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Analysis of corrosion on sintered stainless steel: Mechanical and physical aspects

C. Barile*, C. Casavola, S.L. Campanelli, G. Renna

Politecnico di Bari – Dipartimento di Meccanica, Matematica e Management, Viale Japigia 182, 70126, Bari, Italy

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ABSTRACT

This research aims to examine the effects of a corrosive atmosphere on samples of 316 L sintered stainless steel. A salt spray test chamber was used to simulate cyclic exposure to a corrosive environment. The samples were deposited using different process parameter sets by selective laser melting. The energy density (E_v) was varied on three levels, and the effects of volume energy density on the weight, density, and corrosion resistance were investigated. Furthermore, weight and density measurements were carried out at the end of the accelerated corrosion tests. The morphology of the corrosion sample surfaces was characterized by means of scanning electron microscopy. The mechanical properties before and at the end of the accelerated corrosion were evaluated according to yield strength, tensile strength, and elongation at breakage.

The experimental results demonstrate that both the weight and density increase when E_v is increased. The corrosion tests exhibited slightly different corrosion behaviors as a function of the E_v used. Samples deposited at the maximum energy generally exhibited less corrosion and the highest tensile properties owing to the low distribution of defects inside the sample. However, improved tensile properties continued to emerge following each exposure time interval in the corrosion process. It was found that the influence of the "exposure time interval" factor is non-existent for the ultimate tensile strength, yield stress, and strain at fracture, as these did not change with the accelerated corrosion exposure time.

1. Introduction

The diffusion of stainless steel in numerous different fields, not limited to mechanical and civil productions, is owing to many factors. Among these, of course, [1] named high resistance to corrosion, as well as effective formability and the possibility of achieving products with an agreeable visual appearance. The sintering process of stainless steel powders offers several advantages; it allows for the production of complex shape parts with high dimensional accuracy, and relevant savings in terms of material and energy costs. Sintered stainless steel is widespread in various fields, including the automotive and biomedical industries, as described by [2]. Over the past several years, this product has been thoroughly investigate using both traditional and innovative techniques, according to the detailed descriptions provided by [3–5].

However, it should be considered that corrosion and wear resistance are reduced in sintered materials compared to homogeneous materials, as noted by [6]. The main reason for this relates to the presence of porosities, which modify the mechanical performances, particularly when the parts interact with corrosive environments. Different studies are concerned with the analysis of sintered material corrosion, even if they referred to immersion in a corroding solution followed by air drying, and that by [7] is one of the

* Corresponding author.
E-mail address: claudia.barile@poliba.it (C. Barile).

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most representative. In the scientific literature, the problem has been analyzed by [8] as well as [9], by considering the relation between the stainless steel corrosion strength and its superficial finishing. The combined action of atmospheric contaminants, such as Cl and SO_2-derived ions, was also taken into account by [10–12], while the effects of the presence of non-metallic inclusions were described by [13,14]. In general, corrosion strength is connected to roughness; specifically, [8,9] demonstrated that a low roughness level in stainless steel results in a higher pitting potential. In view of this consideration, it is possible to demonstrate that stainless steel with an effective surface finishing; that is, with low roughness, can be considered to exhibit high corrosion resistance. However, this cannot be taken as a general rule; in fact, [15] considered the possibility that steels with a certain roughness display very different responses to exposure in corrosive environments.

In this study, the effect of exposure to a controlled corrosive environment on the mechanical properties and physical aspects of 316 L stainless steel powders, sintered by selective laser melting (SLM) at three laser energy densities (E_v), was studied. The aim of this work is to assess the possible variations in tensile properties, visual appearance modification, weight loss, and density variation. A salt spray test chamber was used to produce relative corrosion-resistance information for the studied samples, which can both provide a controlled corrosive environment and simulate cyclic exposure. Nine specimens were prepared for each energy density. In particular, one sample for each E_v was tested as delivered, according to ASTM E8M [16], while the remaining eight specimens of each E_v were subjected to accelerated corrosion tests. Four exposure levels were defined: 24, 96, 168, and 240 h, which were selected among the exposure levels suggested by the standard ASTM B 117 [17].

At the end of each step, two samples were removed from the chamber. Detailed analyses were performed of the sample surface morphology modifications at the end of the accelerated corrosion tests. Furthermore, the weight loss/gain, density variation, and mechanical properties of all samples were characterized and discussed for the three process parameter sets. Finally, variations of the mechanical properties related to the exposure time were investigated.

2. Materials and methods

In this study, gas-atomized AISI 316 L stainless steel powder was used for the SLM process. The gas-atomized stainless steel powder exhibited a spherical form, with a particle size in the range of 15–53 μm. Table 1 displays the chemical composition (weight %) of the 316 L stainless steel powder. The 316 L stainless steel is derived from X5CrNi18–10 steel with the addition of 2.5% Mo, and is useful for improving resistance to chlorine corrosion (pitting). This makes it suitable in environments that are affected by seawater and naval applications. The suffix L indicates a low carbon content; that is, lower than 0.035% (316 admits up to 0.080%), which is useful for avoiding chromium carbide precipitation and therefore corrosion complications.

The SLM samples were constructed using a laser machine operating through a Nd:YAG laser source with a 200-mm spot diameter, wavelength of 1.064 μm, and maximum output power of 100 W. Galvanometric scanning mirrors were used to move the laser beam over the powder surface and draw every powder layer selectively.

The powder deposition set-up includes a working basement in which a coater is used to store sequential powder layers along one direction. The working chamber uses a nitrogen atmosphere to prevent part oxidation and limit the initial oxygen level to 0.8%.

Fig. 1a) provides a schematic of the SLM machine equipment used for the experiments. Several input parameters to be controlled and varied characterized the SLM process, and their scope was to reach an optimized parts quality. These include the laser (spot size, power, etcetera) and powder (shape, distribution, size, etcetera) parameters, hatch spacing (H_s), scanning speed (v), and layer thickness (LT). These parameters affect the molten/solidified track zone (Fig. 1b), thereby producing parts with different qualities.

The layer thickness (LT) depends on the working basement stepping. In this study, it was set to 30 μm, which is the minimum step allowed by the employed SLM machine. Casalino et al. [18] used this step value to obtain effective adhesion between layers.

All dog-bone specimens were manufactured following the ASTM E 8 M [16] standard. The sizes (mm) and shapes of the samples are displayed in Fig. 2. Dog-bone specimens were deposited by the SLM system with three different processing parameter sets. In particular, the specimens were processed using different laser powers (P) and scanning speeds (v). The hatch spacing was maintained constant at 140 μm throughout the experiments, allowing for a suitable degree of overlapping between adjacent tracks. Three levels of P and two of $\boldsymbol{v}$ were used, according to the experimental plan displayed in Table 2, where E_v is the volume energy density in Joule per unit volume (J/mm^3). The laser energies per unit volume were determined using Eq. (1), as provided by [19]:

$$E_v = \frac{P}{Hs\ LT\ v} \tag{1}$$

where P represents the laser power (W), H_S is the hatch spacing (mm), LT is the layer thickness (mm), and v is the scanning speed (mm/s).

The selection of these process parameters enabled the investigation of different configurations of SLM samples, characterized by varying values of relative density and mechanical properties.

The same random scanning strategy as that used by [18] was applied in this work, which consists of subdividing the entire part

Table 1
AISI 316 L chemical composition (wt%).

Composition	C	Mn	P	S	Si	Cr	Ni	Mo	Other
AISI 316 L	0.02	0.18	≤ 0.045	≤ 0.015	0.83	17	12.75	2.15	≤ 0.11