximum deviation inside was 532.8 µm and maximum deviation outside was 432.8 µm.

The characteristic of an environment where it take place the heat transfer is called thermal conductivity and is an important issue in studying the influence of temperature variation. This thermal conductivity depends on the nature, composition, pressure and temperature of the environment. This conductivity is different at solid materials and can vary from point to point in case of powder materials.

To study the heat transfer effect have to be known some aspects regarding thermal behaviour of the materials, laser interaction with the powder or the characteristics of a transitory regime.

Against with conduction problem of a solid material, thermal conductivity of a powder, of a part bed, can vary from point to point depending on some factors: local temperature, contact conditions between particles or porosity.

After this experiment of manufacturing the gear, it can be remarked that all the deformations and shrinkage appear as a consequence of heat transfer in ascending heat flow, from bottom of the part to its up and also because of arranging of layers in SLS process.

In figure 2.4 it can be seen how is tacking place the phenomenon of heat transfer on two successive layers, and how the laser beam influences the local temperature. This thing has a great influence especially on metal parts, which suffer of bottom curving.

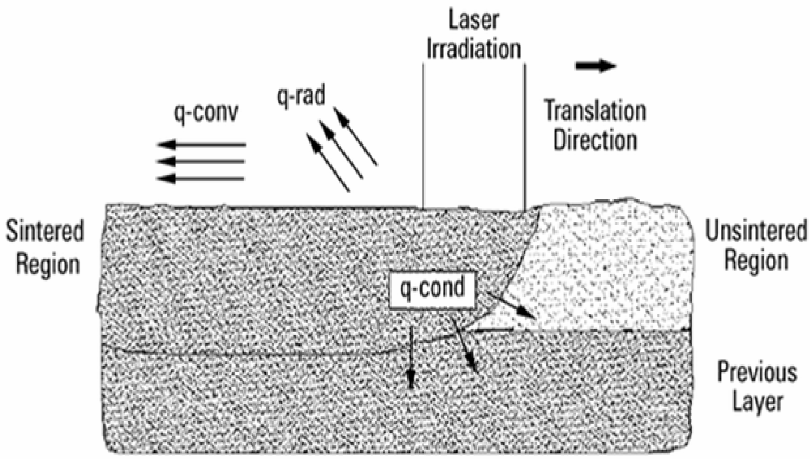


**Fig. 2.4 Heat transfer in two successive layers**

Notations from figure 2.4 represent:
q-conv = convection heat;
q-rad = radiation heat;
q-cond = conduction heat.

## 3. ANALYSIS OF "PUMP GEAR" WITH COSMOSWORKS

To understand better the behaviour of the part, CosmosWorks can offer the possibility to simulate the heat process in post-sintering oven and can also offer images about the dilatations derived from heat transfer process. For finding the temperature field of a part it is necessary to introduce some entrance data useful for analysis. These data refer to powder properties. For this analysis we introduce the properties of a metallic powder, among this: Elastic modulus, Poisson's ratio, Shear modulus, mass density, tensile strength, compressive strength, yield strength, thermal conductivity and specific heat. These parameters are necessary in CosmosWorks analysis and represents physical, thermal and mechanical properties of LaserForm powder.

| Property Name | Value |
|---|---|
| Elastic modulus | 1.37e+011 N/m^2 |
| Poisson's ratio | 0.28 |
| Shear modulus | 5.3516e+010 N/m^2 |
| Mass density | 7700 kg/m^3 |
| Tensile strength | 5.1e+008 N/m^2 |
| Compressive strength | 3.17e+008 N/m^2 |
| Yield strength | 3.05e+008 N/m^2 |
| Thermal expansion coefficient | 1.24e-005 /Kelvin |
| Thermal conductivity | 49 W/(m.K) |
| Specific heat | 460 J/(kg.K) |

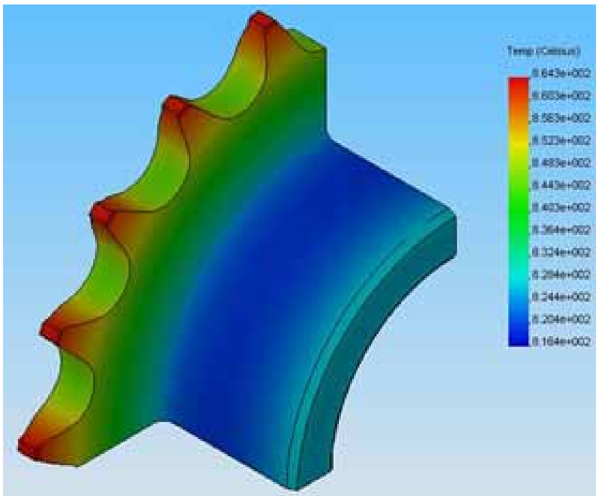

**Fig.3.1. Temperature distribution field for a quarter section of the gear**

Follow the analysis in transitory regime, it can be seen the maximum temperature distribution in active zone (figure 3.1) and after that, it can be find out also the dilatations - made on a quarter section of a part (figure 3.2).

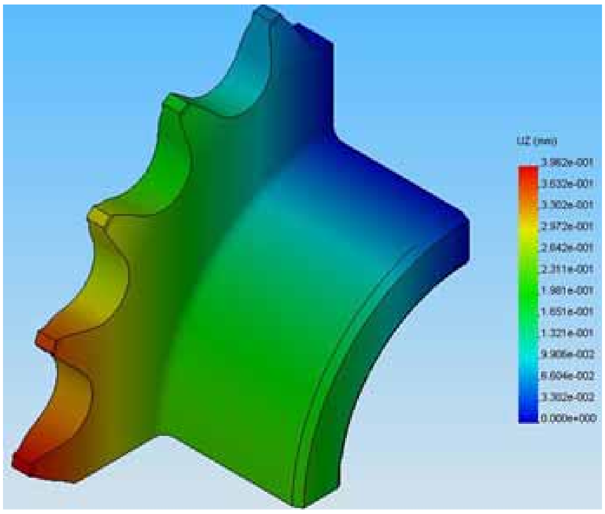

**Fig. 3.2 Dilatations along Z-axis for a quarter section of the gear**

This study was made on quarter section of the part to reduce the thermal time analysis. This simulation of the part behaviour is useful because it can offer information and images before the manufacturing and this thing can reduce the possible errors and shrinkage of the final prototype or part, in this case the pump gear.

Nonuniform distribution of temperature often creates shrinkages, dilatations, curving surfaces and this affects the accuracy and quality surface of the gear. From this reason is very important to control as much as possible this process until the parts are manufactured, to reduce costs and save time.

## 4. CONCLUSIONS

Regardless of the material used in selective laser sintering process (Duraform PA or LaserForm ST-100), the heat transfer effect has great influence on the accuracy of the parts.

The temperature in SLS chamber is very hard to controlled and that’s why turn up a lot of problems like Z-shrinkage, bottom curving of the parts and also great deviations to the profile (in pump gear case-study).

Some aspects regarding temperature variation and heat transfer effect had been presented to understand better this phenomenon and CosmosWorks analysis is a necessary thing to understand better the effect of the heat transfer of any part that implies thermal conductivity in its building.

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