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Characterizing and Analyzing the Tribological Behaviour of Diamond Coated Tungsten Carbide (WC)

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ABSTRACT

In this research work, the deposition of diamond coating was done on the tungsten carbide (WC) substrate utilizing the the thermal Chemical Vapour Deposition (CVD) technique. The carbon precursor used for growing the diamond on the tungsten carbide (WC) substrate material was sugarcane bagasse. The tribological properties of deposited diamond coating were studied examined in this paper. For characterization of the developed coating, Field Emission Scanning Electron Microscope (FESEM), Raman spectroscopy and X-ray diffraction (XRD), were used to characterize the developed diamond coating on the substrate material. These processes were used to confirm the presence of diamond coating on the substrate. For inspecting the hardness of the developed diamond coated and un coated samples, the tests of micro-hardness were also executed. The values of the Vickers hardness for the un-coated and the diamond coated substrates were found to be 964.95 HV to 1457.48 HV respectively. This depicted a rise of 51% in the hardness of the un-coated WC inserts. As per ASTM G-99 standards tribological behaviour of the developed coated substrate was also the scope of this work using a pin-on-disc tribometer. The tribological tests showed improvement in the wear resistance of the diamond coated WC inserts as there was a decrease in the value of wear by 57.84 %. The value of the coefficient of friction (COF) also found to be decreased by 51.48%. This paper presents a combined study of using tribological tests and morphologic study showing the advantages of coating diamond on the tungsten carbide (WC) substrate.

Keywords: Tungsten carbide; Diamond coating; Wear; Friction; Tool inserts.

INTRODUCTION

In today's world of manufacturing there is a boom in the industrial growth there has also been an increase in the demand for the tools with long and better life. For machining of various hard to cut materials viz. aluminium-silicon based alloys and metal-based composites, tool with good life are necessitated. These hard to cut materials are extensively utilized in the automobile and aerospace industries (Tanaka and Akasawa, 1999, Boyer et al., 2015).

While using conventional cutting tools for operating high volume it is not easy to accomplish utmost tolerances as, these materials are hard to cut or machine (Rana et al., 2014, Ullen et al., 2020). Diamond-coated Tungsten Carbide (WC) tools has been an ideal choice for operating on hard to cut materials. These diamond coated tools have shown good properties against wear. The utilization of these diamond coated tool has shown a good track record in the past like giving low surface roughness to the final parts. The achievement of obtaining the low surface roughness has been possible due to low coefficient of friction (COF) (Fraga et al., 2016, Chandran and Hoffman, 2016).

There are many allotrope of carbon but, diamond has been the most beneficial in the several fields of technology and engineering. The reason for this behaviour of diamond is in its underlying properties. In simple words, the hardest allotrope of carbon, compressible to the lowest degree, high resistance to corrosion,better thermal conductivity has been the most important properties of the diamond (Gracio et al., 2010, Srinivasan et al., 2017). Many researchers have utilized the thermal CVD technique for growing diamond coating in the WC substrate material. As, it has considerable applications in the field of engineering and technology (Asmussen and Reinhard 2002, Schneider et al., 2010, Najar et al., 2018).

The technique of thermal CVD has various rewards like ease of operation, unproblematic set-up, uniformness of coating and ability to coat almost all the shapes (Urakami et al., 2019). The deposition of diamond on the WC substrate has resulted in eminent resistiveness towards wear. The diamond coating have also shown good finish on the surface which makes it considerable for the tribological applications (Chandran et al., 2013).

The manufacturing industry uses diamond coated WC tools because of its splendiferous characteristics like low coefficient of friction, high resistance to wear, better conductivity towards thermal changes, high hardness. However, diamond coatings with high adhesive property has at the same time been a task because of its issue of graphitization at the carbide-diamond face junction (Haubner and Lux, 1996, Polini et al., 2012).

Now a day's working environment of industry is mainly dealing with two coupling parts. The performance of tribological behaviour of these mating parts such as wear and friction characteristics has become important (Ullen et al., 2020, Jeyapandiarajan and Xavior, 2019). Hence, the study of tribological properties of coating has become a mandated requirement to understand the functions of the coating. The grounds for reckoning our Thermal Chemical Vapour Deposition CVD technique was because of the utilization of sugarcane bagasse as a carbon precursor. This carbon precursor is further used to grow the diamond coating on the substrate material (Krishnia and Tyagi, 2018). The sugarcane bagasse has always been the major generated waste returned from the various sources of farming. After Brazil, India has been 2nd largest sugarcane producer. 90 million ton of sugarcane bagasse is produced as an agricultural waste from the sugarcane industries of India. This waste is sometimes further reduced as biofuel for the applications on power plant and industrial boilers or sometimes is just burned as normal waste. The amount of sugarcane bagasse burned is roughly 8% of the total consumption of sugarcane bagasse (Madurwar et al., 2015). The burnt residue of sugarcane bagasse has no possibility of any further reduction (Lima et al., 2012).

This paper, reports the tribological performance of as-developed diamond coating using thermal CVD on the substrate material. For characterization of the developed coating, Field Emission Scanning Electron Microscope (FESEM), Raman spectroscopy and X-ray diffraction (XRD), were used to characterize the developed diamond coating on the substrate material.

MATERIALS AND METHODS

Coating Method

In our coating process the substrate material used was Tungsten carbide (WC) inserts. The diamond films were coated on the substrate material using thermal CVD technique at atmospheric pressure. Pyrolyzed sugarcane bagasse (p-SBg) was produced using sugarcane bagasse (SBg), while keeping it at atmospheric pressure and heating it at a controlled temperature of 550°C. This Pyrolyzed sugarcane bagasse (p-SBg) was further used to produce the activated carbon after chemical treatment (Tyagi et al., 2019, Krishnia and Tyagi, 2018). For the growth of diamond films the carbon precursor was used along with a mixture of Ar/H2 in the ratio of 2:1. As stated in the literature, that sugarcane bagasse has been the major waste produced from sugar industries. Also, India is the 2nd largest sugarcane producer and has been producing 90 million ton of sugarcane bagasse as an agricultural waste (Madurwar et al., 2015). Burning this waste is not an environment-friendly solution as the burnt residue of sugarcane bagasse has no possibility of any further reduction (Lima et al., 2012, Tyagi et al., (2019), Krishnia et al., 2018).

Table 1 is showing all the conditions for the experimentation for depositing the diamond film.

Whereas, the flowchart of the process is depicted in the figure 1.

Table 1. Experimental conditions for the development of the diamond coating.

S. No.	Parameters	Values
1	Technique	Thermal CVD
2	Gas Supplied	Ar/H_2 (2:1)
3	Pressure	Atmospheric Pressure (1.013^10^5 Pa)
4	Temp.	~900°C
5	Material for producing Coating	Activated carbon produced from p-SBg
6	Growth Rate (µm/h)	~65
7	Deposition Time (Min)	9-12

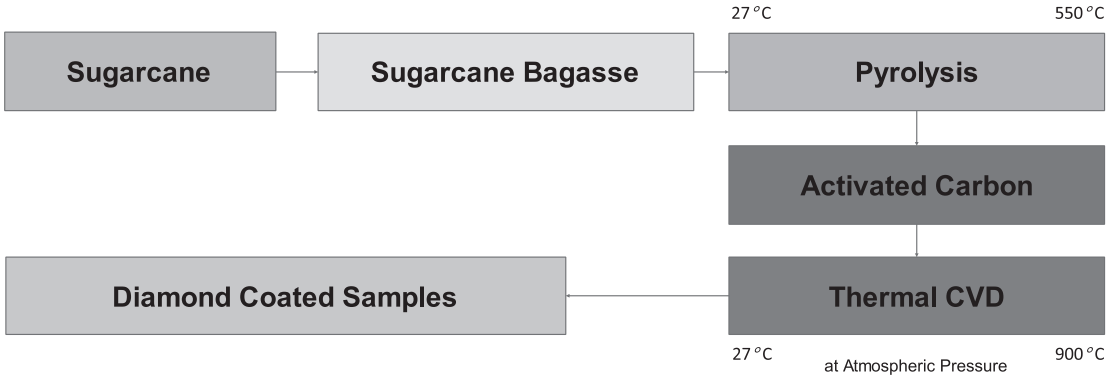


Figure 1. Flow Chart of the Thermal Chemical Vapour Deposition process used for the development of the diamond coating.

RESULTS AND DISCUSSION

XRD and RAMAN SPECTROSCOPY

Rigaku make Ultima IV Automated Multipurpose Diffractometer was utilized to execute the X-ray diffraction (XRD) of the deposited diamond coating on the tungsten carbide WC insert. It was performed at 2θ range from 5° to 80° and the result of the diamond coating on WC substrate material is presented in figure 2. As can be seen in the XRD plot of the coated WC insert in figure 2 (Sarangi et al., 2008).

LabRAM Soleil™ Raman Microscope was employed to affirm the growth of the diamond on the coating by capturing the Raman spectra using 514nm. Obtained Raman spectra for the same is shown in figure 3. The obtained Raman spectra depicted that D and G band lies at 1338.1 cm-1 and 1576.6 cm-1 respectively.

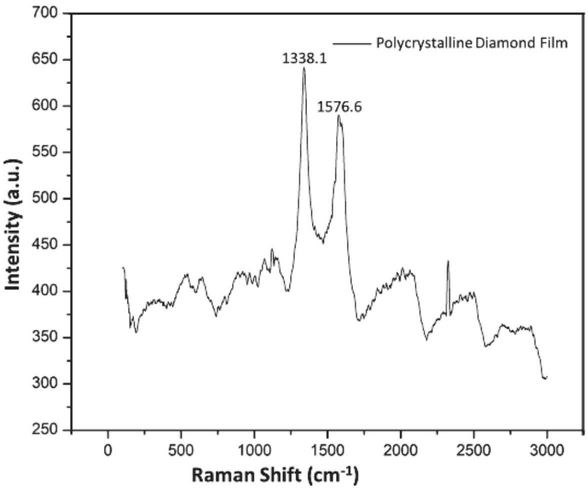


Figure 3. Raman spectra graph plot of the deposited diamond coating on the WC substrate.

Hardness

Fischerscope HM2000s was utilized for micro-hardness test on the coated substrate and un-coated WC inserts. During the indentation process of hardness measurement, the diamond coated indenter and the un-coated indenter was allowed to indent into the surface of the samples. This method of hardness measurement allows the evaluation of the diamond coating film adhesion on the WC substrate surface (Polini et al., 2012, Rana et al., 2021). The evaluated average Vickers Hardness (VH) number were found to be 1457.48 HV and 964.95 HV for diamond coated substrate in addition to un-coated substrates respectively. These values have been diagrammed and demonstrated in figure 4. The obtained average Vickers hardness value of 1457.48 is adequately right for the applications of tribological studies (Akesso et al., 2009, Heaney et al., 2008). The applied tests have shown that after the process of coating diamond on the substrate the hardness have been increased by 50%.

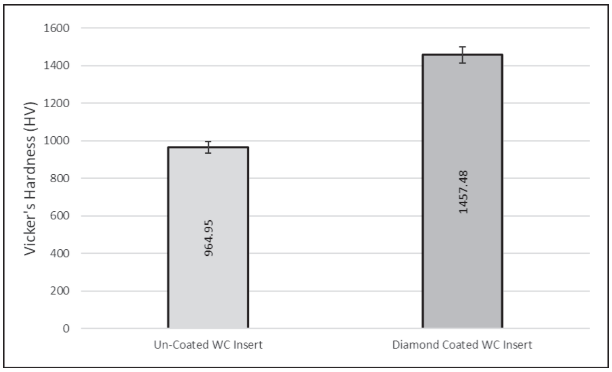


Figure 4. Vickers hardness values as an average for the un-coated and coated substrate.

Fe-SEM

FEI Quanta 200 Fe-SEM machine was utilized for studying the structure of the diamond grown on the coating. Faceted growth of diamonds on the coated surface are seen in the images of Figure 5 (Chandran et al., 2013, Mallika and Komanduri, 1999).

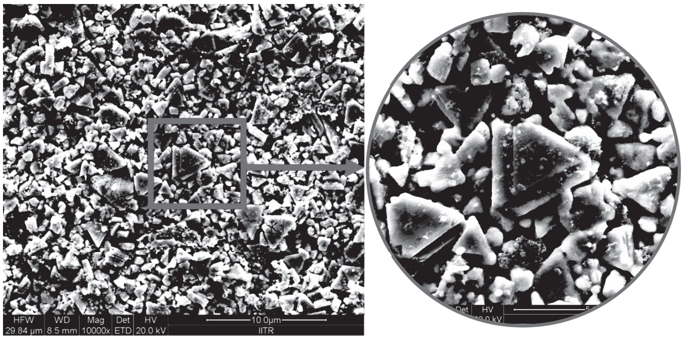


Figure 5. FESEM of the diamond grown on the coated substrate.

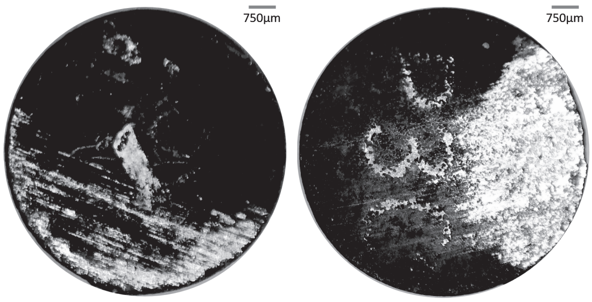
Tribological Analysis

A DUCOMTM made Tribometer (TR-20L-PHM800-DHM850) was used as a pin-on-disc setup for performing the tribological tests. The tribological testing process was completed in two phases. In the first phase, a tribo-pair between the coated carbide pins and die steel disc was made and experiments were performed in unlubricated conditions utilizing a pin-on-disc machine. The experimentation were performed as per the ASTM-G99 standards (Lal and Singh, 2019 Bansal et al., 2021).

The input parameters used for performing the experimentation are mentioned in table 2. In the second phase of the experimentation, the same set of readings were obtained for an uncoated pin. Stereo microscopic images of diamond film coated WC and Un-Coated WC after tribological testing are depicted in the Figure 6 (a) & (b) respectively. It is evident from the images that, the un-coated pin has undergone higher amounts of wear as compared to the coated pin.

Table 2. Experimental conditions of tribological tests.

S. No.	Test Condition	Coated	Uncoated
1.	Sliding Speed (m/s)	2.0	2.0
2.	Load (N)	30	30
3.	Track Diameter (mm)	60	80
4.	Pin diameter (mm)	5.5	5.5
5.	Disc diameter (mm)	100	100
6.	Sliding distance (m)	200	200
7.	Temperature (°C)	20	20
8.	Humidity (%)	50-55	50-55



(a) (b)

Figure 6. (a) Stereo microscopic image of diamond film coated WC after tribological testing, (b) Stereo microscopic image of Un-Coated WC after tribological testing.

Coefficient of friction curves as a function of the sliding time for the coated and un-coated WC inserts is presented in figure 7. The coated and un-coated WC inserts were in the contact with counter faces of the disc, under the dry sliding environment. As it is evident from the plots of the coefficient of friction, the depicted curves of coefficient of friction of the as-developed diamond films exhibit similar plots (Ramasubramanian et al., 2017). These plots indicate that the whole process of sliding can be divided into two parts.

There is an ephemeral peak in the graph of the coefficient of friction with comparatively very high at the amplitude, beginning of the sliding process. This peak characterizes the behaviour of the coefficient of friction. The effect of initial mechanical interlocking occurring on the pin-disc interface results in the attribution of the presence of high initial friction. It is quite evident from figure 7 that coated WC reduces the coefficient of friction (COF) values significantly. The presence of as-developed diamond films on the WC inserts helped in reducing the asperity contact between the tribo-pairs. The average value of the coefficient of friction (COF) obtained for the diamond coated WC insert was 0.196. Whereas the average value of the coefficient of friction (COF) obtained for the un-coated WC insert was 0.404. This shows that the diamond films coated on the WC inserts have been able to decrease the coefficient of friction (COF) by 51.48%.

The wear curves of the samples have been shown as the function of the sliding time in figure 8, which were in contact with counter faces of steel disc, under dry sliding environment. The pin on disc setup measures the wear of the pin in the form of pin length, any changes to the length of the pin are measured with the help of wearable sensors. It is seen that the diamond coating plays a vital role in improving the wear resistance of the WC material. The average value of the wear (μm) obtained for the diamond coated WC insert was 15.79 μm. Whereas, the average value of the wear (μm) obtained for the un-coated WC insert was 37.47 μm. This shows that the diamond films coated on the WC inserts have been able to decrease the wear by 57.84%.

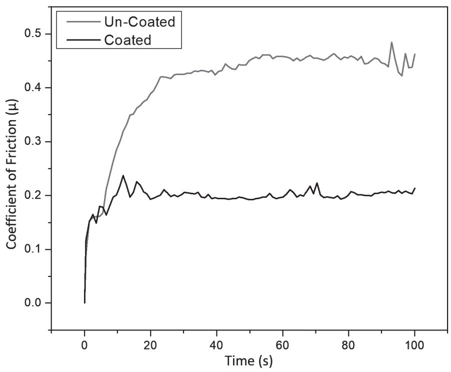


Figure 7 . Variation of coefficient of friction with respect to sliding time.

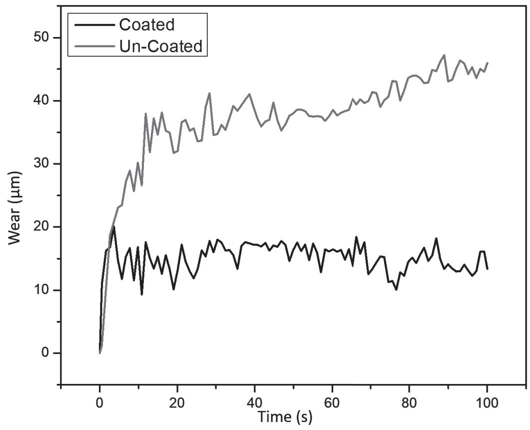


Figure 8. Variation of wear with respect to sliding time.

CONCLUSION

In the present work, the diamond coating was developed and deposited on the substrate tungsten carbide (WC) substrate to improve the wear, friction and micro-hardness of the tungsten carbide (WC) samples. After performing all the experimentation the following conclusions:

(a) The obtained Raman Spectra supported the presence of diamond on the tungsten carbide (WC) inserts substrate by showing the peak at 1338.1 cm-1.

(b) XRD spectra for the coated substrate confirmed the presence of diamond on the developed coated tungsten carbide (WC) substrate.

(c) The diamond coated deposited on the substrate of WC significantly improved the tribological properties of the tungsten carbide (WC).

(d) The decrease of 57.84 % in the value of wear and a decrease of 51.48 % in the value of the coefficient of friction (COF) was observed by the tribological tests.

(e) The hardness of the substrate was increased by 50% after the coating process.

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