

Study of Machinability Characteristics of SAE AMS4413B Aluminum Alloy Using Ethylene Glycol as a Coolant

Roopa K. Rao^{1a}, Sachin C. Kulkarni^{2a} and Manjunath G. Avalappa^{3a*} and Nikhil Rangaswamy^{4b}

Abstract: To understand the efficient machining of aerospace materials and achieve high-quality machining, the application of coolants is essential and depends on several factors, including the types of machining process, workpiece material, tool nose radius, coolant concentration, and cost. With the right coolant, the performance of machining applications and the attributes of responses such as surface roughness and HAZ can be improved. An attempt is made here to study machinability and optimize the process parameters. This paper presents an approach to optimize the machinability studies on SAE AMS4413B alloy using Ethylene glycol as a coolant. The input parameters selected include Cutting speed, Feed, depth of cut, coolant concentration, tool nose radius on Surface Roughness (Ra) and Heat Affected Zone (HAZ). A DOE-based technique is applied to study the response variation using the Central Composite design (CCD). The CCD design is a type of Response Surface Methodology used to design the matrix. The experiments were conducted at a confidence level of 95%. R² predicted for Ra and HAZ are 95.26% and 95.51%, respectively. As per the experimental analysis, it is evident that the individual effects of Cutting Speed, Feed, Depth of cut, tool nose radius, and coolant concentration exist for the Ra and HAZ values. The optimum values of Ra and HAZ are 0.21 μ m and 20.3 IACS. The Coolant concentration for Ethylene Glycol should be in the range of 8-10%.

Keywords: Aluminum Lithium alloy - SAE AMS4413B, Ethylene Glycol, Central Composite Design (CCD) - Response surface methodology (RSM), Surface Roughness (Ra), Heat affected Zone (HAZ)

1. Introduction

Lightweight materials play a prominent role in the aerospace industry, a sector that has been a pioneer in adopting innovative materials and production technologies. Approximately four decades ago, aluminum emerged as a dominant aerospace material, constituting up to 70% of an aircraft [1]. Over time, the aerospace and space industry has been a catalyst for the development of new material systems and manufacturing methods. The primary drivers for these advancements include the need to reduce weight, enhance application-specific performance, and minimize costs [2]. The historical shift from wood to aluminum alloys as the main frame material dates back to the early 1920s [3]. The appeal of aluminum lies in its cost-effectiveness, lightweight nature, ability to achieve high strength, and ease of fabrication. This combination makes aluminum alloys an attractive choice, with their cost-efficiency often directly linked to their ease of fabrication [3]. The initial development of Al-Li alloys can be traced back to research initiatives conducted by both the United States and the Soviet Union during the Cold War era. A notable outcome of these programs was the creation of the AA2020 alloy, patented by Alcoa in 1958 [4]. Thomas Dorin [5]

highlighted the features of third-generation alloys, aligning with contemporary trends in transportation industries, especially aerospace, which emphasize enhancing performance, fuel efficiency, system lifespan, and environmental sustainability to create added value. The Pioneer Aviation companies, such as Airbus, Lockheed, Martin, Mikayan, Gurevich, Tupolev, and others, aim for improved technology using lightweight materials. Considering their strength and density (Figure 1), it becomes clear why aluminum and titanium alloys are the classical lightweight aerospace alloys.

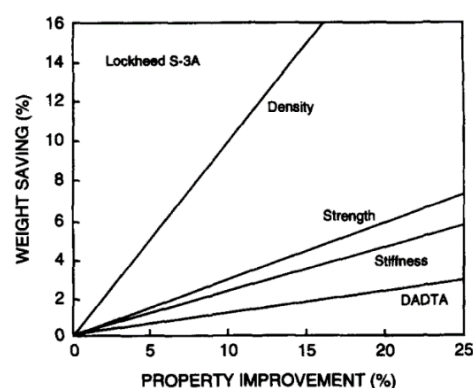


Fig. 1: Graph of weight savings and property improvement [6]

Authors information:

^aDepartment of Mechanical Engineering, K. L. S. Gogte Institute of Technology, Belagavi, 590008, and Visvesvaraya Technological University, Belagavi, 590018 INDIA. rooparao@git.edu¹; sckulkarni@git.edu²

^cDepartment of Mechanical Engineering, Atria Institute of Technology, Bengaluru, 560024, INDIA. vihanamanju05@gmail.com³

^dSchool of Mechanical Engineering, REVA University Bengaluru, 560064, INDIA. nikhil.rangaswamy@reva.edu.in⁴

*Corresponding Author: vihanamanju05@gmail.com

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Al-Li alloys of the third generation are used for aviation applications, as shown in the table below [7]. Alloys 2195, 2196, 2297, 2397, 2198, 2099, 2199, 2050, 2060, and C99N were researched and developed for space and aircraft applications, and they are referred to as 3rd-generation Al-Li Products [8]. The next-

generation Al-Li alloys offer better weight savings and are less expensive to manufacture, operate and repair. The improved material properties enhance damage tolerance. Al-Li alloys offer improvements in the fracture processes [9-10].

Table 1: Chemical composition of Al-Li alloys [11]

Al Li alloys	Li	Cu	Zn	Mg	Mn	Fe	Si	Cr	Zr	Ti	Others
2050	0.7-1.3	3.2-3.9	0.25	0.2-0.6	0.2-0.5	0.1	0.08	0.05	0.06-0.14	0.1	0.2-0.7 Ag
2090	1.9-2.6	2.4-30.0	0.1	0.25	0.05	0.12	0.1	0.05	0.08-0.15	0.15	
2098	0.8-1.3	3.2-3.8	0.35	0.25-0.8	0.35	0.15	0.12		0.04-0.18	0.1	0.25-0.6 Ag
2099	1.6-2.0	2.4-3.0	0.4-1.0	0.1-0.5	0.1-0.5	0.07	0.05	0.1-0.5	0.05-0.12	0.1	0.0001 Be
2199	1.4-1.8	2.0-2.9	2.0-0.9	0.05-0.4	0.1-0.5	0.07	0.05		0.05-0.12	0.1	0.0001 Be

Machining is an essential part of any manufacturing industry to achieve desired components with accurate shape, size, and surface finish through adequate cooling and lubrication [12]. Aluminum is an essential material used in aerospace applications [13]. The machining of lightweight alloys has gained importance in recent years [14-27]. The study of coolants during machining to improve surface finish and HAZ will be required for establishing the results and analysis of the effect of machining parameters. Therefore, there is a need to implement a sustainable cooling/lubrication system that improves the machinability of lightweight alloys [26]. The application of coolants depends on several factors, including the types of machining processes, workpiece material, cutting tool, and cost [27]. Many authors have presented their work using various cooling and lubrication methods. In brief, the different available cooling and lubrication methods. Fig. 2 represents the possible cooling/lubrication strategies.

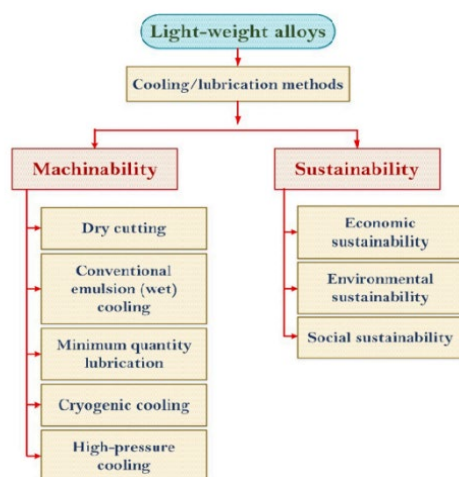


Fig. 2. Coolant strategies and methods for lightweight alloys [28].

A good microbial growth medium requires a balanced supply of macro- and micronutrients. Primary growth-promoting elements include carbon and nitrogen, while trace elements such as sulfur,

phosphorus, and various vitamins serve as vital micronutrients. In a laboratory setting, fungal growth is strongly influenced by the nutrients available in the media, which are essential for their growth, viability and reproduction (Laurie et al., 2015). Microbial culture media are crucial for the enrichment, isolation, and cultivation of microorganisms. Numerous fungal growth media are derived from staple crops that are vital food sources for humans, including corn, malt, oats, and potatoes. A prominent example is Potato Dextrose Agar (PDA), which consists of potato extracts, dextrose, and agar, making it one of the most widely used growth media for fungal cultivation. However, powdered PDA is relatively expensive and relies on potatoes, potentially reducing their availability in the market (Hasanin & Hashem, 2020). The rising cost of microbiological media has driven the development of novel formulations that prioritize both efficiency and affordability (Sawiphak et al., 2021).

In response to these limitations, recent research has increasingly focused on utilizing agro-industrial residues and naturally derived plant-based fluids as viable alternatives to conventional synthetic media. Examples of such substrates include tomato juice (Aliyu et al., 2017), coconut-malt extract (Evangelista et al., 2021), soybean (Malik et al., 2022), Papaya fruit (Oktari et al., 2023), and watermelon peel extract (Hasanin & Hashem, 2020). These materials are typically rich in carbohydrates, minerals, and bioactive compounds that can support microbial growth.

Tender coconut water (TCW), the sterile liquid endosperm of immature coconuts (*Cocos nucifera* L.), presents a promising alternative medium due to its unique nutritional composition and availability in tropical regions. The use of coconut water in microbial culture was first documented in the 1960s, when it was found to support the growth of *Acetobacter xylinum*, the bacterium responsible for producing bacterial cellulose in “Nata de coco” fermentation (Alaban, 1962). Coconut water is naturally sterile within the unopened fruit, reducing the risk of initial contamination when used in microbial cultures (Tuyekar et al., 2021). Coconut water contains simple sugars (glucose, fructose, and sucrose), amino acids, vitamins (B-complex and vitamin C), minerals (potassium, magnesium, calcium, and phosphorus), and

a small amount of protein. Its slightly acidic pH and presence of essential growth factors support the growth of various microorganisms (Rethinam & Krishnakumar, 2022). These nutrients provide carbon and micronutrient sources essential for fungal growth. Furthermore, TCW is a natural source of amino acids, vitamins, and plant hormones such as cytokinins, which may enhance fungal development and metabolic activity. Its high water content creates a favourable environment for fungal growth, while its chemical composition may offer comparable nutrient support to synthetic media in some cases (Burns et al., 2020). In developing countries, the necessity of creating culture media from locally sourced materials has become increasingly significant. Traditional media are often either difficult to access or prohibitively expensive, posing challenges for researchers and laboratories.

2. Literature Review

The literature review covers 2nd generation aluminum alloys [29-41]. Various authors have studied the machinability characteristics of Al 7075 alloys. The responses evaluated suggest the use of cooling strategies for surface roughness, cutting force, temperature, chip morphology, etc. The authors [42-48] examined 3rd generation aluminum alloys. Various authors discussed machinability studies using cooling strategies, for responses such as surface roughness, chip morphology, etc. Table 4 lists the authors [49-53] who used ethylene glycol as a coolant for machinability studies.

Extensive experimental studies have been done on 2nd generation materials. From the literature review, in the field of 3rd generation materials, responses of surface roughness and heat-affected zone using ethylene glycol as a coolant are still at the experimental stage. In this investigation, a DOE-based RSM technique is employed to assess the output parameters. Conventional wet cooling was used for machining third-generation alloys to study the machinability characteristics of SAE AMS4413B.

Table 2: 7075 Aluminum Alloy 2nd generation material

Ref.	Workpiece	Cutting Environment	Machining	Parameters evaluated Responses	Remarks
31	AA7075	Dry, Cryogenic	MQL Turning	CF, Cutting Temperature, chip Morphology, Tool Wear	- Feed component affected by cooling techniques. - MQL and cryogenic led to lower temperature - Cooling techniques affected the lesser Tool wear
32	AA 7075-T6	Dry, MQL Cryogenic (LN2)(air, and vegetable oil emulsion)	HPAJ, Turning	Microstructure, Surface Roughness	- Analytical model for fatigue life prediction - cryogenic technique led to lower temperature
33	Al7075	Dry and Cutting fluid using Gate ECM 1	Drilling	Tool wear, Burr Measurement	- Cutting fluid resulted in lower tool wear - Cutting fluid resulted in 20%lower burr rate
34	Al 7075	Dry	Turning	MRR, SR, Cylindricity error, circularity error	- Optimization of multiple outputs - Increase in speed increased the CF also increase in SR and Circularity and cylindricity
35	Al 7075	Dry	Milling	Temperature,	Behavior of different tool geometries and coatings
36	AA 7075	Dry, wet and cryogenic	Boring	SR, Temperature, Force	- Cryogenic leads to less Cutting force, temperature, Surface roughness - Direct application of coolant recommended
37	Al 7075 –T6	Dry, MQL, Cryogenic and Compressed air	Turning	Tool wear, SR, Micro hardness, Force, Chip Morphology	- MQL, RHVT, and Compressed air, for improvement in SR and Tool wear - Absence of Crater wear due to coolant conditions
38	Al 7075 –T6	Coolant specified	not Milling	SR,	Nose radius and depth of cut significant for minimizing the Surface roughness
39	Al 7075	Wet and LN2	Turning	SR, Temperature, Force	Use of LN2 reduced the temperature, forces and surface roughness

40	Al 7075	MQL, Compressed Air	Milling	SR, MRR	• Speed and Feed rate was the important parameter that affected the SR • Less viscous the coolant is effective
41	Al 7075 –T6	Dry and MQL using Mecgreen 550 Lubricant	Turning	SR and Chip formation	• Chip formation is dependent on feed rate, CS and Lubricating conditions • SR mainly dependent on feed rate • CS is the factor that Affects the SR.
42	Al 7136-T6511	Blastocut BC 35 SW	Milling	SR	• CS is the factor that Affects the SR.
43	Al 7075-T6	Nano Silver and Borax additives with 95% ethylene glycol (Suspension form)	Milling	SR, CF and Chip formation	• Tribological Performance of Borax and nano Silver added EG • Nano Silver particles will improve the SR and solution prepared with EG has an industrial usage.

Table 3: 3rd generation aluminum alloys

Ref.	Workpiece /Tool material	Cutting Environment	Machining	Parameters evaluated Responses	Remarks
44	AA2024-T3	Dry, Base Fluid (Mineral Oil) MQL, NFMQL MoS2	Turning	Surface Topography, Temperature	• Surface Roughness was better with NFMQL than dry and MQL because of MoS2 • BUE is less with NFMQL
45	AA2050	Soluble oil emulsion	Tapping	Machining Distortion MRR	• Optimization of Machining time • Low values of distortion from the geometrical tolerances
46	Al2050	Dry and WET Emulsion Quakercool 7000 ALF 8%	Milling	Chip Morphology	• CS assists in reducing the chip size • Reduction in rake angle reduces the chip thickness
47	2A 97	Dry	Milling	Chip Morphology, Ra	• Cutting Speed played an important role for chip edge • Convenient for replacing the Conventional Al alloys for aircrafts
48	Al 8112	Vegetable oil (Copra Oil) as base oil, nano fluid	Milling	MRR	• Increase in depth of cut increases the MRR • Helix angle plays an important role for improving the MRR
49	Aluminum alloy 24345	Dry	Milling	Ra and Rz	• Uncoated and polished flute cutters perform far better coated cutters • Rz and Sdr give a better picture of the actual surface from the functionality point of view
50	Al 2024-T3	Dry	Drilling	Hole Deviation and Circularity	• Burrs were less with uncoated drill bit • CS is also the significant parameter for geometrical parameters

Table 4: Ethylene glycol as coolant

Ref.	Workpiece	Cutting Environment	Machining	Parameters evaluated Responses	Remarks
51	SUS 304	Cellulose nanocrystal ethylene glycol	Turning	Thermal Conductivity Analysis, cutting tool and chp thermal analysis,	• Thermal conductivity increases as concentration increases
52	AISI 1018	Ethylene glycol as base fluid, TiO ₂ and Al ₂ O ₃ nanoparticles	Turning	Temperature, SR	• Thermal Analysis was studied along with SR
	Al 3303	Water ethylene glycol mixture		Corrosion study	• Corosion properties
53	AISI 304	Ethylene glycol TiO ₂ nano particles	Milling	Tool life, tool wear	• Tool life decreases with an increase in cutting speed • Showed better performance with water soluble coolants in terms of tool life.
54	AA6061-T6	Ethylene glycol mixture with TiO ₂ and ZnO hybrid nano coolant	Milling	SR, MRR	• Suitable alternative and compatible with the use of the hybrid nano-coolant
55	Fe ₃ O ₄ nanofluid	Ehtylene glycol and a water-based mixture		Thermal Conductivity, Effect of temperature	• Thermal Conductivity enhancement

3. Experimental Setup

All machining was carried out on a DMG MORI 3-axis CNC milling machine. Machining was undertaken using three varying cutting parameters: cutting speed, feed rate and depth of cut, and coolant concentration of 8%, 10%, and 12%. Suitable combinations of the cutting parameters were used to develop the design of experiments using the CCD method with three factors and five levels Table 5. A total of 156 experimental combinations were performed. The process parameters are listed in the table below [57]. Milling was carried out with 100% engagement and in a 30 x 30 mm area on the specimen Fig. 2. Aluminum Lithium alloy SAE AMS4413B (Fig. 2) slabs were used for experimentation. The size of each block was 50 x 50 x 20 mm. The chemical composition of the workpiece material and the properties are shown in Table 6. The milling inserts (Fig. 3) were SECO uncoated tools, signature [59][58]. An uncoated insert was XOEX10T304 standard water-soluble ethylene glycol coolant (Table 8).

Table 5. Process parameters

Variables		Levels		
		-1	0	1
Cutting Speed(rpm)	X1	5000	11000	17000
Feed(mm/tooth)	X2	0.04	0.16	0.28
Depth of Cut(mm)	X3	0.5	1	1.5
Tool Nose Radius	X4	0.4	0.8	1.2
Coolant Concentration (%)	X5	8	10	12

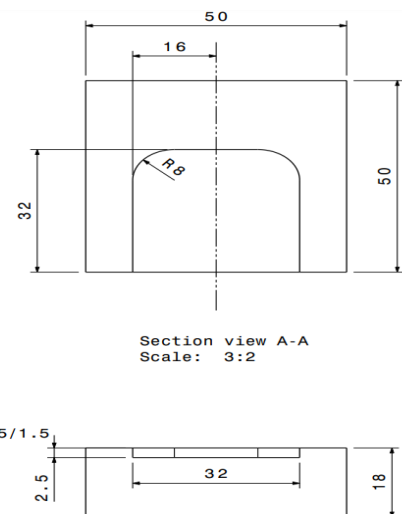


Fig.2. Sample specimen drawing of size 50 x 50 x 20 mm

Table 7. Physical properties of third-generation material

Properties	Value
Density	270 gm/cc
Melting point	510 ° C
Tensile Strength	440 MPa
Yield Strength	370 MPa
Shear Strength	260 MPa
Fatigue Strength	125
Elastic Modulus	70-80 GPa
Poison's Ratio	0.33
Elongation	10%

Table 6: Chemical composition of workpiece material.

Cu	Li	Mg	Mn	Ag	Zr	Bal.
3.5	0.9	0.40	0.35	0.45	0.12	Rem.

SAE AMS4413B

Solution Heat Treated, Stress Relieved, and Artificially Aged

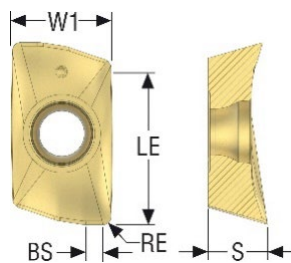

Fig.3. SECO carbide uncoated insert, XOEX10T3

Table 8. Coolant details: Specifications of Ethylene Glycol: MOLYCHEM

Ethylene Glycol	1,2 Ethanediol
Ethylene Glycol Molecular formula	98% C2H6O2
Color	A clear colorless, slightly viscous liquid
Wt. per ML at 20°C	1.112-1.115g

Performance Evaluation

Surface roughness and surface finish are opposite to each other, and are quantitative parameters. Surface roughness can be expressed in units of length after its measurement. Measurement of finely spaced deviations of the actual surface from the nominal surface (datum) in units of length (μm) defines surface roughness. A lower surface roughness value indicates a better surface finish. There are two popular methods of expressing the measured value of surface roughness. According to the "AA" method, surface roughness is the average of vertical deviations from the nominal surface over a specified surface length.

Average roughness (AA)

$$= \int_0^{lm} \frac{Y}{Lm} dx$$

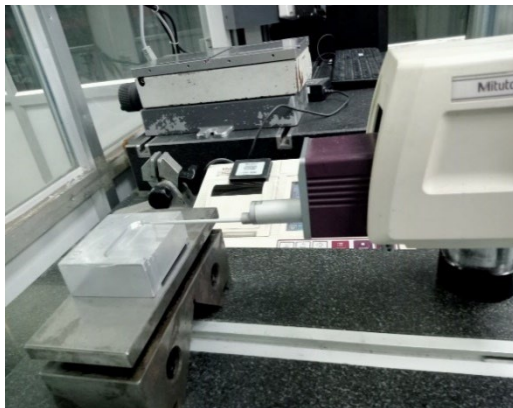
Heat Affected Zone: An eddy current meter was used to measure the HAZ. The portable meter offers a high-resolution color display and an accurate conductivity range: 0.5% IACS to 110% IACS, 0.28-64Ms/m, and a digital temperature readout. The following figures show the experimental setup and testing.


Fig: 4. Specimen Before machining

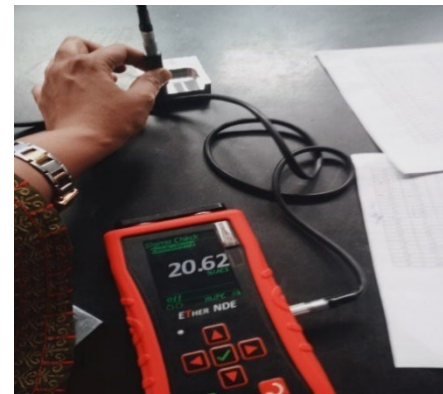
Fig. 5. Secimen After Machining



Fig. 6. Experimental set-up of the milling of a sample specimen



Surface roughness measurement using 410 Surf test on Sample specimen



HAZ measurment using Eddy current meter on Sample specimen

Fig. 7. Testing of Ra and HAZ using a 410 Surf-test and eddy current meter

4. Results and Discussion

To measure the statistical significance, analysis of variance (ANOVA) was used, and the results for Ra and HAZ are shown in Tables 4.1 and 4.2, respectively. The results of the interaction plots are given in Tables 4.2, 4.3, 4.4 and 4.5.

The regression equation obtained for Ra is given below:

$$\begin{aligned} \text{Ra} = & 5.605 + 5.32 X_2 - 1.674 X_4 - 9.02 X_2^2 + 0.0387 X_5^2 + 0.000077 X_1 \\ & * X_5 - 2.573 X_2 * X_4 + 0.3649 X_2 * X_5 - 0.0865 X_3 * X_4 + 0.1102 X_4 * X_5 \\ \text{HAZ} = & 24.511 - 0.2131 X_3 - 1.599 X_4 - 0.582 X_5 - 0.0909 X_3^2 \\ & + 0.583 X_4^2 + 0.02311 X_5^2 - 0.000063 X_1 * X_3 + 0.000117 X_1 * X_4 \\ & - 0.000049 X_1 * X_5 + 1.258 X_2 * X_4 + 0.1430 X_2 * X_5 - 0.0788 X_3 * X_4 \\ & + 0.03185 X_3 * X_5 + 0.07090 X_4 * X_5 \end{aligned}$$

Table 4.1. ANOVA (Ra)

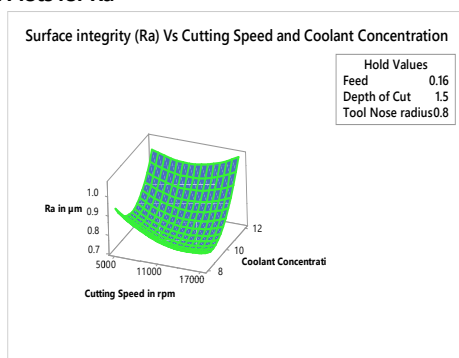
Source Ra	Un-Coded Values	DF	Adj SS	Adj MS F-Value	F-Value	P value	Significant Factors
Model		20	37.69580	1.88480	13.70000	0.00000	
Linear		5	33.27930	6.65590	479.20000	0.00000	
Cutting Speed	X1	1	0.06440	0.06440	4.63000	0.13800	
Feed	X2	1	31.11960	31.11960	2240.51000	0.00000	*
Depth of Cut	X3	1	0.00880	0.00880	0.63000	0.35800	
Tool Nose Radius	X4	1	1.26500	1.26500	91.07000	0.00000	*
Coolant Concentration	X5	1	0.82170	0.82170	59.16000	0.67600	
Square		5	1.00750	0.20150	14.51000	0.00000	*
Cutting Speed * Cutting Speed	X1 ²	1	0.02450	0.02450	1.76000	0.18600	
Feed * Feed	X2 ²	1	0.12530	0.12530	0.02000	0.00300	*
DOC * DOC	X3 ²	1	0.00000	0.00000	0.00000	0.99900	
Tool Nose radius*Tool Nose radius	X4 ²	1	0.04020	0.04020	2.90000	0.09100	

Coolant							
Concentration*Coolant							
Concentration	X5 ³	1	0.17500	0.17750	12.78000	0.00000	*
2-Way Interaction		10	3.40900	0.34090	24.54000	0.00000	
Cutting Speed*Feed	X1 * X2	1	0.01360	0.01360	0.98000	0.32400	
Cutting Speed*Depth of Cut							
Cut	X1 * X3	1	0.00520	0.00520	0.38000	0.54100	
Cutting Speed*Tool Nose radius	X1 * X4	1	0.03700	0.03700	2.66000	0.10500	
Cutting Speed*Coolant							
Concentration	X1 * X5	1	0.20310	0.02031	14.63000	0.00000	*
Feed*Depth of Cut	X2 * X3	1	0.08780	0.08780	6.32000	0.01300	
Feed*Tool Nose radius	X2 * X4	1	1.46420	1.46420	105.42000	0.00000	*
Feed*Coolant							
Concentration	X2 * X5	1	0.73640	0.73640	53.02000	0.00000	*
Depth of Cut*Tool Nose radius	X3 * X4	1	0.11500	0.11500	8.28000	0.00000	*
Depth of Cut*Coolant							
Concentration	X3 * X5	1	0.00000	0.00000	0.00000	0.96000	
Tool Nose radius*Coolant							
Concentration	X4 * X5	1	0.74660	0.74660	53.75000	0.00000	*

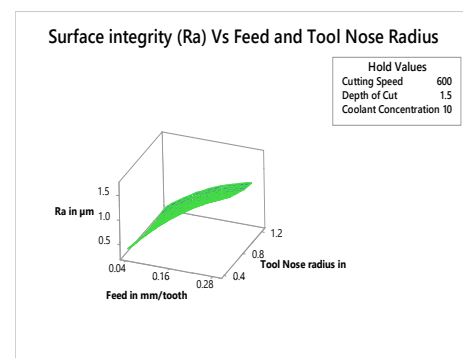
Table 4.2. ANOVA (HAZ)

Source HAZ	Un-Coded Values	DF	Adj SS	Adj MS	F-Value	P value	Significant Factors
Model		20	9.62100	0.48060	143.51000	0.00000	
Linear		5	7.87910	1.57583	470.55000	0.00000	
Cutting Speed	X1	1	0.04055	0.10547	31.50000	0.00000	
Feed	X2	1	0.02100	0.02104	6.28000	0.01300	*
Depth of Cut	X3	1	6.93690	6.93686	2071.40000	0.00000	
Tool Nose Radius	X4	1	0.62510	0.62510	186.66000	0.00000	*
Coolant Concentration	X5	1	0.19070	0.19067	56.93000	0.00000	*
Square		5	0.33000	0.06739	20.12000	0.00000	*
Cutting Speed * Cutting Speed	X1 ²	1	0.00230	0.00229	0.68000	0.40900	
Feed * Feed	X2 ²	1	0.00000	0.00002	0.01000	0.94000	*
DOC * DOC	X3 ²	1	0.06140	0.06137	18.33000	0.00000	*
Tool Nose radius*Tool Nose radius	X4 ²	1	0.06460	0.06460	19.29000	0.00000	*
Coolant Concentration*Coolant Concentration	X5 ³	1	0.06350	0.06345	18.95000	0.00000	*
2-Way Interaction		10	1.39600	0.13960	41.68000	0.00000	*
Cutting Speed*Feed	X1 * X2	1	0.00140	0.00139	0.41000	0.52100	
Cutting Speed*Depth of Cut	X1 * X3	1	0.03470	0.03469	10.36000	0.00200	*
Cutting Speed*Tool Nose radius	X1 * X4	1	0.01880	0.01884	5.63000	0.01900	
Cutting Speed*Coolant Concentration	X1 * X5	1	0.08140	0.08138	24.30000	0.00000	*
Feed*Depth of Cut	X2 * X3	1	0.00310	0.00309	0.92000	0.33800	
Feed*Tool Nose radius	X2 * X4	1	0.34980	0.34981	104.46000	0.00000	*
Feed*Coolant Concentration	X2 * X5	1	0.11310	0.11309	104.46000	0.00000	*
Depth of Cut*Tool Nose radius	X3 * X4	1	0.11310	0.11309	33.77000	0.00000	*
Depth of Cut*Coolant Concentration	X3 * X5	1	0.38950	0.38951	116.31000	0.00000	*
Tool Nose radius*Coolant Concentration	X4 * X5	1	0.30880	0.30883	92.22000	0.00000	*

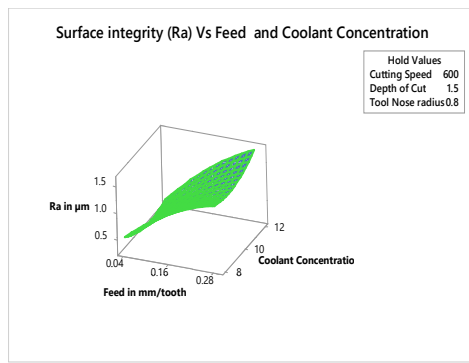
Interaction Plots for Ra



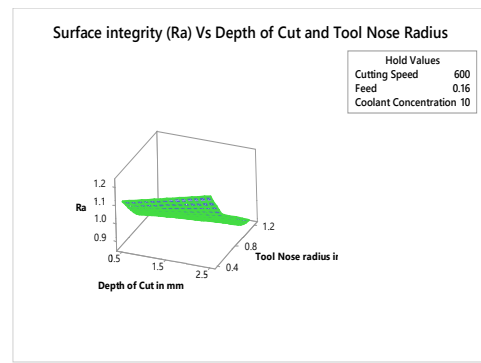
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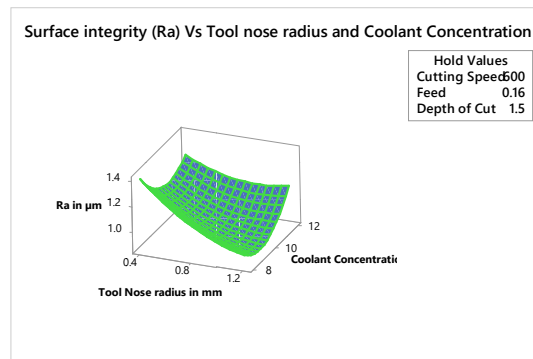
4.1.b



4.1.c



4.1.d

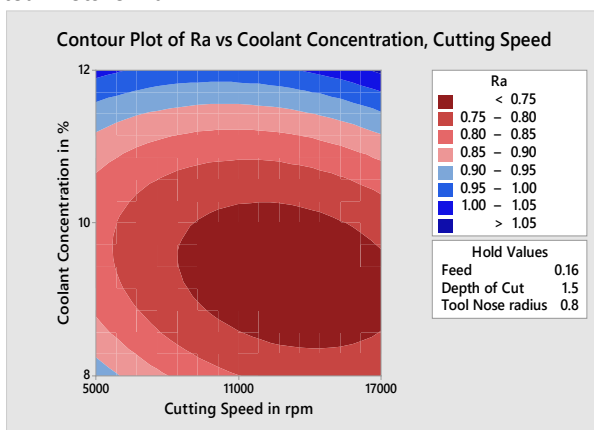


4.1.e

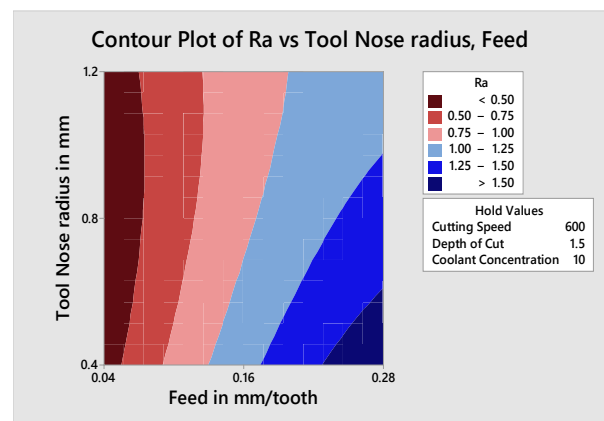
Fig. 4.1. a) Surface plot of CS and Coolant concentration b) Surface plot of Feed and Tool nose radius c) Surface plot of Feed and Coolant concentration d) Surface plot of Depth of Cut and Tool nose radius e) Surface plot of Tool nose radius and Coolant concentration

Fig. 4.1.a - 4.1.e shows the surface plots when ethylene glycol is used as the coolant at 8%, 10%, and 12% concentration. The figures represent the effect of input parameters on the Surface Roughness (Ra). The Surface plots in Fig. 4.1.a indicate a sudden decrease and an increasing trend for cutting speed and coolant concentration, whereas Figs. 4.1.b and 4.1.c indicate an increasing trend for interaction between feed and coolant concentration as well as tool nose radius. Interaction plot 6.d indicates a decreasing trend of Ra with tool nose radius and depth of cut. Fig. 4.1.e shows a decreasing trend, indicating higher values of tool nose radius and coolant concentration of 8-10%.

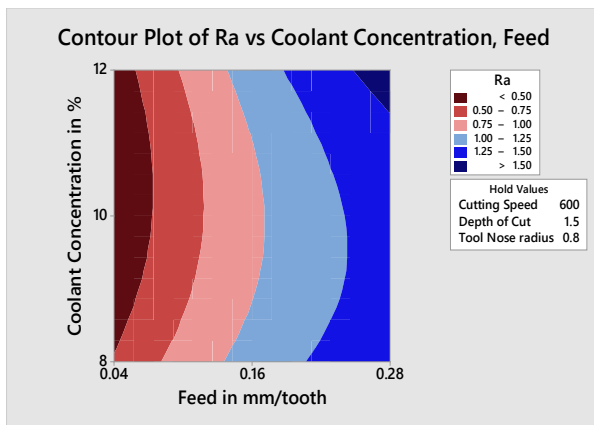
Contour Plots for Ra



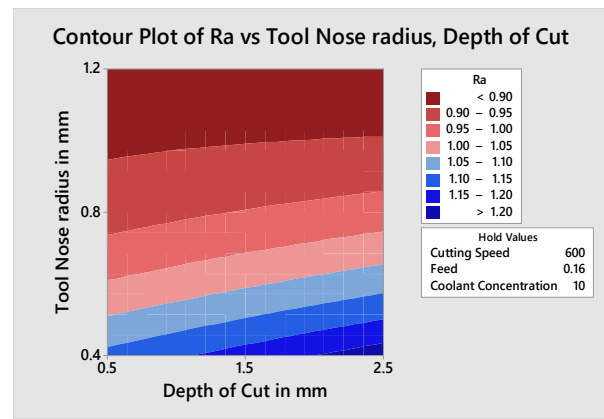
4.2.a



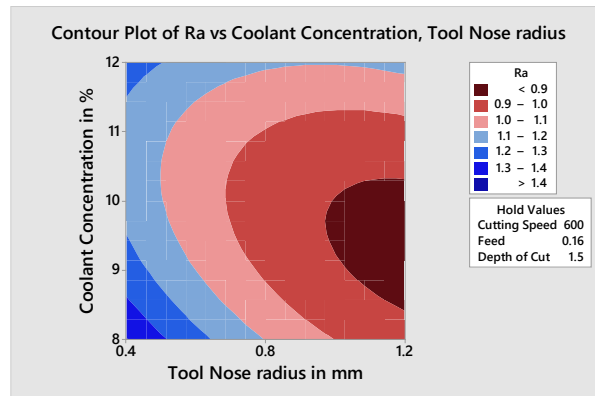
4.2.b Contour plots for Feed and Tool nose radius



4.2.c



4.2.d

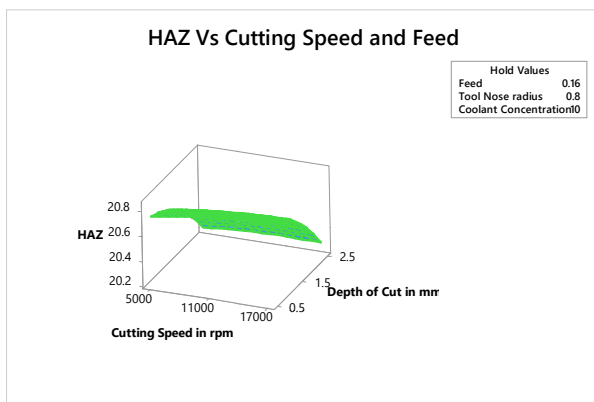


4.2.e

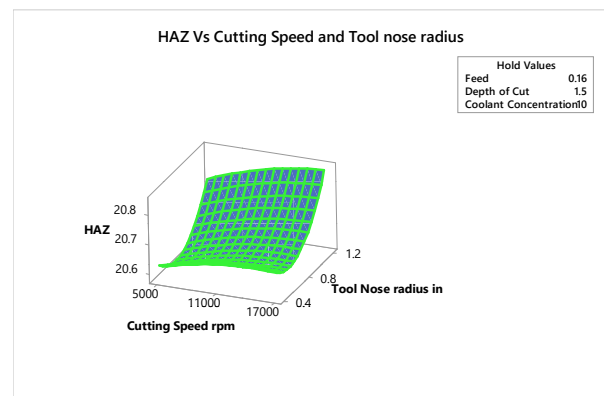
Fig 4.2. a) Contour plots for Cutting speed and Coolant concentration b) Contour plots for Feed and Tool nose radius c) Contour plots for Feed and Coolant concentration d) Contour plots for Depth of cut and Tool Nose radius e) Contour plots for Coolant concentration and Tool nose radius

Fig. 4.2.a – 4.2.e represents the contour plots of the interaction between cutting speed, feed, depth of cut, tool nose radius, and coolant concentration on Surface Roughness (Ra). Fig. 4.2.a shows the simple maximum pattern of the contour plot for the hold values of speed 11000 rpm, 0.16 mm/tooth feed, and a Depth of cut of 1.5mm, with Ra values less than 0.75 μ m. Fig. 4.2.b-4.2.d represents the stationary ridge pattern and 4.2.e the rising ridge pattern on the contour plot with Ra values less than 0.50 μ m, 0.90 μ m, respectively, with the following values of speed 11000 rpm, 0.16 mm/tooth feed, and Depth of cut of 1.5mm. From the above surface and contour plots, it is observed that cutting speed between 11000 rpm and 17000 rpm can be considered with a lower feed of 0.04 mm/tooth and a larger tool nose radius and coolant concentration.

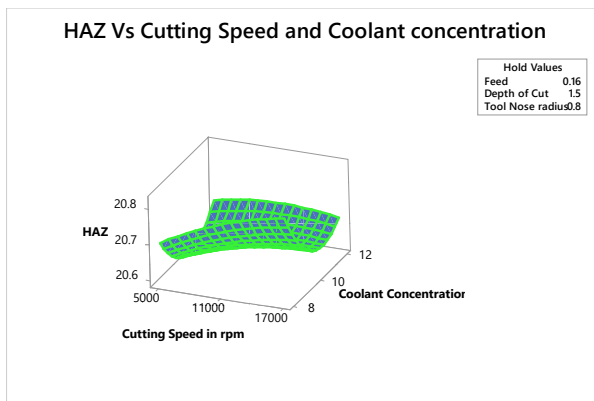
Interaction Plot for HAZ



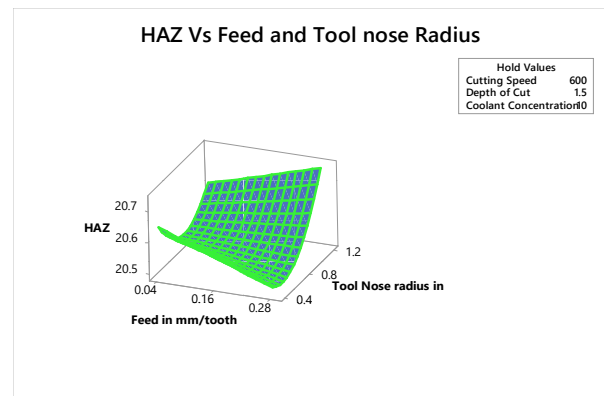
4.3.a



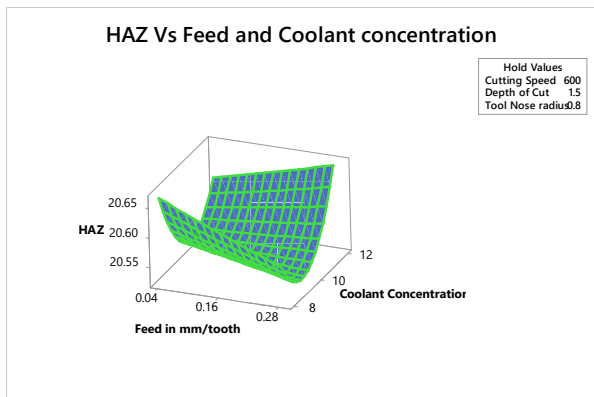
4.3.b



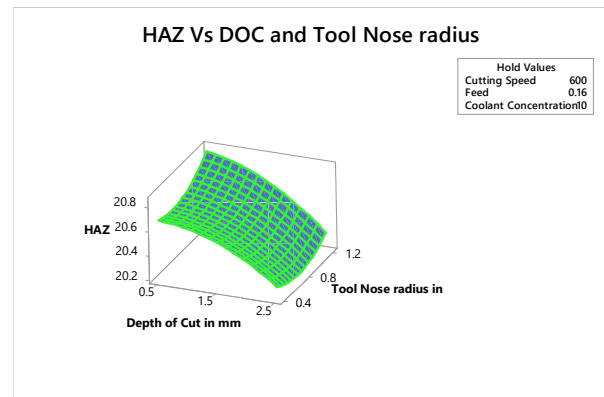
4.3.c



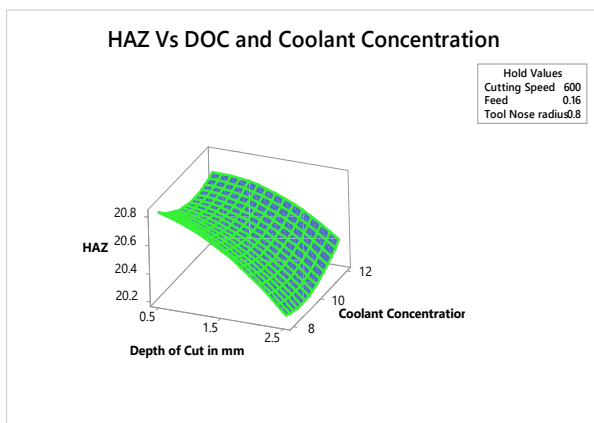
4.3.d



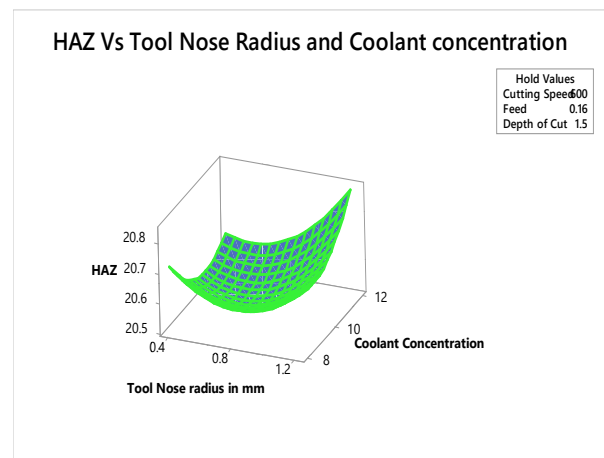
4.3.e



4.3.f



4.3.g

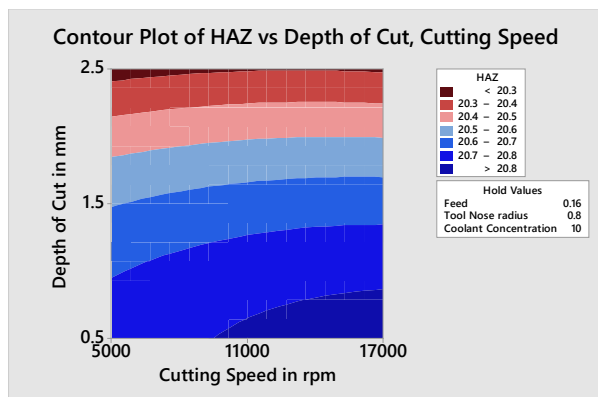


4.3.h

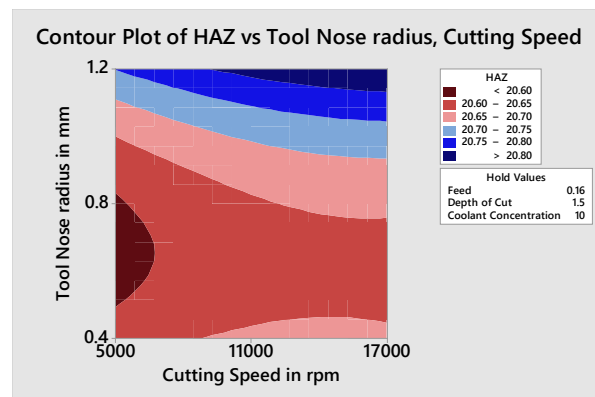
Fig: 4.3. a) Surface plot of Cutting speed and depth of cut, b) Surface plot of Cutting speed and tool nose radius, c) Surface plot of CS and Coolant concentration, d) Surface plot of Feed and Tool nose radius, e) : Interaction plot: Surface plot of CS and Coolant concentration, f) Surface plot of Feed and Tool nose radius, g) Surface plot of Depth of cut and Coolant concentration, h) Surface plot of Coolant concentration and Tool nose radius

Fig. 4.3.a - 4.3.e represents the surface plots for the heat-affected zone. The hold values for all the plots are a cutting speed of 11000 rpm, Depth of cut 1.5 mm, Tool nose radius as 0.8mm and 0.16 mm/tooth feed and 10% coolant concentration. Fig. 4.a indicates better lubrication, since for all speed values the HAZ shows a decreasing trend with increasing depth of cut. Fig. 4.b indicates that a lower HAZ can be obtained by employing a 0.4 mm tool nose radius with 10% coolant concentration. Fig. 4.c shows a sudden decrease and then an increase in the HAZ for interaction between cutting speed and coolant concentration. Figs. 4.d and 4.e indicate lower values of HAZ for a cutting speed of 17000 rpm, lower feed, and smaller tool nose radius, along with 8%-10% coolant concentration. Fig. 4.f and 4.g indicate that lower values of HAZ can be obtained with a coolant concentration of 10% for a depth of cut up to 2.5 mm. Fig. 4.h shows lower HAZ for a tool nose radius of 0.8 mm and 10% coolant concentration. From the surface plots, a coolant concentration up to 10% and a tool nose radius of 0.4-0.8 mm can be used.

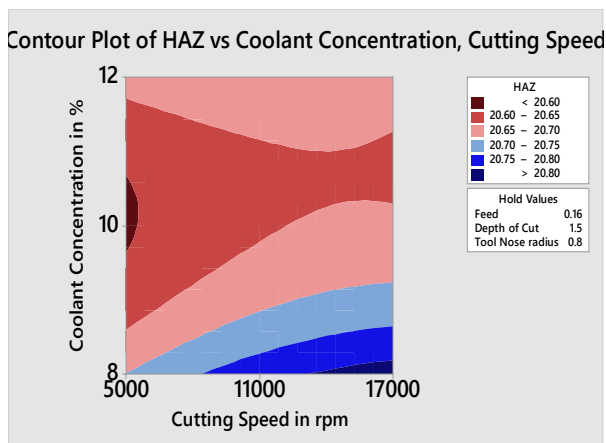
Contour Plots for HAZ



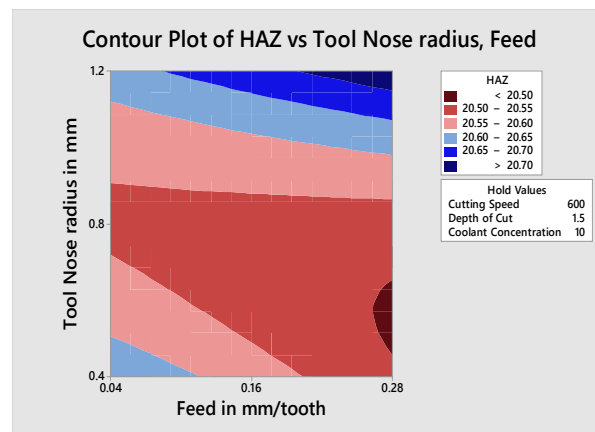
4.4.a



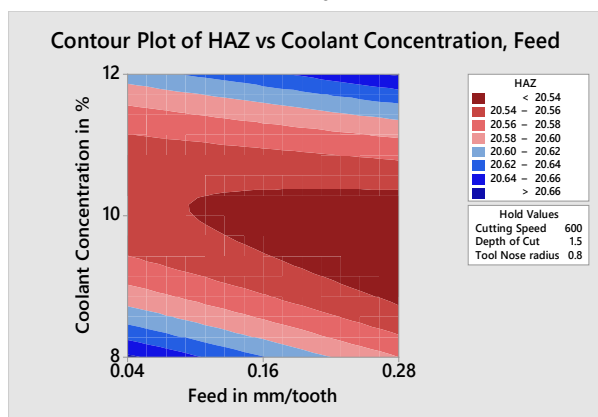
4.4.b



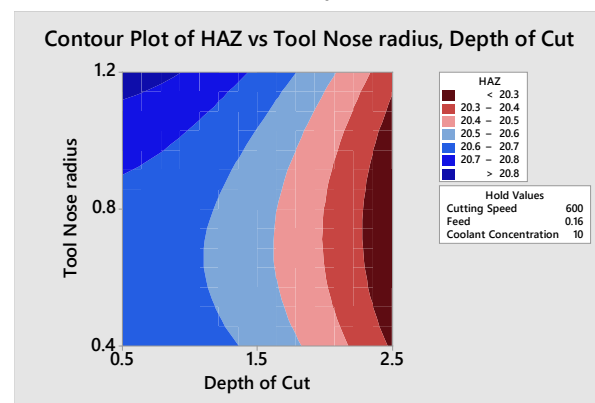
4.4.c



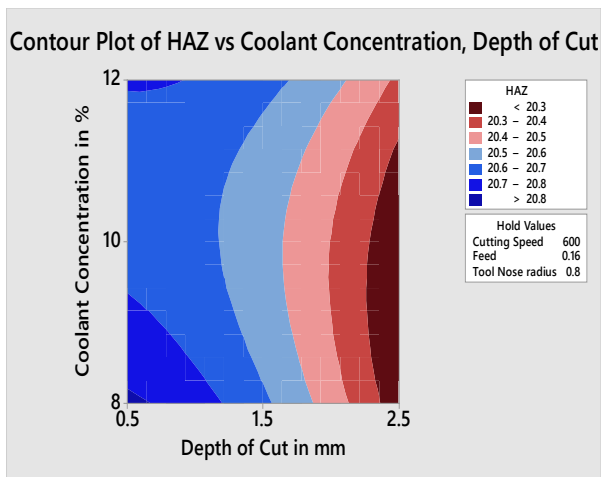
4.4.d



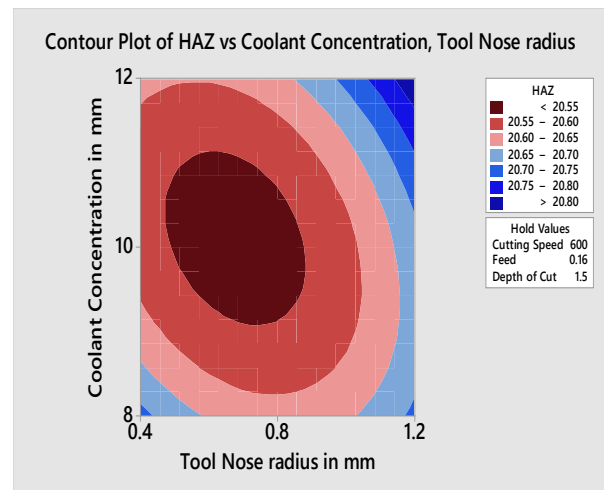
4.4.e



4.4.f



4.4. g



4.4. h

Fig. 4.4. a) Contour plots for Cutting speed and Depth of Cut, b) Contour plots for Cutting Speed and Tool nose radius, c) Contour plots for Cutting speed and Coolant concentration, d) Contour plots for Feed and Tool nose radius, e) Contour plots for Feed and Coolant concentration, f) Contour plots for Depth of Cut and Tool nose radius, g) Contour plots for Depth of cut and Coolant concentration, h) Contour plots for Coolant concentration and Tool nose radius

Fig. 4.4.a - 4.4.h represents the contour plots for the interaction between cutting speed, feed, depth of cut, tool nose radius and coolant concentration on Heat affected zone (HAZ). Fig.4.4.a indicates a stationary ridge pattern with HAZ values less than 20.3 IACS. Fig. 4.4.f-4.4.g shows the minimax pattern of the contour plot for the hold values of speed 11000 rpm, 0.16 mm/tooth feed and depth of cut of 1.5 mm with HAZ values of 20 IACS. Fig. 3.4. b, c, d represents the stationary ridge pattern and Fig. 4.4.e shows the rising ridge pattern on the contour plot with HAZ values of 20.5 and 20.6 IACS, respectively, with the values of speed 11000 rpm, 0.16 mm/tooth feed, and Depth of cut of 1.5mm. Fig. 3.4.e indicates a rising ridge pattern with a HAZ value of 20.55 IACS.

5. Conclusion

Based on the experimental work, the following conclusions were drawn:

The individual effects of Cutting Speed, Feed, Depth of cut, tool nose radius, and coolant concentration exist for the Ra and HAZ values. The optimum values of Ra and HAZ are 0.21 μm and 20.3 IACS. The selection of the Ethylene Glycol concentration should be in the range of 8-10%. The linear model analysis is well within the 95% confidence level, with R² values of 95.27% for Ra and 95.51% for HAZ. The experimental results provide a basis for future researchers.

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7. References

Analysis and optimization of surface quality while machining high strength aluminium alloy", Elsevier, Measurement, Volume 152, February 2020, 107337

A M Zetty Akhtar¹, M M Rahman^{1,2}, K Kadirgama^{1,2} and M A Maleque, Effect of TiO₂ and Al₂O₃-ethylene glycol-based

nanofluids on cutting temperature and surface roughness during turning process of AISI 1018

Afaf M. Abd El-Hameed, Y. A. Abdel-Aziz, Aluminum Alloys in Space Applications: A Short Report, Journal of Advanced Research in Applied Sciences and Engineering Technology 2022, Issue 1 (2021) 1-7

Aishah Najiah Dahnal, Muhamad Ali Abdul Ghani, Natasha A. Raof, Suhaily Mokhtar, and Nor Khairusshima Muhamad Khairussaleh, Analysis of defects on machined surfaces of aluminum alloy (Al 7075) using imaging and topographical techniques, International Journal of Metrology and Quality Engineering Int. J. Metrol. Qual. Eng. 13, 12 (2022) A.N. Dahnal et al., published by EDP Sciences, <https://doi.org/10.1051/ijmqe/2022012>

Aleksandar Košarac, Lana Šikuljak, Čedomir, Cvijetin Mladenović, Milan Zeljković, CUTTING PARAMETERS INFLUENCE ON SURFACE ROUGHNESS IN AL 7075 MILLING, 19th International Symposium INFOTEH-JAHORINA, 18-20 March 2020, DOI: 10.1109/INFOTEH48170.2020.9066273

Arpit Srivastava¹, Mukesh K, umar Verma¹, Ramendra Singh Niranjani¹, Abhishek Chandra¹, Praveen Bhai Patel¹, Experimental Investigation and Optimization of Machining Parameters in Turning of Aluminum Alloy 075-T651, Scienco, PRODUCTION ENGINEERING ARCHIVES2021, 27(4),296-305

- Atul Devl, Smriti Tandon#, Pankaj Kumar\$, and Anup Dutt, Effect of Coating and Polishing of Cutting Tool on Machined Surface Quality in Dry Machining of Aluminium Alloy, Defence Science Journal, Vol. 70, No. 3, May 2020, pp. 299-305, DOI : 10.14429/dsj.70.14831 © 2020, DESIDOC
- Aurel Mihail Titu, Andrei Victor Sandu, Alina Bianca Pop, Stefan Titu, Dragos Nicolae Fratila and Costel Ceoce Design of Experiment in the Milling Process of Aluminum Alloys in the Aerospace Industry. MDPI AG Applied Sciences (Vol. 10, Issue 19)
- Aysegul Yucel, Cagri vakkas yildirim, Murat Sarikaya , Senol Sirin , Turgay Kivak, Munish Kumar Gupta, Italo V . Tomaz . Influence of MoS 2 based nanofluid – MQL on tribological and machining characteristics in turning of AA 2024 T3 aluminum alloy , jmr& Journal of Material Research and Technology , ELSEVIER JOURNAL OF MATERIALS RESEARCH AND TECHNOLOGY 2021;15 : 1688- 1704
- Cindie Giummarra, Bruce Thomas and Roberto J. Rioja, New Aluminum Lithium Alloys For Aerospace Applications, Proceedings of the Light Metals Technology Conference 2007,
- E. A. Starke, Jr and J. T. Staley, Application of modern aluminum alloys to Aircraft, Pro 9. Aerospace Sci. Vol. 32, pp. 131-172~ 1996 Elsevier Science Ltd Printed in Great Britain.
- Elvan Ates, Zafer Evis, Fahrettin Ozturk, "Optimization of cutting parameters and machining Distortion analysis for AA2050", Metal 2022, May 18-19,2022 Brno Czech Republic, EU
- F. C Campbell, Manufacturing Technology for aerospace structural materials, Elsevier, 2011
- G. Ambrogio, L. Filice, F. Gagliardi, Materials and Design Materials and Design, Elsevier, 34 (2012) 501–508 Content
- G. Le
Coz a, M. Marinescu a, A. Devillez a, D. Dudzinski a, L. Velnom b , Measuring temperature of rotating cutting tools: Application to MQL drilling and dry milling of aerospace alloys, Applied Thermal Engineering, Elsevier, Volume 36, April 2012, Pages 434-441
- G.C. Manjunath Patel, Deepak Lokare, Ganesh R Chate, Mahesh.B. Parappagoudar, R. Nikhil, Kapil Gupta,
- Gary Wong Ang Kui1 · Sumaiya Islam1 · Moola Mohan Reddy1 · Neamul Khandoker2 · Vincent Lee Chieng Chen1, Recent progress and evolution of coolant usages in conventional machining methods: a comprehensive review, The International Journal of Advanced Manufacturing Technology (2022) 119:3–40,
- Giovanna Roella, Effect of surface integrity induced by machining on high cycle fatigue life of 7075-T6 aluminum alloy, May 2019, Journal of Manufacturing Processes 41:83-91, 10.1016/j.jmapro.2019.03.031
- Imhade Princess Okokpuije and Lagouge Kwanda Tartibu, Performance Investigation of the Effects of Nano-Additive-Lubricants with Cutting Parameters on Material Removal Rate of AL8112 Alloy for Advanced Manufacturing Application, Advanced Manufacturing Application. Sustainability , MDPI, 2021, 13, 8406. [https:// doi.org/10.3390/su13158406](https://doi.org/10.3390/su13158406),
- Jasjeevan Singh Simranpreet Singh Gill , Turning of Al 7075-T6 aerospace alloy under different sustainable metalworking fluid strategies by coated carbide tools, Pages 275-294 Received 04 Jan 2023, Accepted 08 May 2023, Published online: 20 May 2023 Surface Engineering , Taylor and Fancis Volume 39, 2023 - Issue 3
- Jintao Niu, Zhanqiang Liu, Xing Ai, Weimin Huang, Guijie Wang & Ran Duan Characteristics of machined surface integrity in face milling Al-Li alloy 2A97 with carbide inserts, The International Journal of Advanced Manufacturing Technology, Springer 101, pages839–848 (2019)
- K Thirumavalavan1, Sastry C Chandrasekhar1, Abeens M1, R Muruganandhan1 and M A Muthu Manickam2, Materials Research Express, Volume 6, Number 11, IOP DOI 10.1088/2053-1591/ab522f
- K. Danesh Narooei 1 R. Ramli 2 Optimal Selection of Cutting Parameters for Surface Roughness in Milling Machining of AA6061-T6, IJE TRANSACTIONS C: Aspects Vol. 35, No. 06, (June 2022) 1170-1177
- Kailun Zheng, Denis J. Politis, Liliang Wang, Jianguo Lin, A Review on Forming Techniques for Manufacturing Lightweight Complexed Shaped Aluminium Panel Components", International Journal of Lightweight Materials and Manufacture 1(2018) 55-80
- Kamran Dehghani , Atiye Nekahi , Mohammad Ali Mohammad Mirzaie, Optimizing the bake hardening behavior of Al7075 using response surface methodology, Materials & Design, Volume 31, Issue 4, April 2010, Pages 1768-1775.
- L. Syam Sundar, Manoj Kumar Singh, Antonio Sousa, Thermal conductivity of ethylene glycol and water mixture based Fe3O4 nanofluid, International Communications in Heat and Mass Transfer 49:17–24 DOI:10.1016/j.icheatmasstransfer.2013.08.026
- L. Zhu, N. Li, P.R.N. Childs, "Light-weighting in aerospace component and system design", , Propulsion and Power Research 2018;7(2):103–119

- L. Samylingam , K. Anamalai a, K. Kadirgama , M. Samykano , D. Ramasamy , M.M. Noor , G. Najafi , M.M. Rahman, Hong Wei Xian , Nor Azwadi Che Sidik, Thermal analysis of cellulose nanocrystal-ethylene glycol nanofluid coolant, *International Journal of Heat and Mass Transfer*, Elsevier, Volume 127, Part B, December 2018, Pages 173-181
- M. Huseyin Cetin, Seyma Korkmaz Investigation of the concentration rate and aggregation behaviour of nano-silver added colloidal suspensions on wear behaviour of metallic materials by using ANOVA method, *Tribology International*, Elsevier Volume 147, July 2020, 106273
- M. Peters and C. Leyens, "Materials Science and Engineering – Vol. III – Aerospace and Space Materials, Encyclopedia of Life Support Systems (EOLSS)
- Michael Standridge, Aerospace materials past, present, and future", aerospacemanufacturinganddesign.com/article/amd0814-rockford-aerospace-infographic
- Muhammad Aamir, Khaled Giasinb, Majid Tolouei-Rada, Ana Vafadar, A review: drilling performance and hole quality of aluminium alloys for aerospace applications, *Journal of Materials Research and Technology*. 2020;9(6):12484–12500
- Murat Sarikaya, Munish Kumar Gupta, Italo Tomaz, Mohd Danish, Mozammel Mia, Saeed Rubaiee, Mohd Jamil, Danil Yu Pimenov, Navneet Khanna, Cooling techniques to improve the machinability and sustainability of light-weight alloys: A state-of-the-art review, 179-201, 23, *Journal of Manufacturing Processes*, 62, Published - Feb 2021
- Muthusamy, Y., Kadirgama, K., Rahman, M.M. et al. Wear analysis when machining AISI 304 with ethylene glycol/TiO₂ nanoparticle-based coolant. *Int J Adv Manuf Technol* 82, 327–340 (2016). <https://doi.org/10.1007/s00170-015-7360-3>
- N. Eswara Prasad Amol A. Gokhale R.J.H. Wanhill, Aluminum Lithium Alloys Processing, Properties, and Applications, 2014 Elsevier Inc.
- N. Eswara Prasad, R.J.H. Wanhill, Aerospace Materials and Material Technologies, Volume 1: Aerospace Materials, Indian Institute of Metals Series. Springer Singapore, Chapter 24
- N.S.M. Sahid¹ , M.M. Rahman¹ , K. Kadirgama¹ , D. Ramasamy¹ , M.A. Maleque² and M.M. Noor¹, Experimental investigation on the performance of the TiO₂ and ZnO hybrid nanocoolant in ethylene glycol mixture towards AA6061-T6 machining, *International Journal of Automotive and Mechanical Engineering* ISSN: 2229-8649 (Print); ISSN: 2180-1606 (Online); Volume 14, Issue 1 pp. 3913-3926 March 2017 ©Universiti Malaysia Pahang Publishing DOI: <https://doi.org/10.15282/ijame.14.1.2017.8.0318>
- New Light Alloys, AGARD Lecture Series No. 174", North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development, 1990
- Nihat Tosun¹ and Mesut Huseyinoglu² Effect of MQL on Surface Roughness in Milling of AA7075-T6 Materials and Manufacturing Processes, 25: 793–798, 2010 Copyright © Taylor & Francis Group, LLC ISSN: 1042-6914 print/1532-2475 online DOI: 10.1080/10426910903496821
- P. Rambabu, N. Eswara Prasad, V.V. Kutumbarao and R.J.H. Wanhill, "Aluminium Alloys for Aerospace Applications", Springer, Aerospace Materials and Material Technologies, Indian Institute of Metals Series, DOI 10.1007/978-981-10-2134-3_2
- R.J.H. Wanhill, Aerospace Applications Of Aluminium – Lithium Alloys chapter 15, DOI:10.1007/978-981-10-2134-3_2, In book: Aerospace Materials and Material Technologies (pp.29-52)
- ROBERTO J. RIOJA and JOHN LIU, The Evolution of Al-Li Base Products for Aerospace and Space Applications, *Metallurgical and Materials Transactions A*, Volume 43A, September 2012, 3325.
- S. Kalyanam, A.J. Beaudoin, R.H. Dodds Jr, F. Barlat, Delamination cracking in advanced aluminum–lithium alloys-experimental and computational studies, *Eng Fract Mech*, 2009,76:2174–91.
- S.F. Hamel, A parametric study of delaminations in an aluminum–lithium alloy, In: MS Thesis. Champaign, University of Illinois at Urbana, 2010.
- Stan Imbrogno, Sergio Rinaldi, Asier Gurruchaga Suarez, Pedro J. Arrazola, Domenico Umbrello, High Speed Machinability of the Aerospace Alloy AA7075 T6 Under Different Cooling Conditions, *Proceedings of the 21st International ESAFORM Conference on Material Forming AIP Conf. Proc.* 1960, 070013-1–070013-6; <https://doi.org/10.1063/1.5034909> Published by AIP Publishing. 978-0-7354-1663-5
- Thakur Paramjit Mahesh a, R. Rajesh b Optimal Selection of Process Parameters in CNC End Milling of Al 7075-T6 Aluminium Alloy Using a Taguchi-fuzzy Approach, *Procedia Materials Science*, Volume 5, 2014, Pages 2493-2502
- Thomas Dorin, Alireza Vahid, Justin Lamb, "Fundamentals of Aluminium Metallurgy", Elsevier, DOI: 10.1016/B978-0-08-102063-0.00011-4
- Ujjawal Kumar , Akshay Majumdar , V.K. Hiremath, Properties of Aluminum-Lithium Alloy – A New Aerospace Alloy, *International*

Journal of Engineering & Technology Research Volume 3, Issue 3, May-June, 2015, pp. 29-35 ISSN Online: 2347-4904

V Muthuraman¹, and S Arunkumar Experimental evaluation of machining parameters in machining of 7075 aluminium alloy with cryogenic liquid nitrogen coolant, International Conference on Emerging Trends in Engineering Research IOP Conf. Series: Materials Science and Engineering 183 (2017) 012012 doi:10.1088/1757-899X/183/1/012012

Vasanth Kumar H S. (2022). Impact of Silicon Carbide Particles Weight Percentage on the Microstructure, Mechanical Behaviour, and Fractography of Al2014 Alloy Composites. *Advances in Materials Science and Engineering*, 2022, 1-10, <https://doi.org/10.1155/2022/2839150>.

Vincent Wagner, Arnaud Vissio, Emmanuel Duc, Michele Pijolat, Relationship between Cutting Conditions and Chips morphology during milling of Aluminum Al-2050, *Int. J. Manuf. Technol* (2016), 82:1881-1897

Xuesong Zhang, Yongjun Chen, Junling Hu, "Recent advances in the development of aerospace materials", *Progress in Aerospace Sciences* 97, Elsevier (2018) 22–34

Yue Yang, Jing Bi, Hanwei Liu, Yang Li, Mingyang Li, Sansan Ao, Zhen Luo, "Research progress on the microstructure and mechanical properties of friction stir welded Al–Li alloy joints", Elsevier, *Journal of Manufacturing Processes* 82 (2022) 230-244, <https://doi.org/10.1016/j.jmapro.2022.07.067>

Zainul Huda, Prasetyo Edi, Materials selection in design of structures and engines of supersonic", Elsevier, *Materials and Design* 46 (2013) 552–560