THE INFLUENCE OF THE LASER SURFACE MELTING PARAMETERS (LSM) ON THE STRUCTURE AND MICROHARDNESS OF THE 316L AUSTENITIC STAINLESS STEEL

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Îmbunătățirii caracteristicilor de exploatare ale oțelurilor inoxidabile austenitice printr-un tratament termic executat cu fascicul laser (LSM) a apărut în urma lărgirii domeniului de aplicabilitate al acestor oțeluri şi necesității unor proprietăți superficiale superioare. LSM prezintă interes industrial în special pentru materialele ce nu pot fi durificate prin transformarea martensitei, precum unele oțeluri inoxidabile.

Pentru tratamentul LSM s-a folosit un laser cu CO_2, în undă continuă şi diametrul fasciculului de 3mm. S-a urmărit studierea influenței vitezei de deplasare a probei în condițiile iradierii cu un fascicul laser de putere 800W asupra caracteristicilor oțelului 316L. Pentru evitarea fenomenelor de supraîncalzire probele au fost răcite în azot lichid.

Microstructurile în secțiuni transversale ale probelor iradiate au fost analizate prin microscopie optică şi microscopie electronică scannig. Au fost determinate microdurităţile straturilor prin metoda Vickers $HV_{0,02}$. Au fost studiate transformările de fază în condițiile răcirii ultrarapide.

The improvement of the performances of the austenitic stainless steels by using a laser heat treatment (LSM) started as a result of the field increasing of applications and necessity of improving the surface characteristics of these materials. LSM presents interest from industrial view point especially as a material that can't be hardened by martensitic transformation.

A CO_2 laser with 3mm beam diameter, operating in continuous wave has been used for the LSM treatment. The goal of this paper was to investigate the influence of the velocity of the sample movement on the characteristics of the 316 austenitic stainless steel irradiated with a 800W laser beam. To avoid the overheating phenomena the samples were cooled in liquid nitrogen.

Cross section microstructures of the irradiated samples were investigated by optical and scanning electron microscopy. The microhardness of the layers was determined by the Vickers method at 20 g indentation load. The effects of rapid cooling on the phase transformation were also investigated.

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1. Introduction

Superficial treatments using laser beam allows the improvement of surface properties of materials in circumstances of preserving the structure and properties of the core material. The surface treatments are intended to reduce the costs required by the replacement or repair of mechanical parts.

Laser surface hardening through surface meltig is just a method used for surface modification of the materials without affecting the chemical composition. This treatment implies the melting of the surface of the material by using a focussed beam. Using this procedure one can obtain fine homogeneous structures due to the rapid solidification rates, little thermal penetration, resulting in little distorsion, smootth surfaces, reducing work after processing, process flexibility, due to software control and possibilities in automation. Laser beam hardening can be used for materials that cannot be hardened by martensitic transformation, and a potential application is the hardening of stainless steels [5, 6, 7].

According to recent studies compared with other surface treatments laser surface melting leads to an increase of the wear resistance and to a lower fatigue resistance due to a high level of internal stress induced. A deep understanding of the metallurgical processes involved are necessary when a laser processing method is to be chosen or the processing parameters are to be selected [1-3, 5-8].

2. Experimental procedure

Discs made of annealed austenitic stainless steel AISI 316L, 10 mm in diameter and 15mm thick were used as samples. The chemical composition of the AISI 316L stainless steel is presented in Table 1.

Table 1

Chemical composition of the AISI 316L stainless steel

C	CR	NI	MO	SI	S	P	MN	TI	CU	NB	AL	FE
0,0348	18,12	13,09	2,7	0,51	0,004	0,0033	0,84	0,0095	0,21	0,04	0,024	balance

Laser surface melting was performed by using a continuous CO_2 laser beam, operating at a power of 800W. During the treatment the samples were moved with different velocities. Three different velocities of 5, 7.5 and 10 mm/s were selected for the investigations.

The samples were cooled in liquid nitrogen during the treatment in order to avoid the overheating. The sample was mounted in a special position in such a manner that the nitrogen was in contact with a large surface of the sample.

From a technical view point, the most significant characteristics of the melted layer are the depth of hardening and the microhardness values. These

characteristics, for a certain material, are correlated with the laser beam parameters and the structural transformations.

The cross section microstructures of the treated samples were investigated by optical and scanning electron microscopy. The hardness of the layers was determined by the Vickers method at 20g indentation load. The phase transformations were also investigated during the rapid cooling process.

3. Results and Discussion

The metallographic investigations performed on samples resulted from a cross section through the melted layer followed by a metallographic etching with 1:3 HNO_3-HCl reagent, allowed a qualitative and quantitative analysis of the layers. The depth of the hardened layer depends on the velocity of the samples, and this dependence was plotted in figure 1.

The microhardness, as determined by Vickers method at load of 20g, was 204 $\mu HV_{0.02}$ for the 316L steel in the initial state.

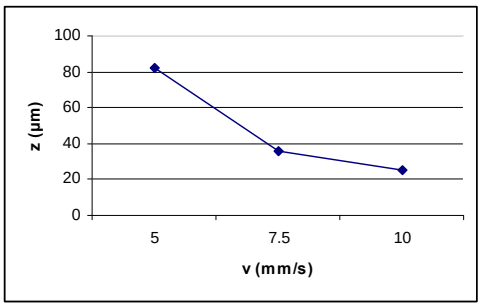


Fig. 1 The dependence of the depth of the melted layer z with the velocity of the sample

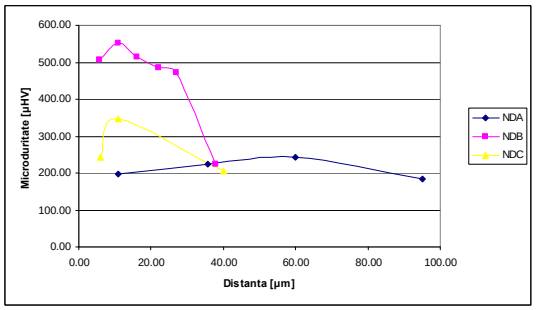


Fig. 2. The evolution of the microhardness with the depth of the melted layer (beam power 800W, sample velocities of: 5mm/s (NDA), 7.5mm/s (NDB) and 10mm/s (NDC)

The distribution of the microhardness with the thickness of the melted layer (Fig.2) presents a decreasing tendency; the slope of the curve becomes steeper with increasing the speed.

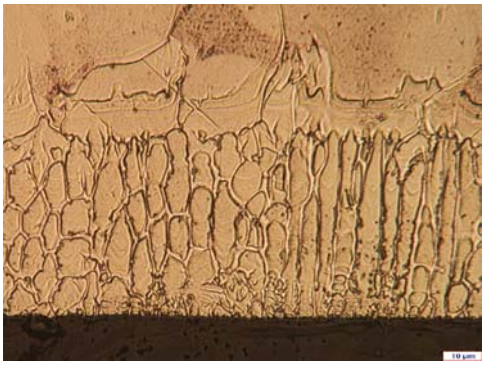


Fig.3. Optical micrograph of the structure of the melted layer
(beam power 800W, sample velocity: 5mm/s (NDA))

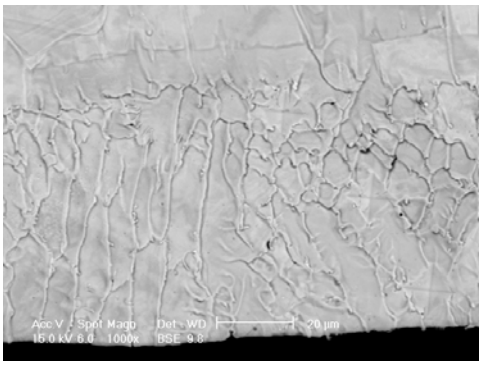
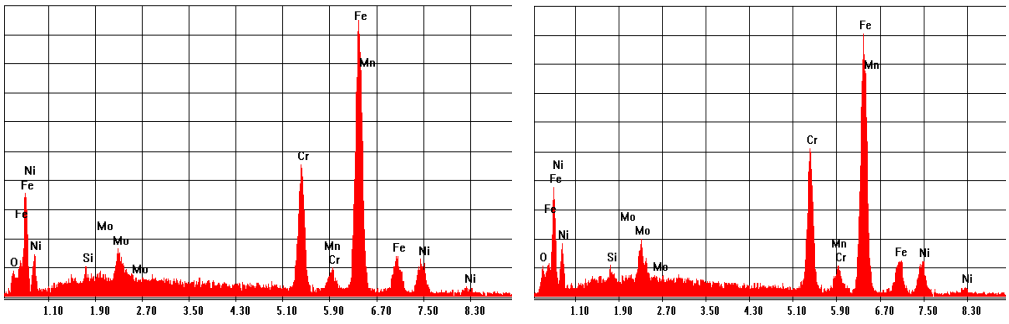


Fig.4. Scanning electron micrograpf of the melted layer for the NDA sample

In general, raising the speed of the sample movement during the treatment leads to an increase of the measured microhardness. Exceptions from this rule have been observed when the treatment was performed at a sample velocity of 7.5mm, situation when the highest microhardness values were obtained.

The microstructures of the laser melted layers resulted after a single pass of the laser beam showed a dendritic structure, perpendicular on the main region corresponding to the direction of heat transfer. At a speed of 5mm/s more homogenous structures have been obtained (fig. 3)

The results obtained by scanning electron microscopy and by chemical analysis performed on the dendritic axis and on interdendritic region of the samples irradiated at a laser power of 800W and a movement velocity of 5mm/s (NDA), confirm the occurrence of some differences of the Cr, Ni, and Mo contents in these regions (fig. 4).



Element	Wt %	At %
O K	1.28	4.34
SiK	0.44	0.85
MoL	2.52	1.42
CrK	17.13	17.84
MnK	1.78	1.76
FeK	62.47	60.54
NiK	14.38	13.26
Total	100.000	100.000

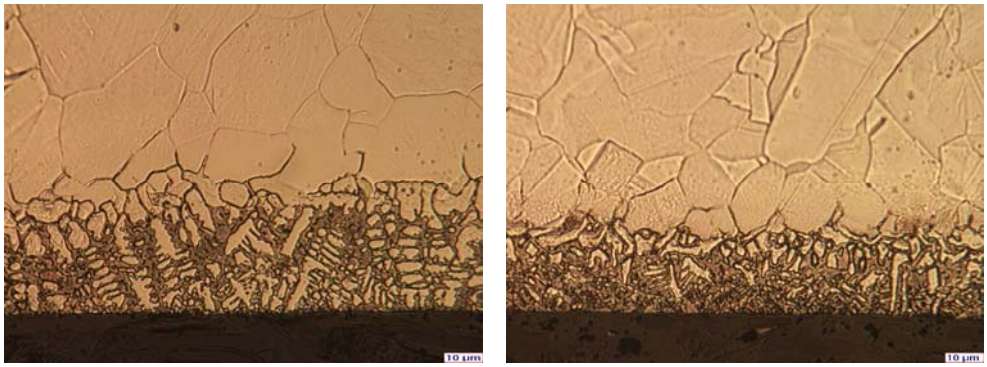
EDX chemical analysis performed within the dendritic axis for the NDA sample

Element	Wt %	At %
O K	1.53	5.16
SiK	0.59	1.14
MoL	4.10	2.30
CrK	19.04	19.77
MnK	1.90	1.87
FeK	59.24	57.26
NiK	13.60	12.50
Total	100.000	100.000

EDX chemical analysis performed within the interdendritic space for the NDA sample

Fig. 5. EDX analysis performed on the samples irradiated at P=800W, v=5 mm/s

In good agreement with the aspect of the dendritic structure of the irradiated samples are the microhardness values. Increasing the velocity of the sample movement at the same laser power produces a smother dendritic structure with differences in chemical composition of the dendritic axis and the interdendritic area (fig.5).



NDB NDC

Fig. 6. Optical micrographs of the melted layer for the NDB sample (treatment conditions P=800W, v=5mm/s) and NDC sample (treatment conditions P=800W, v=10 mm/s)

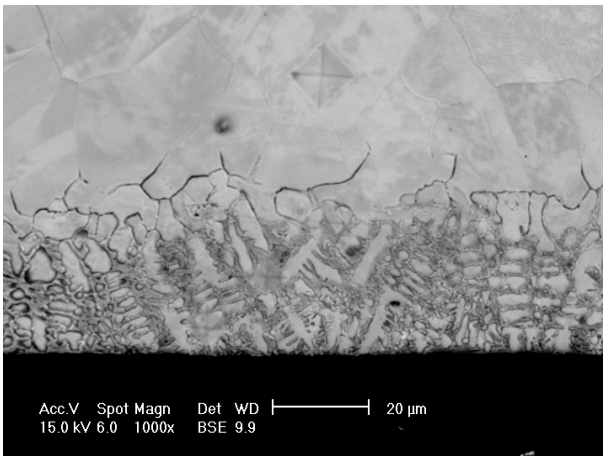


Fig. 7. SEM image of the melted layer for the NDB sample

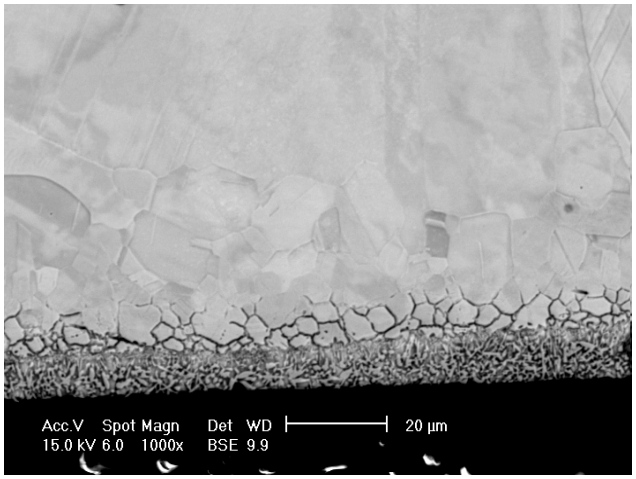
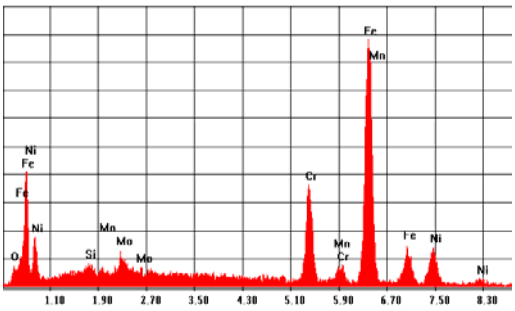


Fig. 8. SEM image of the melted layer for the sample NDC

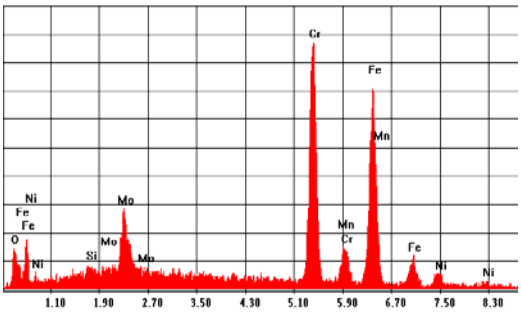
Scanning electron microscopy and EDX investigations performed on the sample irradiated with a laser beam power of 800W and a sample velocity of 7.5

mm/s (fig.7, fig.8) confirm the structural and compositional non-uniformity. The dendritic axis is rich in Ni, whereas the inter-dendritic space is rich in Cr.



Element	Wt %	At %
O K	1.25	4.24
SiK	0.65	1.26
MoL	2.29	1.29
CrK	14.14	14.74
MnK	1.35	1.33
FeK	63.37	61.50
NiK	16.94	15.64
Total	100.000	100.000

EDX chemical analysis performed within dendritic axis for the NDB sample

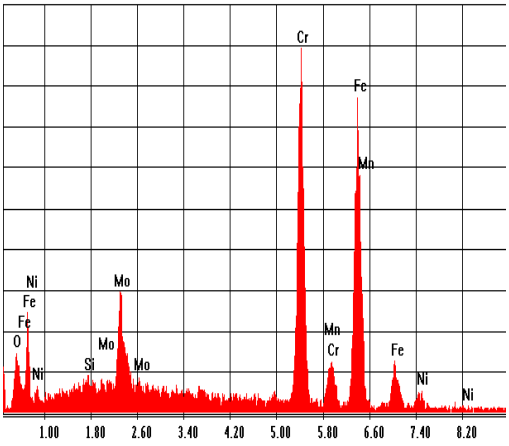


Element	Wt %	At %
O K	2.42	7.95
SiK	0.56	1.05
MoL	6.49	3.55
CrK	37.07	37.43
MnK	1.75	1.67
FeK	45.69	42.96
NiK	6.03	5.39
Total	100.000	100.000

EDX chemical analysis performed within interdendritic space for the NDB sample

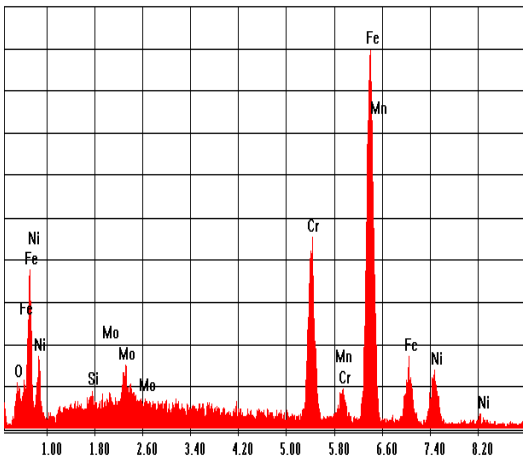
Fig.9. EDX analysis performed on the sample irradiated at P=800W, v=7.5 mm/s (NDB)

As the velocity of the sample movement was increased from 7.5 mm/s to 10 mm/s, the difference in Cr and Ni concentrations between the dendritic axis and the inter-dentritic space (fig.9, fig.10) showed an inconspicuous variation. The increase of the microhardness of the melted layer, corresponding to a sample velocity of 7.5mm/s, is in good agreement with the increase of Cr content within the layer. The increase of microhardneses can be due also to the development of the Cr-Fe-Mo-Ni precipitates in the interdendritic space.



Element	Wt %	At %
O K	2.74	8.95
SiK	0.54	1.01
MoL	6.99	3.81
CrK	36.07	36.22
MnK	1.17	1.12
FeK	48.64	45.48
NiK	3.84	3.42
Total	100.000	100.000

EDX chemical analysis performed within the interdendritic space for the NDC sample



Element	Wt %	At %
O K	1.74	5.83
SiK	0.48	0.92
MoL	2.33	1.30
CrK	17.25	17.75
MnK	1.71	1.66
FeK	61.11	58.53
NiK	15.38	14.01
Total	100.000	100.000

EDX chemical analysis performed on the dendritic axis for the NDC sample

Fig. 10. EDX analysis performed on the samples irradiated at P=800W, v=10mm/s (NDC)

For a velocity of the sample movement of 10mm/s cracks appear in the substrate. Regardless of the laser treatment parameters, like in the case of free cooling; a well defined zone can be observed at the layer-substrate interface (fig.11). According to the EDX analysis (fig. 12) this region has a composition which differs from the compositions of the melted layer and base material (initial austenite). In this region due to a mass transfer process, an austenite with a higher Ni content (16.26%) and a lower Cr (16.95%) and Mo contents (2.47%) was found.

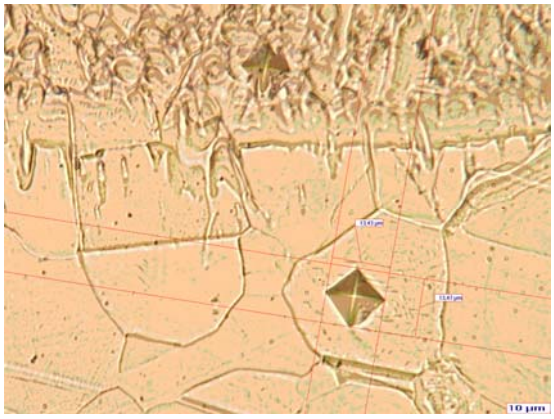
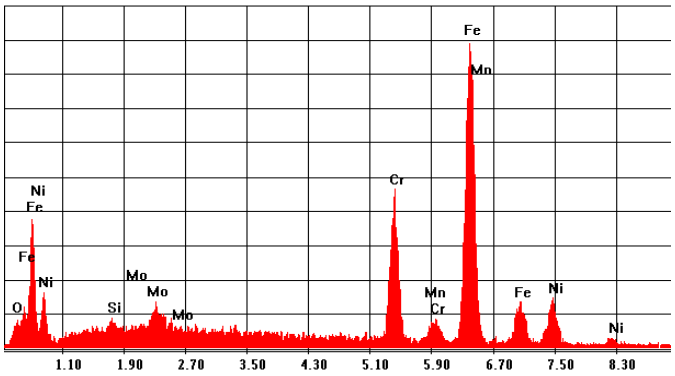


Fig. 11. The microstructure of the melted layer at the interface layer-substrate for the NDA sample (treatment conditions P=800W, v=5mm/s)



Element	Wt %	At %
O K	1.38	4.67
SiK	0.56	1.08
MoL	2.47	1.39
CrK	16.95	17.60
MnK	1.30	1.27
FeK	61.08	59.04
NiK	16.26	14.95
Total	100.000	100.000

Fig. 12. EDX analysis performed at the interface layer-substrate for the NDA sample (treatment conditions P=800W, v=5mm/s)

These microstructural characteristics of the substrate determine lower microhardness values than in the austenitic base material.

4. Conclusions

LSM surface treatment followed by rapid cooling in liquid nitrogen produces an increase of the layer microhardness. This increase depends on the velocity of the samples movement. The highest microhardness increase has been observed for a velocity of 7.5mm/s.

The thickness of the melted layer depends also on the velocity of the samples movements and was in the range 25-82 μm. The microstructures of the melted areas, in the circumstances of a single passing of the laser beam, show a dendritic structure of the austenite growth on in heat transfer direction. The dimensions of these dendrites depend on the velocity of the sample movement. At low velocities, the dendrites are smaller and the chemical non- uniformity between the dendrite axis and the interdendritic region are smaller, due to the occurrence of partial diffusion processes. At higher velocities, and consequently at higher cooling rate, the dendritic structure is finer and the chemical non- uniformity larger.

At a velocity of 7.5mm/s the highest Cr enrichment of the superficial layer resulted as a consequence of mass transfer processes. At the same time the formation of some Cr based precipitates Cr-Mo-Fe-Ni-Mn (Cr-37%), took place. Their presence leads to the increase of layer microhardness.

R E F E R E N C E S

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