Optimization of Machining Process Parameters of Al6061 alloy Subjected to Dry and Nano-fluid Assisted Minimum Quantity Lubrication Approach

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Abstract- Investigation of experimental machining process parameters has been on notice for several decades among researchers. Aluminium (Al) 6061 alloys have been widely used in the field of automobile and aerospace industries owing to exceptional characteristics. Surface finish and less tool wear for better productivity are prime requirements during machining processes. In most machining operations the main objective is the achievement of less surface roughness and tool wear. In this study, analysis has been performed for optimizing CNC machining process using Taguchi Method. We are analyzing the machine parameters and optimization of CNC machining employing Taguchi Method (L9 Orthogonal array); the parameters are cutting speed, feed rate and machining environment. We have considered three process parameters and their levels based on the analysis parameters which are affecting the machining process. For input machining process parameters experiments are designed using Taguchi L9 orthogonal standard array. For this purpose, MINITAB17 software is employed. While optimizing machining parameters lowest surface roughness (Ra) of 0.42310 µm was achieved corresponding to FR: 0.1 mm/rev, CS: 200 m/min. and Machining Environment: Groundnut oil/h-BN based nanofluid MQL-assisted machining.

Keywords - Al6061; Minimum quantity lubrication; Optimization: Machining; Surface finish.

I. INTRODUCTION

Surface finish and less tool wear for better productivity are prime requirements during machining processes. In most machining operations the main objective is the achievement of less surface roughness and tool wear. The higher value of surface roughness generates on the machining parts and due to rework or scrap results in an increase in cost and loss of productivity. Surface roughness and less tool wear are major factors in the modern CNC turning industry.

The purpose of this work is focused on the analysis of optimum cutting conditions to get the lowest surface roughness and less tool wear in CNC turning. To investigate the effect of cutting parameters like spindle speed, feed rate (FR) and depth of cut (DOC) on surface finish. Many researchers had worked to improve those responses. Additionally, in the design of experiments, the Taguchi method is being implemented to refine the outcome of the research being carried out.

There are many methods for optimization Viz. full factorial design, Response surface method, Taguchi method, etc. But the Taguchi method is one of the power full techniques for optimization which takes a minimum number of experiments.

The selection of cutting fluid depends upon the factors shown in **Figure 1.1**.

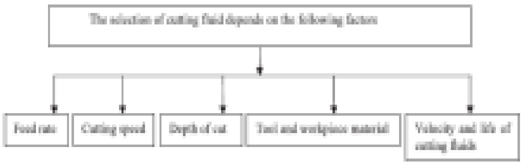

Fig 1.The selection of cutting fluid depends upon the following factors.

The primary functions of a cutting coolant are cooling and lubricating the workpiece in a machining process. Lubrication property in cutting coolant reduces the abrasion and adhesion at low CS as well as greases the contact areas between chips and tool rake face. Today vast variety of cutting fluids are available and the effectiveness of cutting fluid depends upon various factors such as cutting parameters, strategies for cutting fluid application and types of machining.

The properties of cutting fluids should not change within a range of pressure, temperature and time having the same stable chemical composition. For instance, cutting liquids must prevent corrosion between workpiece material and cutting tool as well as lubricating oil of slides and machine bearing. Cooling is one of the most important challenges in the machining process. High adhesion at high CS ranges, high thermal loads as well as the work hardening of the material present some other difficulties in machining. The conventional methods of enhancing the cooling rate have already reached their limits.

The use of novel approaches is essential in order to achieve high-performance cooling and lubrication. Nanofluids provide a potential way to fulfill this requirement. Nanofluids belong to the novel group of potential heat transfer fluids with superior thermophysical properties and heat transfer performance. Results of the latest research with nanofluids in machining show the promising performance of these fluids as a replacement for the conventional metalworking fluids when accompanied with the MQL techniques [1-3].

The excessive use of cutting fluid has negative effects on both the environment and the health of the operator. As a result, the earlier researchers used a proven technology called minimum quantity lubrication. Minimum quantity lubrication (MQL) can be considered a viable substitute for conventional flooded machining. In the MQL, a small amount of lubricant atomized in a compressed air flow is supplied to the cutting zone. Since the cooling capacity of the MQL flow largely depends on the airflow, a complete replacement of the flood cooling media with MQL is still considered complex and the scope of its application is still uncertain. Since a very minute amount of cutting fluid is used in the MQL, its heat-carrying capacity and lubrication capability are inadequate.

Hence, the heat-carrying capacity and lubricating ability of the cutting fluids have to be improved. To achieve the high cooling and lubricating capability with the MQL, a fluid with high thermal conductivity must be utilized. The applicability of the nanofluids as coolants is mainly because of their enhanced thermal conductivity due to the solid particle inclusions. The convection heat transfer coefficient of the fluid can be largely improved by the nanoparticle suspensions. Nanofluids can be conveyed to the cutting zone in a machining process through nozzles like the flooded machining systems, but the higher manufacturing costs of nanofluids and larger wastage during the machining application have urged researchers to explore the greater potential of nanofluids incorporated with the principles of the MQL.

The research on the use of nanofluids as coolants and lubricants in manufacturing is still in the early stages. Dry machining practice can be substituted with MQL practice. A cutting fluid for MQL should be chosen based on its secondary qualities, such as biodegradability, oxidation stability, and storage stability, in addition to its primary characteristics (cutting performance). The use of fluid is often minimal in those processes where friction and adhesion are important factors. In MQL, cutting fluids are utilized in extremely small quantities that are three to four orders of magnitude or less than those used in flooded lubrication conditions. Sometimes the term "near dry lubrication" or "micro lubrication" is used to describe the MQL idea [4].

II. LITERATURE REVIEW

The manufacturing practices and technologies adopted as a part of sustainable machining were evaluated, analyzed and optimized for sustainability impacts. Even though sustainable machining is a critical aspect of sustainable manufacturing, the studies carried out to assess the ecological and social effects of sustainable machining are insufficient. Most of the research that has analyzed the effects of sustainability conducted so far is limited to the economic aspects i.e. from discovering the newer techniques of material removal as a substitute to conventional machining as well as to the optimization of various variables contributing to the machining process.

Demir and Gunduz [5] observed that by increasing the CS the cutting force was decreased. This was because of the decrease in the tool chip interface area and partially by a drop of shear strength because of the increasing temperature with an increase of CS. It was also observed that surface roughness also decreased with the increase of CS. Kumaran and Uthayakumar [6] say that material gets removed more easily when the FR and DOC are increased. It was also observed that at lower CS surface roughness was low but by increasing the speed surface roughness also

gets increased. Kumar and Chauhan [7] conducted the dry turning to figure out the pattern of roughness with the help of SJ301 MITUTOYO roughness tester by varying the parameters like CS (varied from 80-170 m/min), FR (0.05- 0.2 mm/rev) and approach angle ($45^o$to 90^o). It was observed that the hybrid composite (7 wt.% SiC and 3 wt.% graphite) showed lower surface roughness compared to the hard-ceramic composite (10 wt.% SiC). It was also observed that surface roughness decreased in the presence of graphite particles in Al7075 MMC.

Bhushan et al. [8] found that at the FR of 0.1 to 0.3 mm/rev and DOC of the range 0.5-1.5 the surface roughness of Al7075+SiC (10%wt) was found to be the lowest in the experiment. Tool wear of tungsten carbide was also analyzed and it was found that flank wear of tungsten carbide increases by 2.4 factors with varying the CS from 180 m/min to 240 m/min at the FR of 0.1mm/rev and DOC of 0.5mm.

They found that the surface roughness is inversely proportional to CS means for better machining surface CS should be high because at a higher CS formation of the built-up edge can be avoided.

III. OBJECTIVES

Aluminium is the most utilized metallic alloy as a base matrix element in the development of MMCs because of its high availability, good corrosion resistance, high thermal and electrical properties, low density, and high ductility and malleability making it easy to machine. Owing to the above-stated exceptional characteristics Al alloys found their application in numerous industries. Hence, more in-depth investigations on the machining characteristics are required.

Based on the literature review objectives of the current research work are:

- We are analyzing the machine parameters and optimization of CNC machining employing Taguchi Method (L9 Orthogonal array); the parameters are CS, FR and machining environment.

IV. MATERIALS AND METHODS

Design of experiments (DOE) capabilities provides a method for simultaneously investigating the effects of multiple variables on an output variable (response). These experiments consist of a series of runs, or tests, in which purposeful changes are made to input variables or factors, and data are collected at each run. Quality professionals use DOE to identify the process conditions and product components that influence the quality and then determine the input variable (factor) settings that maximize results. MINITAB offers four types of designed experiments: factorial, response surface, mixture, and Taguchi (robust).

The steps we follow in MINITAB to create, analyze, and graph an experimental design are similar for all design types. After we conduct the experiment and enter the results, MINITAB provides several analytical and graphing tools to help us to understand the results. The typical steps for creating and analyzing a factorial design, we can apply the following steps to any design in MINITAB.

Features of MINITAB DOE commands include:

- Catalogs of experimental designs from which we can choose, to make creating a design easier
- Automatic creation and storage of your design once you have specified its properties
- Ability to display and store diagnostic statistics, to help you interpret the results
- Graphs that assist you in interpreting and presenting the results

The lubricant used for MQL is groundnut oil and for nano-fluid MQL machining fluids are groundnut oil/0.25% of h-BN (Nano-fluid-1) and groundnut oil/0.25% of graphene (Nano-fluid-2) nanoparticles. The nanofluid samples are prepared by suspension of h-BN and GNPs in groundnut oil (99.75 % groundnut oil + 0.25 % nanoparticles). Before performing the nano-fluid MQL machining operation, the mixture of Nano-fluid-1 and Nano-fluid-2 was ultrasonicated for 40 minutes to promote its dispersion using ultrasonic sound and hence, increase its solubility so that it gets completely mixed and the solute does not get settled down. In this study, analysis has been performed for optimizing CNC machining process using Taguchi Method. The process parameters are CS, FR and machining environment (presented in **Table 4.1**).

Table 1. Processing parameters.

S. no.	Work material (Al6061)	Tool material (Kennametal Carbide Insert KC850)
	Processing parameters	
1	CS	180, 190 & 200 m/min
2	FR	0.1, 0.2 and 0.3 mm/rev
3	Machining Environment	Dry, MQL and Nanofluid-MQL

We have considered three process parameters (CS, FR and machining environment) and their levels based on the analysis parameters which are affecting the machining process. **Table 4.2** presented the process parameter of the setting. Moreover, **Table 4.3** comprises selected input process parameters and their levels.

Table 2. Input turning parameters & their levels.

Parameters of the setting	
Control factor	Symbol
CS	Factor A
FR	Factor B
Machining Environment	Factor C

Table 3. Selected input machining parameters and levels

Level	Cutting speed(m/min)	FR (mm/teeth) F	DOC (mm) D
1	180	0.1	Dry
2	190	0.2	MQL
3	200	0.3	Nanofluid MQL

For input machining process parameters experiments are designed using Taguchi L9 orthogonal standard array (presented in **Table 4.4**). For this purpose, MINITAB17 software is employed.

Table 4. Machining parameters presented in orthogonal L9 array.

S. No.	CS (m/min)	FR (mm/rev)	Machining Environment
1	180	0.1	Dry
2	180	0.2	MQL
3	180	0.3	Nanofluid-MQL
4	190	0.1	MQL
5	190	0.2	Nanofluid-MQL
6	190	0.3	Dry
7	200	0.1	Nanofluid-MQL
8	200	0.2	Dry
9	200	0.3	MQL

V. RESULT AND DISCUSSION

Design of experiments (DOE) capabilities provides a method for simultaneously investigating the effects of multiple variables on an output variable (response). These experiments consist of a series of runs, or tests, in which purposeful changes are made to input variables or factors, and data are collected at each run. Quality professionals use DOE to identify the process conditions and product components that influence quality and then determine the input variable (factor) settings that maximize results.

MINITAB offers four types of designed experiments: factorial, response surface, mixture, and Taguchi (robust). The steps we follow in MINITAB to create, analyze, and graph an experimental design are similar for all design types. After we conduct the experiment and enter the results, MINITAB provides several analytical and graphing tools to help us to understand the results.

Motive behind the present investigation to found out the optimum machining process parameter for machining Al6061 alloy. **Table 5.1** presented L9 orthogonal array for optimizing surface roughness (smaller is better) in the CNC machining process. The formula for calculating SN ratios (for making the system response as small as possible) is depicted in **Equation 5.1**.

$$\mathbf{SN_S = -10 \log \frac{1}{n}\sum_{i=1}^{n} Y_i^2 \ (\,)\ldots\ldots\ldots\ldots(5.1)}$$

Nine experiments are conducted in a CNC turning machine after DOE preparation. The surface roughness is calculated following each experiment. A quality characteristic for Surface Roughness is smaller is the better. Based on equation 5.1, the signal-to-noise ratios for each experimental run are calculated and are given in **Table 5.1** along with the data.

Table 5. L9 orthogonal array for optimizing CNC machining.

S No.	CS (m/ min)	FR (mm/ rev)	Machining Environment	SR	S/N Ratio
1	180	0.1	Dry	0.86550	1.2547
2	180	0.2	MQL	1.79960	-5.1035
3	180	0.3	Nanofluid MQL	3.15235	-9.9727
4	190	0.1	MQL	0.58820	4.6095
5	190	0.2	Nanofluid MQL	1.47570	-3.3800
6	190	0.3	Dry	3.45350	-10.7652
7	200	0.1	Nanofluid MQL	0.42310	7.4711
8	200	0.2	Dry	1.67920	-4.5020
9	200	0.3	MQL	3.10050	-9.8286

Table 6. Response Table for Signal to Noise Ratios (Smaller is better).

Level	CS (m/min)	FR (mm/rev)	Machining Environment
1	-4.607	4.445	-4.671
2	-3.179	-4.329	-3.441
3	-2.287	-10.189	-1.961
Delta	2.321	14.634	2.710
Rank	3	1	2

Tables 5.2 & 5.3 depicted the Response table for S/N Ratios (Smaller is better) and the Response table for Means, respectively. **Figure 5.1** depicts the main effects

plot for means and **Figure 5.2** depicts the main effects plot for SN ratios. The objective of employing the S/N ratio as performance measurement is to generate products and processes sensitive to the noise factor.

The superlative combination of input machining parameters can be analyzed from **Figure 5.1** i.e. Main effects plot for means, the optimal value of the input process parameter is (A3, B1, C3).

Table 7. Response Table for Means.

Level	CS (m/min)	FR (mm/rev)	Machining Environment
1	1.9392	0.6256	1.9994
2	1.8391	1.6515	1.8294
3	1.7343	3.2355	1.6837
Delta	0.2049	2.6099	0.3157
Rank	3	1	2

With the aid of the Minitab Statistical Software, the output characteristic (surface finish) is analyzed. The preparation of the Main Effects Plots for Means **(Figure 5.1)** and SN ratios **(Figure 5.2)** demonstrates how each influencing element influences surface roughness. This also indicates which aspect of the machining process is more important.

Figure 5.1 contain the graph between mean and control factors. Whereas, **Figure 5.2** contains the actual graph between SN ratio data and input parameter. The aim of using the SN ratio as performance measurement is to generate products and processes sensitive to the noise factor. The Superlative combination of input machining parameters can be analyzed from **Figure 5.2** i.e. graph between S-N ratio and input parameter, the optimal value of input parameter is (A3, B1, C3). The process parameter setting with the highest SN ratio always yields the optimum quality with minimum variation.

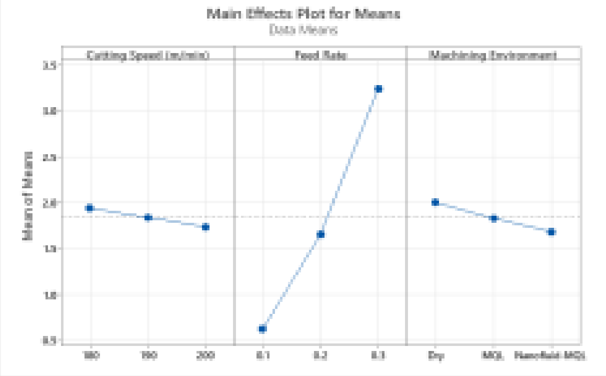

Fig 1. Main effects plot for means.

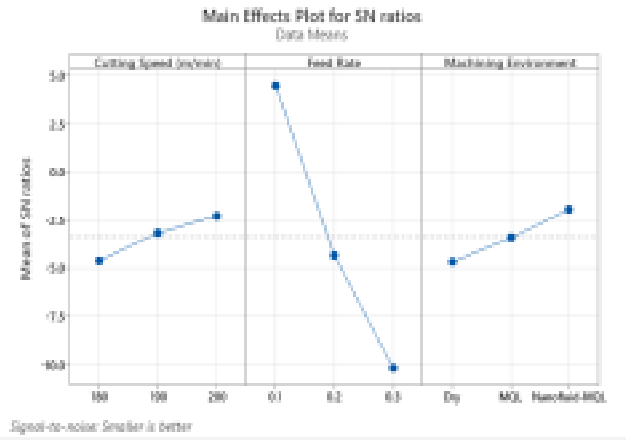

Fig 2. Main effects plot for SN ratios.

Using the S/N ratio the optimum value of surface finish is obtained by the MINITAB SOFTWARE. Moreover, it is found that will percentage contribution connected with FR can be the highest issue intended for modeling surface finish.

The optimum surface finish is obtained at: -

Input Parameters	Values
CS	200 m/min
FR	0.1 mm/rev
Machining Environment	Groundnut oil/h-BN based nanofluid MQL assisted machining

VI. CONCLUSIONS

In this work, optimization of CNC machining process parameters has been performed employing Taguchi Method (L9 Orthogonal array); the parameters are cutting speed, feed rate and machining environment. Al6061 alloy specimen has been used employed for the machining investigation subjected to dry, Groundnut oil-MQL and Groundnut oil-based nanofluid (h-BN and Graphene) MQL-assisted CNC turning operation.

Based on the investigations the concluding remarks are:

- A substantial lessening in surface roughness while machining Al6061 was evident subjected to Groundnut oil-based h-BN nanofluid MQL machining conditions. This may be because of the lubrication effect of MQL.
- While optimizing machining parameters lowest surface roughness (Ra) of 0.42310 µm was achieved corresponding to FR: 0.1 mm/rev, CS: 200 m/min. and Machining Environment: Groundnut oil/h-BN based nanofluid MQL assisted machining.

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