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Corrosion effects on mechanical properties of sintered stainless steels

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Abstract

This paper aims to analyse the effects of corrosion atmosphere on sintered stainless-steel specimens. In particular, it is intended to assess a relation existing between weight and corrosion resistance, density and corrosion resistance, tensile properties and corrosion resistance. Three groups of sintered stainless steels were studied. They differ, one from each other, for the laser power and for the speed scanning. For each group, nine specimens were made up. For all of them, measurements of both weight and density were carried out. One specimen of them was tested, as received, according to the tensile standard for metallic materials. Eight specimens for each class were placed in corrosive atmosphere in conducting the neutral salt spray (NSS) tests for assessment of the corrosion resistance of metallic materials. Four different periods of exposure were defined. At the end of each test period, two specimens were removed from the cabinet. Visual observations, measurements of mass loss, density variations and tensile tests was carried out on all the specimens referring to the specific exposure time, in order to evaluate and record all the changes referring to the specific conditions they were subjected to.

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Keywords: Corrosion atmosphere; Neutral salt spray; Powder metallurgy; 316L stainless steel; Selective laser melting;

1. Introduction

High corrosion resistance, good visual aspect and good formability favored the use of stainless steels in several engineering fields, not only in mechanical industry but also in the building one (Bellezze et al. 2005). In particular, stainless steel powder metallurgy process has numerous advantages to fabricate small pieces of complex shapes,

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because it allows energy and material savings as well as dimensional accuracy. Sintered stainless steels have a wide range of applications, mainly related to the automotive industry but also related to biomedical field (Raza et al. 2017). However, they present lower properties than their wrought counter-parts in terms of corrosion and wear resistance. The main reason for this lower performance is the presence of porosity that could change the performance of material especially if exposed to corrosive environments. Many studies are carried out on corrosion behavior of such materials but all of them referring to immersion of components in corrosive solution and successively drying in air (Vera Cruz et al. 1998). Scientific literature investigates this problem but only in studying the relation existing between corrosion resistance of stainless steels and their surface finishing (Burstein and Pistorius 1995, Coates 1990), the combined action due to the presence of atmosphere contaminants as Cl and SO_2 ions (Johnson 1982, Rosenfeld 1972, Ambler 1970) and the role played by the presence of non-metallic inclusions (Asami and Haschimoto 1979, Manning 1979). Commonly corrosion resistance is related to roughness; more specifically, with a lower roughness the stainless steel shows a higher pitting potential (Burstein and Pistorius 1995, Coates 1990). A stainless steel characterized by a good surface finishing in terms of low roughness of material, could be considered as a steel with good corrosion behavior too. Indeed, the roughness is not always a guarantee of high resistance, since, in some cases, it can be verified that steels with the same roughness gives deep differences in corrosion response (Nishimura 1997).

This paper studies the effects of corrosive atmosphere on mechanical properties of powder metallurgy 316L stainless steel sintered by selective laser melting. Many different criteria for the evaluation of the test results may be applied to meet specific requirements. The aim of this work is to evaluate changing in terms of tensile properties, appearance after corrosion exposure, mass loss, and changing in density. Three groups of sintered stainless steels have been analysed. They differ, one from each other, for the laser power and for the speed scanning. For each class, 9 specimens were made up. For all of them, measurements of both weight and density were carried out. One specimen of them was tested, *as received*, according to the tensile standard for metallic materials (ASTM E 8M 2004). Eight specimens for each class were placed in corrosive atmosphere in conducting the neutral salt spray (NSS) tests for assessment of the corrosion resistance of metallic materials.

Four different periods of exposure were defined, choosing among the recommended standard periods: 24 h, 96 h, 168 h and 240 h (DIN EN ISO 9227 2006). A periodic visual examination of specimens under tests for a predetermined period was made, but the surfaces under test was not disturbed, and the period for which the cabinet is open was the minimum necessary to observe and record any visible changes. At the end of each test period, two specimens were removed from the cabinet. The test specimens removed were leaved at environmental conditions to allow them to dry for 0,5 h to 1 h before cleaning, in order to reduce the risk of removing corrosion products. Before they were examined, the residues of spray solution from their surfaces were carefully removed.

Visual observations, measurements of mass loss, density variations and tensile tests were carried out on all the specimens belonging to the specific exposure time, in order to evaluate and record all the changes referring to the specific conditions they were subjected to.

2. Material and methods

Twenty-seven specimens were made up by using selective laser melting technique on 316L stainless steel powder metallurgy. They were divided into three groups having different values of laser power and speed scanning. Table 1 reports the sintered process parameters for each group.

Table 1. Sintered process parameters.

# Group	Laser Power [W]	Speed Scanning [mm/sec]
1	100	200
2	56,5	200
3	85	300

Visual aspect observation of specimens didn't show great differences between group 1 and group 3; group 2 seems to have more defects on surface probably due to the combination of lowest laser power and lowest speed scanning.

Fig. 1. Surface aspects of specimen for each group: form left to right group 1, 2 and 3.

Specimens were built according to ASTM E 8M (2004) standard. Their shape and sizes are reported in Figure 2.

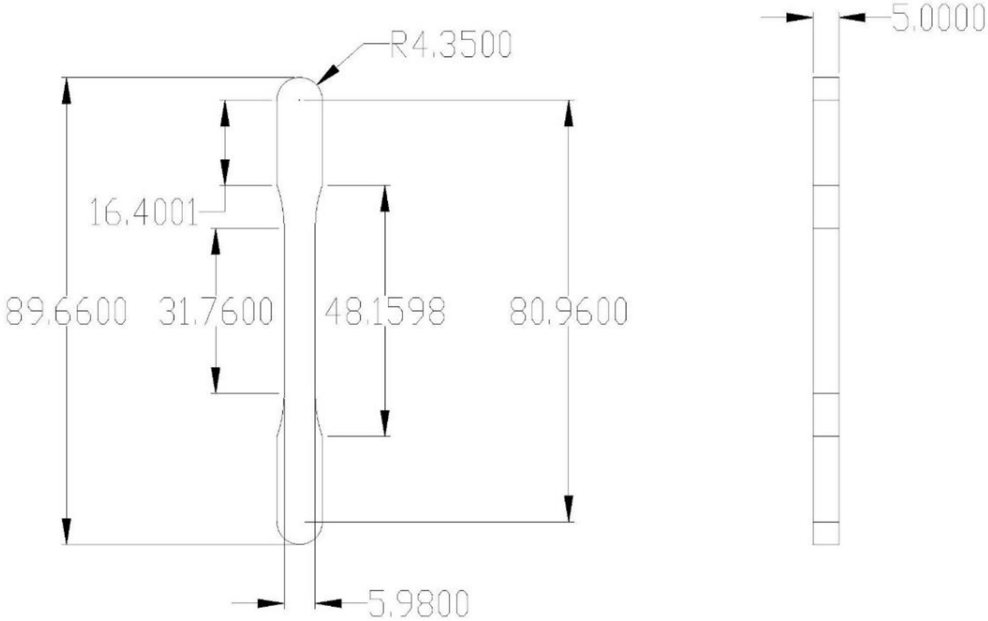

Fig. 2. Shape and sizes of specimen according to ASTM E 8M (2004)

Weight and density were measured on all specimens *as received*. Then one specimen for each group was subjected to a tensile test in order to obtain information on starting mechanical properties. The remaining part of each group's specimens were placed on corrosive atmosphere in conducting the neutral salt spray tests. They were subjected to corrosion cycles according to DIN EN ISO 9227 (2006). Four different periods of exposure were defined, choosing among the recommended ones: 24 h, 96 h, 168 h and 240 h. A periodic visual examination of specimens under tests for a predetermined period was made, but the surfaces under test was not disturbed, and the period for which the cabinet is open was the minimum necessary to observe and record any visible changes. At the end of each test period, two specimens of each group were removed from the cabinet. The test specimens removed were leaved at environmental conditions to allow them to dry for 0,5 h to 1 h before cleaning, in order to reduce the risk of removing corrosion products. Before they were examined, the residues of spray solution from their surfaces were carefully removed.

3. Results and analysis

Before tensile tests, both weight and density were evaluated for all the specimens subjected to corrosion tests. Visual observations of the specimens not highlights substantially changes in surface. Tables 2, 3 and 4 show the results obtained. For each specimen only the mean value of three replications was indicated. The "As received" columns report both the starting weight and density values of all the specimen. As it is expected, higher laser powers correspond to higher density values.

Table 2. Loss mass evaluation group 1 specimens.

		As received		NSS	
	Corrosion atmosphere [h]	Weight [g]	Density [g/cm³]	Weight [g]	Density [g/cm³]
1_1	0 h	17,03	7,88		
1_2	24 h	17,01	7,87	17,01	7,88
1_3		17,31	7,89	17,30	7,92
1_4	96 h	17,05	7,91	17,03	7,94
1_5		17,44	7,88	17,43	7,92
1_6	168 h	17,03	7,92	17,02	7,93
1_7		16,95	7,88	16,96	7,76
1_8	240 h	17,28	7,85	17,27	7,88
1_9		17,26	7,86	17,24	7,90
MEAN VALUE		17,15	7,88	17,16	7,89
STD DEV		0,17	0,02	0,17	0,06

Table 3. Loss mass evaluation group 2 specimens.

		As received		NSS	
	Corrosion atmosphere [h]	Weight [g]	Density [g/cm³]	Weight [g]	Density [g/cm³]
2_1	0 h	14,00	7,37		
2_2	24 h	14,03	7,40	14,28	6,74
2_3		13,67	6,57	13,38	6,15
2_4	96 h	14,01	7,25	14,13	6,65
2_5		14,09	7,08	14,10	6,52
2_6	168 h	14,08	7,22	14,10	6,66
2_7		14,14	7,45	14,16	6,58
2_8	240 h	14,09	7,32	14,11	6,62
2_9		13,89	6,97	14,14	6,24
MEAN		14,00	7,18	14,05	6,52
STD DEV		0,14	0,28	0,28	0,21

Table 4. Loss mass evaluation group 3 specimens.

		As received		NSS	
	Corrosion atmosphere [h]	Weight [g]	Density [g/cm³]	Weight [g]	Density [g/cm³]
3_1	0 h	16,70	7,61		
3_2	24 h	16,84	7,60	16,54	7,68
3_3		16,71	7,65	15,64	6,95
3_4	96 h	16,44	7,60	16,42	7,71
3_5		16,73	7,66	16,44	7,63
3_6	168 h	16,14	7,45	16,38	7,69
3_7		16,38	7,65	16,73	7,68
3_8	240 h	16,42	7,68	16,86	7,40
3_9		16,54	7,64	16,72	7,68
MEAN		**16,55**	**7,62**	**16,47**	**7,55**
STD DEV		**0,22**	**0,07**	**0,38**	**0,26**

Looking at the mean values and at the standard deviation values, group 1 seems not to be affected by none of the corrosion atmosphere periods. On the other hand, looking at group 2 it results that no variations could be considered for weight, but a 9.2 % of density reduction for global corrosion periods must to be accounted. A similar trend is observed for group 3 for which a slightly weight reduction is combined too. This attitude could be justified by observing the surface finishing of group 2 that is affected by more porosity defects than the other groups. This trend is quite limited for group 3 due to the medium value of laser power that, according to the scientific literature (Vera Cruz et al. 1998), create an intermediate state of surface finishing.

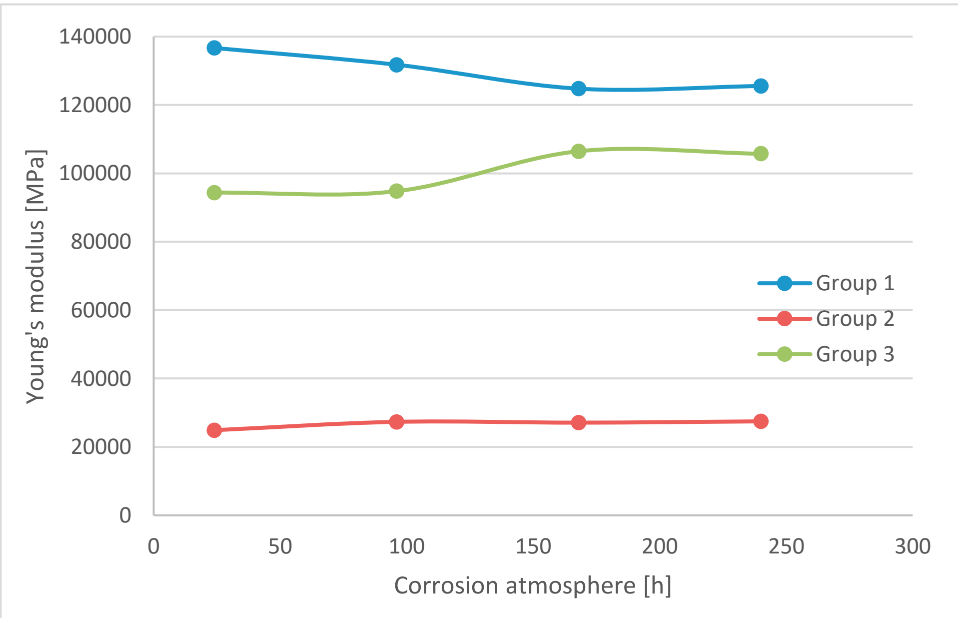

Fig. 3. Young modulus trend of each group as function of periods in corrosion chamber.

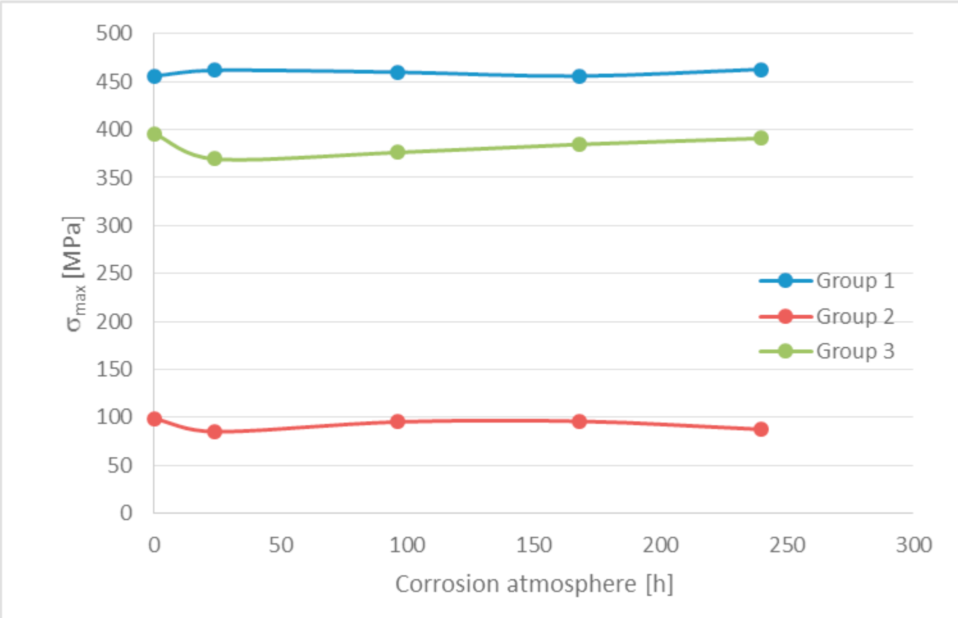

Fig. 4. Maximum stress trend of each group as function of periods in corrosion chamber.

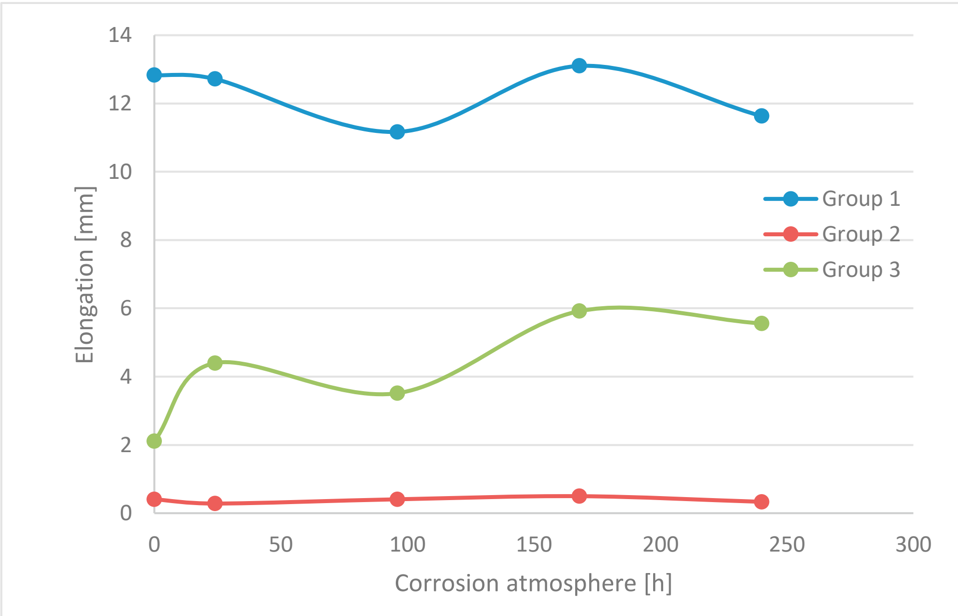

Fig. 5. Elongation trend of each group as function of periods in corrosion chamber.

Figures 3, 4 and 5 report the trend of three mechanical parameters of all specimens of the three groups: Young's modulus, maximum stress and elongation.

It is possible to observe that both Young's modulus and maximum stress, whose mean values are quite different among the groups at the same periods, seems not to be affected by the corrosion atmosphere at least referring to the periods analyzed. Probably longer periods in conducting the neutral salt spray (NSS) conditions could carry on at more spread results. It is obvious to asses that these mechanical properties are higher if the laser power reaches higher values.

Finally, looking at the elongation values it seems that only group 3 is affected in some way by the corrosion atmosphere that seems to increase the total elongation. Groups 1 and 2, characterized by lower speed scanning, show a behavior quite constant to all the periods.

4. Conclusions

In this paper, the analysis of the effects of corrosion atmosphere on 316L sintered stainless-steel specimens was analyzed. It results that different process parameters, as laser power and speed scanning, differently affect the corrosion response of materials. In particular, weight, Young's modulus and maximum strength seems not to be affected in any way. On the other hand density and elongation present a variation respectively for group 2 with more porosity than the other groups, and for group 3 characterized by higher speed scanning.

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