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Experimental investigation of different cutting conditions in turning of Inconel 718

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Abstract. Metal cutting or machining is a backbone of manufacturing industries. During metal cutting process heat generated has to be removed with cutting fluid. Commonly used cutting fluid is hydrocarbon oil based but it contributes to environmental imbalance and the ill health of the operator. Solid lubrication is a good alternative to conventional cutting fluid. Turning process is carried out on Inconel 718 in the present work with solid lubricants filled in parallel, perpendicular and cross direction textured cutting inserts. The two solid lubricants used are Molybdenum Disulfide (MoS_2) and Tungsten Disulphide (WS_2).Taguchi L9 orthogonal array is used to perform experiments and Analysis of Variance (ANOVA) method is used to identify the effect of each process parameter on the output. Solid lubricants are inherently solid as lubricant material but will become smooth due to frictional heat at point of contact. The result uncovered that a persistent film of solid lubricant is formed on the facet of the tool because of the heat produced due to thermal expansion. This film layer may knock down the friction in the machining zone. Among all, perpendicular direction textured cutting inserts have reduced friction and good surface finish is obtained. Compared with MoS_2, WS_2 has shown better results in terms of surface finish.

1. Introduction

It is a known fact that large amount of heat is generated between tool and work piece during machining process. Coolant is used to enhance the cutting conditions and traditional one is hydrocarbon oil based. This will result in deteriorating the operator’s health and environmental imbalance [1]. Some other alternative methods are also available such as dry machining, Minimum Quantity Lubrication (MQL), vegetable oil as cutting fluid, cryogenically treated tool and solid lubricants. Few drawbacks with alternative methods namely, dry machining affects metallurgical changes and releases more heat, vegetable oil depends on its properties, Cryogenic treatment and MQL method need special equipment [2-4].One among the simplest and safest substitute to conventional cutting fluid is solid lubrication. In order to reduce the friction coefficient and contribute to sustainability in machining, texturing on cutting tool is used. As solid lubricant is applied on the textured tool a noticeable reduction in cutting zone temperature, friction and machining forces is observed because a continuous solid lubricant film is produced on tool. This is due to the thermal expansion of heat produced during machining [5].Various types of solid lubricants are explored by different researchers [6-9].

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2. Literature review

Song et al.[10] compared traditional cutting tool with graphite-filled textured tool and concluded that graphite-embedded tool showed lower coefficient of friction, decreased rake face wear and also improved surface quality of the work piece. Song *et al*. [11**]** used micro hole textured tool with CaF_2 powder burnished into the micro holes and studied the wear and friction characteristics of tool and result reported that CaF_2 filled textured tool performed better at higher temperatures. Lei *et al.*[12] has studied the friction force and friction coefficient of micro dimple, micro groove and flat texture on rake face of cutting tool with oil, solid lubricant (tungsten disulphide) and dry machining. The result showed that when machining is done with textured cutting tools with lubrication, the cutting force, friction coefficient and tool-chip contact area were reduced. In order to assess machining zone temperature, machining force and chip morphology. By machining Ti-6Al-4V alloy with MoS2 and SAE 40 oil as semi solid lubricant, arulkirubakaran et al.[8] has explored different textures that is parallel, perpendicular and cross-textured groves on the rake face of tool insert. The results showed that the perpendicular texture cutting insert worked well.

Sharma et al. [9] stated that hybrid textured tool with CaF_2 as solid lubricant has reduced machining forces and tool chip contact length in comparison with cutting inserts with cross, parallel and multiple textured cutting insert. Textured tools performed better than plain tools. By blending nano solid lubricants with sesame oil and coconut oil separately, Padmini et al.[13] conducted turning operations on AISI 1040 steel, resulting in nano solid lubricants with coconut oil showing better results in reducing surface roughness, instrument flank wear, cutting forces, and cutting temperature compared to sesame oil. Yilmaz et al. [14] used the external chip breaker to split the continuous chip when Inconel 718 was being machined and stated that the machining output was improved by the external chip breaker.

The literature concludes that textured tools with solid lubricant are used to remove traditional flood cooling during cutting. To research their efficiency during machining, few researchers have used micro pit, micro groove, parallel, perpendicular and cross textured cutting inserts along with solid lubricants. In the present study the effort has been taken for parallel, perpendicular cross direction textured inserts with two solid lubricants (MoS_2 and WS_2) and their performance on surface roughness is analyzed.

3. Experimental Setup

Inconel 718 is considered as work piece material which is widely used where high temperature and corrosion resistance are required. Turning process is performed on 25mm in diameter with 45mm in length. CNC turning centre is used to perform the turning process. Uncoated tungsten carbide tool is used as cutting insert. Wire EDM is used to make texture on rake face of cutting tool insert. Figure 1 shows the tungsten carbide cutting tool with parallel, perpendicular and cross direction texture. Process parameters with different levels are given in table 1. Experiments are conducted using Taguchi L_9 orthogonal array [15]. Turning process is carried out at a constant depth of 0.6mm.The solid lubricants used in this work are molybdenum disulphide and tungsten disulphide, combined with coconut oil at a ratio of 80 to 20 by weight. Figure 2 shows the machined samples.

Table 1. Process parameter and levels

Symbol	Process parameters	Level 1	Level 2	Level 3
A	Texture pattern	Parallel	Perpendicular	Cross
B	Machining speed(m/min)	91	115	139
C	Feed rate(mm/rev)	0.1	0.15	0.2

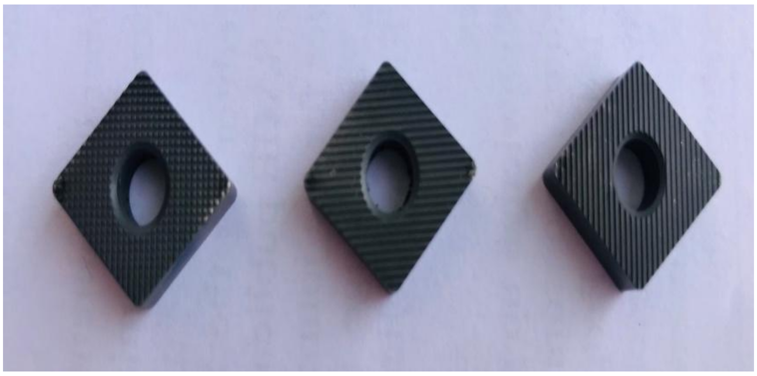

Figure 1. Tungsten carbide cutting tools with different texture

Figure 2. Machined samples & surface roughness tester

For measuring surface roughness, the Mitutoyo SJ-210 surface roughness tester is used. The average surface roughness (R_a) is measured for three times on each machined work piece and the average values are used for further studies. Surface roughness is an imperative machinability characteristic.

Table 2: Experimental results

S. No	Texture pattern	Machining speed (m/min)	Feed rate (mm/rev)	MoS_2 Surface roughness (μm)	WS_2 Surface roughness (μm)
1	parallel	90	0.1	1.18	0.52
2	parallel	115	0.15	1.84	1.08
3	parallel	139	0.2	1.611	1.011
4	Perpendicular	90	0.15	1.37	0.61
5	Perpendicular	115	0.2	1.8	1.04
6	Perpendicular	139	0.1	1.15	0.39
7	Cross	90	0.2	1.65	0.89
8	Cross	115	0.1	1.7	0.97
9	Cross	139	0.15	2.3	1.34

4. Methodology

The Taguchi approach includes orthogonal array, Signal-to-Noise (S/N) ratio and ANOVA method [16]. The orthogonal array is the best statistical tool for design of experiments that minimize the number of tests, which in turn cut down the time of the experimentation and the cost. Moreover, it is also possible to observe the effect of each process parameter on the response [17] for which ANOVA method is used. The Signal-to-Noise (S/N) ratio will estimate the eccentricity between the experimental and actual value.
Steps involved in Taguchi method

1. Selection of quality characteristics

The quality characteristic considered in this work is surface roughness.

2. Identifying factors and levels

Texture type, cutting speed and feed rate are identified as process parameters that is factors with three levels

3. Choosing the orthogonal array

Three levels of process parameters are selected, hence minimum experiments are required as per L_9.

4. Perform the experiments

Experiments are done according to L_9 orthogonal array recommendation.

5. Computation of S/N ratio

Equations (1) and (2) are used to analyze the results for maximization and minimization of output parameters respectively.

Larger-the-better

$$S/N = -10log_{10}\left(\frac{1}{n}\right)\sum_{i=1}^{n}\frac{1}{{y_{ij}}^2} \quad (1)$$

Smaller-the-better

$$S/N = -10log_{10}\left(\frac{1}{n}\sum_{1=1}^{n}{y_{ij}}^2\right) \quad (2)$$

Table 3: S/N ratio values

S.no	Calculated S/N ratio for Surface Roughness	
	MoS_2	**WS_2**
1	-1.43764	5.67993
2	-5.29635	-0.66847
3	-4.14191	-0.09502
4	-2.73441	4.29340
5	-5.10545	-0.34066
6	-1.21395	8.17870
7	-4.34967	1.01219
8	-4.60897	0.26456

9	-7.23455	-2.54209

6. Analyze the results

Main effects plot are used to study the outcome of experiments and to predict the ideal combination of input process parameters for machining.

7. Confirmation experiments

To confirm the optimal process parameters obtained in the course of investigation, the confirmation tests are carried out.

5. Results and Discussion

In this research, conventional cutting fluid is arrested and solid lubrication is attempted. Solid lubricants used in this work include MoS_2 and WS_2. Process parameters are selected taking the pilot experiments and literature into consideration .The input parameters are the texture type, machining speed and feed rate whereas output parameters are average surface roughness (Ra). Using L_9 orthogonal array machining is done and results are provided in table 2. In this experimental analysis, average surface roughness is taken as output parameter of minimization form. Therefore, the smaller-the-best is selected to find ideal process parameters.

A thin lubricating layer is formed by textured inserts with solid lubricants at tool chip interface due to increase in temperature and is used to minimize friction and hence surface roughness [6, 7 and 18]. It is also noted that WS_2 has strong lubricating capacity, high temperature and oxidation resistance and is therefore not sensitive to higher cutting speeds and temperatures [19].This might be the reason for better surface finish of work piece when machined with WS_2 as solid lubricant than MoS_2 as solid lubricant. Parallel, perpendicular, cross and dimple texture are different textures available. Among these, to minimize friction and tool-chip contact duration during machining, perpendicular direction textures are used [20]. Due to these reason, acceptable surface finish is achieved with perpendicular direction textured cutting inserts. The S/N ratio values for surface roughness are given in table 3.

In current research feed rate is the major process parameter which is affecting the responses. The process parameter with the highest S/N ratio will always achieve the optimal output with minimal variance, regardless of the type of quality characteristic. Therefore, the level with the highest S/N ratio should be the optimal level of machining parameters. A2B1C1 is an optimum combination of process parameters for MoS_2 as solid lubricant and it is A2B2C3 for tungsten disulphide as solid lubricant obtained using Taguchi method in turning operation.

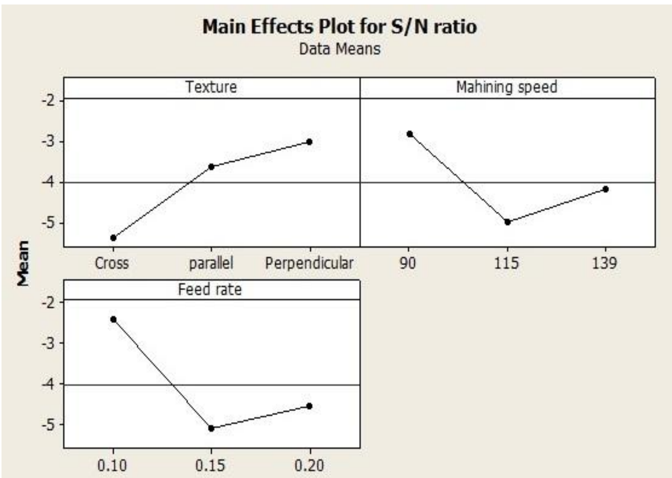

Figure 3. The main effect plots for average surface roughness when machined with MoS_2

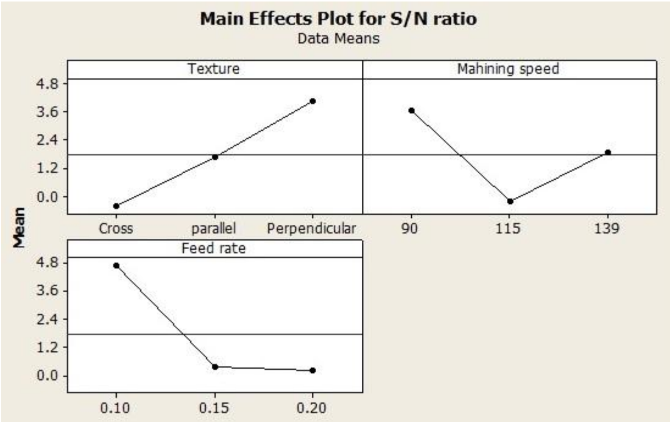

Figure 4. The main effect plots for average surface roughness when machined with WS_2

Table 4. Result of ANOVA for average surface roughness with when machined with MoS_2

Source of variation	DOF	Sum of Squares	Mean Square	F Ratio	Contribution %
Texture pattern	2	9.173859	4.586929	5.831431	30.77862
Machining speed	2	7.168916	3.584458	4.556974	24.05197
Feed rate	2	11.89	5.944998	7.557963	39.89136
Error	2	1.573175	0.786587		5.278057
Total	9-1=8	29.80595			

Table 5. Result of ANOVA for average surface roughness with when machined with WS_2

Source of variation	DOF	Sum of Squares	Mean Square	F Ratio	Contribution %
Texture pattern	2	29.97157	14.98579	5.184111	30.57126
Machining speed	2	22.972	11.486	3.973411	23.43163
Feed rate	2	39.31341	19.65671	6.799946	40.10001
Error	2	5.78143	2.890715		5.897107
Total	9-1=8	98.03841			

Taguchi technique determines the effect of individual parameters for entire process using ANOVA method. The ANOVA results of the average surface roughness for MoS_2 and WS_2 are shown in table 4 and 5. It is noticed that feed rate is affecting more on the responses and next is texture pattern in both solid lubrication conditions. The future work of this investigation is find multiple objectives like temperature, micro hardness, tool flank wear etc. Also, apply multi objective optimization procedure such as Taguchi based method, metahurastic method and MCDM methods [21-26].

6. Conclusions

The important conclusions obtained from this study are.

1. Textured cutting inserts with solid lubrication are best alternatives to traditional cutting fluid. Solid lubrication promotes sustainability in the turning process.
2. Solid lubricants have a low friction coefficient, and compared to molybdenum disulphide, tungsten disulphide provides minimal surface roughness.
3. Perpendicular textured tool with machining speed of 115 m/min and feed rate of 0.2 mm/rev is the ideal combination of input parameters.
4. From the ANOVA method it is seen that feed rate is effecting more on the response with a MoS_2 of 39.8 % and WS_2 solid lubricants of 40.1 %, followed by a perpendicular texture of 30.7 percent in MoS_2 and 30.5 % in tungsten disulphide solid lubricants condition.

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