Characteristics of the laser clad metal made with pow der mixture of Ni-based alloy and tungsten carbide

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ABSTRACT: Metal matrix composite (MMC) coatings composed of Ni-based alloy and tungsten carbides (WC) were deposited on low carbon steel by powder feeding laser cladding. In the present study, a continuous wave laser (CW) was used. The laser processing parameters were optimized. Sections of such coatings were examined to reveal their morphology and microstructure using scanning electron microscope (SEM) and DTA analyses. The results showed that fully dense clad surfaces of WC- Ni- based alloy with an excellent metallurgical bonding and low dilution were deposited and no melting of WC particles in the Ni- based alloy matrix was observed during the microscopy. Different phases, formed in very small submicron dendrites, precipitates, or eutectic structures, were identified with WC particles of various shapes and sizes in the matrix. Owing to this distribution of hard phases, and WC particles, the Vickers hardness is strongly enhanced and may reach 1400 HV.
Finally the quality of the laser cladding is discussed and microstructure observations are presented.

Keywords: Laser cladding; Microstructure; Metal Matrix Composite; Hardness; WC particles

1 INTRODUCTION

Laser cladding is a hardfacing process that uses high power density to melt the feeding material and forms a thin coating with specific quality and low dilution with the substrate [1, 2]. The tungsten carbides (WC) may offer a good resistance to wear, however the carbides alone are very hard and do not offer a good resistance to cyclic stresses [3, 4, 5]. The Ni-Cr-B-Si alloys are widely used in the glassware industry for coating parts working at high temperature in order to ensure a protection against corrosion and abrasion [6]. They can replace cobalt hard alloys in some special cases, for instance to make valves in nuclear engineering whenever cobalt has to be avoided. In recent years, these alloys have been the subject of increased research activity and several intensive investigations aimed at understanding their various metallurgical and mechanical characteristics [7, 8, 9, 10]. However, the laser cladding obtained with continuous wave laser irradiation is by nature the generator of macroscopic heterogeneities, therefore crakes, porosity and partial melting of WC particles in the matrix.

In order to resolve these issues due to significantly higher average heat input during cladding, the laser processing conditions were optimized.

In the present study, laser cladding composed of Ni-based alloy matrix reinforced with WC particles were deposited on low carbon steel substrate using continuous wave (CW) $C0_2$ laser. The microstructure of the clad layer was assessed by optical and scanning electron microscopy. The presence of various phases was investigated using Differential Thermal Analysis (DTA). Finally the quality of the laser cladding is discussed and microstructure observations are presented.

2 EXPERIMENTAL PROCEDURE

2.1 Laser deposit

The experimental set-up used for these experiments is shown in figure.1. A nickel base alloy powder of composition (in weight percent) 0.65C-3.15B-4.5Si-15Cr-4Fe-Ni balance was deposited on low carbon steel substrate (AISI 1020, Fe + 0,2C %wt). The powder particles were globe-shaped with size of 60-120 µm. Samples (rectangular pieces 180x70x10 mm^3) were mounted on a numerically controlled X-Y table and irradiated with a continuous CO_2 laser, the power of which is up to 3.6 kW. The laser beam is focused by spherical 10 inch Zn-Se lens. A coaxial nozzle was used to focus the powder stream in the molten pool created in the substrate. The powder is injected at a constant rate in the laser beam with a METCO 4MP spray system. Argon gas is used as shielding gas to prevent oxidation in the interaction zone and to protect the laser focalisation lens.

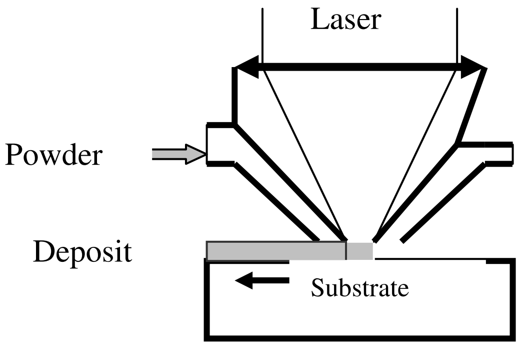

Fig.1. Schematic illustration of laser coating process

2.2 *Optimization of the laser-processing conditions and sample preparation*

The first stage of the optimization sequence is the determination of the laser processing parameters, in which homogeneous and sound surface layers can be obtained, with a small dilution of the addition element into substrate. This requires a very limited surface melting of the substrate. After various attempts, experiments were performed at the following conditions:

- The laser power is between 1500 and 2500W
- The travel speed of the samples under the laser beam is 60cm/mn
- The beam diameter at the impinging point is 1,5 mm
- The powder feed rate is fixed at 30 g/m

The cladded samples were characterized by optical microscopy and scanning electron microscope (SEM). They were sectioned metallographically and polished to a mirror finish using a diamond paste with a grain size of 1µm. A general purpose etchant for Nickel alloy was used to reveal the microstructure (150 cm^3 HCl, 25 g $K_2Cr_3O_7$, 50 cm^3 H_2O Keller's reagent).

3 RESULTS AND DISCUSSION

3.1 Microstructural observation

The microstructure of a typical laser clad material reinforced with WC particles is shown in Figure.2. At optimum parameters, the cross-section observed was dense and free from bulk defects. This cladding, with a thickness between 0.5 and 1.5 mm can be characterized by a fine microstructure. The interface clad/substrate, about one micron thick, is wavy. The microstructure of cladding showed columnar growth traversing the cross section (Fig.3)

The solidification is initiated at the clad /substrate interface and oriented towards the surface of the clad region. Austenite dendrites can be observed in the clad layer on account of partial stirring of the melt and convective stream. The structure change, become cellular and then dendritic, which is typical of laser cladding. This change is further enhanced by chemical segregation. Part of this structure is equiaxial because of undercooling. The WC particles, in an irregular distribution, are not melted and conserve their initial shape in the cladding. In addition some of these carbides particles were observed to be surrounded by epitaxially grown dendrites.

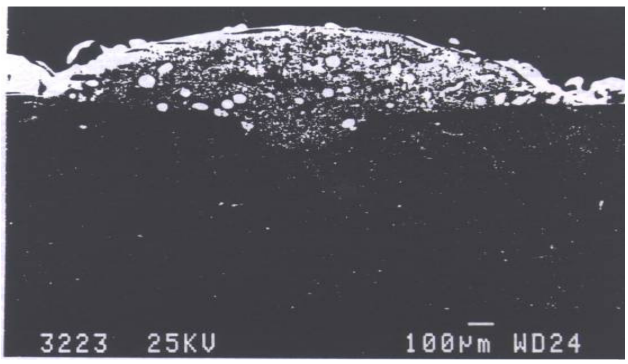

Fig.2. Typical laser cladded material: distribution of the spherical tungsten carbides.

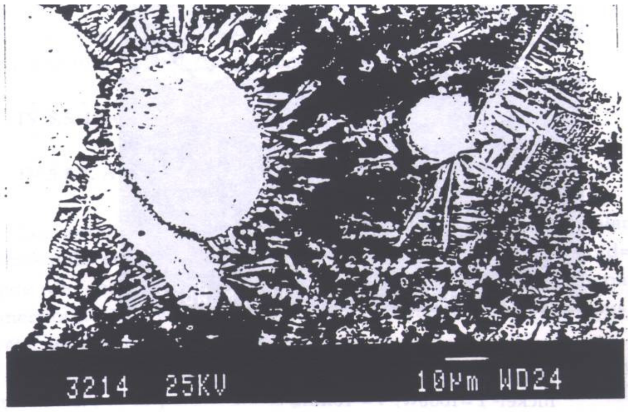

Fig.3. SEM micrograph showing the different shape of CW particles

3.2 Metallurgical analysis

The analysis of the different phase was performed on bulk specimens obtained by melting powder in the furnace of a Differential Thermal Analysis device (DTA). These specimens were slowly solidified and cooled at rate of 300°C. The compositions of the phases obtained in the present investigation are given in table 1.

The alloy contains six elements and all of them except Fe have a role in forming phases. Seven phases were found in the DTA specimens: CrB, $M_{23}C_6$, M_7C_3, Ni_3B, Ni_3Si, Ni_5Si_2 and the matrix Ni. Their compositions are reported in table 1.

at. %	Ni	Si	Cr	Fe	B	C
nominal	60	7.5	12.8	3.4	13.9	2.6
CrB	1		46.6	0.4	52	
M23C6	6		66	3		24
M7C3	1		61-65	0.5		30-36
Ni3B	66-68		3.7	2.9	25-27	
Ni3Si	69	25	4	1.5		
eut.	77	10.5	6.5	6.5		

Table1. Composition of the different phases

3.3 Microhardness

A Vickers's microhardness tester was used to determine the hardness at various locations along the transversal section of deposit. The microhardness profile distribution of the coating is shown in Figure. 4. It is apparent that the microhardness of the matrix is about 420 $HV_{0.2}$. The increase of microhardness is primarily due to the formation of the carbides and borides in the coating during treatment. The reason for increase and fluctuation in microhardness (450-1350 $HV_{0.2}$) is due to higher hardness and distribution of WC particles.

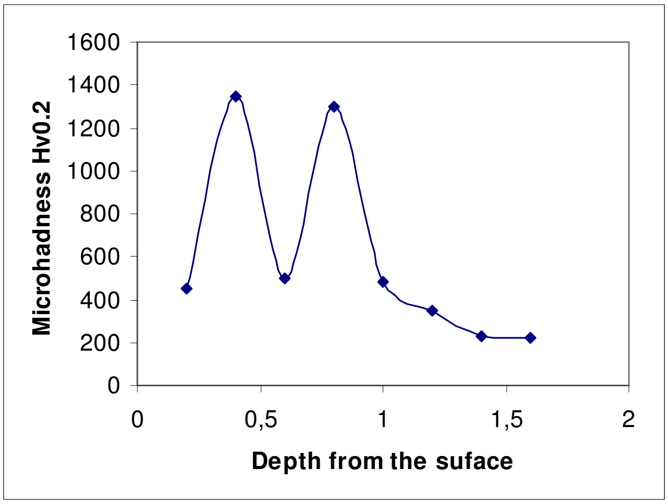

Fig.4. Microhardness measurement of laser cladded samples

4 CONCLUSIONS

Continuous wave laser claddings of WC-Ni base alloy are studied. It is found that by optimizing the process conditions it is possible to obtain claddings with an excellent metallurgical bonding and low dilution. Planar solidification is observed at the interface clad/substrate, followed by cellular, nickel rich dendrites and interdendritic lamellar eutectic from interface to the top surface. Laser treatment led to the precipitations of some carbides and borides causing an increase in microhardness in the laser coating. The cladded region is formed by a fine microstructure combined with WC particles. One method being investigated for future work is to study the abrasive wear resistance of the MMC clad layer.

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