

Effect of print orientation using DMLS method on strength of materials

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Abstract The paper reported the results of a study concerned with the principle of operation of the 3D printing technology using the method of selective sintering of metallic powders, and taking into account their advantages and drawbacks. The principle of the operation of 3D printing technology applying the DMLS (Direct Metal Laser Sintering) method is presented. On the basis of the performed tests, the anisotropy of the printed materials is demonstrated. The reasons responsible for this phenomenon are identified. The paper presents the results of the strength tests which indicate that the crack during the test occur in the building direction of the layers during printing. The results were compiled for two different types of specimens and two different testing machines.

1 Introduction

Over the past few years, there has been a great progress in the development of 3D printing technology, in particular in the areas related to the production of plastic elements. Progress is determined by the versatile use of this technology in industry and the patent release of a given manufacturing method. In addition, 3D printing offers the possibility of producing low-serial construction elements with a complex design that are difficult to manufacture and costly using traditional manufacturing techniques. 3D printing technology involves the building and bonding of successive layers of material with parameters characterized by an adequate structure and thickness. As a result of applying subsequent layers, a compact model is formed that constitutes a final product or a semi-finished product. In most cases, 3D printing requires further processing, most often associated with removing supports or finishing the printed surface. Despite many advantages, this technology also involves drawbacks such as the need to remove the model supports or use finishing machining to generate a better surface [1-4]. However, one of the biggest drawbacks is the anisotropy in the structure of the material. The aim of the study reported here is to analyze the influence of the printout orientation using the DMLS method on the strength of the tested material. The scope of work includes: development of three-dimensional models of specimens for experimental research and printing strategies; performing a static tensile test for flat and round specimens printed at different angles and

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analysis of the results. The specimens applied in the experiment were made using Maraging Steel MS1 tool steel.

2 DLMS printing method

The DLMS method forms one of the methods that apply metallic powders. The diagram that illustrates the process of DLMS printing is presented in Fig 1 and this method involves the following steps:

- applying inert gas and preheating of the printing chamber,
- spreading a thin layer of adequately composed metallic powder through a recoater (application device),
- initial scanning of the cross-section of the element high-power laser,
- selective melting of a metallic powder particles,
- reduction of the platform by a value corresponding to the thickness of a single layer of material,
- distribution of a thin layer of metallic powder through a recoater (application device)
- repeating the process until the full geometry of the object is built,
- removing the full model from the printing base platform after the finished process
- removing supports and performing surface finishing procedures

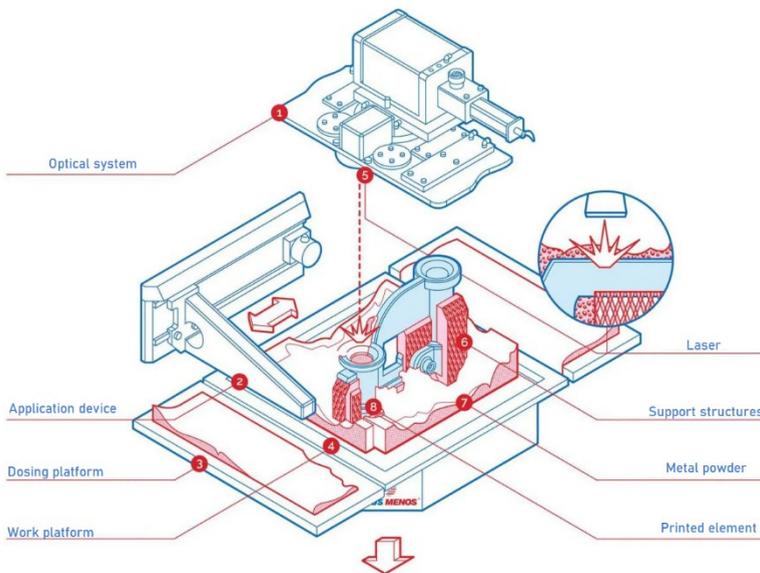


Fig. 1. Schematic illustration of the DMLS printing method [5]

The printing carried out using of the DMLS method consists in application of layers of the material in the element and hardening it in this place by surfacing of the print line. Local stresses occur in the material as a result of acting temperatures and the variable time of application of subsequent layers, and this contributes to heterogeneity of the

material structure. These inhomogeneities are layered (they are located along the direction of the layers of the print line). This has a great influence on the strength of the element. The negative impact of anisotropy may be improved by the use of heat treatment of the finished element.

Due to the possible occurrence of anisotropy in the material, tests will be carried out for specimens printed at different angles. The specimens prepared in this manner will be applied to research concerned with determining whether the arrangement of the infill layers has an impact on the strength of the tested material.

3 Anisotropy of elements produced by 3D printing method

Anisotropy is defined as the differentiation of the value of a given parameter depending on the direction of the measurement. The anisotropy of printed elements results from the layered bonding of the material as a consequence of using elevated temperature [6,7]. Fig. 2 shows the process of layer formation during laser sintering. In addition to the formation of layers, you can also see the undulations of the material and the heterogeneity also occurring between the individual printing paths.

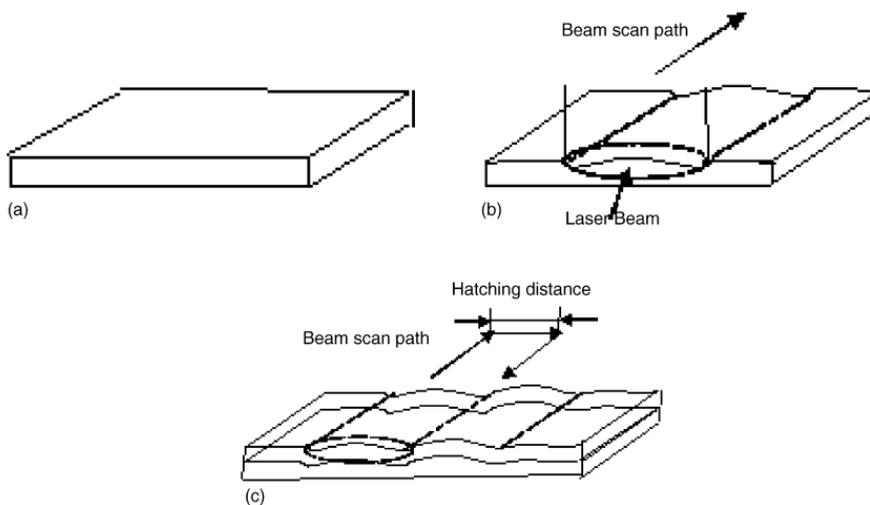


Fig. 2. Schematic illustration of laser sintering. a) prior to sintering, b) finished single scanning path, c) generation of sintering layer [8]

Fig. 3 contains details of the building direction of layers in relation to the direction of print. The layered structure occurs in the entire material and is arranged perpendicular in relation to the direction of layer application and its height overlaps with the thickness of the printed layer.

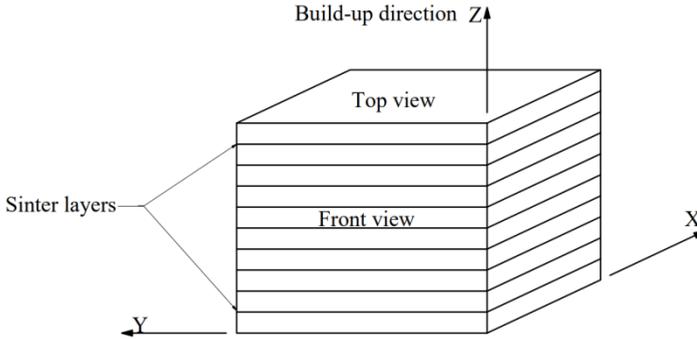


Fig. 3. Structure of layers in the material in relation to the print direction

There are a number of publications on the strength properties of elements made with the additive method [9-11]. The publications available currently mainly involve plastic components, but few studies are concerned with the strength of components made by selective sintering of metal powder. Due to the fact that scientific research contains few studies on the printing technology based on the method of selective bonding of metal powders, this paper focuses on comprehensive aspects regarding the strength of elements generated by the DLMS method.

4 Experimental research

4.1. Material and specimens

The methodology applied in the preparation of the specimens is presented in Fig. 4. The specimens were printed on an EOSINT M280 printer. The printing strategy included printing at different angles: 45°, 60°, 75°, 90° in relation to the printing surface.



Fig. 4. Scheme followed in the preparation of specimens

Flat specimens (Fig. 5) and round specimens (Fig. 6) were applied for strength tests. The specimens are made of Maraging Steel MS1 steel powder. The height of the printed layer was 40µm. In tab. 1 lists the static properties of the tested material immediately after printing (based on manufacturer's data)

Table 1. Static properties of MS1 steels

R_m [MPa]	$R_{0,2}$ [MPa]	A_5 [%]
1200	1020	13

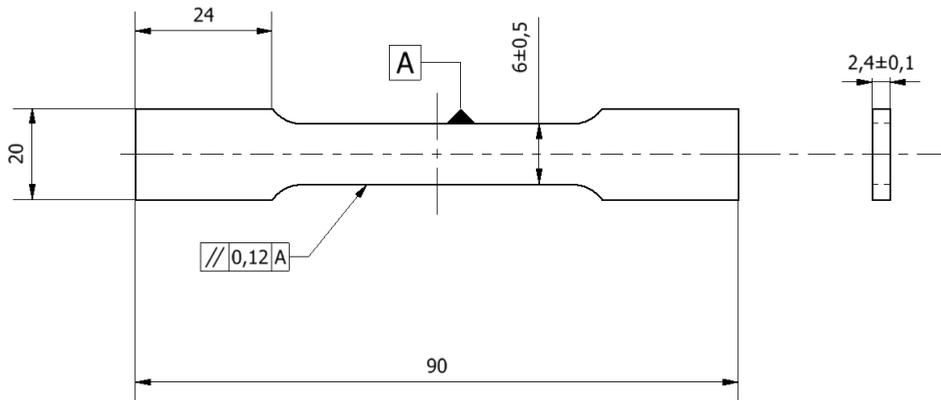


Fig. 5. Geometry of flat specimens

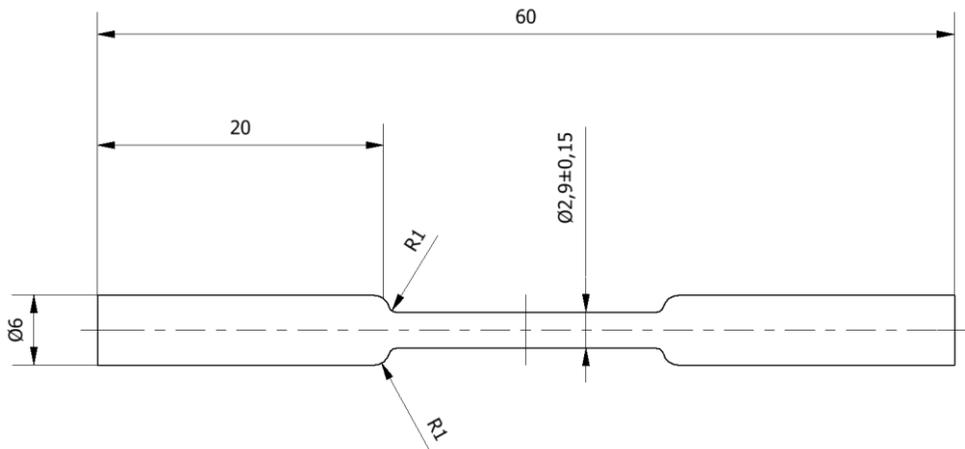


Fig. 6. Geometry of round specimens

The tests were conducted by application of (Figs. 7-8) Instron 8802 (for flat specimens) and Instron ElectroPlus E10000 test system (for round specimens).



Fig. 7. Instron 8802



Fig. 8. Instron ElectroPlus E10000

5 Analysis of the results

As part of the study, a tensile test was carried out, which consists in axial tension of the specimens that allows the continuous increase of the force from zero to the value at which the specimen cracks. The tests were carried out at ambient temperature.

The results of the static tensile test for round specimens made of MS1 steel are presented in Table 2.

Tab. 2 Summary of the results of static tensile tests on round specimens before applying heat treatment

Sample label	Diameter [mm]	Young's modulus [GPa]	Plasticity boundary (0.2% displacement)	Strain for plasticity boundary [%]	Maximum force [kN]	Tensile strength [MPa]
P1 90°	2.83	169.7	1092	-	7.47	1187.80
P2 90°	2.82	175.0	1106	0.83	7.64	1223.25
P3 90°	2.83	171.6	1113	0.85	7.69	1221.75
P4 60°	2.74	173.4	1100	0.83	7.36	1247.40
P5 60°	2.75	177.0	1091	0.78	7.24	1218.59
P6 60°	2.74	174.1	1116	0.84	7.30	1237.92
P7 45°	2.69	177.4	1043	0.76	5.95	1046.52
P8 45°	2.76	193.1	-	-	5.44	908.89
P9 45°	2.95	164.4	979	0.76	7.27	1064.22

On the basis of the analysis of the results contained in Table 2, we can see that the tensile strength slightly differs depending on the building angle of the layers of the printed specimens. The specimens with printing orientation at an angle of 45° have recorded the lowest strength value. Figures 9–11 show the tensile diagrams for round specimens printed at different angles in relation to the printing plane. Tensile diagrams obtained on the basis of the obtained results allow reading the value of the tensile force and other strength properties of the analyzed material. It is worth noting here that the results in the charts overlap, which proves the reliability of the research.

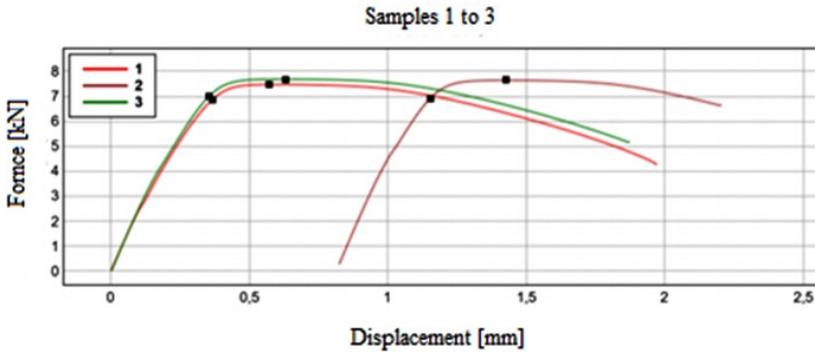


Fig. 9. Tensile test plot for specimens produced at an angle of 90°.

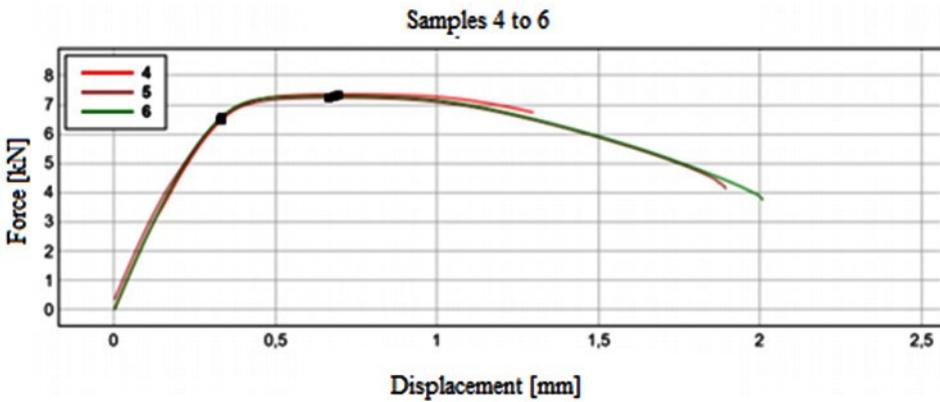


Fig. 10. Tensile test plot for specimens printed at an angle 60°.

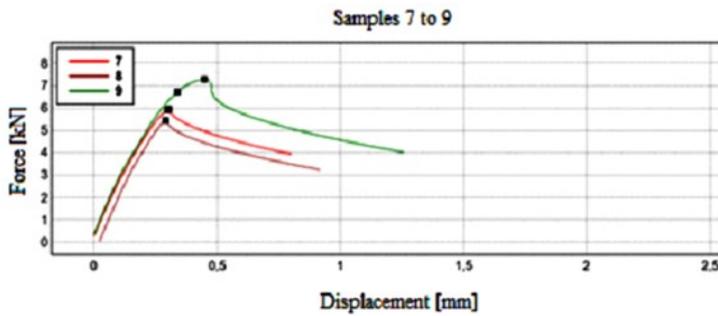


Fig. 11. Tensile test plot for specimens printed at an angle 45° .

Figures 12–13 contain metallographic images of two selected specimens at printed an angle of 90° and 45° . From the analysis of the fracture image, it can be seen that the fracture occurs along the print line, i.e. according to the angle at which the specimen was printing was executed. The crack pattern along the print line also indicates the anisotropy of materials printed with the DLMS method.

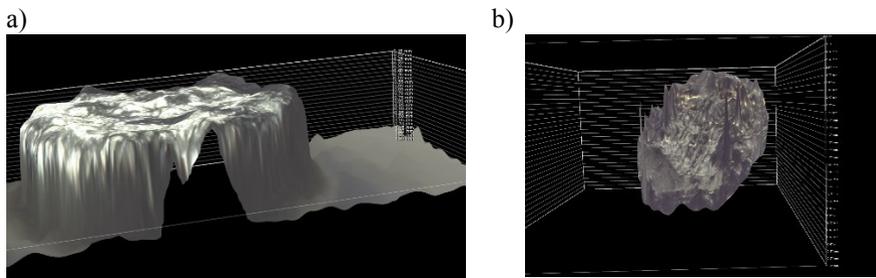


Fig. 12. Fracture of a specimen printed at the angles of a) 90° b) 45°

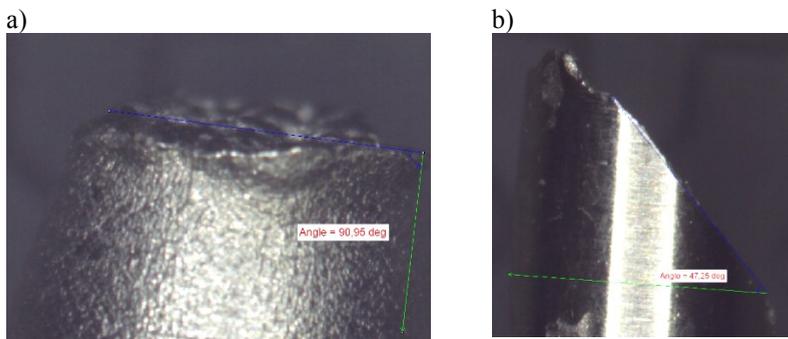


Fig. 13. Fracture of a specimen printed at the angles of a) 90° b) 45°

The results of the static tensile test for round specimens made of MS1 steel are presented in tab. 3

Tab. 3. Summary of test results for a static tensile test of flat specimens prior to the application of heat treatment

Sample label	Thickness [mm]	Young's modulus [GPa]	Plasticity boundary (0.2% displacement)	Strain for plasticity boundary [%]	Maximum force [kN]	Tensile strength [MPa]
P1 45°	2.43	185.6	790.74	1.65	13.44	933.32
P2 45°	2.4	174.4	786.37	1.6	14.18	984.63
P3 45°	2.5	166.0	793.30	1.84	14.23	988.17
P4 75°	2.4	173.7	996.72	1.79	16.58	1151.65
P5 75°	2.44	169.0	889.02	1.77	16.35	1135.21
P6 90°	2.43	150.8	1008.11	3.19	17.25	1198.07
P7 90°	2.44	167.0	969.07	3.14	17.09	1186.56
P8 90°	2.46	159.7	995.64	3.03	17.28	1200.20

On the basis of the analysis of the results given in tab. 3, we can see that the tensile strength increases with the printing angle of the specimens. For example, for specimens printed at an angle of 75°, this value is in the range of about 16% in relation to specimens taken at an angle of 45°.

However, for specimens printed at an angle of 90°, this value varies by around 22% in relation to specimens produced at an angle of 45°. These results prove the high anisotropy of printed materials.

Figs. 14-16 that follow contain tensile test plots developed for round specimens printed at different angles.

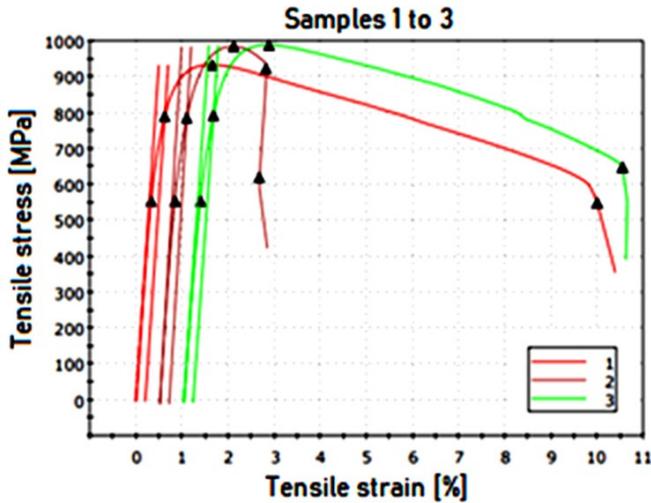


Fig. 14. Tensile test plot for specimens printed at the angle of 45°.

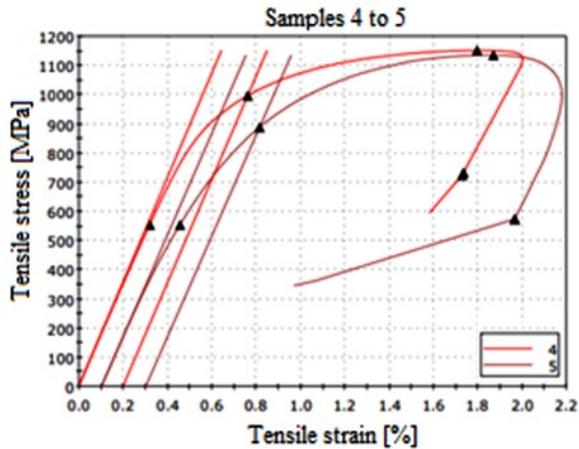


Fig. 15. Tensile test plot for specimens printed at the angle of 75°.

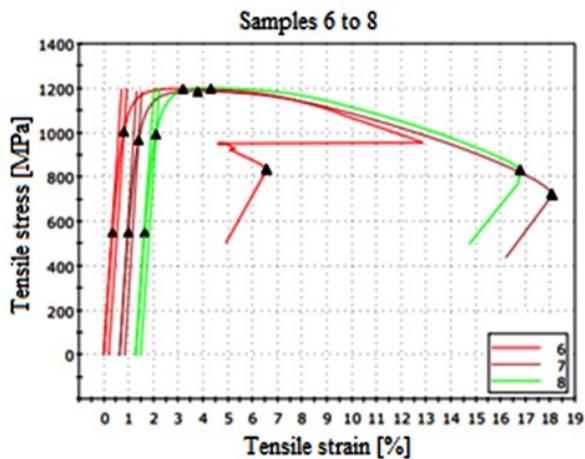


Fig. 16. Tensile test plot for specimens printed at the angle of 90°.

6 Conclusions and summary

On the basis of the analyses carried out the following conclusions can be drawn:

1. The building direction of printing layers has a effect on the strength of investigated materials.
2. The strength parameters only slightly differ from the parameters provided in the manufacturer's data.
3. The cracking of specimens occurs along the line of overlapping of printing layers.
4. The course of the crack along the printing layers indicates the occurrence of anisotropy of the material.
5. Static tests are projected for the same types of specimens following heat treatment.

7 References

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