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ECO-FRIENDLY MACHINING OF SUPER DUPLEX STAINLESS STEEL (UNS S32760) UNDER NITROGEN GAS COOLED AND VEGETABLE OIL BASED MQL SYSTEM

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ABSTRACT

Super duplex stainless steel (SDSS) is most extensively used in offshore and marine applications because of their excellent corrosive resistance and good mechanical properties. Although, due to high levels of various alloying elements machinability of super duplex stainless steel is very poor. In this present work experimental investigation of turning of super duplex stainless steel UNS S32760 in CNC lathe machine (Make: Jyoti DX 200) with (Al,Ti)N coated carbide tools under various cutting conditions like dry, nitrogen gas cooled environment and MQL machining in vegetable oil (Acculube LB 2000) by using Taguchi technique. The experiments were performed at three different cutting speeds (75, 100 and 125 m/min) with three different feed rates (0.05, 0.15 and 0.25 mm/rev) and a constant cutting depth (1 mm). Using signal to noise ratio and analysis of variance, the cutting parameters are optimized. The effects of cutting speed and feed rate on surface roughness, cutting temperature and tool wear were studied. The result shows that the feed rate is the more significant parameter that influencing the surface roughness. The cutting speed was identified as the more significant parameter influencing the cutting temperature and tool wear. The results show that MQL machining has better performance reduction in surface roughness, cutting temperature and tool wear when compared to Nitrogen gas cooled and dry machining.

KEYWORDS: Turning, Super Duplex Stainless Steel, MQL, Vegetable oil, Gas Cooled Machining, Taguchi method, S/N ratio, ANOVA

Nomenclature

DSS – Duplex stainless steel

SDSS – Super duplex stainless steel

ASS – Austenitic stainless steel

SCC – Stress corrosion cracking

PRE - Pitting Resistance Equivalent

MQL – Minimum quantity lubrication

MWF_s - Metal working fluids

Ra – Average Surface Roughness

Introduction

In the past few decades, the usage of stainless steel has been increased enormously in various applications like chemical and power engineering 34%, food and beverage industry 18%, transportation 9%, architecture 5%, domestic appliances & household utensils 28% and small electrical and electronic appliances 6%. The combination of good corrosive resistance, high resistance to oxidation, high mechanical strength, high toughness, aesthetically attractive appearance and good formability have made stainless as a better choice for wide range of applications (Davis1999). The new generation of stainless steel, austenitic-ferritic or duplex grades, is incoming this industrial sector by to a number of reasons. The presence of two phases austenitic-ferritic with different hardness which makes them difficult to cut material. Duplex stainless steel (DSS) have good corrosive resistance, especially to stress corrosion cracking (SCC), double the strength when compared to austenitic stainless-steel (ASS), because ASS have more cost effective because of lower contents of mainly molybdenum and nickel. Duplex stainless steels were originally developed in 1920s, DSS are extensively used in most corrosive environment in sea water applications in desalination plants like Reverse osmosis, evaporator shells, condensers and evaporator shells etc., (Olsson and Snis 2007). Super duplex stainless steel is mostly used in offshore equipment and marine applications in contact with aggressive chemicals like hydrogen sulfide, carbon dioxide, cyanide anion and chloride present in marine oil fields. Super duplex stainless steel has 25% of higher chromium content when compared to duplex stainless steel have 20% chromium content with PRE greater than 40. The “Pitting Resistance Equivalent” (PRE), given by PRE=%Cr+3.3(%Mo)+16(%N) (Tavares et al.2007). The machinability study of 1st generation duplex DSS (SAF 2205), 2nd generation duplex SDSS (SAF 2507) and austenite stainless steel 316L during in drilling process. The result shows that austenite stainless steel has better machinability when compared to duplex and super duplex stainless steel. Both duplex steel has poor machinability features because of higher response to build up edge formation (Nomani et al.2013). The turning operation of SDSS UNS 32750 alloy, the tests were performed using low-and high-fluid pressure cutting speed and cooling conditions as the input variables. The results indicate that turning under high-pressure cooling with PVD-coated inserts resulted in long life of the tool, good roughness of the workpiece and a high resistance to corrosion after machining. The most common wear mechanism found during the tests was notch wear, while attrition was the principal tool wear mechanism (De Oliveira Junior et al. 2014).

A micromilling of super duplex UNS S32750, compared with ferritic AISI 430 and austenitic AISI 316 stainless steels, analyzing the effect of cutting parameters on the cutting force. Although super duplex is known to be a difficult to machine mesoscale steel, the results of cutting force were similar to those of other stainless steels in micromilling processes. It has also been noted that the maximum cutting force of the super duplex steel is located between the forces for stainless steels AISI 316 and AISI 430 (Lopes Mougo et al. 2018).Turning of super duplex stainless steel SDSS-SAF-2507 in longitudinal and taper cutting were tested in indexable conventional and wiper insert geometries with different feeds. The condition of conventional insert in longitudinal cutting with low feed rate offered the longest tool life among all the conditions performed, with good surface finish. The use of taper cutting strategy has not improved the life of the tools. Built-up edge was developed where wiper inserts were used in all conditions (Gamarra & Diniz 2018). Multilayer coating in the cutting tool is the effective way to improve the cutting performance in turning of super duplex stainless steel. From that study [MT-TiCN] -Al_2O_3 coated tool provides the better performance in tool wear, cutting temperature, cutting force and surface integrity when compared to other coating followed by MT-TiCN, Al_2O_3 and TiOCN- Al_2O_3 -TiCN-[MT-TiCN]-TiN coatings (Rajaguru & Arunachalam 2017). Dry machining of super duplex stainless steel was examined using cemented carbide turning inserts with (CVD) TiCN + Al2O3, as well as PVD TiCN and AlTiN inserts. The results shows that the AlTiN PVD coating have reduction flank wear when compared to other two coatings (José et al 2017). During the dry turning of super duplex stainless steel, the wear performance of coated inserts was compared to an uncoated tool and the tribological behavior was also studied. The results show that the AlTiN coating provides the better performance in comparison with TiCrAlN/TiCrAl60SiYN and TiCN+Al2O3 coated insert (Ahmed & Veldhuis 2017). Studied the machinability of dry turning of austenitic stainless steel AISI 316L and Super Duplex 2507 with PVD-TiAlN Nano-multilayer coated carbide insert. It shows that the higher cutting force, higher tool wear and poor surface finish were observed in the Super Duplex stainless steel 2507 over austenitic stainless stainless steel AISI 316L (Dhananchezian et al 2016). Environment conscious manufacturing is a new approach which minimize the adverse effect on human health and environmental pollution (Hricová J 2014). Dry or green machining has become more popular due to environmental safety, reduce the manufacturing cost, cleaning cost and there are no disposal problems. It is also satisfying the machining conditions of cast iron and aluminum alloys (Sreejith & Ngoi 2000).

Conventional cutting fluids are unproductive in overcoming the higher cutting temperature at higher cutting speed and higher feed rate, further they deteriorate the operating space and results in environmental pollution (Paul et al 2001). Used cutting fluid from the machining process is very harmful to human health and environment. The disposal of cutting fluid in soil and water is very toxic to the environment because of chemical substance presence in cutting fluid for the lubrication purpose. By using of petroleum based cutting fluids the worker will affected by skin diseases, allergys, throat cancer, prostate cancer, asthma, breathing problems and respiratory illness (Kun Li, et 2003). Minimizing cutting fluid often leads to cost-effective benefits by saving on lubricant costs and cycle time for workpiece / tool / machine cleaning. Since a decade ago, the concept of minimal quantity lubrication (MQL) has been suggested as a way to address the issues of environmental intrusiveness and occupational hazards involved with the aerial cutting of fluid particles on factory floors (Dhar et al 2006). This research focuses on a detailed analysis of SDSS SAF 2507 machinability and stress corrosion cracking resistance (SCC) in different coolant environments (Dry, Flood, Minimum quantity lubrication). The cutting performance was analyzed using machinability indicators such as tool wear, cutting force, surface roughness, tool wear, residual stress and chip morphology . In the case of dry cutting, abrasion and adhesion dominated the wear mechanism and it caused more tool wear. Compared to dry cutting, machining under flood and MQL environment reduced the built-up edge occurrence and improved tool wear performance by 11.95 percent and 33.08 percent respectively. The results of overall machinability revealed that MQL provided better performance than dry and flood lubrication (Rajaguru and Arunachalam 2020). Machining with MQL also benefits the environment and machine tool operator safety as lubricant consumption is 7-fold lower during service with MQL than in conventional system (Soroush Masoudi 2017). Improved turning process performance was observed with texture tools over untexture tools, so metal cutting industries could adopt this technology to produce cutting tools for difficult-to-cut materials machining. The hybrid texture tool under MQL cutting condition meets the stringent environmental regulations along with Inconel 718 superalloy improved machinability (Sivaiah 2019). In gas-cooled machining, there is no problem of coolant disposal as the gasses merg into the atmosphere. Those gases are already present and harmless in the atmosphere. Gas-cooled machining does not have such an adverse effect on humans and as such can act as an alternative to liquid coolant in machining (Jin & Li2012).Application of several gasses (oxygen, nitrogen and carbon dioxide) in turning of AISI1040 steel with carbide tool, resulting in lower cutting force when compared to dry and wet machining. The surface roughness value in all gasses was found almost equal (Çakir et al 2004).In turning of super duplex stainless steel with uncoated carbide tool compared with dry, wet and CO_2 gas cooled machining. It was found that CO_2 gas cooled machining is an excellent alternative to conventional dry machining and wet machining. By using liquid CO_2 gas is another way to avoid the disposal of conventional cutting fluid (Senthil kumar K, & Senthilkumar 2013).

The most of the researchers deals with UNS S32750 alloy known commercially as SAF2507. However, there are no previous studies in the literature about specific surface roughness, cutting temperature and tool wear values for super duplex stainless steel UNS S32760 grade in turning operation. The chemical composition of UNS S32760 and UNS S32750 are similar, however, the latter contains somewhat more tungsten and copper. The copper content minimum of 0.5, Maximum of 1.0 permits excellent corrosive resistance in many mineral acids and non-oxidizing like hydrochloric and sulfuric acid environment. In this research about the experimentally investigated the turning of super duplex stainless steel UNS S32760 in CNC lathe machine with (Al,Ti)N coated carbide tools under various conditions like dry, nitrogen gas cooled environment and MQL in vegetable oil (Acculube LB 2000).The effects of cutting speed and feed rate on surface roughness, cutting temperature and tool wear were studied**.**

Materials and methods

The workpiece material used in the turning test was UNS S32760 super duplex stainless steel. UNS S32760 is developed to be used in aggressive environments like offshore and marine applications. Properties of UNS S32760 include high strength, toughness, corrosion resistance in a large number of inorganic and organic acids environment. The Material was supplied by Nexus steel, Mumbai, India as a circular rod having a diameter of 32 mm and a length of 150 mm. The chemical composition and mechanical properties of UNS S32760 SDSS are mentioned in table 1 and the mechanical properties of UNS S32760 SDSS are mentioned in table 2.

Table 1. Chemical composition of ASME SA276 Grade UNS S32760 SDSS (wt%)

Alloy	C	Si	Mn	P	S	Cr	Ni	Mo	CU	W	N	Fe
UNS S32760	0.021	0.32	0.58	0.017	0.006	25.49	6.43	3.47	0.62	0.61	0.24	Balance

Table 2. Mechanical properties of ASME SA276 grade UNS S32760 SDSS

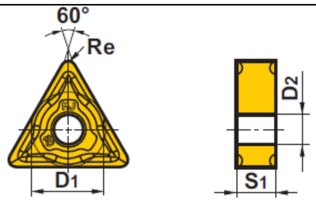
Alloy	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Hardness (HB)
UNS S32760	871.20	682.28	36.77	216

Experimental setup

The turning test were conducted on Jyothi CNC lathe DX 200 machine with a power rating of 7.5 kw. The experimental setup is shown in the figure 1. In this study, CVD type TNMG MJ 160408 (Al,Ti)N coated carbide tool mitsubishi make used in the experimental work. six cutting edges available for the stated insert. For single trial run each cutting edge was used. MQL system - Doml 1500 mist lubrication supplied by Dropco Multilub Systems Private Limited, harayana, India. The surface roughness was measured using a SJ – 210 Surface Roughness tester (mitutoyo make). The cutting temperature was measured by Perfect prime TC41, 4-Channel K type Thermocouple. The tool wear was measured using Scanning electron microscope (SEM - JEOL make, model: JSM 6390). The experimental conditions are shown in the table 3.

Figure 1. Machining setup with MQL system

TABLE 3: Experimental conditions

Work piece Material and size	Super duplex stainless steel UNS S32760 (Ø32mm x 150mm length)
Cutting Inserts	TNMG MJ 160408 (Al,Ti)N coated carbide tool
Tool insert Dimensions	 D1 = 9.525mm S1 = 4.76mm Re = 0.8mm D2 = 3.81mm
Tool holder	2525 MCJNL M16 – Widax make
Turning process parameters	Cutting speed (m/min) - 75, 100, 125 Feed rate (mm/rev) - 0.05, 0.1, 0.15 Depth of cut (mm) - 1 (constant)
Environments	i) Dry condition ii) Gas cooling (Nitrogen gas – 5bar) iii) MQL cooling (Vegetable oil Acculube LB 2000 – 5bar), Flow rate: 150 ml/hr

Experimental Procedure

This experimental work is designed using Taguchi's (L9 orthogonal array) design of experiment method. This research work was carried out in M/S Essarr Engineering, Coimbatore, India. The experimental results were analyzed using the signal to noise ratio (S/N ratio) and analysis of variance (ANOVA). The study of signal to noise ratio (S/N ratio) is used to determine the optimal machining conditions. The ANOVA analysis is used to determine the percentage contribution of the cutting speed and feed rate on surface roughness, cutting temperature and tool wear in dry, nitrogen gas cooled and MQL machining. The cutting parameters and their levels are shown in the table 4 and the experimental layout using Taguchi's L9 orthogonal array are shown in the table 5.

Table 4. Cutting parameters and their levels.

Symbol	Cutting parameters	Level 1	Level 2	Level 3
V	Cutting speed (m/min)	75	100	125
F	Feed rate (mm/rev)	0.05	0.15	0.25

Table 5 Experimental layout using Taguchi's L9 orthogonal array.

Experimental number	Cutting parameter Level	
	Cutting Speed (m/min)	Feed Rate (mm/rev)
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

Taguchi Approach

Analysis of the S/N ratio

The S / N ratio is the ratio of mean and standard deviation. It is used to measure characteristics of quality which deviate from the desired value. The S/N ratio (η) is given by the following equation discussed by (Philip Selvaraj et al.2014 and Yang and Tarng 1998).

$$\eta = -\log(\mathrm{M.S.D}) \tag{1}$$

Here, for the output characteristic M.S.D is the mean square deviation. To obtain optimal cutting parameter, the smaller is better quality characteristic for surface roughness, cutting temperature and tool wear must be taken. The following equations will give the M.S.D. for the smaller is better quality characteristic of surface roughness, cutting temperature and tool wear (Philip Selvaraj et al.2014 and Yang and Tarng 1998).

$$M.\mathrm{S.D} = \frac{1}{m}\sum_{i=1}^{m} R_i^2 \tag{2}$$

$$\boldsymbol{M}.\mathrm{S.D} = \frac{1}{m}\sum_{i=1}^{m} C_i^2 \tag{3}$$

$$\boldsymbol{M}.\mathrm{S.D} = \frac{1}{m}\sum_{i=1}^{m} T_i^2 \tag{4}$$

Here, m is the number of tests, Ri, Ci and Ti are the values of the surface roughness, cutting temperature and tool wear, respectively for the ith test. To predict and verify the quality characteristic at the optimal level, the calculated S / N ratio (η) was used. The calculated S / N ratio (η) can be determined by the following equation at the optimal level of the design parameters (Philip Selvaraj et al.2014 and Yang and Tarng 1998).

$$\hat{\eta} = \eta_m + \sum_{i=1}^{0}(\eta_i - \eta_m) \quad (5)$$

Analysis of the variance

ANOVA is performed to identify design parameters which have a significant affect on the response. The total sum of the square deviations (SST) is determined using the following equation (Philip Selvaraj et al.2014 and Yang and Tarng 1998).

$$SS_T = \sum_{i=1}^{n}(\eta_i - \eta_m)^2 \quad (6)$$

In this case, n is the number of experiments, ηi is the mean S/N ratio for the ith experiment and ηm is the total mean S/N ratio. The two sources of the SST are the sum of the squared deviations (SSd) due to each design parameter and the sum of the squared error (SSe).

Results and discussions

The experimental results of surface roughness, cutting temperature and tool wear with their corresponding S/N ratio are shown in the table 6-8, respectively for dry machining, nitrogen gas cooled machining and MQL machining of SDSS UNS S32760. In the table 9-10, the mean S/N ratio for cutting speed at level 1 is determined by averaging the S/N ratios for the experiments 1– 3. The mean S/N ratio for feed rate at level 1 is determined by averaging the S/N ratios for the experiments 1, 4 and 7. Likewise the mean S / N ratio is measured at levels 2 and 3 for cutting speed and feed rate.

S/N ratio

The S/N response table for surface roughness, cutting temperature and tool wear of dry machining, nitrogen gas cooled machining and MQL machining of SDSS UNS S32760 are shown in the table 9,10 and 11 respectively.

Table 6. Experimental results for surface roughness and S/N ratio of dry, nitrogen gas cooled, MQL machining conditions.

S.No	Cutting Speed (m/min)	Feed rate (mm/rev)	Surface roughness Ra (µm)			S/N ratio (dB)		
			Dry	Nitrogen gas cooled	MQL	Dry	Nitrogen gas cooled	MQL
1	75	0.05	1.37	1.21	0.72	-2.72	-1.68	2.82
2	75	0.15	2.08	1.61	0.91	-6.37	-4.11	0.80
3	75	0.25	2.39	1.90	0.98	-7.56	-5.59	0.16
4	100	0.05	1.18	1.10	0.56	-1.40	-0.80	5.07
5	100	0.15	1.65	1.43	0.65	-4.37	-3.09	3.81
6	100	0.25	2.08	1.67	0.86	-6.38	-4.48	1.29
7	125	0.05	1.27	1.11	0.63	-2.07	-0.88	3.96
8	125	0.15	1.98	1.62	0.88	-5.95	-4.21	1.09
9	125	0.25	2.50	1.78	1.06	-7.95	-5.00	-0.52

Table 7. Experimental results for cutting temperature and S/N ratio of dry, nitrogen gas cooled, MQL machining conditions.

S.No	Cutting Speed (m/min)	Feed rate (mm/rev)	Cutting Temperature (^{o}C)			S/N ratio (dB)		
			Dry	Nitrogen gas cooled	MQL	Dry	Nitrogen gas cooled	MQL
1	75	0.05	210	175	154	-46.44	-44.86	-43.75
2	75	0.15	224	182	160	-47.00	-45.20	-44.08
3	75	0.25	245	194	17	-47.78	-45.76	-

					2			44.71
4	100	0.05	264	206	181	-48.43	-46.28	-45.15
5	100	0.15	283	213	187	-49.04	-46.57	-45.44
6	100	0.25	317	229	200	-50.02	-47.20	-46.02
7	125	0.05	338	230	203	-50.58	-47.23	-46.15
8	125	0.15	362	239	211	-51.17	-47.57	-46.49
9	125	0.25	398	265	220	-52.00	-48.46	-46.85

Table 8. Experimental results for tool wear and S/N ratio of dry, nitrogen gas cooled, MQL machining conditions.

S.No	Cutting Speed (m/min)	Feed rate (mm/rev)	Tool wear (µm)			S/N ratio (dB)		
			Dry	Nitrogen gas cooled	MQL	Dry	Nitrogen gas cooled	MQL
1	75	0.05	152	110	82	-43.64	-40.83	-38.28
2	75	0.15	165	118	89	-44.35	-41.44	-38.99
3	75	0.25	183	123	95	-45.25	-41.80	-39.55
4	100	0.05	197	140	108	-45.89	-42.92	-40.67
5	100	0.15	253	168	131	-48.06	-44.51	-42.35
6	100	0.25	302	179	146	-49.60	-45.06	-43.29
7	125	0.05	429	231	162	-52.65	-47.27	-44.19
8	125	0.15	504	258	179	-54.05	-48.23	-45.06
9	125	0.25	580	273	194	-55.27	-48.72	-45.76

Table 9. S/N response table for surface roughness, cutting temperature and tool wear for dry machining of SDSS UNS S32760.

Cutting Parameter	Mean S/N Ratio (dB)			Max-min
	Level 1	Level 2	Level 3	
Surface Roughness				
Cutting Speed	-5.55	-4.05	-5.32	1.50
Feed rate	-2.06	-5.56	-7.29	5.23
Cutting Temperature				
Cutting Speed	-47.08	-49.16	-51.25	4.17
Feed rate	-48.48	-49.07	-49.93	1.45
Tool Wear				
Cutting Speed	-44.41	-47.85	-53.99	9.58
Feed rate	-47.39	-48.82	-50.04	2.65

Table 10. S/N response table for surface roughness, cutting temperature and tool wear for nitrogen gas cooled machining of SDSS UNS S32760.

Cutting Parameter	Mean S/N Ratio (dB)			Max-min
	Level 1	Level 2	Level 3	
Surface Roughness				
Cutting Speed	-3.79	-2.79	-3.36	1.00
Feed rate	-1.11	-3.80	-5.02	3.90
Cutting Temperature				
Cutting Speed	-45.27	-46.68	-47.76	2.49
Feed rate	-46.12	-46.45	-47.14	1.02
Tool Wear				
Cutting Speed	-41.35	-44.16	-48.08	6.73
Feed rate	-43.67	-44.73	-45.19	1.52

Table 11. S/N response table for surface roughness, cutting temperature and tool wear for MQL machining of SDSS UNS S32760.

Cutting Parameter	Mean S/N Ratio (dB)			Max-min
	Level 1	Level 2	Level 3	
Surface Roughness				
Cutting Speed	1.25	3.38	1.50	2.13
Feed rate	3.94	1.89	0.30	3.63
Cutting Temperature				
Cutting Speed	-44.18	-45.52	-46.49	2.31
Feed rate	-45.02	-45.33	-45.86	0.84
Tool Wear				
Cutting Speed	-38.94	-42.1	-45	6.06
Feed rate	-41.05	-42.13	-42.87	1.82

Surface Roughness

The S/N response graph for surface roughness of dry machining, Nitrogen gas cooled and MQL machining is showed in Fig. 2. In the S/N response graph, V1 stands for cutting speed at level 1 (75 m/min), V2 stands for cutting speed at level 2 (100 m/min), V3 stands for cutting speed at level3 (125 m/min), F1 stands for feed rate at level 1 (0.05 mm/ rev), F2 stands for feed rate at level 2 (0.15 mm/rev) and F3 stands for feed rate at level 3 (0.25 mm/rev). The greater S / N ratio corresponds to the smaller variance of the characteristic of the output around the desired value. From Fig. 2, the higher S/N ratio for surface roughness in dry machining, Nitrogen gas cooled machining and MQL machining is obtained at cutting speed level 2 and feed rate level 1. Therefore, the optimal cutting parameters for surface roughness in dry machining, Nitrogen gas cooled machining and MQL machining are the cutting speed at level 2 (100 m/min) and the feed rate at level 1 (0.05 mm/rev).

Cutting Temperature

The S/N response graph for cutting temperature in dry machining, Nitrogen gas cooled machining and MQL machining of SDSS UNS S32760 is shown in the Fig.3. From Fig.3, the higher S/N ratio for cutting temperature in dry machining, Nitrogen gas cooled machining and MQL machining of SDSS UNS S32760 are attained at cutting speed level 1and feed rate level 1. Therefore, the optimal cutting parameters for the cutting temperature are the cutting speed at level 1 (75 m/min) and the feed rate at level 1 (0.05 mm/rev).

Tool wear

The S/N response graph for tool wear in dry machining, Nitrogen gas cooled machining and MQL machining of SDSS UNS S32760 is shown in the Fig.4. From Fig.4, the higher S/N ratio for tool wear in dry machining, Nitrogen gas cooled machining and MQL machining of SDSS UNS S32760 are attained at cutting speed level 1and feed rate level 1. Therefore, the optimal cutting parameters for the tool wear is the cutting speed at level 1 (75 m/min) and the feed rate at level 1 (0.05 mm/rev). The machining zone at different environment condition at shown in the fig 5.

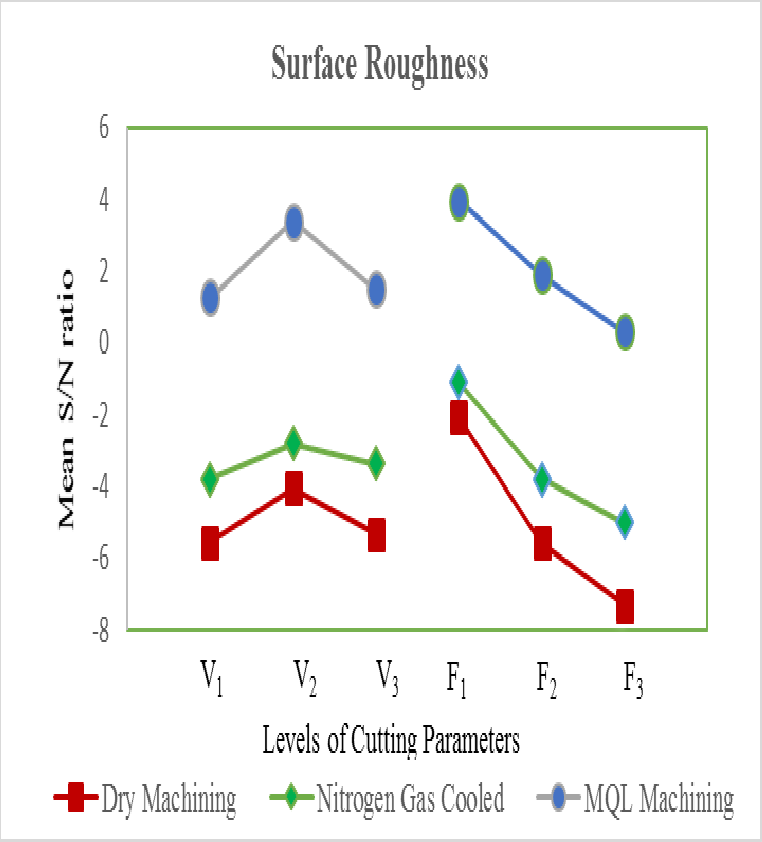


Fig. 2. S/N graph for surface roughness of dry machining, Nitrogen gas cooled machining and MQL machining of SDSS UNS S32760.

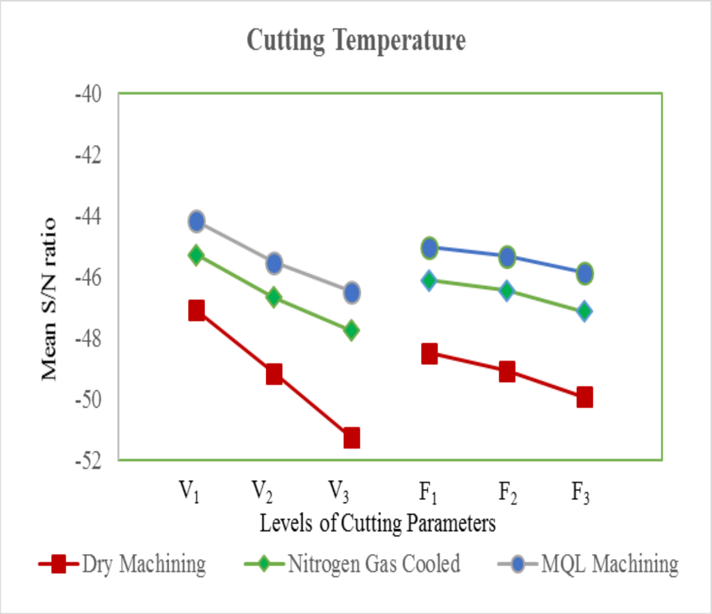


Fig. 3. S/N graph for cutting temperature of dry machining, nitrogen gas cooled and MQL machining of SDSS UNS S32760.

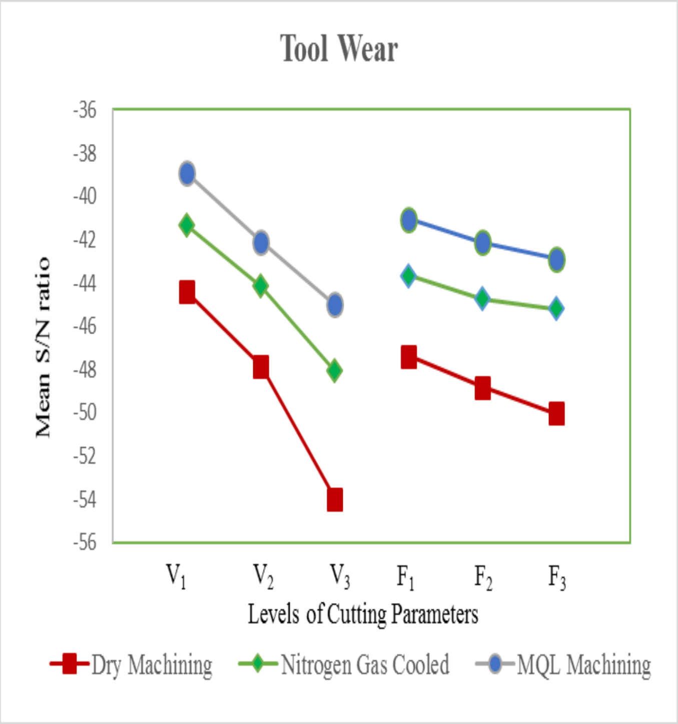
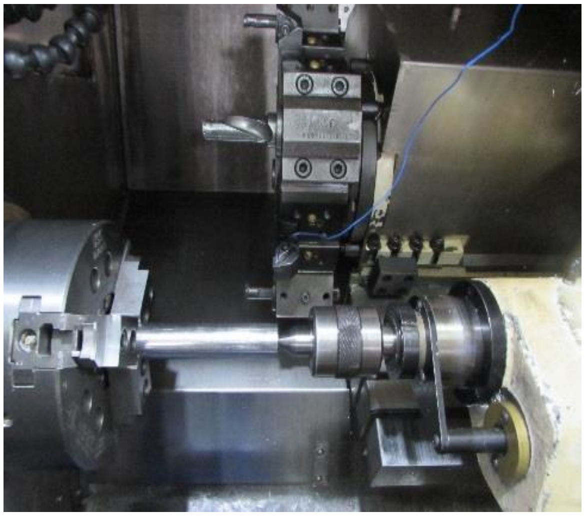
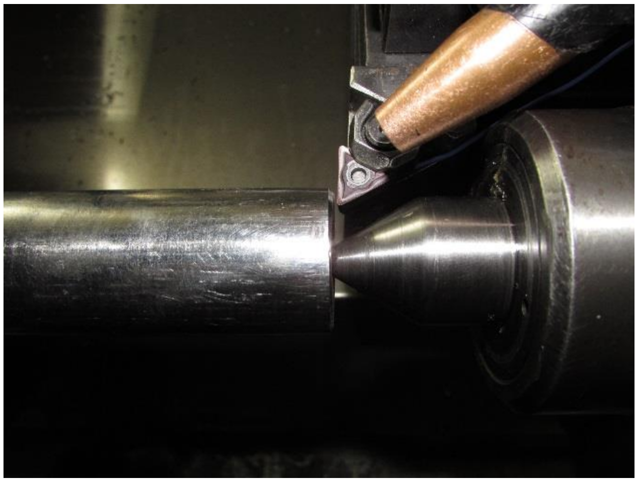


Fig. 4. S/N graph for tool wear of dry machining, nitrogen gas cooled and MQL machining of SDSS UNS S32760.



(A)

(b)



C

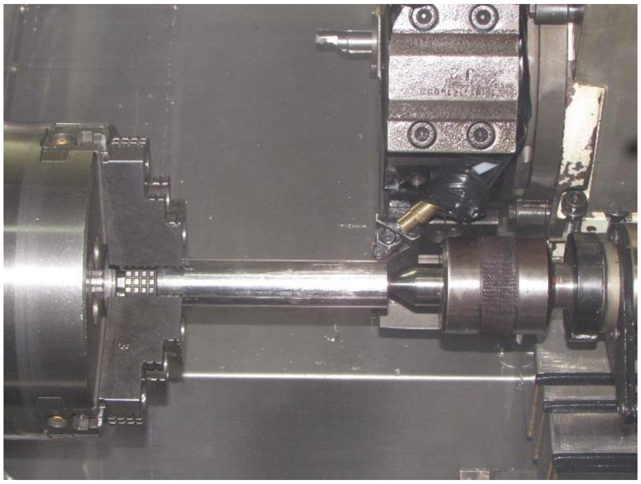


Fig 5. Machining zone at different environment condition
(a) Dry (b) Nitrogen Gas cooled (c) MQL condition

ANOVA results

Dry Machining

Similarly, Table 11 shows that the ANOVA results of surface roughness, cutting temperature and tool wear in dry machining of SDSS UNS S32760. The feed rate has been found to be the more significant cutting parameter affecting the surface roughness. The cutting parameters that influencing the surface roughness are feed rate followed by cutting speed. The results of ANOVA showed that cutting speed and feed rate are affecting the surface roughness in dry machining of SDSS UNS S32760 by approximately 9.16% and 88.87%, respectively. It was observed that the cutting speed is the more significant factor and the feed rate is the less significant factor affecting the cutting temperature and tool wear. The cutting speed and feed rate affect the cutting temperature and tool wear in dry machining of SDSS UNS S32760 by approximately 88.32%, 11.15% and 91.41 and 6.76% respectively.

Table 11. Results of the ANOVA for surface roughness, cutting temperature and tool wear for dry machining of SDSS UNS S32760.

Cutting Parameter	Degrees of freedom	Sum of Squares	Mean Square	F ratio	Contribution (%)
Surface roughness					
Cutting Speed	2	0.17400	0.086998	9.37	9.166
Feed rate	2	1.68705	0.843524	90.84	88.87
Error	4	0.03714	0.009285		1.95
Total	8	1.89819			100
Cutting Temperature					
Cutting Speed	2	29393.6	14696.8	342.23	88.32
Feed rate	2	3714.9	1857.4	43.25	11.15
Error	4	171.8	42.9		0.516
Total	8	33280.2			100

Tool Wear					
Cutting Speed	2	185422	92710.8	100.83	91.41
Feed rate	2	13728	6864.1	7.47	6.76
Error	4	3678	919.4		1.81
Total	8	202828			100

Nitrogen gas cooled machining

Similarly, Table 12 shows that the ANOVA results of surface roughness, cutting temperature and tool wear in nitrogen gas cooled machining of SDSS UNS S32760. The feed rate has been found to be the more significant cutting parameter affecting the surface roughness. The cutting parameters that influencing the surface roughness are feed rate followed by cutting speed. The results of ANOVA showed that cutting speed and feed rate are affecting the surface roughness in nitrogen gas cooled machining of SDSS UNS S32760 by approximately 6.55% and 91.72%, respectively. It was observed that the cutting speed is the more significant factor and the feed rate is the less significant factor affecting the cutting temperature and tool wear. The cutting speed and feed rate affect the cutting temperature and tool wear in nitrogen gas cooled machining of SDSS UNS S32760 by approximately 83.26%, 15.51% and 94.19, 4.92% respectively.

Table 12. Results of the ANOVA for surface roughness, cutting temperature and tool wear for nitrogen gas cooled machining of SDSS UNS S32760.

Cutting Parameter	Degrees of freedom	Sum of Squares	Mean Square	F ratio	Contribution (%)
Surface roughness					
Cutting Speed	2	0.04593	0.022963	7.61	6.55
Feed rate	2	0.64300	0.321500	106.59	91.72
Error	4	0.01207	0.003016		1.72
Total	8	0.70099			100
Cutting Temperature					
Cutting Speed	2	5588.22	2794.11	136.67	83.26
Feed rate	2	1041.56	520.78	25.47	15.51
Error	4	81.78	20.44		1.21

Total	8	6711.56			100
Tool Wear					
Cutting Speed	2	29226.9	14613.4	215.61	94.19
Feed rate	2	1529.6	764.8	11.28	4.92
Error	4	271.1	67.8		0.87
Total	8	31027.6			100

MQL Machining

Similarly, Table 13 shows that the ANOVA results of surface roughness, cutting temperature and tool wear in MQL machining of SDSS UNS S32760. The feed rate has been found to be the more significant cutting parameter affecting the surface roughness. The cutting parameters that influencing the surface roughness are feed rate followed by cutting speed. The results of ANOVA showed that cutting speed and feed rate are affecting the surface roughness in MQL machining of SDSS UNS S32760 by approximately 26.30% and 68.11%, respectively. It was observed that the cutting speed is the more significant factor and the feed rate is the less significant factor affecting the cutting temperature and tool wear. The cutting speed and feed rate affect the cutting temperature and tool wear in MQL machining of SDSS UNS S32760 by approximately 87.96%, 11.92% and 90.10, 8.59% respectively.

Table 13. Results of the ANOVA for surface roughness, cutting temperature and tool wear for MQL machining of SDSS UNS S32760.

Cutting Parameter	Degrees of freedom	Sum of Squares	Mean Square	F ratio	Contribution (%)
Surface roughness					
Cutting Speed	2	0.06327	0.031633	9.42	26.30
Feed rate	2	0.16386	0.081930	24.41	68.11
Error	4	0.01343	0.003357		5.58
Total	8	0.24055			100
Cutting Temperature					
Cutting Speed	2	3664.89	1832.44	1649.20	87.966

Feed rate	2	496.89	248.44	223.60	11.92
Error	4	4.44	1.11		0.10
Total	8	4166.22			100
Tool Wear					
Cutting Speed	2	12113.6	6056.78	138.35	90.10
Feed rate	2	1154.9	577.44	13.19	8.59
Error	4	175.1	43.78		1.30
Total	8	13443.6			100

Comparison between dry, nitrogen gas cooled and MQL turning operation

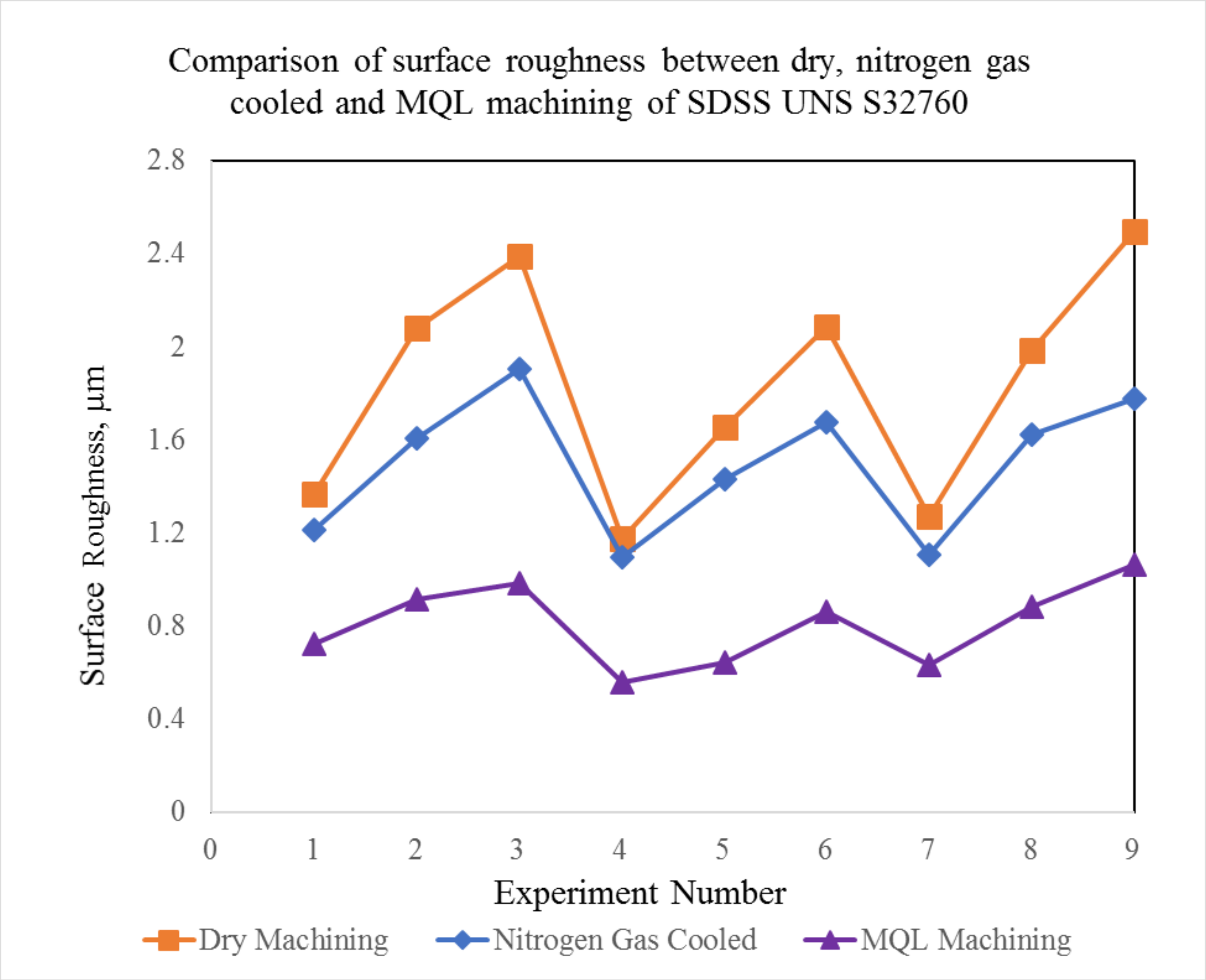


Fig 6. Comparison of surface roughness between dry, nitrogen gas cooled and MQL machining of SDSS UNS S32760

The comparison of surface roughness in dry, nitrogen gas cooled and MQL machining during turning of SDSS UNS S32760 are depicted in the fig 6. The result reveals that surface roughness of nitrogen gas cooled machining and MQL machining reduced by about 6-28% and 47-61% respectively compared to dry machining.

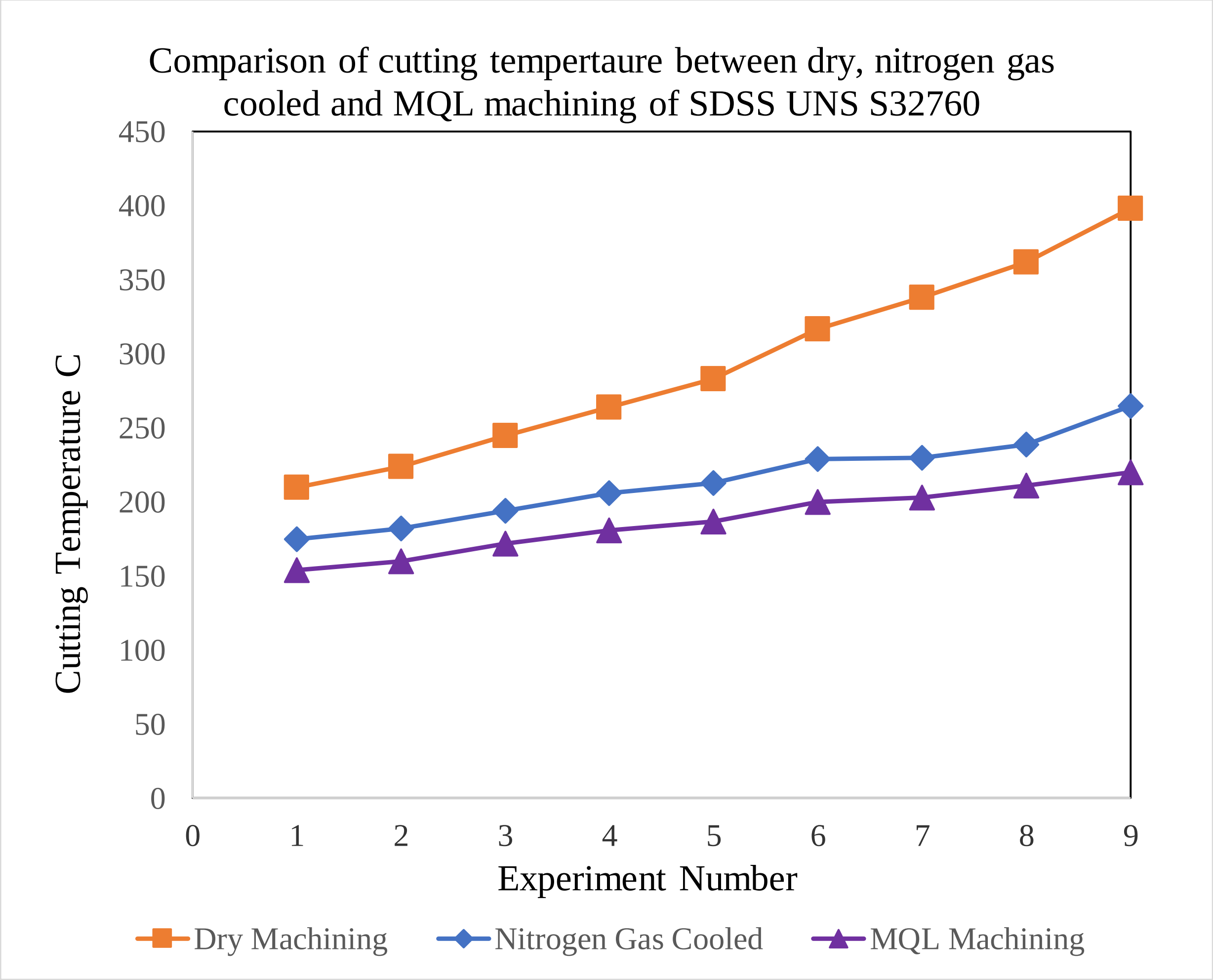


Fig 7. Comparison of cutting temperature between dry, nitrogen gas cooled and MQL machining of SDSS UNS S32760

The comparison of cutting temperature in dry, nitrogen gas cooled and MQL machining during turning of SDSS UNS S32760 are depicted in the figure. The result reveals that cutting temperature of nitrogen gas cooled machining and MQL machining reduced by about 16-33% and 31-44% respectively compared to dry machining.

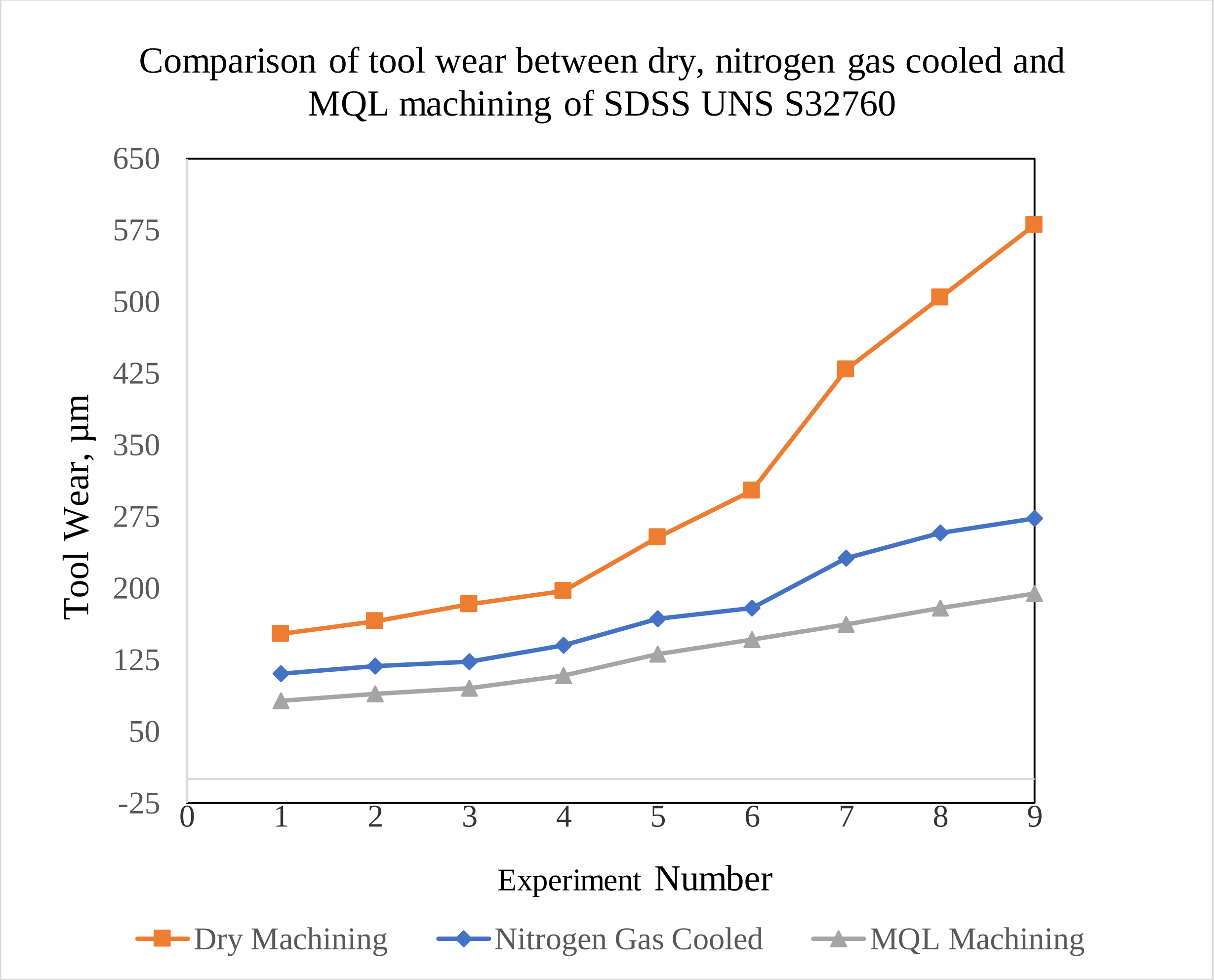
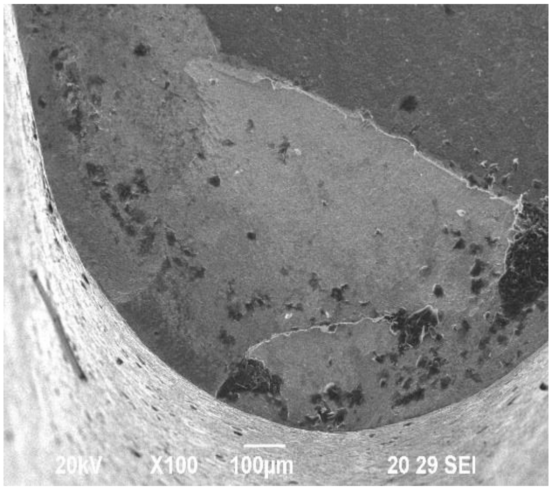


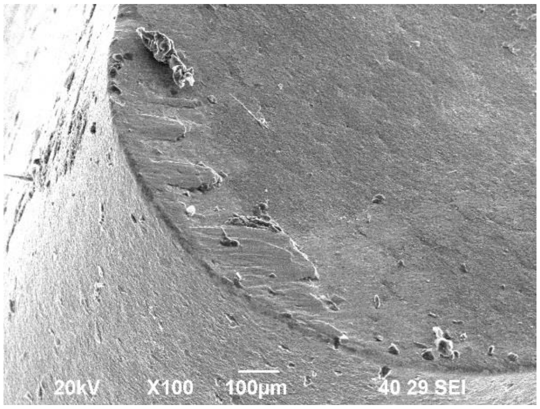
Fig 8. Comparison of tool wear between dry, nitrogen gas cooled and MQL machining of SDSS UNS S32760

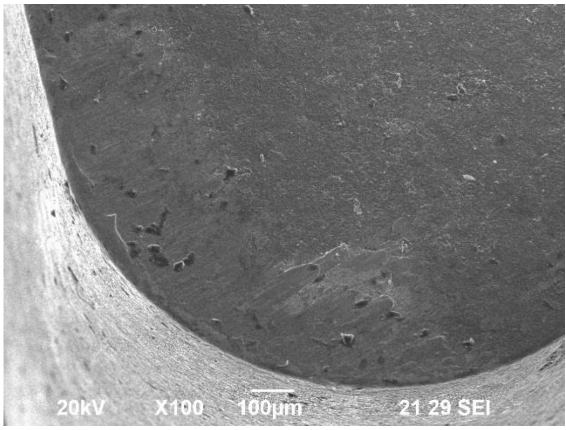
The comparison of tool wear in dry, nitrogen gas cooled and MQL machining during turning of SDSS UNS S32760 are depicted in the fig 8. The result reveals that tool wear of nitrogen gas cooled and MQL machining reduced by about 27-52% and 45-66% respectively compared to dry machining. The SEM images of tool wear is shown in the fig 9.


20kV
X100
100μm
20 29 SEI

(a)

(b)


20kV
X100
100μm
40 29 SEI


20kV
X100
100μm
21 29 SEI

C

Fig 9. Sem images of tool inserts at v 100 = m/min, f = mm/rev, (a) dry machining, (b) Nitrogen gas cooled machining, (c) MQL machining.

CONCLUSIONS

Based on the Taguchi analysis is used to identify the optimal cutting parameters in dry machining, Nitrogen gas cooled and MQL machining in turning of SDSS UNS S32760. This research presents the following specific conclusions.

A cutting speed of 100 m/min and a feed rate of 0.05 mm/rev are found to give the better surface roughness in dry, Nitrogen gas cooled and MQL machining in turning of SDSS UNS S32760. A cutting speed of 75 m/min and feed rate 0.05 mm/rev are found to give the lowest cutting temperature and tool wear in dry, Nitrogen gas cooled and MQL machining.

ANOVA analysis showed that cutting speed and feed rate are affecting the surface roughness in dry machining of SDSS UNS S32760 by approximately 9.16% and 88.87%, respectively. The cutting speed and feed rate affect the cutting temperature and tool wear in dry machining by approximately 88.32%, 11.15% and 91.41, 6.76% respectively

ANOVA analysis showed that cutting speed and feed rate are affecting the surface roughness in nitrogen gas cooled machining of SDSS UNS S32760 by approximately 6.55% and 91.72%, respectively. The cutting speed and feed rate affect the cutting temperature and tool wear in nitrogen gas cooled machining by approximately 83.26%, 15.51% and 94.19, 4.92% respectively.

The results of ANOVA showed that cutting speed and feed rate are affecting the surface roughness in MQL machining of SDSS UNS S32760 by approximately 26.30% and 68.11%, respectively. The cutting speed and feed rate affect the cutting temperature and tool wear in MQL machining by approximately 87.96%, 11.92% and 90.10, 8.59% respectively.

The result shows that surface roughness of nitrogen gas cooled machining and MQL machining reduced by about 6-28% and 47-61% respectively compared to dry machining. The result reveals that cutting temperature of nitrogen gas cooled machining and MQL machining reduced by about 16-33% and 31-44%

respectively compared to dry machining**.** The result shows that tool wear of nitrogen gas cooled and MQL machining reduced by about 27-52% and 45-66% respectively compared to dry machining.

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