Effect of scanning speed on the damage behaviour of SLM printed Inconel 625

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Abstract. This study investigates the effect of scanning speed on the mechanical properties and porosity distribution of Inconel 625 samples fabricated using selective laser melting (SLM) additively manufacturing. The research demonstrates that higher scanning speeds lead to increased porosity, particularly lack-of-fusion defects, compared to lower speeds which generate mainly gas pores. This rise in porosity negatively affects the mechanical response of the material, reducing both tensile strength and ductility. The findings highlight the importance of optimizing scanning speed to achieve a balance between printing efficiency and desired mechanical properties in SLM-produced Inconel 625.

Introduction

Additive manufacturing (AM) of metallic materials builds 3D metal objects layer-by-layer from a digital input [1]. Additively manufactured Inconel finds use in high-temperature, high-stress applications like jet engine parts and implants due to its excellent strength and heat resistance [2]. Inconel 625 (IN625) is one of the commonly preferred superalloys that has outstanding mechanical properties, high thermal stability, resistance to corrosion and creep [3]. Numerous investigations have been carried out to examine the mechanical characteristics and microstructure of IN625 alloy components produced by selective laser melting (SLM) AM in both as-built and different post-process heat-treated conditions [4-6]. As commonly known, scanning speed in AM plays a critical role, directly affecting the molten pool's temperature, size, solidification rate, and ultimately the final part's properties [7]. In the present investigation, the influence of scanning speed on the mechanical properties and damage response of SLM printed IN625 samples was experimentally investigated.

Material and Method

The TruForm 625 (Praxair Surface Technologies) and Xact Metal XM200G were used in the current investigation to create samples with the suggested spot size of 100 µm. For consistency, the powder utilized in each AM operation was fresh out of a sealed container and in its pristine state. The apparent density of the powder was 4.54 g/cm^3 and hall flow measurement was 13 seconds. Also, the distribution of the particle size was 21, 31 and 46 for d10, d50 and d90, respectively. The measurements of apparent density, hall flow, and microtrac were performed in compliance with ASTM B212, B213, and B822 test standards, correspondingly. The printing parameters were selected as the recommend parameters by the machine manufacturer. Three different scanning speeds were selected: 1400 (SS_1400), 1700 (SS_1700), and 2000 (SS_2000) mm/s. The layer thickness was 55 µm, build direction was selected vertical to the build plate and printing power was set to 350 W. To determine the mechanical properties of the as-printed samples, tensile tests were performed using a Zwick Roell tensile tester with a capacity of 10 kN. During the tests, velocity of the moving gripper was set to 5 mm/s and the strain data was obtained via attached extensometer. Also, the test was conducted according to ASTM E8-22 standard [8].

After the printing process, small pieces (having 6 mm width, 10 mm length and 2 mm thickness) were cut from the as-printed tensile testing samples by using the waterjet cut. Skyscan X-ray nanotomograph was used to identify the porosity. A voxel size of 5 µm was selected to identify the porosities inside the substance. To decrease the spectrums width and raise its mean energy, 0.5 mm copper filtering was selected. A 145 kV accelerating voltage and 80 µA current were employed for the scanning procedure. Four thousand millisecond exposure times yielded a total of three thousand projections.

Experimental Results

3-D reconstruction of these samples is represented in Fig 1a. Also, the volume of the porosity inside the as-printed samples were evaluated by using Dragonfly software. The volume of the pores inside the SS_1400 sample is shown in Fig. 1b having a 0.11% porosity level. Most of the pores seems to be porosity induced by the gas pores. A relatively low-level defects related to lack of fusion is observed. However, when the printing speed increased to 1700 mm/s, the level of porosity boosted to 0.37% accompanied by a raise in the lack of fusion defects (Fig. 1b). Also, when the scanning speed was set to 2000 mm/s, highest level of porosity among the tested samples were obtained as 0.72%. The reconstruction of the pore volume distribution represented the lack of fusion related defects constitutes the highest volume of the total volume of pores.

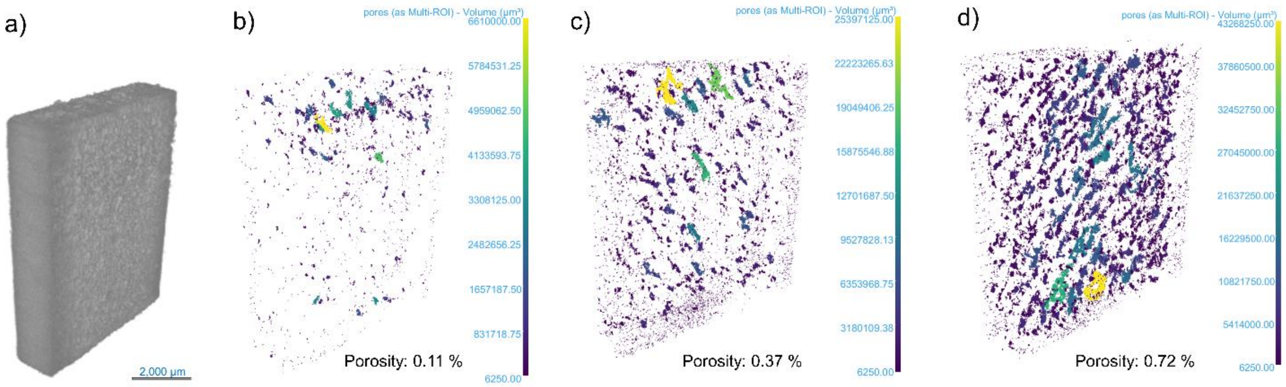

Fig. 1: a) Reconstruction of the CT Sample b) Volume of pores for the scanning speed at 1400 mm/s c) 1700 mm/s d) 2000 mm/s.

According to Fig. 1 increasing the scanning speed also changed the type of defects from gas pores to lack of fusion defects. In addition, the mechanical response of the tested material represented a well agreement between the tomography results, as shown in Fig. 2. Increasing the printing speed reduced both ductility and tensile strength which is attributed to the level of porosity and volume of initial defects related to scanning speed.

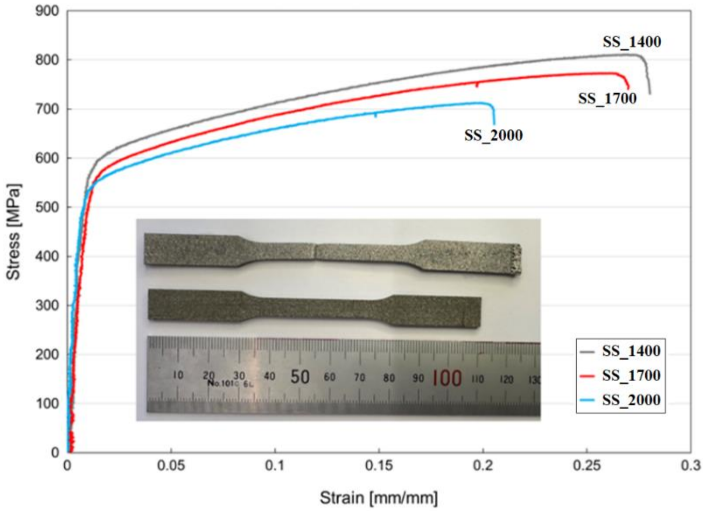

Fig. 2: Tensile testing results for the samples produced by different scanning speeds.

Conclusion

To conclude, more wide and irregular unfused pores were produced by high scanning speeds, while more small and spherical vapor pores were produced by lower speeds. Also, the defects related to the manufacturing process had a crucial role on the mechanical response of the material.

References

[1] B. Onuike, A. Bandyopadhyay, Additive manufacturing in repair: Influence of processing parameters on properties of Inconel 718, Materials Letters 252 (2019) 256-259.

[2] Q. Jia, D. Gu, Selective laser melting additive manufacturing of Inconel 718 superalloy parts: Densification, microstructure and properties, Journal of Alloys and Compounds 585 (2014) 713-721.

[3] S.K. Rai, A. Kumar, V. Shankar, T. Jayakumar, K. Bhanu Sankara Rao, B. Raj, Characterization of microstructures in Inconel 625 using X-ray diffraction peak broadening and lattice parameter measurements, Scripta Materialia 51(1) (2004) 59-63.

[4] O.G. Rivera, P.G. Allison, J.B. Jordon, O.L. Rodriguez, L.N. Brewer, Z. McClelland, W.R. Whittington, D. Francis, J. Su, R.L. Martens, N. Hardwick, Microstructures and mechanical behavior of Inconel 625 fabricated by solid-state additive manufacturing, Materials Science and Engineering: A 694 (2017) 1-9.

[5] A. Gamon, E. Arrieta, P.R. Gradl, C. Katsarelis, L.E. Murr, R.B. Wicker, F. Medina, Microstructure and hardness comparison of as-built inconel 625 alloy following various additive manufacturing processes, Results in Materials 12 (2021).

[6] H. Hack, R. Link, E. Knudsen, B. Baker, S. Olig, Mechanical properties of additive manufactured nickel alloy 625, Additive Manufacturing 14 (2017) 105-115.

[7] R.A. Yildiz, A.-A. Popa, M. Malekan, On the effect of small laser spot size on the mechanical behaviour of 316L stainless steel fabricated by L-PBF additive manufacturing, Materials Today Communications 38 (2024).

[8] ASTM, Standard Test Methods for Tension Testing of Metallic Materials, 2012.