EFFECTS OF HEAT TREATMENT PRODUCED BY SELECTIVE LASER MELTING (SLM) ON SS 316L

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Abstract. This research systematically examines the microstructural evolution and mechanical property alterations in 316L austenitic stainless steel fabricated by Selective Laser Melting (SLM) following post-process heat treatment. As a material of critical importance in high-tech industries including aerospace, automotive, and biomedical applications, 316L alloy owes its widespread adoption to its remarkable combination of mechanical strength, exceptional ductility, and superior corrosion resistance. In the present investigation, SLM-fabricated 316L stainless steel specimens underwent heat treatment at 400˚C, 650˚C, 950 ˚C, and 1150 ˚C for two-hour durations, followed by rapid water quenching. The influence of varying temperature parameters on microstructural characteristics, including grain morphology and porosity, and mechanical performance was comprehensively analysed. Our findings demonstrate that optimized heat treatment parameters can significantly enhance critical properties of SLM-produced 316L stainless steel, including hardness, ductility, wear resistance, and corrosion performance. These results provide important insight for improving the reliability and performance of SLM technology, particularly for manufacturing geometrically complex components in aerospace and automative applications. This study is anticipated to contribute to the development of industrial heat treatment optimization strategies for SLM processes.

1 Introduction

Modern manufacturing has witnessed a paradigm shift with the emergence of additive manufacturing (AM) technologies, transitioning from prototyping applications to functional part production. Unlike conventional subtractive methods, AM builds components vertically through sequential material deposition and controlled energy application [1]. Among laser-based AM (LBAM) techniques for metal, two principal categories exist: powder bed fusion (PBF-L) methods including SLM [2] and directed energy deposition (DED) approaches such as Direct Laser Deposition (DLD) [3] and Laser Engineered Net Shaping (LENS). SLM has

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emerged as a particularly promising AM technique due to its design flexibility, material efficiency, and production speed advantages. This technology's capability to manufacture intricate, topology- optimized geometries as monolithic components using diverse raw materials has driven its adoption across biomedical, aerospace, automative, marine, and space applications. The process utilizes a higher-power laser to selectively fuse powdered material in successive layers.

This investigation employs ss316L powder due to its exceptional mechanical properties, an optimal balance of strength and ductility coupled with remarkable corrosion resistance, making it ideal for demanding aerospace and automative applications. Research into SLM parameter optimization has revealed significant relationships between processing conditions (laser power density, scanning velocity, hatch spacing, and build orientation) and resultant material characteristics. Chery at al. [4] demonstrated laser power density's influence on SLM- produced 316L's hardness and porosity characteristics. Livani's team [5] systematically optimized scanning parameters to enhance mechanical performance while minimizing defects. Li et al. [6] examined build orientation effects on tribological properties through dry sliding wear tests, revealing anisotropic behaviour. Sun at al. [7] correlated minimized porosity with maximized wear and corrosion resistance, noting substantial mechanical improvement over conventional manufacturing.

Microstructural investigation of SLM produced components reveal unique solidification patterns. Melt pool boundaries exhibit epitaxial growth from partially melted grains, with solidification dynamics governed by heat flux, thermal gradients, and crystallographic growth directions [9,10]. The rapid cooling rates (10^3-10^8 K/s) characteristic of SLM promote submicron cellular dendritic structures aligned with thermal gradient [11,12], resulting in directionally dependent microstructural and mechanical anisotropy [13,14].

Post processing heat treatments significantly alter SLM 316L's properties. Kamariah's et al. [16] observed δ-ferrite phase reduction and corresponding hardness decrease at elevated temperatures. Salman's et al. [17] reported strength reduction and cellular structure coarsening with increasing treatment temperatures. Sistiage et al. [18] noted improved impact energy at 950˚C while maintaining tensile strength. Kong et al. [19] demonstrated enhanced corrosion resistance following recrystallization treatments, while Röttger et al. [20] documented HIP- induced ductility improvements despite strength reductions. Bedmar et al. [21] revealed temperature dependent corrosion mechanisms transitions, with high-temperature treatments reducing polarization resistance.

The unique microstructural features of AM metals, including residual stress, internal defects, and ultrafine precipitates (<1 μm), necessitate distinct heat treatment approaches compared to conventional processed materials. Recent studies highlight critical phenomena:

- δ-ferrite phase composition (Cr, Si, Mn, O) significantly influences corrosion behavior [22].
- Subcritical treatment 950°C optimally preserves cellular substructures while eliminating melt pool boundaries [23].
- Oxide content and passive film thickness govern post- treatment corrosion performance [19].
- 950°C treatments efficiently mitigate residual stress and stress corrosion cracking susceptibility [24].
- Microstructural evolution during subcritical treatments requires further systematic investigation [25].

Advanced characterization reveals additional insights:

- Si-O-Mn silicate fractions vary with treatment temperature, affecting mechanical properties [26].
- δ-ferrite formation relates to Mo dissolution and Cr equivalency [27].

- Density remains unaffected by thermal processing [28].
- Annealing suppresses intergranular fracture but challenges strength- ductility balance [29].
- Grain growth control is paramount for optimal mechanical performance [30].

2 Methods

2.1 Powder Characteristics

In this study, commercially available steel powders were utilized in the laser metal powder melting process. The material selection was guided by the objective of performing experimental analyses on components commonly found in aerospace systems, where enhanced performance under demanding conditions is essential. These steels were selected due to their favourable mechanical and operational characteristics. Among the materials frequently used in SLM applications, stainless steel and maraging steel stand out because of their low susceptibility to chemical degradation and ease of commercial production. For the experimental work, AISI 316L powder, manufactured through gas atomization and provided by Renishaw, was chosen. This specific alloy is a non-magnetic, austenitic stainless steel characterized by its low carbon content and alloying elements such as chromium, nickel, and molybdenum, along with trace amounts of other elements. The full chemical composition of the powder material is detailed in Table1.

Place the figure as close as possible after the point where it is first referenced in the text. If there are many figures and tables, it might be necessary to place some before their text citation.

Table 1. Chemical composition of the virgin powder of 316L. All elements are in [wt. %].

Fe	Cr	Ni	Mo	Mn	Si	N	O	P	C	S
Balance	**18**	**14**	**3**	**< 2**	**< 1**	**< 0.1**	**< 0.1**	**<0.045**	**<0.03**	**<0.03**

2.2 Settings and Samples Fabrication

The experimental samples were produced by employing the parameters listed in Table 4, which were determined as the optimal settings for the SLM method. The SLM technique, chosen to align with the scope and aims for this research, is extensively applied in modern aerospace and biomedical applications. As a subtype of the power bed fusion additive manufacturing technologies, SLM involves layer-by-layer melting of powdered material using a laser source to construct the final component. In terms of its operational mechanism, the process starts with a recoater that evenly distributes a thin layer of metal powder onto the build platform. A laser beam, guided by scanning mirrors, selectively melts the powder to generate the desired geometry of each cross section. After completing a layer, the build platform lowers by the defined layer thickness, and the cycle continues until the complete

geometry is fabricated. Through specialized software, the 3D model is prepared by conducting steps such as orientation adjustment on the build platform, generation of necessary support structures, slicing into individual layers, and assigning appropriate process parameters**.**

Fig. 1. Representation of after production.

Table 2. Fabrication Condition for an SLM 3D Printer

Parameter	Value
The power of lasers	200 W
The strategy of printing	Meader
Hatch Spacing	0.11 mm
Preheating Temperature	Ambient
The speed of Scanning	650 mm/s
Layer Thickness	50 µm

Tensile test specimens based on ASTM E8 standards and Charpy impact specimens based on ASTM E23 standards were produced using the SLM Renishaw AM500 3D printer available in the inventory of the PROTOLAB laboratory at the Technical University of Ostrava, Czech Republic. The optimal SLM printing parameters were applied, as shown in Table 2. As-built samples were obtained using the meander printing strategy. The production and heat treatment processes were carried out utilizing the infrastructure of the PROTOLAB laboratory. Since the focus of this study is not on printing parameters but on determining the

optimal values for heat treatment parameters, the printing parameters and strategy were kept constant for the tensile and impact test specimens.

2.3 Heat Treatment

Post-processing techniques are extensively utilized in studies that aim to improve the mechanical properties of components fabricated using AM technologies. Among these methods, heat treatment stands out as a widely adopted approach due to its effectiveness in enhancing both mechanical performance and microstructural features. The main objectives of heat treatment include relieving residual stress, refining the grain structure, improving microstructural homogeneity, and reducing porosity ultimately contributing to increased fatigue life, wear resistance, and corrosion performance.

A critical aspect of heat treatment is the selection of the furnace atmosphere, which entails deciding whether the process will occur in air, under vacuum, or within an inert gas environment. This choice depends heavily on chemical characteristics of the material and its susceptibility to oxidation. For oxidation sensitive materials, inert atmospheres such as argon or nitrogen are typically favored over ambient air. In this study, atmospheric conditions were selected based on the use of ss316L. However, when corrosion resistance is a primary goal, heat treatments are often conducted under reducing environments, such as hydrogen atmospheres or vacuum conditions. For most metal alloys produced via AM, protective gas environments are recommended, with aluminum alloys being a notable exception.

Heat treatment significantly affects the surface characteristics of materials, as microstructural transformation lead to changes in surface morphology. Empirical evidence indicates that surface roughness can vary post treatment [31], which in turn influences mechanical properties such as corrosion resistance, fatigue strength, and wear behavior.

Stress relief heat treatment has been observed to increase material ductility; however, when performed at excessively high temperatures, it may adversely impact both fatigue performance and tensile strength. Therefore, accurately assessing the level of residual stress before the application of stress relief treatments it vital for selecting the appropriate temperature [32]. In this context, a heat treatment at 650 ˚C was selected for ss316L produced via SLM, as literature suggests that while significant changes to the microstructure are not expected at this temperature, a notable reduction or even elimination of residual stress may occur. This assumption was investigated experimentally in the present study.

Prior studies have reported that higher heat treatment temperatures lead to reductions in both hardness and internal porosity levels [33], primarily due to grain structure homogenization. Annealing also contributed to improved corrosion resistance by modifying the key mechanical attributes such as hardness and wear behavior, as well as by altering the oxide layer formed on surface [34]. Typically, parts produced through AM techniques exhibit inferior corrosion resistance compared to conventionally manufactured components. However, subjecting AM parts to appropriate annealing protocols has been shown to significantly enhance their corrosion resistance. In fact, with properly selected parameters, the corrosion resistance of AM parts may even exceed that of traditionally manufactured equivalents. Experimental investigations have particularly focused on the temperature range of 950-1150˚C, which has been identified as critical for maximizing corrosion resistance.

Fig. 2. During heat treatment process

In this study, samples intended for tensile and Charpy impact testing were heat treated at four different target temperatures (400˚C, 650 ˚C, 950˚C, and 1150˚C) for a duration of 2 hours. Following the heat treatment, samples were rapidly quenched in water. The resulting microstructural and mechanical property changes due to both the selected temperature levels and the quenching process were examined through various characterization techniques.

Table 3. Experimental Set-up and Heat Treatment Cycle

Sample	Type of specimen	Heat treatment cycle
HT-0 (As-built)	Tensile Testing Specimen	-
HT-1	Tensile Testing Specimen	400˚C for 2 hours, water cooling
HT-2	Tensile Testing Specimen	650˚C for 2 hours, water cooling
HT-3	Tensile Testing Specimen	950˚C for 2 hours, water cooling
HT-4	Tensile Testing Specimen	1150˚C for 2 hours, water cooling
HT-5	Charpy Impact Testing Specimen	400˚C for 2 hours, water cooling
HT-6	Charpy Impact Testing Specimen	650˚C for 2 hours, water cooling
HT-7	Charpy Impact Testing Specimen	950˚C for 2 hours, water cooling
HT-8	Charpy Impact Testing Specimen	1150˚C for 2 hours, water cooling

3 Results

3.1 Mechanical Properties

To assess the mechanical performance, tensile test results of as-built samples produced via SLM, without any heat treatment, were compared with those of samples subjected to identical cooling conditions (water quenching) following heat treatments at various temperatures for a consistent duration. While an overall increase in yield strength was noted with heat treatment, the enhancement was particularly evident between 400˚C and 650˚C. However, beyond 650˚C, a decline in yield strength became apparent. Despite these changes, a notable disparity in yield strength remains when compared to the as-built specimens.
Analysing the YS/UTS ratio, a key indicator of ductility, the results revealed that optimal ductility occurred at 650˚C, in agreement with trends previously reported in the literature. Furthermore, samples treated at 950˚C demonstrated tensile behaviour like that of the as-built condition. This outcome suggests underlying microstructural factors, which will be explored in detail through further microstructural characterization.

Table 4. Mechanical Properties of Samples

Sample Identify	**R_m**	**$A_{5,65}$**	**$R_{p0.2}$**	**YS/UTS ratio**	**Impact Energy**	**Toughness**
	MPa	%	MPa		J	J/cm^2
400˚C,2h, water cooling	612	13,02	420,3	0,68	37,67	47
650˚C,2h, water cooling	635,7068	11,7124	483,852	0,76	44	55
950˚C,2h, water cooling	625,6863	16,3364	359,22	0,574	46,67	58,34
1150˚C,2h, water cooling	517	25,8595	263,118	0,5089	50	62,34
As-Built	630,766575	20,5201	361,736655	0,57348	44,5	55,75

The Charpy impact test results indicate that the as-built specimen can absorb 44.5 J of energy, leading to the conclusion that heat treatment improves impact energy. Following the heat treatment at 650°C, an enhancement in impact energy was observed, with increases of 4.8% and 12.36% at 950°C and 1150°C, respectively, as the temperature rose. This improvement is believed to be influenced by the choice of water quenching as the cooling method. The detailed underlying mechanism can be elucidated after examining the fracture morphology.

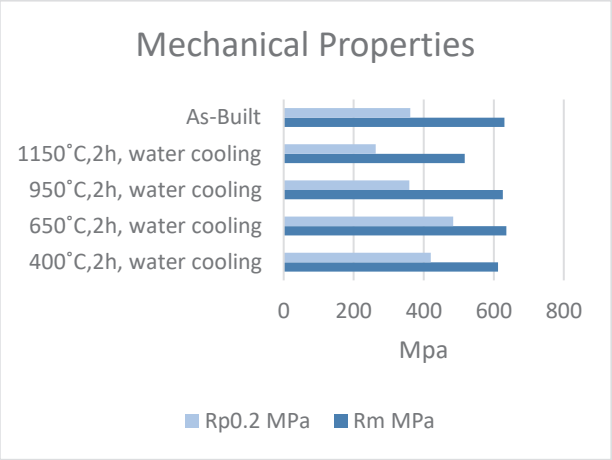

Fig. 3. The light blue color represents the yield strength, while the dark blue color represents the ultimate tenile strength.

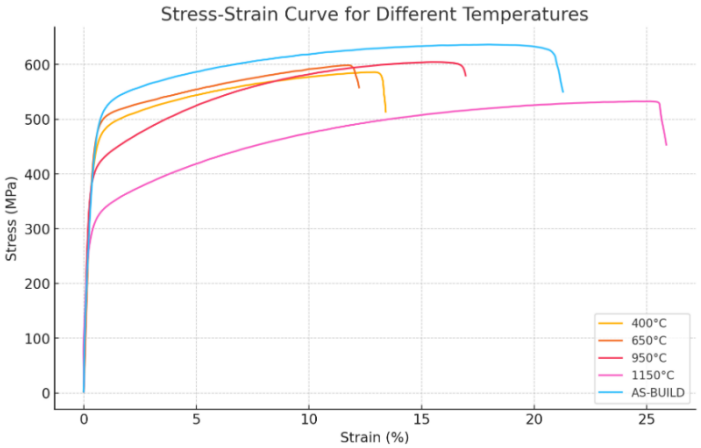

Fig. 4. HT1 400°C; HT2 650°C; HT3 950°C; HT4 1150°C; HT5 as built

4 Discussion

Contrary to several findings in existing literature, the existing literature, the mechanical properties observed at 650°C in this experimental study did not align with those of the as-built condition. Beyond the influence of temperature, this study also highlighted the role of the cooling method as a determining factor in shaping both mechanical performance and microstructural characteristics. A comparative evaluation of different cooling strategies demonstrates that water quenching at elevated temperatures yields superior mechanical results compared to atmospheric or furnace cooling techniques.

To gain a deeper understanding of these observations, the relationship between microstructural evolution and mechanical behaviour will be investigated through detailed microstructural analysis. Additionally, this work aims to offer a comprehensive contribution to the literature by examining the role of residual stress in mechanical performance, along with how specific experimental variables influence both residual stress development and microstructural transformation.

5 Conclusions

This study aims to identify the necessary parameters for extending the use of post-processing methods to optimize the properties of ss316L, a material extensively utilized in aerospace and defence sectors, following its fabrication through the SLM technique. Considering the critical demands of these application areas such as superior strength- ductility synergy, resistance to corrosion, high- temperature performance, surface integrity, and appropriate hardness, this research experimentally explores the impact of selected heat treatment parameters. The mechanical property variations resulting from different heat treatment conditions are systematically presented.

In samples subjected to heat treatment at 400°C followed by water quenching, a 3% reduction in yield strength was observed, along with a 16% increase in ultimate tensile strength and a 6% enhancement in elongation, relative to the as-built specimens. However, when compared with existing literature, quenching at this temperature appears to adversely affect both yield strength and the general strength characteristics of the material. Moreover, due to the associated decline in toughness and energy absorption capacity, the mechanical behaviour does not fully align with desired performance standards.

Heat treatment at 650°C resulted in mechanical properties approaching those of the as-built state in terms of strength, while yielding notable gains in both ultimate tensile strength and ductility. This temperature condition provided a well-balanced strength- ductility combination. Additionally, yield strength showed improvement compared to the 400°C case. Charpy impact test outcomes also demonstrated toughness and absorbed energy levels that were consistent with the as-built condition.

At 950°C, yield strength exhibited a downward trend once more. Interestingly, the elongation and ductility values were found to be like those of the as-built samples, which contrasts with trends typically reported in the literature. The observed increases in toughness and absorbed energy at this temperature are attributed to microstructural phase transformations that occur during the heat treatment process.

References

1. A. Yadollahi, N. Shamsaei, S. M Thompson, & D. W. Seely, (2015). Effects of process time interval and heat treatment on the mechanical and microstructural properties of direct laser deposited 316L stainless steel. *Materials Science and Engineering: A, 644*, 171–183. https://doi.org/10.1016/j.msea.2015.07.056
2. Y. Xiong, W.H. Hofmeister, Z. Cheng, J.E. Smugeresky, E.J. Lavernia, J.M. Schoenung, In situ thermal imaging and three-dimensional finite element modeling of tungsten carbide–cobalt during laser deposition. Acta Mater. 57, 5419-5429 (2009)
3. Y. Xue, A. Pascu, M.F. Horstemeyer, L. Wang, P.T. Wang, Microporosity effects on cyclic plasticity and fatigue of LENS™-processed steel. Acta Mater. 58, 4029-4038 (2010)
4. J.A. Cherry, H.M. Davies, S. Mehmood, et al., Investigation into the effect of process parameters on microstructural and physical properties of 316L stainless steel parts by selective laser melting. Int. J. Adv. Manuf. Technol. 76, 869–879 (2015)
5. E. Liverani, S. Toschi, L. Ceschini, A. Fortunato, Effect of selective laser melting (SLM) process parameters on microstructure and mechanical properties of 316L austenitic stainless steel. J. Mater. Process. Technol. 249, 255-263 (2017)
6. H. Li, M. Ramezani, M. Li, C. Ma, J. Wang, Tribological performance of selective laser melted 316L stainless steel. Tribol. Int. 128, 121-129 (2018)
7. Y. Sun, A. Moroz, K. Alrbaey, Sliding Wear Characteristics and Corrosion Behaviour of Selective Laser Melted 316L Stainless Steel. J. Mater. Eng. Perform. 23, 518–526 (2014)
8. Yadroitsev, I. Smurov, Surface Morphology in Selective Laser Melting of Metal Powders. Phys. Procedia 12, 264-270 (2011)

9. D. Dai, D. Gu, Thermal behavior and densification mechanism during selective laser melting of copper matrix composites: Simulation and experiments. Mater. Des. 55, 482-491 (2014)
10. G. Casalino, S.L. Campanelli, N. Contuzzi, A.D. Ludovico, Experimental investigation and statistical optimisation of the se-lective laser melting process of a maraging steel. Opt. Laser Technol. 65, 151-158 (2015)
11. Y. Zhong, L. Liu, S. Wikman, D. Cui, Z. Shen, Intragranular cellular segregation network structure strengthening 316L stainless steel prepared by selective laser melting. J. Nucl. Mater. 470, 170-178 (2016)
12. E. Yasa, J-P. Kruth, Microstructural investigation of Selective Laser Melting 316L stainless steel parts exposed to laser re-melting. Procedia Eng. 19, 389-395 (2011)
13. Riemer, S. Leuders, M. Thöne, H.A. Richard, T. Tröster, T. Niendorf, On the fatigue crack growth behavior in 316L stainless steel manufactured by selective laser melting. Eng. Fract. Mech. 120, 15-25 (2014)
14. A.B. Spierings, T.L. Starr, K. Wegener, Fatigue performance of additive manufactured metallic parts. Rapid Prototyp. J. 19, 88-94 (2013)
15. J. Lei, Y. Ge, T. Liu, Z. Wei, Effects of Heat Treatment on the Microstructure and Mechanical Properties of Selective Laser Melting 316L Stainless Steel. Shock Vib. 2021, 6547213, 12 pages (2021)
16. M.S.I.N. Kamariah, W.S.W. Harun, N.Z. Khalil, F. Ahmad, M.H. Ismail, S. Sharif, Effect of heat treatment on mechanical properties and microstructure of selective laser melting 316L stainless steel, in *IOP conference series: materials science and engineering* (IOP Publishing, 2017) Vol. 257, p. 012021.
17. O.O. Salman, C. Gammer, A.K. Chaubey, J. Eckert, S. Scudino, Effect of heat treatment on microstructure and mechanical properties of 316L steel synthesized by selective laser melting. Mater. Sci. Eng. A 748, 205-212 (2019)
18. M. Montero-Sistiaga, S. Nardone, C. Hautfenne, J. Humbeeck, Effect of heat treatment of 316L stainless steel produced by Selective Laser Melting (SLM). (2016)
19. D. Kong, C. Dong, X. Ni, L. Zhang, J. Yao, C. Man, X. Cheng, K. Xiao, X. Li, Mechanical properties and corrosion behavior of selective laser melted 316L stainless steel after different heat treatment processes. J. Mater. Sci. Technol. 35, 1499-1507 (2019)
20. Röttger, K. Geenen, M. Windmann, F. Binner, W. Theisen, Comparison of microstructure and mechanical properties of 316L austenitic steel processed by selective laser melting with hot-isostatic pressed and cast material. Mater. Sci. Eng. A 678, 365-376 (2016)
21. J. Bedmar, S. García-Rodríguez, M. Roldán, B. Torres, J. Rams, Effects of the heat treatment on the microstructure and corrosion behavior of 316 L stainless steel manufactured by Laser Powder Bed Fusion. Corros. Sci. 209
22. Q. Chao, S. Thomas, N. Birbilis, P. Cizek, P.D. Hodgson, D. Fabijanic, The effect of post-processing heat treatment on the microstructure, residual stress and mechanical properties of selective laser melted 316L stainless steel. Mater. Sci. Eng. A 821
23. L. Zhou, A. Mehta, B. McWilliams, K. Cho, Y. Sohn, Microstructure, precipitates and mechanical properties of powder bed fused inconel 718 before and after heat treatment. J. Mater. Sci. Technol. 35, 1153-1164 (2019)
24. E.D. Bruycker, M.L.M. Sistiaga, F. Thielemans, K. Vanmeensel, Corrosion testing of a heat treated 316 L functional part produced by selective laser melting. MSA 08, 223-233 (2017). https://doi.org/10.4236/msa.2017.83015
25. M. Laleh, E. Sadeghi, R.I. Revilla, Q. Chao, N. Haghdadi, A.E. Hughes, W. Xu, I. De Graeve, M. Qian, I. Gibson, M.Y. Tan, Heat treatment for metal additive manufacturing.
26. N. Chen, G. Ma, W. Zhu, A. Godfrey, Z. Shen, G. Wu, X. Huang, Enhancement of an additive-manufactured austenitic stainless steel by post-manufacture heat-treatment. Mater. Sci. Eng. A 759, 65-69 (2019)
27. K. Saeidi, X. Gao, F. Lofaj, L. Kvetková, Z.J. Shen, Transformation of austenite to duplex austenite-ferrite assembly in annealed stainless steel 316L consolidated by laser melting. J. Alloys Compd. 633, 463-469 (2015)
28. E. Tascioglu, Y. Karabulut, Y. Kaynak, Influence of heat treatment temperature on the microstructural, mechanical, and wear behavior of 316L stainless steel fabricated by laser powder bed additive manufacturing. Int. J. Adv. Manuf. Technol. 107, 1947–1956 (2020)

29. T. Ronneberg, C.M. Davies, P.A. Hooper, Revealing relationships between porosity, microstructure and mechanical properties of laser powder bed fusion 316L stainless steel through heat treatment. Mater. Des. 189 (2020)
30. L. Liu, Q. Ding, Y. Zhong, J. Zou, J. Wu, Y-L. Chiu, J. Li, Z. Zhang, Q. Yu, Z. Shen, Dislocation network in additive manufactured steel breaks strength–ductility trade-off. Mater. Today 21, 354-361 (2018)
31. Majeed, A. Ahmed, A. Salam, M.Z. Sheikh, Surface quality improvement by parameters analysis, optimization and heat treatment of AlSi10Mg parts manufactured by SLM additive manufacturing. Int. J. Lightw. Mater. Manuf. 2, 288-295 (2019)
32. Dutta, S. Babu, B.H. Jared, *Science, technology and applications of metals in additive manufacturing* (Elsevier)
33. L. Zhou, A. Mehta, B. McWilliams, K. Cho, Y. Sohn, Microstructure, precipitates and mechanical properties of powder bed fused inconel 718 before and after heat treatment. J. Mater. Sci. Technol. 35, 1153-1164 (2019)
34. Y. Xu, Y. Lu, K.L. Sundberg, J. Liang, R.D. Sisson, Effect of annealing treatments on the microstructure, mechanical properties and corrosion behavior of direct metal laser sintered Ti-6Al-4V. J. Mater. Eng. Perform. 26, 2572-2582 (2017)