Improvement of Surface Properties of Carbon Fiber Reinforced Epoxy Composites Using Solid Lubricants During Machining Processes

Ibrahem R. A.

Industrial Engineering Department, Jazan University, Jizan 45142 KSA,
Ribrahem@jazanu.edu.sa

Abstract

Polymeric composites become the most common alternatives for traditional metallic materials for a wide range of industrial applications for example, in the automotive industry, polymeric materials and polymeric composites replaced a huge percentage of metallic parts. Polymeric composites are light in weight, easy to form, and have a lot of other properties that are recommended for automotive and other industries. However, the machining of polymeric parts still faces some restrictions and limitations because of the likelihood of damage to these parts during machining operations. Cracks, tears, fiber pull-out, softness, fracture as well as surface distortion are common examples of damage to polymeric composites while machining. The present work is concerned with measuring of surface finish and generated temperature of machined parts during the drilling operations of carbon fiber-reinforced composites. Some metallic additives were proposed as a solid lubricant additive for carbon fiber-reinforced epoxy. Reducing surface roughness and generated temperature are the objectives of this work to improve the ability of polymeric composites to be safely drilled (machined). The proposed polymeric composites consist of epoxy reinforced with carbon fiber as well as some fillers to enhance the machining properties of epoxy composites. The results show that using metallic fillers (copper powder, MoS2 powder) under selected cutting conditions remarkably improved the machinability of carbon fiber-reinforced epoxy composites.

Keywords:

Machining of polymer composites; epoxy composites; solid lubricant; metallic fillers; surface roughness.

1. Introduction

A wide range of parts that are used in industry are made of polymeric composites and polymeric materials, these promised alternatives have a lot of properties that are recommended for industrial applications, it has a lightweight, high mechanical strength, good chemical and thermal stability, availability, affordability and so on [1-2]. In general, composite materials are difficult to machine because of their anisotropic and non-homogeneous structure as well as the high abrasiveness of their reinforcing constituents. This typically results in damage being introduced into the workpiece and in very rapid wear development in the cutting tool. Ibrahem et al. [3-6] introduced Vegetable oil based emulsion (VOBE) as a cutting fluid for turning operations, it was concluded that Coconut oil-based emulsion with 30 % oil content shows better enhancement of surface roughness for high cutting speed (145 rpm) and high feed rate (0.117 mm/rev).

It is recommended to apply this emulsion as lubricant/cooling medium instead of conventional mineral oil-based emulsion. Brinksmiere et al. proposed drilling experiments with minimum quantity lubrication (MQL) using different cutting fluids and supply strategies. They investigated the optimum drilling conditions based on tool shape, tool material, and machining parameters. Another objective of their investigations was to analyze surface defects of the hole and the resulting diameter tolerances due to the high mechanical and thermal loads when machining titanium. It was concluded that the use of adapted step drills improves diameter tolerances, surface quality, and tool wear [7-12]. Carbon fiber-reinforced composites are used in a wide range of industrial and automotive industries. Machining of these parts whether it will be turned, milled, or drilled utilizing conventional machining processes will be subjected to an expected failure or damage. It was concluded that with increasing CNT content or depth of cut, the resultant cutting force tends to shift along the cutting direction with a decreased coefficient of friction along the tool/chip interface, Yanli et al. [13-14]. The present work proposed a new strategy for lubrication operation during the drilling process based on the use of solid lubricants. This study investigates the effect of solid lubricant on the surface finish and generated temperature at the cutting area for the drilling process of Carbon Fiber Reinforced Epoxy Composites

2.Materials and Experiments

Carbon fiber reinforced epoxy (CFRECs) composites are the proposed workpiece material for this work; test specimens were designed in rectangular plates. Test specimens consist of epoxy resin (matrix) and carbon fiber (reinforcement) as well as metallic fillers (Cu or MoS_2 powder), test specimens were prepared using the hand-layup technique in an open Mold by placing a layer of resin that was mixed by the suitable amount of solid lubricant powder followed by a layer of carbon fiber and another layer of epoxy resin and so on to complete the hole cavity of the mold. After complete solidification of polymeric composite plates, it was cut into rectangular specimens 50 x 20 x 5 mm. A conventional drilling press with variable speed is used to perform the machining (drilling) operation to produce some through holes on the composite plates. Different cutting conditions - speed and feed – as well as different filling powder – types and content- were proposed as affecting factors for the surface roughness of the produced holes and the generated temperature at the cutting area. HSS twist drill was used to perform the drilling operations in two diameters 6mm & and 10mm. SRT 6200S surface roughness tester was used to perform the measurements of surface roughness for the drilled holes, as well as a BT-METER infrared thermometer was also used for remote measuring of temperature during the cutting operation. The effect of filling powder, cutting conditions (table 1), and tool diameter on the surface roughness and temperature were investigated.

Table 1. Cutting conditions.

Condition	Description	N, rpm	F, mm/.sec
C1	,Low speed low feed	860	0.5
C2	,Low-speed high-feed	860	2
C3	,High-speed low feed	1700	0.5
C4	,High-speed high-feed	1700	2

3. Results and Discussion

To investigate the effect of filling materials, cutting conditions, and tool dimensions on the machining of carbon fiber-reinforced polymeric composites; bar charts were constructed to obtain the relation between the surface roughness of the drilled hole and the type of filling particles under different cutting conditions as mentioned in table1. Another bar chart was constructed for the generated temperature at the cutting area.

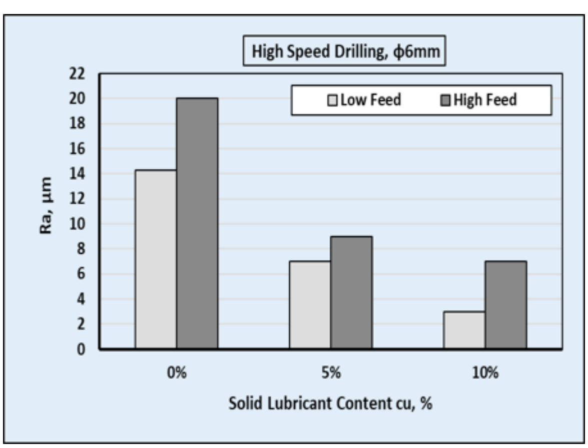


FIGURE.1 Surface roughness of ϕ 6 mm drilled CFRECs filled with Cu, under High cutting speed

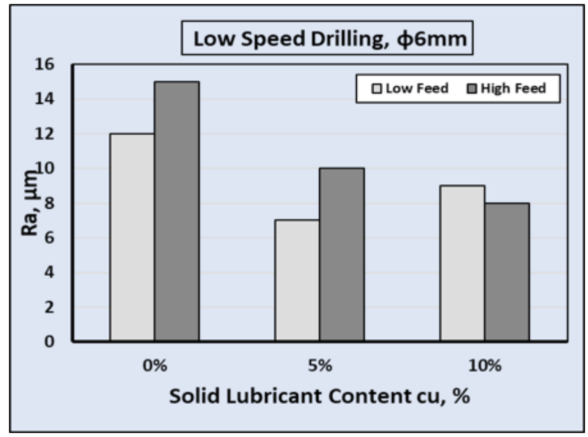


FIGURE.2 Surface roughness of ϕ 6 mm drilled CFRECs filled with Cu, under Low cutting speed

Figure 1 shows the relation between the surface roughness of 6 mm drilled holes in epoxy composites and the amount of copper filler under high cutting speed (1700 rpm) for two different values of feed rate. As shown in this figure the surface roughness of carbon fiber epoxy composites decreases remarkably with increases in copper content, for low feed rate the surface roughness (Ra) decreases from 14 µm for free samples to 3µm for composites filled with 10 % copper powder. Also, for the same composites under high feed rate; increases in copper fillers decrease the surface roughness of epoxy composites from 20 µm to 7 µm. Fig.2 shows the effect of a low cutting speed of 860 rpm on the same carbon fiber epoxy composites, the values of surface roughness decrease with the increase of copper content from 15 µm to 8 µm and from 12 µm to 9 µm under high and low feed rates respectively.

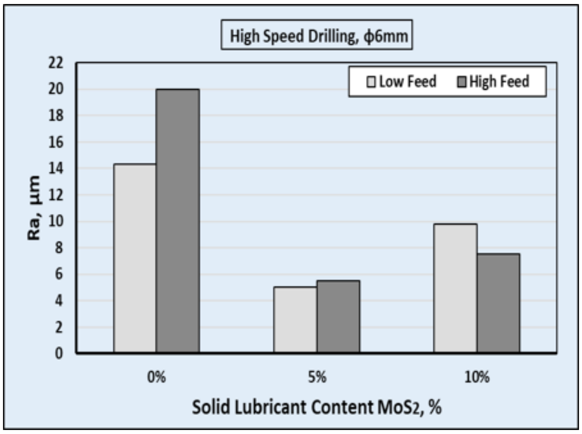


FIGURE 3 Surface roughness of ϕ 6 mm drilled CFRECs filled with MoS2 under High cutting speed.

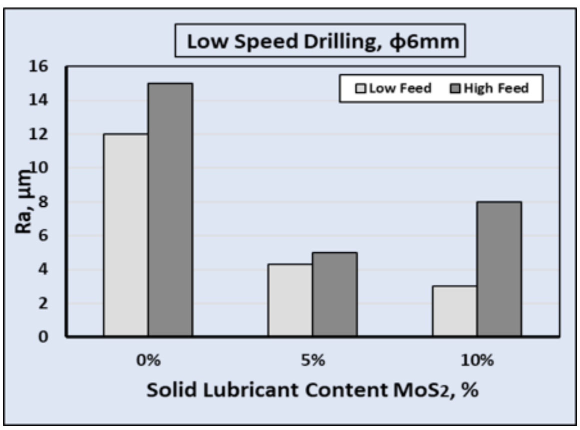


FIGURE 4 Surface roughness of ϕ 6 mm drilled CFRECs filled with MoS2 under Low cutting speed.

It seems that adding copper particles improves the internal properties of epoxy composites which may be responsible for the improved surface finish of drilled holes. Figs. 3 and 4 show the effect of using MoS2 powder as a solid lubricant filler for carbon fiber epoxy composites, concerning the effect of cutting speed for the same composite; low cutting speed shows high surface roughness under high feed rate. From the previous investigation, it can be said that the use of MoS2 powder remarkably decreases the surface roughness of carbon fiber epoxy composites than copper fillers.

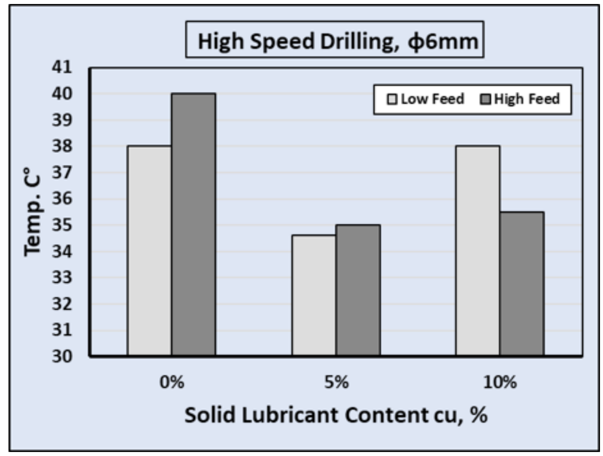


FIGURE 5 Generated Temperature of ϕ 6 mm drilled CFRECs filled with Cu under High cutting speed.

Figures 5 -8 show the relation between the cutting temperature and the amount of solid lubricants for carbon fiber epoxy composites under different cutting speeds and feed rates. Using copper powder or MoS2 as solid lubricants decreases the generated temperature at the cutting area from 40C° to 32C° for free composite and 10% powder content composite respectively. It seems that the presence of solid lubricants -Cu or MoS2 – helps in friction reduction between the cutting tool and epoxy composite workpiece which is responsible for improving surface finish as well as decreasing the cutting temperature.

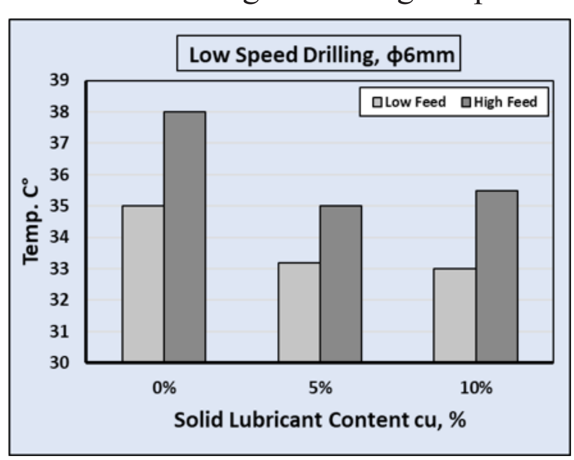


FIGURE 6 Generated Temperature of ϕ 6 mm drilled CFRECs filled with Cu under Low cutting speed.

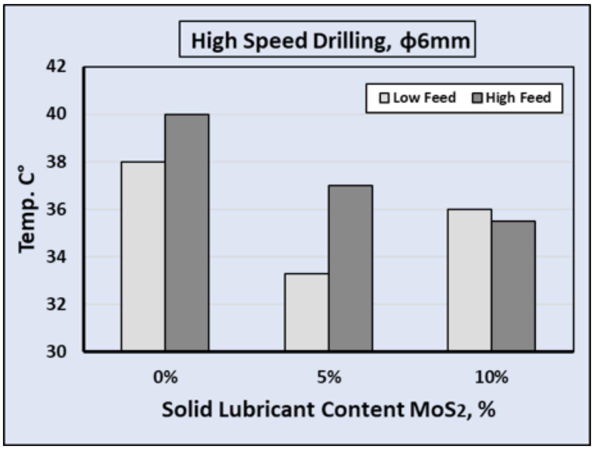


FIGURE.7 Generated Temperature of ϕ 6 mm drilled CFRECs filled with MoS2 under High cutting speed.

Figures 9-16 show the effect of increases in the hole diameter for the proposed carbon fiber reinforced epoxy composites under the previous conditions of solid lubricant content as well as the cutting conditions on the surface roughness and generated temperature at the cutting zone Figs 9 and 10 investigate the effect of copper content on the surface finish of large-diameter drilled holes (10 mm) under high and low cutting speeds respectively, it seems that there is a little improvement in the surface finish of drilled holes with increases of copper content to 5% under high feed rates.

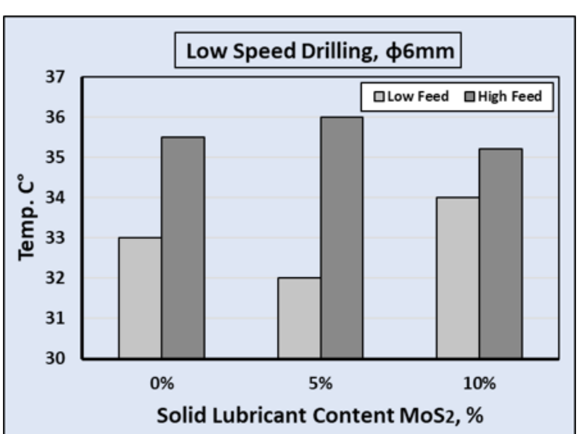


FIGURE.8 Generated Temperature of ϕ 6 mm drilled CFRECs filled with MoS2 under Low cutting speed

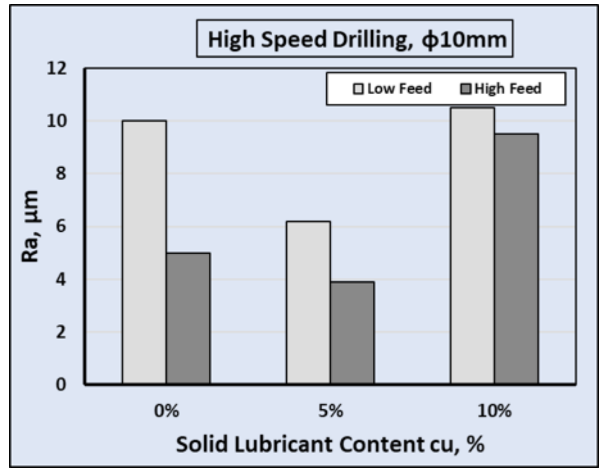


FIGURE.9 Surface roughness of ϕ 10 mm drilled CFRECs filled with Cu, under High cutting speed.

As shown in Figs. 11 and 12 using MoS2 instead of copper powder as a solid lubricant for drilling of epoxy composites decreases the surface roughness of drilled holes from 12 μm to 2 μm with 10 % MoS2 at low cutting speed and low feed rates. Generated cutting temperature at the working area of drilling 10mm diameter through holes in carbon fiber epoxy composites decreases with increases of proposed fillers under different cutting conditions, figures 13-16 show that using copper powder or MoS2 powder improved the thermal properties of carbon fiber reinforced epoxy composites. From the investigated results of this experimental study, it can be recommended that the use of copper powder or MoS_2 additives enhance the machining properties of polymer matrix fiber composites.

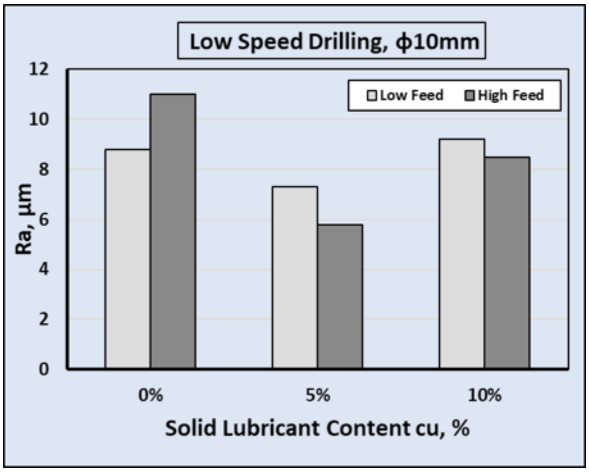


FIGURE.10 Surface roughness of ϕ 10 mm drilled CFRECs filled with Cu, under Low cutting speed.

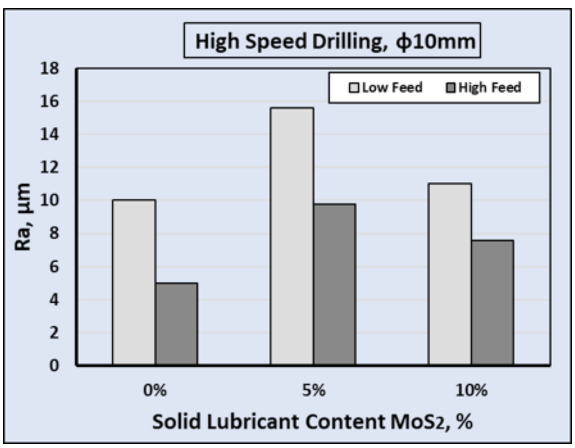


FIGURE.11 Surface roughness of ϕ 10 mm drilled CFRECs filled with MoS2, under High cutting speed

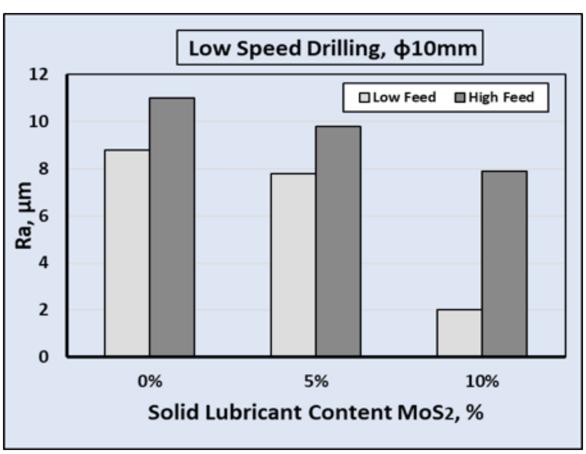


FIGURE.12 Surface roughness of ϕ 10 mm drilled CFRECs filled with MoS2, under Low cutting speed

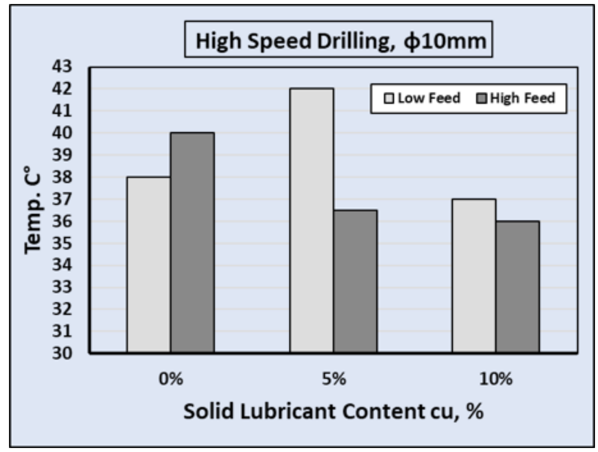


FIGURE.13 Generated Temperature of ϕ 10 mm drilled CFRECs filled with Cu under high cutting speed.

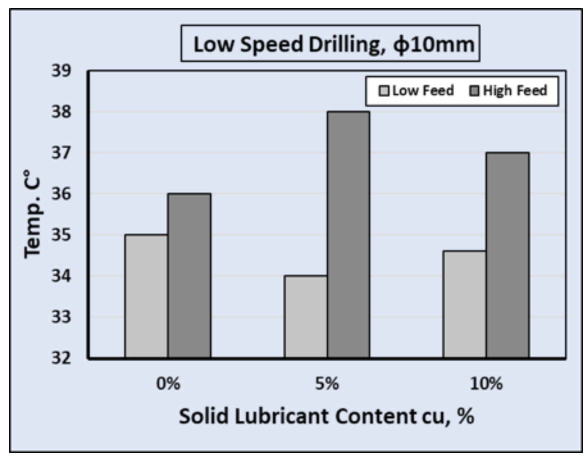
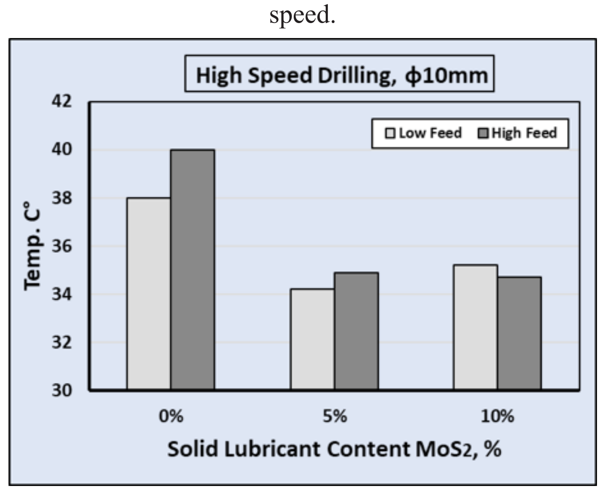


FIGURE.14 Generated Temperature of ϕ 10 mm drilled CFRECs filled with Cu under low cutting speed.



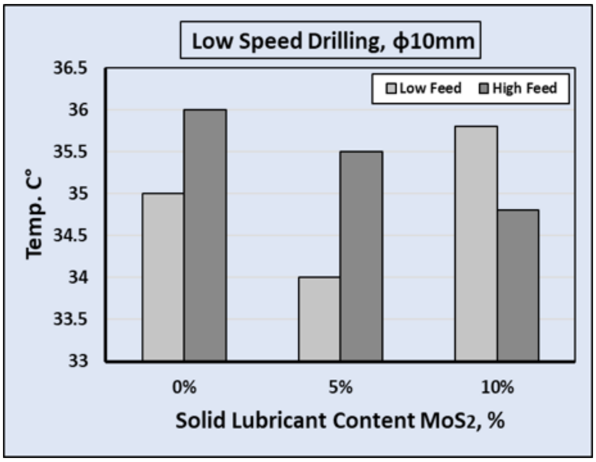


FIGURE.16 Generated Temperature of ϕ 10 mm drilled CFRECs filled with MoS2 under Low cutting speed.

Table 2: Summary of the best results

Solid lubricant Additives	Cutting conditions & Solid Lub. contents	Percentage of reduction in Surface Roughness	Percentage of reduction .in Cutting Temp
Cu	High-speed, low feed copper 10%	70%	13%
	High-speed, high-feed copper 10%	62.5%	12.5%
	Low speed, low feed copper 5%	41.6%	5%
	Low speed, high feed copper 10%	46%	13%
MoS_2	Low-speed, low-feed MoS_2 10%	77%	3%
	Low-speed, high-feed MoS_2 5%	63%	3%
	High-speed, low-feed MoS_2 5%	61%	11.8%
	High-speed, high-feed MoS_2 5%	70%	10%

4. Conclusion

Depending on the results of this work, it can be concluded that:

- Machining of carbon fiber epoxy composites can be improved using metallic additives that behave as a solid lubricant.
- Surface roughness of polymeric composites increases during the drilling process due to the presence of reinforcing fiber.
- Presence of solid lubricants -Cu or MoS2 – helps in friction reduction between the cutting tool and epoxy composite workpiece which is responsible for improving surface finish as well as decreasing the cutting temperature.
- Using metallic fillers in epoxy decreas-

es the amount of generated cutting temperature.

- Increases in copper content to 5% improved the surface quality of carbon fiber-reinforced epoxy composites.
- Increases of MoS2 content to 10% improved the surface quality of carbon fiber-reinforced epoxy composites.

Conflict of Interest

None declared

References

[1] Ibrahem R. A., 2020. "Effect of Molybdenum Disulfide Nano-particles on Dry Sliding Behavior of Carbon Fiber Reinforced Epoxy', Tribology in Industry Vol. 42, No. 1 pp. 115-120

[2] Ibrahem R. A., 2016. "Friction and Wear Behaviour of Fibre / Particles Reinforced Polyester Composites, International Journal of Advanced Materials Research, vol. 2, no. 2, pp. 22-26,

[3] Ibrahem R. A., Ali A. S., Shewakh W. M., 2021. "Effect of vegetable oils as lubricating/cooling medium during Machining processes on surface roughness", Journal of the Egyptian Society of Tribology V. 18, No. 1, pp. 1 – 7.

[4] Ibrahem R. A., 2015. "Effect of Date Palm Seeds on the Tribological Behaviour of Polyester Composites under Different Testing Conditions, Journal of Material Sciences & Engineering, vol. 4, issue. 6, doi: 10.4172/2169-0022.1000206

[5] Ibrahem R. A., Ali W. Y. 2010. Tribological performance of polyester composites filled by vegetable oil. Journal of Material Science and Engineering Technology 5: 287 - 292.

[6] Teti R.,2002. " Machining of Composite Materials, CIRP Annals, Volume 51, Issue 2, Pages 611-634,

[7] Ibrahim R.A., 2015. "Tribological performance of polyester composites reinforced by agricultural wastes, Tribology International, Volume 90, Pages 463-466,ISSN 0301-679X,

[8] Brinksmeier E., R. Janssen, 2002. "Drilling of Multi-Layer Composite Materials consisting of Carbon Fiber Reinforced Plastics (CFRP), Titanium and Aluminum Alloys, CIRP Annals, Volume 51, Issue 1, Pages 87-90,

[9] Park K.Y. et al. 1995. "Delamination-Free and High-Efficiency Drilling of Carbon Fiber Reinforced Plastics J. of Composite Materials.

[10] Chen P., 1992. "High-Performance Machining of SiC Whisker-Reinforced Aluminium Composite by Self-Propelled Rotary Tool Annals of CIRP.

[11] Weinert K., 1993. "A Consideration of Tool Wear Mechanism when Machining Metal Matrix Composites (MMC) Annals of CIRP.

[12] Brinksmeier, E., Berger, U., Janssen, R., 1998, Advanced Sensoric and Machining System for Manufacturing and Repair of Jet Engine Components, Proceedings of 31" CIRP International Seminar on Manufacturing Systems, 26.05. - 28.05. Berkeley (USA).

[13] Klocke, F., Krieg, T., 1999, Coated

Tool for Metal Cutting - Features and Applications, Keynote Paper, Annals of the CIRP,

[14] Yanli He, Ming Luo, Baohai Wu, Changfeng Yao, Dechao Wang, 2023. “Study on the cutting force responses in machining multiscale carbon nanotube/ carbon fiber reinforced polymer composites, Journal of Manufacturing Processes, Volume 95, Pages 160-170,