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LASER SURFACE ALLOYING OF SOME STEELS FROM SiC PREDEPOSITED POWDERS

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ABSTRACT

For the purpose of studying the possibilities of increasing the wear resistance, specimens of three steels with 0.2%C, 0.46%C and 1%C were surface alloyed with reinforcement from overlapping pastes with green SiC hard particles with the granulation 800 and 320. The melting of surface layer was performed by CO_2 continous wave laser on a numerical x-y table. On these specimens the micro structural characteristics, geometry of molten zone, micro hardness variation in the alloyed layer depth and the HV5 hardness on a laser processed surface were determined, which allowed defining the added material with the best hardening effect. The conditions to obtain compact surface layers with 2-3 time higher hardness than the base material were determined.

KEYWORDS: laser alloying, SiC, microstructure, micro hardness.

1. Introduction

Improved durability of tools and machine parts subject to intense wear led to the promotion of unconventional technologies of surface treatments to the active zones under the action of concentrated energy beams, such as laser and electron beams. The laser processing provides an ultrafast thermal cycle into the ambient atmosphere, on small and difficult to access areas, of complex geometry, with accuracy and high productivity. The results of the interaction between the laser beam and the processed material are off balance structural states, impossible to make by traditional treatment methods. They results in a strong hardness, increased resistance to plastic deformation, resistance to fatigue and corrosion, less wear, improved lubrication, etc.

The interaction of the laser radiation with the material surface can take place in the presence or absence of an additional material injected or pre deposited. Depending on the desired thermal effect, the structural modification procedures can be divided into [1, 2]:

-procedures without additional material, which do not modify the chemical composition of the base material, such as: hardening from the solid or liquid state, granulation finishing, glazing or vitrification, shock hardening.

-procedures with additional materials which do modify the chemical composition of the base material, such as: deposition, alloying, hard particles reinforcement.

There are various additional materials used for surface hardening and increasing the wear resistance, such as [3]:

-Hard materials of metal atom bonds: carbides (WC, W_2C, Cr_3C_2, $Cr_{23}C_6$, TiC, MoC, TaC) [4], [5], [6], [7], carbides mixtures (WC-TiC; TaC-Nb), nitrides (TiN, ZrN, TaN) [8], borides (TiB_2, ZrB_2, LaB_6) [8];

-Hard materials of non metallic atom bonds: oxides (Al_2O_3-Cr_2O_3; Al_2O_3-MgO; Al_2O_3-TiO_2; TiO_2; ZrO_2-CaO) [9], carbides (SiC, B_4C) [9, 10] nitrides (Si_3N_4, AlN), borides (AlB_{12}, SiB_6);

-Hard alloys: Fe-Cr-W-Mo-V-C-Si; Co-Cr-W-Mo-C-Si; Ni-Cr-B-Si [10, 11, 12].

The paper shows the researches on surface alloying and SiC hard particles reinforcement from overlapping pastes of the low alloyed steels having various carbon contents. Special attention was paid to the effect of the carbon content, the additional material granulation, as well as the laser processing parameters on the structure and hardness of the SiC alloyed and/or reinforced layers.

2. Experimental materials and working method

To investigate the sensitivity of the alloying process to the carbon contained in the steel base, three low alloyed steels were selected for the experiment purpose. Chemical composition is given in Table 1. The samples were cut as 40x15x15mm.

Table 1*.Chemical composition of the experimental samples*

Base material	Grade of steel	Condition	Chemical composition [%]						
code			C	Mn	Si	Cr	V	S	P
1	16MnCr5 SR EN 10084:2000	annealed	0.20	1.15	0.37	1.12	-	0.032	0.028
2	51CrV4 SR EN 10083-1:1994	annealed	0.46	0.85	0.32	1.08	0.17	0.027	0.031
3	16MnCr5 SR EN 10084:2000	carburized	0.98	1.15	0.37	1.12	-	0.032	0.028

Table 2*. Additional materials*

Additional material code	Additional material	Chemical composition [13] [%]	Granulation mesh/″linear
AM1	Green SiC	97-98.8%SiC, 0.6%Si	800
AM2			320

Table 3*.Physical properties of the silicon carbide [13]*

State	Crystalline structure	Density	Tm^1	Tv^2	α^3	λ^4	HV
		[kg/m^3]	[°C]		[kJ/kgK]	[W/mK]	[GPa]
SiC α	diamond	3170	-	2830	1,80	45-450	26-37
SiC β	hexagonal	3210	2150	2780	1,76	45-450	21-29

Note: 1- melting temperature, 2-boiling temperature, 3-linear dilatation coefficient, 4-thermal conductivity.

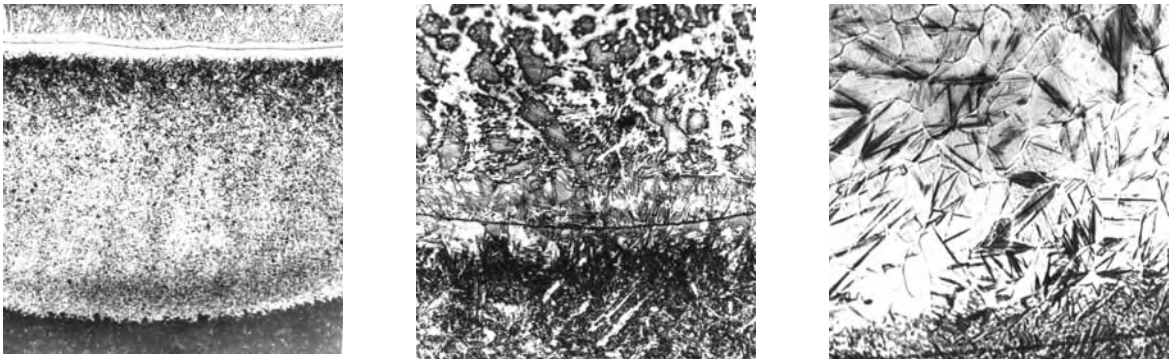
The additional material consisted of green SiC particles; their chemical composition and granulation are presented in Table 2. The silicon carbide is polymorphous. Less than 2100°C the SiCα modification is stable as it has a diamond type structure. Above 2100°C in the SiCβ changes, as this has up to eight structural types in hexagonal and tetragonal systems. In green SiC technical powders there is a mixture of SiCα and SiCβ with hexagonal system [12]. A number of physical properties of these modifications are given in Table 3. Before the laser processing, the sample surface was degreased and covered by a paste resulting by mixing a part of hydroxiethylcellulose with tree parts of SiC powder. After drying, the thickness of the additional material was calibrated by grinding to 0.15 mm. The laser processing was made by marking single strips in an inert argon atmosphere on a LASER GT 1200W (Romania) system, by numerically controlling on a computer the working table according to direction x-y. The surface covered with the additional material has been processed by CO_2 continuous wave laser with different energy factors $K = P / d \cdot v$ [J/mm^2], obtained by keeping constant the emission power P = 950 W and the variation of the laser beam diameter d = 2.18 and 2.84 mm and of the scanning speed, v = 1…2.5 mm/s. The samples were subject to metallographic investigations on the surface and the laser strip cross section. The sensitivity to vaporization and fissuring, the geometry of the laser strip, structural modification to SiC alloying under various regimes of heat transfer, determination of the micro hardness HV0,1 (load 100gf) variation in the alloyed layer depth and the hardness HV5 (load 5kgf) on a laser processed surface.

3. Experimental results and discussions

The analysis of the cross section microstructure of the laser processed strip reveals an alloyed layer on a steel base quenched to martensite from solid phase (fig.1a). The alloyed layer was obtained from very fast melting of a thin base material layer, including the predeposited SiC particles by thermal capillary convection, followed by fast solidification and martensitic hardening. The structure of the alloyed layer is a dendritic columnar and contains martensite, residual austenite and SiC particles in an interdendritic arrangement, in amount that depend on the amount of carbon to be found in the steel, the granulation of the SiC particles, and the laser processing operation.

In the case of alloying steel of SiC powders of 320 granulation, the new structure consists of SiC particles among the branches of the martensite dendrite and residual austenite increasing with the extent of the austenite alloying. Partial dissolving of the SiC takes place even when processed under very high energies (fig.1b). In the case of steel alloying with SiC powder of 800 granulation, is found that the SiC particles have been completely dissolved (fig.1c).

The structure is made up of austenite dendrite which, when cooled, get into high alloyed martensite and an increased amount of residual austenite.



a). b). c).

Fig. 1. *Microstructure of alloyed layers: a). steel code 2, AM2, K=407.3 J/mm^2, x100; b). steel code 2, AM2, K=407.3 J/mm^2, x500; c). steel code 3, AM1, K=227.6 J/mm^2, x500; Nital2%.*

Table 4*. Strip geometry and macro hardness HV_5 (d_1 = 2.84mm; *d_2 = 2.18mm)*

Added material	K [J/mm^2]/ [mm/s]	Strip geometry					HV_5 [MPa]	Observation
		Δh	ha	hq	la	lq		
1 - 16MnCr5								
AM2	133.8	-0.05	0.11	0.97	1.60	3.06	9800	N
	167.2	-0.05	0.14	1.19	2.20	4	8420	N
	230.7	0.03	0.30	1.39	2.40	3.60	9470	**R**
	283.4	0.00	0.14	1.44	2.60	3.73	6870	N
	369.3*	0.05	0.42	1.42	2.60	4.13	7270	N
2 - 50CrV4								
AM1	217.9*	0.00	0.14	0.50	1.11	1.61	10000	N
	290.5*	0.01	0.10	0.44	1.08	1.55	8470	N
	407.3*	0.01	0.11	0.54	1.28	1.80	8380	N,V
AM2	217.9*	0.01	0.13	0.55	1.22	1.86	9800	N
	290.5*	0.05	0.19	0.55	1.22	1.83	9580	**R**
	407.3*	0.01	0.13	0.61	1.47	1.97	9410	N, V
3 - 16MnCr5 carburized								
AM1	172.4	-0.01	0.17	0.94	1.97	2.83	6120	N
	227.6	0.03	0.18	1.00	1.94	2.92	8520	N
	334.4	0.04	0.18	0.94	1.54	2.78	6590	N
	217.9*	0.03	0.06	0.58	1.39	1.94	7770	N
	296.5*	-0.05	0.14	0.61	1.31	1.97	8000	N
	435.8*	-0.05	0.14	0.67	1.50	2.11	7590	N
AM2	172.4	0.03	0.17	0.80	1.86	2.55	9490	P
	227.6	0.05	0.19	0.89	1.83	2.61	9170	-
	334.4	0.00	0.15	0.78	1.83	2.55	9170	P
	217.9*	0.03	0.19	0.61	1.31	1.92	9930	**R**
	296.5*	0.03	0.17	0.58	1.36	1.97	9720	**R**
	435.8*	0.03	0.17	0.64	1.44	2.03	9420	N, F

Note: **R** – recommended; N – None recommended; P – pores; V –vaporizations; F- fissures.

The extent of the carbide dissolving is affected by the content of carbon in the steel and the operation conditions. An increased amount of carbon limits the carbides dissolving and favors the composite structures. The increased scanning speed reduces the distance between the dendrites axes and increases the amount of SiC not dissolved. At steel of code 1 processed by maximum energy density, the advanced silicon alloying makes the lamellar graphite to appear in the structure as well. At the fusion limit it can be seen a lighter color area of high inter-diffusion in the alloyed layer which is free of SiC particles and has a martensitic structure. Under the fusion limit the layer hardened from solid phase has an increased granulation and a higher amount of residual austenite, with softening effect. Table 4 shows a number of results on the dimensions of the laser processed strip (Δh - the deviation from the processed surface; ha, hq - the depth; la, lq - the width of the alloyed layers and quenched to martensite layers) and the hardness HV5 measured on the laser processed surface. The irregularities of the laser processed surface are highlighted by the sign and size of the deviation Δh from the level of the initial surface. It can be seen that an over height generally appears due to the inclusion of the addition material and the higher volume at the martensitic transformation. There is a negative deviation especially at the alloying of steel code 1 which exhibits a higher melting interval and a lower viscosity of the melting bath. Also the low energy density regime, which provides a lower surface temperature as well as the additional material of rough granulation which remains in suspension in the melt bath, reduces its fluidity and causes specific irregularities.

Fig. 2 shows the dependence of the alloying and quenching and from the solid phase depth according to the energy density.

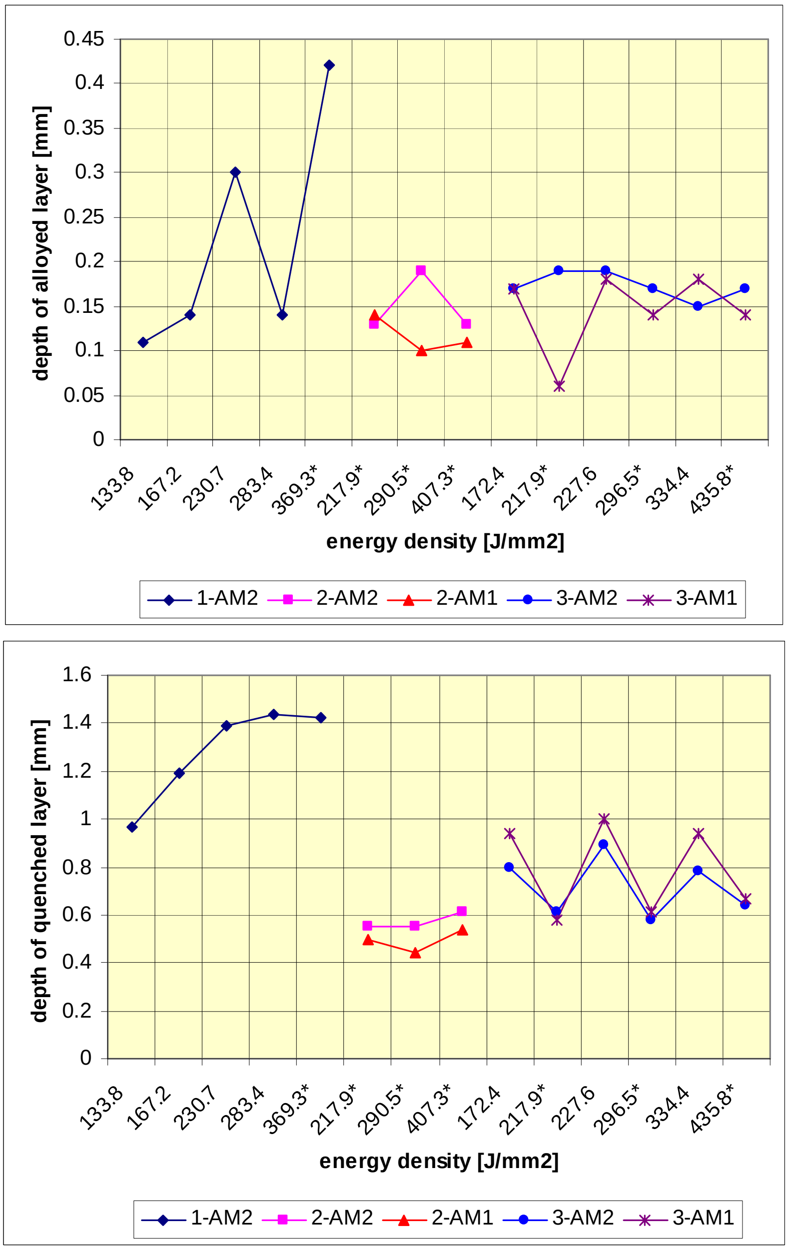


Fig. 2 *Dependence of alloying and quenching depth versus energy density K. 1, 2, 3 – code of steel; AM1- 800 granulation SiC particles; AM2- 320 granulation SiC particles; *d_2=2.18mm.*

When is used AM2 additional material, the maximum depths are encountered with steels code 1 of minimum carbon content and they increase with the energy density. This may be due to the fact that when the carbon in the steel increases, the carbides in the steel increase as well and the thermal conductivity of steel decreases. Particles SiC with 320 granulation are dissolved in melted bath with high density energy and this generally determines, in the same condition of laser processing, an alloying and depth better than 800 granulation SiC particles (AM1). The micro hardness analysis (Fig.3) in the depth of the laser processed strip shows a higher hardening of the alloyed layer as compared with the steel sub layer hardened from solid phase. The micro hardness of these zones increases with the steel carbon concentration. It should be noted the softening occurring in the transition zone from alloyed layer to quenched layer, which is more intensive with the amount of carbon in the steel. The HV$_5$ hardness is strongly affected by the additional material, the carbon in the steel and the beam diameter. With steel code 3 the strongest hardness is caused by the alloying with AM2 - green SiC of granulation 320 (Fig.4), as a result of obtaining some composite phase structures. The minimum hardness is caused by the additional material AM1 of granulation 800, when the additional material is dissolved. The hardness of the alloyed layer increases with the carbon in the steel which provides higher reinforcement to the composite layer. At the same time it decreases with higher energy densities due to the high amount of residual austenite in the matrix. The steel code 1 of minimum carbon content shows the most drastic decrease in hardness due to the additional capacity of alloying its matrix and also due to the high depth of the alloyed layer which makes that the amount of additional material be distributed in higher volumes. The maximum hardness appears when the process is performed by concentrated beams of lower diameters.

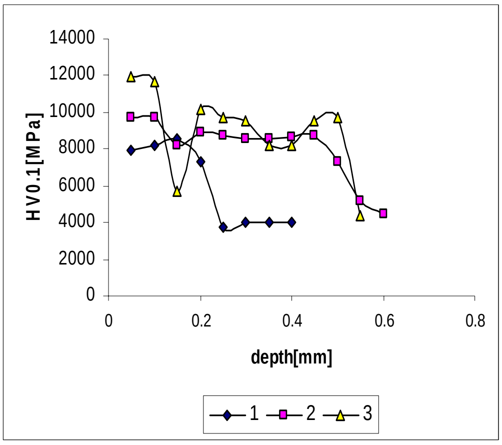


***Fig.3.** The variation of micro hardness in the depth of alloyed layer for AM2: steel code 1 - 230.7 J/mm^2; steel code 2 - 217.9 J/mm^2; steel code 3 - 296.5 J/mm^2.*

4. Conclusions

The laser alloying of low alloyed steels from pre deposited pastes containing SiC particles leads to the steels more alloyed with carbon and silica than the base material or to the composite structures with SiC reinforcing elements, featuring higher hardness than the laser quenching from the solid phase layers of base material.

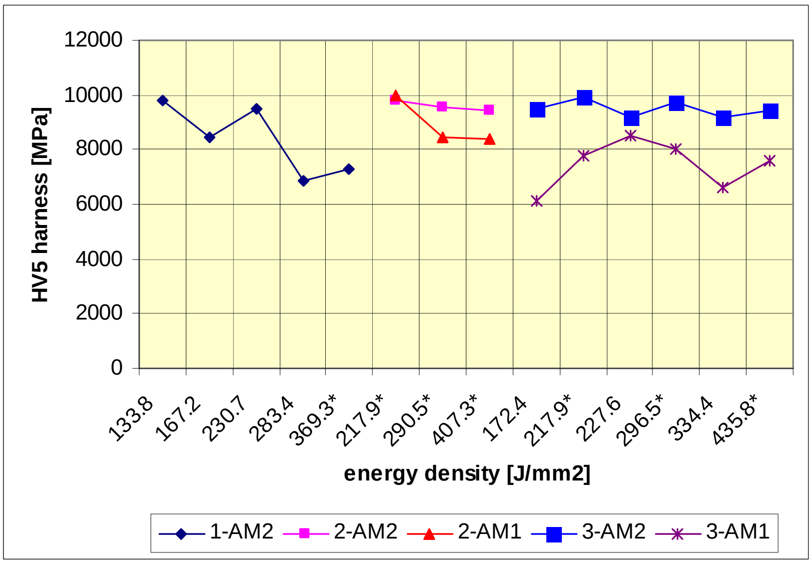


***Fig.4.** Dependence of hardness HV5 by additional material and carbon content of steel; 1, 2, 3 – code of steel; AM1- 800 granulation SiC particles; AM2 - 320 granulation SiC particles; *d$_2$=2.18mm*

Improved alloyed layers may be obtained when using green SiC of 320 mesh/″linear granulation. Hardness is improved when the concentration of the carbon in steel is higher under laser processing. This process results in partial dissolving of the SiC particles and employing concentrated beams. For alloying purpose it is convenient to use steel code 2 and 3 of medium or high carbon content, which provides a hard under layer quenched from the solid.

From these experiments results that, the optimum condition for steel code 2 consists in laser alloying with 320 granulation green SiC particles, with P = 950W; d = 2.18mm; v = 1.5mm/s. This condition ensure a 0.19mm adequate depth of alloyed layer and a high hardness HV5 = 9580MPa.

For steel code 3 is recommended laser alloying with 320 granulation SiC green particles, P = 950W, d = 2.18mm, v = 2…1.5 mm/s. The depth of alloyed layer is 0.19…0.17mm with a high hardness HV5 = 9930…9720MPa.

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