Effects of Laser Treatment on WC-12%Co Cermet Coating Deposited by Air Plasma Spraying Technique

Mohammad Ajmal[a], Muhammad Afzal[a], Muhammad Yousaf Anwar[a], Liaqat Ali[a] and
Aameer. Nusair Khan[b]

[a]Dept. of Met. and Materials Engineering, University of Engineering and Technology, G. T Road, Lahore, Pakistan.
[b]Institute of Industrial Control System, Rawalpindi, Pakistan
mohammad_ajmal@hotmail.com, afzalmaz@gmail.com, myanwar@uet.edu.pk, liaqat_kasuri@uet.edu.pk and
aamer.nusair@yahoo.com

Abstract

Tungsten carbide powder with 12% Co was deposited on AISI 321 stainless steel substrate using Air Plasma Spraying (APS) technique. The coating was produced at 80 mm standoff distance. The coated samples were treated with CO_2 Laser under the shroud of nitrogen gas. A series of experimentation was carried out in order to optimize the laser parameters. After laser melting, the modified surfaces were characterized and compared with as sprayed surfaces.It was observed that the laser melting process produced defect free surfaces compared to conventional coating.

Key Words: Air plasma spraying, WC-12%Co coating, Laser treating, Microhardness, Microstructure.

1. Introduction

During the last several decades, tungsten carbide in a cobalt binder, has been widely used in number of engineering applications like cutting tools, dies, rock drills, mining, wear resistant nozzles and other applications. These variety of applications are possible due to distinctive combination of high hardness, high resistance to abrasive or erosive wear and toughness of the WC–Co cermet and the ability of material being employed as a bulk or as a coating [1, 2]. WC–Cocermets 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 [3, 4]. APS, in these coating techniques, provide higher temperatures. However, the decarburization of WC into W_2C, W_3C and even metallic W phase leads to the degradation of coating properties and limits the application of these coatings to temperature below 450 □C [5].

On the other hand, the microstructure of plasma sprayed coatings has many defects such as comparatively high percentage of porosity, weak interconnection between the solidified splats and a relatively inhomogeneous coating structure. The porosity, in particular, not only reduces the mechanical properties of the coating, but can also reduce the corrosion resistance due to the micro-channels through which the corrosive media can reach the substrate [6].

Laser re-melting is a relatively new technique by which the inherent defects in the coating microstructure can be controlled and significantly improved. Further, Laser Surface Alloying (LSA) is also a recent and important area of research used to enhance the surface properties of materials. The objective of both techniques is to fuse, completely or partially, a material having good surface properties (e.g. ceramic or cermets) so that the newly solidified material exhibits more homogeneous behavior. There are number of researchers recently worked in this field [7–15], though few studies reported the results of carbides treatments [6].

As with most thermal spraying processes, laser cladding and melting could also lead to WC dissolution and precipitation of brittle phases, depending on laser parameters [1, 16–18]. Thus process parameters have to be carefully controlled to minimize the carbide dissolution [17–19]. In the present study, the effects of laser modification on WC - 12% Co, sprayed by Air Plasma Spraying System, has been studied.

2 Experimental

2.1 Air Plasma Spraying

In these experiments, first of all APS conventional coating was applied on AISI 321 stainless steel substrate having 5mm thickness and 25.4 mm diameter. These substrate coupons were placed in an aluminum fixture which rotated during the spraying operation so that uniform coating could be made possible on all the substrates. The substrates were preheated to 150º C using plasma gun just prior to plasma spraying. After preheating, the plasma gun was allowed to coat the substrates. All the coatings were deposited at the standoff distance of 80 mm. The parameters used during coating are given in Table 1.

Table 1: Parameters used during plasma spraying.

Parameters	Values
Current, (A)	500
Voltage, (V)	50
No. of Passes	59
Carrier Gas Flow Rate, (SCFH)	20
Powder Feed Rate, (lb/hr)	10
Spraying distance, mm	80

2.2 Laser Treating Procedure

The surface of WC - 12% Co coated 321 stainless steel was re-melted with 2.5 KW transverse flow CO_2 laser. The spot size having diameter 2.5 mm of laser beam was adjusted on the work piece with a 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. Nitrogen was used as an inert shielding gas to prevent the formation of oxides on the sample's surface. The laser parameters are given in Table 2.

Table 2: Parameters used during the laser treatment.

Parameters (Unit)	Values
Laser Power (Watts)	700
Spot size (mm)	2.5
Focal length of lens (mm)	120
Shielding gas, Nitrogen, (bar)	0.5
Working speed (mm/min)	50

2.3 Characterization Techniques

The samples were cut, mounted, ground and polished along the cross-section for metallographic study. The microstructures of the APS coating and laser treated zone were examined under optical and electron microscopes and Vickers hardness was measured as a function of case depth as well as across the laser bead width. SEM was also used for microstructures and compositions analysis.

3. Results and Discussions

3.1 APS Coating

As sprayed WC – 12 %Co coating i.e. before any laser treatment was observed under the SEM. It was noted that the coating comprised of many features including the presence of porosity throughout the coating, un-melted WC particles, entrapped gas voids, interfacial defects, rough surface and the presences of different phases within the coating, as shown in Figure1. Regarding the percentage porosity of the coating system, the cross section of the sample was analyzed on image analyzer attached with optical microscope. It was observed that the percentage of porosity vary from place to place and the average value lie closed to the 10%. Similarly, the other features were also characterized on the image analyzer and it was found that the size of un-melted particles was about 5 µm to 9 µm. The presence of un-melted particles demonstrates that either the temperature was not enough or the particles were too large to completely melt in the plume of the plasma.

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, Figure1, and, therefore, the formation of splats is less. Some fine cracks were also observed which might be formed during the cooling of the sprayed particles. Further, it was also noted that the interface between the coating and the substrate became poor. The weaker interface might be resulted due to less splat formation, and hence the quality of the coating deteriorated. The increase in coating thickness also contributes towards the increase in residual stresses which may increase up to an extent that the coating delaminated from the substrate. In other characteristics, the surface roughness of the coating varied from 5 to 6 µm and the hardness ranging from 650 to 1050 Hv. A large variation in hardness is due to the presence of different phases in the coating. X-Ray diffraction analysis of the as sprayed coating revealed that 65% W_2C phase was found along with 25% $Co_3W_9C_4$ and 10% WC phases. The cross section of the samples revealed that the coating had 430 µm thickness.

3.2 Dissolution of WC Particles Using APS Technique

In the plasma plume there were different sizes of powder particles ranging from 5 µm to 45 µm. When these particles passed through the plasma, they experienced different velocities due to their difference in masses. The smaller particles comparatively lost their velocity more quickly as compared to larger particles; this is due to high inertia related with the large particles. Therefore, sufficient chances for larger particles to travel longer as compared to smaller one. Consequently, the dissolution of comparatively larger particles can be observed in microstructures, as shown in

Figure 2. The dissolution of particle can be explained by a typical behavior of WC-12%Co powder during the plasma spraying, the schematic of the geometric changes are shown in Fig. 2.

In this regard, the mechanism of dissolution of the tungsten carbide particle can be seen in Fig. 2, where a WC particle is dissolving in the surrounding cobalt matrix. The process of dissolution is also evident by observing the chemical composition profile (Figure 3), where the change in weight percentage of W and Co can be observed for different regions.

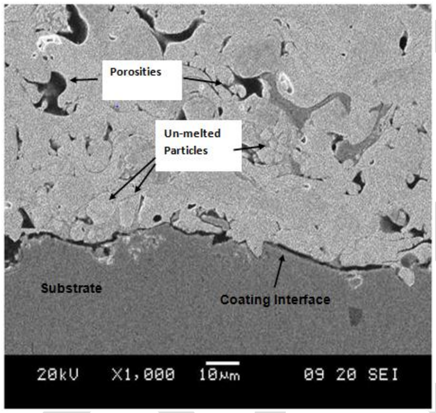

Figure 1: Important features of conventional APS coating.

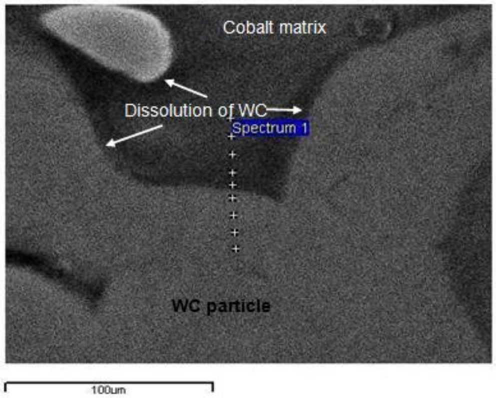

Figure 2: Dissolution of WC particles into cobalt matrix.

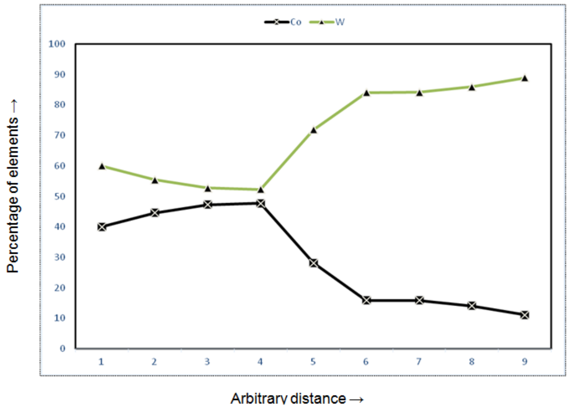

Figure 3: SEM composition profile shows that WC particles melted in Co matrix.

3.3 Surface Modification by Laser Re-melting

Due to CO_2 laser, WC-Co layer starts to melt and the melting depth increases with decreasing the working speed of laser. It was observed that the WC-Co layer intermix with base metal to form a new composite material which naturally has good adhesion and excellent surface properties. EDS profile, Figure 4 and Figure 5, demonstrates the chemical composition variation with depth.

It was detected that the modified surface properties depend upon the coating thickness and laser energy density. The variation of compositions along the laser melted zone is shown in the Figure 4. At the top surface the variation in the composition was smooth which predicts the uniform mixing of the WC-Co with base metal however some refinement were also found near the interface of melting zone and base metal. It can be explained that the cooling rate was maximum at the interface and temperature might be insufficient to homogenize the material. Further, the composition of major components along the depth changes drastically at each point. This was due to the higher thickness of WC-Co layer. The fluctuation in composition may be appeared owing to clustering in the laser treated zone.

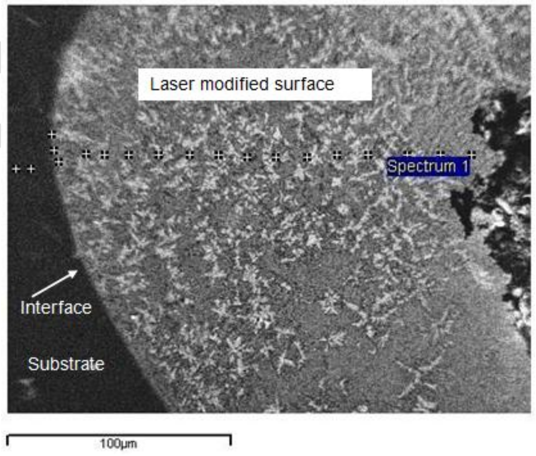

Figure 4: Chemical profile of modified surface from laser bead height to substrate.

It was observed that the modified laser treated layer has good appearance without any discontinuities as well free of cracks. Further, it was also observed that a continuous and sound interface was developed after the laser treatment, as shown in Figure 4.

Improper features such as cracks or separation were not observed in laser modified layers, as were in as sprayed APS coating as shown in Figure 4 and Figure 6.

A cellular dendritic structure obtained after laser treatment showing uniform mixing of WC-12%Co coating into SS 321 substrate as shown in Figure 6. EDS analysis indicate that white region has major in W constituents while dark regions have maximum Fe.

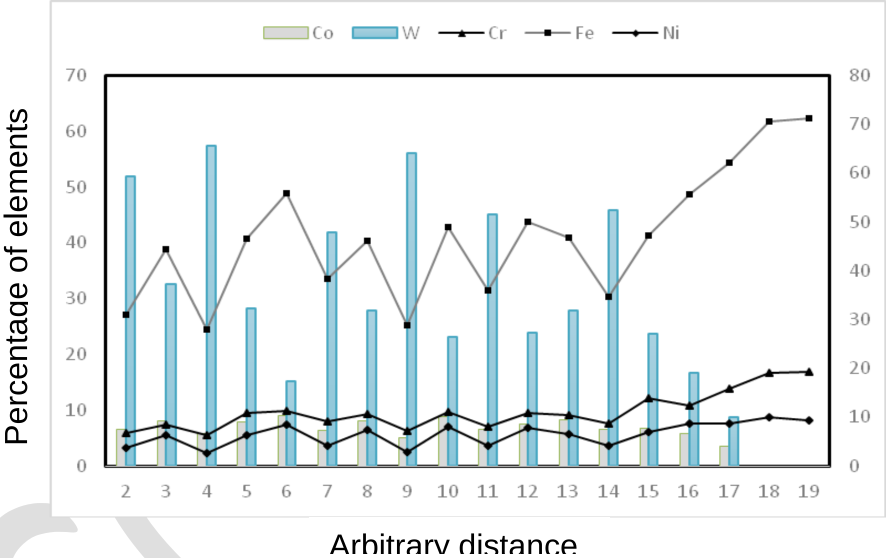

Figure 5: EDS profile showing the variation in composition along the depth of the laser melted zone.

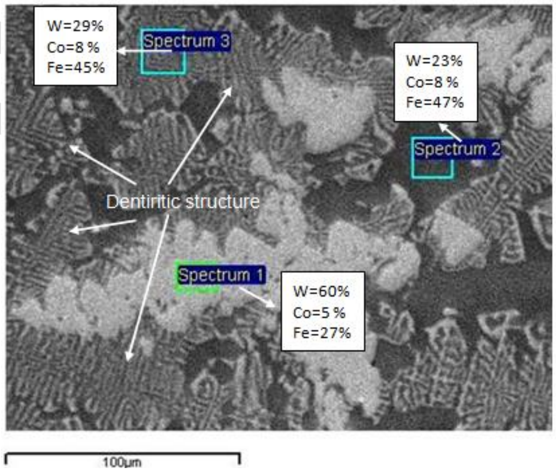

Figure 6: Microstructure showing the morphology of dendrites after solidification of laser modified surface.

3.3 Micro-hardness Testing

The micro-hardness profiles along the depth and width of laser melted zone for different speeds are shown in the Figure 7 and Figure 8. It was observed that the depth of the laser treated zones showed a uniform hardness values with a minimum variations. Thus, the percentage of WC phase increases with increasing the laser speed because less base metal was available to intermix with overlay coating. The increase in WC phase in shallower beads resulted in an increased hardness of the surface.

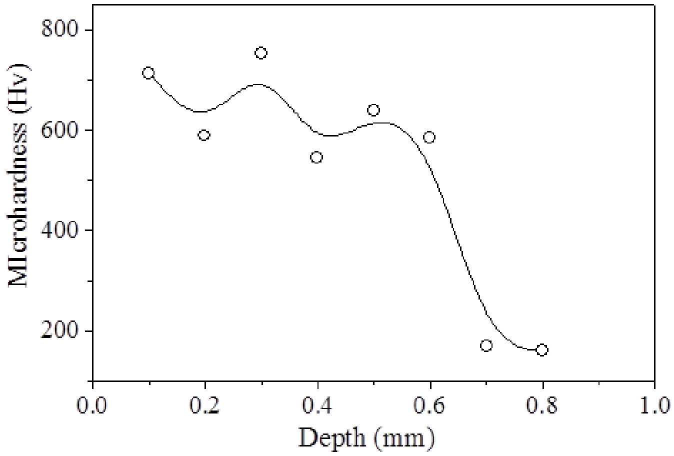

Figure 7: Hardness profile against the depth of modified surface.

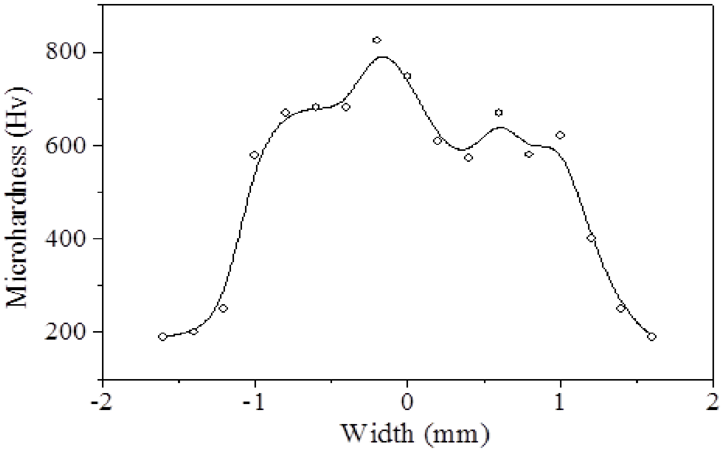

Figure 8: Hardness profile against the width of modified surface.

Conclusions

This study shows that overlay coatings deposited by Air Plasma Spraying can be improved by laser treatment. From the microstructure of the treated samples it can be inferred that, after laser treatment the adhesion of the top surface improved drastically. The melting and solidification process reduces the inherent defects within the APS sprayed coatings. It was observed that the tungsten carbide mixed with the base metal enhanced significantly the hardness of the substrate. It was observed that the surface hardness can be homogenized by controlling the laser parameters especially the speed of a laser gun.

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References

[1] Xiong Y, Smugeresky J. E, Schoenung J. M., “The influence of working distance on laser deposited WC-Co”, J Mater ProcTechnol; 209(10): 4935–4941(2009).

[2] Balla V. K, Bose S, Bandyopadhyay A., “Microstructure and wear properties of laser deposited WC–12%Co composites”, Mater Sci Eng. A; 527(24-25): 6677–6682(2010).

[3] Xie G, Zhang J, Lu Y, He Z, Hu B, Zhang D, Wang K, Lin P., “Influence of laser treatment on the corrosion properties of plasma-sprayed Ni-coated WC coatings”, Appl Surf Sci; 253(23): 9198–9202(2007).

[4] Rhys-Jones T. N., “Thermally sprayed coating systems for surface protection and clearance control application in aero engines”, Surf Coat Technol.; 43–44(1): 402–415(1990).

[5] Mann B. S, Prakash B., “High temperature friction and *wear* characteristics of materials for steam valve spindle application”, Wear 240(1-2), 223–230(2000).

[6] Mateos J, Cuetos J. M, Fernandez E, Vijande R., “Tribological behaviour of plasma-sprayed WC coatings with and without laser remelting”, Wear; 239(2): 274–281(2000).

[7] Barletta M, Rubino G, Gisario A., “Adhesion and wear resistance of CVD diamond coatings on laser treated WC–Co substrates”, Wear; 271(9-10): 2016–2024(2011).

[8] Li T, Lou Q, Dong J, Wei Y, Liu J., “Modified surface morphology in surface ablation of cobalt-cemented tungsten carbide with pulsed UV laser radiation”, Appl Surf Sci; 172(3-4): 331–344(2001).

[9] Wang K, Liu J, Han D., “Microstructure and properties of laser remelted cobalt based and nickel based plasma sprayed coatings”, Surf Eng.; 12 (3): 235–238(1996).

[10] Tjong S. C, Ku J. S, Ho N. J, “Corrosion behaviour of laser melted plasma sprayed coatings on 12% chromium dual phase steel” Mater Sci Technol; 13 (1): 56–60(1997).

[11] Liu Y, Wang H. M., “Microstructure and wear property of laser-clad Co_3Mo_2Si/Co_{ss} wear resistant coatings”, Surf Coat Technol; 205 (2): 377–382 (2010).

[12] Zhang Y. M, Hida M, Sakakibara A, Takemoto Y., “Effect of WC addition on microstructures of laser melted Ni-based alloy powder”, Surf Coat Technol; 169-170: 384–388(2003).

[13] Cheng F. T, Kwok C. T, Man H. C, “Cavitation erosion resistance of stainless steel laser-clad with WC-reinforced MMC”, Mater Lett; 57 (4): 969– 974(2002).

[14] Zhou S, Dai X, Zheng H., “Microstructure and wear resistance of Fe-based WC coating by multi-track overlapping laser induction hybrid rapid cladding”, Opt Laser Technol; 44 (1): 190–197(2012).

[15] Taha-al Z. Y, Hashmi M. S, Yilbas B. S, “Effect of WC on the residual stress in the laser treated HVOF coating”, J Mater Proc Technol; 209 (7): 3172–3181(2009).

[16] Wu P, Zhou C. Z, Tang X. N, “Microstructural characterization and wear behavior of laser cladded nickel-based and tungsten carbide composite coatings”, Surf Coat Technol; 166 (1): 84–88(2003).

[17] Yang Y, Man H. C, “Microstructure evolution of laser clad layers of W–C–Co alloy powders”, Surf Coat Technol; 132(2-3): 130–136(2000).

[18] Przybylowicz J, Kusinski J., “Structure of laser cladded tungsten carbide composite coatings”, J Mater Proc Technol; 109 (1-2): 154–160(2001).

[19] Riabkina-Fishman M, Rabkin E, Levin P, Frage N, Dariel M. P, Weisheit A, Galun R, Mordike B. L, “Laser produced functionally graded tungsten carbide coatings on M2 high-speed tool steel” Mater Sci Eng A; 302(1): 106–114(2001).