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Processing and characterization of laser clad NiCrBSi/WC composite coatings — Influence of microstructure on hardness and wear

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ABSTRACT

NiCrBSi/WC composite coatings containing various amounts of WC/W2C particles were laser cladded on low carbon steel substrate S235JR. Coatings were processed using two different laser systems, a 1 kW Nd:YAG and a 3.8 kW high power diode laser (HPDL). Coatings obtained with the Nd:YAG source demonstrate significant changes in the matrix microstructure with WC/W_2C particle addition. Specific analysis shows the formation of new carbides $(W,Cr)_xC_y$ and boride phases $(W,Cr)_xB_y$ resulting from a partial dissolution of the WC/W_2C particles within the metal matrix. The Brinell macrohardness of the coatings reveals surprisingly low values for coatings containing 10 vol.% and 20 vol.% WC/W_2C. Through nanoindentation measurements, it is suggested that the low hardness of these new carbide and boride phases most likely counteracts the WC/W_2C addition and may explain this unexpected behavior. On the contrary, the same coatings deposited using the HPDL source exhibits no change in the microstructure of the NiCrBSi matrix and display an expected monotonic increase of composite hardness with WC/W_2C amount. It is suggested that the microstructural appearance of new carbide and boride phases may not be related to the type of laser used but to the specific laser energy during the coating process. Contrarily to hardness, measurements show that the erosive wear is marginally affected by the microstructural differences of the coatings. These results demonstrate that evaluating the quality of laser cladded coatings by simply assessing their density and the absence of a crack (as usually done) is insufficient as it does not automatically guarantee reaching optimal mechanical performance.

1. Introduction

Nowadays, industry urges for high performance materials and energy saving processes. To fulfill this goal, an appropriate approach is to coat pieces with high performance materials exhibiting enhanced properties. Production costs can be significantly reduced if the protection is restricted only to the solicited areas. This strategy proved highly efficient to protect metallic parts against wear resistance at high temperature. Laser cladding is well suited to elaborate such coatings. Literature reports numerous advantages for this technique in comparison with other conventional methods: a minimal dilution of the coating in the substrate, a reduced heat affected zone (HAZ), a good surface quality and a minimal distortion of the substrate [1–3]. Coatings produced by laser cladding can be obtained with an auto-feeder powder in a coaxial or lateral way (one-step method) or a pre-placed layer on the substrate (two-step method) [1,2].

Metal matrix composites (MMCs) composed of a ductile metal matrix with embedded hard ceramic reinforcement particles are known to be very efficient coatings for wear applications [3–17]. Usual MMCs typically comprise Co [4–8] or Ni [3,8–17] based alloys mixed with hard carbide particles (SiC, TiC, WC, B4C,…). By combining the high resilience of metals and the hardness of ceramic materials, improved wear resistances have been obtained. The toughness, strength and hardness of the ceramic phase as well as its bonding with the metallic matrix are key factors influencing the wear resistance of MMCs. However, depending on the manufacturing process used, several new phases resulting from the interaction between the metallic and ceramic phases may likely appear, increasing or degrading the MMC properties. Moreover, it may happen that certain properties will be degraded while some other will not. Therefore, it is of primary importance to know exactly which properties are going to be affected (positively or negatively) in order to accurately match the material properties with the targeted application.

This study aims to answer this important question for laser cladded MMC coatings. To do so, laser clad NiCrBSi-matrix coatings reinforced with tungsten carbide particles were deposited on a S235JR+AR steel substrate. In order to vary the conditions of elaboration and cover the diversity of laser sources used in the industry, two different laser sources were considered. The influence of processing conditions has been investigated by assessing the macro-hardness, nano-hardness

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and erosive wear resistance of the composites for various amounts of ceramic phase. Unexpected microstructural effects are reported leading to significant variations in the coatings' mechanical behavior despite similar density and homogeneity.

2. Experimental procedure

2.1. Raw materials and coatings

A NiCrBSi alloy was used as metal matrix (Surfit 1560® — Fig. 1a). Quasi-spherical non-cemented tungsten carbide particles were considered as reinforcement ceramic phase (Spherotene® — Fig. 1b). These particles exhibit a typical hardness of 3000 HV with $WC/W_2C/W_2(C,O)$ phases as shown by XRD analysis (Fig. 2). Low carbon steel S235JR plates were used as substrates. Table 1 reports the chemical compositions of the matrix and reinforcement particles. The small amount of oxide phase detected by XRD (most likely a superficial oxidation) for the WC particle is not revealed by EDS. It will be hereafter shown that XRD analysis on the composite coatings does not identify the $W_2(C,O)$ phase either.

The powders were dry-mixed together to reach a ceramic volume fraction comprised between 0% and 30%. Coatings were deposited by one-step laser cladding in a coaxial way. Two different laser sources were used: (i) a 1 kW (cw mode) Nd:YAG laser source (Lumonics) with a 1.5 mm diameter beam and (ii) a 3.8 kW (cw mode) high-power diode laser source (HPDL) with a 4 mm diameter beam.

Cladding experiments were performed under Ar gas for shielding and powder carrying.

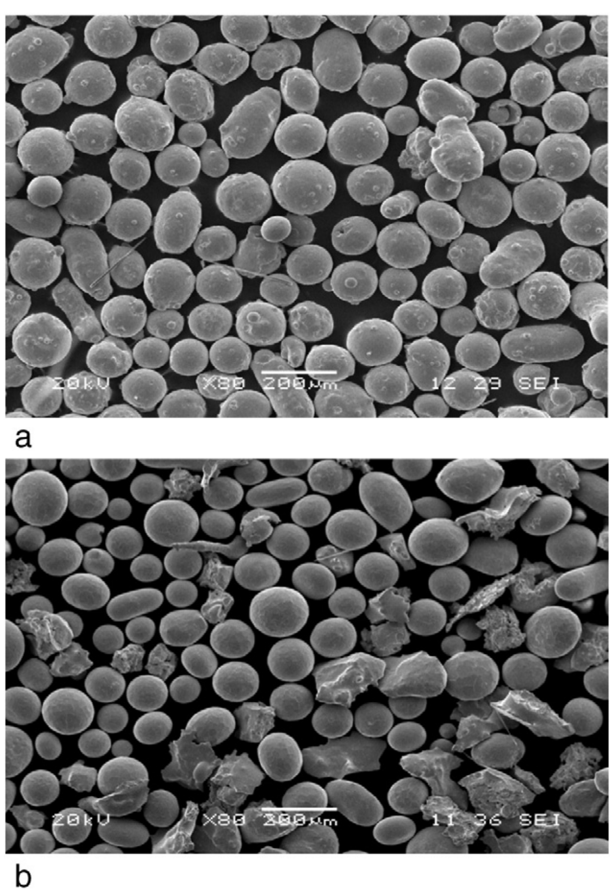

Fig. 1. a: NiCrBSi powder. b:WC powder.

2.2. Characterization

After cladding, coatings were ground to obtain smooth flat surfaces and then polished with diamond paste for microscopic inspection and subsequent mechanical property characterization. Clad coatings were also examined by optical and scanning electron microscopy (SEM, JEOL JSM-5900LV). The presence of potential cracks or porosities was controlled by means of a fluorescent dye (ARDROX 920A) which helps reveal defects (pores, cracks) under UV light. The crystalline and chemical compositions of the powders and coatings were determined by X-ray diffraction (Brucker D8, 40 kV, 30 mA, Cu-Kα radiation, scanning ranging from 25° to 80°), EDX (JEOL JSM-5900LV) and WDX analysis (CAMECA SX50).

Light absorption measurements were performed using a PerkinElmer λ750 spectrometer.

Two different hardness measurements were considered: a macro-hardness analysis to obtain the mean hardness of composites (these tests involve a large analysis area) and a nanohardness analysis to get the hardness of each individual phase in the coatings. For the macrohardness analysis, Brinell hardness was assessed in accordance with ISO 6506 standard under a load of 187.5 kgf and a 5 mm WC-Co ball (HBW 5/187.5). The nanohardness analysis was performed with a Nano-combi tester (CSM Instruments) using a Berkovich indenter. Measured values are automatically converted into Vickers units.

The wear resistance was assessed by wheel tests in dry conditions. These measurements were performed using a steel wheel and corundum abrasive particles (F80; 80 g/min) for a test duration of 16 min (adapted from EN ISO 10545-6). To evaluate the wear resistance, volume loss was measured using a roughness measurement equipment (Somicronic Surfascan 3D). The mean value of the wear track length was obtained by three different measurements and then multiplied by the track width which is kept constant in our tests (10 mm).

3. Results and discussion

3.1. Qualitative assessment of the coatings

Tables 2 and 3 report the laser parameters used to obtain defect-free composite clad coatings for both laser systems.

To prevent cracking and limit thermal shocks in the coatings, cladding was performed by heating substrates at 400 °C. After cladding, samples were left to cool down gently to room temperature.

Depending on the amount of WC in the coatings, due to a growing shadow effect [18], used laser power (P) had to be adjusted from 700 W to 900 W for the Nd:YAG laser source. The power was optimized for each composition to get qualitatively dense (with neither cracks nor porosities) and well bonded coatings with minimal used power. Scanning speed (V) was kept constant at 20 mm/s and powder mass flow (q) at 12 g/min.

For the HPDL source, all samples were deposited with a power of 1.5 kW, a scanning speed of 11.66 mm/s (700 mm/min) and a powder flow of 25 g/min.

For both sources, coatings were deposited with an overlap of 50% between consecutive tracks and the final coating thickness after grinding was typically comprised between 1.5 and 2 mm. The microstructure analysis of the coatings didn't exhibit any influence of overlap area, and the microstructures were fully homogeneous.

All samples characterized in this study were free of cracks and porosities as checked with a fluorescent dye under UV light.

3.2. Microstructures obtained with the Nd:YAG laser

The microstructure of the pure metal matrix is similar to that previously reported in literature for NiCrBSi: rich-containing Cr clusters of small dimensions are noticed (approximately 10 μm) in the Ni rich matrix, and Fe and Si are quite homogenously dispersed in the Ni phase.