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Experimental Investigation and Analysis on Surface Roughness, During Turning Operation of Titanium Using Taguchi Method

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Abstract: This project aims to analyze and optimize the primary reason for the present manufacturing businesses is to deliver ease, excellent items in brief time. They are centered on accomplishing high caliber, in term of part exactness, surface completion, and high creation rate and so on. Thus, the determination of ideal cutting parameters is a significant issue for each machining procedure so as to diminish the machining costs and increment the nature of machining items. Present postulation manages the cutting of Alloy Steel under wet and dry condition utilizing CNC machine. Taguchi technique is utilized to Plan the test format. The impact of cutting condition (shaft speed, feed rate and depth of cut) on surface roughness are examined and dissected. The CNC turning machine is utilized to direct trials dependent on the Taguchi plan of analyses (DOE) with orthogonal L9 cluster. Ideal cutting parameters for every exhibition measure are gotten utilizing Taguchi systems. The orthogonal exhibit, sign to clamor proportion and investigation of difference were utilized to discover least surface roughness. Ideal outcomes are at last checked with the assistance of affirmation tests.

Keywords: Turning, Orthogonal array, roughness, MRR, Taguchi Method, Signal-to-noise, CNC.

1. Introduction:

Metal cutting is a common type of machining in a metal cutting industry. In any metal cutting processes, the cutting action of the tool is accomplished by overcoming the shear strength of the work piece material. Higher shear strength developed will increase the load on the various machine components and tool components. Other parameters such as cutting speed, feed rate and depth of cut will also increase the load on the tool component. The total work done by the cutting tool is approximated by the amount of material removed during the metal cutting process. This amount of work is the amount of heat energy generated that is dissipated into the work piece and tool interface. Machining is considered to be an important manufacturing process which is used by almost all manufacturing industries to produce products of high quality and high precision. The tool used for metal cutting may be either single point cutting tool or a multi-point cutting tool. The operations such as turning, shaping etc., involve metal cutting using a single point cutting tool. The operations such as milling, drilling etc., involve metal cutting using a multi-point cutting tool. The conditions which influence severely on metal cutting processes are as follows:

1. Work material
2. Cutting tool material
3. Cutting tool geometry
4. Cutting speed
5. Feed rate
6. Depth of cut
7. Cutting fluid used for machining etc.,

In this research work, machining of pure titanium material is considered using a single point cutting tool. The cutting forces are lesser and machining is better in case of higher rake angle. But the limit of the rake angle is limited to a particular range, if this range is exceeded, then strength of the tool tip is decreased and also heat dissipation becomes reduced in the tool chip interface.

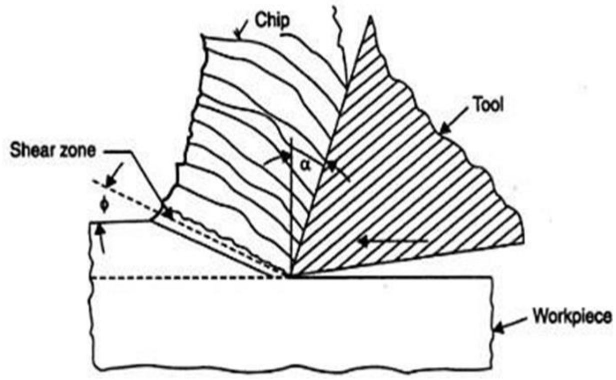

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Figure 1. Mechanics of metal cutting

Generally, zero rake angles are also possible in cutting tool geometry, which gives higher strength to the tool tip while machining. The plastic deformation takes place in the vicinity of the cutting edge. It is called as the shear zone and the plane acting along this shear zone is termed to be as the shear plane. The schematic diagram showing the mechanics of metal cutting of turning operation involved with a single point cutting tool is shown in the Figure 1. Automobile and aerospace industries have tremendous challenges and interest in materials with improved mechanical properties. Aerospace super alloys, such as nickel base and titanium alloys, as well as other advanced engineering materials like structural ceramic and tantalum are usually used in the manufacture of components for aerospace engines. Nickel based super alloy about 50 % of weight material used in aerospace parts.

1.1 Cutting Tool Materials

Choosing the proper cutting device material for a particular application is vital in accomplishing proficient activities. Expanding sliding velocity to build profitability is just conceivable to a restricted degree as this abbreviates the instrument life, expanding apparatus re- pounding / substitution costs and expanding interferences to creation. No single material meets all prerequisites. The properties required by cutting instruments mean tradeoff is required, for instance expanding hardness by and large outcomes in lower strength.

The Ideal cutting apparatus material ought to have the entirety of the accompanying attributes:

Harder than the work it is cutting

High temperature security

Resists wear and heat stun

Impact safe

Chemically idle to the work material and cutting liquid

To successfully choose apparatuses for machining, a mechanic or architect must have explicit data about:

The beginning and completed part shape

The work piece hardness

The material's rigidity

The material's abrasiveness

The sort of chip produced

The work holding arrangement the power and speed limit of the machine instrument

2. Literature Review:

This chapter introduces the review of research work which is closely related to this thesis work. An overview of various techniques used for the optimization of manufacturing processes has been presented. Then an overview of surface roughness process optimization based on different materials, different geometry of the work piece material with their conclusion has been discussed. Finally, the problem has been formulated with the critical finding of literature survey. Pawan kumar et. al (2023) The study focuses on optimizing machining performance for Ti6Al4V alloy using the Taguchi method. Key factors, including approach angle, depth of cut, cutting speed, and feed rate, were investigated for their impact on material removal rate, surface roughness, and tool wear. L9 (34) orthogonal array trials on a lathe machine were conducted, with analysis revealing feed rate as the most influential factor (86.63%) on the combined objective function. The proposed method highlights optimal machine settings and employs microanalysis of chips and cutting tools for a comprehensive understanding of the process.[1].

H. Akkus and H. Yaka (2022) In this study, Ti 6Al-4 V (grade 5) ELI alloy was machined with minimum energy and optimum surface quality and minimum tool wear. The appropriate cutting tool and suitable cutting parameters have been selected. As a result of the turning process, average surface roughness (Ra), tool wear and energy consumption were measured. The results have been analyzed by normality test, linear regression model, Taguchi analysis, ANOVA, Pareto graphics and multiple optimization method. It has been observed that high tool wear value increases Ra and energy consumption. In multiple optimizations, it was concluded that it made predictions with 89,1% accuracy for Ra, 58,33% for tool wear, 96,75% for energy consumption. While the feed rate was the effective parameter for Ra and energy consumption, the effective parameter in tool wear was the cutting speed. Our study has revealed that by controlling energy consumption, surface quality can be maintained and tool wear can be controlled.[2]

T.P. Gundarneeya et. al. (2022) This study investigates surface roughness and dimensional accuracy in hard turning of EN24 steel using CBN tools. CNC lathe experiments with varying spindle speed, feed rate, nose radius, and cut depth were conducted. Taguchi method and ANOVA were employed to determine optimal process parameters. Results indicate spindle speed as the most influential factor for surface roughness, followed by insert nose radius. Cutting depth has a significant impact on dimensional accuracy, with spindle speed and nose radius also playing important roles. Feed rate has a lesser influence on both factors.[3]

Waheed Sami Abushanab et.al. (2022) The evolution of industrial development enabled massive improvements in the lightweight materials for products with high strength to weight ratios and superior corrosion resistance used in turbine and aerospace structures. Titanium and its alloys possess excellent service properties especially in the biomedical field, due to inherent difficulties arise while cutting these alloys using conventional processing operations. Therefore, in this research, abrasive water jet machining (AWJM) is employed as a nontraditional process to investigate the post-processing surface characteristics of Ti6Al4V alloy. The effects of process factors including water pressure, abrasive flow rate, feed rate and stand-off distance on the characteristics of the cut surfaces have been investigated. Comprehensive experimentation is carried out to determine parametric ranges involving lesser heat affected regions and improved surface characteristics. Through Taguchi based design of experiments, it is observed that abrasive flow rate and stand-off distance are the most significant parameters that affect the surface roughness and material morphology.[4]. R. Thirumalai et. al. (2021) This study applies the Taguchi method and Response Surface Methodology to optimize process parameters in the manufacturing of titanium parts. The focus is on achieving optimal conditions for surface quality and production efficiency. Performance evaluation, considering factors like cutting tool temperature and surface roughness, is conducted for various cutting tools. The analysis highlights cutting speed as the most influential parameter in machining titanium, followed by depth of cut. Additionally, the combined effect of feed and depth of cut significantly contributes to the machining process.[5]

Pytlak et.al (2021) developed a multi-criteria optimization method for hard turning of cemented 18 HGT [Poland standard of compound assistant steel] steel. CBN enhancements of wiper geometry were used. The model considered the going with parameters profundity of cut, feed and cutting velocity. Optimization criteria were generation cost, time per unit and resultant cutting force. Weighted goals procedure and Modified division technique was used to make Pareto sets of courses of action. To ensure low creation cost and low advantages of cutting forces a different leveled procedure was used. Sieben et al. (2010) used plan and assessment of PC tests (DACE) for the exploratory demonstrating of hard turning of AISI 6150 steel. PCBN tool was used hence. The different parameters picked were feed, profundity of cut and cutting rate. The DACE technique can be used to show complex non direct factors.[6].

Cappellini et al. (2020) used AISI 52100 circles to consider the improvement of white and dull layers in hard cutting. Thus, Polycrystalline Cubin Boron Nitride (PCBN) installs were used. The essayists found that as the temperature goes above austenizing temperature, the martensite is quickly smothered and white layer is formed. Cutting speed and feed rate were the parameters. The white layers surrounded were seen under Scanning Electron Microscope (SEM). It was furthermore considered that to be the tool wears the thickness of layers extended. As the speed extended or the feed rate extended thicker white layers were molded and progressively thin diminish layers were encircled.[7] D. PhilipSelvaraj et. al (2020) used AISI 304 Austenitic treated steel to consider the effect of cutting parameters like cutting rate, feed rate and profundity of cut superficially unpleasantness. A plan of assessments subject to Taguchi's technique has been used to pick up the data. A symmetrical exhibit, the sign to uproar (S/N) extent and the assessment of contrast (ANOVA) are used to look into the cutting qualities of AISI 304 austenitic solidified steel bars using TiC and TiCN secured tungsten carbide cutting tool. Finally, the certification tests that have been finished to differentiate the foreseen characteristics and the preliminary regards assert its ampleness in the assessment of surface unpleasantness. [8].

R. Ramanujam et.al (2019) presents another technique for the optimization of the machining parameters on turning Al-15%SiCp metal network composites. Optimization of machining parameters was done by an examination called appealing quality limit assessment. Taguchi's L27 symmetrical cluster is used for preliminary arrangement. The machining methodology parameters, for instance, cutting velocity, feed rate and profundity of cut are streamlined with various execution considerations to be explicit surface harshness and power use. The perfect machining parameters have been recognized by a composite appealing quality worth got from charm work assessment as the introduction list, and important responsibility of parameters would then have the option to be managed by examination of progress. Certification test is similarly prompted endorse the test result. Exploratory results have shown that machining execution can be improved effectively through this strategy. [9]. D. Mittal et.al (2011) investigates the effect of technique parameters in turning of Titanium grade 2 on conventional machine. Three parameters specifically pivot speed, profundity of cut and feed rate are varied to look at their effect on material removal rate and tool disillusionment. The preliminaries are driven using each factor thus approach. In addition, a few sporadic examinations are in like manner passed on to inspect the wonder of tool frustration. The assessment reveals that material ejection rate is truly influenced by all the three methodology parameters. At any rate the effect of shaft speed and feed rate is more when stood out from profundity of cut. A perfect extent of data parameters has been separated as a definitive outcome for finishing further investigate.[10]

S. Pahda, S. et.al (2011) analyzed surface harshness by considering the cutting parameters like cutting velocity, feed rate and profundity of cut. The CNC turning machine is used to direct tests experimentation is EN-8 steel with 150 mm length and 35 mm separation over. Taguchi technique has been used for organizing and optimization of the examination. Moreover, Minitab 16 writing computer programs is in like manner being used to lead ANOVA test to predict the immensity level for singular parameter and it has been found that the cutting rate is most gigantic parameter contributing towards surface unpleasantness sought after by profundity of cut the significance of these results was finally checked by performing demonstrative assessment as suggested by the Taguchi technique.[11]. M. Vellibor et.al (2011) presented Taguchi solid parameter plan for displaying and optimization of surface unpleasantness in dry single-point turning of infection moved blend steel 42CrMo4/AISI 4140 using TiN-secured tungsten carbide installs. Three cutting parameters, the cutting speed (80, 110, 140 m/min), the feed rate (0.071, 0.196, 0.321 mm/fire up), and the profundity of cut (0.5, 1.25, 2 mm), were used in the preliminary. All of various parameters was taken as steady. The typical surface unpleasantness (Ra) was picked as an extent of surface quality. The examination was organized and did dependent on standard L27 Taguchi symmetrical cluster. The instructive file from the investigation was used for driving the optimization frameworks, as showed by the models of the Taguchi system. The delayed consequences of figurings were in extraordinary simultaneousness with the exploratory data. A particular dissimilarity between the exploratory results and figures could be deciphered as the proximity of estimation bumbles, various inconsistencies and deficiencies in the turning technique, similarly as biological impacts. The results showed in this work assert the ampleness of Taguchi's methodology in optimization of cutting techniques.[12]

J.S. Senthilkumaar et.al (2010) used Inconel 718 to improve surface unpleasantness and flank wear in complete turning. Slicing examinations were coordinated by the full factorial structure under dry cutting conditions. The effects of the machining parameters on the show evaluations surface unpleasantness and flank wear were investigated. The association between the machining parameters and the presentation measures were set up using the non-straight backslide examination. Taguchi's optimization examination shows that the components level, its criticalness to affect the surface harshness and flank wear for the tuning and defying structures. Attestation tests were aimed at a perfect condition to make an assessment between the preliminary outcomes anticipated from the referenced connections.[13]. H. Yanda et al (2010) investigate the effect of the cutting pace, feed rate and profundity of cut on material departure rate (MRR), surface harshness, and tool life in customary turning of adaptable cast iron FCD700 assessment using TiN shrouded cutting tool in dry condition. The machining condition parameters were the cutting rate of 220, 300 and 360 m/min, feed pace of 0.2, 0.3 and 1mm/fire up, while the profundity of cut (DOC) was kept consistent at 2 mm. The effect of cutting condition (cutting pace and feed rate) on MRR, surface unpleasantness, and tool life were examined and researched. Preliminaries were coordinated reliant on the Taguchi plan of examinations (DOE) with symmetrical L9 exhibit, and after that sought after by optimization of the results using Analysis of Variance (ANOVA) to find the most outrageous MRR, least surface unpleasantness, and most noteworthy tool life. The perfect MRR was gotten when setting the cutting rate and feed rate at high

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characteristics, yet the perfect tool life was landed at when the cutting pace and feed rate were set as low as could be normal the situation being what it is. Low surface fulfillment was gotten at high cutting rate and low feed rate.[14]

2.1 Objective of the Proposed Research Work

In this study, multiple response parameters are optimized to get the accuracy of the product, enhance the productivity and process reliability. In order to improve the process performance, experiments were conducted on turning operation on titanium for investigating the effect of surface roughness during process. A Taguchi method based on the basic underlying philosophy of Taguchi methodology was used to optimize the process and confirmation experiment was conducted to verify the optimal condition. The main objectives of the proposed research work are given below:

- To understand the effect of control parameters of EDM-Drill on output process.
- To determine the optimum level of control parameters for high MRR, less EWR, less OC and less TA simultaneously to operate the EDM-Drill more efficiently.
- To validate the experimental result based on the confirmation experiment

3. Experimentation:

The experimentation is as systematic and scientific and scientific approach to manipulate one or more output variables and control or measure the input variables. Every experimenter must plan and conduct experiments to obtain enough and relevant data. Modern industry promotes the use of alternative advanced materials (composites, super alloys, and ceramics) for establishing design and manufacturing. AISI 4147 that is precipitation hard enable, due to the additions of Aluminumis given as-

Table 1 Properties of Experimental Work piece

Properties	Monel K-500
Density	7.85g/cm^3
Melting point	1427 C
Coefficient of expansion	13.7µm/m^0C(20-100^0C)
Modulus of rigidity	66KN/mm^2
Modulus of elasticity	179KN/mm^2

AISI 4147 having good resistance to oxidation and corrosion at high temperature, extensively used in pump shafts, fasteners, marine propeller shafts, oil well tools, instruments & springs. The chemical composition of AISI 4147 is given as-

Table 2 Chemical Composition of Monel K-500

Element	Fe	C	Si	Mn	Cr
Concentration (weight %)	96.73	0.45	0.30	0.75-1.0	1.1

3.1 Taguchi Philosophy

Calibrations to existing cost of doing business in space indicate that to establish human presence on the Moon and Mars with the Space Exploration Initiative (SEI) will require resources, felt by many, to be more than the national budget can afford. In order for SEI to succeed, we must actually design and build space systems at lower cost this time, even with tremendous increases in quality and performance requirements, such as extremely high reliability. This implies that both government and industry must change the way they do business. Therefore, new philosophy and technology must be employed to design and produce reliable, high quality space systems at low cost. In recognizing the need to reduce cost and improve quality and productivity, Department of Defense and National Aeronautics and Space Administration (NASA) have initiated Total QualityManagement (TQM).

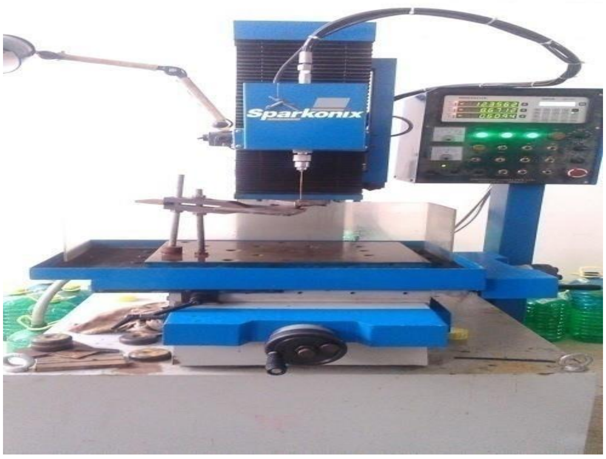

Figure.2 EDM-Drill machine

TQM is a revolutionary management strategy in quality assurance and cost reduction. TQM requires complete management commitment, employee involvement, and use of statistical tools. The quality engineering methods of Dr. Taguchi, employing design of experiments (DOE), is oneof the most important statistical tools of TQM for designing high quality systems at reduced cost. Taguchi methods provide an efficient and systematic way to optimize designs for performance, quality, and cost.

4. Result and Discussion:

This paper presents experimental results for individual and multi-response optimisation of Monel K-500.

The graphs between the control parameters and response parameters were obtained using Minitab 16 software.

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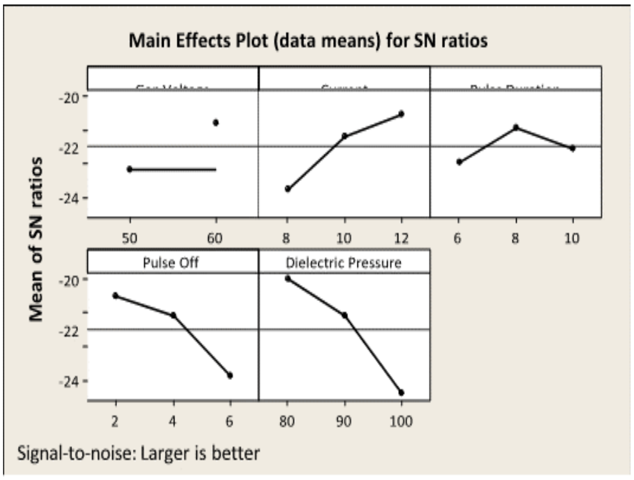
4.1 Variation of MRR with Control Parameters

Table 3 SNR Table of MRR (* indicates the optimum level of control parameter)

Control Parameter	Level-1	Level-2	Level-3
V	-24.37	-21.63*	-
I	-25.55	-22.37	-21.09*
T_{ON}	-23.96	-21.93*	-23.11
T_{OFF}	-21.05*	-22.19	-22.17
P_D	-20.04*	-22.17	-26.79



Figuew.3 SNR plot for MRR

4, Conclusions:

Conclusions for surface roughness

In the experiment Taguchi L9 design was used to study the effect of spindle speed, feed rate and depth of cut on surface roughness in dry and wet condition.

Conclusions from surface roughness in dry surface

The Surface roughness is mainly affected by feed rate, depth of cut and spindle speed. With the increase in feed rate the surface roughness also increases, as the depth of cut increases the surface roughness first increase and decrease and as the spindle speed increase surface roughness decreases. Also, it is observed from the S/N ratio graph that surface roughness minimizes at a combination of spindle speed = 300 rpm, feed = 0.4 mm/rev. and Depth of cut = 0.8 mm which gives a surface roughness of 2.18.

Conclusions from surface roughness in wet surface

The Surface roughness is mainly affected by depth of cut, feed rate and spindle speed. With the increase in depth of cut the surface roughness also increases, as the feed rate decreases and as the spindle speed increase surface roughness decreases. Also, it is observed from the S/N ratio graph that surface roughness minimizes at a combination of spindle speed = 160 rpm, feed = 0.4 mm/rev. and Depth of cut = 0.9 mm which gives a surface roughness of 2.10.

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