

Experimental Studies on Performance of Tungsten Carbide Coating on Grey Cast Iron by Detonation Gun Thermal Spray Coating Method

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Abstract

The detonation gun (D-gun) is widely recognised as the first high-velocity thermal spray method, providing highly hard wear resistance, strong adhesive strength, low porosity, and dense micro-structured coatings. The current study focuses on the effect of tungsten carbide (WC) coating on the grey cast iron (GI300) substrate, which is used primarily in automotive parts such as flywheels, gearbox cases, manifolds, and disc brake rotors, among others, and when coated with wear resistant powders helps to increase the service life of the component. The tungsten carbide nano powder is D-gun coated on the grey cast iron substrate to protect it against surface-based breakouts such as wear, corrosion, erosion, and fatigue. When compared to the bare uncoated GI300 substrate, the WC coated substrate showed a significant reduction in cumulative volume loss, wear rate, and coefficient of friction. The greatest hardness of the WC coated substrate is 402 Hv, with the lowest surface roughness measurement values of 2 µm.

Keywords: *Detonation gun, Thermal spray, Coating, Wear, Tungsten carbide.*

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Introduction

The need for thermal spray coatings with higher wear resistance and corrosion on numerous functional components has steadily risen over the years [1-2]. Detonation gun (D- Gun) spraying is a sort of thermal spray technology that is well-known for producing coatings with low porosity and high toughness [3-4]. Detonation spraying includes spraying high velocity particles on target surfaces, resulting in exceptionally dense coatings with strong binding strength between the substrate and coated substance. The composition of the explosion products is determined by the fuel oxygen combination. Spraying factors include barrel diameter and length, explosive mixture volume and composition, powder injection point placement on the barrel, and particle size distribution of the feedstock powder [5-7]. In a study by Prashant et al., three coatings—WC-12Co, Stellite 6, and Stellite 21—were applied to SAE213-T12 boiler steel using the Detonation Gun (D-gun) spray method, and their erosion performances were assessed at a temperature of 400 °C. All of the coatings showed evidence of oxidation-enhanced erosion wear at this temperature [8-9]

Tools have traditionally been made of tungsten and its alloys. Grey cast iron (GI300), a grey iron that contains graphite flakes and is more brittle than SG iron but has high compressive strength and machinability, is a grey iron that contains graphite. The lubricating qualities of graphite are advantageous in applications involving sliding wear. A potential and affordable method of preventing machine tool wear has been found as the creation of strong ceramic coatings [10–12]. The corrosion resistance, wear resistance, and beautiful look of this surface coating are improved. To create the surface coatings of the metals, a number of methods are available, including Physical Vapour Deposition (PVD), Chemical Vapour Deposition (CVD), Thermal Spray Coating (TSC), etc. [13–14].

Important moving elements such driving systems, car components, exploration and production installations, oil pipelines, and valves are all at risk from wear, corrosion, and their interactions [15]. The main obstacle to industrial components' application range expansion is wear, which manifests as early failure and low dependability. The life and performance of a component in the manufacturing sector are dependent on the surface material; as a result, during design, the characterisation of engineering materials is crucial to the usability and lifespan of any engineering component [DG10] [16–17].

As a result, the investigation of strategies for obtaining the necessary surface requirements and their behaviour in service for engineering components is critical. As a result, the current work focuses on the influence of tungsten carbide (WC) coating on the grey cast iron (GI300) substrate, as well as some research into the wear performance, micro-hardness, and microstructural characterisation of the coating substrate. This work also focuses on D-gun coating approaches to increase coating performance.

Experimental

For this investigation, GI300 grey cast iron was chosen as the substrate to deposit the WC coatings. The specimens were manufactured with defined dimensions of ø 8 mm and 50 mm in length. The specimens were washed with acetone according to conventional cleaning procedures before being

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grit blasted with silicon carbide grit particles (mesh size 30) to generate a rough surface on the cross-sectional surface to aid in appropriate coating adherence. The surface roughness of the blasted surfaces was then thermally sprayed with WC coatings. Table 1 shows the chemical components of GI300.

Table 1 Chemical composition (wt. %) of the GI250 grey iron

GI300						
C	Si	Mn	P	S	Ni	Fe
3.36	2.18	0.51	0.116	0.122	0.295	Remaining

The tungsten carbide (WC) nanopowder with hexagonal shape, diameter ranging from 150-200 nm, 99.25% purity were purchased from the supplier M/s. Sigmaaldrich. When detonation spray coating is used, it generates coatings that are exceedingly hard, dense, and have a high bonding strength. The coating is applied to the substrate using a D-gun spray method. Table 2 lists the process parameters utilised during the D-gun spraying procedure.

Table 2 Process parameters of D-gun spraying process

Process Parameters	**Values**
Flow Rate - Oxygen	4250 LPM
Flow Rate - Acetylene	2400 LPM
Flow Rate - Nitrogen	960 LPM
Pressure – Oxygen	2 bar
Pressure - Acetylene	1.5 bar
Pressure - Nitrogen	3 bar
Stand-off Distance	150 mm

During the spraying operation, the coating process parameters were kept constant. The coatings were created utilising a commercial D-Gun equipment and the fuel gases oxygen and acetylene, with nitrogen serving as a carrier gas. The thickness of the coating was measured using a Minitest manufacture thin film thickness gauge, and attention should be given to create consistent thickness coatings.

Dry sliding wear tests were performed on uncoated and detonation spray coated cylindrical specimens utilising an ASTM G 99 compliant pin-on-disc machine (Wear and Friction Monitor Tester TR-20E). The specimens were securely mounted in the pin-on-disc apparatus, and then a lever mechanism delivered dead weight to push these samples against the hardened disc of 100 mm diameter. Wear tests were performed on each thermally sprayed sample to reveal just the top coated surface. Loads of varied magnitudes were applied to both the bare and covered substrates. Finally, by normalising

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the weight loss (starting weight - final weight) with the coating density, the cumulative volume loss was calculated. The surface profilography (SURFCOM 1400 G, Japan) tests were run to assess the topography of the coated surface.

The morphology of coatings was examined using a field emission scanning electron microscope (FE-SEM), and the chemical composition of the interface layer was determined using an energy-dispersive X-ray spectroscope. Vickers micro-hardness tester was used for the micro-hardness testing.

Results and Discussion

Wear Behaviour

Three samples of bare GI300 substrate were taken and subjected to wear on Pin-On Disc-wear test rig at different load conditions of 30N, 40N and 50N. Then, these three samples were coated by WC powder and subjected to wear using same experimental conditions. The cumulative volume loss vs. time for the bare substrate and substrate with coating is plotted as shown in Figure 3.1. From the plot shown in fig. 3.1, it is seen that cumulative volume loss for the detonation sprayed wear resistant WC coatings show better wear resistant in comparison to bare GI300. This demonstrates that the WC coating layer created over the substrate withstands stresses and protects the GI300 from material loss. The rate of volume loss for the coatings lowers as the load increases. In other words, with larger loads, coating performance increased with reduced material loss, providing proof for the high wear rate.

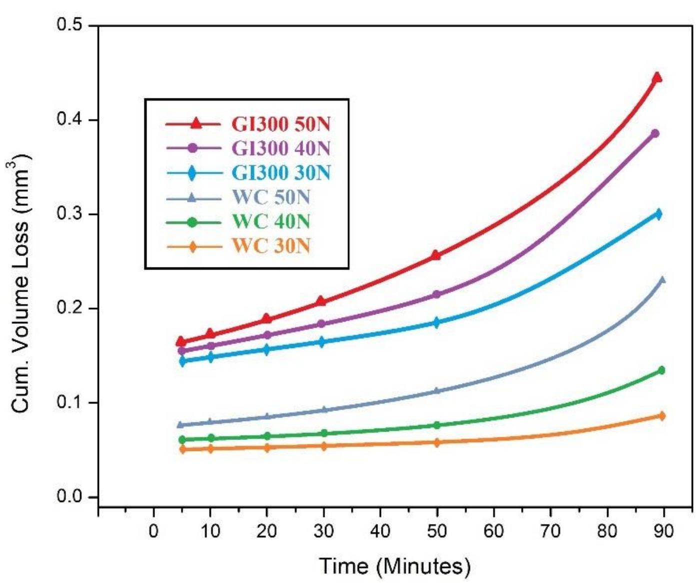

Figure 3.1 Cumulative Volume Loss (mm^3) Vs time for the substrates at different loads

The average wear of the bare substrate and WC coated substrate under the loading conditions of 50 N with respect to time is plotted and depicted in the fig. 3.2. From the fig. 3.2, it is understood that

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the average wear value of GI300 increases as the testing time increases. The WC coated substrate had shown a considerable reduction in the wear rate as compared to the bare substrate, because of the formation of hardened layer over the top surface and stronger bonding that aroused between the nano tungsten carbide particles and the GI300 substrate under higher loading conditions.

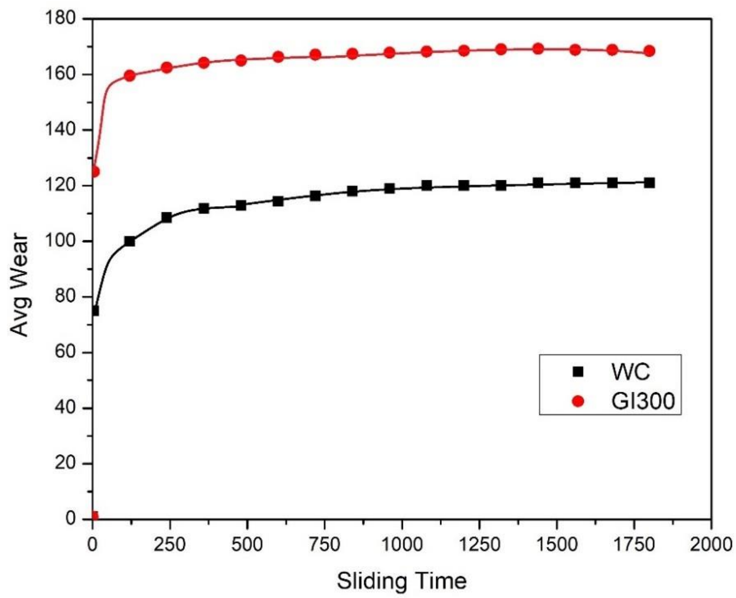

Figure 3.2 Average Wear rate vs. Sliding time for the bare and WC coated substrate

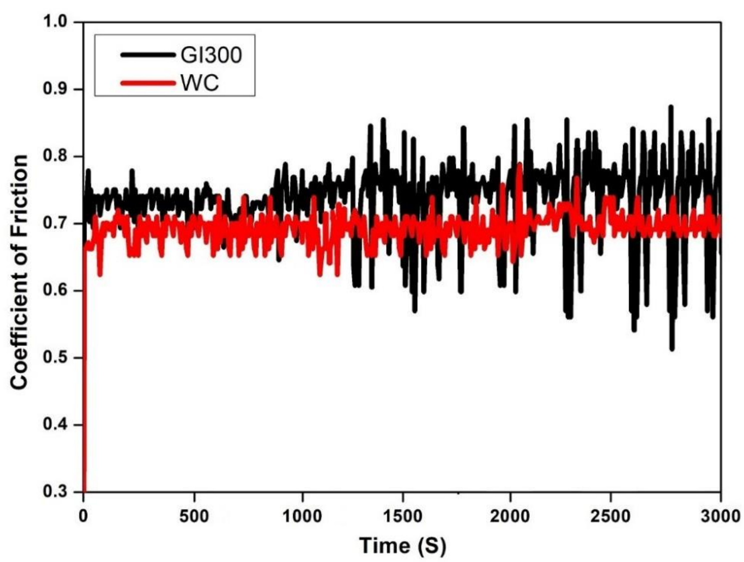

Figure 3.3 Coefficient of friction vs. Sliding time for the bare and WC coated substrate

The coefficient of friction for the bare substrate and WC coated substrate under the loading conditions of 50 N with respect to time is plotted and depicted in the fig. 3.3. The friction coefficients determined on the WC coated sample under identical conditions show similar behaviour, with their values remaining relatively constant or increasing slightly during the test. The inner layer of WC coatings is reported to have hard grains of carbide particles integrated on a softer grey cast iron substrate. These hard micro carbide particles on the top layer contact with the sliding ball of the test instrument, preventing GI300 substrate deformation. Under the imposed load circumstances, it is possible that elastic deformation of the substrate under the coating occurs, which has a significant impact on the sliding conditions and friction coefficient values.

Micro-hardness

The micro hardness values are measured at 10 random points along the cross section of the coating and the average values are reported. Figure 3.4 depicts the average hardness values of coatings and substrates using a bar chart with an error bar to demonstrate standard deviation. The maximum hardness of the WC coated substrate under 50N loading circumstances is 402 Hv, which is somewhat greater than the sample with a hardness of 379 Hv under 30N loading conditions. This might be because, when the load is applied by the indenter, the WC coating gives resistance to deformation by indentation due to improved bonding between the surrounding splats, as indicated in the sem picture in figure 3.7.

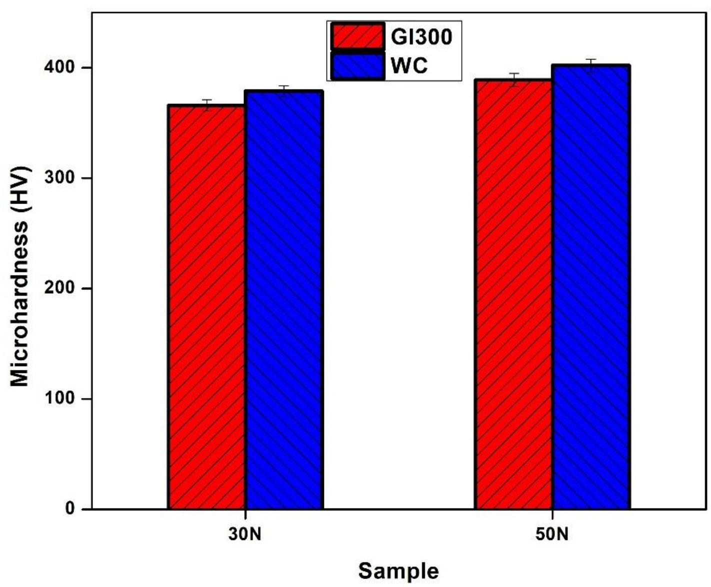

Figure 3.4 Micro hardness for the bare and WC coated substrate at different loads

Surface Profile

Surface profile evaluation is often done with a stylus profilometer following the standard (ASTM D7127). The most frequent surface profile measurement is the average peak height (Ra), which is the arithmetic mean of the deviations from the surface profile's mean height over n measurement

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sites. Figures 3.5 and 3.6 illustrate the surface profiles recorded for the uncoated and coated specimens. It is found that the coated substrate has a lower average roughness value than the uncoated one, which is a well-known finding from numerous literatures. However, in this work, the performance of the WC coating reduces the surface roughness to a higher level. This might be related to the D-gun method of deposition of consistent thickness of coating on the substrate.

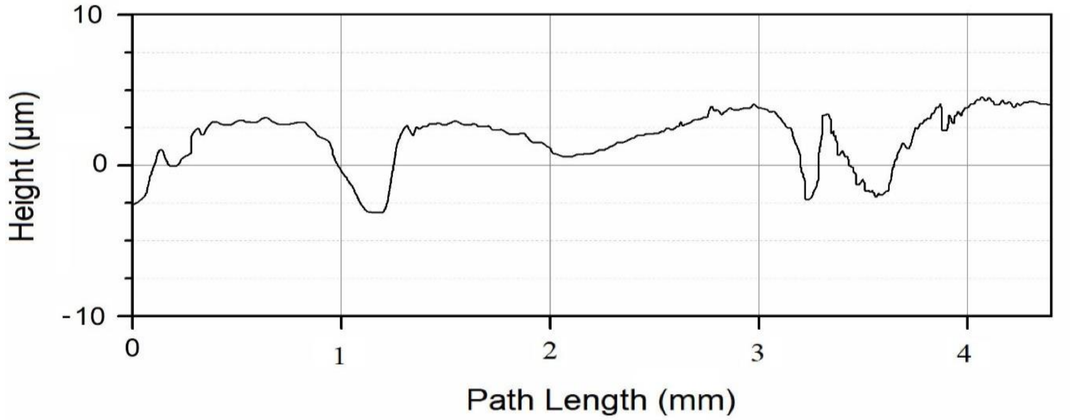

Figure 3.5 Surface Profile for the GI300 Substrate (Uncoated)

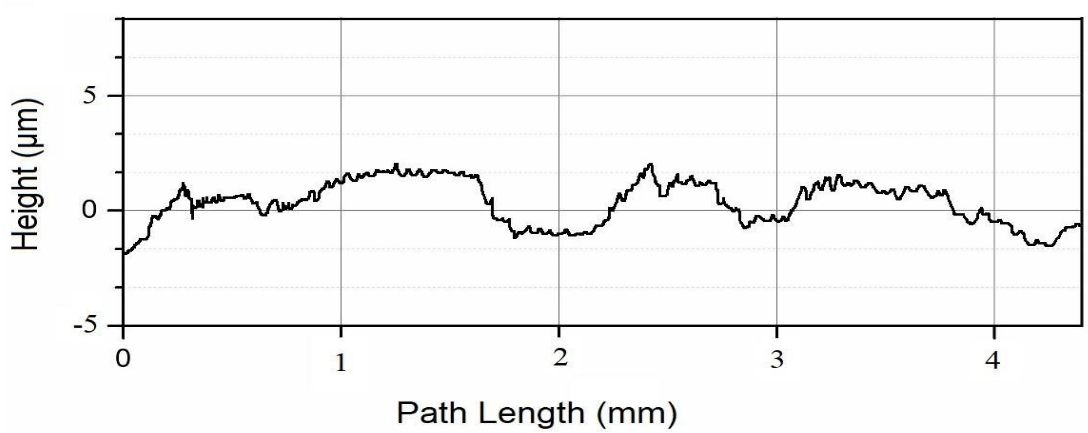

Figure 3.6 Surface Profile for the WC coated Substrate

Microstructural Characterization

The microstructure characterization is done by scanning electron microscope on the WC coated substrate material samples and the images are analysed for porosity and phase distribution before subjected to wear. The micrographic features from the figure 3.7, indicates that the coatings were uniform, homogeneous and free from any surface cracks. The tungsten carbide particles are very hard and evenly distributed throughout the top surface of the GI300 substrate. Figure 3.8 depicts the coated substrate after it has been subjected to a wear test. The WC coating contained very fine splats, indicating that it had higher hardness and a lower wear rate. The greater hardness and reduced wear rate have been proven by earlier data. The topography also exhibits less stress concentrated white layers, which are

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normally more prominent in coated samples, indicating that the sample is subjected to the least abrasive wear of all coatings.

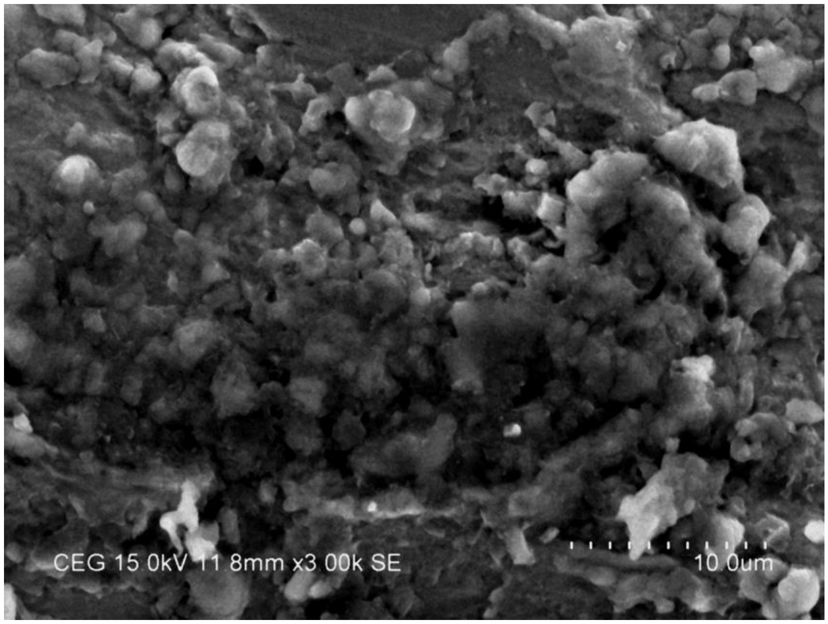

Figure 3.7 SEM image of WC coated GI300 surface before wear

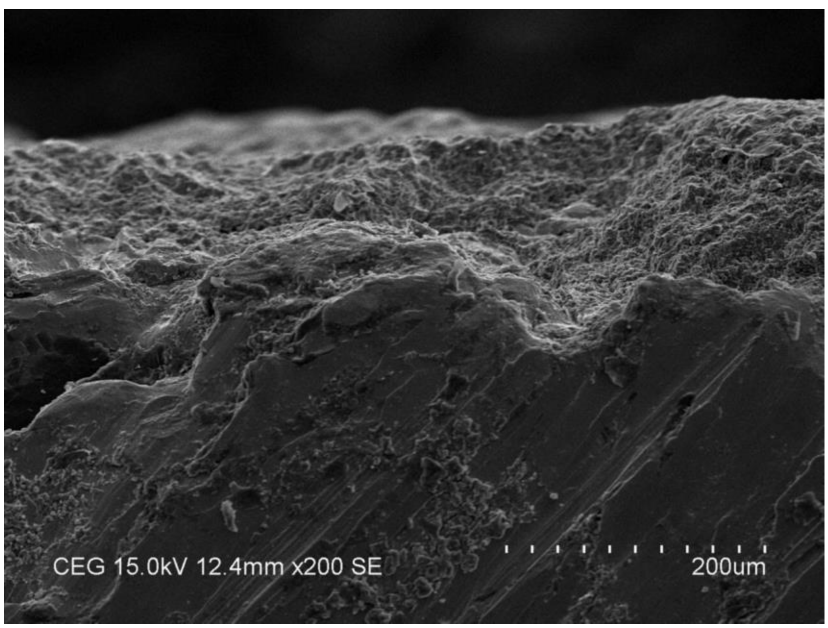

Figure 3.8 SEM image of WC coated GI300 showing worn out surface after wear

Conclusions

The wear mechanism and different environmental conditions to which the engineering parts are subjected necessitate a high level of technical awareness. The following conclusions have been formed

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based on the experimental data acquired in this study:

- When compared to an untreated substrate, detonation sprayed WC coated on GI300 specimen demonstrated a much reduced cumulative volume loss.
- The cumulative volume loss for detonation sprayed WC coated and untreated GI300 specimens increased as the load increased.
- When compared to the uncoated substrate, the average wear rate and coefficient of friction for the detonation sprayed WC coated substrate were much lower.
- The greatest hardness of the detonation sprayed WC coated substrate is 402 Hv, with the lowest surface roughness measurement values of roughly 2 m.
- The microstructure characterisation of the coated sample displays tiny splats, indicating excellent hardness and increased wear resistance.

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