REST Journal on Emerging Trends in Modelling and Manufacturing
Vol: 7(4), 2021
REST Publisher
ISSN: 2455-4537
Website: www.restpublisher.com/journals/jemm

Optimization of Machining Parameter in CNC Turning of Aluminium Alloy by Taguchi's Orthogonal Array Experiment

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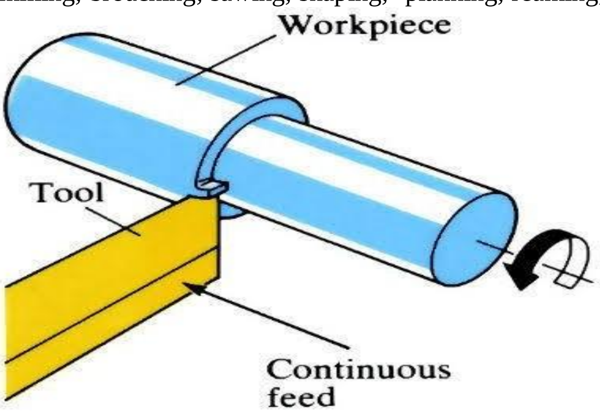
Abstract

Every manufacturing industry aims at producing a large number of products within relatively lesser time. This study applies Taguchi design of experiment methodology for optimization of process parameters in turning of Aluminium Alloy 6063 using tungsten coated carbide tool. Experiment have been carried out based on L9 standard orthogonal array design with three process parameters namely Cutting Speed, Feed, Depth of Cut for Material removal rate and Machining time. The signal to noise ratio and analysis of variance were employed to study the performance characteristics in turning operation. ANOVA has shown that the speed has significant role to play in producing higher surface roughness and lesser machine time. Thus, it is possible to increase machine utilization and decrease production cost in an automated manufacturing environment. The objective of this work is to machine AA6063 Aluminium alloy material by using CNC Turning operation and to investigate the affecting parameters while machining materials are surface roughness. The CNC Turning process parameters are feed rate, depth of cut and spindle speed, and Surface roughness. Carbide tip tool used as a cutting tool for the experiments.

Key Words: AA-6063, surface roughness Material Removal Rate, Machining Time, Taguchi's Technique, ANOVA.

1. Introduction

Machining is any of various processes in which a piece of raw material is cut into a desired final shape and size by a controlled material-removal process. The many processes that have this common theme, controlled material removal, are today collectively known as subtractive manufacturing, in distinction from processes of controlled material addition, which are known as additive manufacturing. Exactly what the "controlled" part of the definition implies can vary, but it almost always implies the use of machine tools (in addition to just power tools and hand tools).The precise meaning of the term machining has evolved over the past one and a half centuries as technology has advanced. In the 18th century, the word machinist simply meant a person who built or repaired machines. This person's work was done mostly by hand, using processes such as the carving of wood and the hand-forging and hand-filing of metal. At the time, millwrights and builders of new kinds of engines (meaning, more or less, machines of any kind), such as James Watt or John Wilkinson, would fit the definition. The noun machine tool and the verb to machine (machined, machining) did not yet exist. Around the middle of the 19th century, the latter words were coined as the concepts that they described evolved into widespread existence. Therefore, during the Machine Age, machining referred to (what we today might call) the "traditional" machining processes, suchas turning, boring, drilling, milling, broaching, sawing, shaping, planning, reaming, and tapping.



In these "traditional" or "conventional" machining processes, machine tools, such as lathes, milling machines, drill presses, or others, are used with a sharp cutting tool to remove material to achieve a desired geometry. Since the advent of new technologies such as electrical discharge machining, electrochemical machining, electron beam machining, photochemical machining, and ultrasonic machining, the "conventional machining" can be used to differentiate those classic technologies from the newer ones. In current usage, the term "machining" without qualification usually implies the traditional machining process Machining is a part of the manufacture of many metal products, but it can also be used on materials such as wood, plastic, ceramic, and composites. A person who specializes in machining is called a machinist. A room, building, or company where machining is done is called a machine shop. Machining can be a business, a hobby, or both Much of modern day machining is carried out by computer numerical control (CNC), in which computers are used to control the movement and operation of the mills, lathes, and other cutting machines.

2. CNC machining

Machining is the metal removing process from the work piece to achieve desired geometry by using a single or multi point cutting tool. The three principal machining processes are classified as turning, drilling and milling. Other operations are falling into miscellaneous categories include shaping, planning, boring, broaching and sawing. In turning operation, the tool with a single point cutting edge is used to remove material from a rotating work piece to generate cylindrical shape. The speed motion is provided by the work piece and feed motion is achieved by tool. Computer numerical control (CNC) is the automation of machine tools by means of computers executing pre-programmed sequences of machine control to commands. This is in contrast to machines that are manually controlled by hand wheels or levers, or mechanically automated by cams alone. In modern CNC systems, the design of a mechanical part and its manufacturing program is highly automated. The part's mechanical dimensions are defined using computer-aided design (CAD) software, and then translated into manufacturing directives by computer- aided manufacturing (CAM) software. The resulting directives are transformed (by "post processor" software) into the specific commands necessary for a particular machine to produce the component, and then loaded into the CNC machine.

3. Design of experiment

Design of experiments (DOE) is a structured method that is used to identify relationships between several input variables and output responses. With the help of DOE, the resources needed to carry out the experiment can be optimized. Hence, it finds wide use in R & D studies. A few methods used as DOE are Taguchi Method, Response Surface Method and Factorial Designs. We will be focusing on the Response Surface Methodology during the ensuing study.

4. Taguchi's method

It is a statistical method used to improve the quality of manufactured product. According to Taguchi "Quality is the loss imparted to society from the time a product is shipped." Science experimental procedures are generally expensive and time consuming we need to satisfy the design objective with minimum number of tests. Taguchi method involves laying out the experimental condition using orthogonal array. It is a specially constructed table which ensures that experiment design is both exploration needed to get the required design is significantly reduced. Hence testing time and experimental cost both are reduced. Orthogonal array provides much reduced variance for the experiment resulting optimum setting of process control parameter. It is carried in three step approach i.e. system design, parameter design, tolerance design. In system design, scientific and engineering principles are used to generate a prototype of the product that will encounter functional requirements. Parameter design is to optimize the settings of process parameter values for enlightening performance characteristics. And in tolerance design, tolerances are set around the target a value of the control parameter identified in the parameter design phase and is done only when the performance variation attained by the settings identified in the parameter design stage is unacceptable.

5. Material removal rate

The material removal rate (MRR) in turning operations is the volume of material/metal that is removed per unit time in mm 3/min. For each revolution of the work piece, a ring shaped layer of material is removed. MRR = (v x f x d × 1000)n mm^3/min.

$$MRR = {}^{w_b - w_a}/_{\rho t}$$

Where,

wb= weight of workpiece before cutting

wa= weight of workpiece after cutting.

P=density-2.70g/cm^3

Research limitations: The accuracy of the results was strongly influenced by the chosen of the instruments. The suitable measuring instrument will be determining the measuring instruments will be determining the accuracy on the result of study. Furthermore, reference to relevant support, with the access to reference study related will facilitate the next coming research in the samefield and differences method and instruments.

- The taguchi method is statistical tool, adopted experimentally to investigate influence of surface roughness by cutting parameters such as cutting speed, feed and depth of cut.
- The taguchi process helps to select or to determine the optimum cutting condition for turningprocess.

6. Methodology and Experimental work

Methodology

- Selection of material.
- Selection of suitable tool.
- Selection of turning parameter based on literature.
- Selection of range of parameters and levels.
- Conducting experiment based on orthogonal array.
- Analysis of MRR, surface roughness.
- Developing statistical analysis by ANOVA.
- Analysis of result and conclusion.

Experimental work: Taguchi method, a powerful tool for parameter design of performance characteristics, was used to determine optimal machining parameters for minimum surface roughness in turning process. Taguchi proposed to acquire the characteristic data by using orthogonal arrays, and to analyse the performance measure from the data to decide the optimal process parameters. This method uses a special design of orthogonal arrays to study the entire parameter space with small number of experiments only, according to the Taguchi quality design concept, there are three categories of performance characteristics in the analysis of the S/N ratio: the lower-the better, the higher-the-better, and the nominal-the better. A smaller S/N ratio corresponds to better performance characteristic. Therefore, the optimal level of the process parameters is the level with the smallest S/N ratio. Also, a statistical analysis of variance (ANOVA) is performed to identify the process parameters that are statistically significant. The lower the better criterion for the surface roughness was selected for obtaining operation.

L9 Orthogonal array: To choose a suitable orthogonal exhibit for analyses, the aggregate degrees of opportunity should be processed. The degrees of opportunity are characterized as the quantity of examinations between procedure parameters that should be made to figure out which level is better and particularly how much better it is. For instance, a Three-level procedure parameter means four degrees of flexibility. The degrees of opportunity connected with collaboration between two procedure parameters are given by the result of the degrees of flexibility for the two procedure parameters. Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions.

TABLE 1. Levels of control component

Levels	Speed	Feed	Depth of cut
1	1000	0.10	0.2
2	1300	0.15	0.4
3	1600	0.20	0.6

TABLE 2. L9 orthogonal exhibit frame work

Levels	Speed	Feed	Depth of cut
1	1000	0.10	0.2
2	1000	0.15	0.4
3	1000	0.20	0.6
4	1300	0.10	0.4
5	1300	0.15	0.6
6	1300	0.20	0.2
7	1600	0.10	0.6
8	1600	0.15	0.2
9	1600	0.20	0.4

Minitab Software Introduction: Minitab is a statistics package developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. It began as a light version of OMNITAB 80, a statistical analysis program by NIST. Statistical analysis software such as Minitab automates calculations and the creation of graphs, allowing the user to focus more on the analysis of data and the interpretation of results. It is compatible with other Minitab, LLC software.

Optimization Software: Here for obtaining the optimal values of cutting parameters we applied the Minitab 17 stastical data optimization software, the brief information about the software are described below. Minitab is a software product that helps you to analyze the data. This is designed essentially for the Six Sigma professionals. It provides a simple, effective way to input the statistical data, manipulate that data, identify trends and patterns, and then extrapolate answers to the current issues. This is most widely used software for the business of all sizes - small, medium and large. Minitab provides a quick, effective solution for the level of analysis required in most of the Six Sigma projects.

7. Operators of Genetic Algorithms

1. Selection Operator: The idea is to give preference to the individuals with good fitness scores and allow them

to pass their genes to the successive generations.

2. Crossover Operator: This represents mating between individuals. Two individuals are selected using selection operator and crossover sites are chosen rand. Mutation Operator: The key idea is to insert random genes in offspring to maintain thediversity in population to avoid the premature convergence.

8. Material Chemical Composition

Aluminium alloy 6063: AA 6063 is an aluminium alloy, with magnesium and silicon as the alloying elements. The standard controlling its composition is maintained by The Aluminium Association. It is similar to the British aluminium alloy HE9. 063 is the most common alloy used for aluminium extrusion. It allows complex shapes to be formed with very smooth surfaces fit for anodizingand so is popular for visible architectural applications such as window frames, roofs, and signframes. Applications requiring higher strength typically use 6061 or 6082 instead.

TABLE 3. chemical composition of material

ELEMENT	SAMPLE 1.D.1	SAMPLE 1.D.2
	%COMPOSITION	**%COMPOSITION**
Silicon	0.409	0.443
Manganese	0.059	0.061
Chromium	0.027	0.007
Copper	0.016	0.008
Iron	0.217	0.177
Cobalt	<0.003	<0.003
Titanium	0.038	0.0311
Zinc	0.108	0.108
Magnesium	0.7217	0.617
Vanadium	0.0073	0.006
Antimony	0.0127	0.0130
Lead	0.0155	0.0130

9. Properties of Material

Physical properties

- Corrosion resistance
- Electrical and thermal conductivity
- Reflectivity
- Ductility
- Non magnetic

Mechanical properties

- Tensile strength
- Yield strength in tension
- Tensile elongation
- Hardness
- Fatigue strength

FIGURE 2. Aluminium alloy

Applications

- Products including cans, foils, kitchen utensil, window frames.
- Aero plane parts and etc.

Pure aluminium is soft, ductile, corrosion resistant and has a high electrical conductivity. It is widely used for foil and conductor cables, but alloying with other elements is necessary to provide the higher strengths needed for other applications. Aluminium is one of the lightest engineering metals, having a strength to weight ratio superior to steel. By utilising various combinations of its advantageous properties such as strength, lightness, corrosion resistance, recyclability and formability, aluminium is being employed in an ever- increasing number of applications. This array of products ranges from structural materials through to thin packaging foils.

10. Result and Discussion

Material Removal Rate Analysis: Material removal rate (MRR), otherwise known as metal removal rate. Is the measurement for how much material is removed from a part in a given period of time. The material removal rate can be calculated from the volume of material removal or from the weight difference before and after machining. It is an indication of how much fast or slow the machining rate is and an important performance parameter is usually very slow process. Higher machining must also be achieved with desired accuracy and surface finish .the MRR greatly, duty cycle, and lower values of pluse interval can result in higher MRR. The data observed for material removal rate for the 9 experiment are given below:

TABLE 7. Material Removal Rate Analysis

Exp. No	**Speed(rpm)**	**Feed(mm/rev)**	**DOC(mm)**	**MRR(mm3/min)**
1	1000	0.10	0.2	727.22
2	1000	0.15	0.4	1591.16
3	1000	0.20	0.6	2974.99
4	1300	0.10	0.4	1295.18
5	1300	0.15	0.6	1835.04
6	1300	0.20	0.2	3126.58
7	1600	0.10	0.6	2241.43
8	1600	0.15	0.2	3058.40
9	1600	0.20	0.4	4884.31

Using minitab software the regression model has been developed.

MRR=3476.30mm3/min

11. Surface roughness analysis

Surface roughness often shortened to roughness. Is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough. If they are small the surface is smooth. In surface metrology, roughness is typically considered to be the high frequency. short –wavelength component of measured surface. However, in practice it is often necessary to know both the amplitude and frequency to ensure that a surface is fit for a purpose. Roughness plays an important role in determining how a real object will interact with its environment. A portable surface roughness tester is used after ever trial to get the surface roughness value inμm. A regression equation is formed by using experimental values by using the Minitab 18 software. The validation of experimental result is obtained by using the regression analysis. Regression equation is also one of the most widely used statistical tools because it provides simple methods for establishing functional relationship among variables. The regression equation is employed to develop a suitable model for predicting dependent variables from a set of independent variables. The relationship between the experimental result and validated result for this investigation is presented. Surface roughness often shortened to roughness, is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. Surface structure plays a key role in governing contact mechanics, that is to say the mechanical behavior exhibited at an interface between two solid objects as they approach each other and transition from conditions of non-contact to full contact.

TABLE 8. Surface Roughness Analysis

Exp. No	Speed(rpm)	Feed (mm/rev)	DOC(mm)	SR(μm)
1	1000	0.10	0.2	0.70
2	1000	0.15	0.4	0.31
3	1000	0.20	0.6	0.39
4	1300	0.10	0.4	0.28
5	1300	0.15	0.6	0.45
6	1300	0.20	0.2	1.46
7	1600	0.10	0.6	0.54
8	1600	0.15	0.2	0.52
9	1600	0.20	0.4	0.89

Surface roughness for the 9 experiments are given below.
Using minitab software the regression model has been developed.
SR=1.22556 μm

12. Confirmation Test

The Taguchi's L9 mixed type orthogonal array experiments have been carried out on AA6063 by considering the lubrication, feed rate, depth of cut and rotational speed as input parameters, MRR and surface roughness as output response and also from the experimental analysis the optimal process parameters have been identified to maximize material removal rate and to minimize the surface roughness. The optimum setting parameters of CNC turning and confirmation test results of predicted and experiment value for MRR and Ra. From the results it is conclude that the MRR is and surface roughness. In order to validate the results obtained, there are three confirmation experiments conducted for each of the response characteristics (MRR, Ra) at optimal levels of the process variables and at initial levels of process variables. The average values of the optimum characteristics at initial levels, predicted value levels and experimental value levels are obtained. The last step of Taguchi parameter design is to verify and predict the improvement of surface roughness (response) using optimum combination of cutting parameters. The predicted optimal value can be calculated by means of additive law. The predicted values and the associated experimental values were compared. The error percentage is within permissible limits. So, the response equation for the surface roughness predicted through RSM can be use to successfully predict the surface roughness values for any combination of the feed rate, tool nose radius, cutting speed and depth of cut within the range of the experimentation performed.

TABLE 9. Confirmation table

Speed	Feed	Depth of cut
1600	0.20	0.2

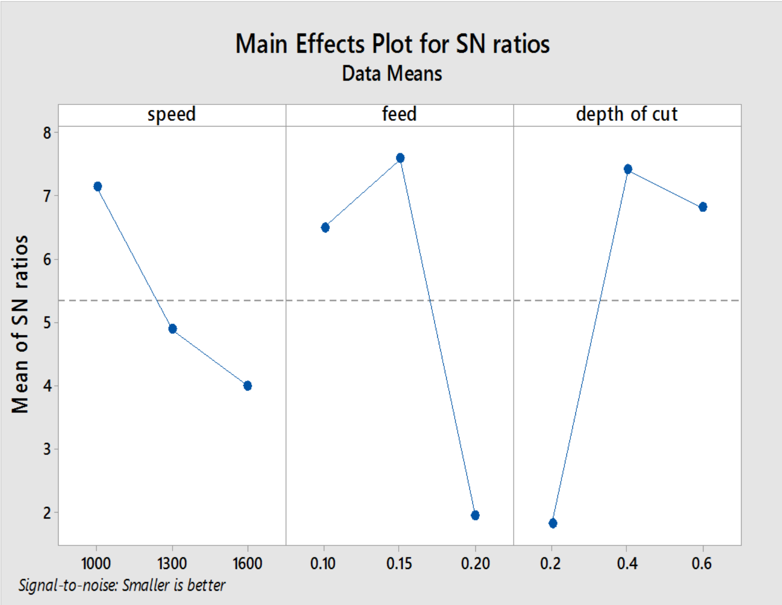


Figure Main effect for SN ratio

Signal to noise ratio (S/N) analysis: Signal to noise ratio is defined as a log function that serves to determine the effect of individual variables on the desired output. It is classified as Nominal value is the best, smallerthe better and larger the better.

For the nominal is the $= -10log\frac{1}{n}\{\sum\frac{\bar{y}}{n}\}\frac{-}{2}\frac{-}{s_y}$

For smaller the better $s = -10\log\frac{1}{n}\{\sum y^2\}\frac{-}{n}$

Where,
n – the number of observations, y – observed data, –
y – average of observed data and $s2y$ –
variation of y

In this study, the 'Smaller the better' equation predicts the S/N ratio since the objective is to minimize the nanoparticles' deposition rate. The output obtained from the numerical solution is fed as the response parameter for the S/N ratio analysis. The predicted deposition rate of nanoparticles and the corresponding S/N ratio value for the 9 experiments are given the Table7.The main effects plot for Mean and S/N ratio. From the plots, it is witnessed that the nanoparticle deposition rate is minimum for the combination. The minimum deposition rate for the above optimum parameters is predicted as 1.22556.shows the normal probability plot of residuals for the responses. The residuals are normally distributed to satisfy the normalityassumptions for all the responses.

TABLE 10. Response Table for Means

Level	Speed	Feed	Depth of cut
1	0.4667	0.5067	0.8933
2	0.7300	0.4267	0.4933
3	0.6500	0.9133	0.4600
Delta	0.2633	0.4867	0.4333
Rank	3	1	2

TABLE 11. Response Table for Signal to Noise Ratios

Level	Speed	Feed	Depth of cut
1	7.150	6.502	1.830
2	4.902	7.596	7.414
3	4.015	1.968	6.822
Delta	3.135	5.628	5.584
Rank	3	1	2

Conclusion

The CNC turning investigation on material removal rate surface roughness has been carried out for AA6063, in this research work the effect of lubrication, feed rate, depth of cut and rotational speed on response have been studied under L9 Taguchi's orthogonal array and significance of process parameters are analyzed via ANOVA. The following important conclusions drawn from this study.

- The material removal rate increases with increases in feed rate, MRR, depth of cut andspindle speed is high at dry machining condition compare to coolant.
- The surface roughness decreases with increasing the depth of cut and spindle speed, bylowering the feed rate the Ra can reduce and at coolant condition the surface roughnesscan minimize.
- Feed rate and spindle speed has significant effect on both M R R and surface roughness.
- Lubrication and depth of cut has insignificant effect of material removal rate and surface roughness

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