EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 9, NO. 3, JULY 2012, pp. 1 - 12 ISSN 2090 - 5882

TOOL WEAR AND SURFACE ROUGHNESS IN TURNING GRP PIPES

EL-HOSSAINY T. M. and EL-HABAK A.

Faculty of Engineering, Cairo University, Giza 12613, Egypt.

ABSTRACT
Composites have received considerable attention due to their excellent engineering properties and have become large leading materials in industry. Glass reinforced plastic (GRP) composite materials are used in many engineering fields because of its good properties such as high specific strength, high specific stiffness, and corrosion resistance. Flank wear and surface roughness are discussed through dry turning process. GRP composite pipe has been used with polyester volume fraction of 61.3 %. Different tool materials were used; polycrystalline diamond (PCD), Ceramic and Carbide tools. Results show that PCD tools are suitable in cutting this composite material of reduced machinability. However, Carbide and Ceramic tools show higher wear rates with deteriorated surface roughness. PCD diamond tools are the most preferred, while carbide tools are preferred over ceramic tools for a dry turning process of GRP composites.

KEYWORDS
Turning, GRP composites, polycrystalline diamond tools, tool wear, surface roughness.

INTRODUCTION
The use of polymer composite materials has increased in various engineering technology fields due to their physical and mechanical properties. Fiber Reinforced Plastic (FRP) have been widely used in a variety of applications, such as aircraft, robots and machines, therefore high quality machined surface is essential for such applications, [1].

Machining of composite materials differs significantly in many aspects from machining of conventional metals and their alloys. Because of the complexity of this structure, the deformation mechanisms of the materials under cutting are still far from deep understanding, [2]. The flank wear is the most important type wear observed in diamond cutting tools and the mechanism of abrasive wear mechanism is predominant in machining of these composites, [3 - 6]. But there was no sign of the chemical wear, [6 - 7]. Sahin, [8], observed that abrasive wear when using various ceramic coatings was the main mechanism responsible for wear of tools in machining composites. On the other

hand, Kannan and Kishawy, [9], found that the conventional application of coolant have no beneficial effect on the surface finish compared to dry turning.

PCD tools are important in cutting composite materials of reduced machinability, [10 - 11]. Dandekar and Shin, [12], added that PCD diamond tools are the most preferred, while carbide tools are preferred over ceramic tools. Davim and Mata, [10, 11, 13], carried out turning tests of FRP's using PCD tool and concluded that the surface roughness increases with the feed rate and decreases with the cutting speed. Lin et al.,[14], mentioned that the flank wear being dominant in the quoted speed-feed range. They concluded that the surface finish deteriorates with increasing feed rates, but does not change significantly with the change of cutting speed.

The Chemical vapour deposition (CVD) diamond coated tools show short life, as tools wear evolution becomes very fast after coating rupture[15]. On the contrary, PCD insert tools showed a slow and progressive wear leading to long tool life and good surface roughness. Qin et al., [16], found that coating delamination remain the primary wear mode that often results in catastrophic tool failures. Chou and Liu, [17], mentioned that only diamond tools are technically suitable in machining composites but diamond coatings seem to be more economically viable than PCD. Their results show that tool wear is sensitive to cutting speed and feed rate, and the dominant wear mechanism is coating failure due to high stresses. Sahin and Sur, [3], concluded that the cutting speed was found to be more effective in machining the composite and that tool life decreased with increasing cutting speeds in all cutting conditions.

However, carbide or, better, PCD are found suitable as a tool materials while Ceramic materials are unsuitable because their low strength and high brittleness make them very sensitive to shocks and their low heat conductivity does not allow for the dissipation of the heat generated during FRP composite machining, [18]. When comparing PCD with Carbide tool, he found that PCD can be an economical alternative to carbide in the machining of FRP despite the much higher purchase cost because tool life is longer and higher processing speeds can be used. Davim and Mata, [19], concluded that PCD and CVD diamond tools can be used for the finishing of composite materials while Cemented carbide (K10) tool presents the worse behavior for machining these materials. They added that the obtained results showed a best cutting performance for CVD diamond coated tool when compared with PCD and K10 cutting tools due to the minor production costs of CVD diamond coated tools in comparison with PCD tools.

Machining of fiber reinforced composites is quite complex, first due to the inherent heterogeneity resulting from the reinforcements/matrix assembly and second due to the presence of high modulus/high strength fibers, [20]. The full application of MMCs is however cost sensitive due to machinability problems such as rapid tool wear of tungsten carbide (WC) tools incurring high machining costs, [21]. Kilickap, [6], concluded that surface roughness mostly affected with cutting speed so that higher cutting speed produced better surface finish. Palanikumar et al., [22], found that the

hand lay-up process produces better surface roughness than filament winding process in the machining of FRP composites and that deformation mechanisms under cutting such structure are still far from deep understanding. The polycrystalline cubic boron nitride (PCBN) tools showed the highest fracture resistance and PCD tool exhibited higher wear resistance than all PCBN tools and lower propensity for work material adhesion, [23]. Teti, [18], mentioned that CBN, which is as expensive as PCD, presents no advantage over the latter. He added that PCD tools are one and two orders of magnitude better than carbide tools in terms of wear resistance. He found that Carbide tools could be used economically for roughing operations, PCD tools should be used for finishing operations because of their longer tool life.

Cutting speed has greater influence on tool flank wear, followed by feed rate. The flank wear observed at the higher cutting speed is more than that at lower cutting speed. When increasing cutting speed, abrasion, diffusion and deformation due to thermal plasticity effects become pronounced indicating that most of the mechanisms of the tool wear have been thermal dependent. The feed rate is also one of the important factors, which affects the tool wear so that higher feed rate leads to the increase of chatter during machining, which in-turn produces more wear, [24].

It is clear from the available literature that the reinforcement GRP complexity which is difficult to be machined is the most important factor on choosing the economical tool material to achieve lower tool wear with enhanced surface roughness. The aim of the present work is to investigate the tool wear of different tool materials; PCD, Ceramic and Carbide when machining. The present study is devoted to investigate the composite pipe structure that contains the reinforcement glass fiber in forms chipped and filament laid with polyester resin and filled with a certain volume fraction of sand.

EXPERIMENTAL PROCEDURE

TURNING TESTS

Dry turning experiments were carried out on GRP composite pipes of 325 mm outside diameter and 8.1 mm thickness using three different tool materials namely; PCD, ceramic and carbide inserts shown in Fig. 1. Tests were conducted on a 7.5 KW Centre Lathe ZMM SILVEN of type CU580M using different cutting conditions. Experimental details are mentioned in Table 1. The tool wear and the surface roughness were measured at predetermined intervals with three times repeatability. The surface roughness results were measured using Talysurf 4 (TAYLOR–HOBSON). The work piece surface is cleaned and brushed before measuring surface roughness for trying not to read false results due to the particles chipped from work piece surface. The flank wear results were examined using tool maker microscope. Experimental setup is presented in Fig. 2.

WORKPIECE MATERIAL

Glass fiber reinforcements, thermosetting polyester resins, and sand filler developed by Owens-corning material specialists by creating a very dense laminate that maximizes the

contribution from these three basic raw materials as shown in Fig. 3. The composite pipe structure is burned according to ASTM D-2584, and presented starting from the inner diameter to the outer diameter in Table 2. Continuous glass roving fiber and chopped fiber are impregnated with a polyester resin through specified curing conditions in specified stacking sequence. The sand fortifier is also used to provide increased stiffness with placement near the neutral axis in the core. The manufactured pipe's stiffness, hoop and axial tensile, glass and resin composition are mentioned in Table 1. Turning tests were carried on the outer 1.6 mm layer where the percentages of Glass fiber reinforcements is 38.7 % (Roving & Chopped) and the percentages of thermosetting polyester resins is 61.3 %.

Carbide tool

Ceramic tool

PCD tool

Tool holder

Fig. 1 The three different tool materials with the tool holder.

Table 1. Experimental details

Physical properties of work piece material*	
Pipe stiffness at 5% deflection (ASTM D-2412	**14834 N/m2**
Hoop tensile (ASTM D-2290)	**1290 Kn/m**
Axial tensile (ASTM D-638M)	**532 Kn/m**
Work piece material **Burning results according to (ASTM D-2584)**	**Glass fiber reinforcements 23 %** **(Roving & Chopped)** **Thermosetting polyester resins 36.4 %** **Sand filler 40.6 %**
Tool specifications	
PCD	**SNMA 12 04 04 H90**
Ceramic	**SNMA 12 04 08**
Carbide	**SNMG 12 04 08 PM**
Tool holder	**PSSNR 25 25 M12**
Cutting conditions	
Cutting speed (V), m/min.	**102, 204, 321**
Feed (f), mm/rev.	**0.05, 0.1, 0.2**
Depth of cut (d), mm.	**0.5**

*** Data obtained from AMIANTIT FIBERGLASS EGYPT S.A.E.**

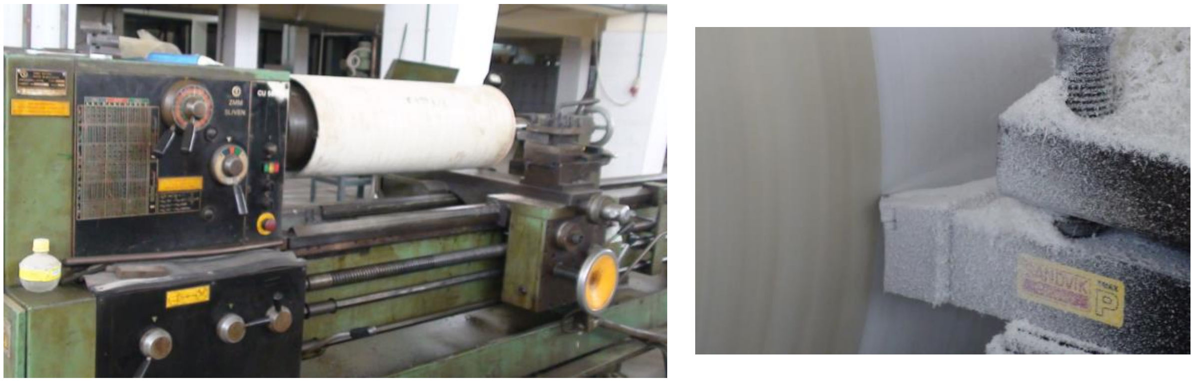

Fig. 2 The experimental setup using Centre Lathe ZMM SILVEN of type CU580M.

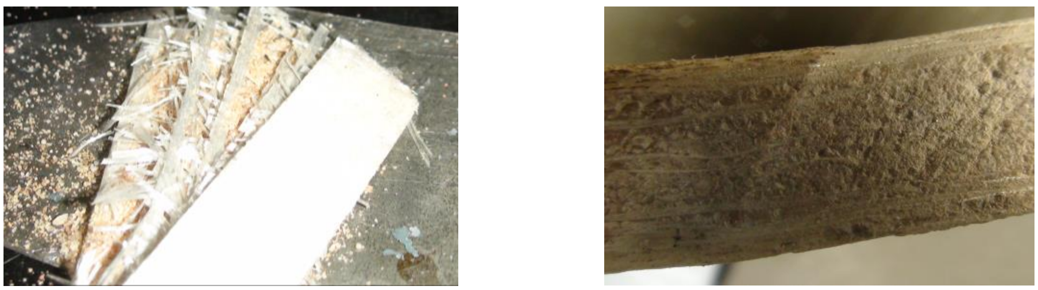

Fig. 3 The three basic raw materials; glass fiber reinforcements, thermosetting polyester resins, and sand filler.

Table 2. The composite pipe structure.

<table>
<tr><th>Thickness (mm) from Inner Diameter</th><th>Layer constituents</th><td rowspan="15">R = Glass Filament Roving

C = Chopped Glass

S = Sand</td></tr>
<tr><td>0.1</td><td>C</td></tr>
<tr><td>0.6</td><td>R + C</td></tr>
<tr><td>0.6</td><td>R + C</td></tr>
<tr><td>0.6</td><td>R + C</td></tr>
<tr><td>0.7</td><td>S</td></tr>
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<tr><td>0.7</td><td>S</td></tr>
<tr><td>0.6</td><td>R + C</td></tr>
<tr><td>0.7</td><td>S</td></tr>
<tr><td>0.5</td><td>R</td></tr>
<tr><td>1</td><td>R + C</td></tr>
<tr><td>0.1</td><td>C</td></tr>
</table>

RESULTS AND DISCUSSION

The following results represent the machining process with 0.5 mm depth of cut which affects the first layer of filament glass fiber which has an excess of chopped glass fiber. Dry cutting process has been achieved at room temperature.

Flank wear was examined and measured for three types of tool materials using tool maker microscope at different interval times as shown in Fig. 4. These results show the wear curves for different tool materials. PCD tools sustained the least tool wear compared to Ceramic and Carbide tools. This is undoubtedly due to PCD's superior hardness and wear resistance, as well as low coefficient of friction, together with high thermal conductivity. This led to lower cutting temperatures when PCD tools were employed. On the other hand, Ceramic and Carbide tools suffered from edge chipping as found by [7]. PCD insert tools showed a slow and progressive wear leading to long tool life.

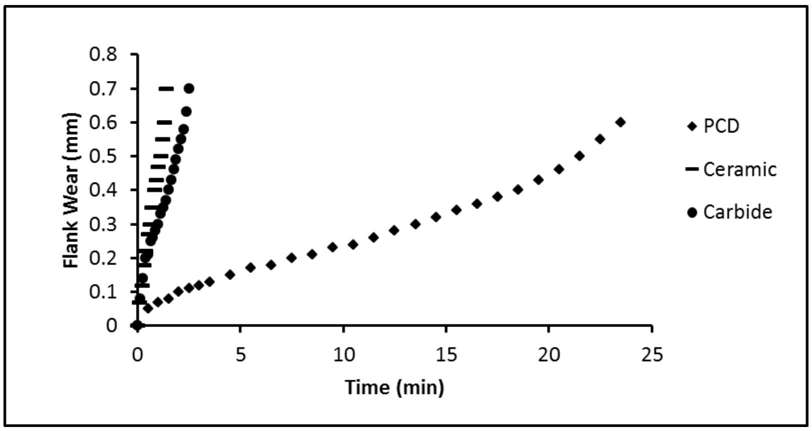


Fig. 4 Wear curves for different tool materials
V = 315 m/min, f = 0.2 mm/rev, d = 0.5 mm

The tool flank wear photograph for different tool materials after certain wear values as shown in Figs. 5-7. It reveals that tool wear mechanism occurred on the flank face was abrasion and there was no sign of chemical wear. Wear mechanisms are extremely related to the physical and mechanical characteristics of different fiber-matrix systems. Chopped fiber glass shows a strongly abrasive behavior because of is extremely abrasive by nature. It is also clear that the Glass Filament Roving is predominant in identifying tool wear.

As machining proceeds, surface roughness deteriorates for all used tool materials as shown in Fig. 8 but the worst surface deterioration is dramatically clear in case of Ceramic followed by that of Carbide. This means that Ceramic and Carbide are sensitive to time.

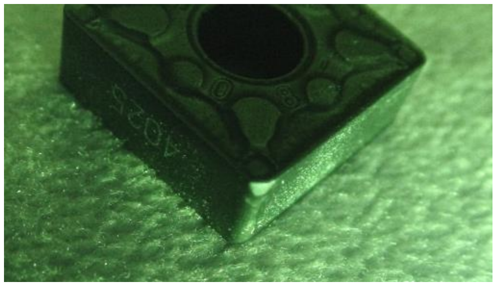


Fig. 5 Carbide edge at 0.7 mm flank wear

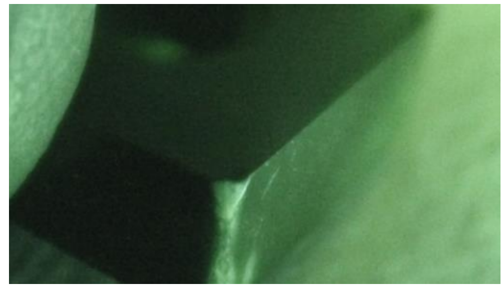


Fig. 6 Ceramic edge at 0.7 mm flank wear

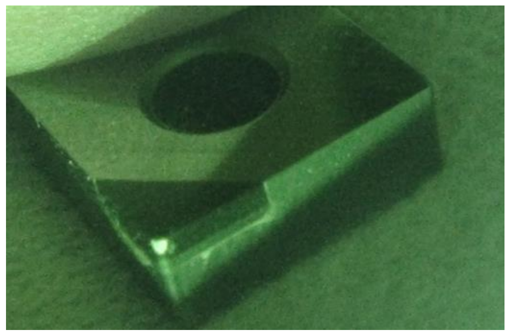


Fig. 7 PCD edge at 0.6 mm flank wear.

Accordingly, this proves that Ceramic and Carbide are not only low wear resistance to GRP composite material but also low thermal conductivity. Flank wear results shown in Fig. 4 & Fig. 8 illustrates that PCD tool which have lower tool wear provides better roughness than that of Carbide and Ceramic tools.

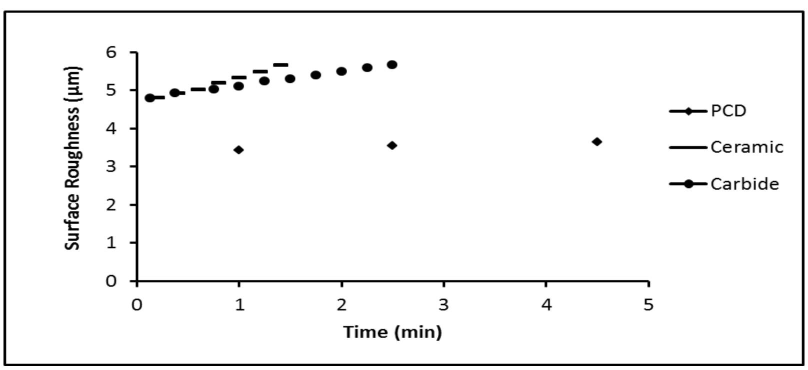
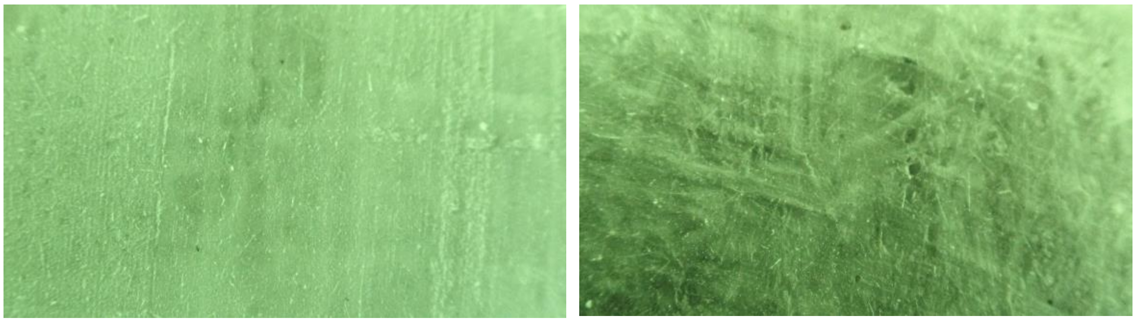


Fig. 8 Surface roughness-Time curves for different tool materials
V = 315 m/min, f = 0.2 mm/rev, d = 0.5 mm.

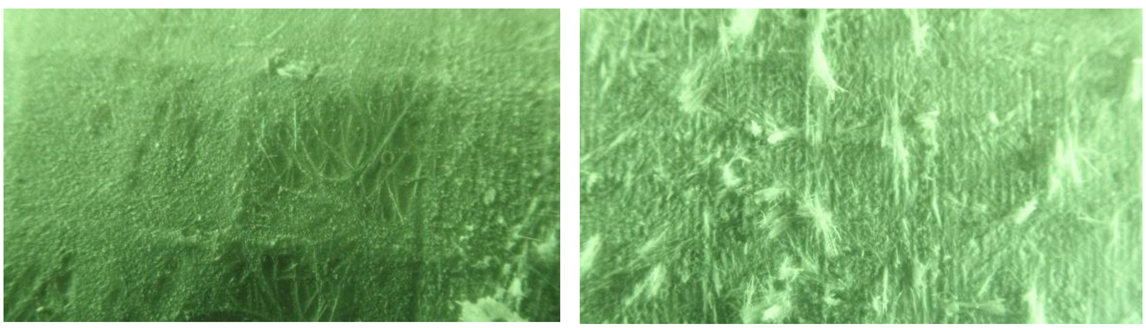
The surface roughness photos of the composite GRP pipe due to the turning process are shown in Figs. 9 - 11. These photos have been taken at two different cutting interval times with the corresponding flank wear for each cutting tool material. PCD cutting tool provides smoother surface roughness than the Carbide and Ceramic tools. This may be due to its high wear resistance which leads to decreased tool wear. It was observed that the Carbide tool cutting edge had some deficiency to cut the glass fiber. Moreover, the

using of Ceramic tool has a great effect on the cutting shape of glass fiber either filament or chopped. This considerable decline in surface finish can be attributed to edge chipping due to Ceramic tool is very hard and brittle and cannot resist dynamic loads, while glass fiber reinforcements and Glass Filament Roving may produce micro chipping leads to rapid destruction of tool tip leads to catastrophic failure.



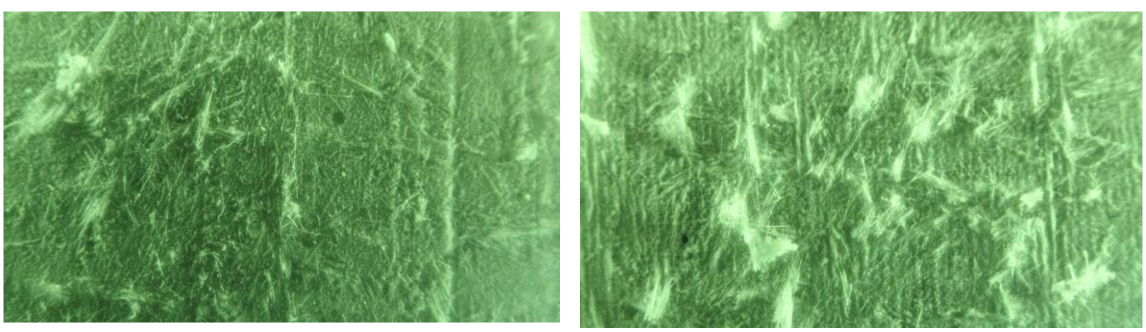
(a) (b)

Fig. 9 Composite material after cut using PCD Tool (scale 5:2).
(a) Flank Wear = 0.12 mm after 3 min. (b) Flank Wear = 0.5 mm after 21.5 min.



(a) (b)

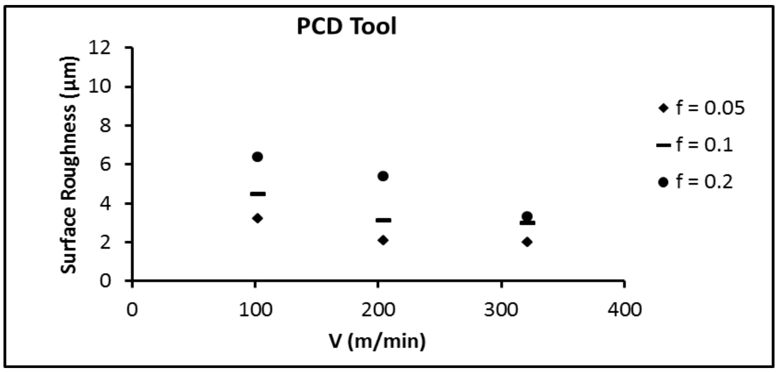
Fig. 10 Composite material after cut using Carbide Tool (scale 5:2).
(a) Flank Wear = 0.2 mm after 0.375 min. (b) Flank Wear = 0.52 mm after 2 min.



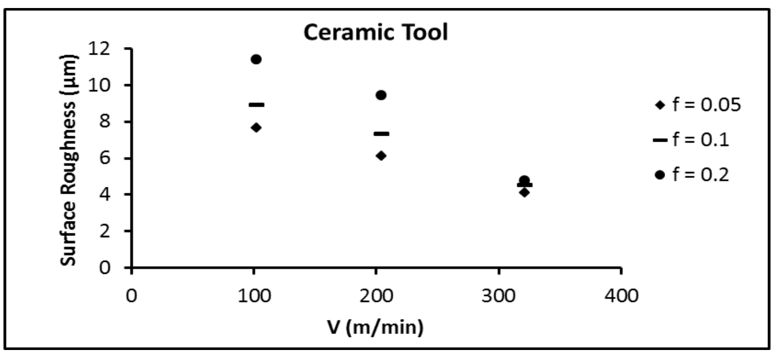
(a) (b)

Fig. 11 Composite material after cut using Ceramic Tool (scale 5:2).
(a) Flank Wear = 0.12 mm after 0.2 min. (b) Flank Wear = 0.7 mm after 1.4 min.

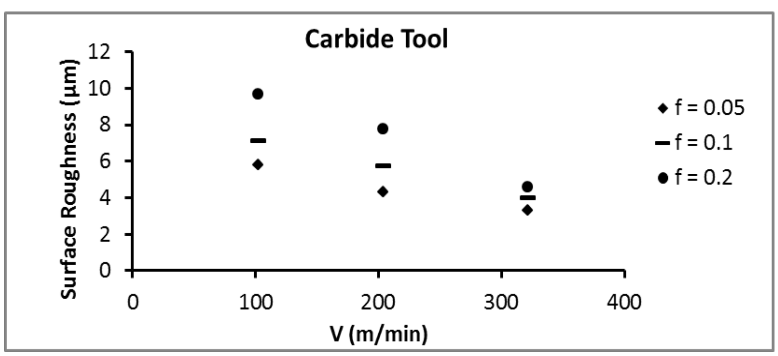
The variation of the measured surface roughness of machined composite pipe structure a different cutting velocities and feeds for different tool materials are shown in Fig. 12. It i noted that the surface roughness is mostly affected by cutting speed and feed values Higher cutting speed enhances surface finish, while higher feed deteriorates surfac roughness.



(a)



(b)



(c)

Fig. 12 Influence of cutting velocities on surface roughness of composite for different feeds and tool materials.

The influence of cutting tool material on surface roughness for different feeds at 321 m/min cutting speed is shown in Fig. 13. It is known that the cost of PCD tools is higher than Ceramic and Carbide tools. But the Ceramic and Carbide tools are available in market. So, Carbide tool can be used at feed of 0.05 mm/rev to give the same surface roughness of PCD tool at feed of 0.2 mm/rev for the same cutting speed. In the same manner, the Carbide tool at feed of 0.2 mm/rev can yields the same surface roughness obtained from Ceramic tools with feed of 0.1 mm/rev.

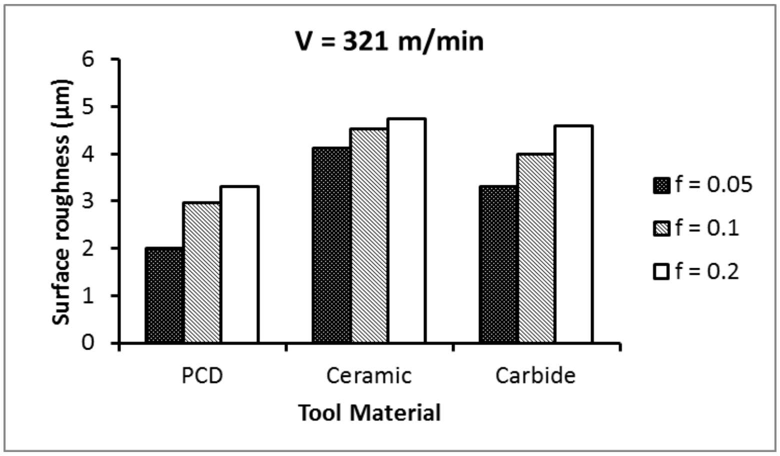


Fig. 13 Influence of tool material on surface roughness of composite at different feeds.

CONCLUSIONS

Turning tests were carried for investigating tool flank wear and surface roughness when machining the presented GRP composite containing both Chopped fiber glass and Glass Filament Roving in its constituents using different tool materials; PCD, Ceramic and Carbide. The following conclusions can be drawn from the experimental results:

1. PCD tools sustained the least tool wear compared to Ceramic and Carbide tools. This is undoubtedly due to PCD's superior hardness and wear resistance, as well as low coefficient of friction, together with high thermal conductivity. This led to lower cutting temperatures when PCD tools were employed. On the other hand, Ceramic and Carbide tools suffered from edge chipping. PCD insert tools showed a slow and progressive wear leading to long tool life.

2. The tool wear mechanism occurred on the flank face was abrasion and there was no sign of chemical wear. Wear mechanisms are extremely related to the physical and mechanical characteristics of different fiber-matrix systems. Chopped fiber glass shows a strongly abrasive behavior because it is extremely abrasive by nature. It is also clear that the Glass Filament Roving is predominant in identifying tool wear.

3. As machining proceeds, surface roughness deteriorates for all used tool materials but the worst surface deterioration is dramatically clear in case of Ceramic followed by that of Carbide. This means that Ceramic and Carbide are sensitive to time. Accordingly, this proves that Ceramic and Carbide are not only low wear resistance to GRP composite material but also of low thermal conductivity. PCD tool which shows lower tool wear provides better roughness than that of Carbide and Ceramic tools.

4. PCD cutting tool provides smoother surface roughness than the Carbide and Ceramic tools. This is due to its high wear resistance which leads to decreased tool wear. It was observed that the Carbide tool cutting edge had some deficiency to cut the glass fiber. Moreover, the using of Ceramic tool has a great effect on the cutting shape of glass fiber either filament or chopped. This considerable decline in surface finish can be attributed to edge chipping due to Ceramic tool is very hard and brittle and cannot resist dynamic loads, while glass fiber reinforcements and Glass Filament Roving may produce micro chipping leads to rapid destruction of tool tip leads to catastrophic failure.

5. Surface roughness is mostly affected by cutting speed and feed values. Higher cutting speed enhances surface finish, while higher feed deteriorates surface roughness.

6. Carbide tool can be used at feed of 0.05 mm/rev to give the same surface roughness of PCD tool at feed of 0.2 mm/rev for the same cutting speed. In the same manner, the Carbide tool at feed of 0.2 mm/rev can yield the same surface roughness obtained by Ceramic tools with feed of 0.1 mm/rev.

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