Acta Polytechnica CTU Proceedings **44**:1–4, 2023
https://doi.org/10.14311/APP.2023.44.0001

EFFECT OF HEAT-TREATMENT ON MATERIAL PROPERTIES OF L-DED PRINTED AUSTENISTIC ALLOY 08CH18N10T FOR NUCLEAR REACTOR APPLICATIONS

Štěpán Jedlan[a,*], Martin Ševeček[a], Antonín Prantl[b], Josef Hodek[b], Pavel Podaný[b], Michal Brázda[b]

[a] *Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, Department of Nuclear Reactors, V Holešovičkách 2, 180 00 Prague 8, Czech Republic*

[b] *COMTES FHT a.s., Průmyslová 995, 334 41 Dobřany, Czech Republic*

[*] corresponding author: jedlaste@fjfi.cvut.cz

Abstract. This paper deals with the evaluation of material properties of the additively manufactured austenistic alloy 08CH18N10T, which is widely used in the Czech Republic nuclear power plants Temelín and Dukovany and other VVER reactors around the world. For purposes of utilization of additive manufacturing technologies for nuclear core components fabrication, two sets of samples were prepared from horizontally and vertically L-DED printed blocks from 08CH18N10T material. Experiments such as microstructure analysis, porosity and Vickers hardness were then performed on L-DED printed and heat-treated 08CH18N10T material, and the obtained material properties were then compared with the properties of L-DED printed 08CH18N10T material without heat-treatment for examination of its effect and also with material properties of conventionally made 08CH18N10T material.

Keywords: Additive manufacturing, 3D printing, laser direct energy deposition, 08CH18N10T, hardness, porosity, microstructure, EBSD, metallography.

1. Introduction

Additive manufacturing (AM) provides a faster, cheaper and flexible way to prototype, fabricate, or improve components. So far, AM methods have been applied in many industrial applications, but despite the advantages, it is very challenging to implement them in highly regulated and conservative industry field such as nuclear power engineering. This paper deals with the material properties of L-DED fabricated and heat-treated 08CH18N10T material and comparison to conventionally fabricated. The alloy 08CH18N10T has been widely used in many VVER reactors around the world and have been studied in detail [1–4]. It has been used for both in-core and out-of core components. With the life extensions of the operating units, it is crucial to find and qualify suitable manufacturing and reparation processes that will allow the utilities to replace or repair components manufactured decades ago. Additionally, AM provides significant benefits in terms of availability of components and security of supplies. However, AM processes are fundamentally different from conventional manufacturing processes, resulting in different material microstructure, mechanical properties or behavior under irradiation [5–7]. Therefore, it is crucial to study the AM materials in detail before they can be implemented in commercial power plants.

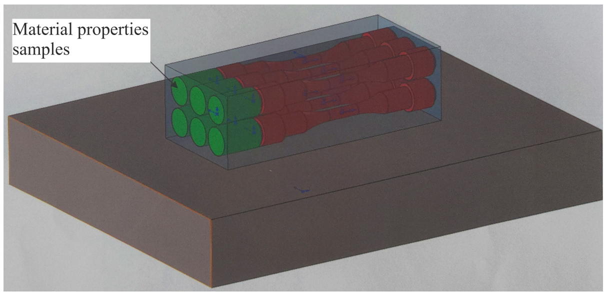

Figure 1. Sample orientation in L-DED deposited block (see green cylinders).

2. Materials and methods

2.1. Samples preparation

The additive manufacturing method Laser Direct Energy Deposition (L-DED) was used to fabricate a vertical and horizontal block (see Figure 1), using a powdered 08CH18N10T material and 1600 μm laser (see the chemical composition of the conventionally manufactured material in Table 1). After fabrication, heat-treatment was applied (3 h – 1150 °C) with air cooling. From each block, six samples were prepared (see Figure 1) to further investigate the properties of the as-fabricated material. The samples from the horizontally fabricated block were taken from the side of the deposited block (see Figure 1) however, the samples from the vertically deposited block were taken from the top of the fabricated block.

C	Si	Mn	Cr	Ni	Ti	S	P
≤ 0.08	≤ 0.8	≤ 2	17.0–19.0	9.0–11.0	$5 \cdot$ C–0.7	≤ 0.02	≤ 0.04

Table 1. Chemical composition of conventionally fabricated 08CH18N10T in wt % according to GOST 5632:2014 [8].

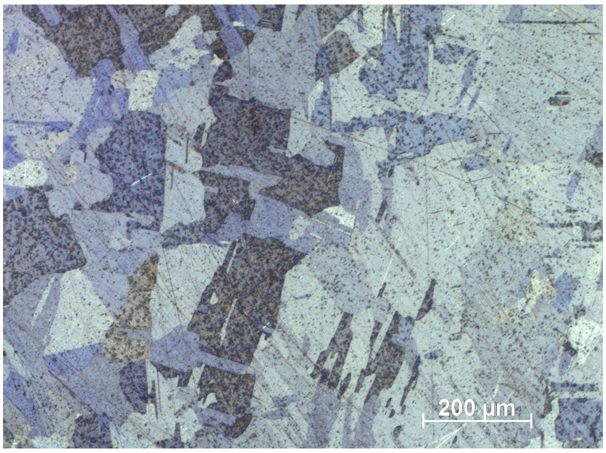

Figure 2. LOM analysis image of recrystallized microstructure of L-DED fabricated 08CH18N10T material.

2.2. Metallography analysis

Metallographical analysis of the microstructure was performed using a light optical microscopy (LOM) and scanning electron microscopy (SEM). For further analysis of grain structures, electron back-scatter diffraction mapping (EBSD) was also used [9]. Metallography was performed on heat treated and non-heat treated L-DED fabricated 08CH18N10T to observe differences in microstructure. To reveal the microstructure, the analyzed samples were cut in half, both in the vertical and horizontal plane, and then etched using a V2A etchant (HCl:HNO_3:H_2O – 10:1:10) for ~40 s.

From images of individual samples taken during LOM, the porosity was evaluated as a proportion between the area of the individual pores and the area of the whole sample. This was carried out to investigate the differences between samples from horizontally and vertically fabricated blocks.

2.3. Vickers hardness

Vickerss hardness test (HV1) according to EN ISO 6507 was performed on 12 samples (6× vertical and 6× horizontal) in 9 evenly distributed points, using a Struers DuraScan. In ecos Workflow software, the mean value and standard deviation were calculated for each sample.

3. Results

The results of the LOM metallography analysis show complete recrystallization of the microstructure of the L-DED fabricated 08CH18N10T material due to the applied heat treatment (see Figure 2). Using a LOM

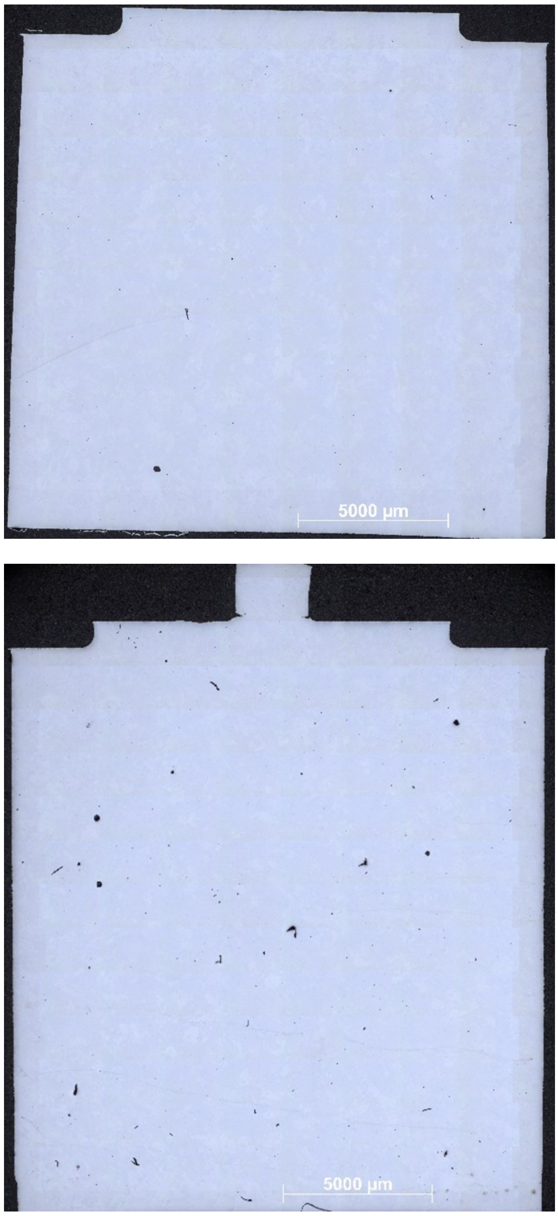

Figure 3. Porosity of samples from verticaly (top) and horizontaly (bottom) fabricated blocks.

analysis, a greater number of pores was observed in samples from a horizontally fabricated block, as opposed to samples from a vertically fabricated block (see Figure 3). This was also confirmed in the porosity evaluation (see Table 2), which shows that samples from the vertically fabricated block have ~2.5× lower porosity than samples from the horizontally fabricated block.

SEM analysis also showed recrystallization of the microstructure as a result of the applied heat treatment. EBSD mapping results showed columnar grains

Fabricated block (samples)	Porosity [%]
Vertical	0.040
Horizontal	0.108

TABLE 2. Mean value of porosity for samples from horizontally and vertically fabricated blocks.

Fabrication	Vickers hardness
L-DED vertical	132.89
L-DED horizontal	131.80
Conventional	127-178

TABLE 3. Comparison of Vickers hardness mean values for conventionally and L-DED fabricated 08CH18N10T material with heat-treatment.

directed from the outside line of individual meltpools toward their center in the non-heat treated material. In the heat treated material, the recrystallized microstructure was observed with large equiaxed grains without specific direction (see Figure 4).

The results of the Vickers hardness test at room temperature (HV1) are similar for both vertically and horizontally deposited blocks, due to the applied heat treatment. Heat treatment thus reduces the anisotropy of the AM-fabricated materials, which is positive for future applications. The mean values of all samples from vertically and horizontally fabricated blocks were then compared with the values of conventionally fabricated 08CH18N10T material with heat treatment 1020–1100 °C (see Table 3) according to GOST [10].

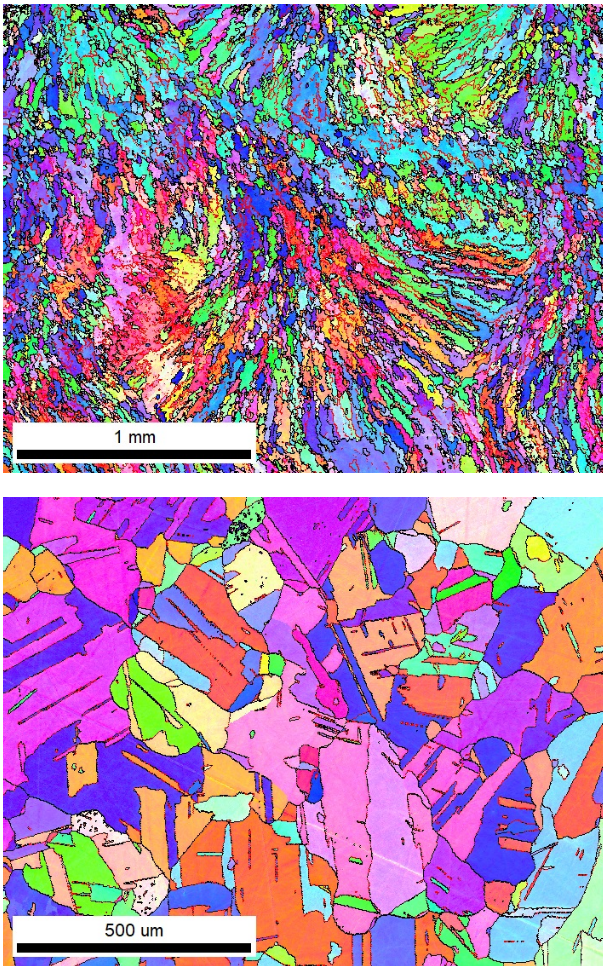

FIGURE 4. EBSD maps of non heat-treated (top) and heat-treated (bottom) material.

4. Conclusions

In this study, metallography, porosity and Vickers hardness were measured on L-DED fabricated 08CH18N10T material to gain comprehensive information about the effects of applied heat treatment and to compare the material properties with conventionally fabricated material.

In conclusion, our comprehensive study of the material properties of L-DED fabricated alloy 08CH18N10T through metallography, porosity analysis, and Vickers hardness testing has provided valuable insight into the performance of this material. Through metallography, fine microstructure with a homogeneous distribution of large equiaxed grains was observed; however, in the case of samples from vertically deposited block, a lower number of pores were present. This could have been due to better heat transfer during the vertical block deposition process.

Furthermore, Vickers hardness tests revealed that the hardness values of the L-DED fabricated alloy 08CH18N10T in both types of samples (vertical and horizontal) are almost the same, due to the applied heat treatment. The values of the measured hardness are also in close agreement with those typically observed in conventionally fabricated materials. This suggests that the 3D printed alloy possesses comparable mechanical strength and wear resistance.

In summary, the results of this study affirm the potential of the L-DED fabricated alloy 08CH18N10T as a reliable material with comparable performance to conventionally fabricated; however, further research and testing of its mechanical properties is needed to better understand its capabilities and also the effects of applied heat treatment. It is also foreseen to study the effects of irradiation on AM-manufactured materials with optimized heat treatment in the near future.

References

[1] A. Materna, P. Haušild, J. Ondráček, et al. Effects of cold-working and annealing at 700 °C on hardness of 08Ch18N10T steel. *Procedia Structural Integrity* **23**:425–430, 2019. https://doi.org/10.1016/j.prostr.2020.01.124

[2] P. Pavel, M. Petr, N. Jan, B. Martin. Heat treatment of reactor vessel steel 08CH18N10T. In *Materials Science and Technology Conference and Exhibition 2012, MS and T 2012, 2*, pp. 1036–1043. 2012.

[3] B. Fekete, J. Kasl, D. Jandova, et al. Low cycle thermomechanical fatigue of reactor steels:

Microstructural and fractographic investigations. *Materials Science and Engineering: A* **640**:357–374, 2015. https://doi.org/10.1016/j.msea.2015.05.093

[4] T. Janda, Š. Jeníček, L. Kučerová, et al. Influence of higher stabilization temperatures on the microstructure and mechanical properties of austenitic stainless steel 08Ch18N10T. *Metals* **13**(5):975, 2023. https://doi.org/10.3390/met13050975

[5] N. Sridharan, M. N. Gussev, K. G. Field. Performance of a ferritic/martensitic steel for nuclear reactor applications fabricated using additive manufacturing. *Journal of Nuclear Materials* **521**:45–55, 2019. https://doi.org/10.1016/j.jnucmat.2019.04.020

[6] J. Simpson, J. Haley, C. Cramer, et al. Considerations for application of additive manufacturing to nuclear reactor core components. Tech. rep., Oak Ridge National Lab. (ORNL), Oak Ridge, TN (United States), 2019.

[7] Š. Jedlan, M. Ševeček, A. Prantl, et al. Utilization of additive manufacturing in nuclear power industry. In *2022 8th International Youth Conference on Energy (IYCE)*, pp. 1–6. IEEE, 2022. https://doi.org/10.1109/IYCE54153.2022.9857541

[8] GOST-5632:2014. High-alloy steels and corrosion-resistant, thermally resistant and refractory alloys. Standard, GOST, 2014.

[9] P. Gávelová, P. Halodová, B. Křivská, et al. Microstructure of zirconium fuel claddings: TEM and EBSD studies of as-received and neutron-irradiated materials. *Manufacturing Technology* **20**(6):720–727, 2020. https://doi.org/10.21062/mft.2020.088

[10] Steel 08X18N10T. AUREMO, 2023. [2023-09-27]. https://auremo.biz/materials/stal-08h18n10t-ei914.html