Effect of argon flow rate and standoff distance on the microstructure and wear behaviour of WC-CoCr TIG cladding

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Abstract. This study examines the micro-hardness and abrasive wear resistance of WC-CoCr cladding produced by tungsten inert gas (TIG) welding process. The effect of argon flow rate and standoff distance on the microstructure and properties of the cladding was also investigated. The morphology of WC-CoCr powder and its corresponding claddings was examined by FE-SEM analysis. The tribological behaviour of cladding was analysed by using pin-on-disc wear tribometer. High hardness and wear resistance were observed at higher values of standoff distance and argon flow rate. Wear in the cladding is mainly due to pull out of tungsten carbide particles along with plastic flow caused by yielding and extrusion of CoCr binder.

1. Introduction

Cermets are extensively employed in different industrial applications where high abrasion resistance is needed. Cermets combine the properties of ceramics and metals. Ceramics provide high hardness and wear resistance whereas metals provides high fracture toughness that makes the cermet a favourable material to be used in adverse wear conditions such as cutting and drilling. Tungsten carbide based cermets consists of hard phase tungsten carbide (WC) reinforced in ductile metallic phase in different proportions. Generally, Co, Cr, Ni and CoCr are used as metallic binders in WC based cermets[1].

Different methods have been employed to apply the coating of WC-CoCr cermet material such as high velocity oxy-fuel (HVOF) spray process, atmospheric plasma spray (APS) process and high-velocity air fuel (HVAF) spraying process etc. All of these methods have their own advantages, limitations and characteristics due to which the coatings produced by these methods have different microstructural, mechanical and tribological properties. The abrasive and sliding behaviour of WC-CoCr coating deposited on AISI 304 stainless steel substrate using high-velocity oxy-fuel (HVOF) process was analysed [2]. The results showed that fine grain cermet coating exhibited improved wear resistance as compared to the conventional coating. The influence of spray parameters of HVOF spray process on the microstructure, hardness and wear has been studied [3]. It was observed that the spray distance has lesser effect on the coating properties and wear resistance as compared to the oxygen gas flow rate and powder feed rate. The microstructure and abrasive wear behavior of WC-CoCr coating with different size of WC carbide particles deposited by HVOF spray process was also examined [4]. The results revealed that 1.2 μm-sized WC particles exhibited the higher wear resistance. The HVAF sprayed WC-CoCr coating demonstrated minimum decarburisation, better sliding and abrasive wear resistance in comparison to HVOF sprayed coating [5].
The use of alternate techniques such as plasma cladding, laser cladding and tungsten inert gas (TIG) cladding for surface modification is under intensive study. However, the varying absorption rate of laser beam in different cladded powder restricted the use of laser cladding[6]. Complex components manufactured by laser cladding are expensive and requires equipment that are sophisticated. Compared to other surface modification techniques, TIG cladding provides higher deposition rate, ease in operation and less expensive as compared to other cladding techniques [7], [8].

Various researchers have used the TIG welding for surface modification. The WC powder was deposited on AISI 304 substrate by using TIG welding [9]. The effect of processing speed and powder contents on the abrasive wear of cladding was investigated. It was observed that wear resistance and microhardness were improved. The TIG welding is also employed to coat the austenitic stainless steel powder on low carbon steel and in order to further enhance its properties and wear resistance, certain elements such as Ti, Mo and Co are also mixed in austenitic stainless steel powder [10].

In another study, AISI 1010 steel was cladded with the Ni-WC powder by using TIG as a heat source for surface modification. The effect of preplaced powder thickness, torch travel speed and current on the microstructure and hardness of coating were analysed [11]. The wear performance of TiC, TiN and WC TIG claddings deposited on carbon steel specimen were investigated by some researchers [6]. The TIG welding process was also used to clad TiC powder on the AISI 304 stainless steel plates [12]. The effect of current and torch travel speed on cladding dimensions and microstructure was analysed. The results showed remarkable improvement in wear resistance of cladding as compared to the substrate.

In present study, WC-10Co-4Cr cermet powder was cladded on the surface of the AISI 304 steel plate by using TIG welding process. To the best of author’s knowledge, the literature did not reveal the investigation of WC-10Co-4Cr cermet TIG cladding. In addition, the effect of argon gas flow rate and standoff distance on the microstructure, hardness and wear behaviour of cermet cladding was also investigated.

2. Experimental procedure:

The AISI 304 stainless steel plates of 100 mm X 50 mm X 8 mm dimension were selected as the substrate material. The top surface of the substrate was polished using 220 grit SiC emery paper, cleaned and then rinsed with acetone prior to the TIG cladding deposition in order to improve its bonding with the substrate. The commercially available WC-10Co-4Cr (WC-CoCr) powder was mixed with polyvinyl alcohol (PVA) solution to make a semi solid paste. The WC-CoCr + PVA paste was applied uniformly over the cleaned specimen. The preplaced specimens were dried in a furnace at 120 °C for 2 hours to remove the moisture contents and to increase the adhesion between substrate and the cladding material. The preplaced layer on stainless steel specimen was melted and cladded by using TIG welding. 3-Axis controlled CNC welding manipulator, as shown in Fig. 1 regulated the torch speed and motion.

![Figure 1: Tungsten inert gas cladding process.](image-url)
A tungsten electrode of 2.4 mm diameter was used to provide the stable arc. The TIG cladding parameters [9] are presented in Table 1.

**Table 1: Process parameters for TIG cladding**

| Parameters             | Values         |
|------------------------|----------------|
| Welding Current        | 100 A          |
| Voltage                | 16.2 V         |
| Torch travel speed     | 150 mm/min     |
| Preplaced thickness    | 1 mm           |
| Current                | DC straight polarity |
| Shielding gas          | Argon          |

The argon gas flow rate and standoff distance were varied as per the test conditions of TIG cladding mentioned in Table 2.

**Table 2: Experimental condition for TIG cladding**

| Exp. No. | Argon Flow rate (lit/s) | Standoff distance (mm) |
|----------|-------------------------|------------------------|
| 1        | 9                       | 2                      |
| 2        | 9                       | 3                      |
| 3        | 9                       | 4                      |
| 4        | 10                      | 2                      |
| 5        | 10                      | 3                      |
| 6        | 10                      | 4                      |
| 7        | 11                      | 2                      |
| 8        | 11                      | 3                      |
| 9        | 11                      | 4                      |

After cladding process has been completed by moving the torch over the entire area of preplaced layers. Then, samples for microstructural examination and mechanical testing were taken out by using wire cut EDM. These samples were cut from centre of the bead and in a direction perpendicular to the torch travel. The specimens were polished on double disc polishing machine using SiC emery papers of different grit size. The hardness measurements were carried out on polished cross-sections of claddings. The samples were etched for microstructural examination by using 2% Nital solution.

SEM micrographs of WC-CoCr powder and the cross-sections of different claddings were taken by using FESEM (QUANTA 200F). The microhardness of claddings was measured by fully automatic Vicker’s micro-hardness tester (XHVT-1000Z, Jinan testing equipment corporation, China) with 300g load and 10 sec dwell time. Abrasive wear test of claddings was performed by following ASTM G99 standard. The square pins of size 6 mm X 6 mm X 8 mm having clad layer on square side were slided against the SiC emery paper counterface of 220 grit on pin-on-disc test rig (TR-20, Make: Ducom Instruments, India). The abrasive wear of the cladded pins were calculated in terms of average weight loss of the pins. The parameters of abrasive wear test are presented in Table 3.
### Table 3: Conditions of Abrasive Wear test

| Parameters                  | Values  |
|-----------------------------|---------|
| Load                        | 30 N    |
| Sliding Speed               | 1 m/s   |
| Sliding distance            | 1000 m  |
| Wear track diameter        | 40 mm   |
| Disc speed                  | 478 rpm |
| Test duration               | 17.07 min |
| Abrasive medium             | 220 Grit SiC emery paper |

3. Results and discussion

3.1 Micro-hardness Measurement

The micro-hardness of WC10Co4Cr cladding was measured at the cross-section of cladding and average value of micro-hardness was determined by taking 10 reading randomly on the cladding cross-section. The Fig. 2 presented the variation of microhardness value when standoff distance changes from 2 mm to 4 mm. The Fig. 2 also showed that higher hardness value of cladding at 4 mm standoff distance and least value of hardness at 2 mm standoff distance.

Hardness value goes on decreasing in the range of 900 to 700 HV0.3 when standoff distance decreases from 4 mm to 2 mm. At 4 mm torch to workpiece distance, the heat input to the preplaced layer decreases because of heat losses due to radiation increases and arc is less concentrated [13][14]. A lower heat input will decrease the decarburization of WC phase in the clad layer. Moreover, less amount tungsten will be dissolved in the CoCr binder resulting in the higher hardness value of the cladding.

At 2 mm standoff distance, heat input to cladding is large due to which WC phase will decompose more by decarburization and dissolution of W in the CoCr matrix. Furthermore, high heat input results in lower cooling rate of weld pool. The grain coarsening will be observed to a large extent because of the greater solidification time. Hence, the microhardness of cladding is decreased.

The Fig. 2 indicates that microhardness of cladding increases with increasing argon flow rate i.e. minimum for 9 l/s and maximum for 11 l/s for all values of standoff distance. This increase in microhardness may be attributed to the fact that with increasing gas shielding the decarburization of WC phase is reduced due to its inhibited reaction with atmospheric oxygen at high temperature. The increasing gas shielding also reduced the dissolution of atmospheric gases in the cladding which could result in the porosity and hence the microhardness is increased [15].

![Figure 2. The variation of Microhardness of cladding w.r.t argon flow rate and standoff distance.](image-url)
3.2 Microstructural examination and wear behaviour

Fig. 3 (a) represents the SEM image of WC-CoCr powder exhibiting a spherical morphology and Fig 3 (b) shows the different sized WC particles (bright) bonded by CoCr matrix (dark).

![Figure 3](image1.png)

**Figure 3.** (a) Lower & (b) Higher magnification SEM images of WC10Co4Cr powder

Fig. 4 (a) & (b) illustrates the SEM micrographs of the cladding cross-section corresponding to parameter setting-9 and 1 of Table 2, respectively. The SEM images revealed that the thickness of cast layer present in the claddings developed by these parameters. The cast layer thickness is minimum in Fig. 4(a) where the values of argon flow rate and standoff distance were maximum (setting-9) while its thickness is maximum in Fig. 4(b) when the values of argon flow rate and standoff distance were minimum (setting-1). Moreover, coarse grain microstructure can be observed in Fig. 4(b), as a result of high heat input. The increased argon flow rate may also results in the arc cooling leading to reduced heat input during the arc scanning. Consequently, the thickness of cast layer is minimum in present in case of parameter setting-9 with fine grain size microstructure.

![Figure 4](image2.png)

**Figure 4.** The morphology and distribution of WC in claddings corresponding to parameter (a) setting-9 and (b) setting-1.

Below the cast layer, the microstructure and phases of WC-CoCr powder is in the retained form which provides the hardness and wear resistance to the clad layer. The Fig. 5 shows the variation of wear with respect to standoff distance and argon flow rate. Wear is reported in milligrams which is the
weight loss of sample pins measured before and after the abrasive wear test. The weight of the samples is measured by using semi-automatic digital weighing machine having accuracy ±0.1 mg.

As mentioned earlier, a 6 mm square cross-section cladded pin was removed from each cladding track by using wire cut EDM machine. To achieve the abrasive wear condition, 220 grit emery paper was pasted on rotating steel disc of the tribometer. Before abrasive wear test, samples pins were polished with 600 grit SiC emery paper to remove the protuberance of arc scanning and to attain flat surface.

The Fig. 5 indicates that the weight loss of pins due to abrasive wear is varying from 178 to 232 mg depending upon argon flow rates and standoff distances. The Fig. 5 also revealed that wear loss is maximum for 2 mm and minimum for 4 mm standoff distance. Furthermore, it also indicates that wear is minimum for 11 lit/s and maximum for 9 lit/s of argon flow rate for all the values of standoff distances. At 4 mm standoff distance, heat input to the cladding is minimum and hence, dilution of WC particles in the CoCr matrix is less. Lesser dilution resulted in higher micro-hardness and minimum wear loss of cladding specimen. Heat input to the cladding is maximum for 2 mm standoff distance and at 9 lit/s argon flow rate. Fig. 5 also indicates that wear of pins is maximum while hardness is minimum for this combination of standoff distance and argon flow rate.

![Figure 5](image_url)

**Figure 5.** The variation of wear of cladding w.r.t argon flow rate and standoff distance

![Figure 6](image_url)

**Figure 6** showing the FESEM images of worn out surfaces of coating obtained at parameter (a) setting-9 and (b) setting-1, respectively.
Abrasive wear in both the cladding is due to pull out of tungsten carbide particles along with plastic flow caused by yielding and extrusion of CoCr binder[16]. Fig. 6(a) shows relatively a smooth surface and less damage of the cladding developed by parameter setting-9. Less damage was observed due to the lower dilution and high microhardness of cladding [17]. While Fig. 6(b) shows that large wear tracks observed in the cladding developed with parameter setting-1. The lower wear resistance of this coating may be attributed to lower micro-hardness value.

4. Conclusion:

WC-CoCr claddings were deposited on AISI 304 steel by TIG welding process. Cladding parameters were selected to minimize the heat input to the WC-CoCr powder particles that resulted in lesser dissolution of WC phase in the CoCr matrix. During the pin-on-disc wear testing, wear tracks were found to be deeper for the cladding deposited with lowest value of argon flow rate and standoff distance causing decarburization of WC phase and resulting in the lower micro-hardness of the cladding. The material removal was found to be in the form of pull-out of WC grains and ploughing of soft CoCr matrix, which is a common behaviour of WC-CoCr material under abrasive wear testing. Higher value of standoff distance and argon flow rate reduces the heat input to the preplaced powder layer and hence the high hardness and wear resistance of cladding is achieved.

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