Effect of Grinding Process Parameters on Surface Area Roughness of Glass fibre Reinforced Composite Laminate under Dry and Coolant Environment

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***Abstract*— This paper presents a comparative study on dry and wet grinding of chopped strand mat glass fibre reinforced polymer laminates using an alumina wheel. Investigations were performed to study the impact of the grinding parameters, namely feed, speed, and depth of cut on grinding force ratio and surface area roughness. Effective grinding parameters were sought in this study to maximize grinding force ratio and minimize surface area roughness. Test results show that coolant helped to decrease surface area roughness, but inevitably reduced the grinding force ratio in some cases. These findings lead to economic machining solution for optimum grinding conditions in grinding composite laminates.**

Keyword- Composite laminates, Grinding, Grinding Force Ratio, Surface Area Roughness

I. INTRODUCTION

Glass fibre-reinforced polymer (GFRP) composites are suitable for aeronautical and marine parts due to superior mechanical properties, i.e. stiffness to weight ratio, corrosion resistance and good damping characteristics. Expanding uses of glass fibre reinforced polymer (GFRP) composites in many engineering fields extend the requirements for subsequent machining and grinding to meet desired surface finishes during assembly. Although mechanical fastening is a common assembly method for composite structures, alternative joining methods such as adhesion may offer attractive cost benefit [1]. Grinding is vital to achieve the required surface finish and dimensional accuracy for such application [2].

The machining process, being the last operation of composite manufacturing, demands great engineering care for satisfactory machining quality [3]. Significant insight on the machining mechanisms of fibre-reinforced composites can be gained by performing and observing the conventional machining processes, i.e. drilling, turning, milling and grinding. However, the cutting theories of homogenous materials cannot be applied to composites because of its non-homogeneous microstructures. Fibre reinforcement in GFRP composites strongly affects their grindability [4].

During machining, fibre particles cause fast tool wear and irregular cutting forces, hence workpiece surface roughness [5]. The grinding process consumes more energy than other machining processes for the removal of a unit volume of material. Most of the energy is dissipate as heat and friction by rubbing and cutting. Reference [6] reported that high temperatures in grinding might have negative impact on the surface quality of workpiece.

It is common to use coolant and a set of optimized process parameters to lower grinding temperature for improved workpiece quality and extended grinding wheel life, for instance, reported that tangential cutting force reduced with the utilization of neat oil [7]. Reference [8] reported that grinding in coolant produced better surface roughness than in compressed cold air. In conformance with the results, [9] concluded that grinding in dry environment increased workpiece temperatures and its surface layer alteration than with wet grinding. Although higher workpiece temperature promotes the grindability of the material and reduces the forces and power, it decreases the quality of the surface [10]. Consequently, many researches on composite machining were carried out for reduction of forces and temperature and improved surface quality by optimizing grinding variables [11]. In machining GFRP, [1] claimed that feed and, in a slightly lesser degree, cutting speed are the major factors affecting surface roughness. On the other hand, depth of cut shows insignificant effect on surface roughness. Further he concluded that to attain great surface finish on the GFRP work piece, high cutting speed, high depth of cut and lower feeds are favoured. The search for the optimal grinding conditions for the best surface quality is difficult due to the heterogeneous property of composites. Reference [4], affirmed that the longitudinal surface roughness of multidirectional composites varied with the fibre positioning.

Grinding process quality, accuracy and the resulting workpiece surface quality were affected by the forces in grinding. Grinding forces consist of frictional force, chip forming force and ploughing force respectively by rubbing, cutting and ploughing actions. All the three forces are greatly dependent on process parameters [12].

The relationship between grinding parameters and the ensuing grinding forces and surface roughness is further confounded by the use of coolant [13]. Improper grinding can induce surface damage and unacceptable grinding economics due to inefficient material removal and/or unnecessary wheel degradation. Therefore, an investigation of the impact of coolant on forces at different process parameters in grinding of CSM GFRP is warranted and the effect of coolant in reducing workpiece surface roughness under varying grinding parameters needs to be explored.

II. Materials and Methods

Glass fibre reinforced polymer composite laminate utilized in this test was made by hand layup process using chopped strand mat fibre (R-glass) and polyester (Reesol) [14]. The property of the material is given in Table I. Each specimen is 50 mm length X 15 mm width X 10 mm height. Grinding test was done on workpiece 50 mm x 10 mm side surface. Spindle speed, feed and depth of cut of each test were listed in Table 2. These parameters were chosen because of their significant impact on grinding process [1] and their values determined based on machine and grinding wheel specifications. The grinding wheel is a alumina profile mounted wheel (OA46QV) of 25 mm diameter x 19 mm length. The grinding was done under dry and synthetic (Yushiroken SC95) coolant environment.

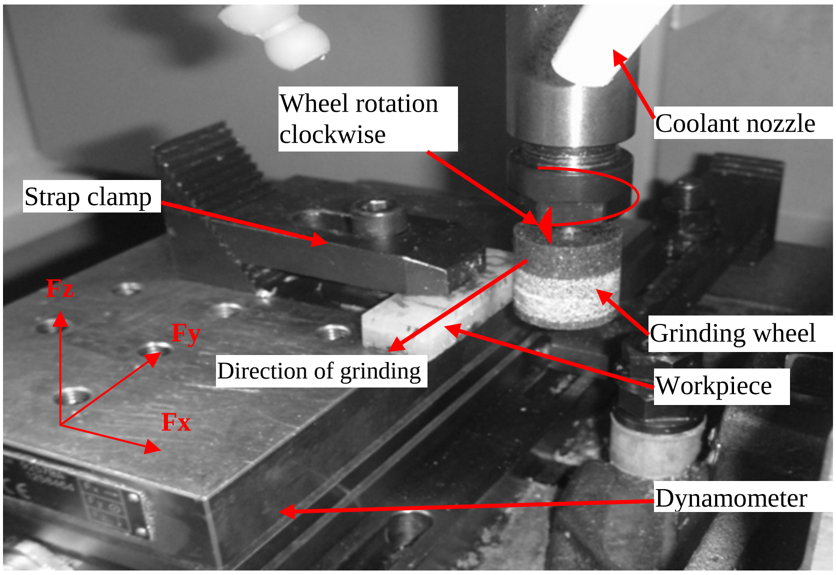

Fig. 1. Grinding experimental setup

TABLE I. Properties of GFRP Composite

Parameter	Value
Tensile strength	80-90 MPa
Tensile modulus	1.55 – 1.65 GPa
Density	1600 kg/m^3
Hardness	53-56 HRB
Coefficient of thermal expansion	5.3-7.5 x 10^{-6} K^{-1}

Grinding force is an important parameter in studying the mechanism of grinding. Grinding forces were measured using three-component Kistler type dynamometer, 9257BA and values were recorded with DEWETRON software [15]. Generally, the grinding force consist of three directional forces, to be specific, normal grinding force Fx, tangential grinding force Fy and component force acting along the direction of longitudinal feed (Fz), which is typically ignored because of its unimportance. In this study, grinding force ratio (μ), which is the ratio of tangential force (Fy) to normal force (Fx) as a measure of grinding efficiency is used. The average ground surface area roughness (Sa) of workpiece was measured using Sensofar PLμ 2300 surface profiler. Grinding experiments were conducted and results were tabled in Table 2. American National Standard Institute (ANSI) B46.1-1962, define waviness as the more widely spaced repetitive deviations, attributed to machining processes. Profilometry was used to analyze ground workpiece surfaces. The surface profile images demonstrate the waviness variations, which is the dominant factor contributing to the surface area roughness.

III. Results and Discussion

The grinding forces were measured while grinding in dry and coolant environment, and surface area roughness of the workpiece materials were shown in Table II.

TABLE II. Experiment parameters and measured values

Run No.	Speed (rpm)	Feed rate, (mm/min)	Depth of cut, (mm)	Grinding without coolant (dry)				Grinding with coolant			
				Fx (N)	Fy (N)	Sa (μm)	Grinding force ratio, (μ)	Fx (N)	Fy (N)	Sa (μm)	Grinding force ratio, (μ)
1	4000 [314]	1000	0.20	101.36	34.20	5.35	0.34	98.92	26.625	1.65	0.27
2	7000 [550]	1000	0.20	212.27	45.19	19.25	0.21	89.40	19.293	3.59	0.22
3	4000 [314]	1500	0.20	62.53	22.96	6.75	0.37	121.92	27.845	3.4	0.23
4	7000 [550]	1500	0.20	133.09	36.40	13.47	0.27	147.03	28.818	5.77	0.2
5	4000 [314]	1000	0.30	131.94	36.40	3.78	0.27	110.42	27.357	2.31	0.25
6	7000 [550]	1000	0.30	93.08	25.40	6.56	0.27	132.91	23.445	2.59	0.18
7	4000 [314]	1500	0.30	243.24	53.00	13.94	0.22	165.63	35.661	2.2	0.22
8	7000 [550]	1500	0.30	143.11	31.51	9.87	0.22	147.32	27.357	1.59	0.19

* speed values in [ ] are in m/min

A. *Analysis of Grinding Force Ratio*

Fig. 2 shows the comparison for grinding force values for different experimental runs. The data shows that in almost all test runs, dry grinding resulted in higher grinding force ratio, indicating more efficient cutting. Even in the exception, the difference was not significant. On the other hand, in all scenarios, the use of coolant lowers the ground surface area roughness.

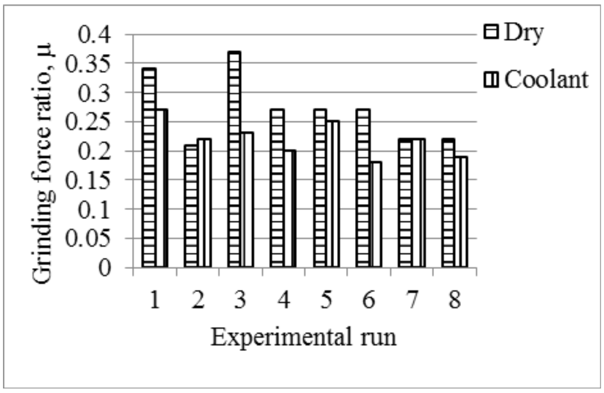

Fig. 2. Grinding force ratio for different experimental runs

I) Speed effect

At low depth of cut regardless of feed, when the speed was increased, grinding force ratio decreased in both dry and wet grinding. This low efficiency represents predominant roughing and ploughing as indicated by [11]. At high depth of cut regardless of feed, speed increase resulted in virtually no change in grinding force ratio in dry grinding but lower grinding force ratio, hence less effective cutting in wet grinding. In grinding CSM GFRP with alumina wheel, increasing speed generally decrease the grinding efficiency.

II) Feed effect

At low speed and low depth of cut, increasing feed increased the grinding force ratio in dry condition, but reduced it in the presence of coolant. The presence of coolant reduce the effective wheel work contact area, this in turn reduce the material removal. This shows that coolant does not always promote effective cutting. At low speed and high depth of cut, increasing feed decreased the grinding force ratio regardless of dry or coolant environment. This correlates to the theory proposed [11] that high depth of cut increases ploughing, causing plastic flow of material rather than cutting. In addition, this increases the actual wheel work contact area, which in turn results in high normal forces that reduces the material removal efficiency. This also shows that increasing feed will only improve grinding efficiency when the workpiece is dry and the speed and depth if cut is low. Otherwise, increasing feed does not help grinding economics.

III) Depth of cut effect

At low speed and feed, increasing depth of cut reduced grinding ratio in both grinding situations because it corresponded to more pronounce ploughing and not cutting. At high speed and low feed, as depth of cut was increased, grinding force ratio increased in dry grinding because more material can be removed with deeper cut and repeated cutting actions. The presence of coolant did not promote similar improvement. However, at high feed and low speed, increased depth of cut reduced grinding force ratio because of ploughing operation. Reference [16] said that, grinding wheel of multiple grits ploughed more on a surface than a single grit due to smaller engaging width, in addition to the fact that the material trapped in the middle of multiple-grit abrasives will not removed. This shows that increasing depth of cut is only effective in increasing cutting in one tested condition, that is when the speed is high the feed is low, and the workpiece is dry. With alumina wheel, low speed, low feed and low depth of cut is preferred for cutting effectiveness in both dry and wet grinding.

B. Analysis of surface area roughness

Surface area roughness, that is the average area roughness measured from three-dimensional profiles of the ground workpiece by each grinding condition, as given in Table II. Fig. 3 shows the correlation of surface area roughness for the investigative runs.

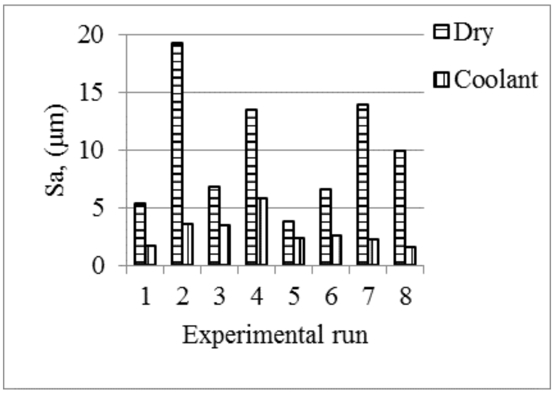

Fig. 3. Surface area roughnesses (Sa) for different experimental runs

I) Speed effect

Increasing speed generally led to increase in surface area roughness in both dry and wet grinding conditions, except for the cases in which feed rate and depth of cut were high. Therefore, speed has a strong positive correlation with surface area roughness

II) Feed effect

In dry grinding, increasing feed increased surface area roughness except in the case of high speed and low depth of cut. However, for grinding with coolant, surface area roughness increased when the depth of cut was low for a particular speed. These trends were reversed, when the depth of cut was high. Higher feed and depth of cut increase the material removal; low actual contact area could be the likely cause for this trend.

III) Depth of cut effect

Increasing the depth of cut decreased surface area roughness in dry grinding except when the speed was low and the feed rate was high. In the case of grinding with coolant also surface area roughness decreased except in low speed and low feed combines.

C. Analysis of surface profile

Fig. 4 and 5 are surface profile images of 20x magnification of areas of 636x477µm^2 each. They illustrate the different ground surface characteristics resulting from various grinding conditions. Attempts were made to recognize the surface area roughness using the surface profile images and measured irregularity heights.

Increasing speed increased surface area roughness due to increased cutting, which led to more height and width of irregularities on ground surfaces for both grinding (Figs. 4(a), (b) and Figs. 5(a), (b)). When grinding in dry environment, increasing feed increased roughness too, but at relatively lower magnitude than speed (Figs. 4(a), (c)). In the case of increasing feed at high depth of cut, surface appears to be flatter but, the high roughness value could be due to increased width and height between irregularities (Figs. 4(e), (g)). Profile images of ground surface with coolant have similar width and height of irregularities. The observed phenomena are due to high material removal combined with low actual contact area (Figs. 5(e), (g)). Deeper cut produced lower roughness for grinding in dry environment since it made flat cut uniformly with low irregularity height (Figs. 4(a), (e)). At increased depth of cut, grinding in coolant environment resulted in increased surface area roughness. This could be due to more irregularities induced by ploughing (Figs. 5(a), (e)).

The use of coolant made the cutting more even, lowered the grinding force ratio and produced low surface area roughness. Increasing speed in wet grinding, however, increased the surface area roughness, as more peaks and valleys on the surface were produced by an increased amount of non-uniform cutting. The surface area roughness values in wet grinding are in lower range than those in dry grinding.

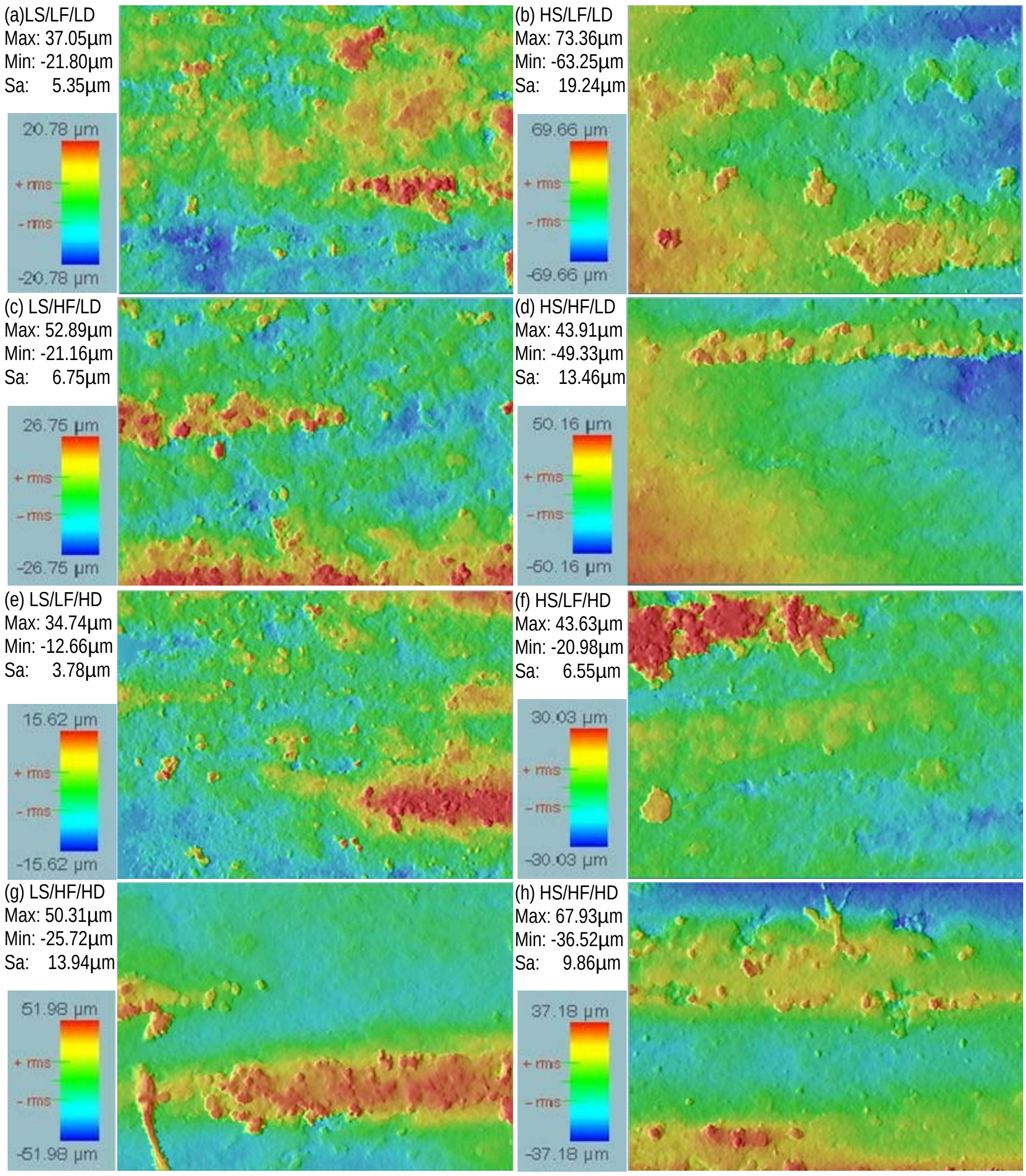

Fig. 4. (a-h) Profilometer images workpiece ground in dry condition L-Low; H-High; S-Speed; F-Feed; D-Depth of cut

In the meantime, rubbing between grinding wheel and workpiece in the presence of lubricating coolant lowered the grinding force ratio. Throughout the experiment, grinding with coolant produced lower surface area roughness than those in dry grinding. In wet grinding, low speed, feed and depth of cut produces the greatest grinding efficiency and lowest surface roughness. On the other hand, no single set of grinding parameters in dry grinding resulted in maximum grinding force ratio and minimum surface roughness. This seems to suggest that a set of grinding parameters for maximized grinding efficiency and minimized surface roughness exists for wet grinding but not for dry grinding.

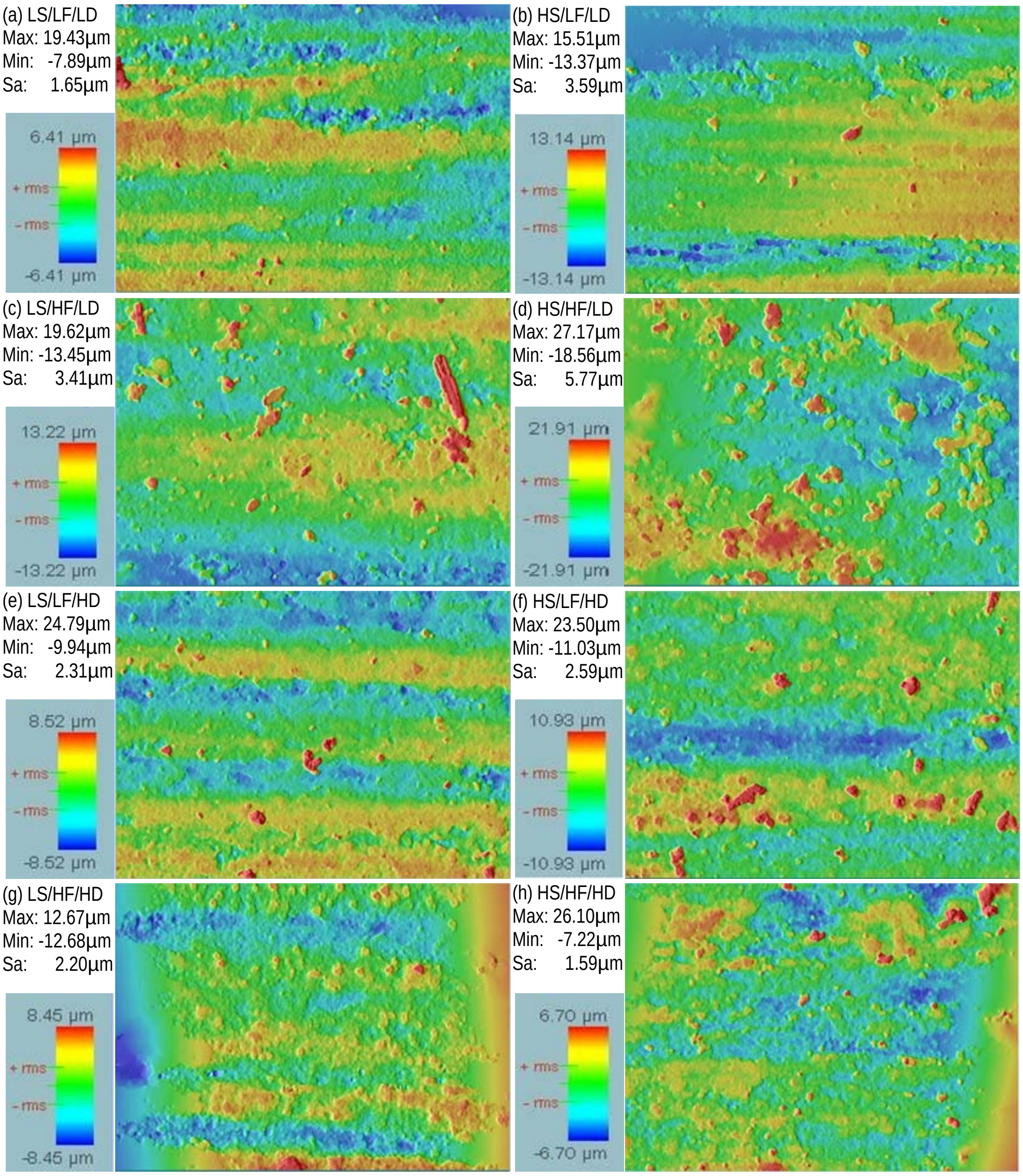

Fig. 5. (a-h) Profilometer images workpiece ground with coolant L-Low; H-High; S-Speed; F-Feed; D-Depth of cut

IV. CONCLUSION

In light of the grinding experiments done in this research, the following conclusions are drawn. GFRP grinding in dry condition is more efficient than grinding with coolant in most scenarios. Within the experimental range tested, the use coolant in grinding lowered the resulting surface area roughness. A set of grinding parameters for maximized grinding efficiency and minimized surface roughness seems to exist for wet grinding but not for dry grinding of CSM GFRP using alumina wheel.

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Dr. P. Chockalingam is a mechanical engineer, swimming in academics and research for more than two decades. An ardent researcher, he has many research papers in indexed international peer reviewed journals, with impressive citation scores, and is involved in research grants projects. His areas of research interest include machining of metals and composite, and sustainable processing of materials.

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