

## SELECTIVE LASER MELTING OF NICKEL BASE HEAT RESISTANCE ALLOY EP648

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**ABSTRACT:** For successful development of selective laser melting technology, it is important to increase the range of suitable materials. One of the most interesting materials for aerospace, automotive, shipbuilding and energy industries is heat-resistance superalloys. In this research EP648 nickel base heat resistance alloy was used for SLM. For determination of influence of SLM process parameters on EP648 4x4x4 mm cubic specimens were fabricated in SINTERSTATION® Pro DM125 SLM machine by using different process parameters (laser power, layer thickness, point distance, exposure time). The porosity of fabricated specimens was determined by scanning electron microscopy of polished cross-sections. SLM mode with lowest porosity (less than 1%) was selected for produce specimens for tensile strength tests. Tensile tests were carried out by using Gleeble 3800 Thermal-Mechanical Testing System for different test temperatures (up to 1073 K). Results of tests (ultimate tensile strength) showed that SLM produced EP648 by mechanical properties not inferior to cast material.

**KEYWORDS:** Selective Laser Melting, Nickel base heat resistance alloys, Superalloys, EP648

## INTRODUCTION

Selective Laser Melting (SLM) technology is widely used for producing metal details in world now. In comparison with conventional metal part fabrication technologies SLM have some advantages, such as: ability to produce of details with complex 3D shape and internal cooling channels; cheapness and rapidity of single or low volume production of complex shape parts (surgical and dental implants, design prototype); minimal quantity of production residuals. However SLM process is defined by a large number of parameters: laser power, scanning speed, layer thickness, point distance, exposure time, hatch space, stripe width, scanning strategy, powder bed temperature, building atmosphere and other), this complicates optimization of SLM process for each new metal or alloy. One of the most perspective materials for SLM fabrication is nickel base heat resistance alloy EP648, Evgenov et al. (2015), that is used in aerospace and energy industries, Evgenov et al. (2015), Nerush&Evgenov (2014). Now follow nickel base heat resistance alloys are well studied in point of view of SLM technology: Inconel 625, Amato et al. (2012), Mumtaz&Hopkinson (2010), Inconel 718, Parimi et al. (2012), Jia&Gu (2014), Lu et al. (2015), Rickenbacher et al. (2013), CM247LC, Carter et al. (2014), CMX486, Carter et al. (2015), Hastelloy X, Harrison et al. (2015), Waspalloy, Mumtaz et al. (2008), Nimonic 263, Vilaro et al. (2012), but EP648 is very different by chemical composition from this alloys.

The purpose of this paper is studying of influence of the SLM process parameters on heat resistance alloy EP648.

## RESEARCH METHODOLOGY

There are 4 stages in this work: fabrication of cubic specimens EP648 by selective laser melting for determination of porosity, choice of mode selective laser melting, fabrication of specimens EP648 by selective laser melting for tensile strength tests.

In this work, inert gas atomized EP648 powder were used. EP648 is nickel base heat resistance alloy. Chemical composition of EP648 presents in Table 1. Chemical composition of EP648 is significantly different in comparison with widely used in SLM Inconel 625 and Inconel 718.

Table 1. Chemical composition of EP648 and some nickel base superalloys (wt.%)

Material	Ni	Cr	W	Mo	Nb	Al	Ti	Mn	Co	Cu	C
Nominal EP648	Balance	32-35	4.3-5.3	2.3-3.3	0.5-1.1	0.5-1.1	0.5-1.1	-	-	-	≤0.1
Precursor powder EP648 by EDS	53.92	34.10	6.06	3.12	0.76	1.06	0.96	-	-	-	-
Inconel 625	≥58	20-23	-	8-10	3.15-4.15	≤0.4	≤0.4	≤0.5	≤1	-	≤0.1
Inconel 718	50-55	17-21	-	2.8-3.3	4.75-5.5	0.2-0.8	0.65-1.15	≤0.35	≤1	≤0.3	≤0.08

For characterization of EP648 powder, scanning electron microscopy (SEM) was used. SEM micrographs of EP648 powder were presented in Figure 1. Most of powder particles have a regular spherical shape.

The cubic specimens (4x4x4 mm) EP648 were fabricated in SINTERSTATION® Pro DM125 SLM machine (Table 2) by using different process parameters (laser power, layer thickness, point distance and exposure time).

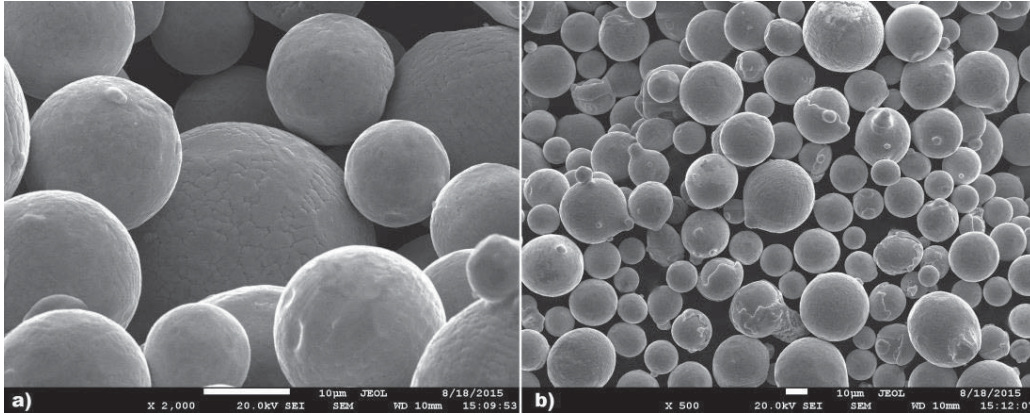


Figure 1. SEM micrographs showing EP648 powder morphology: a) x 2000; b) x 500

Table 2. Parameters of SINTERSTATION® Pro DM125 SLM System

Laser	CO <sub>2</sub> laser redPower SP-200C-04
Max laser power	200 [W]
Scanning speed	up to 1000 [mm/s]
Layer thickness	20-100 [µm]
Laser beam diameter	35 [µm] at powder surface
Max part building area	125x125x125 [mm]
Inert atmosphere	argon
O <sub>2</sub> level controlling	from 100 to 5000 [ppm]
Powder bed heating	up to 200 [°C]

Surface Eq.(1) and volume Eq.(2) energy densities were used to describe SLM modes.

$$E_v = \frac{P \cdot ET}{PD \cdot HS \cdot h} \quad (1)$$

$$E_s = \frac{P \cdot ET}{PD \cdot HS} \quad (2)$$

Where P is laser power; ET is exposure time; PD is point distance; HS is hatch space; h is layer thickness.

The porosity of obtained specimens was determined by using JSM-6400LV electron microscope (Figure 2). The specimens were prepared by polishing. The cross-section images of the specimen were obtained by the microscope and processed using MATLAB Image Processing tools to determine the area of pores. Porosity was calculated by using Eq. (3):

$$\text{Porosity} = \frac{\text{area of pores}}{\text{area of cross-section}} \quad (3)$$

Tensile tests were performed at ambient and evaluated temperature by using Gleeble 3800 Thermal-Mechanical Testing System. For tensile tests three cylindrical specimens with 6 mm diameter and 120 mm length were fabricated for each test temperature.

## RESULTS AND DISCUSSION

In Figure 2 polished cross-section micrographs of specimens with the lowest (1.04%) and highest (29.8%) porosity are presented. These two regimes differ only by output laser power (200 and 50 W).

Pores of both specimens have different formation mechanism. Pores of 200 W laser power regime is small (maximum size - 32  $\mu\text{m}$ ) (Figure 2,b). For this regime laser power is sufficient for melting of metal powder and pore formation is explained by balling effect, Gu et al. (2009). In other hand, for regime with 50 W laser power is insufficient for completely melting of metal powder then pores are very large (Figure 2,b) and have many unmelted powder particles.

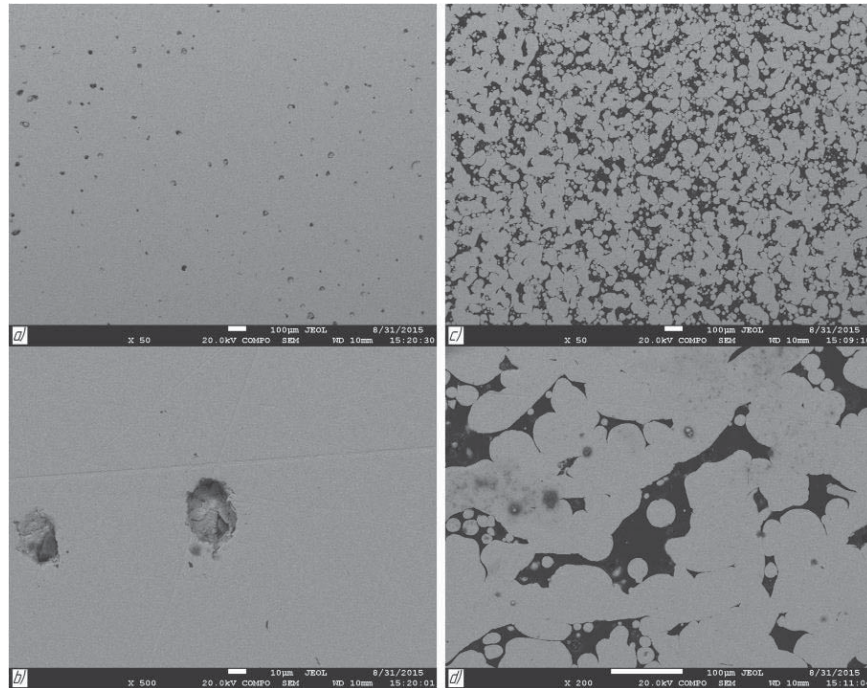


Figure 2. Polished micrographs of cross-sections: a),b) specimen with the lowest porosity (1.04%); c),d) specimen with the highest porosity (29.8%)

In Figure 3, the porosity of specimen from their surface and volumetric energy density dependencies were presented. As it can be seen in Figure 3 porosity dependencies from surface

and volumetric energy densities have a good correlation for both layer thickness values. It is explained that layer thickness values is very close (35 and 40  $\mu\text{m}$ ).

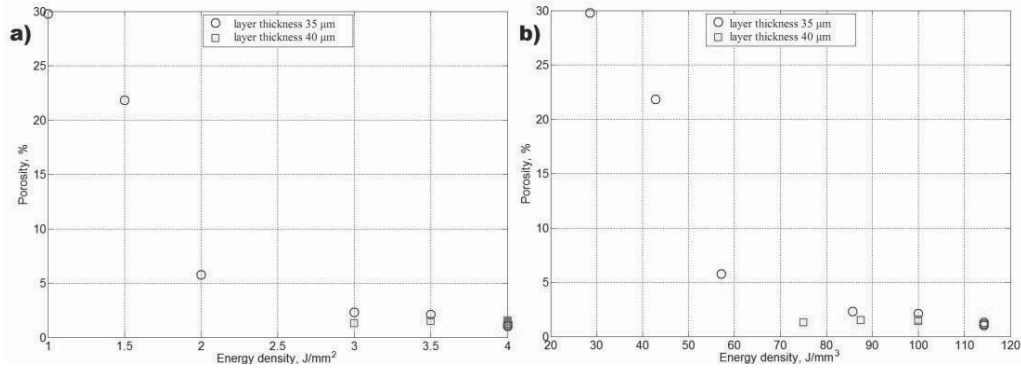


Figure 3. Influence of surface (a) and volumetric (b) energy density on the porosity of specimens

In result of analysis of plots in Figure 3, we made the following conclusion: for SLM fabrication of dense parts from EP648 alloy with layer thickness of 35-40  $\mu\text{m}$  minimum surface and volumetric energy density should be not less than 3  $\text{J}/\text{mm}^2$  and 75  $\text{J}/\text{mm}^3$ . These results have good correlation with paper Harrison et al. (2015), where four nickel base alloys (Inconel 625, Inconel 718, CM247LC, CMX486) was studied.

The decrease porosity of the material with increasing surface end volume energy densities may be explained by the changing nature of processes. Apparently, the increased energy density leads to a complete meltdown and overheating of the metal in the coordinate of the laser spot. The overheating of the melt increases the fluidity and the filling of pores in the material.

Results of tensile tests presents in Table 3. Ultimate tensile strength of SLM produced EP648 by mechanical properties are close to the cast material: for 300 K test temperature UTS of SLM produced EP648 was 97.77% form the cast EP648, for 1073 K – 93.33%. Good UTS of SLM produced EP648 can be explained by high SLM process cooling speed (up to  $10^7$  K/s, Trijis et al. (2013)).

Table 3. Results of tensile tests

Material	T=300 K	T=923 K	T=1073 K
	Ultimate tensile strength (UTS), MPa		
SLM produced EP648	880-910	665-675	560-600
Cast EP648	900-950	-	600-640

## SUMMARY

In this paper an influence of SLM process parameters on porosity of EP648 nickel base heat resistance alloy porosity was studied. For determination of porosity an optical method was used. For this purpose 4x4x4 mm cubic specimens were fabricated by using different SLM process parameters (scanning speed, laser power, layer thickness). It was determined that for SLM fabrication of dense parts from EP648 alloy with layer thickness of 35-40  $\mu\text{m}$  surface and volumetric energy density should be not less than 3  $\text{J}/\text{mm}^2$  and 75  $\text{J}/\text{mm}^3$ . The lowest porosity that

was achieved is 1.04%. Tensile tests showed that ultimate tensile strength of SLM-EP648 specimens are close with ultimate tensile strength of cast EP648.

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