MACHINABILITY STUDY OF A KEVLAR AND GLASS REINFORCED POLYESTER COMPOSITE UNDER DRY AND COMPRESSED AIR-COOLING CONDITION

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Abstract: *Modern manufacturing industries are continuously seeking for products which will be light weight, robust, less costly and possess good quality in terms of surface finish and dimensional accuracy. To attain the needs, material engineers are constantly striving to develop new metal alloys as well as composite materials. Composite materials' light weight, high specific strength and high specific modulus are being regarded as some gifted properties which are largely facilitating their applications in different engineering sectors. High speed machining is often considered as an accurate manufacturing process for making fiber reinforced plastic (FRP) products. It is also established that with high cutting speed and feed productivity increases but high tool wear also takes place hence cost increases. It is found that compressed air-cooling environment has been very effective in machining FRPs when surface roughness and cutting force are taken into consideration. In this research work, turning operation has been performed on a hybrid composite i.e. Kevlar and glass reinforced polyester under both dry and compressed air-cooling condition. Investigation has been carried upon due to compare the performances of two machining environments. Cutting parameters in the machining process are cutting speed, feed and depth of cut and measured responses are surface roughness and cutting force.*

Keywords: *KFRP composites, GFRP composites, CFRP composites, Hybrid composites.*

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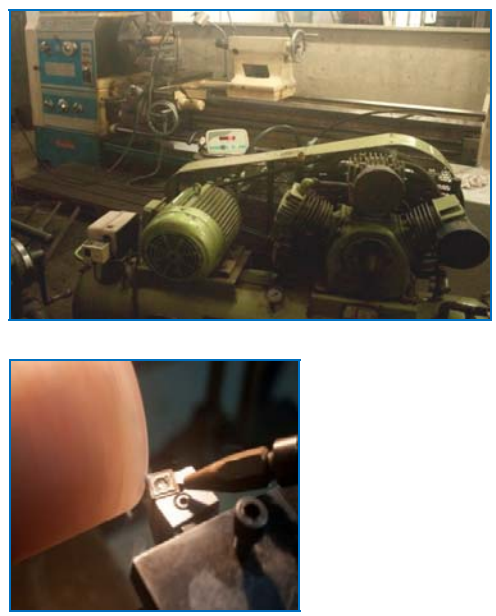
INTRODUCTION

Machining of fiber-reinforced plastic (FRP) materials has become very popular these days despite their relatively high cost. FRP composites pronounce a number of distinguished advantages over conventional engineering materials such as aluminum, steel etc. Among these high specific strength and high specific modulus are of great significance. They have found their applications in high-performance products which need to be lightweight yet strong enough to work on harsh loading conditions such as aerospace components, automobiles, car bodies, portable bridges, offshore structures, containers, corrosion resistant goods [1]. Since, composite materials are inhomogeneous and anisotropic in nature and protrusion of fibers occurs during their machining, the desired surface finish is often harmed. During machining whenever the cutting tool gets subjected to severe load fluctuations cutting flanks get damaged [2]. Again, Santhanakrishnam et al. [3] affirmed that a combination of plastic deformation, shearing and bending rupture would take place during machining of FRP composites. After performing face turning operation on glass fiber reinforced plastic (GFRP), carbon fiber reinforced plastic (CFRP) and Kevlar fiber reinforced plastic (KFRP) they found, CFRP gave a surface of better quality compared to other FRP composites. KFRP exhibited poor surface finish due to their higher toughness. Bhattacharya et al. [4] studied cryogenic machining of Kevlar composites and they concluded, with the increase in cutting force, surface roughness increased. The degrees of fiber pull out and fiber protrusion depended on various cutting parameters. Better surface quality was found under cryogenic condition even though tool wear slightly appeared to be of higher growth. Sonbaty et al. [5] performed drilling operation on GFR-epoxy composite. The drilling processes were carried out on epoxy resin and glass fiber reinforced epoxy composite (GFREC) with back plate. It was found that, for epoxy resin, increasing cutting speed had not any considerable effect on thrust force. On the other hand, torque decreased with increasing cutting speed. Isik [6] performed turning operation on Kevlar fiber reinforced plastic and found decreased surface roughness with increasing cutting speed whereas increased surface roughness with increasing feed rate. Controlled parameters such as cutting condition and non-controlled parameters such as work-piece non-homogeneity, tool wear, machine motion errors, chip formation and other random disturbances; all have effects on surface roughness. It is proved that both controlled and non-controlled parameters cause relative vibrations in the cutting tool and work-piece. Gill et al. [7] performed machining operation in unidirectional glass fiber reinforced epoxy composite. Turning operation was done on a workpiece of diameter 42 mm and length 840 mm in both dry and wet environment. The cutting tool used in the experiment was carbide insert (K10). The objective of the experiment was to predict cutting force while cutting speed, feed rate, tool nose radius and tool rake angle were varied during the whole operation. Three levels of cutting speeds, three levels of feed rates, two nose radii and three different rake angles were used in the experiment. It was found that depth of cut was the major parameter that can be attributed to high cutting force. It was also found that the tangential, feed and radial force decreased with decrease in tool nose radius. The tangential, feed and radial force increased with decrease in tool rake angle. Shahrajabian and Farahnakian [8] performed drilling operation on CFRP with varying spindle speed, feed rate and point angle of the twist drill bit. The spindle speeds used in the experiment were 1250 rpm, 2625 rpm and 4000 rpm; while feed rates were 50 mm/min, 425 mm/min and 800 mm/min and point angles were 60^0, 10^0 and 140^0. The objective of the experiment was to determine optimal cutting parameters keeping surface roughness, thrust force and delamination constrained up to certain level. Response surface methodology (RSM) has been used coupled with genetic algorithm to determine the optimal condition. Minimum surface roughness (R_a= 0.685 μm) was achieved at spindle speed of 4000 rpm, feed rate of 50 mm/min, tool angle point of 140^0 and the maximum surface roughness (R_a= 2.542 µm) was achieved at spindle speed of 1250 rpm, feed rate of 800 mm/min, point angle of 100^0. The minimum delamination (F_d= 1.02) was achieved at spindle speed of 4000 rpm, feed rate of 50 mm/min, point angle of 100^0, and the maximum delamination (F_d = 2) was achieved at spindle speed of 1250 rpm, feed rate of 800 mm/min, point angle of 140^0. Kumar et al. [9] performed turning operation in glass fiber reinforced plastic using carbide (10) cutting tool where the process parameters selected for the study were tool nose radius, tool rake angle, feed rate, cutting speed, depth of cut, and cutting environment. The cutting speeds used in the experiment were 55.42 m/min, 110.84 m/min and 159.66 m/min, the feed rates were 0.05 mm/rev, 0.10 mm/rev and 0.15 mm/rev, chosen depth of cuts were 0.2 mm, 0.8 mm and 1.4 mm and the cutting environments were dry, wet and cooled. They found that the developed model based on the Taguchi approach and the utility concept was effective to achieve good performance characteristics. The depth of cut, cutting speed, and feed rate had a significant effect on the utility function based on the ANOVA significant process parameters for multiple performances. The optimal condition was cutting speed 110.84 m/min, feed rate 0.1 mm/rev and the depth of cut was 1 mm.

EXPERIMENTAL RESULTS

During the experimental investigation, the main cutting force was measured by a lathe tool dynamometer and the magnitude of the main cutting force was displayed by the charge amplifier in 'kg' unit. After performing the cutting operation surface roughness was measured respectively using a Talysurf (Surtronic 3+ Roughness checker, Taylor Hobson, UK) using a sampling length of 4.00 mm.

Fig. 2.2 to Fig. 2.4 present the variation of main cutting force (P_z) with feed (S_o) whereas from Fig. 2.5 to Fig. 2.7 present the variation of main cutting force (P_z) with cutting speed (V_c) while machining FRP by coated carbide insert (SNMG) under both dry and compressed air-cooling condition. The figures from Fig.2.8 to Fig.2.10 present the variation of surface roughness (R_a) with feed (S_o) while from Fig.2.11 to Fig.2.13 present the variation of surface roughness (R_a) with cutting speed (V_c) while machining FRP by coated carbide insert (SNMG) under both dry and compressed air-cooling condition (CAC).



Nozzle position

Fig. 2.1 Photographic view of the experimental setup

DISCUSSION ON RESULTS

Cutting Force

According to the graphical representations of the variation of main cutting force with feed rate, it is evident that for almost every cutting condition; reasonable values of cutting force are found. Fig. 2.2 to Fig. 2.4 affirms that cutting force is increased with increased feed rate regardless of the machining environment. Combining both of the environments along with all the cutting conditions, compressed air cooling provided the best result under 213 m/min. cutting speed. One notable thing is that for increased depth of cut the value of the cutting force increased drastically.

2.1 Table. Experimental conditions

Machine Tool	:	KL-3280C/2000 (Sunlike Engine Lathe, 7.5 kW).
Work Material	:	Kevlar and glass reinforced Polyester
Dimension	:	300 mm length and 100 mm diameter.
Cutting Insert	:	Titanium nitride coated tungsten carbide (SNMG)
Cutting Tool Geometry	:	-6°, -6°, 6°, 6°, 15°, 75°, 0.8 (mm)
Process Parameters		
Cutting Speed, V_c	:	74, 106, 149 and 213 (m/min)
Feed, S_o	:	0.10, 0.12, 0.14 and 0.16 (mm/rev.)
Depth of cut, t	:	1.0, 1.5 and 2.0 (mm)
Machining Environment	:	Dry and Compressed air cooling (Air pressure-20 Bar)

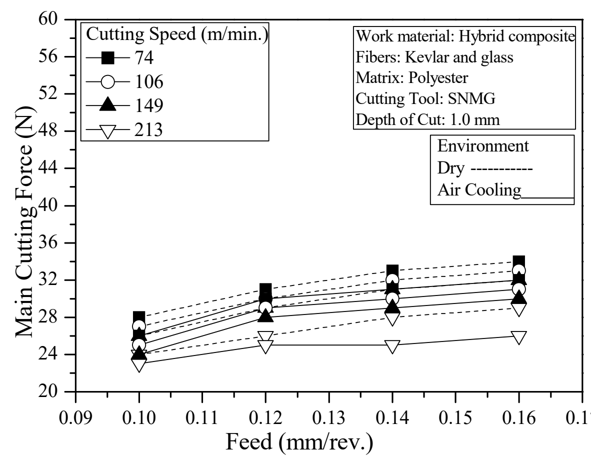


Fig 2.2 Variation of P_z with S_o at different V_c and 1.0 mm depth of cut under both dry and CAC condition

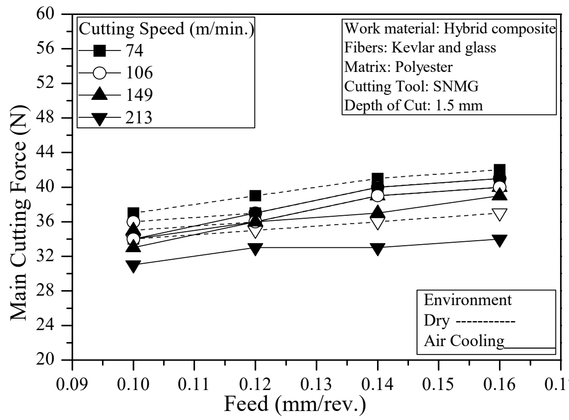


Fig 2.3 Variation of P_z with S_o at different V_c and 1.5 mm depth of cut under both dry and CAC condition

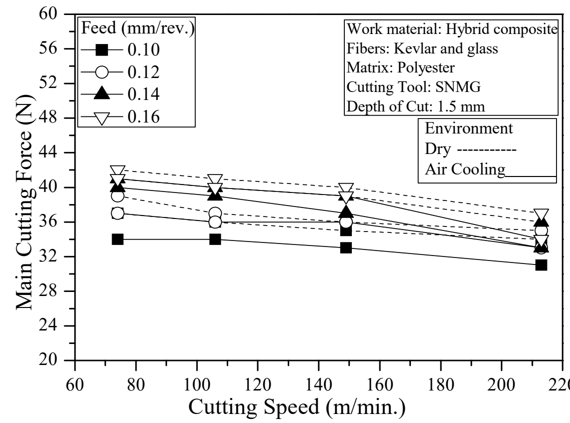


Fig. 2.6. Variation of P_z with V_c at different S_o and 1.5 mm depth of cut under both dry and CAC condition

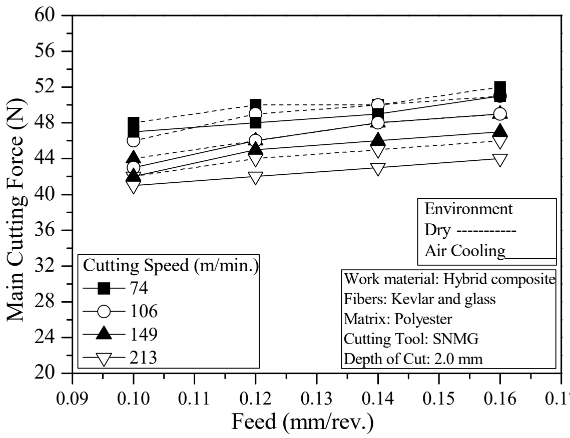


Fig. 2.4. Variation of P_z with S_o at different V_c and 2.0 mm depth of cut under both dry and CAC condition

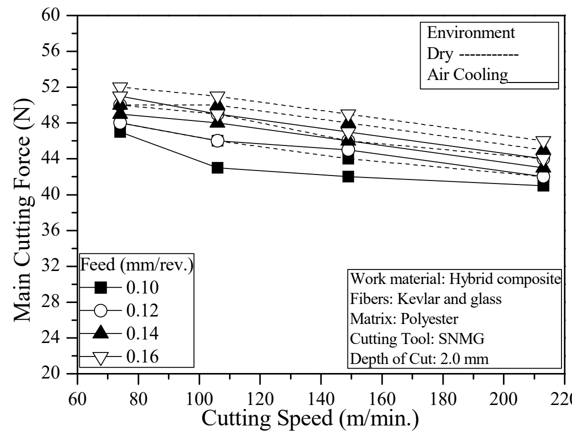


Fig. 2.7 Variation of P_z with V_c at different S_o and 2.0 mm depth of cut under both dry and CAC condition

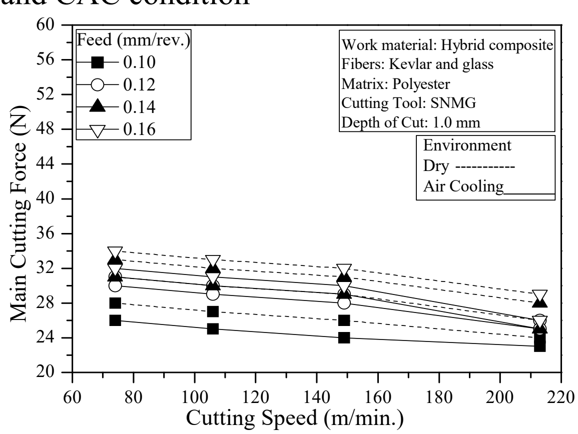


Fig. 2.5. Variation of P_z with V_c at different S_o and 1.0 mm depth of cut under both dry and CAC condition

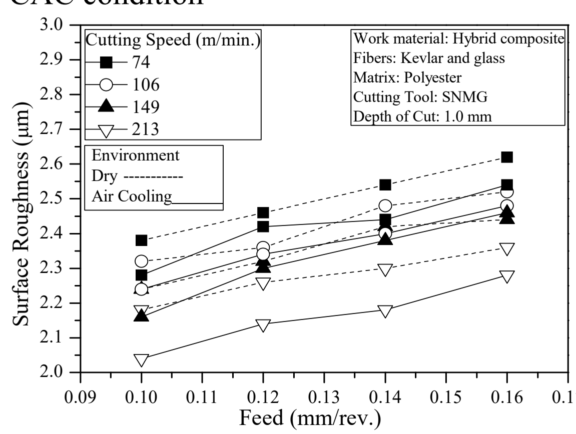


Fig. 2.8. Variation of R_a with S_o at different V_c and 1.0 mm depth of cut under both dry and CAC condition

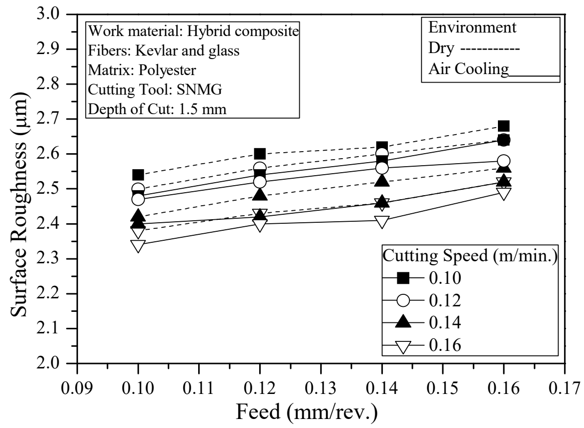


Fig. 2.9 Variation of R_a with S_o at different V_c and 1.5 mm depth of cut under both dry and CAC condition

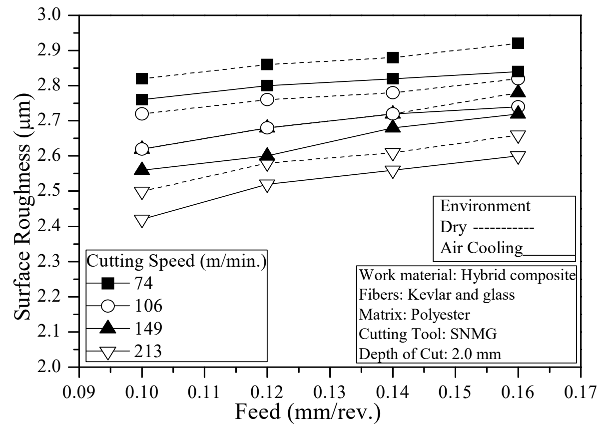


Fig. 2.10 Variation of R_a with S_o at different V_c and 2.0 mm depth of cut under both dry and CAC condition

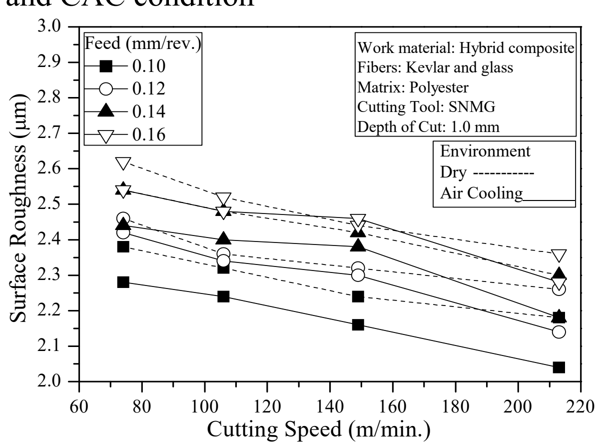


Fig. 2.11 Variation of R_a with V_c at different S_o and 1.0 mm depth of cut under both dry and CAC condition

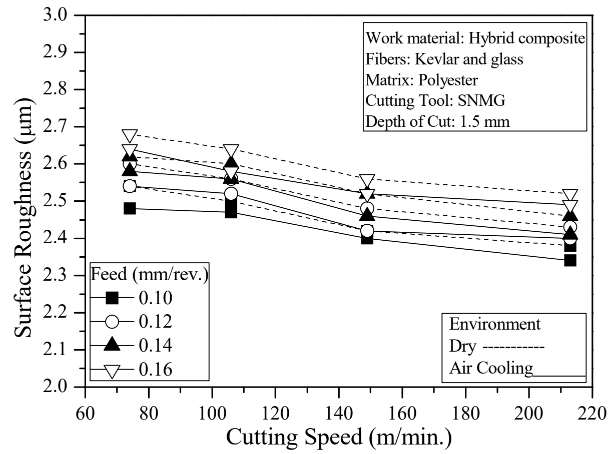


Fig. 2.12 Variation of R_a with V_c at different S_o and 1.5 mm depth of cut under both dry and CAC condition

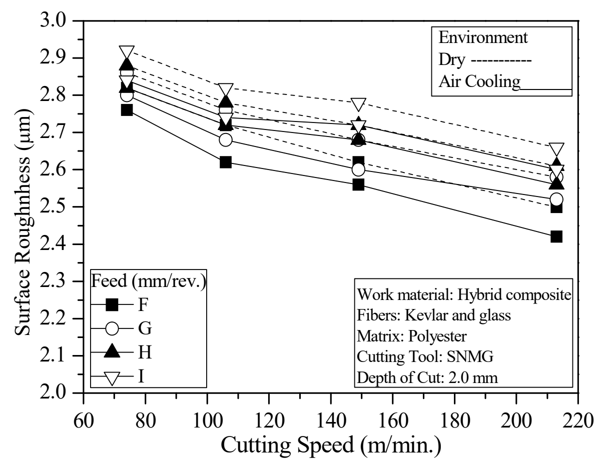


Fig. 2.13 Variation of R_a with V_c at different S_o and 2.0 mm depth of cut under both dry and CAC condition

The reason is with increased depth of cut, the cutting tool penetrates more and removes more amount of material resulting increased cutting force. With varying feed and keeping the cutting speed constant, the optimal result has been obtained when the material is machined under cutting speed of 213 m/min. and feed rate of 0.10 mm/rev. and depth of cut of 1 mm.

The reason of increased cutting force with increased feed is that more amount of material is cut per revolution of the workpiece and this requires higher amount of energy which ultimately leads to generate higher cutting force. Fig. 2.5 to Fig. 2.7 mainly displays the variation in main cutting force with varying cutting speed while feed rate is kept constant. It is evident as Fig. 2.6 to Fig. 2.8 present, for almost every cutting condition reasonable values of cutting force are found regardless of the machining environment. The trend of cutting force is mainly decreasing with increased cutting speed. In any machining process with the increase in cutting speed, shearing of the material becomes a very easy phenomenon and during the experiment the higher the cutting speed was the easier the shear became which generated lesser cutting force. When the results of two machining environments are compared to each other, it is found that compressed air-cooling condition has produced much better result than dry condition in terms of lower cutting force as presented in Fig. 2.2 to Fig. 2.7. The degree of improvement in cutting force under compressed cooling was not consistent in all the cutting conditions but lower cutting forces were found nonetheless. The reason behind improvement of cutting force under compressed air cooling is mainly due to the continuous cooling of chip tool interface. The process of forced cooling helped the machining process to get a lower value of cutting force as well as lesser temperature generation. Very few anomalies have been found during machining which do not conform to established knowledge to the machining of steels and FRP composites. Since, composite materials possess at least two different materials suggesting two materials that have completely different sets of mechanical and thermal properties, complex phenomenon can often occur during their machining. Different materials can also have different amount of thermal expansion during machining which can lead to unexpected results sometimes. Result also depends on how well the work material has been manufactured such as blow hole can deteriorate the machining quality.

Surface Roughness

According to the graphical representations of variation of surface roughness in different cutting conditions, it is evident that for almost every cutting condition, reasonable surface roughness is found. From Fig. 2.8 to Fig. 2.10, it is evident that the trend of surface roughness is mainly increasing with increased feed regardless of the cutting speed and machining environment. The higher the feed, the more the tool covers an axial distance per revolution of the workpiece and wavy surfaces tend to produce. When the cutting speed is in concern, surface roughness is mainly decreased with increased cutting speed regardless the values of feed as shown in Fig. 2.11 to Fig. 2.13. Each one of the graphs of surface roughness vs. cutting speed is showing without any major deviation from the trend that with increasing cutting speed, surface roughness is decreased regardless of the feed rate. With increased cutting speed the deformation of the work material becomes very easy and in general a lower surface roughness is produced. In this investigation, lower surface roughness is found in general with increased speed and easy deformation of the work material might have worked as a reason. Few anomalies to the established knowledge of machining metals have been found. Since composite material is inhomogeneous in and its fiber distribution may not be well distributed within the matrix so anomalies might have found during the machining operation. Again, another important thing to notice was the increase of surface roughness with the increase in depth of cut. It is obtained from the figures, maximum depth of cut produced maximum surface roughness, the reason might be that due to the increase in cutting force and higher tool wear also took place with increased depth of cut and deteriorated the surface quality.

CONCLUSIONS

i. In depth investigation of the machinability of Kevlar and glass reinforced polyester has been performed under both dry and compressed cooling air condition from the perspectives of surface roughness and cutting force.

ii. Surface roughness has been found to improve while the work was turned under compressed air cooling in comparison that of dry machining.

iii. Different cutting condition provided different degrees of improvements. In terms of surface roughness, the best result was obtained under compressed air-cooled environment when the cutting speed was 213 m/min., feed 0.10 mm/rev. and depth of cut was 1 mm. The value of the surface roughness was 2.04 μm.

iv. The maximum surface roughness was found under dry condition when the cutting speed was 74 m/min., feed 0.16 mm/rev. and depth of cut was 2 mm. The value of the maximum surface roughness was found to be 2.92 μm.

v. Cutting force was also substantially reduced while machined under compressed air-cooling environment as compared to that of dry machining.

vi. Again, different cutting condition showed different degrees of improvements. When cutting force is in concern, the best result was found under compressed air-cooled environment when the cutting speed was 213 m/min., feed 0.10 mm/rev. and depth of cut was 1 mm. The value of the minimum cutting force was found to be 23 N.

vii. The maximum main cutting force was found under dry condition when the cutting speed was 74 m/min., feed 0.16 mm/rev. and depth of cut was 2 mm. The value of the cutting force obtained was 52 N.

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