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Optimizing the Machining performance of CNC tools inserts coated with Diamond like Carbon Coatings under the dry cutting environment

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ABSTRACT

In this research work we have coated WC (tungsten carbide) tool inserts with diamond like carbon coatings. The deposition was done using the thermal Chemical Vapour Deposition (CVD) method. We have used bagasse of sugarcane which is an agriculture waste as a carbon precursor for developing the diamond like carbon coatings. Surface finish, cutting temperature and cutting forces of as-developed diamond like carbon coatings on the WC inserts were examined and analyzed in this research work. For confirming the presence of diamond like carbon coatings on the surface of coated tungsten carbide (WC) tool inserts substrate we have used Raman spectroscopy, X-ray diffraction (XRD) and Field Emission Scanning Electron Microscope (Fe-SEM). The increase in the hardness on the developed coated samples were inspected by performing the hardness test on the coated substrates. The average evaluated Vickers Hardness number were found to be 1455.24 HV and 950.65 HV for both coated as well as un-coated samples respectively. This shows 53% rise in the hardness of the un-coated WC inserts.

Key words: Tungsten carbide; Diamond coating; Wear; Friction; Tool inserts.

INTRODUCTION

A vast requirement of tool has emerged now a days with better tool life in the manufacturing industry. The tool are basic requirement in the manufacturing processes, but the requirements of manufacturing industries are getting changed day by day in very rapid pace. These rapid changes have increased the demand of tools for machining hard materials used in aerospace & automobile industries (Tanaka and Akasawa, 1999, Boyer et al., 2015). It is getting difficult for machinist to get high tolerances while producing the high volumes of machined parts and material. These hard to cut materials with high precision require something other than conventional cutting tools (Rana et al., 2014, Ullen et al., 2020).

Coated tungsten carbide (WC) tools are ideal for the use in the field of manufacturing industries for machining the hard difficult metals. These tools offer good resistance to the wear and friction while producing the better surface fining while machining. Moreover, these WC tools have an established track record of being productive in producing large amount of parts (Fraga et al., 2016, Chandran and Hoffman, 2016).

An allotrope of carbon which is also known as diamond has drawn a lot of positive attention from the researcher, machinists, worksman, etc. from the field of technology and engineering because of its high underlying properties (Gracio et al., 2010, Srinivasan et al., 2016). As we already know that the diamond is the hardest and least compressible material. It has one of the best thermal conductivity when measured at the room temperature. Technique of thermal chemical vapour deposition (CVD) is used to grow the diamond film on the substrate material like tungsten carbide (WC). This technique has pulled considerable attention of many researchers and scientist for many years now because of it's possible usage in the area of technology and manufacturing (Asmussen and Reinhard 2002, Schneider et al., 2010, Najar et al., 2018). The major source of agricultural waste produced is the sugarcane bagasse (SBg). Indian is the 2^{nd} largest agricultural waste producing country, as sugarcane industries of India produces 90 million ton of sugarcane bagasse. This waste is just normally burned as any other normal waste material produced (Madurwar et al., 2015, Jeyapandiarajan and Xavior 2019). One cannot reduce the burnt sugarcane bagasse any further (Lima et al., 2012).

There are several advantages to thermal chemical vapour deposition (CVD) technique, like ease of operation, adaptability for all difficult geometries (Urakami et al., 2019). The diamond after being coated on the tungsten carbide (WC) substrate tool material produces a very hard cutting tool. These qualities of diamond coated tungsten carbide (WC) tools produces better results in machining operations (Sein et al., 2003, Bobylyov and Storozhenko, 2019). These self-developed diamond coated tungsten carbide (WC) tools have good surface finish because of which they have good applications (Chandran et al., 2013, Bansal et al., 2021). The industry focusing on the cutting or in other words machining application uses diamond coated tungsten carbide (WC) tools, these tools have splendid properties like better thermal conductivity and extravagant hardness (Haubner and Lux, 1996, Polini et al., 2012).

This paper, reports the parametric optimization of the developed diamond like carbon coated tungsten carbide (WC) tool insert for machining processes using TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) (Rana et al., 2021b). XRD along with Fe-SEM and Raman spectroscopy were also utilized to characterize the as-developed diamond like carbon coatings.

MATERIALS, METHODS AND CHARACTERIZATION

Coating Method

In this work, diamond like carbon coatings were coated on the WC inserts using thermal CVD technique. Pyrolyzed sugarcane bagasse (p-SBg) was produced by SBg, which then is used to produce activated carbon (Tyagi et al., 2019, Krishnia and Tyagi, 2018). Bagasse of sugarcane was used to grow the diamond like carbon coatings. As stated, that sugarcane bagasse has been the major waste produced from sugar industries (Madurwar et al., 2015) and burning this waste is not an environment-friendly solution (Lima et al., 2012). The deposition rate for diamond like carbon coating was found ~55 μm/h (Krishnia et al., 2018, Rana et al., 2021a).

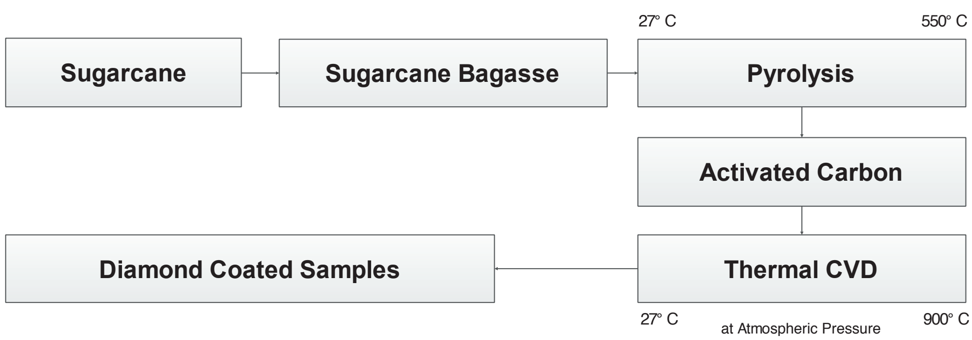

Figure 1. Flow chart of the deposition process for coating diamond like carbon on the samples (Tyagi et al., 2019, Krishnia and Tyagi, 2018, Krishnia et al., 2018)

CHARACTERIZATION

FESEM image of the worn out diamond like carbon coated sample is shown in Figure 2. Raman spectroscopy method was used to affirm the growth of the diamond like carbon coating and the graph of the same is shown in Figure 3. The obtained Raman spectra depicted that D and G band lies at 1337 cm^{-1} and 1575.4 cm^{-1} respectively. An upshift was observed on the peak at 5 cm^{-1}, because of the developed stresses on the coating (Sein et al., 2003, Krishnia and Tyagi, 2018, Krishnia et al., 2018). The SEM pictures shown in Figure 11 are in correlation with above results. Micro-hardness test were performed on the on the coated and un-coated samples. After several measuring processes the measured Vickers Hardness number were found to be 1455.24 HV and 950.65 HV for both coated as well as un-coated samples respectively. These same has been plotted as a graph in Figure 10 (Sarangi et al., 2008, Ghadai et al., 2020). FESEM machine was used for studying the growth of the diamond like carbon coating. The quality of the coating on the sample is mostly similar on the developed surface. The existence of the diamond like carbon coating is shown in Figure 11 (Rana et al., 2020, Knight and White, 1989).

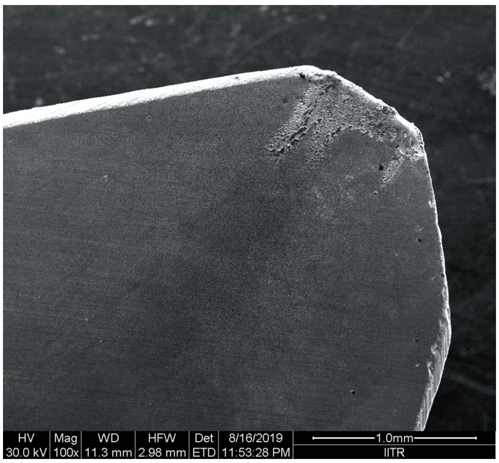

Figure 2. Fe-SEM image of the tool wear of the diamond like carbon coated sample.

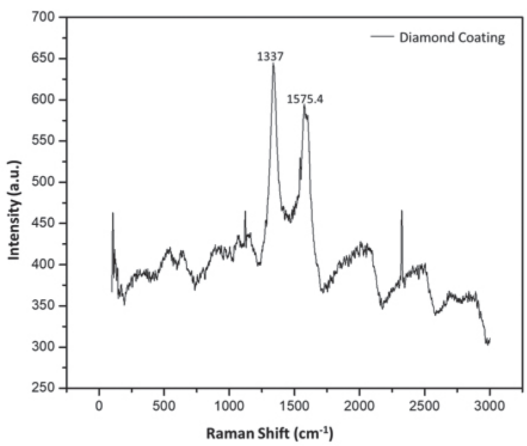

Figure 3. Raman spectra of the diamond like carbon coated sample.

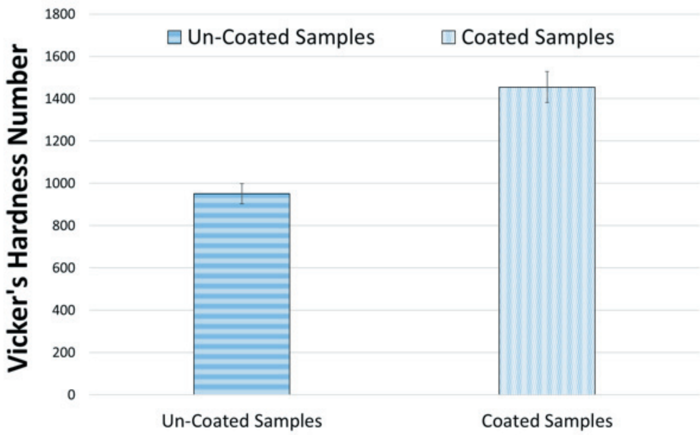

Figure 4. Graph of the Vickers hardness numbers of coated and un-coated samples.

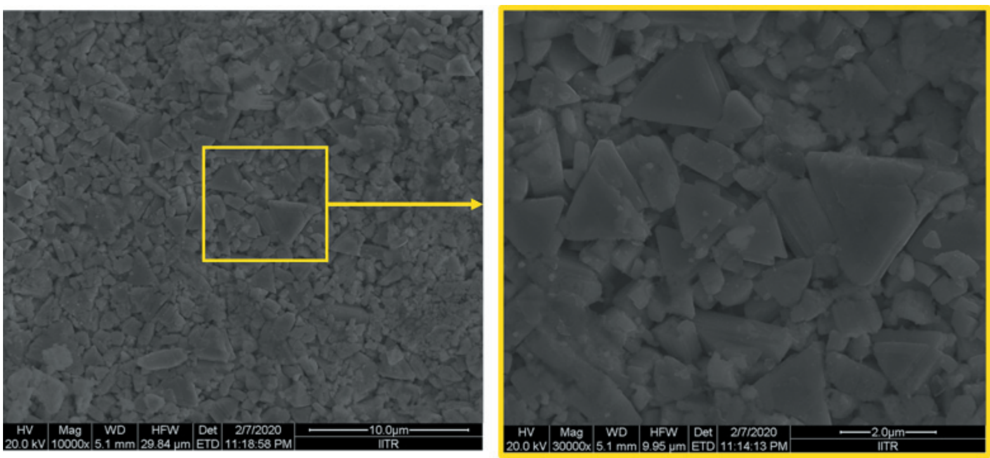

Figure 5. FESEM images depicting the Existence of coating.

RESULTS AND DISCUSSION

Selection of Orthogonal Array

With the aim to find the optimal combination of the effect of input parameters viz. cutting depth of cut (DOC), speed (V_c) and feed (*f*) on the output variables like resultant cutting temperature, surface roughness and cutting force. The orthogonal array (OA) was selected in such a way that we have least number of experimental runs. In this paper, we have used the L9 orthogonal array shown in Table 1.

Entropy Weight Method of Topsis

A statistical tool named entropy weight method was used to enlarge the distance from a negative ideal solution. In addition this statistical tool uses the optimum result from the ideal solution (Shanian and Savadogo, 2006).

Decision Matrix

The decision matrix is evaluated for all the values of responses of the variables [42].

An initial decision matrix, consisting of the response variables is also shown in Table 1.

$$A = (a_{ij})_{mxn} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \tag{1}$$

Table 1. Used orthogonal array (OA) along with the initial decision matrices.

Order of Exp.	Experiment No.	Parameters of Input			Variables of Response		
		DOC	Vc	f	F	Tc	Ra
8	1	0.3	60	0.15	85.49	285.50	0.44
5	2	0.1	60	0.1	51.49	139.70	0.36
1	3	0.1	90	0.15	62.06	154.00	0.37
9	4	0.1	30	0.05	47.84	144.30	0.34
6	5	0.5	60	0.05	109.63	447.40	0.52
7	6	0.3	30	0.1	78.47	277.50	0.44
4	7	0.5	30	0.15	101.18	589.90	0.46
2	8	0.3	90	0.05	88.44	277.90	0.53
3	9	0.5	90	0.1	127.96	423.30	0.66

Standardization

For having uniform units for all the selected responses we have to standardization of the decision matrix (Tiwari et al., 2019). We used "lower the better" as a criteria for the responses. The response variables are shown in Table 2.

a_{ij} = the response variables "lower the better".

$$(r_{ij})` = a_{ij} / max\ (a_{ij}),\ i=1,2,3....m; j = 1,2,3....,n \tag{2}$$

$$(r_{ij})` = (r_{ij})` / \sum_{i=1}^{m} (\mathbf{r}_{ij})`,\ i=1,2,3....m; j = 1,2,3....,n \tag{3}$$

Method of Entropy

We calculated the weight for performance indicator using this technique. The calculations for the performance indicators are:

$$e = -k \sum_{i}^{m} r_{ij\ lnr_{ij}}, j = 1,2, \ldots, n \ and \tag{4}$$

$$k = \frac{1}{\ln(m)} \tag{5}$$

$$E = \sum_{j=1}^{n} e - j = -\frac{1}{\ln(m)} * \sum_{j=1}^{n} \quad \sum_{i=1}^{m} r_{ij}\, ln(r_{ij}) \tag{6}$$

$$d_j = |1 - e_j|,\ j = 1,2,3, \ldots n \tag{7}$$

Table 2. Response variables in the form of obtained standardized decision matrix

Run No.	Variables of Response		
	F	**Tc**	**Ra**
1	0.3261	0.2817	0.3111
2	0.1964	0.1378	0.2567
3	0.2368	0.1520	0.2631
4	0.1825	0.1424	0.2460
5	0.4182	0.4415	0.3704
6	0.2994	0.2738	0.3132
7	0.3860	0.5821	0.3275
8	0.3374	0.2742	0.3790
9	0.4882	0.4177	0.4705

Whensoever d_j will be greater, we propagate r_{ij}, which in turns will make performance indicator the important one. Calculations are:

$$w_j = d_j / \sum_{j=1}^{n} d_j \tag{8}$$

Table 3 is showing the weight of evaluated responses.

Weight Determination

w_j = Calculated weight of the evaluated responses,
R = Standardized decision matrix = $(r_{ij})_{m\times n}$,
Following matrix was used to calculate the response variables:

$$v = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} \cdots & w_n r_{1n} \\ \vdots & \ddots & \vdots \\ w_1 r_{m1} & w_2 r_{m2} \cdots & w_n r_{mn} \end{bmatrix} = \begin{bmatrix} v_{11} & v_{12} \cdots & v_{1n} \\ \vdots & \ddots & \vdots \\ v_{m1} & v_{m2} \cdots & v_{mn} \end{bmatrix} \quad (9)$$

Table 4 is showing the Weighted and standardized decision matrices of Performance indicators.

Table 3. Weights of the performance indicators.

F	Tc	Ra
0.3481	0.2739	0.3781

Table 4. Weighted and standardized decision matrices of Performance indicators.

Run No.	F	Tc	Ra
1	0.1135	0.0771	0.1176
2	0.0684	0.0377	0.0971
3	0.0824	0.0416	0.0995
4	0.0635	0.0390	0.0930
5	0.1456	0.1209	0.1400
6	0.1042	0.0750	0.1184
7	0.1344	0.1594	0.1238
8	0.1174	0.0751	0.1433
9	0.1699	0.1144	0.1779

Positive and Negative Ideal Solutions:

The formula for finding the ideal solution is:

$$V^+ = \{v_1^+, v_2^+, \cdots\cdots, v_n^+\} = \{(max\ v_{ij}|j\varepsilon J_1), (min\ v_{ij}|j\varepsilon J_2)|\mathrm{i} = 1,2, \cdots\cdots, \mathrm{m}\} \quad (10)$$

$$V^- = \{v_1^-, v_2^-, \cdots\cdots, v_n^-\} = \{(min\ v_{ij}|j\varepsilon J_1), (max\ v_{ij}|j\varepsilon J_2)|\mathrm{i} = 1,2, \cdots\cdots, \mathrm{m}\} \quad (12)$$

Relative Distance

$$S_i^+ = \sqrt{\sum_{i=1}^{n}\left(v_{ij} - v_j^+\right)^2}, i = 1, 2, 3, \ldots.., m \tag{13}$$

$$S_i^- = \sqrt{\sum_{i=1}^{n}\left(v_{ij} - v_j^-\right)^2}, i = 1, 2, 3, \ldots.., m \tag{14}$$

Table 5 is showing the , and calculated "C_j".

(15)

Table 5. Weighted and standardized performance indicators.

Run No.	S_i^+	S_i^-	C_j	Rank
1	0.0682	0.1165	0.6307	5
2	0.0063	0.1779	0.9657	2
3	0.0203	0.1664	0.8911	3
4	0.0012	0.1817	0.9932	1
5	0.1259	0.0592	0.3199	7
6	0.0607	0.1224	0.6684	4
7	0.1441	0.0647	0.3099	8
8	0.0826	0.1052	0.5600	6
9	0.1562	0.0450	0.2237	9

The ranks obtained from the table 5 shows that the experiment run no. 4 produces the best optimum solution. The TOPSIS (technique for order of preference by similarity to ideal solution) method helped us in identifying the optimal parameter for the machining process while using the diamond like carbon coated samples.

CONCLUSION

The hardness of the coated sampled increased by 53% in as comparison to the uncoated samples. In the Raman Spectra, we obtained the peak of D band at the position of 1337 cm^{-1} which supported the presence of diamond on the coated samples. These results were in correlation with the obtained FESEM images. For optimizing the process parameters of machining processes for diamond like carbon coated WC samples, using TOPSIS technique was the main aim of this research. Optimum values of process parameters are 0.05 mm/rev, 0.1 mm and 30 m/min for feed rate, depth of cut and cutting speed respectively. The TOPSIS (technique for order of preference by similarity to ideal solution) method has been successfully applied as a computational technique for optimizing the process parameters for the turning process using the developed diamond like carbon coated samples.

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