WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Taguchi Method-Based Experimental Analysis of Surface Roughness in Titanium Turning Operations

Kamlesh Kushwaha[1], Rajesh Kumar Ahirwar[2]

[1]M.Tech Scholar, Department of Mechanical Engineering, VIST Bhopal M.P. India
[2]Assistant Professor, Department of Mechanical Engineering, VIST Bhopal M.P. India
[1]kamlesh.kushwaha52@gmail.com , [2]rajesh.ahirwal0124bits@gmail.com

ABSTRACT

This study investigates the surface roughness characteristics during the turning of Titanium Grade 2 using a systematic experimental approach. Due to its low thermal conductivity, titanium retains heat at the cutting interface, which adversely affects tool life and limits its machinability. Key machining parameters—cutting speed, feed rate, and depth of cut—significantly influence surface finish and tool performance during titanium turning operations.

In this research, an L8 orthogonal array from the Taguchi method is employed to design experiments efficiently, using two levels for each parameter. The turning operations are carried out under dry conditions on a CNC lathe, utilizing various cutting inserts including CNMG 0.4, CNMG 0.8, Inconel, and diamond. Surface roughness measurements are taken for each experimental setup, with three trials per condition to ensure accuracy and repeatability. The average values of surface roughness are used for analysis.

Minitab version 15 software is utilized for designing the experimental layout and conducting statistical analysis. Signal-to-noise (S/N) ratios are calculated to identify optimal parameter settings for minimizing surface roughness. The experimental results indicate that the combination of low depth of cut and high cutting speed yields the best surface finish. The study demonstrates that the Taguchi method is an effective tool in optimizing turning parameters with a reduced number of experimental runs, thus saving time and resources while improving machining outcomes.

Keywords: Turning, Orthogonal array,Surface roughness,TaguchiMethod,Signal-to-noise,CNC.

INTRODUCTION:-

MANUFACTURING

Manufacturing refers to the transformation of raw materials into finished products to meet human needs and demands. This transformation involves various processes that alter the material's shape, size, and physical properties. Depending on the desired outcome, different manufacturing methods are applied to metals to achieve the required specifications and performance characteristics.

1. **Metal Casting:**
   Casting is a manufacturing process in which metal is heated until it becomes molten and then poured into a mold cavity. Once the metal cools and solidifies, it takes the shape of the mold, forming the desired component.
2. **Metal Forming and Molding:**
   In this process, simple metal shapes are transformed into more complex forms through plastic deformation. The material is reshaped by applying compressive forces using tools or dies. Common techniques include rolling, forging, extrusion, drawing, sheet metal forming, powder metallurgy, and other shaping methods.
3. **Joining Processes:**
   These methods involve the temporary or permanent union of similar or dissimilar materials. Common joining techniques include welding, brazing, soldering, diffusion bonding, adhesive bonding, and mechanical fastening.
4. **Machining:**
   Machining involves the removal of excess material to achieve the desired shape and dimensions. It includes operations such as turning, drilling, boring, milling, planing, shaping, broaching, grinding, and others.

5. **Finishing Operations:**
   Finishing processes are used to enhance the surface quality of a material. These include honing, lapping, buffing, polishing, deburring, coating, and plating techniques, which improve appearance, functionality, or corrosion resistance.

Material Property Alteration Processes:

These processes involve modifying the properties of materials to achieve desired characteristics and performance. Common techniques include hardening, quenching, annealing, and case carburizing, which are used to enhance strength, toughness, ductility, or surface hardness.

1.Advanced Manufacturing Processes:

Advanced manufacturing involves non-conventional machining techniques that go beyond traditional methods. These include ultrasonic machining, abrasive jet machining, chemical machining, electrical discharge machining (EDM), electrochemical machining (ECM), and high-energy beam machining. These processes are often employed for materials that are difficult to machine using conventional techniques or when precision and complex geometries are required.

1.1 Overview of Machining

Machining, particularly metal cutting, is one of the most widely used manufacturing processes in the metalworking industry. It involves the removal of material from a workpiece to achieve the desired shape and dimensions, typically through the action of a cutting tool. In any metal cutting process, the tool cuts by overcoming the shear strength of the work material. As the shear strength increases, the force required by the machine and tool components also rises. Additionally, parameters such as cutting speed, feed rate, and depth of cut directly influence the mechanical load on the cutting tool.

The energy consumed during machining is primarily converted into heat, which is distributed between the workpiece, the cutting tool, and the surrounding environment. This heat generation and distribution significantly affect tool wear and the quality of the machined surface.

Machining is critical across nearly all manufacturing sectors due to its ability to produce high-precision and high-quality components. Cutting tools used in machining can be categorized as single-point or multi-point tools. Operations like turning and shaping use single-point cutting tools, while processes such as milling and drilling utilize multi-point cutting tools.

Several factors critically influence the efficiency and quality of metal cutting processes, including:

1. Properties of the work material
2. Material composition of the cutting tool
3. Tool geometry
4. Cutting speed
5. Feed rate
6. Depth of cut
7. Type and application of cutting fluids

In this research, the machining of commercially pure Titanium is performed using a single-point cutting tool. It is observed that using a higher rake angle can reduce cutting forces and improve machinability. However, there is a practical limit to increasing the rake angle—beyond a certain point, the tool tip may lose strength and its ability to dissipate heat efficiently at the tool-chip interface diminishes. In cutting tool design, zero rake angles are often used, as they provide greater strength to

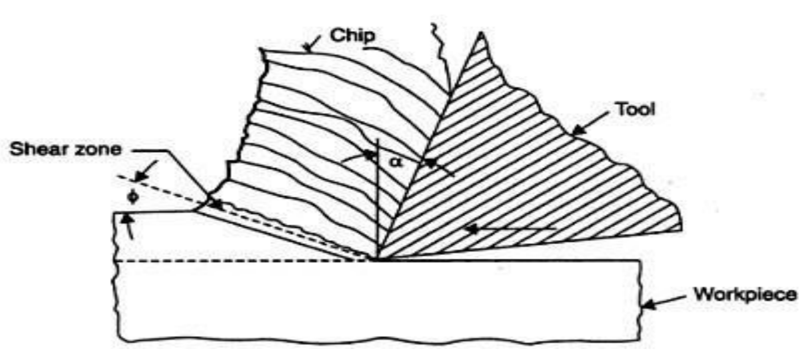

Figure 1

the tool tip during machining operations. During the cutting process, plastic deformation occurs near the cutting edge, forming what is known as the *shear zone*. The plane along which this deformation takes place is referred to as the *shear plane*. A schematic representation of the metal cutting mechanics in a turning operation using a single-point cutting tool is illustrated in **Figure 1**.

The automotive and aerospace industries face significant challenges and show strong interest in using materials with enhanced mechanical properties. In aerospace applications, super alloys particularly nickel-based and titanium alloys are commonly used for manufacturing critical engine components due to their superior strength, heat resistance, and performance under extreme conditions. In fact, nickel-based super alloys alone account for approximately 50% of the total material weight used in aerospace parts. Other advanced engineering materials, such as structural ceramics and tantalum, are also increasingly used to meet the demanding requirements of aerospace engine manufacturing.

EXPERIMENTAL SETUP & METHODOLOGY

Theobjectivesofthepresentworkhavejustbeenmentionedintheforgoingsection.Accordingly the present examination has been done through the following plan of experiment.

1. CheckingandpreparingCNCLathepreparedforperformingthemachiningoperation.
2. CuttingTitaniumbycontrolsawandperforminginitialturningoperationinLathetogetdesireddimension (of diameter 50 mm and length 85 mm) of the work pieces.
3. Performingturningoperationonspecimensinvariouscombinationsofprocedurecontrol parameters like: spindle speed, feed and depth of cut.
4. Lengthofcutwaskeptsteadyat 30 mm.
5. Measuringsurfaceroughnessandsurfaceprofilewiththeassistanceofaconvenientstylus-type profilometer, Talysurf (Taylor Hobson, Surtronic 3+, UK).

MATERIAL USED

PureTitaniumGrade2isusedasthetestspecimeninthisresearchwork.Titaniummaterial specifications are checked and confirmed with the local authorized laboratories for confirmation. The test specimensizes are 50 mm in diameter and 85 mm in length. These test specimens are turned in a CNC lathe by varying the process parameters to study the responses in LMW Smart Turn CNC lathe.

Table Chemical Composition of Titanium grade 2 in%

N	C	H	Fe	O	Al	Ni	Ti
0.03	0.1	0.015	0.3	0.25	-	-	Bal

EXPERIMENTALSETUP

WORK PIECE DIMENSION

The diameter of bar is 50 mm and of length 85 mm. The size was measured with the help of digital vernier caliper. The experiment was done on a piece eight times of Pure Titanium Grade 2 having same composition to measure the value of surface roughness and to determine which value of cutting parameters will be optimum to minimize it. The cutting parameters considered in this research work are cutting speed, feed, and depth of cut. The responses observed and measured against these cutting parameters are surface roughness. The figure shows a typical test specimen used in this research work.

Picture of work piece material

MACHINE USED

Side Base CNC Lathe machine with coated cemented carbide cutting tool was used in the experiments. Cutting speed, feed rate and depth of cut were selected as the machining parameters to analyze their effect on surface roughness.

TOOL INSERT DESCRIPTION

The cutting tool holder PCLNR2020 used in this research work for machining Titanium material has CNMG 0.8 Inconel inserts. The cutting tool inserts are clamped on the tool holders and then used for machining purposes. The cutting edge once machined is replaced by a new cutting edge or a new insert. The performance of these cutting tool materials in assessment of surface roughness and cutting temperature are studied in this work. A typical machining operation

performed by the cutting tool on to the work piece material is shown in Figure.

CNC lathe

MACHINING PARAMETERS AND LEVELS

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L8 Orthogonal Array (OA) design have been selected using MINITAB 17 software. The machining parameter levels are chosen based on the recommendations of the industrial experts and manufacturers. In this research work two levels of the three cutting parameters viz., cutting speed, feed and depth of cut are selected and presented in Table .

Symbol	Machining Parameters	SIUnit	Levels	
			Low	High
v	Cutting speed	m/min	250	300
f	Feed	mm/rev	0.075	0.375
d	Depthofcut	mm	0.1	0.5

Table Machining parameters and their levels

DESIGN OF EXPERIMENT

Experiments have been carried out using Taguchi's L8 Orthogonal Array (OA) experimental design which consists of 8 combinations of spindle speed, longitudinal feed rate and depth of cut. According to the design catalogue prepared by Taguchi, L8 Orthogonal Array design of experiment has been found suitable in the present work. It considers two process parameters (without interaction) to be varied in three discrete levels. The experimental design has been shown in Table.

Table Combination of process parameters using orthogonal array

Experiment No.	A	B	C
1	1	1	1
2	1	1	2
3	1	2	1
4	1	2	2
5	2	1	1
6	2	1	2
7	2	2	1
8	2	2	2

Table machining parameters combination

Sl.No	Cutting Speed_v' m/min	Feed_f' mm/rev	Depthofcut _d' mm
1	250	0.075	0.1
2	250	0.075	0.5
3	250	0.375	0.1
4	250	0.375	0.5
5	300	0.075	0.1
6	300	0.075	0.5
7	300	0.375	0.1
8	300	0.375	0.5

Conclusions and Future Scope

In this study, an L8 orthogonal array was utilized to design and conduct eight experimental runs for evaluating machining parameters. The investigated process parameters included cutting speed**,** feed rate, and depth of cut, each set at two levels. The selected levels were:

- Cutting speed**:** 250 m/min (low) and 300 m/min (high)
- Feed rate**:** 0.075 mm/rev (low) and 0.375 mm/rev (high)
- Depth of cut**:** 0.1 mm (low) and 0.5 mm (high)

These parameter combinations were developed using factorial design in Minitab software. Surface roughness was recorded as the primary response variable.

To identify significant factors and interactions, the experimental data was analyzed using Analysis of Variance (ANOVA)**.** The findings revealed that:

- The interaction between cutting speed and depth of cut had a major influence on surface roughness, contributing **16.4%** to the variation.
- This was followed by the cutting speed and feed interactionwith a **7.8%** contribution, and the feed and depth of cutinteraction, contributing **2.4%**.

The ANOVA results also reported an R-squared value of 95.6%, indicating a high level of model accuracy and reliability.

However, a separate interaction analysis showed slightly different dominance:

- The feed and depth of cut interaction contributed **18.2%**,
- Followed by cutting speed and depth of cut at **1.4%**,
- And finally, cutting speed and feed with less than **1%**.

These discrepancies highlight the complexity of interaction effects in machining processes, suggesting that multiple interactions may need to be considered simultaneously for accurate prediction and optimization.

Future Scope

Future work could expand on this study by:

- Incorporating more levels for each parameter to capture non-linear effects.
- Including additional process parameters such as tool material, cutting environment, or tool wear.
- Applying advanced optimization techniques like genetic algorithms or machine learning models for predictive analysis.
- Extending the study to other difficult-to-machine materials beyond titanium for broader applicability.

REFERENCES

[1] Pytlak, B.; (2020) "Multicriteria optimization of hard turning operation of the hardened18HGTsteel", InternationalJournal Advance Manufacturing Technology, Volume 49: pp. 305-312.

[2] Sieben,B.,Wagnerite.andBiermann,D.;(2010),,"Empiricalmodelingofhardturningof AISI6150steelusingdesignandanalysisofcomputerexperiments",ProductionEngineering ResearchDevelopment,Volume4:pp.115-125.

[3] Cappellini,C.,Attanasio,A.,Rotella,G.andUmbrello,D.;(2020)"Formationofdarkand white layers in hard turning: influence of tool wear", International Journal of Material Forming, Volume 3 No.1: pp. 455 - 458.

[4] D. Philip Selvaraj, P. Chandramohan; (2020) "Optimization of surface roughness of AISI 304 Austenitic stainless steel in dry turning operation using Taguchi design method", Journal of Engineering Science and Technology, Volume 5, No. 3: pp 293-301.

[5] R. Ramanujam, R. Raju, N. Muthukrishnan; (2019) "Taguchi-multi machining characteristics optimization in turning of Al-15% SiC_pcomposites using desirability function analysis", Journal of Studies on Manufacturing, Volume 1 Issue2-3: pp 120-125.

[6] J.S. Senthilkumaar, P. Selvarani, RM. Arunachalam; (2010) "Selection of machining parametersbasedontheanalysisofsurfaceroughnessandflankwearinfinishturningand facing of Inconel 718 using Taguchi Technique", Emirates Journal for Engineering Research, Volume 15, No.2: pp 7-14.

[7] H. Yanda, J.A. Ghani, M.N.A.M. Rodzi, K. Othman and C.H.C. Haron; (2010) "Optimizationofmaterialremovalrate,surfaceroughnessandtoollifeonconventionaldry turning of FCD 700", International Journal of Mechanical and Materials Engineering, Volume 5 No. 2: pp 182-190.

[8] D. Mittal, M.P. Garg, R. Khanna; (2011) "An investigation of the effect of the process parameters on MRR in turning of pure Titanium (Grade -2)", International journal of Engineering Science & Technology, Volume 3 No. 8: pp 6345-6349.

[9] S. Pahda, S. M Sharma, N. Malhotra; (2011) "Analysis of variance and Optimization of surfaceroughnessinCNCTurningofEN-8steelbyTaguchimethod",InternationalJournal of Advanced Engineering Technology, Volume 3 Issue 1: pp 264-267.

[10] M.Vellibor,M.milos;(2011)"Optimizationofsurfaceroughnessinturningalloysteelby using Taguchi method", Scientific Research and Essays, Volume 6(16): pp 3474-3484.

[11] S. Khrais, A.M. Hassan, A. Gazawi; (2011) "Investigations into the turning parameters effect on the surface roughness of flame hardened medium carbon steel with TiN-Al_2O_3- TiCN coated inserts based on Taguchi techniques", Word Academy of Science, Engineering and Technology, published online: pp 2137-2141.

[12] U. K. Yadav, D. Narang, P.S. Attri; (2012) "Experimental investigation and optimization of machining parameters for surface roughness in CNC turning by Taguchi method", International Journal of Engineering Research and Applications, Volume 2 Issue 4: pp2060-2065.

[13] M.V.Ramana,A.V.Vishnu,G.K.M.Rao,D.H.Rao;(2012)"Experimentalinvestigations, optimizationofprocessparametersandmathematicalmodelinginturningofTitaniumalloy underdifferentlubricantconditions",JournalofEngineering,Volume2Issue1:pp86-101.

[14] K.Hassan,A.Kumar,M.P.Garg;(2012)"ExperimentalinvestigationofMaterialremoval rateinCNCturningusingTaguchimethod",InternationalJournalofEngineeringResearch and Applications, Volume 2 Issue 2: pp 1581-1590.

[15] R.K.Patel,H.R.Prajapati;(2012)"ParametricAnalysisofSurfaceroughnessandMaterial removal rate of Harden steel on CNC Turning using ANOVA Analysis: A Review", International journal of Engineering Science and Technology, Volume 4 No. 7: pp 3111- 3117.

[16] B Kumaragurubaran, P Gopal (2013), "Optimization of Turning Parameters of En-9 Steel UsingDesignofExperimentsConcepts",InternationalJournalofMechanicalEngineering and Robotics Research, Vol. 6, Issue7, PP: 182-190.

[17] Sachin C Borse (2014), "Optimization of Turning Process Parameter in Dry Turning of SAE52100 Steel", International Journal of Mechanical Engineering and Technology, Volume 5, Issue 1, PP: 1-8.

[18] KaushalPratap Singh, GirishDuttGautam, RupeshYadav, LalitBisht, GavendraNorkey (2014), "Selection of Optimum Machining Parameters for EN36 Alloy Steel in CNC Turning Using Taguchi Method", International Journal of Scientific & Engineering Research, Volume 5, Issue 3, PP: 976- 982.

[19] Aswathy V G, Rajeev N, Vijayan K (2015), "Effect of machining parameters on surface roughness, material removal rate and roundness errorduring the wet turning ofTi-6Al-4V alloy", International Journal of Applied Sciences and Engineering Research, Vol. 4, Issue 1, PP: 1-10.

[20] **[20]**SaurabhSinghvi, M.S. Khidiya, S. Jindal, M.A. Saloda (2016), "Investigation of Material Removal Rate in Turning Operation", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 5, Issue 3, PP: 2890-2895.