STUDY OF SELECTIVE LASER SINTERING – A QUALITATIVE AND OBJECTIVE APPROACH

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Abstract: *This paper makes a synthetic overview of the process of selective laser sintering (SLS). At first, the SLS process was experimented performed mainly on polymers and nylon to create prototypes for audio-visual help and fit-to-form tests. Gradually, the SLS process has unfolded and expanded including metals and alloys to manufacture functional prototypes and develop rapid tooling. Subsequently, computational modeling has been used for the computer management of the SLS process, optimize the process parameters and enhance the efficiency and dialogue between the sintering machine - operator.*

Keywords: laser sintering, intelligent manufacturing, computational modeling, machine-operator dialogue.

1. INTRODUCTION

Selective laser sintering (SLS) is an intelligent manufacturing process based on the use of powder-coated metal additives, a process generally used for rapid prototyping and instrumentation. A continuous Laser beams are used or pulsating as heating source for scanning and aligning particles in predetermined sizes and shapes of the layers. The geometry of the scanned layers corresponds to various sections of the models established by computer-aided design (CAD) or from files produced by stereo-lithography (STL). After scanning the first layer, the scanning continues with the second layer which is placed over the first, repeating the process from the bottom to the top until the product is complete.

SLS is known also as solid free and open shape manufacturing process, as a layer fabrication technology, rapid prototyping technology, a selective sintering of metal powders. SLS is reactive when using a chemical reaction of mixing components in the presence of a laser and a selective laser melting (SLM), a direct metal laser sintering (DMLS) or direct metal laser re-melting, when the complete melting of powders is pervasive over the solid state dust sintering.

This process was also used in manufacturing moulds, rapid handling of electrodes manufactured, polymer moulds, die casting, die casting of titanium zirconium, bio-medical applications, pieces of zirconium-titanium (PZT) and sheet metal parts. [2]

Currently, the experiments in the laboratory of INCDMTM and dedicated magazines and articles draw attention to a new comprehensive, integrated approach, of the SLS process.

2. MATERIALS USED IN SELECTIVE LASER SINTERING

The SLS process flexibility allows a variety of materials. Some of these materials make the SLS process superior to other rapid prototyping techniques, where the material properties depend on the process. Among these materials, the most common are: wax, paraffin, polymer-metal powders, or various types of steel alloys, polymers, nylon and carbonates. Polycarbonate powders were initially used as starting materials for both experimentation and modelling in the SLS process.

For example, a number of systems and metal alloys (Fe-Cu, Fe-Sn, Cu-Sn), metals (Al, Cr, Ti, Fe, Cu), ceramics (Al_2O_3, FeO, NiO, ZrO_2, SiO_2, CuO) and other alloys (bronze, nickel, Inconel 625) were tested for laser sintering. The results demonstrated that any material could be combined with another material with a low melting point and acts as an adhesive. INCDMTM researchers tested the use of bonding a protective polymer, commonly used in conventional SLS sintering, thus revealing that a wide range of laser sintered materials can be bonded without protection, which is an advantage compared with other rapid prototyping techniques. [3]

It appears that the use of special materials for rapid prototyping is growing and the quality of products is visibly higher.

The sintering achieves higher performance if you use a powder mixture consisting of two groups of materials:

• thermoplastic materials (nylon, polyesters, waxes, some nylon or polycarbonate mixtures especially);

• completion materials whose mechanical properties and thermal properties determined decisive use of new products (metal, non-metallic and composite).

With such networks, some remarkable performances have been achieved:

(a) Some sustainable forms made from a special polycarbonate or a polyamide completing ceramics are used frequently (currently, fine casting workshops of metal parts in serial production conditions);

(b) The direct implementation of successive layers of metallic parts in the future lead to a replacement casting processes for a satisfactory performance in terms of materials such as:

- Copper alloys;
- Titanium alloys;
- Tool steel;
- Fire-resistant steel.

They were made by selective sintering that takes place in a controlled atmosphere, a melting temperature, but their cost is very high and, for the time, it is not being implemented in the industry.
After [3], a great success and achievement is the metal part made from different metals in better economic conditions:

- Ambient temperature
- No protective atmosphere.

Laser sintering powders used may have different components depending on the purpose for which the final product will be used. For example we show some basic features and processes that occur when working with DM20 (DirectMetal 20) Powder for EOSINT M270 from EOS GmbH - Electro Optical Systems, Germany.
Photo ME, Co-Cr powder mixtures are shown in figure 1.

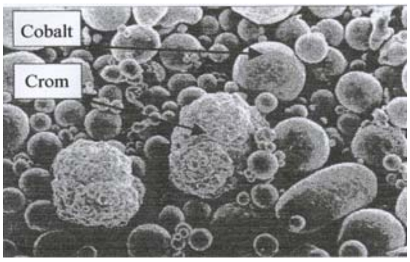


Fig. 1

Sampling batches purity and their repeatability are paramount conditions closely followed by manufacturers of metal powder mixtures recipes of biocompatible metallic powders, any abnormality leading to product rejection (both in terms of physics, mechanics and biomedicine).
The particle size diagram is shown in figure 2.

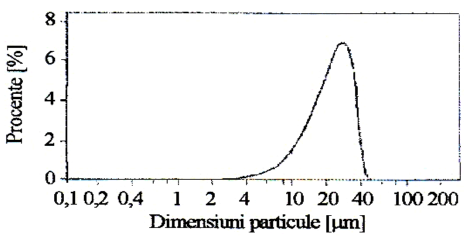


Fig. 2

The procedures of selective sintering (SLS - Selective Laser Sintering) developed after 1992 are based on the experience gained in designing and manufacturing stereo lithography equipment (STL) and the expansion of technological research on other groups of materials with mechanical properties closer to the technological needs of functional assemblies engineering (ceramics, ferrous and nonferrous metals).
In this way, we managed to demonstrate that a thin layer of certain mixtures of powders under the action of the laser beam can reach the local level, function and duration of exposure, which marks the transition of the melting temperature of the powder layer in the liquid phase.
Based on the physical properties of the powders used, immediately after the laser beam action ceases, the local solidification takes place, achieving a compact drawstring made after the directions of molecular chains, surrounded by a volume of powders unexposed to the beams mentioned above.
A view with emphasis on individual layers of the solidified powder bed is shown in figure 3.

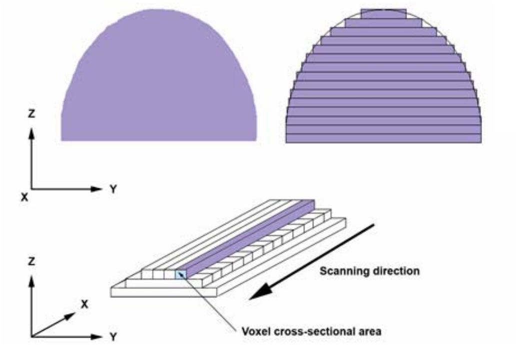


Fig. 3

The explanation is more complex because the solidification range of materials is especially diverse. It is essentially based on stereo lithography processes exposed to the same mechanism: the installation of chemical bonds that form macromolecular linear chains, or three-dimensional tree.
For these situations state transitions, which involve a significant local heat input, they can be accelerated by inhibiting initialized and controlled substances, and energy intake may be given by concentrated heat sources on the desktop, laser radiation etc.
Micrographic appearance of pure metal powder is shown in figure 4.

These sources must be adapted and adjusted on the fly, so as to give extra heat necessary to achieve the melting temperature, which provides thermo-kinetic conditions favorable for the development process by establishing the macromolecular chains and a partially crystalline structure, with the transition of the liquid state to the solid state, reinforced, which marks the sintering prod

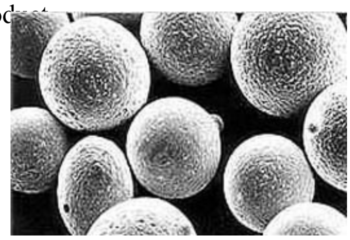


Fig. 4

In terms of energy, the powders used in the in powdery have a wide range of melting temperatures which require a different input of heat from the concentrated source of energy. Choosing the necessary activation energy is possible by selecting rapid heating schemes in accordance with the dynamics of the sintering

process. The diversity of these schemes has attracted a final designation of laser sintering.
In conclusion, this phase is superior to the anterior period when the stereo lithographic technologies and equipments have been researched, designed and homologated.
Selective laser sintering processes are based on a variety of materials which will result in superior products at a stage performance, is the physical and mechanical properties close to the loads of the usual parts of a machine.
Rapid prototyping and manufacturing technologies using materials and processes have been developed in recent years in several directions, depending on the material used and the technology of solidification of the material.

3. METALLIC POWDERS FABRICATION PROCESSES

The most modern powders and granular mixtures used by all major manufacturers of carbide or drying by atomization is atomization spray - drying, being the only one that combines high productivity with high quality grain.
The atomizer and its related annexes are, by scale and complexity of their facilities, an independent micro-fabrication in any technological process of making pieces of hard carbide alloys. It is the main facility that provides the development of the granule in any modern manufacturing in large series production and requires high precision and dimensional parts, such as the production of interchangeable cutting plates.
Granules obtained by atomization are perfectly spherical in shape (fig. 5 and fig. 6), being developed under protective gas with no risk of oxidation in a plant partly sealed.
The atomization takes place continuously and applies to basic components (fuel-oil-binder sintering), achieving good flow properties. The powder (12%Co, 88%WC) spray, grit 105 micron (600 x magnifications) is shown in figure 5.
Atomized powder (12%Co, 88%WC), granulation 45 micrones (zoom x 300), is shown in figure 6.

Fig. 5

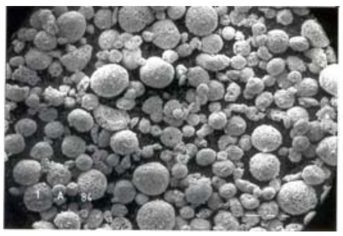


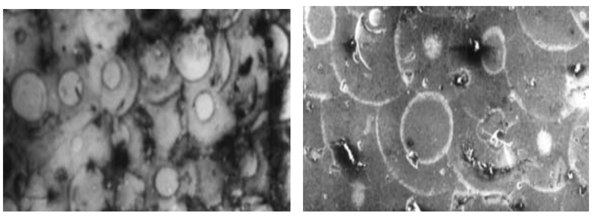
Fig. 6

The first operation of the process of producing atomized granules - mixing the components in a continuous flow – uses a machine called *Attritor* to ensure homogenization of the components and a fine wet grinding in a vertical centrifugal ball mill.
The objective of this milling – mixing operations is not only to produce a uniform dispersion of cobalt as a binder or sintering of the mass composition of various hydrocarbons, but also to crush, pulverize and mechanically connected with the particles of cobalt carbide in order to obtain a good sintering.

4. EXPERIMENTAL DETAILS

4.1. Bonding-adhesion mechanisms

When laser energy is absorbed by the material, the powders are bound by the following mechanisms: viscous flow bonding effect of curvature, particle wetting, sintering in solid state, liquid phase sintering, melting. Bounding the viscous flow is dominant in materials with suitable temperatures and depends on the viscosity, while the effect of curvature is the driving force in nano-crystalline materials. [4]
Laser sintering is conducted in a short period of time (milliseconds) - not enough time for bonding to take place because of the diffusion of the solid layer. For this reason, the bonding of the powders is caused by the melting of the powder components with low melting points or complete melting of the entire mass. The sintering by melting a powder part is the most common and is carried out using particle systems in a combination of components with high and low melting points. In this situation, the laser beam attacks the local powder layer inducing only the melting of the solid with a low melting point that, after subsequent wetting, bonds the components with high melting points. Wetting the space between particles can be made by bringing together two phases, to prevent the emergence of the "formation of lumps" phenomenon. [4]
Research in this area is focused on the study of the SLS process of metals, the next stage of research after sintering metals, alloys and ceramics. In the direct SLS process, the agglomeration of particles and porosity problem is addressed through changes in process parameters. The sintered portion (fig. 7) shows clearly the circular forms, and agglomerations formed.



a **b**

Fig. 7. Optical micrographs (a) and electron scanning micrographs (b) – sintered particles made up of iron and graphite.

In the actual fusion process, it was found that the complete melting of the powder causes problems such as warped surfaces and inadequate size of the finished piece.

4.2. Pre-processing

The deposition of powders and the mechanism of sintering depend on the density of the powder on the sintering mechanism, the shape and size, and flow rate.
The deposition on the mould (pattern) has a significant effect on the tension and on the bending of the part. For a better sintering of powdered metal layers, the density increase. This can be achieved by optimizing the particle shape and surface. Ordinary particles produce porous layers of high density, appropriate size and appropriate composition. For formation of dense layers, an electrostatic technique is used. Prior to optimizing the performance and SLS process, the powder sintering ability can be improved by thermal pre-treatment. [5]

4.3. Experimental parameters

Parameters that vary in SLS process are: powder size, scanning speed, powder density, frequency pulsars, energy intensity laser scan size, scan of the surface temperature of the piece, laser performance, size distribution, particulate mixture and the volume of related material. [6] For sintering, are taken into account other factors such as: working speed, building height, volume play. In addition, the manufacture and assembly orientation are important parameters for the optimal use of space and reducing execution time.
Figure 8 shows schematically the process parameters involved in SLS.
The design of experimental data is needed to determine important parameters, their interaction effect for process optimization and to determine the operating window.
Experiments and regression analysis can also be used to develop a quantitative model of SLS-related factors and coefficients.

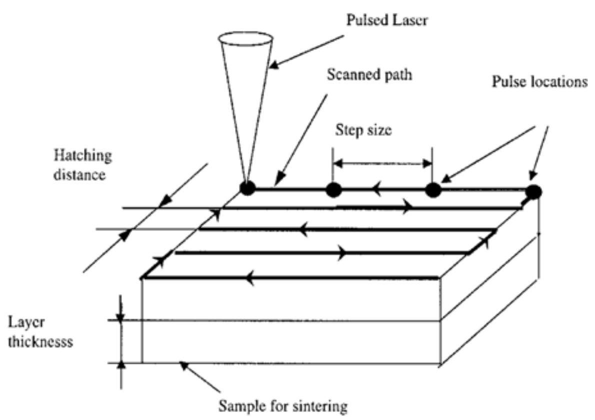


Fig. 8. Schematic presentation of the parameters of the SLS process.

4.4. Experimental parameters role

Measurable properties of the sintered parts are: yield strength, elongation, Young modulus, hardness, surface roughness, shrinkage, thickness, porosity, degree of wear, tensile strength, depth and speed of scanning sintering.
Shrinkage is measured to determine the accuracy of the piece. It varies from one track to another, and the degree of deformation is difficult to estimate and to predict because it is independent of the geometry, size and weight of the piece.
The effects of experimental parameters can not be generalized, differing according to their variation. Below are, however, several examples of the role and influence of these parameters. Thus, in the sintering of polymers, the laser beam is good but its density is greater than the critical value, resulting in the degradation of polymers. [7] Strengthening metal powder compaction occurs at a lower average energy and a density compacted sample is higher than continuous wave. For the laser radiation interaction with 316L stainless steel, high scanning speed and distance scanning improve the cohesion characteristics of the layer obtained. The double laser beam technology, improves the ductile character of the metallic material obtained when the part is melted and solidified by the laser wave Nd: YAG and CO_2 laser reheated, with an appropriate delay time. In the case of high speed steel powders, high intensity laser induces a high density of the surface, appearing a tendency in the growth and the surface roughness of the work piece dimensional error. When the scanned area increases, the rugosity of the surface is improved and side pores form. [8]
In addition, when the peak effect of the laser beam was examined it was established that the solid piece and the maximum temperature of the powder have been affected more than the peak during laser radiation.

4.5. Post-processing

Defects are observed at concentrations of SLS powder, lumps, cracks due to pressing, twisting layers, cohesion and adhesion weak, porous or uneven surfaces which cause contractions, stress and porosity, low mechanical strength, rough surface and lack of accuracy and precision scale product.
Therefore, it was found that SLS products post-processing is needed, an operation which improves the integrity and compactness, mechanical properties, surface roughness of the structure while reducing the porosity.
The most popular processing operations are: Nickel Electroplating, semi-clean Nickel Electroplating (bright), polishing, annealing, liquid phase sintering, heat treatment, coating, protection, laser surface treatment SLS (HIP) and hot isostatic pressing.
In the case of coating and protection, the pores are closed and the hardness increases while the wear rate decreases.
The heat treatment of the sintered parts depends on the temperature and duration of treatment. Such treatment reduces the hardness, decreases surface tension and heat, while the cover protection increases the tensile strength and surface hardness. Infiltration with epoxy resin, silver, zirconium, aluminium and copper helps to achieve a density and high bending strength, the

surface finish, hardness, stiffness and reduced component wear rate.
Selective laser sintering HIP is a technique for obtaining net play, developed outside combination independent HIP and SLS parts, the boundary limit is sintered at a higher density. The process is similar to laser exposure method (SK) that creates a waterproof and gas operating capability of freedom release of the SLS part.
Over time, robots were used for surface finishing and processing, but production is postponed because of the need to track the robot's programming.

4.6. Mathematical modelling

Many attempts have been made on thermal modelling of the sintering of an amorphous polymer (bisphenol-A-polycarbonate) in which the temperature distribution in a given area was found by the following equation for calculating density using the equations in the assessment and calculation of sintering.
The thermal conductivity of the layer of powder should be approximated or found through experimentation. The purpose of simulation and experimental analysis was to determine the depth, thickness and sintering for different geometrical dimensions of the laser control parameters. Thus, the mathematical modelling showed the need for numerical simulation measurements (absorption rate, specific heat, viscosity, melting powders), the depth and thickness of sintering increases with laser intensity and decreases the scan. In another situation, you can successfully use the volume control method for determining the density and thermal conductivity of polymers. [9]
In the SLS process modelling using metallic powders, the latent heat of fusion is high and, therefore, the melting and solidification phenomena have a significant effect on temperature distribution, the residual tension of the piece and sometimes on the sintering regime. These factors, together with the weight of the solidified part, were the base of simulations taken into account when determining changes in the number of pulses using finite element modelling.
When striving for mixing two metal powders with very different melting points, many factors need to be taken into account many factors, such as fluid flow flowing, gravity and capillary contraction induced by solid particle velocity layer powder.
A different approach to modelling the SLS process may be made without the use of finite element simulation. This approach is based on geometric simulation, reflection and absorption of a large number of laser beams in the layer of powder. Each time a beam attacks a powder particle, the amount of energy absorbed and reflected is calculated, and the reflected beam is then drawn. The model used has shown that dimension of the sintering for the mixture consisting of two metal powders. [3]

5. PERSPECTIVES

In the future, the SLS activity may continue in several areas. Materials can be tested for SLS with low volume production, with specific properties. However, it is envisaged that the size of pre-sintered parts will become more than a critical value, the minimum thickness of the layer will decrease and, consequently, the surface roughness decreases. It is therefore necessary to study the microstructure properties to be developed in future research studies.
Another area of future research is to manufacture various parts of the same product using different materials. Desired properties of parts can be achieved by using different materials for different layers, resulting in new features metallurgical and mechanical parts.
Various process parameters can be optimized either by modelling or by a subsequent experimental strategy, so that laser energy transfers to the surface to make the anterior surface near the interface. Optimizing these parameters is also necessary to anticipate resistance, strength and hardness in a SLS product.
Because the product post-processing is inevitable and time-consuming and pre-processing of powders takes time, an improved version of the SLS can be developed with post-processing techniques for better surface finish, track resistance, dimensional accuracy to achieve a and a reduced working time. It is envisaged that the metals with a special performance will be tested in future for complex products of good quality.
In addition, to achieve this goal, the melting will be used for chemical reactions between phases.
In recent years, new technologies have been successfully developed and applied in the field of components for research and biomedical devices, implants, 3D scanning, CT scan, MRI scan, handling DICOM files, 3D design, e-Manufacturing (Rapid Prototyping, Rapid Manufacturing, Rapid Tooling). They open a new era of collaboration between the engineer, the physician and the IT expert. [1]

6. CONCLUSIONS

Since its emergence, the SLS has attracted attention from both researchers and users. As a result, various aspects of the processes and materials used for SLS sintering have been studied and there have been established that this is a modern and at the same time also a rapid means for prototyping and manufacturing.

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