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Laser surface alloying of 316L stainless steel: different hardening routes and related microstructures

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Abstract The goal of this study is to investigate different hardening routes for 316L stainless steel by laser surface alloying. We have investigated the incorporation of hard submicronic particles of TiC, the precipitation of titanium carbide from mixtures of Ti and SiC and the formation of iron-chromium carbides by carbon incorporation. For each hardening route we present the microstructure and the hardness of the processed surface alloys and the conditions leading to the best compromise between highest hardness, best homogeneity and lowest occurrence of cracks. From these results it can be reasoned that hardening by iron-chromium carbides is the best route and that this surface alloy is a good candidate for some tribological applications.

I. INTRODUCTION

The more traditional way for improving or altering the surface properties of solids involves the deposition of films and coatings from solid, liquid and vapor sources. A more recent approach is based on the modification of existing surfaces using directed energy sources such as lasers [1-2]. We focus this study on laser-surface alloying of 316L stainless steel. This process consists of melting the surface of the base alloy with known amounts of predeposited materials. The 316L austenitic stainless steel is widely used owing to its high corrosion resistance, but, due to its low hardness (200 HV), its tribological properties are very poor. Moreover, because of its austenitic structure, it cannot be hardened by heat treatment and therefore there is no easy means for improving its wear resistance. Different hardening routes for the 316L austenitic stainless steel using laser alloying were investigated, (i) formation of iron-chromium carbides by carbon and SiC incorporation, (ii) incorporation of submicronic particles of TiC, (iii) precipitation of titanium carbides.

II. RESULTS

The substrate material used for the experiments was the austenitic stainless steel 316L. The samples, about 5 mm thick were mechanically polished before laser irradiation. The different powders, TiC, SiC, Ti + SiC and C were deposited onto the surface. Surface alloying was carried out using a 300 W continuous wave Nd-YAG laser with argon as a shielding gas to prevent oxidation. The beam was guided by an optical fiber to give a circular spot of 950 μm in diameter leading to a maximum power density of 4.10^8 W/m^2 . The criteria for determining the quality of the coatings were a compromise between highest hardness, best homogeneity and lowest occurrence of cracks.

SiC alloying

X-ray diffraction analysis showed that the surface alloy is composed of austenite (γ) and M_7C_3 carbides ($\text{M} = \text{Fe}, \text{Cr}$). It is thought that the high temperatures (superior to 3000°C)

reached during the treatment lead to the decomposition of SiC in silicon and carbon. During the solidification, silicon, and maybe some amounts of carbon dissolve in austenite, the remaining carbon leading to carbide precipitation. A micrograph of the laser alloyed region (about 150 μm thick) is illustrated in fig. 1. The structure consists of primary austenite cells or dendrites surrounded by a fine eutectic containing M_7C_3 carbides. Microhardness measurements revealed a mean value of 500-600 HV in the melted area. With the process parameters used, the surface alloy is crack-free. For higher surface coverages cracks are frequently observed due to the formation of a much harder (1000 HV) but brittle phase.

Carbon alloying

In order to complete our understanding on the role of the carbon in the hardening of 316L stainless steel, we have focussed our attention on the incorporation of carbon alone. X-ray diffraction analysis revealed the presence of austenite (γ) and carbides M_7C_3 ($\text{M} = \text{Cr}, \text{Fe}$). Figure 2 shows the microstructure of the alloyed layer. The periphery of the tracks exhibits a dendritic (γ) microstructure leading to an averaged microhardness of 400 HV, whereas the top center of the tracks displays a higher microhardness (650 HV) : the related structure still couldn't be observed by SEM, but it was interpreted as an eutectic austenite-carbides. The concentration of carbon in the supposed eutectic area, measured by EPMA is about 3.0 wt%.

TiC submicronic particles alloying

X-ray diffraction analysis showed the presence of TiC and austenite (γ) within the alloyed layer. The alloyed layer appears to be crack-free, but heterogeneous. Some large clusters of TiC, from 10 to 50 μm in size are distributed within the alloy. Outside these areas, the alloyed layer exhibits a regular microstructure (fig 3) composed of austenite grains (dendrites) with TiC located in the interdendritic spacings. Some faceted crystals of TiC, about 1 μm in size, are also present, regularly distributed within the alloyed layer. This microstructure exhibits only a slight increase in microhardness (about 280HV).

Ti + SiC alloying

Laser alloying of 316L stainless steel with a mixture of titanium and SiC was planned because, in one hand, laser alloying with submicronic TiC particles had lead to the formation of TiC aggregates irregularly dispersed in the resulting surface alloy; on the other hand, when using SiC, our observations have shown that SiC was totally dissociated into Si and C during laser melting. Therefore, laser melting of a Ti + SiC coating appeared as an interesting route to obtain a surface alloy enriched in silicon for corrosion applications [2], and strengthened by hard TiC precipitates resulting from the carburization of Ti. The different phases detected by X-ray diffraction are austenite (γ), TiC and ferrite (α). The formation of ferrite is the result of the presence of silicon which is ferrite former. A regular dispersion of fine TiC precipitates, about 0.5 to 1 μm in diameter was evidenced by SEM (fig. 4). The average microhardness of the surface alloy fluctuates between 350 HV and 700 HV.

III. CONCLUSION

We have shown that 316L austenitic stainless steel can be hardened by laser surface alloying. The tribological and hot corrosion properties of these coatings will be characterized.

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Fig. 1 : SEM photomicrograph of a 316L - SiC sample showing the dendritic microstructure (surface coverage = 5.5 mg/cm^2 , $P = 200 \text{ W}$, $v = 10 \text{ mm/s}$)

Fig. 2 : SEM photomicrograph of a 316L - C sample showing the dendritic and eutectic microstructures (surface coverage = 5 mg/cm^2 , $P = 200 \text{ W}$, $v = 5 \text{ mm/s}$); concentration of C in the eutectic region (measured by EPMA) : about 3 wt%.

Fig. 3 : Backscattered electron image of a 316L - TiC sample showing the microstructure outside the aggregates (surface coverage = 15 mg/cm² in 5 times, P = 200 W, v = 10 mm/s); concentration of TiC (measured by EPMA) : 3.5 wt%.

Fig. 4 : Backscattered electron image of a 316L - Ti+SiC sample (surface coverage = 7.5 mg/cm² P = 200 W, v = 5 mm/s); concentration of TiC (measured by EPMA) : about 8 wt%.