Analysis of Mechanical Proprieties of Selective Laser Sintered Polyamide Parts Obtained on Different Equipment

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In the last years, researches regarding the manufacture of polyamide parts using selective laser sintering process have developed increasingly more because of the advantages this materials offer. This paper was focused on a comparative study about the mechanical proprieties and surface roughness of parts manufactured by Selective Laser Sintering (SLS) from PA2200 powder. Tested parts were achieved on DTM Sinterstation 2000 Machine and EOS Formiga P 100 Machine. The results obtained lead to the conclusion that the mechanical proprieties obtained for the test parts made at 7,5W laser power on DTM Sinterstation 2000 Machine, are close to the results obtained for the test parts made at 30W on EOS Formiga P 100 Machine.

Keywords: Polyamide, Selective Laser Sintered, mechanical proprieties, roughness

Selective laser sintering, process known for achieving prototypes, represents a manufacturing process in freeform of the components by sintering powders [1].

This method is based on the materialization of a CAD product by the addition of successive layers. Finally, by heating and sticking of powder at a temperature below their melting point, three-dimensional components are obtained [2].

Polyamides, their chemical derivatives and their copolymers, and are often referred to in the literature as nylon. There is a wide range of materials - fibers, crystalline plastic materials, amorphous plastic materials, adhesives and rubbers, that are classified as polyamides [3].

Polyamides with the acronym PA, have multiple applications both in industry and in medicine, especially in the manufacture of medical implants.

Polyamide has good biocompatibility with various human tissues and cells, probably because of its similarity with proteins of collagen due to the active group from its chemical structure [4].

In the literature there are a number of references about the manufacture of polyamide parts using selective laser sintering process [5 - 8].

The mechanical properties of polyamides are influenced by the material structure and by the working parameters used in the manufacturing process. Polyamide 6.6 reinforced with 20% glass fibres, offers very good mechanical, thermal and frictional proprieties [9].

A testing sample can help to determine four standard basic mechanical proprieties: tensile strength, yield strength, elastic modulus and Poisson ratio [10].

Bacchewar P.B. [11] studied the effect of working parameters on roughness surface achieved on the machine EOS 380P Sinterstation (scanning speed, thickness of the powder, laser power, the piece orientation in working space) using the SLS process, and PA2200 powder.

Taking into consideration the previous researches in the field, the purpose of this study was to evaluate the influence of laser power, as working parameter, on the characteristics of polyamide (PA2200) parts obtained, using SLS technology, on DTM Sinterstation 2000 machine (produced by *DTM Corporation)* and on EOS Formiga P 100 machine (produced by Electro Optical Systems - EOS GmbH).

The material used in this research was the PA2200 polyamide powder (mean grain size 50 - 90 microns, bulk densitiy > 0.430 g/cm^3), produced by the Electro Optical Systems - EOS GmbH, Munich, Germany.

This paper is part of a larger research that is focused on the behavior and properties of parts intended for custom implants manufactured from polyamide PA2200 using selective laser sintering process at different laser powers. The group of samples obtained by SLS on EOS Formiga P 100 machine at 30W laser power (control group) was compared with samples achieved at different laser powers on the DTM Sinterstation 2000 machine. Analyzing the obtained results, it was concluded that the nearest values of mechanical properties are found in parts produced with 7.5 W laser power on DTM Sinterstation 2000 machine compared to control group.

Taking into account the manufacturing conditions, mechanical characteristics (tensile / compression / flexure) and surface roughness were evaluated for the two obtained materials: PA2200 to 7.5 W on DTM Sinterstation 2000 machine and PA2200 to at 30W laser power on EOS Formiga P 100 machine.

Experimental part

Materials and methods

In this paper, samples from PA 2200 (with melting point between 172 and 180° C) were produced by Selective Laser Sintering Technology (SLS) on DTM Sinterstation 2000 Machine, at 7.5 W laser power and on EOS Formiga P 100 machine at 30 W laser power.The working parameters used to manufacture the specimens on DTM Sinterstation 2000 machine were: temperature: 170°C, thickness of the deposited layer100 μm, laser power 7.5 W, type of laser: CO_2, scan speed 1257.3 mm/s (table 1).

The working parameters for EOS Formiga P 100 machine were: laser power 30 W, type of laser: CO_2, 100μm thickness of the deposited layer and the scanning speed between 1,6-5 m/s, according to curve geometry (table 1).

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Parameter	DTM Sinterstation 2000 machine	EOS Formiga P 100 machine
Type of Laser	CO_2	CO_2
Laser Power	7,5 W	30 W
Scanning speed	1,2573 m/s	1.6 ~ 5 m/s (according to curve geometry)
Thickness of the deposited layer	100 μm	100 μm
Working temperature	170°C	170°C

Table 1
WORKING PARAMETERS USED IN MANUFACTURING PROCESS

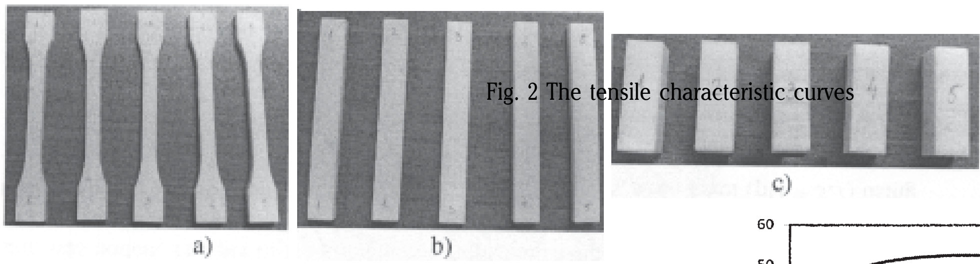

Fig. 1. Samples from PA 2200 manufactured using SLS proces for testing at a) tensile; b) flexure; c) compression

Table 2
DIMENSIONS OF PA2200 SPECIMENS

Type of test	Dimensions, [mm]		
	Lenght	Width	Tickness
Tensile	150	10	6
Flexure	80	10	4
Compression	30	10	10

Using the above described technology there have been manufactured sets of specimens for each type of mechanical tests (tensile, compression, flexure) for each studied SLS machine.

The three dimensional models of the specimens have complied with established standards for mechanical testing of plastics *(tensile test: EN ISO 527-4*, flexural test: *EN ISO 178:2011*, compressive tests: *EN ISO 604:2004)*. Thus, the specimens had the dimensions: according to (table 2)

Mechanical tests were performed using INSTRON 3366 testing machine (10 kN), five specimen of each type being tested.

To determine the tensile mechanical properties an INSTRON 3560 biaxial mechanical extensometer was used. Test speeds were 2 mm / min for tensile test and 5 mm / min for flexure and compression tests.

Surface roughness measurement was performed using Mitutoyo SJ 210 Surface tester in each 5 points on the two surfaces of each sample.

The results were statistically analyzed by comparing the obtained averages between the control group (PA 2200 at 30 W) and samples from PA2200 at 7.5 W laser power, using Microsoft EXCEL software. When comparing averages the "t" test was used and the calculations were done by the following mathematical formulae:

$$s' = \sqrt{\frac{n_1 \cdot s_1^2 + n_2 \cdot s_2^2}{n_1 + n_2}} \quad [12]$$

$$t = \frac{\bar{x}_1 - \bar{x}_2}{s' \cdot \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad [12]$$

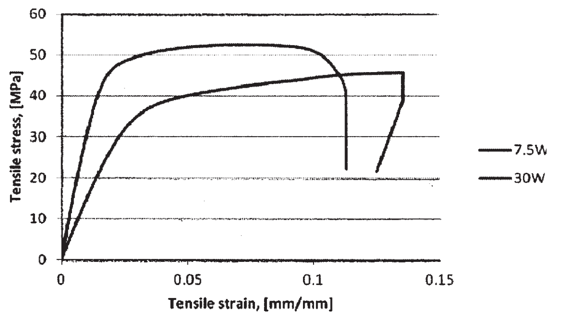

Fig. 2. The tensile characteristic curves

where:
s = standard deviation of the samples
n_1 = number of samples from PA 2200 at 30W
n_2= number of samples from PA 2200 at 7.5 W
$\bar{x}_1$ = averange of samples made at 35 W laser power
$\bar{x}_2$= averange of samples made at 7.5 W laser power

Considering the liberty degree (f = 8), calculated on the formula $f = (n_1+n_2) - 2$, [12], were compared the obtained values of t_{calc} with tabled values (t_{tab}) and the probability (p) values were chosen.

Results and discussions

Figure 2 shows characteristic tensile curves for the two materials. Analyzing the results obtained at tensile test, it is observed that although the laser power is significantly different, the mechanical characteristics of the material obtained at 7.5 W laser power on DTM Sinterstation 2000 machine, are superior to those obtained at a higher laser power. The tensile strength obtained was 52.41 MPa for 7.5 W laser power, respectively 45.39 MPa for 30 W laser power. The strain at tensile strength is similar for both types of material. The break of the material manufactured to a higher laser power occurred suddenly in comparison with that produced at lower laser power, whose break is progressive, fact favorable, given that the material is recommended for medical applications. The value of the E-modulus at ambient temperature is also greater by 7.5 W laser power on DTM Sinterstation 2000 machine with about 15% the material being stiffer.

The results of the 3 point bending test conducted on manufactured specimens is shown in figure 3 and the

Type of material	Maximum Load, [N]	Tensile stress, [MPa]	Tensile strain, [mm/mm]	E-modulus, [MPa]
PA2200 7,5W	2124.47	52.41	18.77	1646.50
Standard deviation	625.094	0.376	1.028	18.262
PA2200 30W	2,226.54	45.39	19	1,388.92
Standard deviation	189.75	1.22	2.07	55.58

Table 3
MECHANICAL PROPERTIES OBTAINED AT TENSILE TESTS

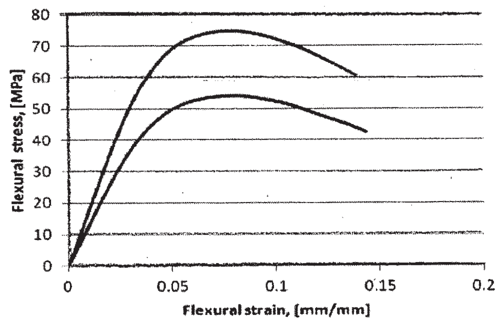

Fig. 3. Flexural characteristic curves obtained by 3 point bending test

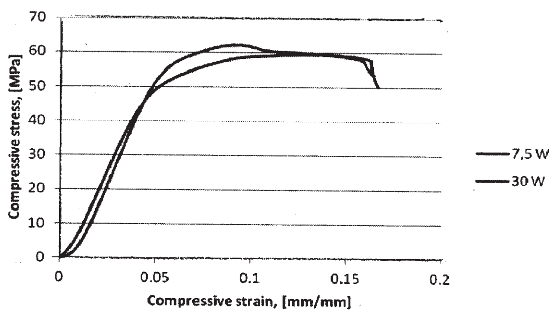

Fig. 4. Compressive characteristic curves

Table 4
MECHANICAL PROPERTIES OBTAINED AT FLEXURE TESTS

Type of material	Flexure Load at Tensile Strength, [N]	Flexure stress at Tensile Strength, [MPa]	Flexure strain at Tensile Strength, [mm/mm]	Flexural modulus, [MPa]
PA2200 7,5W	137.02	74.48	0.082	1687.05
Standard Deviation	1.96	1.31	0.001	29.33
PA2200 30W	91.02	54.80	0.079	1304.54
Standard Deviation	5.98	4.10	0.002	135.48

Table 5
MECHANICAL PROPERTIES OBTAINED AT COMPRESSIVE TESTS

Type of material	Compressive load at Tensile Strength, [N]	Compressive stress at Tensile Strength, [MPa]	Compressive strain at Tensile Strength, [mm/mm]	E-modulus, [MPa]
PA2200 7,5W	6326.96	62.39	0.10	1378.57
Standard Deviation	253.31	2.45	0.01	16.82
PA2200 30W	4894.24	54.15	0.12	1196.54
Standard Deviation	299.98	3.27	0.01	51.03

Table 6
SURFACE ROUGHNESS VALUES FOR THE TWO SURFACES OF THE SPECIMENS

Sample No.	Average of values determined in 5 points, [μm]			
	Surface 1 of samples		Surface 2 of samples	
	7,5 W	30 W	7,5 W	30 W
1	11.787	24.015	10.588	10.679
2	12.282	23.898	9.911	12.078
3	11.960	25.899	10.886	10.333
4	12.007	25.759	10.429	10.539
5	12.008	23.676	10.492	11.276
Averange	**12.009**	**24.649**	**10.461**	**10.981**
Standard deviation	**0.178**	**1.085**	**0.354**	0.707
s'		**0.777**		**0.559**
t		**25.731**		**1.472**

values of flexure strain and stress and bending modulus of elasticity are presented in table 4. Also in this test the better characteristics has the material fabricated on DTM Sinterstation 2000 machine; higher flexure stress (~27%), similar flexure strain and higher bending modulus (~23%).

Figure 4 shows the compressive curves of the two materials. Analyzing the mechanical characteristics and constants obtained by compression test it can be noticed the same behaviour, the differences being reduced (~13% for compressive stress and elastic modulus).

It must be noted that surface 1 was considered as surface area in direct contact with the powder bed on the working cylinder of the machine. Surface 2 represented the upper surface of the sample (the last sintered layer of the part).

In the case of surface 1 analyzed, at the comparison of the control group averages roughness with the test group there appeared significant statistical differences at p = 0.999, so, the averages differ so much, only in 0.001% of cases, can be close values.

By applying "t" test to compare averages of the group of samples realised at 7.5 W laser power, with those of the group realised at 30 W laser power, for surface 2, there resulted significant statistical differences at p = 0.90 (only in 0.1% of cases can appear close values of compared averages).

Conclusions

There have been analyzed the mechanical characteristics of PA 2200 specimens obtained at 7.5 W on DTM Sinterstation 2000 Machine with the specimens manufactured at 30 watts on EOS Formiga P100 Machine, highlighting the fact that the two types of samples have relatively similar mechanical behaviour.

It was also evaluated the influence of working parameters on the physico-mechanical properties of polyamide PA 2200 parts, manufactured by SLS method, both on DTM Sinterstation 2000 Machine and on EOS Formiga P100 Machine.

The scanning speed had a significant influence upon the mechanical proprieties. A lower scanning speed combined with a lower laser power lead to similar or better results on one machine.

The surface roughness was evaluated for the two mentioned materials (PA 2200 manufactured at 7.5 W on DTM Sinterstation 2000 Machine and PA 2200 at 30 W manufactured on EOS Formiga P100 Machine) and statistical processing of the results were conducted. The mechanical properties of the material and the surface roughness are influenced by the working parameters used during the manufacturing process.

The values obtained for the surface 2 of the parts manufactured at 7.5 W are more close to the values obtained at 30 W (difference between the averages 0.520μm), in the comparison with the situation obtained for surface 1, where the difference between the averages is 12.641μm.

The paper shows that the SLS process on DTM Sinterstation 2000 machine, proves to be an efficient process to obtain PA2200 parts with good mechanical proprieties.

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