Experimental of surface roughness and tool wear on coolant condition technique using Aluminium alloy 319 used in automotive industries

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***Abstract*—** *The present day the applications of machining part tolerances, like the automotive industries aimed to reduce the fuel consumption of their vehicle by reducing the total mass per vehicle and the method process for machining. Understanding of the interaction and significance machining parameters are important to improve the efficiency of any machining process and the accuracy part produced. The objective of this research is to analyze the machining parameters (spindle speed, depth of cut and feed rates) in a three machining conditions (dry, wet and 1.0 mm coolant nozzle size on the surface roughness and tool wear using Respond Surface Method (RSM) on the CNC Lathe machine with 2 axes movements. The synthetic soluble oils, and coated cemented carbide Al2 O3 insert were used as a workpiece material and cutting tool respectively. The result of the machining experiment for Aluminum alloy 319 was investigated to analyze the main factor affecting surface roughness using the analysis of Variance (ANOVA) method. The optimum selection of the cutting conditions effectively contributes to the increase in the productivity and reduction in the production cost; therefore almost attention is paid to this problem. In cutting process, optimization of cutting parameters is considered to be a vital tool for improvement in output quality of a product as well as reducing the overall production time. The acquired results showed that the coated cemented carbide* $Al_2 O_3$ *insert gives the optimum overall performance in terms of surface roughness and tool wear with the smallest orifice size coolant. The research also beneficial in minimizing the costs incurred and improving productivity of manufacturing firms using the mathematical model and equations, generated by CCD based on RSM method.*

***Keywords*— *Turning, infrared, cutting temperature, coated carbide tool, Response Surface Method*.**

I. INTRODUCTION

In metal cutting industries, machining types, especially turning operation is very basic type of machining [1]. Traditionally, the selection of cutting conditions for machining was left to the manufacturing engineer, machine operator or machine setup technician is often expected to utilize experience and published shop guidelines for determining the proper machining parameters to achieve a specified level of requirement condition like surface roughness. In such cases, the experience of the operator plays a major role, but even for a skilled operator has a problem to obtain the optimum values each time[2] [3]. Usually machining parameters used in metal cutting are cutting speed, feed rate, depth of cut and condition of coolant. The setting of these parameters determines the quality characteristics of machined parts. Application of with combination machining condition parameter using new approach of designing a 1.0 mm size nozzle is highlighted as one of the more important areas of research due to the move toward high removal rates and higher quality. Most of CNC Turning machine equipped with soluble oil which is a type of flood coolant. A review of nozzle designs presently available and an analysis of the suitability of each for different applications is presented. The objectives of this project are to evaluate the effects of the surface roughness of a three machine condition (design sizes nozzle 1.0 mm, dry, wet coolant) using coated carbide tool when machining Aluminium alloy 319. This research applies RSM method approach to studying the impact of turning parameters on the roughness of turning surfaces. RSM analysis method approach is quality control methodology that combines control charts and process control with product and process design to achieve a robust total design [4].

Aluminum alloy 319 has become a preferred materials for the automotive components because of its lightweight and good mechanical properties, hence offers the better strength-to-weight ratio material to these industries [5]. It is widely used for structural application such as cylinder head component. This is account on its excellent casting characteristics and good mechanical properties. Aluminum alloy 319 is a precipitation hardening Aluminium alloy 319, containing magnesium and silicon as its major alloying elements. It has good mechanical properties and exhibits good weld ability. It is one of the most common alloys of aluminum for general purpose use. The mechanical properties of Aluminum alloy 319 depend greatly on the temperature, or heat treatment, of the material. Aluminum alloy 319 is widely used for construction of aircraft structures, such as wings and fuselages, more commonly in homebuilt aircraft than commercial or military aircraft. It is also used for yacht construction, including small utility boats [3]. Others than that it is also used in automotive parts, such as wheel spacers and used in the manufacture of aluminum cans for the packaging of foodstuffs and beverages [6].

Most of the researches are focused on the cutting speed, feed rate, depth of cut, during the cutting tool process. In this research, there is an investigation on the technique coolant influence of available three machine condition (sizes nozzle 1.0 mm, dry, wet (flood cooling) over the range of turning operation parameter on Aluminum alloy 319. The effectiveness of the three machine condition (sizes nozzle 1.0 mm, dry, wet coolant) systems is evaluated of surface roughness (microstructure and micro hardness). Although manufacturing techniques have become more sophisticated, many processes and tool designs are still based on experience and intuition. Advances in computer and material sciences have greatly enhanced the ability to develop predictive capability and to achieve the goal of optimization for a wide variety of applications. These techniques have resulted in reduction in friction and heat at the cutting zone, hence improved productivity of the process.

1.1 History of Recent Machining Optimization coolant condition techniques in metal cutting process

Over the past century, Besides, [7]in the article Investigation of Cryogenic Cooling By Liquid Nitrogen in the Orthogonal Machining Process believed that cryogenic cooling is able to cut down the cutting temperature which strengthen the chip tool interaction, preserve the cutting edge and has a better dimensional accuracy than dry and wet machining. The article “Hydrogen gas generation in the wet cutting of aluminium and its alloys.” stated that the wet cutting of aluminum and alloys by the generation of hydrogen gas is because of the chemical reaction between the fresh surface of aluminum and water. Finally, the article “The effect of applying high-pressure coolant (HPC) jet in Machining of 42crmo4 steel by uncoated carbide inserts” by [6], opined out that Supply of high-pressure coolant (HPC) on high velocity might give an excellent control to decrease the cutting temperature and tool wear besides increasing the tool life.

Workpiece material is very important in choosing tools, machining parameters and cooling strategy. According to [8], is quantified by various parameters, such as, tool life, chip size, achievable surface finish and/or the amount of specific power consumed. It is influenced by a material’s alloy chemistry, additives, microstructure, heat treatment, temper and physical and mechanical properties [9]. In addition, different workpiece materials have different degrees of sustainability for near dry and dry machining. There are various workpiece materials to enhance machinability. In addition, according to [10], lead acts as a lubricant, thus reducing the friction coefficient of friction between the chip and the tool. It also creates discontinuities in the atomic structure, which promotes chip fragmentation, reduce cutting forces and also reduce tool wear. However, lead has caused recent environmental concern, which has made metal manufacturers looking for alternative additives.

Minimum Quantity Lubrication (MQL), which is also known as near dry machining, is an alternative to traditional flood coolant. It is also known as dry machining that applies a small amount of oil, commonly 10-50 mL/hr [11]. MQL is a useful, environmentally-friendly alternative to flood cooling when dry machining is not practicable [12]. It can be applied to all machining operations. Furthermore, studies have shown that MQL is effective at reducing temperature , material adhesion [11], tool wear and thermal distortion, when compared to dry machining. A study by [9] showed that near-dry machining is implementation-ready for drilling, milling, reaming and tapping, with that production rate and also quality were equal to wet machining. Technique of temperature measurement includes: (1) thermocouple – artificial and natural thermocouple, (2) infra- red photography, (3) Optimal infrared pyrometer, (4) thermal paints, (5) Metallurgical change in work piece/cutting tool material, (6) Thermal Camera technique. Several detailed review is available in literature for these techniques of temperature measurement. Every method has its own pros and cons depending upon physically arrangements developed in an analytical prediction model for the measurement of cutting temperature. They came with conclusion that cutting temperature is a function of cutting speed and feed rate with following equation:

$$8_t = V^{0.5} f^0 \tag{1}$$

where 8_t is the average cutting temperature, V is the cutting speed and f is feed rate.

In this study of temperature measurement, the most widely used infrared thermometer laser was selected for the measuring of cutting tool’s average temperature during turning operation. The values within certain range of cutting parameters like cutting speed, depth of cut and feed rate were selected and used for building the mathematical model using CCD based Response Surface Method (RSM). The temperature data of cutting tool was obtained by experimentation and the optimization of selected cutting parameters obtained successfully.

II. EXPERIMENTATION WORKS

Experiment were conducted on CNC PUMA 250 Daewoo to study the technique cooling condition used in this research that will bring for better cutting performance like cutting temperature. The experimental setup is shown in Fig.1. Furthermore, the range of the operating parameters for experimentation has also been discussed

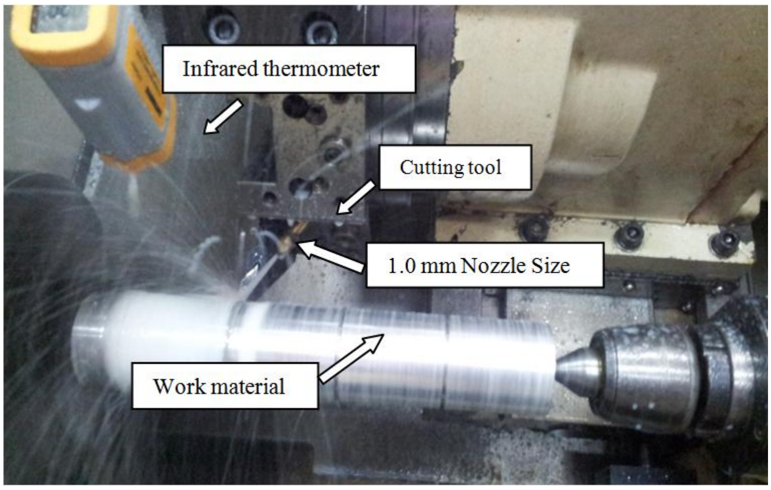


FIG.1. THE EXPERIMENTAL SETUP

This machine is equipped with a pump system, whereby the flow rate from this pump is kept constant throughout the experiment. The tool holder remains the same with coolant technique cooling condition used. The workpiece is mounted on the jaw in to spindle in order to ensure that workpiece is fixed in its position during machining.

Fig. 2. shows the experiment setting, equipment, and workplace. Surface roughness (Ra) was measured with a Mitutoyo Surftest S-J-301 portable surface roughness tester. The average value of surface roughness was used in the analysis. Surface roughness (Ra) = 6.0μm. For tool wear, the average value of surface roughness was used in the analysis. For tool wear, the most commonly used criteria for the straight cut is flank wear, which was measure by SEM TM3030 plus Tabletop Microscope -Hitachi. The tool life criteria were set at maximum flank wear width of 0.3 mm or failure

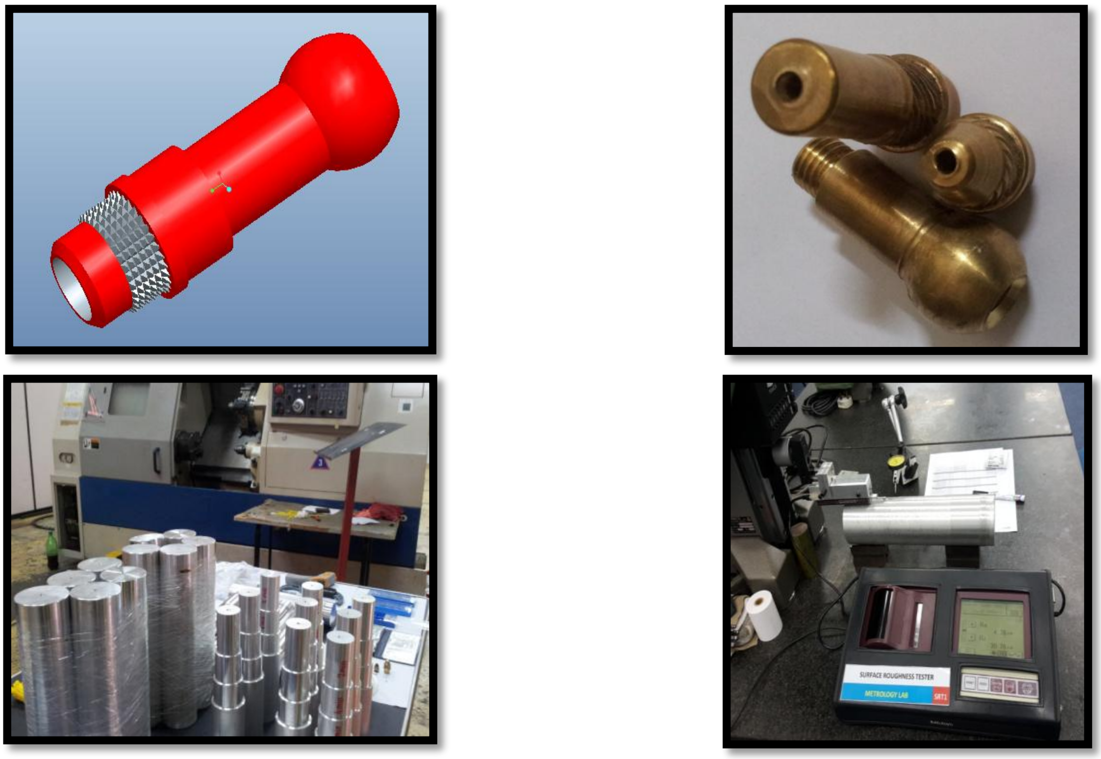


FIG. 2. EXPERIMENT EQUIPMENT, WORKPLACE, DESIGN OF 1.0 mm SIZE NOZZLE ORIFICE AND ANALYSIS SETTING

2.1 Material and Methods

The workpiece material used for this investigation is Aluminum alloy 319 with an axial length of 250 mm and the Ø 60 mm. The physical characteristics of the material are present Table 1. The cutting tool used for this study, Cemented Coated Carbide, is designated as ISO VCGT 160404. The turning process was performed in an environment coolant condition technique, (1.0 mm nozzle size, Wet and dry)

TABLE 1
PHYSICAL DATA OF ALUMINUM ALLOY 319

Physical Data	Value
Density	2.79 g/cm^3
Melting Point	2.79 g/cm^3
Modulus of Elasticity Tension	10
Modulus of Elasticity Torsion	3.8

RSM is a dynamic, important tool of the design of experiment (DOE) and is based on fitting empirical models with experimental data. These data are obtained from the relationship between response and input decision variable to maximize or minimize response properties. RSM is a set of statistical technique that employ linear or square polynomial function to describe and explore experimental conditions of a study system until its optimization. This method is useful for any field of engineering [6, 13].

2.2 Experiment Conditions

The turning process was performed in an environment condition cutting fluids. Since wet (flood cooling), dry cutting and 1.0 mm orifice nozzle sizes internal diameter following the experiment condition as shown in Table 2. The Central Composite Design (CCD) based RSM was used for the determination of optimum control factors 3- level factor design with center point six was selected. Values of those factors had been achieved with consideration of the machine tool capacity. There were total 30 combinations of the turning runs were carried out using design expert software to complete experimentation.

TABLE 2
EXPERIMENT CONDITIONS AND THEIR LEVELS STANDARD CUTTING CONDITIONS

Experimental conditions		
WORKPIECSE	Material Shape Diameter Length	Aluminum alloy 319 Cylindrical rod with axial or Round 60 mm 350 mm
TOOL	Material Insert type Holder Type	Al_2O_3-coated cemented carbide VCGT 160404 TH K10 SVJCL - 2525M16
CUTTING DATA	Operation Cutting Speed Feed rate Depth of cut	Turning 150 – 270 m/min 0.08 – 0.24 mm/rev 0.2 – 1.0 mm
CUTTING ENVIROMENT	Coolant Research Method	Synthetic soluble oil Various parameter of coolant (1.0 mm orifice nozzle sizes , Dry, Wet Coolant
RESPONSES	Cutting Environments	Surface Roughness, Temperature and tool wear

III. RESULT AND DISCUSSION

The observation made during the 30 run experiment. Table 3 implies the effect of surface roughness on individual cutting parameters. The change in depth of cut has very high effect on surface roughness while cutting speed and feed rate have moderate effect on surface roughness. For the given range of cutting parameters, feed rate has been found as the most significant parameter. Figure 3, which was generated by software, shows the correlation between feed rate and surface roughness with points indicates that the significance rate between feed rate and surface roughness is 0.7667 Central Composite Design based RSM was selected in this work [22]. RSM requires more data compare to the Taguchi method to ensure the optimum condition [23, 24]. RSM relates the independent input variables with output (process response). Design Expert software was used and obtain the set of experimental runs of CCD which would help to investigate the influence of three cutting parameters (cutting speed, depth of cut and feed rate) on the output (surface roughness and temperature). Show in table 4, the CCD with its output as a surface roughness and temperature. Again this data had been utilized to analyze through Design-Expert Software. The result of Analysis of Variance (ANOVA) has been carried out and as per Table 3 and 4 the value of R-squared (0.8352) and predicted R-squared (0.6814) were obtained

TABLE 3
VALUE OF R-SQUARED AND ADJUSTED R-SQUARED

Std. Dev	0.25	**R-Squared**	0.8352
Mean	1.47	**Adj R-Squared**	0.6814
C.V	17.14	**Pred R-Squared**	0.3094
PRESS	3.98	**Adeq Precision**	7.317

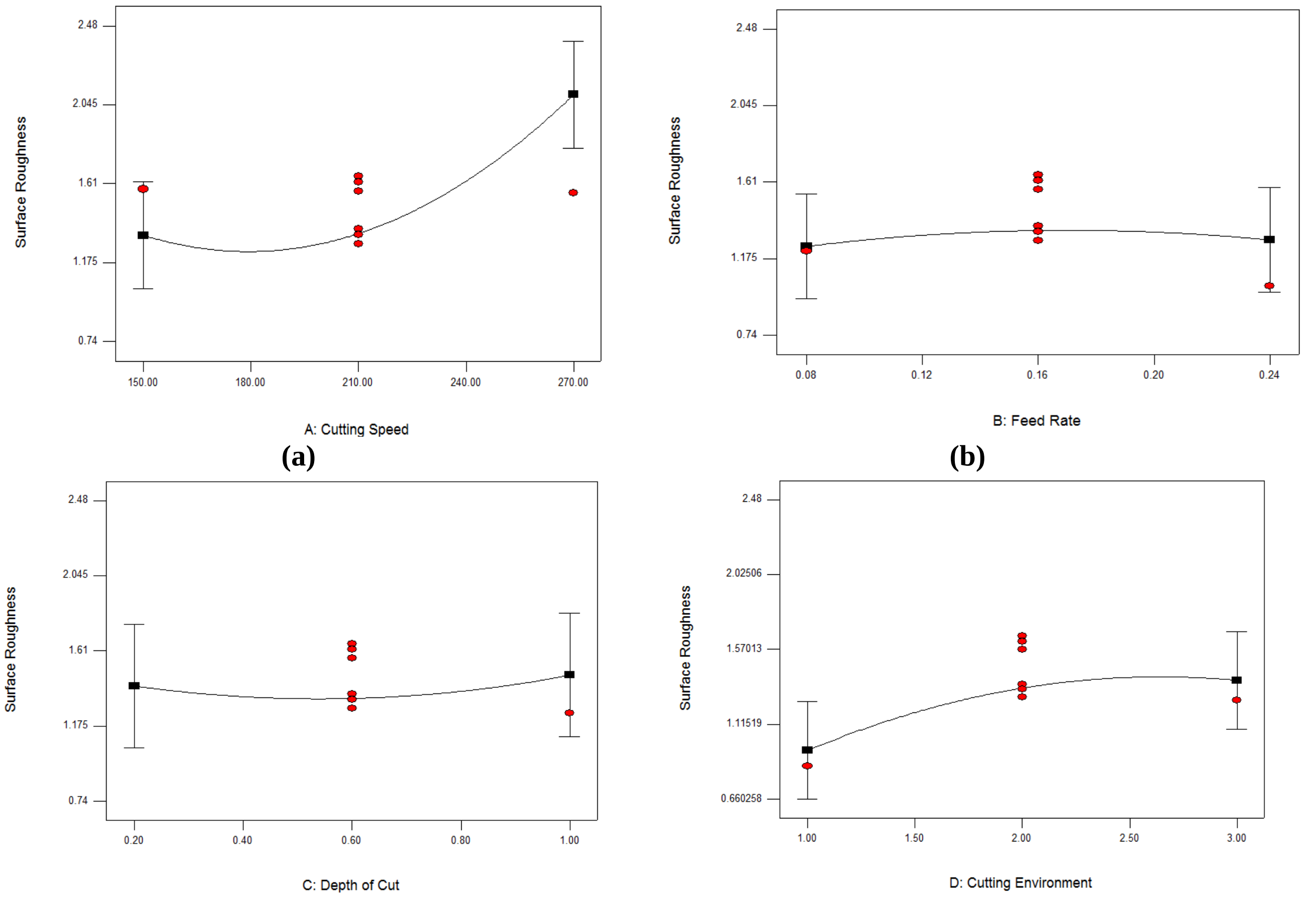
TABLE 4
ANOVA AND R-SQUARED TABLE FOR AVERAGE SURFACE ROUGHNESS (Ra)

Source	Sum of Squares	DF	Mean Square	F Value	Value Prob > F	significant
Model	924.15	14	66.01	3.52	0.0106	significant
Residual	281.22	15	18.75			
Lack of Fit	217.72	10	21.77	1.71	0.2870	not significant
Pure Error	63.50	5	12.70			
Cor Total	1205.37	29				

FROM THIS ANOVA RESULT THERE WAS ALSO RELATIONSHIP OBTAINED IN FORM OF EQUATION AS SHOWN IN EQUATION 1 WHICH RELATES THE INPUT AND OUTPUT PARAMETERS AFTER BACKWARD ELIMINATION INSIGNIFICANT MODEL TERMS FROM IT. FOLLOWING IS THE FINAL EQUATION IN TERMS OF CODED FACTORS.

Temperature = + 62.9466 + 0.41185 ± 4.66598 + 0.50203 - 8.56037e004 + 1002.85416 + 5.21418 + 1.687771 - 0.13021 + 0.041667 + 1.6667E-003 + 11.71875 - 35.93750 - 4.29080

Fig 3 shows the main effect plots for surface roughness, which had the most significant influence of feed rate on surface roughness in the dry turning process. The slot of Ra line verses feed rate showed that Ra value substantially increased when feed rate increased from 0.08 mm/rev to 0.24 mm/rev (Figure 3b). Surface roughness did not change significantly when change speed from 150 - 270 m/min (Figure 3a). The Ra value was slightly influenced by cutting speed, followed by depth of cut. Therefore, feed rate is a significant factor that influences the value of surface roughness, similar to [40], feed rate is the main parameter that influences the turning of Aluminum alloy 319.

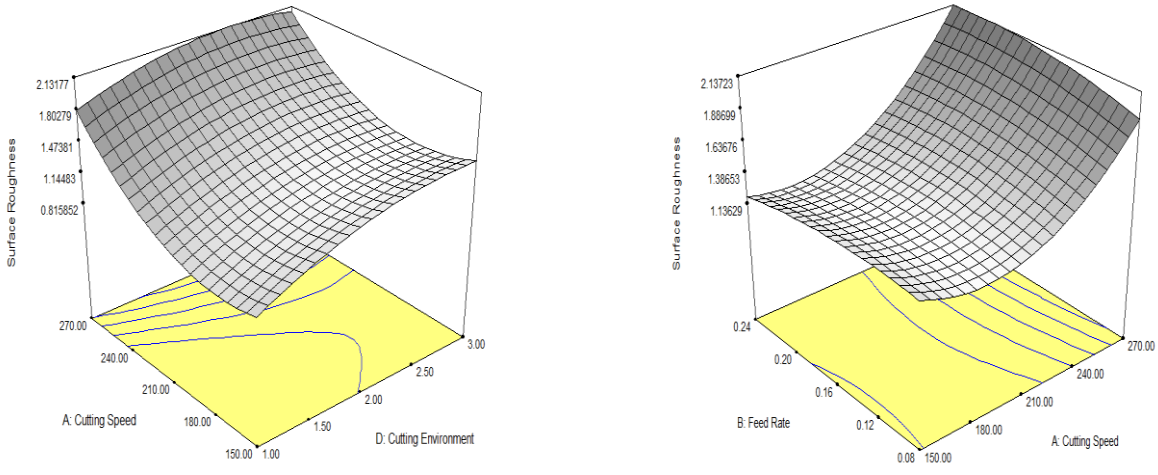


(a) (b)

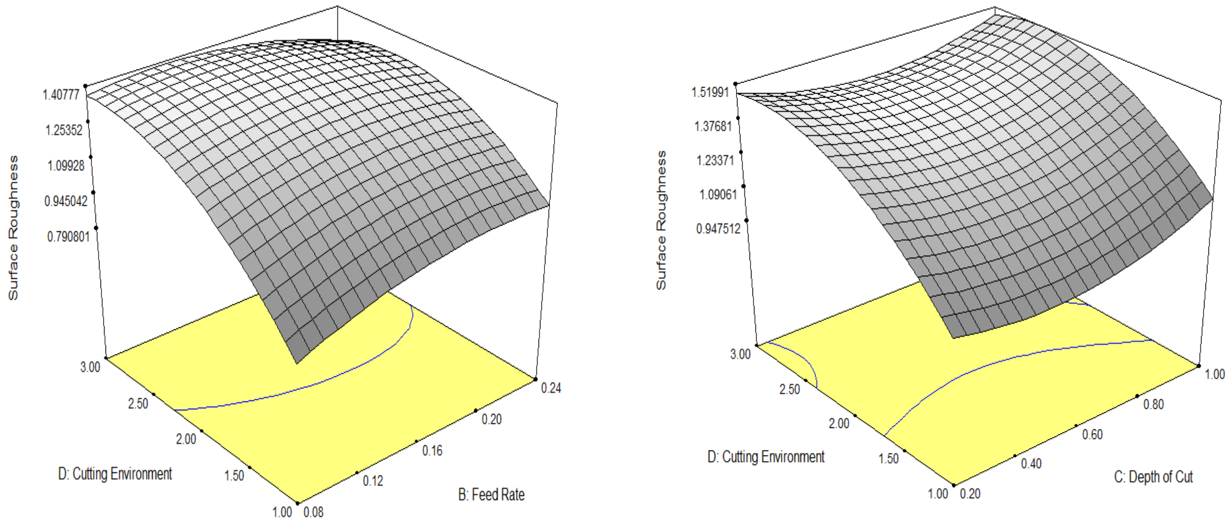
(C) (D)

Fig. 3: Main plots of surface roughness (Ra) versus (A) cutting speed (B) feed rate (C) depth of cut (D) cutting inverment

The 3D surface plot between feed rate and depth of cut is presented in Fig 4. Surface roughness was minimized when feed rate and depth of cut ware at lowest levels. A significant mutual interaction occured between cutting speed , feed rate, and depth of cut with cutting inviromental. The optimal derease in surface roughness was from 0.56 (μm) to 2.45 (μm), where feed rate was within the range of 0.08 - 0.24 mm/rev, depth of cut in the range of 0.8 - 1.0 mm, and cutting speed in the range of 110 -270 m/min. These findings were reported by Hanafi et al. (2012) and Camposeco -Negrete (2013).



(a) (b)

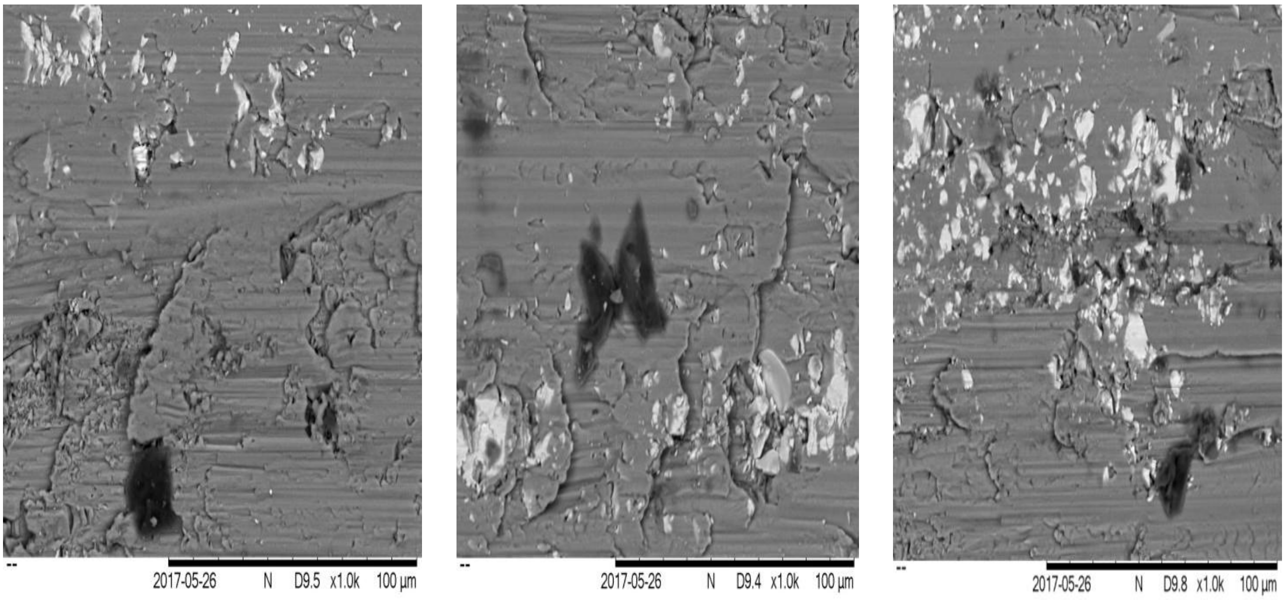


(c) (d)

FIG. 4: MAIN AND 3D SURFACE PLOTS OF SURFACE ROUGHNESS (RA) (A) EFFECT OF CUTTING SPEED AND CUTTING ENVIROMENT (B) FEED RATE OF AND CUTTING SPEED (C) EFFECT OF CUTTING ENVISOMENTAL AND FEED RATE (D) EFFECT OF CUTTING ENVIROMENT AND DEPTH OF CUT

3.1 Surface Roughness

Severe deterioration in the machined Surface roughness was observed at flank wear of approximately 0.30 mm. A phenomena similar to the coolant technique effect (1.0 mm nozzle size, wet and dry) in machining of hardened steel occurred gradually on the part surface when turning with a worn insert. 25 x 25 mm metallographic sample were extracted from the surfaces obtained with both sharp and worn inserts and then analyzed obtained using SEM. The result is present in Fig. 5. As illustrated, it can be see that the cutting coolant technique with machining parameter was a factor in the occurrence of the described phenomena. As the cutting increases, higher cutting temperature is generated in the tool workpiece interface, which increases the volume of materials adherence to the machined surface and cutting edge. Upon completion of the experiment tests, all work pieces were examined for the burr formation. Based on SEM examination of the parts, it can be concluded that the severity of the burr formation is a direct function of the method of coolant technique and cutting speed and the progress of tool wear.



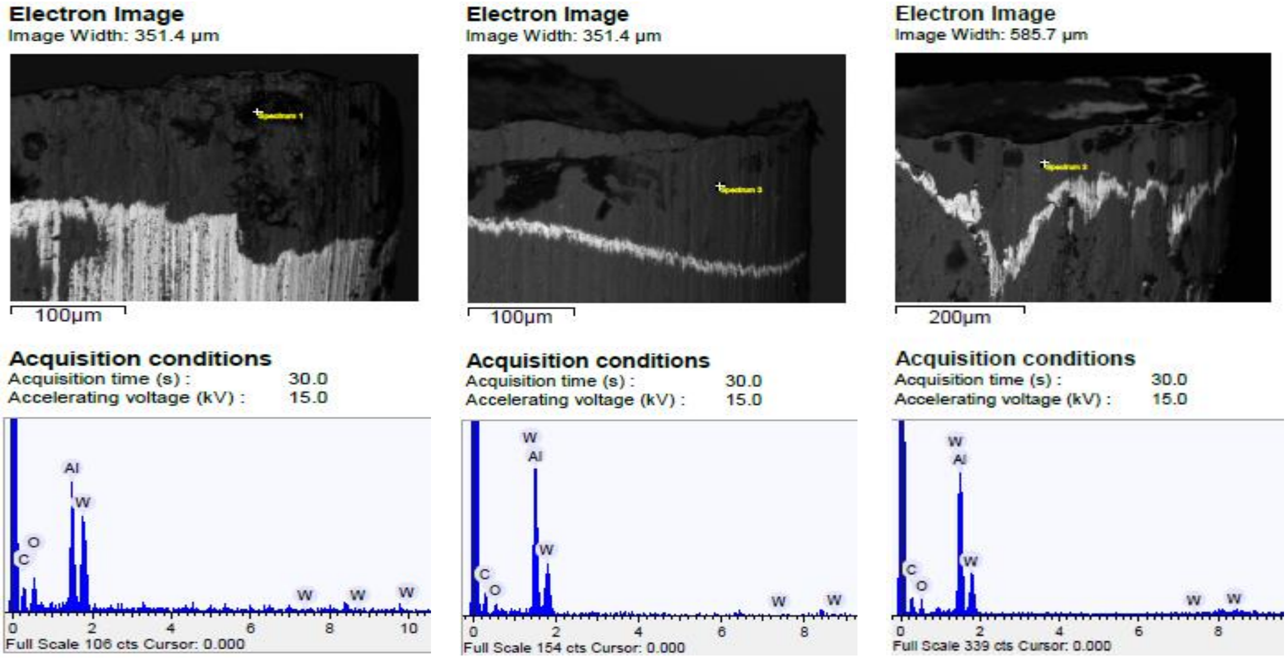
(a) 1.0 mm nozzle orifice **(b) wet coolant** **(c) Dry machining**

FIGURE 5. SCHEMATIC ILLUSTRATION SURFACE ROUGHNESS BETWEEN 1.0 mm NOZZLE ORIFICE, WET COOLANT, AND DRY MACHINING

3.2 Tool Wear

3.2.1 Effect of tool wear

NORMAL INSERT



(a) 1.0 mm nozzle orifice (b) wet coolant (c) Dry machining

FIGURE 6. SCHEMATIC ILLUSTRATION BETWEEN 1.0 mm NOZZLE ORIFICE, WET COOLANT, AND DRY MACHINING

Fig. 6a, 6b, and 6c shows the variation in flank wear with machining time under 1.0 mm nozzle orifice, wet coolant and dry machining under coolant technique condition. 1.0 mm nozzle orifice reduces average auxiliary flank wear on auxiliary cutting edge. The temperature also grew very low considerably. It appears on Figure 3 that temperature and flank wear grows quite fast under dry machining due to more intensive temperature and stress at the too-tips. 1.0 mm nozzle orifice technique appeared to be more effective in reducing tool wear and temperature. However, it is evident that coolant technique condition appeared to be effective in reducing tool wear and temperature as well as controlling the deterioration of the auxiliary cutting edge by thermal effect to adhesive wear and built - up edge formation.

IV. OPTIMIZATION

In this study, RSM has been utilized for single response optimization. The use of response surface optimization helps to calculate the optimal values of input in order to minimize the surface roughness during the turning process of Aluminum alloy 319. The constraints for optimization of cutting parameters have been shown in table 5. Table 6 shows the values for the input parameters for minimizing surface roughness. It is clearly seen that obtained optimal value is 0.74 (µm) for the respective values of cutting speed, depth of cut and feed rate.

TABLE 5
CONSTRAINTS FOR OPTIMIZATION OF PARAMETER

Parameter	Lower limit	Higher limit
Cutting speed (rpm)	150	270
Depth of cut (mm)	0.2	1.0
Feed Rate (mm/rev)	0.05	0.24
Environments Cutting	Dry , Wet and Nozzle Size 1.0 mm	

TABLE 6
OPTIMIZATION RESULTS

Cutting Speed	Depth of Cut	Feed Rate	Flank wear	Desirability
150	0.2	0.08	0.34	0.8352

4.1 Confirmation Test

Fig. 7. shows the variation in flank wear with cutting speed under aluminum alloy 319 with 1.0 mm nozzle size) wet and dry coolant environments. As 1.0 mm nozzle size reduces average auxiliary flank wear on auxiliary cutting edge, temperature also grew very lower under 1.0 mm nozzle size coolant condition. It appears that temperature and flank wear grows quite fast under dry machining due to more intensive temperature and stresses at the tool-tips, 1.0 mm nozzle coolant techniques appeared to be effective in reducing tool wear. However, the variation in machining time with flank wear, it is evident that 1.0 mm nozzle coolant techniques improves and mainly through controlling the deterioration of the auxiliary cutting edge by thermal effect to adhesive wear and built - up edge formation.

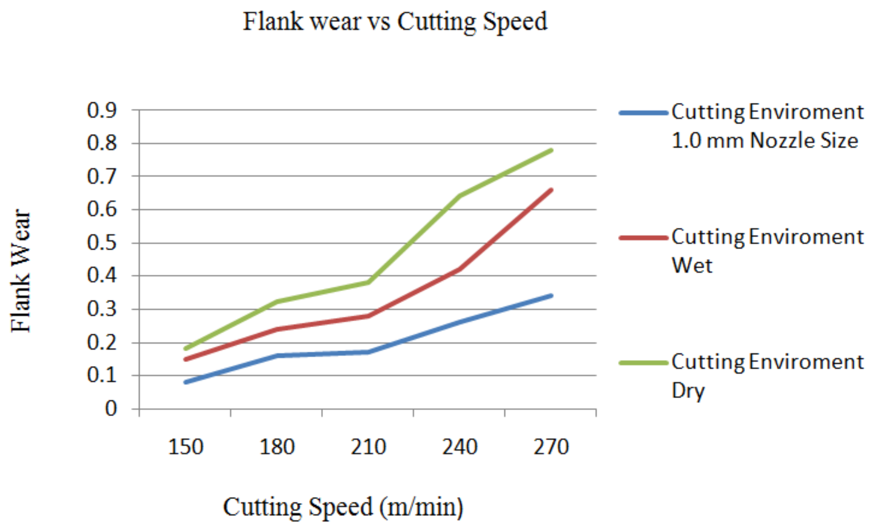


FIG.7. EFFECT OF TECHNIQUE COOLANT APPLICATION METHOD ON THE RESULTANT FLANK WEAR (VS 150, DEPTH OF CUT 0.2 AND FEED RATE 0.08, CEMENTED COATED CARBIDE)

V. CONCLUSION

In conclusion, the effects of surface roughness and tool wear on coolant condition technique on different parameters like cutting speed, feed rate and depth of cut can be summarized as below:

- Data extrapolated from experiment result average resultant of surface roughness and flank wear progress indicated that the optimal performance of the cemented coated carbide insert was obtained when using 1.0 mm nozzle size method of coolant.
- Tool wear management is also an issue that needs further investigation; the result indicated that up to a cutting speed of 270 mm/min, a tool wear are generated and course surface roughness.

- The optimization values of cutting parameters have been achieved for minimum surface roughness with desirability of 0.8352 %, which is highly acceptable.
- The technique condition nozzle size 1.0 mm, mean smaller nozzle opening focuses the coolant flow to a smaller area, eliminating the waste of wide spray of coolant and provides a more concentrated flow which is a relatively new technique of technology that allows cutting fluid to penetrate tool workpiece and tool chip interfaces.

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