SURFACE MODIFICATION OF HVOF THERMAL SPRAYED WC–CoCr COATINGS BY LASER TREATMENT

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ABSTRACT: In this work the affects of laser characteristics on microstructure and microhardness of high velocity oxygen fuel sprayed (HVOF) WC–CoCr coatings were investigated. The coating was deposited with a Sulzer Metco WokaJet™-400 kerosene fuel and the laser surface treatments were applied using CO_2 laser with 10.6 µm wavelength. Large variations in surface properties were produced from variation in the laser processing parameters. In total, four levels of peak power (100, 200, 300 and 350 W), four levels of spot diameter (0.2, 0.4, 0.6 and 1 mm) and three levels of pulse repetition frequency (PRF) were investigated. An initial set of tests were followed by a more detailed 3^3 factorial design of experiments. Pulse repetition frequency and duty cycle were set in order to maintain the same overlap in the x and y directions for the raster scanned sample spot impact dimensions. Overlaps of 30% were used in the initial tests and 10% in the more detailed trials. The results have shown that care must be taken to keep the irradiance at a relatively low level compared to uncoated surfaces. High irradiance can in this case result in rough and porous surfaces. Lower levels of irradiance are shown to provide more uniform microstructures, reduced porosity and increased microhardness.

KEYWORDS: Thermal spraying; Laser surface hardening; WC-CoCr; Tooling

1 INTRODUCTION

HVOF thermal spray process has become a reliable alternative to electrolytic hard chrome plating in the aeronautical industry to coat landing gear components [1-3]. The process is ideal for both the coating of new components and for the repair and overhaul of worn components. Tungsten cabide and chromium cabide based coatings, in particular, have developed into a viable alternative in component life extension applications due to their strong adhesion, high cohesive strength, high residual stresses, wear and silt erosion resistance capabilities [4, 5]. Tungsten cabide particles in the coating provide high hardness and wear resistance while the coating toughness is generated by the metal binder Cobalt-Chrome. Studies [5, 6] show that WC-CoCr HOVF sprayed display remarkable life extention qualities compared to the conventional coating i.e. applied by atmospheric plasma spraying technique, PVD and boronising at different testing velocities. Tungsten cabide alone has a very high hardness of 2200 Hv, however, the HVOF coating of WC-CoCr based powder has a low hardness of 1200 Hv [7, 8]. Furthermore, although the bonding strength of HVOF is greater compared to other spray coating its use is rendered by the poor interface characteristics [9].

Several reports have suggested that abrasive wear resistance is controlled by several factors like powder morphology, sizes and distribution of carbide particles, hardness of the particles, matric properties and volume fraction [8,10,11].

In order to further improve the range of applications thermally sprayed cermet coatings, laser surface treatment of the coating has been introduced to tackle the homogenity and porosity defects while improving the hardness. Surface laser treatment has been found to be an effective method to alter the microstructure and mechanical properties of conventional coatings. Improving the hardness and wear resistance of WC–CoCr by reducing homogeneity, porosity and other microstructural defects of the coatings would have good potential for tooling applications [12-14].

Previous work has examined the effects of laser processing parameters, including scanning velocity, on the microstructure, hardness, wear resistance and porosity of High Velocity Oxygen Fuel (HVOF) thermally sprayed WC-CrC-Ni coatings [7, 15]. This work showed that the laser surface hardening of WC-CrC-Ni coatings can effectively increase the hardness and reduce the porosity in the coating with a corresponding reduction in the thickness of the coating. Decrease in porosity and thickness of the coating were mainly attributed to the laser scanning velocity reduction.

The effect of laser beam spot size, peak power and degree of beam overlap between subsequent passes on coating porosity and hardness has not been previously optimised for WC-CoCr coated mild steel. The work presented in this study aims to address this gap of knowledge.

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2 EXPERIMENTAL

Samples of mild steel 20 mm wide, 5 mm thick and about 100 mm in length were thermal spray coated with WC-10Co4Cr. Coatings of 0.1 mm thickness were deposited with a Sulzer Metco WokaJet™-400 kerosene fuel and subsequently laser surface treatments were applied. Separate sets of laser processing conditions were applied over 20 mm by 20 mm areas. A Rofin 1.5kW CO_2 laser with 10.6 µm wavelength operating in pulsed mode was used for this work. The sample traverse speed was set to 83 mm/s and overlap at approximately 30%. The initial conditions investigated are shown in Table 1.

A second design of experiments was performed with lower processing powers in order to avoid total fusion of the coating and provide for less microstructural diffusion of iron from the substrate. With a goal to achieve a sample coating with uniform microstructure and low porosity the processing conditions for the second design of experiments were chosen. A 3^3 factorial design was used with the PRF, power and spot size set as the experimental parameters. PRF levels were 463, 596, and 834 Hz; power levels were 100, 200 and 300 W; and spot size levels were 0.2, 0.6 and 1.0 mm. The PRF of 463, 596, and 834 Hz respectively represent subsequent spot overlaps of 10, 30 and 50%. The duty cycle was set to 30% for all tests.

Table 1: *Processing conditions for initial laser processing conditions*

Sample	Peak Power (W)	Duty Cycle (%)	PRF (Hz)	Spot Diameter (mm)
L1	300	29.7	271	0.4
L2	350	25.5	271	0.4
L3	300	29.7	542	0.2
L4	350	25.5	542	0.2

Cross sectional microscopy views were achieved by sectioning the sample perpendicular to the longitudinal axis. An initial grinding process was done and subsequent polishing at 6µm, 3µm and 0.5 µm particle sizes. Microstructure analysis was carried out using a scanning electron microscope, Carl Zeiss (Evo LS15), set at high contrast to reveal the coating defects. Vickers microhardness characterisation was completed using a 300p load.

3 RESULTS

A discontinuous coating with the presence of some large pores was produced from the initial experiments. The Vickers microhardness results for these samples are shown in Table 2.

Table 2: *Vickers micro-hardness results ($HV_{0.3}$) for initial samples*

Sample	Max	Average	Min	Std. Dev.
L1	1570	1467	1338	79
L2	1437	1296	1139	108
L3	1595	1525	1458	59
L4	1570	1421	1301	76
Not treated	1625	1503	1390	118

No significant changes in average hardness compared to the untreated coating were observed. This was due to the highly fused coating/substrate mixture with cracks evident within these coatings as shown in Figure 1. From this initial work it was clear that lower levels of irradiance would be required in order to produce less fragile coatings.

The large scale discontinuities across the sample surface were found to be due to a variation in the speed of the sample beneath the laser head during sample processing. The speed profile of the traversing table was determined by high speed camera and video processing. It was determined that within the initial and final sections of the displacement, the speed of the sample movement was significantly less than had been set. This would provide a non-uniform exposure time for samples and was seen in the result of non-homogenous coating results in the initial tests. To overcome this problem in the subsequent tests the sample was set to traverse a distance of 50 mm before laser processing was started and a for a further 50 mm off the sample before coming to a stop.

The microhardness results of a sub-set of the tested conditions from the second set of experiments are shown in Table 3. This represents the results for all of the samples processed at 463 Hz or 10% overlap.

It can be seen from these results that micro-hardness values are greater than that of the untreated coating, 1503 $HV_{0.3}$, were achieve in many of the samples. The best set of conditions was found by using the lowest peak power of 100W and the spot size of 0.2 mm which represents approximately a 30% increase in hardness.

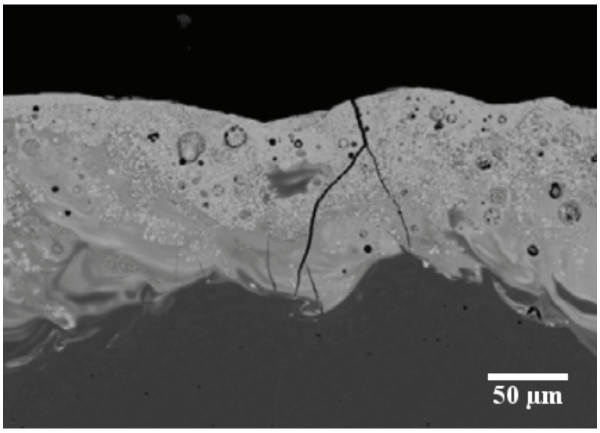

Figure 1: *SEM image of initial trial runs, 0.4mm spotsize and 300W peak power.*

Table 3: *Vickers micro-hardness results (HV0.3) for initial samples*

		Power (W)		
		100	**200**	**300**
Spotsize (mm)	**0.2**	1937	1642	Coating ablated
	0.6	1539	1518	1501
	1.0	1725	1641	1238

High peak powers show a decrease of microhardness at all laser beam spotsizes. Ablation of the coating was also observed at high peak power and low beam spotsizes, see Figure 2. This was due to the extremely high irradiance; the ablation threshold was estimated to be approximately 600 J/cm^2.

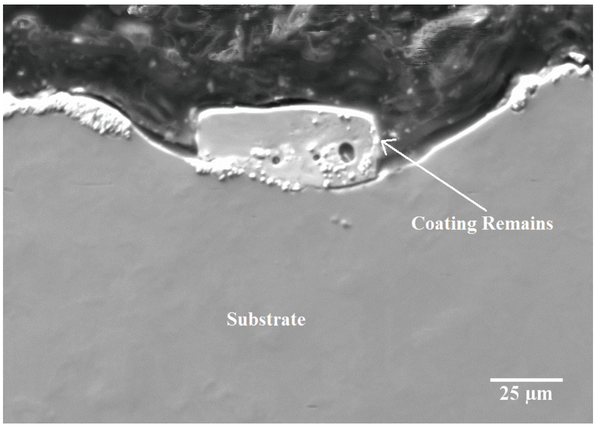

Figure 2: *SEM images of showing coating ablation at 300W and 0.2 mm spot size.*

SEM images of the untreated and treated surfaces are shown in Figure 3. Figure 3 (a) and (b) show the thermally sprayed coating respectively without and with laser heat treatment applied. Figure 4 (a) and (b) show higher magnifications of the coating/substrate interface respectively without and with laser heat treatment applied. Some porosity can be seen in the micrographs of the non-heat treated samples. In Figure 4 (a), the faceted WC particles (lighter shade) can be seen in the CoCr matrix. Common problems of the laser treatments included relatively rough surfaces produced and cracks emanating from the laser processed region into the coating, see Figure 3 (b) which represents the surface after processing with a power of 200W, PRF of 463 Hz and spot size of 0.2 mm. Figure 4 (b) shows the coating/substrate interface after laser processing with 100W, PRF of 463 Hz and a spot size of 0.2 mm. When compared to the untreated surface, Figure 4 (a), it can be seen that much less porosity and a more uniform appearance in structure is present. This can be attributed to the melting of the CoCr binding phase and subsequent re-distribution.

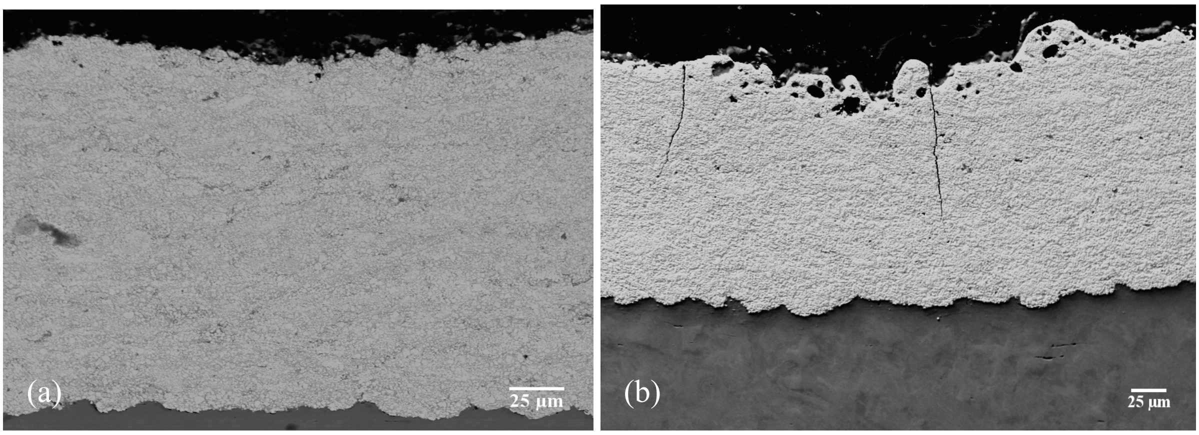

Figure 3: *SEM images of (a) thermally sprayed coating without any laser treatment; and (b) laser treated coating with peak power of 200W, PRF of 463 Hz and spot size of 0.2 mm.*

4 CONCLUSION

From the first set experimental laser processing parameters, cracked and fragile structures were obtained. No significant change in microhardness was found from these initial trials. However these tests showed the potential to melt the binding phase and locally fuse the microstructure, and pointed to the care needed during laser surface heat treatment to keep the irradiance at a relatively low level compared to processing parameters for uncoated surfaces. High irradiance resulted in visually poorer roughness and porous surfaces. High energy densities also resulted in ablation of the coating but also signified non porous coating remains. A broader range of processing parameters, largely with lower levels of irradiance, was investigated in the second set of experiments. These lower levels of irradiance have been shown to provide more uniform microstructures, reduced porosity and increased micro-hardness compared to the non laser treated samples. High irradiance settings produce a reduced microhardness compared to the non laser treat sample. Future work is needed in order to optimise this process in terms of providing smoother, pore free and uniform coating structures that can be repeatably used in industrial applications.

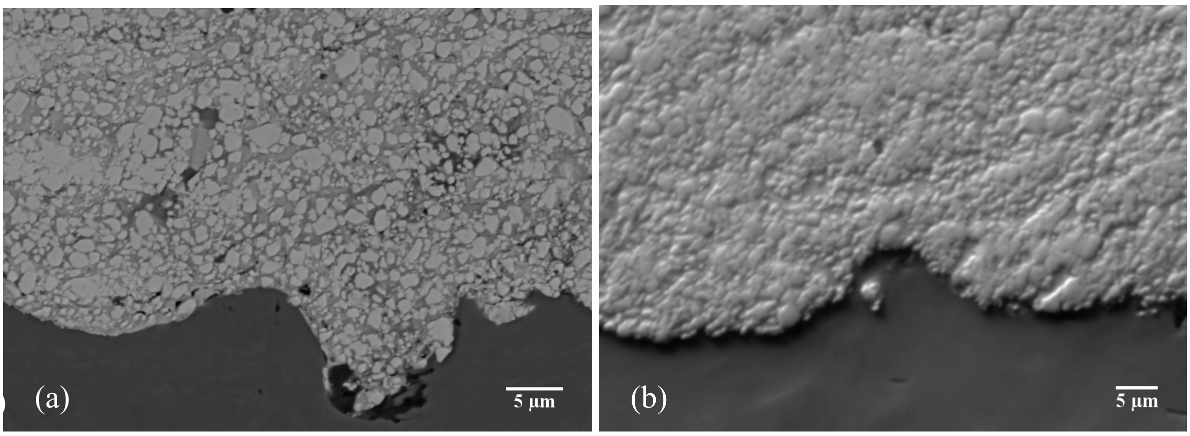

Figure 4: *SEM images of (a) high magnification of thermally sprayed coating without laser treatment at substrate/coating interface; and (b) laser treated coated with peak power of 100 W, PRF or 463 Hz, and spot size of 0.2 mm.*

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