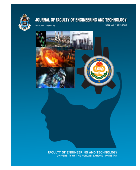
JFET 24(2) (2017) 01-10

Journal of Faculty of Engineering & Technology

journal homepage: www.pu.edu.pk/journals/index.php/jfet/index



EFFECT OF SURFACE PROFILE OF MILD STEEL SUBSTRATE UPON ADHESION STRENGTH OF WC-11%CO FLAME SPRAY COATING

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Abstract

Improving surface properties especially high wear and impact resistance is always an existing challenge for automotive, aerospace, defense and agriculture industries etc. Surface engineering has developed various processes and methods to encounter this problem using plasma spray, electric arc, HVOF, PVD and flame spray etc. Amongst them flame spray technique has its own features to produce cermet coatings on steel substrates.
In the present study, behavior of WC-11%Co coatings deposited on Mild Steel by means of flame spray process has been studied. It was found that surface roughness of substrate plays a vital role in the adhesion of such type of coatings. Therefore, different surface roughness profiles on substrate were generated by blasting sand and steel grits of various sizes.
Surface profilometer was used to evaluate the surface roughness of substrates while the adhesion strength of flame spray coatings was determined by Pull test. SEM/EDX was used to study the morphology of flame spray coated samples and hardness was measured by micro-Vickers hardness tester. The results illustrate the optimum values of surface roughness to achieve better properties of WC-11%Co coatings for various engineering applications.

Keywords: Wear, Surface Engineering, Cermet Coatings, Surface Roughness, Adhesion Strength, Profilometer, SEM/EDX

1. Introduction

A phenomenon of spraying molten or liquefied material onto a metallic substrate to provide coating is known as Flame spray process. In this process material in the form of fine particles is melted in a flame (oxy-acetylene or hydrogen most common) to form a refined spray. The spray when comes into contact with the ready face of a substrate, the fine liquefied droplets quickly consolidate and solidify to form a coating. The development of the Plasma Flame Spray technique was surely a big accomplishment in Flame spray technology. This improvement allowed the use of materials with a melting point over 5000 °F (limit for oxy-acetylene). The plasma flame allows the choice of an inert gas for the flame medium to avoid chemical reaction such as oxidation, during heating and application of the spray material. Later, the term 'Flame Spray' was generally replaced by the term 'Thermal Spray' [1].

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D. J. Varacalle et al. [2] explained that surface preparation and roughness were the significant features affecting the adhesion strength of a coating. Properly cleaned and roughened surface provided the critical interface upon which the plasticized or molten particles stroke during the thermal spray process. A better metal to metal contact was offered by an appropriately prepared surface for inter atomic interaction between work piece and particles being sprayed. Further, it was reported that the adhesion strength was affected by spray distance, current and spray gun pressure [2].

S. Amada and T. Hirose [3] made useful attempts to improve adhesive strength of ceramics and cermets' coatings. For this, surfaces of substrates were scratched by blasting grits, sometimes by angled blasting as a pretreatment. The highest value of adhesion strength was resulted by blasting angle of 75° [3].

M.H. Staia et al. [4] studied thermal sprayed WC-Co coatings and reported their higher hardness, abrasion and erosion-induced wear resistance. In addition, number of studies has reported the variation in wear resistance and hardness with respect to coating composition.

Table 1: Roughness values for AISI 1020 steel substrate as a function of grit blasting pressure [4]

Sand blasting pressure (MPa)	**Ra** (Avg.)
0.345	9.74
0.483	10.99
0.621	12.57

Variation in grit blasting pressure from 0.345 to 0.621 MPa, resulted in a surface roughness of Ra 9.74 -12.5 µm. Moreover, it was concluded that bonding properties of WC-Co coatings were strongly influenced by surface profile [4].

S. V. Zakharov et al. [5] explained few reasons for the failure of coating due to inadequate bonding between substrate and coating. High internal stresses at interface of substrate and coating, insufficient cohesive and adhesive forces among the atoms of the substrate and coating were the key factors contributing to the low bond strength [5].

Y.Y. Wang et al. [6] explained the deposition phenomena of both WC-Co and NiCrBSi on the substrates having different surface profiles. The purpose was to explore the interlocking mechanism at the interface. WC-Co particles were deposited during high velocity oxy-fuel (HVOF) spray process due to unique thermo-physical properties. Adhesive strength of the coating was increased with increase in the surface roughness from Ra 0.059 to 9.0 µm [6].

Previous studies highlighted the effects of various compositions of cermet coatings to improve the hardness and wear properties of substrate. However, it is worth mentioning that the surface roughness of substrate may play a key role in further improving hardness, wear and impact properties of materials. In the present research work, the major objective was to study the effect of surface roughness of mild steel substrate upon adhesion strength of flame sprayed WC-11%Co coatings.

2. Experimental Methods

In the current work, coated samples of WC-11%Co were taken to study the effect of surface roughness of substrate upon adhesion behavior of applied coating. For this purpose different tests were carried out according to ASTM standard 633C to evaluate adhesion strength of coating. The ASTM C633 test method is used to determine the adhesion of a thermal spray by subjecting it to tension perpendicular to the surface. The substrate fixture that spray coating is applied to is most commonly a cylinder made of the same metal that would be used as the substrate of the coating in its actual use. If a substrate is not specified for your application, then the ASTM C633 standard specifies to use SAE 1018 or 1020 steel. A similar, but uncoated, fixture is then glued to the surface of the coating with a suitable adhesive bonding agent. The adhesive bonding agent should not be the "weakest link", but should be at least as strong as the minimum required adhesion or cohesion strength of the coating.

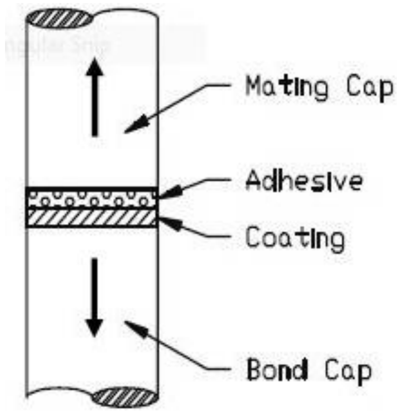

Figure: Samples assembled for adhesion test [Thermal Spray Society]

According to standard, the first step before adhesion testing was to select the suitable epoxy. The adhesion strength of ceramics and cermets flame spray coatings is comparatively lesser than 30 MPa [7]. Two identical cylindrical pairs of MS samples were taken and further two unlike (commercially available) epoxies were separately applied to face of one sample from each pair and afterward epoxy cured samples were joined head-to-head with their paired MS samples. Both pairs were placed in ovens for drying out. Samples treated with Epoxy (A) and (B) were left for 15 mins at 150°C and for 120 mins at 40°C respectively, as per epoxy instruction manuals.

The major aspect in this study is the effect of surface roughness on adhesion strength of WC-11%Co flame spray coating. For this purpose, the cylindrical MS samples were shot blasted with three types of grits. Same experimental methodology of ASTM 633 C standard was followed to evaluate adhesive strength of WC-11%Co coating.

Hardness profile is an imperative test with respect to this study because WC-Co coatings are widely used for cruel wear tear environment. It must be hard enough to suffer severe wear and tear conditions [8]. The hardness of WC-11%Co coated samples was determined using Micro Vickers hardness testing machine. Consecutive Indents were applied form substrate to coating at equal distance. The morphology of WC-11%Co was further investigated by using SEM/EDX.

3. Results and Discussion

3.1 Adhesion Test

In accordance with ASTM standard 633 C, epoxy to be used for adhesion test of coating must have greater strength than the standard coating strength. For the selection of appropriate epoxy, strengths of both epoxies were analyzed and results are given in Table 2. [9].

Table 2: Adhesion strength of both A and B epoxies

Epoxy	Failure Load (KN)	Surface Area (m^2)	Adhesion Strength (MPa)
A	15.78	5.06×10^{-4}	31.18
B	4.63	5.06×10^{-4}	9.50

The adhesion strength of both A and B epoxies are compared and graphical representation is shown in figure 1.

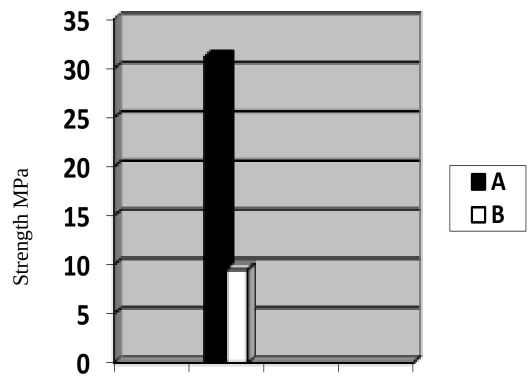

Figure 1: Comparison of Adhesion strengths of epoxies A and B.

It is clear form figure 1 that epoxy A has far better strength (~31 MPa) as compared to epoxy B (~10 MPa) resulting in its selection to fulfill the requirement of having higher strength.

3.2 Surface Roughness of Substrate and Adhesion Strength of Coating

The surfaces of all specimens were prepared by using a procedure of sand and steel grit blasting. Surface roughness values in terms of Ra were determined by using surface profilometer and results are shown in Table 3.

Table 3: Experimental values of Adhesion strength with relevant surface roughness

Sample Description	Nature	Particle Size (mm)	Ra (µm)	Adhesion Strength (MPa)
1	Coarse Sand	0.18 - 1.2	6.403	17.80
2	Steel grits	0.2 - 0.3	4.258	11.77
3	Fine Sand	0.14 - 0.7	2.618	3.159

It can be concluded from the results that high Ra value of surface roughness produced by coarse sand particles resulted in better adhesion strength of 17.8 MPa. In the light of above fallouts, it is acknowledged that adhesion strength of WC-Co flame spray coating is significantly affected by surface profile Ra [10-11].

Table 4: Relationship between Fracture load and Adhesion strength

Sample Description	**Fracture Load** (KN)	**Surface Area** (m^2)	**Adhesion Strength** (MPa)
1	5.82	3.26×10^{-4}	17.80
2	5.96	5.06×10^{-4}	11.77
3	1.03	3.26×10^{-4}	3.159

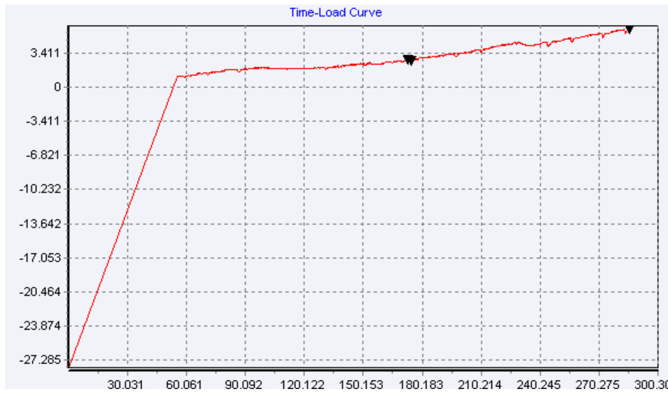

Figure 2: Time vs Load curve for sample 1.

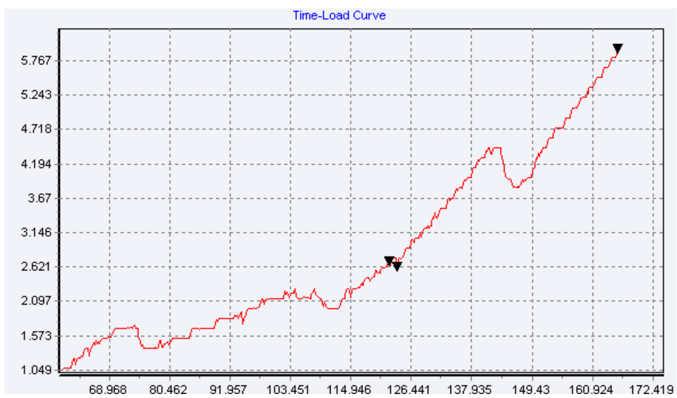

Figure 3: Time vs Load curve for sample 2.

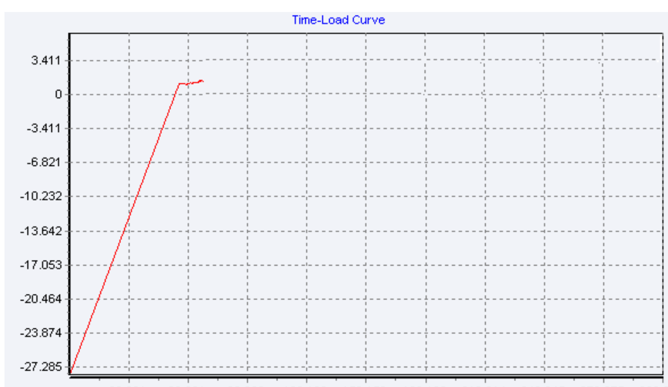

Figure 4: Time vs Load curve for sample 3.

From Figure 2, it can be stated that key coating parameters such as, elastic modulus and strength are acceptable. Figure 3 elaborates that sample with Ra value 4.258 µm generated the coating with better adhesion strength i.e. 11.77 MPa and few ductile properties. According to Figure 4, the elastic modulus came out to be fine but Ra value was not high enough to engender a coating with enhanced adhesion strength.

3.3 Hardness Profile

Shamidzu brand Micro Vickers Hardness Tester was used to determine the hardness values for all three samples and the results are shown in Table 5.

Table 5: Hardness values from substrate to coating

Indent distance (µm)	**Hardness** (HV)		
	Sample 1	Sample 2	Sample 3
20	90.5	107.4	86.8
40	91.3	107.6	89.3
60	96.2	106.0	91.3
80	122.6	104.6 *(min)*	92.6
100	661.5	628.4	648.6
120	593	838.7 *(max)*	639.1
140	600	423.7	690.7

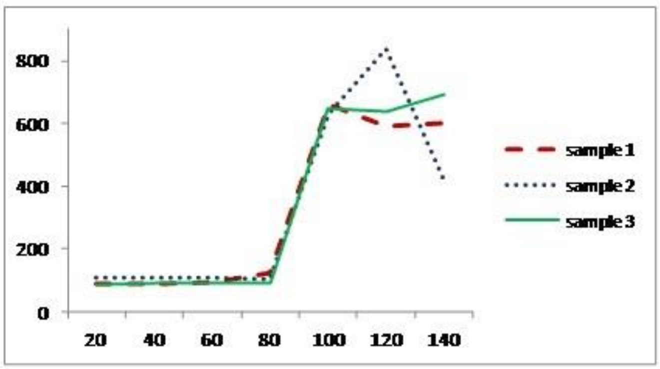

Figure 5: Line graph of samples 1, 2, and 3 showing hardness in HV (y-axis) against indent distance in µm (x-axis).

It can be seen from figure 5 that sample 2 showed maximum hardness value (838.7 HV) from 120 µm indent distance whereas it was minimum (104.6 HV) from 80 µm indent distance. The reason behind this variation in hardness is very obvious as the nature of substrate is MS and that of coating is cermet (WC-11%Co), and as the indent moved on towards coating; hardness increased consequently. Moreover, thermal spray coatings are distinguished because of their exceptional surface properties including high wear resistance and high hardness. On the other hand, 104.7 HV has been observed near the surface of substrate. This value is at higher side even with respect to MS, as the surface of substrate has been treated earlier with sand blasting in order to attain a better adhesion with coating.

3.4 Light Optical and Electron Microscopy

Samples were prepared for metallographic study following standard procedures and practices. Light optical microscope was used to capture microstructures of all three samples. Low porosity and substrate/coating interface in the sample 1 is visible as shown in Figure 6.

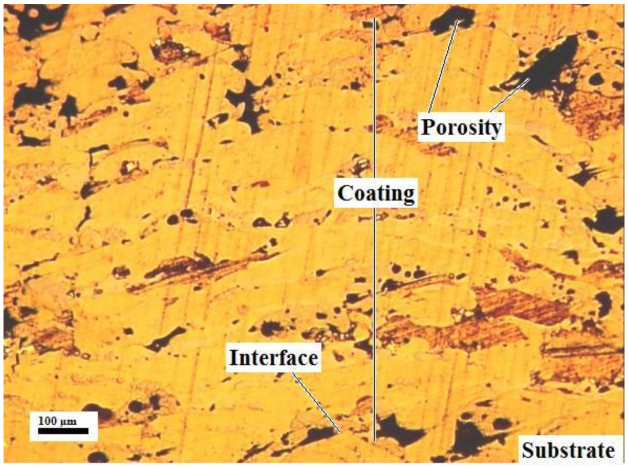

Figure 6: Micrograph showing porosity and substrate/coating interface on sample 1.

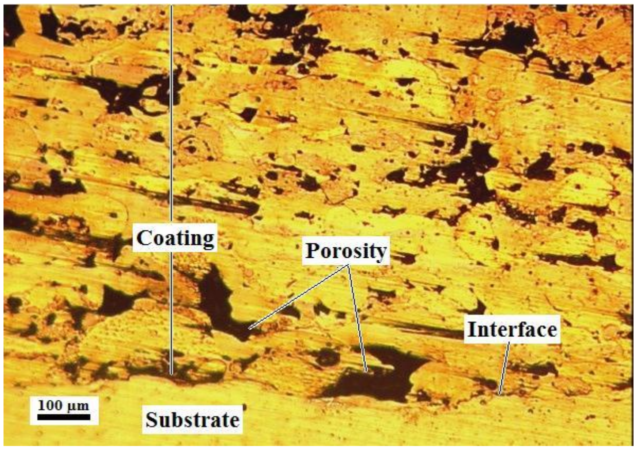

Figure 7: Micrograph showing porosity and substrate/coating interface on sample 2.

A very thin line present at the substrate/coating interface indicates good adhesion of coating of the sample 1 that was blasted by the coarse sand (0.18-1.2 mm) particles. Good adhesion could be due to strong mechanical bonding in case of coarse surface finish of the substrate.

The microstructure of sample 2 as shown in figure 7 demonstrates relatively higher porosity as compared to sample 1. The substrate/coating interface shows a satisfactory adhesion on sample 2 as revealed in Figure 7.

It can be seen that the coating on sample 3 has relatively higher porosity as compared to sample 1 and 2 as shown in Figure 8.

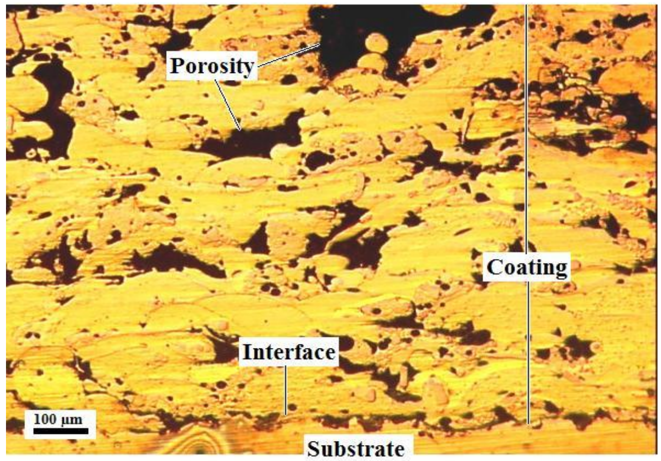

Figure 8: Micrograph showing substrate/coating interface on sample 3.

The sample 3 was blasted with fine sand particles of 0.14 - 0.7 mm size, resulting in fine surface finish. The dark spaced interface line shows poor adhesion of coating revealed in Figure 8.

3.5 SEM/EDX Analysis

Results of EDX and SEM analysis are shown in figure 9 and 10 respectively.

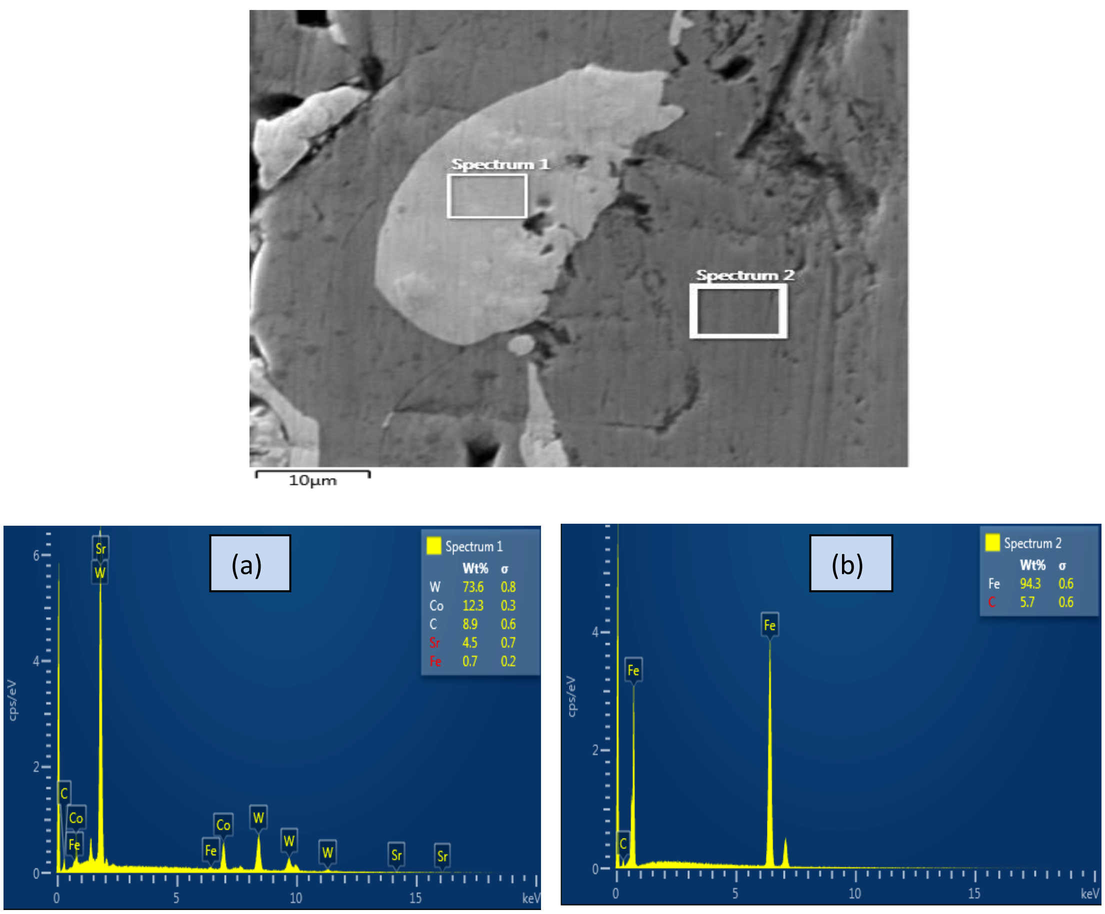

Figure 9: Sectional EDX Spectrum of coating.

EDX sectional analysis of the white phase is revealed in Figure 9 (a) i.e. Spectrum 1. Spectrum 1 illustrates the presence of WC-Co coating. Figure 9 (b) i.e. Spectrum 2 from the gray area indicates mild steel substrate.

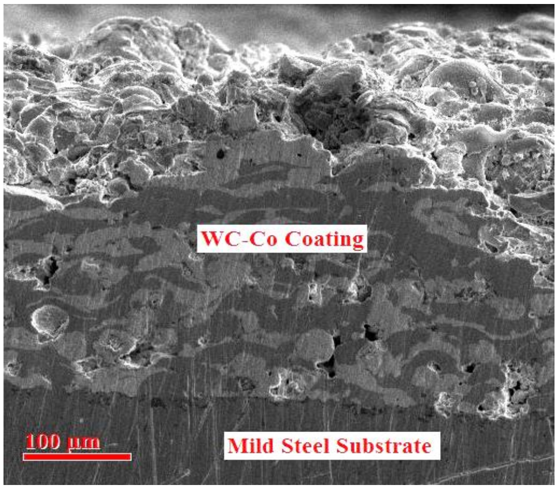

Figure 10: SEM micrographs of MS substrate and WC-Co coating.

The SEM/EDX analysis shows the melted and un-melted particles of WC in Co matrix whereas the good mechanical interlocking is being observed between the interfaces of substrate and coating.

4. Conclusions

The following conclusions are made:

- Adhesion strength of flame sprayed WC-Co coating largely depends upon the extent of surface roughness. As roughness R_a value increased from 2.618 to 6.40 µm, adhesion strength increased from 3.159 to 17.80 MPa.
- Among the grits, sand with particle size 0.18 mm – 1.2 mm induced more roughness due to its hardness and sharp edges. While steel grits with particle size range 0.2 – 0.3 mm produced satisfactory roughness. However, the sand having particles in the range 0.14 – 0.7 mm has been failed to produce appropriate roughness.
- It has been observed that surface prepared by steel grits produced the coating having a better hardness profile as compared to the coating produced by other blasting mediums.
- Keeping in view the above facts WC-Co coating may show promising results in improving the wear and impact properties of the surface of the substrate.

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