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TENSILE STRENGTH OF PURE IRON SAMPLES MANUFACTURED BY SELECTIVE LASER MELTING METHOD

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Abstract: *This paper deals with the tensile strength measurement of samples produced by additive manufacturing. Tested samples were made of pure iron on machine SLM280HL based on Selective Laser Melting method (SLM). The pure iron was selected as a semi-finished product for future manufacturing of a magnetic circuit in magnetorheological damper. The magnetic circuit is an inseparable part of damper piston, which is high mechanically loaded during the operation. Therefore, it is highly important to have suitable mechanical properties. The free-cutting steel 11SMn30 was used as a reference sample. Five different settings of laser power, scanning speed and hatch distance were used for preparation of five sets of samples. The highest tensile strength was achieved at samples produced with the highest energy density and the lowest volume speed of building. These conditions were achieved by laser power 300 W, scanning speed 750 mm/s and hatch distance 84 μm. The tensile strength of these samples was 461 MPa, which is higher than at reference steel (452 MPa). From the point of view of economic aspects, the second most strength steel is better choice, because its tensile strength is 456 MPa but the building speed is about 50 % higher.*

Keywords: Selective Laser Melting, Pure iron, Tensile strength, Magnetorheological valve.

1. Introduction

The Selective Laser Melting (SLM) is one of the most progressive techniques in the field of Additive Layer Manufacturing (ALM). This technique uses laser beam to melt the metal powder and builds the final product layer by layer. Ilčík (2014) tested material AlSi12 on SLM 280HL and achieved guaranteed roughness Ra10 μm for surfaces inclined at an angle 0 to 140 ° from the building platform. The surface roughness for stepper angle was significantly higher, around Ra50 μm. The best geometrical accuracy was measured around 0.02 mm. The common accuracy was around 0.05 mm. These very good results were achieved in the second production batch after the subsequent calibration and show, that SLM is suitable method for magnetic circuit manufacturing. Koukal (2015) described processes and method leading to manufacture of samples from high strength aluminum alloy EN AW 2618 with relative density 99.66 %. This high relative density promises good mechanical properties. Vrána (2016) published paper describing special lattice structure with high impact resistance. Especially gyroid structure can be advantageously used for lightweight parts with high strength in all directions of loading.

This paper focuses on the manufacture of samples from pure iron powder and measurement of their tensile strength. If the material strength is suitable, this material can be used in future for building ultra-fast magnetic valves by SLM technology – magnetorheological or electromechanical valves, which are nowadays limited by occurring eddy currents (Strecker et al., 2014).

2. Methods

The material of samples was high purity iron ATOMET Fe AM (Rio Tinto, QMP) (Palousek et al., 2017) with high permeability, high magnetic saturation and low remanence. The machine SLM 280HL (SLM Solution GmbH) was used for manufacturing of all samples. The machine uses one 400 W ytterbium laser and argon atmosphere.

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The choice of perspective parameters was carried out in two steps. Firstly the 1-D tracks (single tracks) were produced by melting of one 50 μm layer of powder on building platform. All combinations of laser power (300, 350 and 400 W) and scanning speed (200, 300, 400, 500, 550, 600, 650, 700, 750 and 800 mm/s) were tested. Each single track was built in two directions – after and against the direction of gas stream because of build influence by gas stream (see Fig. 1). The metallographic microscope OLYMPUS GX 51 with 200x magnification was used for polished samples evaluation. The ideal weld should be 50 μm high and the weld root should reach from 30 to 50 μm under the surface.

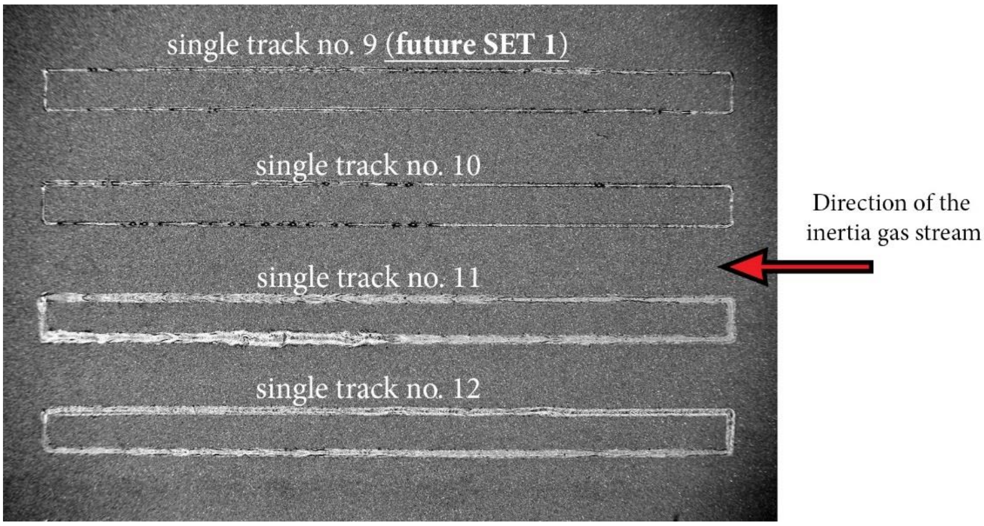

Fig. 1: Example of single tracks no. 9 to no. 12.

Secondly, three the best selected sets of parameters from single track test were used in cube test for porosity analysis. The print of cubes with dimensions 5 x 5 x 5 mm used a chessboard scanning strategy. Hatch distance (distance between two laser tracks) was set according to weld width obtained from single track test and according to overlap ratio. Interval of overlap ratio was chosen from 5 to 50 %. For example, hatch distance for 120 μm weld was changing from 60 to 116 μm, where 60 μm means 50 % overlap. One hatch distance set corresponds to one cube. The 24 combinations were created with one repeating. It gives 48 cubes (see Fig. 2a). The identical cube variants were placed on the platform at opposite sides from the inert gas inlet. The printed cubes were polished and analyzed by the software ImageJ. This SW can recognizes the porosity as white places. Compact material is presented by black color. Ratio between white and black determines a cube porosity. The analysis was carried out within the inscribed square to the cube outline that the uneven outline does not enter to the analysis (see Fig. 2b). The three best results were selected for printing of samples for tensile strength test. Other two sets of parameters were selected because of observation of high porosity and high scanning speed influence on tensile strength.

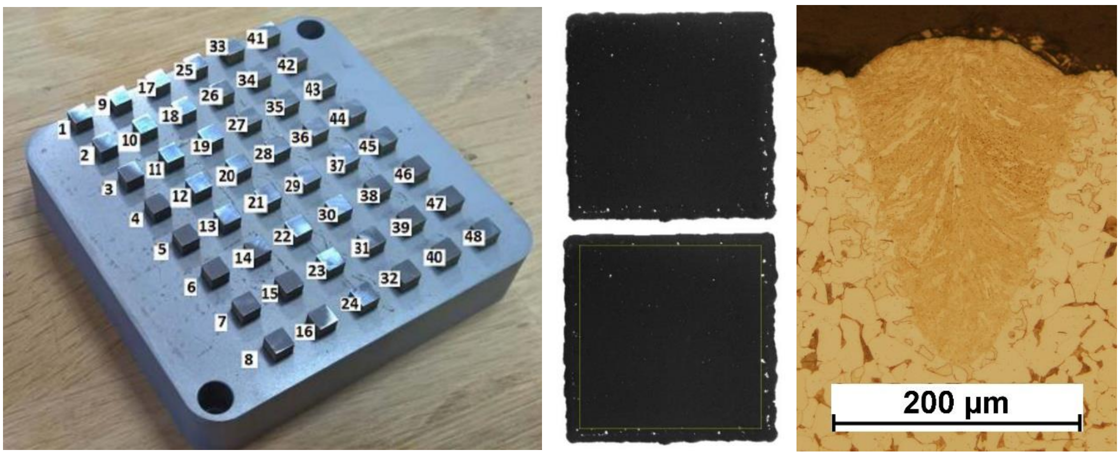

Fig. 2: a) Built cubes on platform; b) Polished cube with square area used for porosity analysis; c) Polished single track.

Two samples from each set of parameters were manufactured, i.e. together 10 samples. The samples were cut from building platform by electro-spark machining. The samples were manufactured with square cross-section, which was subsequently machined on circular (circular cross-section need support structures during the print and has imperfect contact with heated building platform). The sample cross-section was changed in the second print batch on semi-circular for ensuring of faster print. The sample dimensions were obtained from standard DIN 50125 – diameter of tested section was 6 mm.

The tensile strength test was carried out on hydraulic linear actuator Inova. Firstly, the stiffness of fixing frame had to be obtained for result correction. Measured frame stiffness was 44000 N/mm. The free-cutting steel 11SMn30 was used as a reference. Two tests of reference samples were performed on testing machine Zwick Z250 because of results verification of measurement on Inova. The difference between Inova and Zwick measurement was 20 MPa – Inova 452 MPa, Zwick 471 MPa. This difference is considered sufficient for comparative measurement (see Fig. 4b).

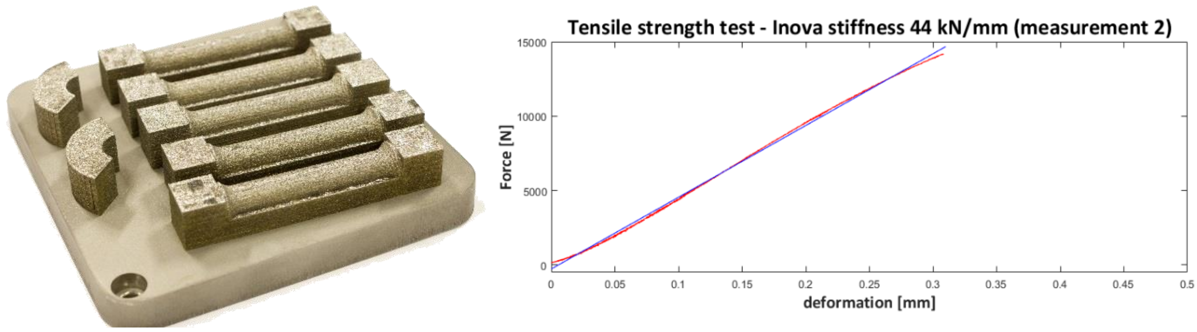

Fig. 3: a) Semi-circular cross section of samples; b) Frame stiffness of Inova machine.

3. Results

Tab. 1 shows parameters of printing selected on the base of tests with single tracks and cubes (No. 1, 2 and 3). Parameters set No. 4 presents high relative porosity and No. 5 maximal scanning speed in combination with maximal laser power. In fact, parameters No. 5 do not provide the fastest building due to small hatch distance (see last column in the table). Fig. 4a shows measurement on Inova machine.

Tab. 1: Overview of selected sets of parameters for 3D printing of samples for tensile strength test.

Set No. [-]	Laser Power [W]	Scanning Speed [mm/s]	Hatch Distance [μm]	Energy [J/mm^3]	Building Speed [mm^3/s]
1	300	750	84	95	3.15
2	400	700	138	83	4.83
3	300	750	108	74	4.05
4	350	700	186	54	6.51
5	400	1400	84	64	5.88

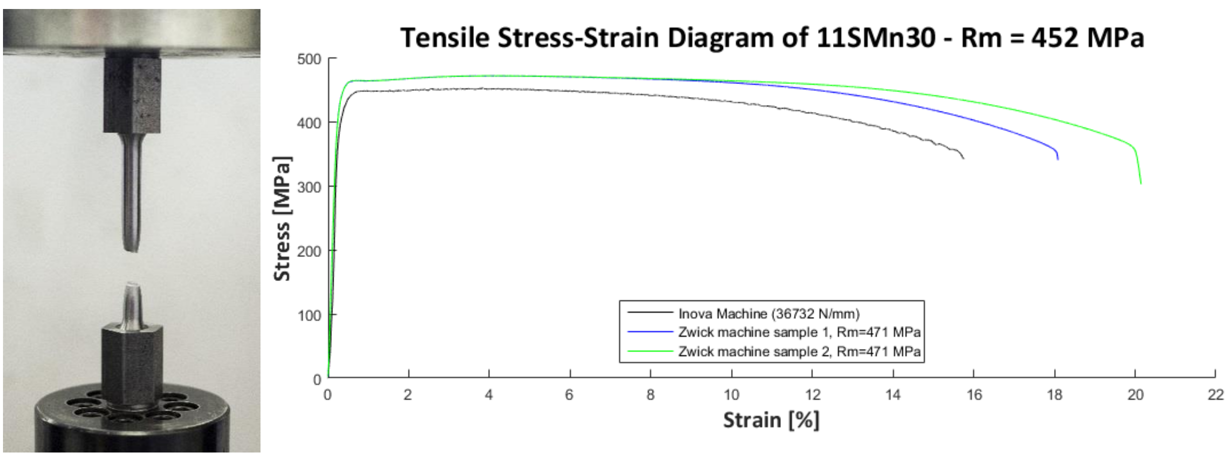

Fig. 4: Tensile strength test of free-cutting steel 11SMn30: a) Inova; b) Difference (Inova versus Zwick).

Fig. 5 shows results of tensile strength tests of samples made by parameters No. 1 and No. 2, which have the highest strength. Both samples have almost similar tensile strength which is simultaneously little higher than reference steel. Contrary to reference steel, the region of yielding is significantly developed and characterized by lower and upper yield strength. Both samples show very good elongation at fraction. On the other hand, the time for printing of the second sample is about 50 % shorter than for the parameters No. 1.

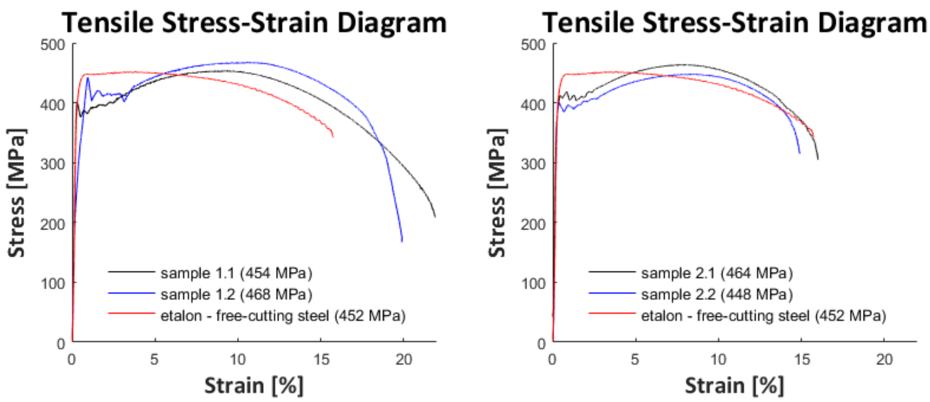

Fig. 5: Tensile Stress-Strain diagram of a) set No. 1; b) set No. 2.

Fig. 6: Fractured samples produced wit parameters a) No. 1; b) No. 2.

4. Conclusion

The published work provides a method for determination of suitable parameters for 3D printer. The tensile strength is around 460 MPa which is in accordance with result published by Palousek (449 MPa) (Palousek et al., 2017).

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