Lasers in Manufacturing Conference 2017

Study of resistance of stainless steels manufactured by selective laser melting to pitting and crevice corrosion

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Abstract

Pitting and crevice corrosion resistance of martensitic (AISI 410L) and austenitic (AISI 316L) stainless steels manufactured by selective laser melting was studied. Corrosion resistance was evaluated by ASTM G 48 test method with 10% $FeCl_3 \cdot 6H_2O$ solution.
Unusual increase of stainless steels tendency to pitting and crevice corrosion was revealed after surface machining of specimen, probably because of removing of dense surface layer and the subsurface pores opening. There is shown that heat treatment reduced negative influence of surface machining by dissolving chromium carbides. As a result, corrosion losses are decreased and pitting amount reduce is observed.

Keywords: stainless steel, selective laser melting, pitting corrosion, crevice corrosion;

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1. Introduce

The laser technology is efficiently for metal surfacing and welding as well as metal production without machining. In this respect, additive techniques are more promising especially selective laser melting (SLM) [1]. SLM enables to receive compound configuration products from alloy and steel powders, including stainless steel powder, with required service properties and chemical composition without additional manufacturing operations. At the same time, taking into account the possible application of metal powder production for marine construction, corrosion resistance is the most important characteristic of the material, particularly stainless steels resistance to pitting and crevice corrosion in chloride solutions.

It is known that high corrosion resistance of stainless steels is obtained by the chromium and molybdenum alloying, heat treatment that promotes the alloying elements dissolving into solid solution and surface machining that decreases the roughness and thus the possibility of condensation of moisture and accumulation of electrolyte [2]. However, these regularities are established for the conventional manufactured steels. The SLM specimen corrosion resistance has not yet been fully studied. Therefore, the goals of this work were study of the resistance to pitting and crevice corrosion of SLM specimens of two widely used martensitic and austenitic stainless steel grades AISI 410L and AISI 316L and determination of the influence of SLM modes, specifically laser beam speed, as well as heat treatment and machining on corrosion resistance.

2. Experimental

2.1. Material

A test specimens 2,5 by 30 by 50 mm were made of powders by selective laser melting in protective nitrogen atmosphere by EOSintM270. A power of solid-state laser beam was equal to 190 watt. The scan rate laser beam for AISI 410L was selected 650 and 800 mm/sec, for AISI 316L – 800mm/sec. The powders of stainless steel AISI 316L and AISI 410L (produced by Höganas) were used as source material. The grain-size powder composition that is in the range 20 – 50 µm was determinated by dynamic light scattering analyzer Mastersizer 2000. An applying powder layer thickness was 40 µm.

Presented in table 1 chemical composition of specimen manufactured by selective laser melting stainless steels was detected by X-ray fluorescence (XRF) spectrometer NitonXLT and by carbon/sulfur analyzer LECO CS-230 and TC-500.

Table 1. Chemical composition of the studied stainless steels, %

Steel grade	C	Cr	Ni	Mn	Mo	N	O	S
AISI 410L	0,02	12,5	0,8	0,8	-	-	-	0,025
AISI 316L	0,025	16,9	13,0	1,6	2,6	0,05	0,092	0,0045

2.2. Heat treatment and machining

The specimens of austenitic stainless steel AISI 316L were studied in 3 conditions:
1 – in the initial state, after SLM;
2 – SLM specimens were machined;
3 - SLM specimens were solution-treated at 1100-1150°C for 30 minutes, and then water quenched. After the heat treating dross was removed by machining.

The specimens of martensitic stainless steel AISI 410L were solution-treated at 1000°C for 1 h, then were cooled in oil, after that tempering was carried out at 700°C for 1 h and then specimens were cooled in oil. After the heat treating dross was removed by machining too.

2.3. Corrosion test

The pitting and crevice corrosion resistance was evaluated by the standard ASTM G 48 test method that consists in immersion of SLM specimens 2,5 by 30 by 50 mm in 10% $FeCl_3 \cdot 6H_2O$ solution and determination weight loss. The AISI 410L specimens were exposed at 22°C for 24 h and the AISI 316L specimens were tested at 60°C for 5 h.

2.4. Microstructure research

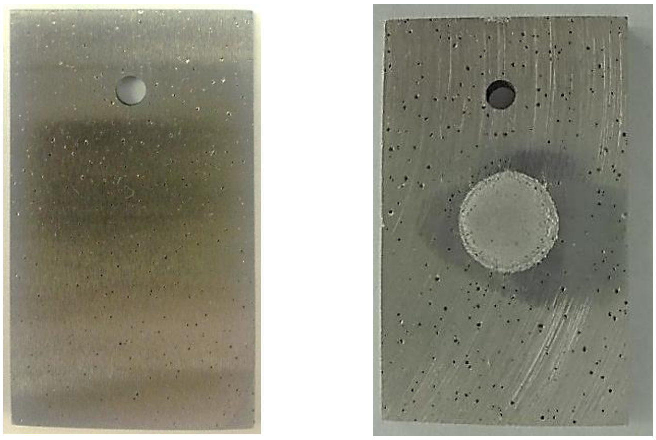
The specimens exposed in corrosive environment were prepared for microstructure research by light microscope Leica DM 3 with electrochemical etching in a 10% water solution of oxalic acid.

Study of corrosion damages was carried out by scanning electron microscope TescanVega 3 SBH.

3. Results and discussion

3.1. Machining influence study

The heat treated AISI 316 L steel specimens form is shown in Fig. 1a and Fig. 1b. There are many pits on the specimen surface, except the sites where the TFE-fluorocarbon washers are installed and crevice corrosion are developed. The most intensive crevice corrosion is observed along the added washer contour (Fig 1b). There is a similar type of corrosion damage for all SLM-specimens of the studied steels.



a b

Fig. 1. The common view of the heat treated AISI 316 L steel specimens tested to pitting (a) and crevice (b) corrosion

Figure 2 shows the influence of heat treatment and machining of the AISI 316L SLM-steel specimens on the weight loss of pitting and crevice corrosion.

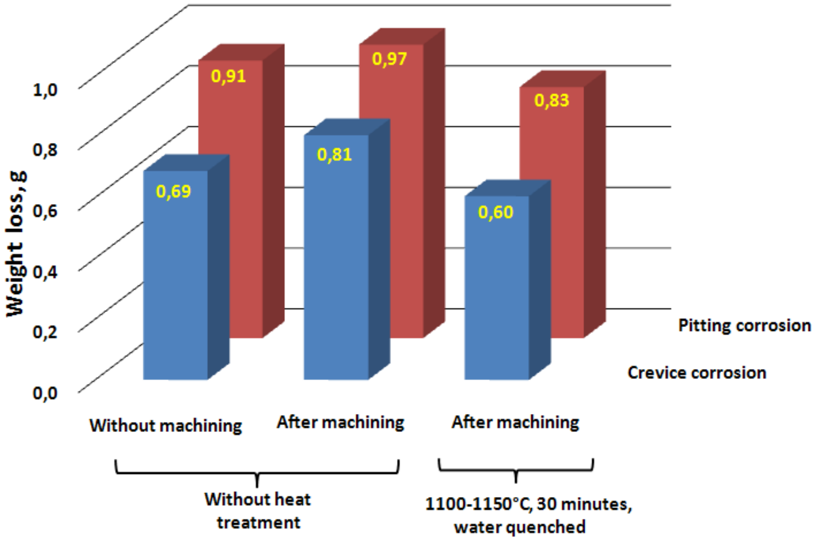
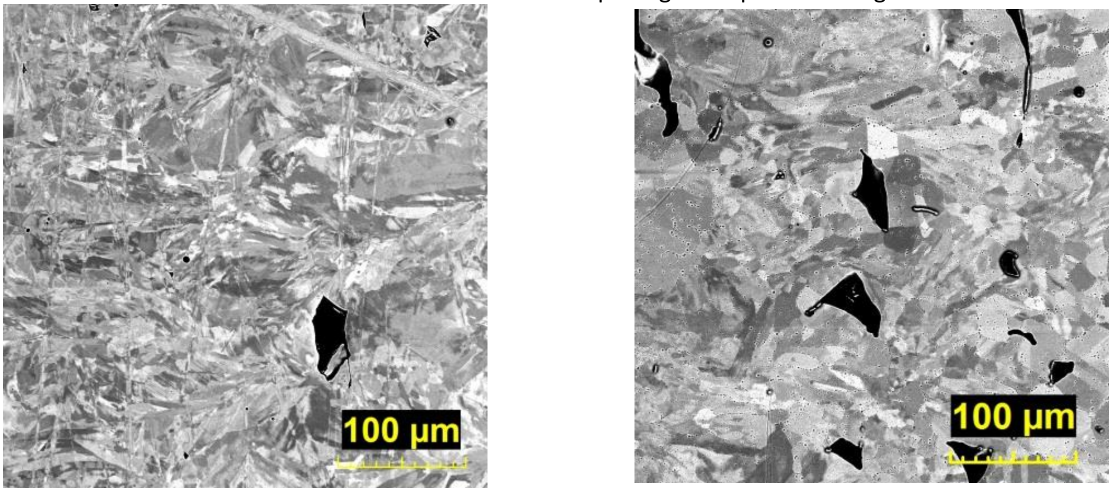


Fig. 2. Influence of additional treatments of the AISI 316L SLM-steel specimens on the weight loss of pitting and crevice corrosion (10% $FeCl_3 \cdot 6H_2O$ at 60 °C for 5 h)

Corrosion tests of the initial SLM state of AISI 316L steel was revealed the negative effect of machining on the resistance to pitting and crevice corrosion. After surface machining the weight loss increased by 6 and 12% during pitting and crevice corrosion tests respectively (Fig 2). This fact contradicts the results of conventional stainless steels tests, when the presence of a ground surface allows to increase the corrosion resistance. It can be explained by the feature of the SLM specimens' construction. At first, the solid-state laser beam courses for fusion the specimen contour and the powder inside the specimen contour, then the laser beam passes the contour second time. At the same time, the pores are presented in the inner volume SLM specimens (Fig. 3).

Thus, the outer layer obtains denser compared to inner structure. The denser layer removal by machining leads to decreases the corrosion resistance that because of opening inner pores coming out.



a b

Fig. 3. Microstructure of AISI 316L steel before (a) and after heat treatment (austenitization) (b)

3.2. Investigation of the effect of heat treatment

The machining specimens tests have shown positive effect of austenitization on corrosion resistance.

It is known that for conventional stainless steels, an increase of resistance to pitting and crevice corrosion is possible due to alloying with chromium, molybdenum and nitrogen. Their influence on the steel corrosion resistance is expressed in the well-known formula for calculating the pitting resistance equivalent [3]

$$PRE = \%Cr + 3{,}3 \cdot \%Mo + 16 \cdot \%N \quad (1)$$

For steel AISI 316L PRE is 26 units, but it is necessary to take into account that the positive influence of Cr and Mo, included in the chemical composition of this steel grade, is possible only when these elements are in a solid solution. It was found (Fig. 2) that the heat treatment (in this case, austenitization) of the AISI 316L steel SLM-specimens tends to 20 - 25% decrease in the rate of pitting and crevice corrosion. The beneficial effect of high-temperature solution annealing followed by quenching is related to the formation of an equiaxed austenitic structure without carbides and nitrides precipitations [4]. Metallographic studies have confirmed the obtaining of a homogenous structure of AISI 316L steel after heat treatment (Fig. 3).

Similar results of the heat treatment influence on the structure were obtained by the authors of [5] in the study of aluminum alloys specimens manufactured by the SLM method. In [6] the useful effect of heat treatment obtained by the SLM method was explained by the elimination of microsegregations and chromium carbides inherent to the initial cast structure.

It is shown that the change in the steel microstructure affects the form of the corrosion relief obtained during the crevice corrosion tests. Specimens without austenitization have corrosion cracks at the point of contact with the TFE-fluorocarbon washer imitating the crevice (Figs 4a-c), while heat-treated specimens show a crevice groove as caverns, pits (Figure 4d -e).

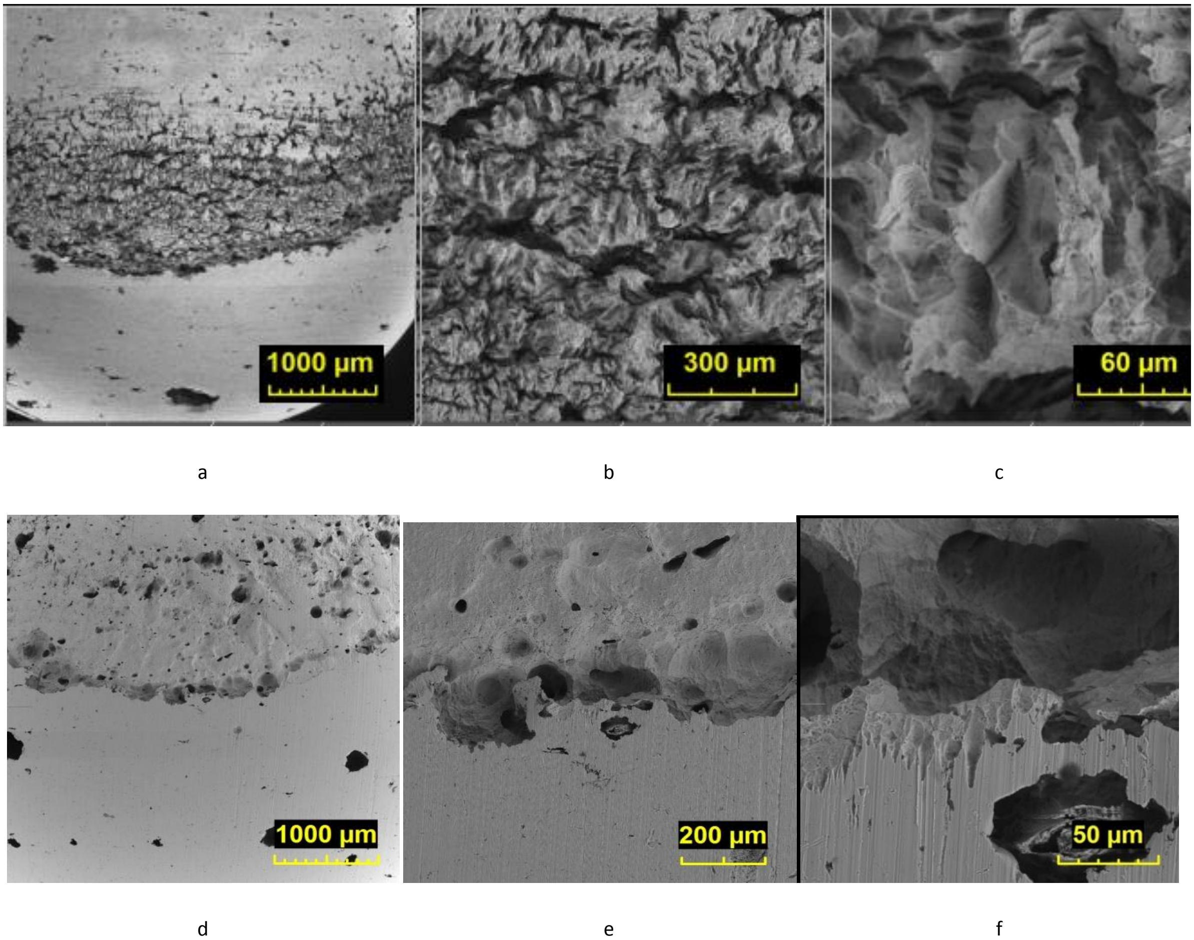


Fig. 4. Crevice corrosion on the surface of machined specimens of AISI 316L steel without (a-c) and after (d-f) heat treatment (austenitization)

3.3. Investigation of the SLM laser beam speed influence

The influence of the technological parameter as the laser beam speed on the tendency to pitting and crevice corrosion was investigated on specimens of heat treated AISI 410L steel (quenching and tempering inherent for martensitic steels) and mechanical dross removing.

Considering that this steel grade is less chromium-alloyed and have no molybdenum alloying (PRE = 13), corrosion tests were carried out at room temperature. However, this has not prevented the occurrence of general corrosion simultaneously with pitting and crevice corrosion.

The test results demonstrated weight loss increase in pitting and crevice corrosion with the speed up of laser beam movement in the production of AISI 410L SLM specimens (Fig. 5).

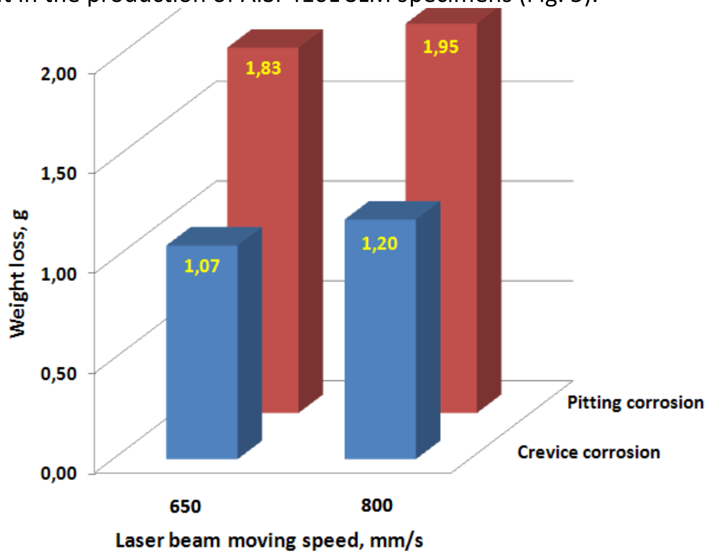


Fig. 5. Influence of the laser beam moving speed in the manufactured of AISI 410L steel SLM-specimens on weight losses during the pitting and crevice corrosion in 10% $FeCl_3 \cdot 6H_2O$ solution at 22 ° C for 24 hours

Comparison of the weight loss values (Fig. 5) with the metallographic analysis (Fig. 6), shows the correlation between number of defects, incl. non-melted areas, pores and corrosion resistance. The lowest corrosion resistance is observed for specimens produced with higher laser speed - 800 mm/s. At the same time, increased content of pores is inherent to the material (Figure 6c, d). Assumedly, these defects have been induced by the rapid movement of the laser beam. With that, the presence of high pore density enables the local corrosion process because of repassivation process prevention in the near-surface SLM-metal microvolumes. Decreasing the speed of the surface laser scanning to 650 mm / s can reduce the number of defects inside the specimen (Fig. 6, a, b), and thereby reduce corrosion losses (Fig. 5).

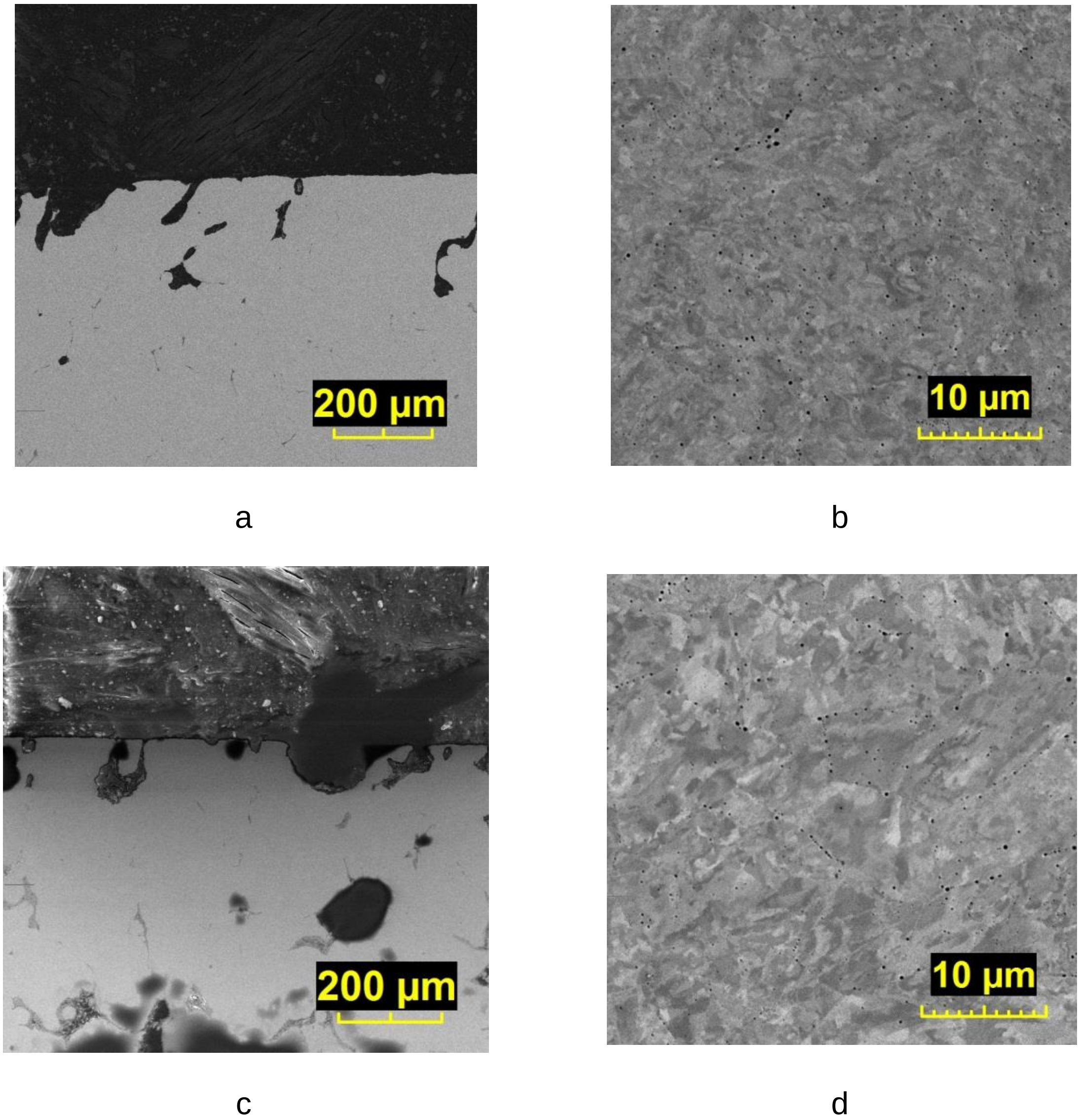


Fig. 6. Microstructure of AISI 410L SLM specimens obtained at a laser beam moving speed 650 mm / s (a, b) and 800 mm / s (c, d). The thin section cut from the metal volume (a, c) and from the surface (b, d)

4. Conclusions

It is shown that high resistance to pitting and crevice corrosion of stainless steels manufactured by selective laser melting can be obtained by:

- the porosity minimization of the SLM specimens due to the laser scanning speed and machining optimization;
- heat treatment of stainless steel, transferring the alloying elements into a solid solution.

Acknowledgments

The authors gratefully acknowledge support from the Russian Science Foundation, grant № 15-19-00210. Studies were carried out on equipments of common use center of CRISM "Prometey".

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