Optics & Laser Technology 56 (2014) 202–206

Contents lists available at ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

# Surface modification of air plasma spraying WC–12%Co cermet coating by laser melting technique

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ARTICLE INFO

*Article history:*
Received 2 June 2013
Received in revised form
15 August 2013
Accepted 21 August 2013
Available online 13 September 2013

*Keywords:*
Air plasma spraying
WC–12%Co coating
Laser melting

ABSTRACT

Tungsten carbide cermet powder with 12%Co was deposited on stainless steel substrate by air plasma spraying method. Two types of coatings were produced i.e. thick (430 μm) and thin (260 μm) with varying porosity and splat morphology. The coated samples were treated with $CO_2$ laser under the shroud of inert atmosphere. A series of experimentation was done in this regard, to optimize the laser parameters. The plasma sprayed coated surfaces were then laser treated on the same parameters. After laser melting the treated surfaces were characterized and compared with as-sprayed surfaces. It was observed that the thickness of the sprayed coatings affected the melt depth and the achieved microstructures. It was noted that phases like $Co_3W_3C$, $Co_3W_9C_4$ and W were formed during the laser melting in both samples. The increase in hardness was attributed to the formation of these phases.


## 1. Introduction

Tungsten carbide (WC) based cemented carbides are widely used for tools, dies and wear resistant parts in variety of applications including machining, mining, metal cutting, forming, construction and other applications in the form of bulk parts or coatings [1]. These coatings have various applications where very high resistance to abrasive or erosive wear is required. WC cermets can be applied as coatings by thermal spraying processes such as air plasma spraying (APS), high velocity oxygen fuel (HVOF) spraying and detonation gun methods [2,3]. In these, plasma spraying is one of the better techniques that provide good properties of these materials due to high temperature achieved by the plasma. Also, little chance of distortion of the substrate exists during deposition, since its temperature does not rise above 300 °C [4].

However, the properties of the plasma sprayed coatings can be limited by the existence of microstructural defects, such as high porosity, weak interconnection between splats and a considerable lack of chemical homogeneity. The porosity, in particular, can reduce the corrosion resistance because it provides channels of penetration through which the aggressive media reaches the substrate [4].

Laser re-melting is comparatively a new technique to improve the quality of thermal spray coatings. Similarly laser surface alloying (LSA) is a recent and important process used to enhance surface properties of materials. The objective of these techniques is to fuse, totally or partially, the ceramic/cermets layer so that the newly solidified material becomes more homogeneous and the pores disappear. Several researchers have worked in this field [5–14], although few studies reported the results of carbides treatments [4].

As with most thermal spraying techniques like plasma spraying, HVOF and detonation gun based processes; laser cladding and melting could also lead to WC dissolution and precipitation of other phases depending on laser power, particle size, volume fractions of WC, etc. [1,15–17]. Thus, process parameters have to be carefully controlled to minimize the carbide dissolution [16–18].

The present paper focuses on an experimental study of the microstructural chemistry of plasma-sprayed WC–12%Co coatings deposited at different standoff distances, before and after $CO_2$ laser remelting. Further, the effects of treatment on porosity, microhardness and phase composition of the materials have also been analyzed and discussed.

## 2. Experimental

WC–12%Co cermet coating powder AMDRY-301, Sulzer Metco, USA with particle sizes ranging from 5 μm to 45 μm was used in the experiments of conventional coatings. Scanning electron microscope (SEM) analysis showed that powder has angular morphology and mostly particles were irregular and elongated in shape. The substrate material used for this conventional APS wear

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0030-3992/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.optlastec.2013.08.017

resistance coating was AISI-321 stainless steel having 5 mm thickness and 25.4 mm diameter.

### 2.1. Air plasma spraying

Thermal spraying was carried out using an air plasma spraying system consisting of a Sulzer Metco 3MB spraying gun. In order to produce a rough surface on substrate for good bonding, all specimens were grit blasted with alumina and preheated to about 150 °C prior to thermal spraying. Table 1 summarized the principal parameters used to produce different coatings.

Spray distance was the principal parameter that was varied to obtain the different coating thicknesses. For this purpose two spraying distances were utilized i.e. 80 and 100 mm, whereas, the other working parameters were same and given in Table 1. By utilizing these parameters two types of coatings were produced i.e. C-1 and C-2 which were sprayed from 80 mm and 100 mm standoff distances respectively.

### 2.2. Laser melting

After plasma spraying the coated samples were laser remelted with 2.5 kW transverse flow $CO_2$ laser. The spot size of laser beam having diameter 3 mm was adjusted on the work-piece with a ZnSe focusing lens of 120 mm focal length. For laser treatment, the samples were fixed on a CNC table which moves under the laser beam along *x*-axis. An inert shielding gas (nitrogen) was used to prevent the formation of oxide on the sample′s surface. In order to optimize the working speed for proper surface melting of coated steel, at fixed laser power, single pass on the samples were carried out at different speeds. Finally, the multiple passes with 25% overlap on the samples were performed at 50 mm/min. Before treating the samples at 50 mm/min a number of experiments were conducted to select the right laser melting speed. In this regard, the laser speed was the principal parameter which varied from 25 to 100 mm/min. However, it was observed that 50 mm/min was the most optimum in terms of microstructure. The optimized laser parameters are mentioned in Table 2.

The two laser treated coatings i.e. thick (S-1) and thin (S-2) were analyzed with optical and scanning electron microscope using standard metallographic techniques. The coating systems were studied in both cross-section and the surface of the samples. The microstructure of the conventional and laser treated zone was examined under optical microscope and Vickers hardness was measured as a function of case depth. For micro hardness measurement, LECO micro hardness tester was used. During the test 100 g of load was applied for 20 s. The hardness testing was done on the cross sections of the coated samples. At least five to ten readings were recorded in this regard.

SEM was used for microstructures and compositions analysis. X-ray diffraction analysis was done for the analysis of metallurgical phase composition. Ni-filtered Cu-K$\alpha$ radiations were utilized to scan the coated samples and the spraying powder using JEOL JDX-8030 diffractometer. The samples were scanned from 20° to 100° 2$\theta$ with scan step of 0.05°. The relevant amount of phases was estimated by integrated intensity ratio method.

**Table 1**
Principal parameters used in plasma spraying at different spraying distance.

| Parameter | Spraying distance, mm | |
|---|---|---|
| | 80 | 100 |
| Current (A) | 500 | 500 |
| Voltage (V) | 50 | 50 |
| Time (min) | 3 | 3 |
| No. of passes | 59 | 58 |
| Carrier gas flow rate (SCFH) | 20 | 20 |
| Powder feed rate (lb/h) | 10 | 10 |

**Table 2**
Optimum parameters used during laser melting of two types of coatings.

| Parameter | Values |
|---|---|
| Laser power (W) | 700 |
| Spot size (mm) | 3 |
| Focal length of lens (mm) | 120 |
| Shielding gas | Nitrogen |
| Working speed (mm/min) | 50 |

## 3. Results and discussion

### 3.1. Metallography of as-sprayed coatings

After grinding and polishing, two set of coatings were observed under optical and scanning electron microscope. The cross section of the samples revealed that the coating sprayed at 80 mm and 100 mm standoff distance having 430 μm and 260 μm thickness, respectively, Figs. 1 and 2. It was also observed that the coating sprayed at 80 mm standoff distance was more porous as compared to that deposited at 100 mm distance, Figs. 3 and 4. This may be due to lesser flight time available to the particles in plasma flame when sprayed at 80 mm distance. The carbide particles did not melt properly, Fig. 3, and therefore the formation of splats is less than that as in 100 mm distance coating. Some fine cracks were also observed in both samples which were formed during the cooling of the sprayed particles. Further, it was also noted that when the coating deposited at 80 mm distance, the interface between the coating and the substrate became poor as compared to that sprayed at 100 mm. The weaker interface maybe resulted due to less splat formation, as discussed above and hence the quality of the coating deteriorated. The increase in coating thickness also contributes towards the increase in residual stresses [19] which may increased up to an extent that the coating delaminated from the substrate.

### 3.2. Metallography of laser treated coating

In as polished condition, the cross section of the samples revealed a modified layer, Fig. 5. The thickness of these layers varies from 610 to 690 μm for S-1and S-2 respectively. It was observe that in both

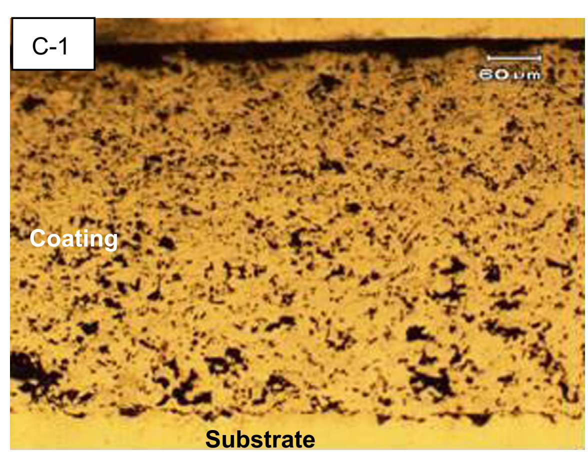


**Fig. 1.** Coating thickness deposited at 80 mm standoff distance.