AUSTENITIC STEEL MODIFICATION BY LASER-RELATED PROCES PARAMETERS

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1. ABSTRACT

The microstructure and mechanical properties of additively manufactured metal parts are closely tied to the cooling rate and the temperature gradient direction during solidification. Traditionally, these properties have been modified by changing the scanning strategy. This study explores an alternative approach by varying laser speed and power while maintaining a consistent bidirectional meander scanning strategy, without rotating the following layers, in the fabrication of X30Mn22 austenitic steel. The aim of this paper was to determine whether different crystallographic textures could be achieved under these conditions and to assess their mechanical properties. The results confirm that variations in laser parameters can produce distinct microstructures with different grain shapes, sizes, and orientations. Furthermore, these structural differences were found to correspond with significant variations in mechanical properties, demonstrating the potential of this method for fine-tuning material characteristics in additive manufacturing.

KEYWORDS

Laser powder bed fusion, Selective laser melting, High manganese steel, Microstructure, Modification

2. MATERIAL AND METHODS

2.1 Powder material

- The X30Mn22 high manganese austenitic steel metal powder (Thyssenkrupp Materials Trading GmbH, Germany) was selected for samples manufacturing (composition is given in Table 1).
- Gas atomization method was used to produce the powder.
- Powder particle size analysis showed following distribution characteristics: Q_{10} = *16.2 µm*, Q_{50} = *30.0 µm* and Q_{90} = *51.0 µm* which met expectations.

Table 1 Chemical analysis of high manganese austenitic steel X30Mn22 powder

Elem.	Fe	Mn	C	Cr	Ni
wt-%	Bal.	21.5	0.29	0.33	0.26

2.2 Test samples and manufacturing

- The cubes with nominal dimensions of *10 x 10 x 10 mm* for structure evaluation were designed.
- The blocks with nominal dimensions of *12 x 12 x 70 mm* for tensile samples were designed and machined according to DIN 50125 – B 6 x 30.
- All samples were manufactured using SLM 280^{HL} machine (SLM Solutions, Germany), equipped with 700W Ytterbium fibre laser with spot diameter *82 µm*.
- Bidirectional (meander) contourless scanning strategy without rotation of the following layer was used to manufacture both kinds of samples.
- The following general process parameters were used: *100 °C* platform heating, Ar_2 inert atmosphere, *50 µm* layer thickness. Variety of laser related process parameters (listed in Table 2) were used.

Table 2 Process parameters used to manufacture samples

Sample	Laser Power (W)	Laser Speed (mm·s^{-1})	Hatch Distance (mm)
A	250	100	0.1986
B	150	200	0.0996
C	250	500	0.0900

2.3 Microstructure evaluation

- Porosity was measured by ImageJ software from cube samples. The images were taken by light microscope Keyence VHX-600 (Keyence, Japan).
- Microstructure was evaluated on EBSD maps acquired by SEM microscope TESCAN LYRA 3 XMU (Tescan, Czech Republic)

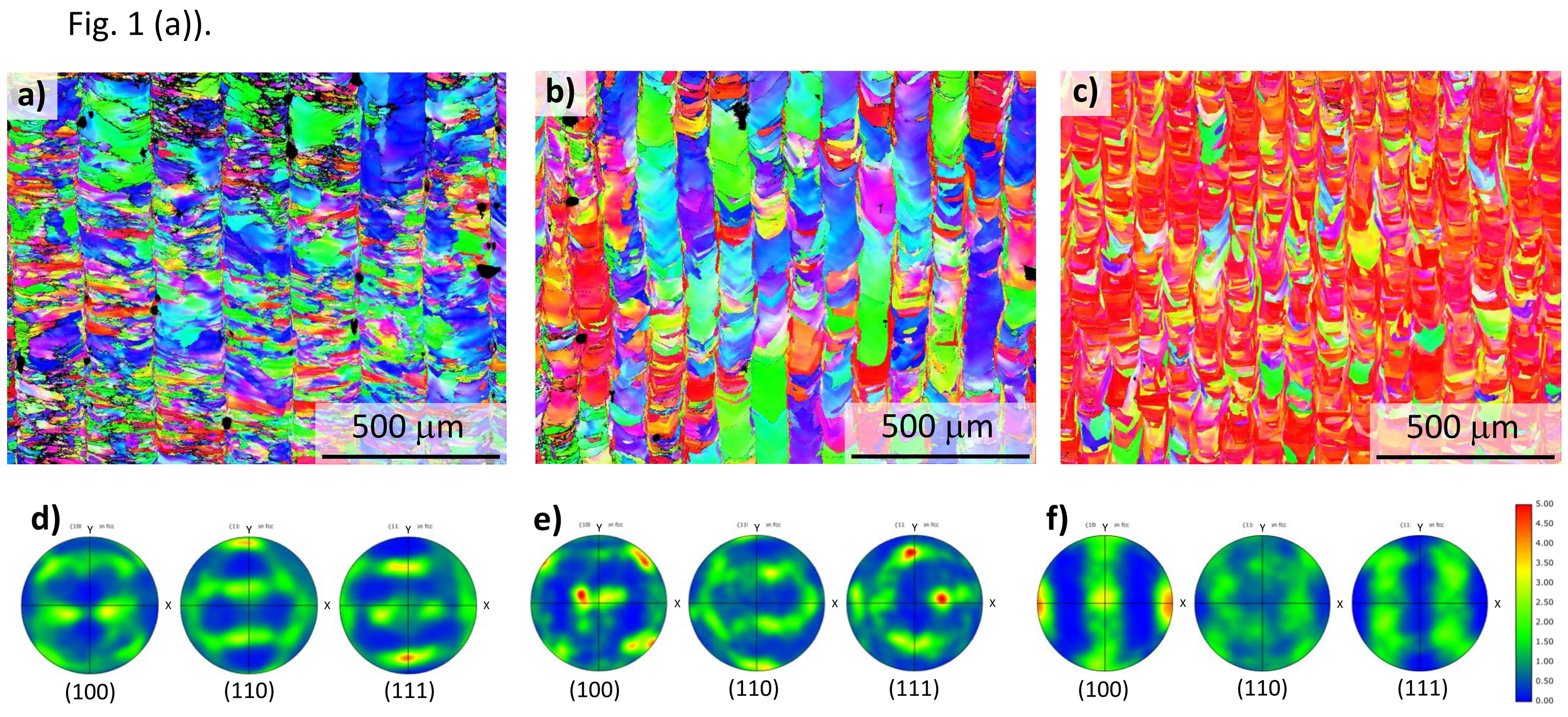
2.4 Quasi-static tensile test

- Quasi-static tension test was performed on Zwick Z250 machine (Zwick Roel Group, Germany).
- The loading test was performed at the loading velocity of 0.6 mm·min^{-1}.
- The bidirectional laser scanning was perpendicular to loading direction of tensile samples.

3. RESULTS AND DISCUSSION

3.1 Microstructure evaluation

- The resulting microstructure was strongly dependent on the input laser-related process parameters.
- The microstructure of sample A is formed by a numerous horizontally elongated grains. EBSD map showed random crystallographic structure with significant influence ⟨111⟩ and ⟨101⟩ orientation (see Fig. 1 (a)).



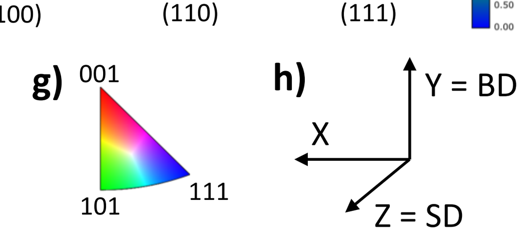


Fig. 1. a-c) IPF X colour-coded map of microstructures (X-Y section) of samples A,B and C obtained by different laser-related process parameters; d-f) Respective pole figures; g) IPF X colour coding; h) Fabrication coordinate system, BD-build direction, SD- scanning direction.

- Lamellar structure with large grains growing through several meltpools were formed in sample B. All three main crystallographic orientations ⟨001⟩, ⟨101⟩ and ⟨111⟩ appeared in EBSD map however none is preferential (see Fig. 1. (b)). Pole figure of this sample showed pronounced *cube* texture (see Fig. 1. (e)).
- The grains of sample C formed „L“ and „U“ shape-like grains. Unlike the previous samples, ⟨001⟩ crystallographic orientation is significant (see Fig. 1. (c)). Pole figure clearly shows, that *fibre* texture will be achieved in this sample (see Fig. 1. (f))
- EBSD maps of evaluated samples showed significant differences in grain sizes, grain shapes and grain orientations obtained by different laser related process parameters with preservation of scanning strategy.
- Pole figures point out differences in FCC structure. Cube texture and fibre texture were obtained for sample B and C, respectively.

3.2 Mechanical properties

- Due to the high influence of porosity of sample A, just tensile samples B and C were evaluated, and respective stress-strain curves can be seen in Fig. 2. Both samples show deformation behaviour with insignificant yield point.
- Young's modulus (E) was evaluated from linear part of stress evolution of the tensile sample. Steeper slope of the linear part of curve for sample B indicates higher value of E.
- Yield strength (YS), ultimate tensile strength (UTS), deformation to failure (ε_t) was evaluated and measured values are listed in Table 3.
- Porosity (Ψ) of tensile samples was measured on perpendicular cross sections of tensile specimen threaded heads.

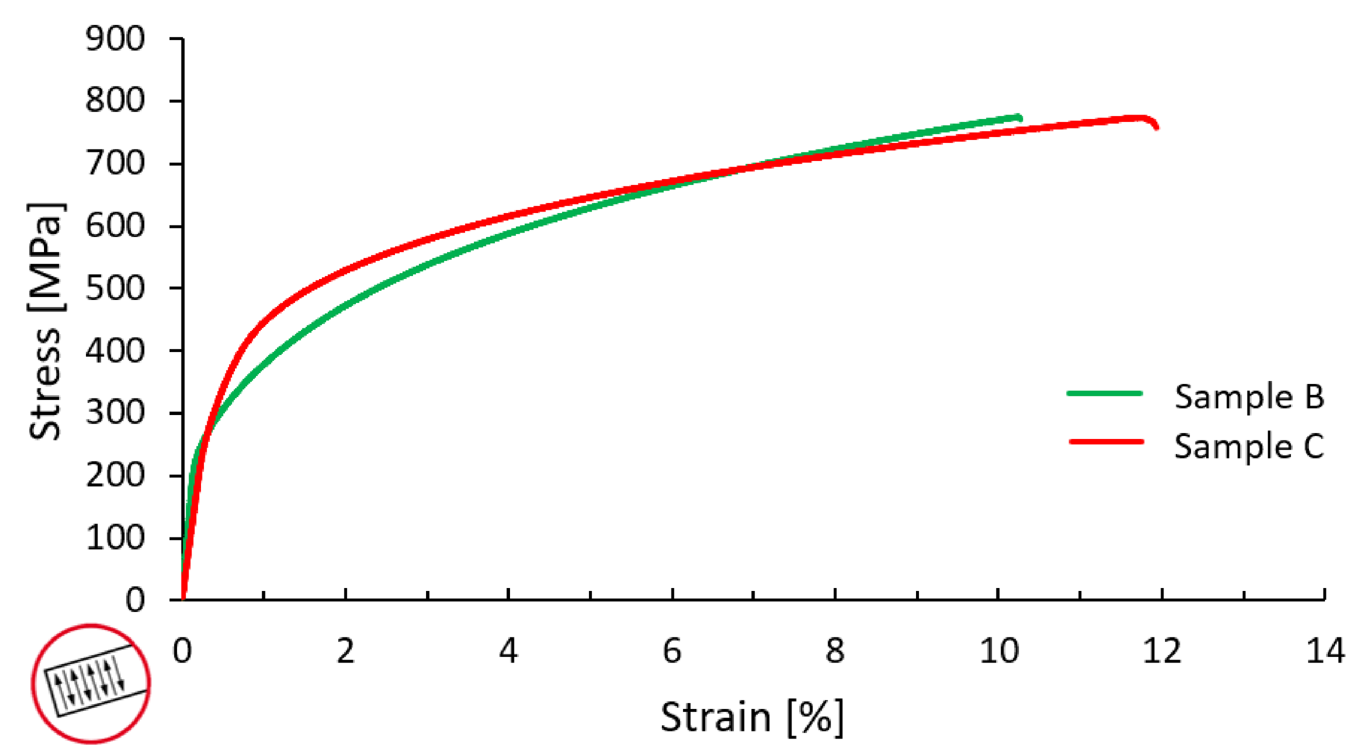


Fig. 2 . Stress-strain curve of tensile samples B and C

Table 3 Measured mechanical properties of tensile samples

Sample	E (GPa)	YS (MPa)	UTS (MPa)	ε_t (%)	Ψ (%)
B	156	283	775	10.3	0.31
C	101	356	774	11.9	0.11

- Graphic comparison of measured mechanical properties of sample B and C is shown in Fig. 3.
- UTS of both samples is nearly identical, however YS of sample C was 20% higher than sample B (see Fig. 3 (a)).
- Deformation to failure was about 13% higher for sample C. (see Fig. 3. (c)).
- The most significant difference was in Young's modulus, which was about 50% higher for sample B (see Fig. 3. (b)).

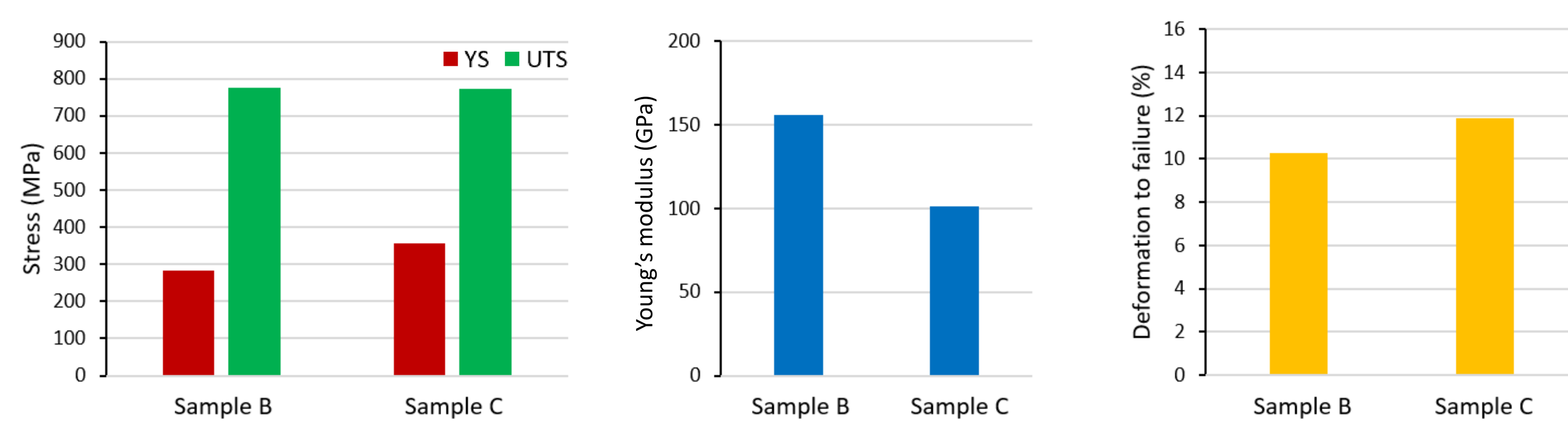


Fig. 3. a) Comparison of YS and UTS ; b) comparison of Young's modulus; c) comparison of deformation to failure samples B and C

4. CONCLUSION

- The preliminary results of this study indicates fundamental insights into how altering laser-related process parameters in LPBF process can modify the microstructure of X30Mn22 austenitic steel. The key finding is that different microstructures can be achieved without changing the scanning strategy, highlighting the influence of laser power and scanning speed on the resulting crystallographic nature of structure.
- The research demonstrated that varying laser parameters led to the formation of distinct crystallographic textures with different grain sizes, shapes, and orientations. Structure of sample A exhibited small but wide grains with a specific orientation along one axis, while sample B showed larger grains spanning through multiple layers with significant cube structure. Structure of sample C developed a fibre-like configuration with uniquely shaped grains. These variations were achieved using a consistent bidirectional scanning strategy without rotating the follow-up layers.
- The mechanical properties of these structures were evaluated through tensile testing. Notably, samples C exhibited a 20% higher yield strength and a 13% higher deformation to failure compared to sample B, despite having the same ultimate tensile strength.
- Future research will aim to explore additional microstructures within the established process window and further investigate their mechanical properties. Addressing the issue of porosity in the produced samples will be the key to confirming these findings and improving the overall material mechanical properties.

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