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INFLUENCE OF PRINTING PARAMETERS ON THE MECHANICAL PROPERTIES OF POLYAMIDE IN SLS TECHNOLOGY

WPŁYW PARAMETRÓW TECHNOLOGICZNYCH NA WŁAŚCIWOŚCI MECHANICZNE POLIAMIDU W TECHNOLOGII SLS

A b s t r a c t

This paper presents the research results of the influence of selected process parameters on the tensile strength samples obtained according to the ISO 527 standard. Bio-capable polyamide powder PA 2200 was the material used in the process. The research included such parameters as energy density transmitted to the sintered layer, laser power and speed, printing direction and the number of scanning. A computer program based on artificial neural network was used to analyze the research results. The program allowed us to assess the influence of printing parameters on the tensile strength, based on previously made research without the need to prepare samples according to the experimental plane.

Keywords: Additive Manufacturing, SLS, Polyamide PA 2200, Formiga P100

S t r e s z c z e n i e

W artykule przedstawiono wyniki badań wpływu wybranych parametrów procesu technologii Selektywnego Spiekania Laserowego na wytrzymałość na rozciąganie próbek wykonanych zgodnie z normą ISO 527 z użyciem poliamidowego proszku PA 2200. Uwzględniono parametry takie jak: gęstość energii, prędkość i moc lasera, kierunek wydruku oraz liczbę naświetleń. Do analizy uzyskanych wyników badań wykorzystano program działający w oparciu o modele sztucznych sieci neuronowych, pozwalający na oszacowanie wpływu opisanych czynników na wytrzymałość uprzednio wykonanych próbek

Słowa kluczowe: Technologie Przyrostowe, SLS, Poliamid PA 2200, Formiga P100

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1. Introduction

Unconventional manufacturing technologies, well known as 3D printing have been developing rapidly during the last few years. The first additive technology was invented by Charles Hull in the 80s of the last century. In the last years, a special committee ASTM F42 has prepared a valuable standard where basic terminology related to additive technologies was described. Standard ASTM F2792-10 [2] describes the main phenomena related to additive technologies and standardizes the procedure. Standard ISO 527 [5] and ASTM D638 [3], which are usually used for research in uniaxial tensile tests, are limited in their application because of their layer manufacturing structure. Additive technologies have many advantages e.g. reduction of production time, no need to produce manufacturing tools, small cost in case of singular production and possibility to obtain very complicated shapes, especially inner dimensions. The disadvantages of additive technologies include e.g. anisotropy properties, shrink of material and cost in mass production. There are many papers describing the main area of additive technologies, their mechanical properties and accuracy. In work [9] authors described the influence of proportion of two types of polymer powder which were mixed together, PA12 and HDPE, on mechanical properties in relation to the selected composition. Mechanical properties of selective laser sintering technology were also described in paper [12], where authors determined tensile and bending strength of samples manufactured according to the ISO 527 standard. In work [7], a selective laser sintering technology was used to build two types of element in the form of a shaft and sleeve. The authors determined the influence of selected printing parameters on the accuracy and shape deviations e.g. roundness, cylindricity and straightness. The samples were made in two types of fit which reflect real assembly elements.

Almost all additive technologies have several printing parameters which have a great influence on mechanical properties, accuracy [1] and rheological properties. We can usually set printing direction and layer thickness. Many technologies have additional parameters, especially those which use the laser [11]. In this research, the authors used a computer program based on artificial neural network EASY NN as a calculation tool.

2. Applied Technology

Selective Laser Sintering is one of the oldest additive technologies. It was invented in 1987 at the University of Texas in the United States by Carl Deckard. This technology uses CO_2 laser power to bind sintered powdered material to create a solid structure. In the sintering process, a currently built and previously made layer are joined to obtain a solid model. Building chamber is heated to the temperature little below the melting point. The whole manufacturing process is performed in a chamber filled with neutral gas e.g. nitrogen. In this technology, we can use plastic, ceramic or metal powder to produce objects. The most popular material based on plastic powder is polyamide PA 2200. Cooling process in the SLS technology is quite similar to casting process. In both processes, in case of too fast cooling process in a building model, stresses arise which change model dimensions and can cause damage [8, 10].

3. Research

The aim of the presented research was to determine the influence of 5 printing parameters e.g. printing direction, energy density transmitted to the sintered layer, building layer thickness, laser speed and power on the tensile strength. The samples were designed in the CAD program SolidWorks 2012 and then manufactured by a machine Formiga P100. Polyamide PA 2200 with mechanical properties presented in Table 1 was the material used to build the models. Each type of samples were made in 5 pieces to include statistical calculations. The printing parameters are shown in Table 2. A tensile test machine Inspect Mini 3000N was used to determine mechanical properties. During this research, the samples were subject to tension according to ISO 527 standard. Further, the research results were analyzed by the EASY NN program. In the program it is possible to set a number of hidden neurons and a number of neurons layer. In the calculation phase, the program was used „learning with teacher", which allowed to compare their results with real data obtained from the tensile test. Samples 5, 7 and 13, 15 were excluded from the "learning process" to determine the accuracy of artificial neural network. Placement samples on the virtual platform are shown in Fig. 1.

Table 1

Polyamide PA2200 mechanical properties [4]

Mechanical Properties	Value	Unit	Standard
Young's modulus	1700	[MPa]	EN ISO 527
Shore'a hardness	75	[–]	ISO 868
Density	930	[kg/m^3]	EOS
Melting temperature	176	[°C]	ISO 11357-1/-3

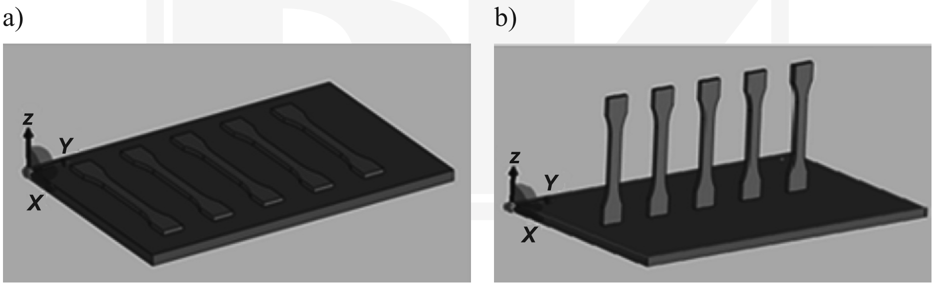


Fig. 1. Placement samples on the virtual platform: a) horizontal samples, b) vertical samples

Energy density transmitted to the sintered layer can be calculated the from relation (1) [12].

$$ED = \frac{P}{vh} x \quad (1)$$

where:

ED – energy density [J/mm^2],

P – laser power [W],
v – laser speed [mm/s],
h – hatching distance [mm],
d – diameter of focussed beam,
x – beam overlay ratio $x = d/h$.

The use of artificial neural network allowed us to set 5 different values of laser power, 4 laser speeds, 5 energy densities, 3 different amounts of exposures and 2 printing directions. The only limitation was the number of input variables, limited to 10.

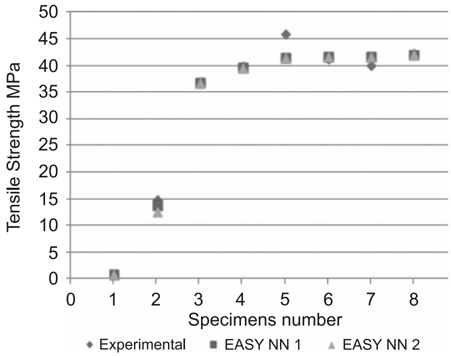
Table 2

Printing parameters

Samples No.	Laser power [W]	Laser speed [mm/s]	Energy density [J/mm^2]	Number of scanning	Placement on the platform
1	7	3000	0.016	1	Horizontal
2	14	3000	0.031	1	Horizontal
3	25	3000	0.056	1	Horizontal
4	21	2500	0.056	1	Horizontal
5	22	1400	0.1	1	Horizontal
6	22	1000	0.147	1	Horizontal
7	21	2500	0.056	2	Horizontal
8	21	2500	0.056	3	Horizontal
9	7	3000	0.016	1	Vertical
10	14	3000	0.031	1	Vertical
11	25	3000	0.056	1	Vertical
12	21	2500	0.056	1	Vertical
13	22	1400	0.1	1	Vertical
14	22	1000	0.147	1	Vertical
15	21	2500	0.056	2	Vertical
16	21	2500	0.056	3	Vertical

4. Results

The simulation research results obtained by artificial neural networks are shown in Fig. 2. The average absolute error in the EASY NN 1 model was equal to 2.95% for samples 1–8 and 9.8% for samples 9–16. For models EASY NN 2, absolute error was respectively 4.5% and 11.5%. The largest error occured in the samples 5, 7, 13 and 15 was excluded from the learning processes. The average error for samples 5, 7 was 6.9%, and for samples 13, 15–14%.



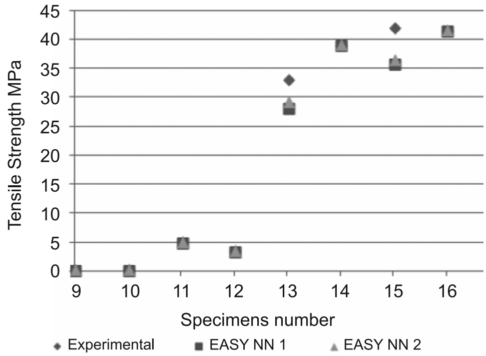


Fig. 2. Tensile strength

Table 3

Research results

Samples No.	Tensile divice [MPa]	EASY NN 1 [MPa]	Absolute error NN 1[%]	EASY NN 2 [MPa]	Absolute error NN 2 [%]
1	1	0.99	1	0.96	4.04
2	15	13.94	7	12.78	15.92
3	37	37	0	37	0
4	40	39.9	0.25	39.9	0.25
5	46	41.61	9.54	41.61	10.55
6	41.5	41.92	1.01	41.92	1.01
7	40.3	41.92	4.01	41.87	3.74
8	42.5	42.18	0.75	42.15	0.82
9	0.2	0.22	10	0.27	31.81
10	0.4	0.26	35	0.32	30.76
11	5	4.99	0.2	4.99	0.2
12	3.5	3.52	0.57	3.52	0.56
13	33	28.2	14.54	29.2	13.47
14	39	38.99	0.02	38.98	0.05
15	42	35.84	14.66	36.35	15.76
16	41.5	41.52	0	41.5	0.09

Table 3 shows the research results of tensile test [9] and simulation results obtained by EASY NN. The marked samples were excluded from the network during the learning process. The lowest tensile strength equals 0.2 and 0.4 MPa, present in samples 9 and 10, where the printing direction was vertical to the building Z-axis and the energy density transmitted to the sintered layer was the lowest. By increasing the number of scanning from 1 (sample 4) to 3 (sample 8), tensile strength increased from 40 MPa to 42.5 MPa in the case of horizontal print. In the vertical print, for samples 12 and 16 tensile strength increased respectively from 3.5 MPa to 41.5 MPa. By Increasing the energy density from 0.056 J/mm^2 (sample 4) to 0.1 J/mm^2 (sample 5) and 0.147 J/mm^2 (sample 6) tensile strength increased respectively from 40 MPa to 46 MPa and 41.5 MPa for the samples printed horizontally. In case of vertical samples, tensile strength increased respectively from 3.5 MPa (sample 12) to 33 MPa (sample 13) and 39 MPa (sample 14).

5. Conclusion

The analysis of the research results obtained by artificial neural network models indicated that each of the above mentioned printing parameters affects the research results. When energy density is increased above 0.056 J/mm^2 or the number of exposures, tensile strength increases. This is very a positive aspect which allows for minimizing the effects of anisotropy, thereby excluding the influence of the printing direction. Despite the beneficial effects on the mechanical properties, accuracy in these cases decreases. When the number of exposures is increased, the building time significantly increases. The influence of laser power and speed in case of obtaining the same energy density is negligible, as evidenced by the previous research results. The use of artificial neural network models as a calculation tool allows for a quick assessment of the impact of input parameters on the studied phenomena. By increasing the number of neurons in some cases, it can have adverse effect on the results, e.g. Samples 7, 10, 13. For various „printing" directions, the research results obtained by means of the same neural network change. It means that it would be better to design a separate artificial neural network model for each type of printing direction.

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