Ni-based metal matrix composite functionally graded coatings

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Abstract

Functional graded materials (FGMs) are a class of composites that have a continuous variation of material properties. One of the aims of such variation is to relieve the stress concentrations that appear in laminated materials. Coating techniques using powder as filler material can be adapted for the manufacture of composition gradients by means of a mixing unit in a powder feed system which is the basis of the laser cladding technology. The aim of this paper is to get coats with layers of the highest possible ceramic concentration on a metal matrix composite (MMC) with the help of the FGM methodology.

1. Motivation / State of the Art

   Functional graded materials (FGMs) are a class of composite materials that have a continuous variation of properties from one point to another. FGMs are not new but they could be an approach for eliminating the sharp interface between clad and substrate in the laser cladding process. It is possible to relieve stress concentration appearing in these laminated materials because the gradation may reduce both thermal and residual stresses [1,2,3].

   Coating techniques using powder as added material can be adapted for the manufacture of composition gradients if a mixing unit is included in the powder feed system. The powder feed is the basis of laser cladding technology for the production of layers with composition closer to the fed material. FGM is obtained if mixing parameters are changed along the process.

   In a previous work[4] NiCr-WC composited coatings, with 60%wt. carbide concentration were deposited by laser cladding. Three commercial premixed materials were used which differed in the chromium concentration of the NiCr metal matrix. It was found that the susceptibility for cracking was

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Keywords: Metal Matrix Composite; Functionally graded materials; Laser cladding; Tungsten Carbides
strongly related to the nominal hardness of the matrix, i.e., to the chromium content of the metallic alloy. Crack free layers were obtained with Cr bellow ~8% wt., corresponding to a hardness of 30 HRC (300 HV). It should be noted however that preheating was yet needed (400ºC) to avoid crack formation.

The aim of the present work was to deposit coatings with the same properties in terms of hardness and WC concentration, but eliminating the need for the preheating procedure. Achieving this goal would imply a significant advantage for the hardfacing process, simplifying the procedure and therefore time costs. The methodology chosen was to produce a graded WC concentration by means of an intermediate layer with a reduced concentration of ceramics. Different sets of graded concentration layers were tested and the results were evaluated in terms of microstructure, microhardness, porosity and also cracking susceptibility.

2. Experimental

The equipment for carrying out the experiments was composed by a continuous wave diode pumped Nd:YAG laser (Rofin DY022) with a maximum power of 2200 W. Laser is sent through a fiber to the YC50 Precitec cladding head installed in a ABB IRB2400 six axis robot arm. Powder feeding is made with a Sulzer-Metco Twin 10C unit, which counts with two hoppers allowing for online alloy powder mixing.

AISI 1025 carbon steel was selected as base material, in virtue of its high thermal conductivity which is a common property of the steels used in abrasive environment. The NiCr-WC layers were produced from mixture of NiCrBSi (Deloro 30) and tungsten carbide (WOKA 3303) alloys. Element composition is listed in Table 1. The nominal hardness of the metallic matrix alloy is 30 HRC. The WC powder is of the cemented carbide type.

|               | Ni   | Cr  | B   | Si  | Fe  | C   | W   |
|---------------|------|-----|-----|-----|-----|-----|-----|
| WOKA 3303     | 10.9 |     |     |     |     | 5.5 | Bal.|
| Deloro30      | Bal. | 8.6 | 1.1 | 3.2 | 2.2 | 0.12|     |

The steels plates were sand blasted to reach a roughness of $R_a=8.06 \mu m$. The NiCr and WC were separately stored in each of the two powder feeding hoppers. Both hoppers were calibrated independently and the mixing of the two materials was performed in flight. The mixing parameters were automatically changed by the robot controller. Cladding was performed on 5 mm thick probes of steel. Laser beam was defocused to a diameter of 3mm on the working surface. Extended areas of approximately 30 mm x 30 mm were covered by overlapped laser scans, at 35%-45% overlapping ratios.

All samples were cut transversally, grounded, polished and etched. Cross-sections of resulting coatings were examined by scanning electron microscopy (SEM). Microhardness measurements were performed. Liquid penetrant dye test was used to reveal cracks in the deposited layers.

3. Results and Discussion

3.1. Single NiCr-WC layers

Single layer cladding samples were developed at different tungsten carbide concentrations, namely, 15%, 30%, 45% and 60% (percentage in weight). Optimum laser process parameters were searched in a
parameter window defined by laser power, scanning speed and power deposition per unit length varying respectively between 1500-2000W, 10-20 mm/s and 10-35 gr/mm. SEM micrographs of the 45% and 60% coatings obtained with the considered optimum parameters are shown in fig 1. The microstructure conform to the metal matrix composite pattern: the spherical cemented carbides are clearly distinguished within the metallic matrix. The microstructure is magnified in the bottom part of the same figure, where a good bonding between matrix and carbides is observed.

The volume concentration of the carbide spheres, as measured by image analysis, is compatible with the expected values in all cases (based on WC weight percentage concentration and mass density). However a certain extent of dilution of WC phases into the metal matrix was present for all the tested samples. This was evidenced by the microhardness measurements of the metal matrix of the composite layers. Mean values of 430, 500, 520 and 570 Vickers hardness were obtained respectively for the 15, 30, 45 and 60% carbide concentration. In all cases well above the 300 nominal Deloro30 value. This effect seems to be unavoidable and could be explained by the agglomerate structure of the cemented carbides being prone to disaggregate under the melting environment of the process.

Fig. 1. Cross sectional views of NiCr-WC layers with (a) 60% and (b) 45 % carbide concentration. Corresponding magnified view of the microstructure is shown below: (c) 60% and (d) 45 %. Process parameters: 35 gm/mm, 2000W, 20 mm/s
Microstructure is mainly formed by four different phases (fig. 2); the original tungsten carbide particle, γ-Ni dendrites, eutectic interdendritic and precipitated carbides. The percentage of each of them changes depending on the tungsten carbide concentration.

As for the cracking susceptibility, no cracking was observed in any of the 15 %, 30% and 45 % WC percentage. Layers with the higher WC concentration (60%) however, developed transversal cracks as shown in fig. 4.

3.2. Two layers. Functionally graded NiCr-WC layers

Coatings made up of two layers, outer and inner, NiCr-WC layers were deposited with the same processing parameters. The outer layer was set to 60% WC concentration whereas the carbide percentage of the inner layer was set to 15%, 30% or 45%. SEM micrographs of some of the obtained coating microstructure are shown in fig. 3. The graded structure due to the two different carbide concentrations used is clearly distinguished, with a smooth microstructure transition between the two layers. Same features in terms of hardness and phase distribution as those described for the single layers were found under hardness measurement and SEM inspection.
Cracking was observed for the 30% and 45% WC inner layer. Recalling that no cracks were obtained with these concentrations in single layers, this result could reflect the thermal stress build-up during multilayer deposition. However, no cracks were observed for the 15% case. This indicates the feasibility of producing harfacing coatings with a high WC concentration even with no preheating procedures by means of a graded structure. In particular, as suggested by this study, just two layers might be enough as long as the inner one is made with sufficiently low tungsten carbide content (>15%).

Fig. 4. Liquid penetrant test for cracks inspection: Single layers at a) 60% and b) 45% WC concentration. Two layers: 60% WC upper layer over c) 15%, d) 45% and e) 30% WC concentration layer.

4. Conclusions

Different NiCr-WC functionally graded were deposited on AISI 1025 steel by means of laser cladding. The material was a cemented carbide (WOKA 3303) added to a NiCrBSi alloy (Deloro 30). The process was first optimized to produce coats with different but constant carbide concentration, namely 15%, 30%, 45% and 60% (percentage in weight). No cracking was observed in any of them excepting the layers with the highest WC concentration.

Two layer coatings were produced, keeping the outer layer concentration at 60% WC concentration with different inner concentrations. The result shows homogeneous microstructure and same hardness as those found in monolayer. In the case of 15% inner layer no cracks were observed. This indicates that is possible to produce high ceramic concentrations coatings without preheating.

Acknowledgements

This works has been done under the financial support of Xunta de Galicia, project reference 10TMT019CT, Programa de Tecnoloxías dos Materiais e da Construción.
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