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A Review of Optimization of Surface Roughness of Inconel 718 in End Milling using Taguchi Method

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ABSTRACT
Nickel based super alloy, Inconel 718 is a very hard material (46 HRC). Because of its hardness, work hardening and low thermal conductivity, its machining is very difficult. End milling is an effective method for machining, drilling, slotting, and making key ways of Inconel 718. Tensile residual stress takes place during machining of Inconel 718. It is a critical problem, which is minimized to obtain better quality. Residual stress becomes more in the presence of rough machined surface. In this paper we optimize the surface roughness of Inconel 718 in end milling under dry condition. The surface roughness is optimized using four parameter nose radius, depth of cut, feed rate and cutting speed by using a cemented carbide tool. L_{27} orthogonal array of Taguchi method uses to analyse the result. 27 experimental runs based on L_{27} orthogonal array of Taguchi method.
Keywords- End Milling, Inconel alloy, nose radius, orthogonal array, surface roughness

I. INTRODUCTION

Inconel 718 is a nickel base super alloy contains 46% nickel. Nickel is the main dominant element of Inconel 718. It imparts Niobium that gives enlarged strength without decrease in ductility. It can withstand at the temperature range -220º to 780ºC, therefore it is used in cryogenic tankage. It has high oxidation resistance, corrosion resistance even at very high temperature and maintain a high mechanical strength. Inconel 718 is widely used in aircraft gas turbine, reciprocating engines, space vehicles (e.g., rocket engine parts), nuclear power plants, chemical application, high temperature fasteners, springs, rings and pulp and paper industry [1]. Each machining action evacuates habitual affirmation on the machined surface. This affirmation in the form of fine spaced micro irregularities left by the end mill. Each type of cutting tool evacuates its own discrete pattern which therefore can be identified. This pattern is called as surface roughness. Surface roughnessis measured in µm [2]. Milling is the operation of machining curved, flat, irregular and complex surface by feeding the workpiece against a rotating cutter. Milling process contains a motor that driven spindle, which install and rotates the milling cutter. A reciprocating adaptable worktable, which install and feeds the workpiece. Milling is basically classified in three categories [3]:

- Peripheral Milling- It is also known slab milling. The axis of rotation of the cutter is parallel to the machined surface, and the action is performed achieved by cutting point (edges) on the outer circumference of the cutter. The primary motion is the rotation of the cutter. The feed is transmitted to the workpiece.

- Face Milling- In face milling, the cutter is installed on a spindle. The axis of rotation of cutter is perpendicular to the workpiece surface. The diameter of cutter either equal to width of workpiece or greater than width of workpiece which has to be machined.

- End Milling- In this process various operations (profiles) can be produced by milling of flat, irregular and curved sufaces. The cutter which is used in end milling has either straight or tapered shanks for smaller and larger cutter sizes respectively. The axis of rotation of cutter is perpendicular to the surface of the workpiece which has to be machined. The surface initiated is at a 90º to the axis of the cutter. The cutter, called end mill, has a diameter less than the width of workpiece.

Table-1 Properties of Inconel 718 [1, 4]

Workpiece material	Tensile strength (MPa)	Yield strength (MPa)	Melting Temp. (ºC)	Elongation (%)	Hardness (HRC)	Density (g/cm³)
Inconel 718	1400	1040-1160	1350	14-16	4248	8.17

Table-2 Chemicalcomposition of Inconel 718 alloy (wt %) [1, 2, 4]

Elements	Fe	Ni	Cr	Nb	Mo	Ti	Al
Percentage	2.8	68.10	21.10	5.07	3.60	1.15	0.65

Inconel 718 alloy is strenuous to machine for the following causes [1].

- Excessive work hardening rates at machining strain rates conducts to maximum cutting forces,
- Low thermal properties conducting to high cutting temperatures,
- Extreme propensity to weld to face of the tool and create build up edge.

Fig-1 Process principle of end milling [4]

The common machining operation performed by end milling are as [5]:

- Closed and open pockets,
- Facing operations for narrow areas,
- Counterboring and spotfacing,
- Peripheral end milling,
- Milling of keyways and slots,
- face grooves, Channel groves and recesses
- Chamfering

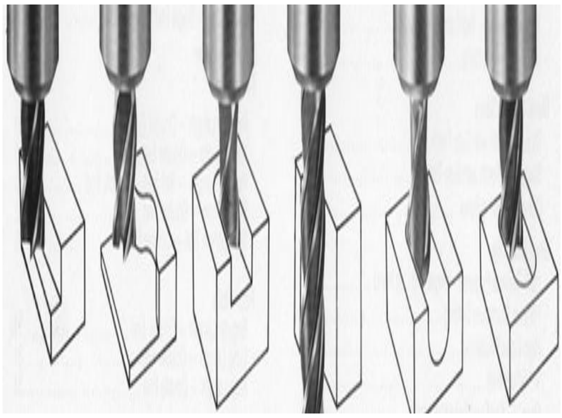


Fig-2 Common machining operations by end milling [5]

II. PROCESS PARAMETERS

Although End Milling gives good quality surface finish, proper execution of the process and control of a number of parameters is required for a successful outcome. Recent experimental and computational works have provided insight into how process parameters influence on surface roughness. Process parameters, such as tool design, tool geometry, workpiece material, feed rate, cutting speed, depth of cut, cutting fluid and nose radius are found to exert significant effects on the surface roughness. In this we takes four parameters cutting speed, feed rate, depth of cut and nose radius to optimize output parameter surface roughness [1, 4]. M. Alauddin*et al*., [1] studied the optimization of surface finish in end milling Inconel 718 by using a tungsten carbide insert in dry condition. The nose radius of insert is 0.80 mm. for the analysis of result he has taken two process variables: cutting speed and feed rate. Used response surface method for experimental design. He found that if feed rate is increased, then the surface roughness is also increased and vice versa. And if cutting speed is increased, then the surface roughness is decreased and vice versa. Lohithaksha M Maiyer*et al*., [6] studied the optimization of machining parameters for end milling of Inconel 718 super alloy using Taguchi based grey relational analysis. Cutting speed, feed rate and depth of cut ate optimized with consideration of surface roughness and material removal rate (MRR). Used uncoated tungsten carbide tool of 10mm diameter and 4 flutes. L_9 orthogonal array of Taguchi method are applied. Analysis of variance (ANOVA) and grey relational analysis is also applied to get the most significant factor. He found that cutting velocity is most affecting factor and followed by feed rate affecting the multiple performance characteristics. It has been also found that the optimal cutting parameters for the machining process lies in 75m/min for cutting velocity, 0.06mm/tooth for feed rate and 0.4mm for depth of cut. When material removal rate is increased, then surface roughness is decreased. W. Li *etal*., [7] studied the effect of tool wear during end milling on the surface integrity and fatigue life of Inconel 718. Tool wear is measured and determined by an optical tool inspection and measurement system. Effect of tool wear on surface integrity and fatigue life of Inconel 718 is determined by using four process parameters cutting speed, feed rate, axial depth of cut and radial depth of cut and used PVD (pressurised vapour deposition) coated carbide insert for end milling. He found that no fatigue occurred within four million cycles for all the machined samples up to tool wear VB 0.2 mm. tool wear within a certain range doesn't necessarily affect the fatigue life. Babur Ozcelik*et al*., [8] studied optimum surface roughness in end milling Inconel 718 by coupling neural network model and genetic algorithm. Cutting experiments are designed based on statistical three-level full factorial experimental design technique. The optimization problem is solved by an effective genetic algorithm for variety of constraint limit. He has taken four process variables cutting speed, feed rate, axial depth of cut and radial depth of cut to optimize the surface roughness and used sandvikcoromant tool for machining operation. He found that the Inconel 718 is very hard material and its machining is very difficult and also found that surface roughness values are highly influenced by MMRs and it is not possible to reduce the surface roughness values without considering any sacrifice on the MRR. FarshidJafarian*et al*., [9] studied improving surface integrity in finish machining of Inconel 718 alloy using intelligent system. He said that controlling and optimizing residual stress and surface roughness in machining of Inconel 718 are needed. The optimal machining parameters including cutting speed, depth of cut and feed rate to optimize the residual stresses, and surface roughness. Used cubic boron nitride end mill for machining and artificial neural network and Genetically Optimized NeuralNetwork System (GONNS) method for the analysis of result. He found that low values of surface roughness were obtained in the highest cutting speed and moderate range of the feed rate and depth of cut. And also minimized the values of residual stresses at highest value of cutting speed. M. A. Hadi*et al*., [10] studied the comparison between up-milling and down-milling operation on tool wear in milling Inconel 718. He found that tool flank wear propagation in the up-milling operation was more rapid compared to down-milling operation. Tool wear is increased with increased depth of cut, feed rate and cutting speed. The chip morphology is different in both operation, where up-milling operation produced a segmented chip with typical saw-tooth shape and down-milling operation.

III. TOOL

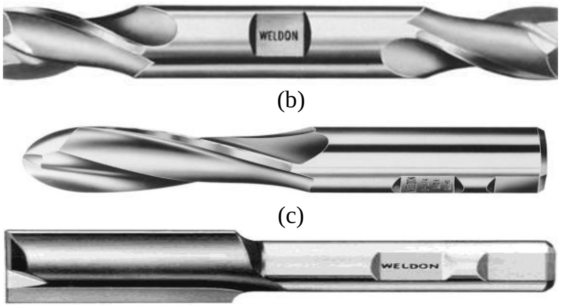
End mill, which includes material selection and geometry, is one of the most important factors that influence surface roughness and the mechanical properties. Tool materials, apart from having to satisfactorily endure the milling operation, affect surface roughness and tool wear. In the context of machining, a cutting tool (or cutter) is any tool that is used to remove material from the workpiece by means of shear deformation [3]. Cutting tools must be made of a material harder than the material which is to be cut, and the tool must be able to withstand the heat generated in the metal-cutting process. Also, the tool must have a specific geometry, with clearance angles designed so that the cutting edge can contact the workpiece without the rest of the tool dragging on the workpiece surface [8]. The desirable cutting tool material used for machining of Inconel 718 has characteristics [11]:

- wear resistance should be good,
- high hot hardness,
- strength and toughness should be high,
- thermal shock properties should be good,
- adequate chemical stability at elevated temperature.

Cemented carbide tools are still mostly used for machining of nickel based super alloys (Inconel 718). For good surface quality and high material removal rate cemented carbide tools are used. For higher cutting speed coated cemented carbide tools developed for machining Inconel 718 [10].

We use two uncoated cemented carbide tool of 10 mm diameter for smooth cutting of Inconel 718 during machining. One end mill has 0.4 mm corner radius and another has 0.8 mm corner radius. The carbide tool has widely used in milling for its better toughness, wear resistance and thermal conductivity. High surface quality is obtained by carbide tool for machining of Inconel 718. Inconel is a very hard alloy, it is hard to machine. So we use carbide tool for better surface finish [5]. Here are common end mills, which are used in end milling operations.

(a)



(b)

(c)

(d)

Fig 3. Common End Mills [5]: (a) single end helical tooth End Mill (b) double end helical tooth End Mill (c) ball-end End Mill (d) Straight-tooth End Mill

IV. SURFACE ROUGHNESS EVOLUTION

The eminence of machined surface is specified by the precision of its manufacture concerning to the dimensions identified by the researcher. Each machining action evacuates predictable affirmation on the machined surface. This affirmation in the form of finely spaced micro deformity port by the cutting tool. Each type of cutting tool evacuates its own discrete pattern which consequently can be determined. This pattern is known as surface finish or surface roughness. There are various ways to reported surface roughness. Surface roughness is of two types: arithmetic surface roughness (R_a) and root mean square surface roughness (Rrms). Arithmetic roughness also known as average roughness. It is denoted by R_a. Arithmetic surface roughness is described as the average value of the divergence of the outline from centreline along the workpiece length, as shown in Fig. 4. It can be indicated by the subsequent mathematical relationships [8].

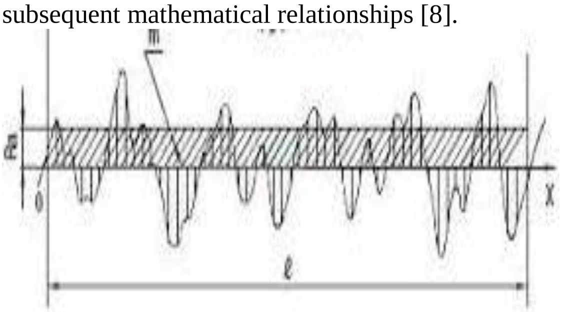
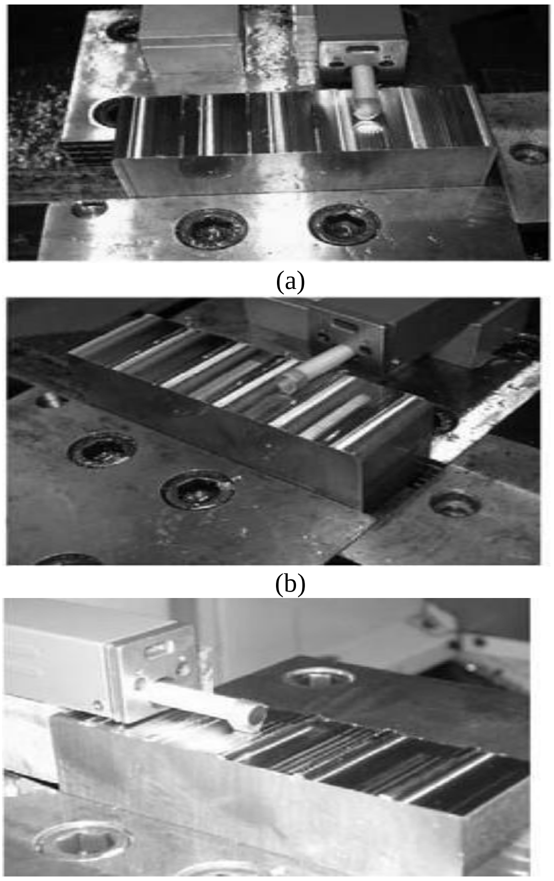


Fig- 4 Mathematical deviation of R_a[8]

(1) $Ra = \frac{1}{L}\int_0^l y(x)dx$

Machined surfaces are measured by a portable surface roughness tester (surfcorder or mohr stylus). In end milling of Inconel 718 the heat generated in milling operation is conveyed away by chips. An evident percentage of heat still dissolves into the machined surface. In end milling operation (high cutting speed, small depth of cut and small feed rate), it is possible that adequate heat will regulate into the workpiece and cause phase changes to build a white film on the machined surface [7]. Machined surfaces are dignified by using a transferable surface roughness tester in three measurement directions as shown in Fig.5. alongfeed, across feed and transverse feed directions.



(a)

(b)

(c)

Fig-5. Roughness measurements directions [8]: (a) along feed (b) across feed (c) transverse direction

Surface roughness is a broadly used key of product eminence and in most action a technical essential for mechanical products. Attaining the craved surface eminence (quality) is of great significance for the practical operation of a part [12]. The fishbone diagram shows the various parameters which affect the surface roughness are shown in fig 6.

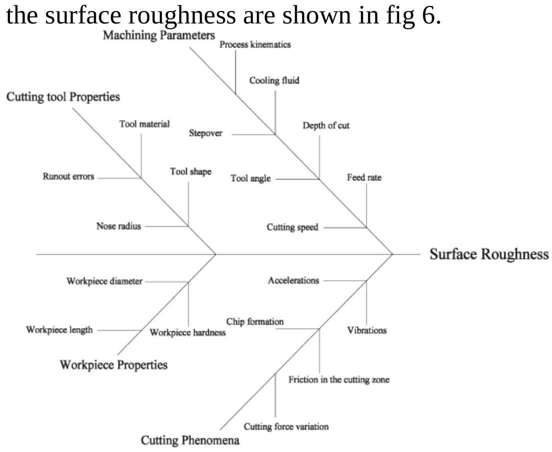


Fig-6 Fish-bone diagram [12]

V. METHODOLOGY

A properly planned and accomplished experiment is of the most predominant for obtaining clear and precise conclusions from the experimental observations. Design of experiment is considered to be a very useful procedure for achieving these job. The science of statistical experimental design originated with the work of Sir Ronald Fisher in England in 1920s. Fisher founded the basic principle of experimental design and the associated data-analysis technique called Analysis of Variance(ANOVA) during his attempt to improve the yield of agricultural crops. The theory and applications of experimental design and the related technique of response surface methodology have been advanced by many statistical researchers. Various types of matrices are used for planning experiments to study several decision variables. Among them, Taguchi's Methodmakes heavy use of orthogonal arrays. While designing the experiments for the present study the Taguchi's Experimental Design method has been employed [13].

5.1Taguchi experimental method

Taguchi's comprehensive system of quality engineering is one of the great engineering achievements of the 20th century. His methods concentrate on the practical application of engineering strategies rather than advanced statistical techniques. Taguchi described the quality of a product, in terms of the loss presented by the product to the community from the time the product is transfer to the consumer. Few of these losses are due to variation of the product's serviceable characteristic from its desired object (target) value. These are called losses due to functional variation. The factors which are uncontrollable cause functional characteristics of a product to deviate from their target values are known as noise factors. Taguchi's philosophy is developed on the following three very easy and elemental concepts [13]:

- Quality should be model into the product and not examine into it.
- Quality is the best attained by minimizing the variation from the target. The process should be so designed that it is uncesceptible to uncontrollable environmental variables.
- The cost of quality should be sustained as a function of variation from the standard and the losses should be measured.

5.1.1 Experimental Design Approach

Taguchi recommends orthogonal arrays (OA) for putting out of experiments. These orthogonal arrays are generalized Graeco-Latin squares. To plan an experiment is to select the most suitable OA and to assign the parameters and interactions of interest to the appropriate columns . To operate of linear graphs and triangular tables suggested by Taguchi makes the assignment of parameters simple. The arrangement forces all researchers to design almost identical experiments [13].

Taguchi method is used to analyse the results of the experiments to achieve one or more of the following objectives [13]:

- To evaluate the optimum condition for a product or process.
- To evaluate the contribution of single parameters and interactions.
- To evaluate the response under the optimum condition.

The optimum condition is identified by studying the main effects of each of the parameters. The foremost effects specify the general trend of influence of every one parameter. The understanding of contribution of individual parameters is a key in deciding the nature of control to be established on a production process [20]. Taguchi strongly recommends for multiple runs is to use signal-to-noise (S/N) ratio for the same steps in the examination. The S/N ratio is a simultaneous quality metric linked to the loss function. Through increases the S/N ratio, the loss associated can be decreases. The S/N ratio regulates the most robust set of working conditions from variation within the results [14].

5.1.2 Determination of S/N ratio

The experimental approach used to obtain the effect of each factors on surface roughness. The experimental approach is mainly applied in cases where there can be no analytical formulation of the cause and effect relationships between the various parameters. The quality of process is computed, by a single criteria, or by a combination of multiple criteria, the measure will possess one of the following categories [13, 14]:

- the bigger the better
- the smaller the better
- the nominal the best

Taguchi used signal-to-noise ratio (S/N) to check the quality of product. The mean and standard deviation are proportional to each other. When mean is decreases, the standard deviation is also decreases and vice versa. Therefore S/N ratio is used, because it is measurable value besides of standard deviation. We can also say, the standard deviation does not be minimized first and the mean brought to the target. By keeping the mean on target while standard deviation becomes minimum. The production factor can be divided in to three factors [14]:

- Control factors, which influence process variability as calculated by the S/N ratio.
- Signal factors, which do not affect the S/N ratio.

- Factors, which do not affect the S/N ratio or process

When the characteristic is continuous, the S/N ratio is divided in to three types [14]:

- Nominal is the best characteristics:

$$(2) \quad \frac{S}{N} = -10 \log \frac{1}{n} \left(\frac{\bar{y}}{{s_y}^2} \right)$$

- Smaller the best characteristics:

$$(3) \quad \frac{S}{N} = -10 \log \frac{1}{n} \left(\sum y^2 \right)$$

- Larger the better characteristics:

$$(4) \quad \frac{S}{N} = -10 \log \frac{1}{n} \left(\frac{1}{y^2} \right)$$

Where-
$\bar{y}$ = average of observed data
S_y = variance of y
n = no. of observations
y = observed data

For each type of attributes, with the above S/N ratio modification, the higher the S/N ratio the better is the result. For smaller the better the target value is zero. For larger the better type, the inverse of each large value becomes a small value and again the target value is zero [14].

5.1.3 Orthogonal array of Taguchi method

In selecting an appropriate OA, the following prerequisites are required:

- Assortment of process parameters and/or their interactions to be evaluated.
- Assortment of number of levels for the selected parameters.

The total degrees of freedom (DOF) of an experiment are a direct function of total number of trials. If the number of levels of a parameter increases, the DOF of the parameter also increase because the DOF of a parameter is n-1 (the number of levels - one). Thus, increasing the number of levels for a parameter increases the total degrees of freedom in the experiment which in turn increases the total number of trials. Thus, two levels for each parameter are recommended to minimize the size of the experiment. If curved or higher order polynomial relationship between the parameters under study and the response is anticipated, at least three levels for every one parameter should be considered. The standard two-level and three-level arrays are [13, 14,]:

- Two-level arrays: L_4, L_8, L_{12}, L_{16}, L_{32}
- Three-level arrays: L_9, L_{18}, L_{27}

VI. SUMMERY AND FUTURE WORK

In this review article, surface roughness optimization, end milling operation and application of Inconel 718 have been addressed. Surface roughness is very important factor for determining product quality. Machining parameters, cutting speed, feed rate, depth of cut and nose radius are crucial to roughness free surface. End milling gives a good surface finish of Inconel 718. The scope of this review article covered study and analysis about surface roughness. The review is focused on milling of Inconel 718 in end milling under dry condition. Machining parameters considered are cutting speed, feed rate, depth of cut and nose radius. The main aim of this review article is to minimize the surface roughness during machining conditions.

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