

Characterization of Additively Manufactured Parts of Alloy UNS N07718 in the API 6ACRA Chemical Composition

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ABSTRACT

After an era of prototyping, the additive manufacturing (AM) processes are currently passing through an industrialization period, when the production of real parts and complex field-applicable components is beginning to take part in the industry. Together with this fast development, the need to compare and evaluate the properties of additive manufactured products arises.

Among the most used wrought and additively manufactured nickel alloys in the oil & gas industry is the Alloy UNS⁽¹⁾ N07718, a precipitation hardening nickel-chromium-iron alloy enriched with niobium, molybdenum, titanium and aluminum, which confer to the material excellent mechanical properties combined with satisfactory corrosion resistance. Despite the significant application of this material, limited information is available on the literature regarding the properties achieved by the material on heat-treated printed parts.

In this context, the aim of these studies is to develop an optimized heat treatment for printed parts of Alloy UNS N07718 with chemical composition in accordance to the API⁽²⁾ 6ACRA¹, printed in a SLM⁽³⁾ machine and to characterize the properties obtained by the manufacturing process to get them compared to available data in the literature and to standard forged bars.

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INTRODUCTION

The Selective Laser Melting (SLM) process is the most widely used process to fabricate additive manufactured parts of metallic materials. The SLM process enables the production of complex and customized parts for the different sectors of the industry, such as the aerospace, automotive, medical, and energy. By the application of this additive manufacturing method, a fully dense solid structure, reported in the literature to be greater than 99.7%,^{2,3} is created through the selective melting of the surface of a metal powder bed by a laser beam, which grants structures with mechanical properties comparable to those achieved by wrought material when proper powder composition and printing parameters are selected.^{2,4}

Besides the well known advantages of the use of additive manufacturing, like the possibility of producing small batches, more customized products, material savings and the easily reuse of waste material not used during the manufacturing, some authors also list the current challenges of this manufacturing process. Cost and speed of production, changing of designing, validation of mechanical and thermal properties, development of standardization and post processing, for example, are among the most challenging characteristics of AM implementation in the industry.⁵

Nickel alloys are important high technology metallic materials, since they can present good corrosion properties combined with outstanding mechanical resistance at both low and high temperatures. Among the most used wrought and additively manufactured nickel alloys in the oil & gas industry is the Alloy UNS N07718, a precipitation hardening nickel-chromium-iron alloy enriched with niobium, molybdenum, titanium and aluminum. Despite the significant application of this material, limited information is available on the literature regarding the properties achieved on AM post-manufactured parts with emphasis on improved microstructure and reduced anisotropy.

Wang Z. et al reported fine dendritic cast structures formed after additive manufacturing of Alloy UNS N07718 by SLM process and attributed the fine elongated structure to the high heat exchanges due to high laser energy densities.³ Due to the energy transfer effect caused by the heat dissipation in the direction of the substrate, regular solidification structure on the building (vertical) negative z-direction is reported, composed by dendrites that grown parallel to the z-building direction. Similar structures were observed by X. Wang et al⁴ and other authors. On the other hand, the cross section planes to the building direction often shows

periodic morphologies resulting from the laser beam overlapping, which are characterized by larger equiaxed grains and dendritic arm spacing compared to single-pass regions.²

Usually, the dendritic structure is reported to be dissipated after carrying out the defined post-manufacturing heat treatment cycles and the area of equiaxed recrystallized grains drastically increases due to nucleation and grain growth.^{2,3,4}

Some authors report mechanical properties at room temperature of additive manufactured parts of Alloy UNS N07718 comparable to those of solution annealed and age hardened wrought material.^{3,4,6,7,8}

The present work evaluates the development of an optimized heat treatment for printed parts of Alloy UNS N07718 and the characterization of the properties obtained by the manufacturing and post-manufacturing process. The discussion of such information is of relevant importance to the further development and optimization of AM and post-AM processes and its future industrial application.

EXPERIMENTAL PROCEDURE

Material

The Alloy UNS N07718 powder material used in these studies was a mix of 4 VIM/AR (Vacuum Induction Melting / Argon atomization) heats with main chemical composition according to the API 6ACRA as shown on **Table 1**.

Table 1: Main chemical composition of powder heats

Heat	C	Cr	Ni	Mo	Ti	Nb	Fe	Al	B
P1	0.013	18.4	53.85	3.05	0.94	5.01	Balance	0.55	0.004
P2	0.011	18.4	54.24	3.07	0.95	5.06	Balance	0.5	0.004
P3	0.011	18.1	54.12	3.03	0.95	4.96	Balance	0.43	0.002
P4	0.011	18.3	53.77	3.02	0.95	5.02	Balance	0.46	0.003
API 6 ACRA for UNS N07718	Max 0.045	17.0- 21.0	50.0- 55.0	2.80- 3.30	0.80- 1.15	4.87- 5.20	Balance	0.40- 0.60	Max 0.0060

In order to define the printing parameters, 15 cubes were printed with different combinations of printing speed and power as exemplified on **Figure 1**.

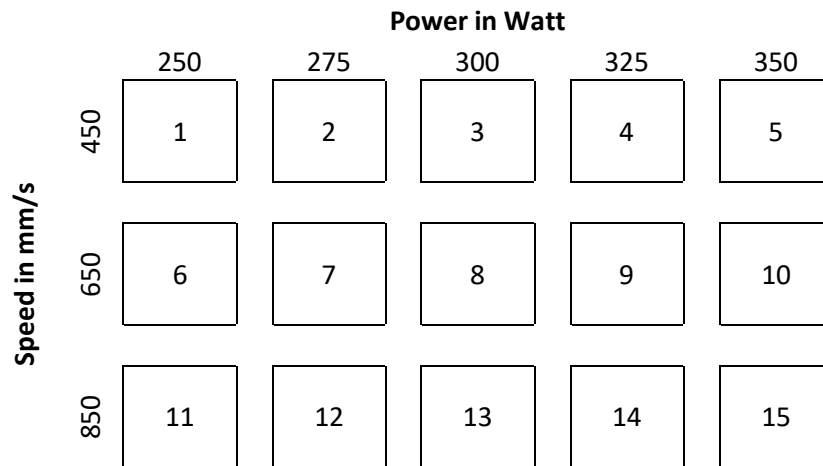


Figure 1: Scheme of printed cubes for parameter evaluation

After printing, each cube was analyzed for the presence of pores and/or lack-of-fusion defects. The combination of speed and power numbered 13 (850 mm/s, 300 W) with hatch 0.1 mm and layer thickness of 0.04 mm was chosen for printing the testing parts. The parts were printed using alternate 45°, 135° print strategy, as exemplified by **Figure 2**.

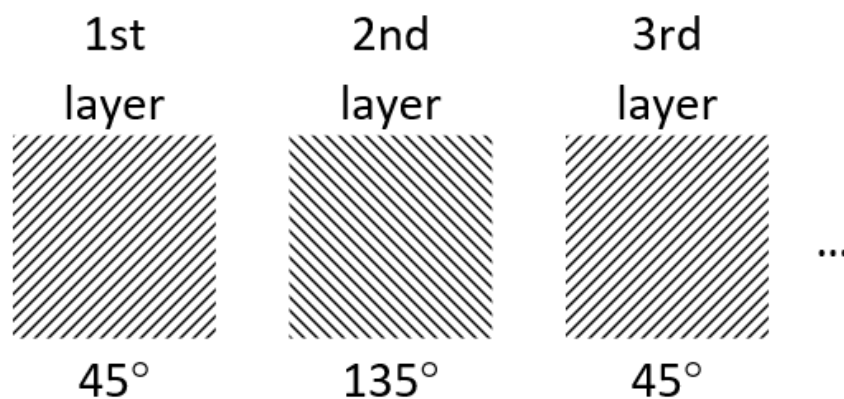


Figure 2: Schema of print strategy using alternate 45°, 135°

After definition of the printing parameters and strategy, raw samples were printed for the definition of heat treatment temperatures and testing program. The printed samples include parallelepiped samples, which were machined to testing samples with the desired dimensions.

The metallographic aspect of as-printed samples is shown on **Figure 3**. The dendritic cast structure and periodic morphology fit well with the structures described in the literature. Z. Wang et al.,³ X. Wang et al.⁴ and F. Cappuccini et al.,⁷ reported to have achieved similar structures on as-printed samples of Alloy UNS N 07718. The porosity level is low with a slightly increase in regions close to the border of the samples.