OPTIMIZATION OF SURFACE ROUGHNESS IN TURNING OPERATION IN MACHINING OF TI-6AL-4V
(Titanium grade -5)
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Abstract: - In the present scenario the productivity and the quality of the machining products are the main important challenges of metal cutting or in production industry during turning processes. Due to which manufacturing industries are competing in the market field. In the improvement of output quality of the product, the optimization technique like Taguchi’s method is a very good tool and effective method to improve performance and quality of manufacturing industries. This paper presents optimization parameters such as cutting speed, depth of the cut and feed in the dry conditions of titanium grade-5 materials and PVD carbide tool. To achieve minimum tool wear the surface temperature of the workpiece should be low. The experiment design or design of experiment based on the Taguchi’s L9 orthogonal array technique was performed to identify the effect of cutting parameters on the different response variables. The results of the turning machining experiments of titanium-grade-5 characterize the main factors affecting the surface roughness by analysis of variance (ANOVA) method. The minimum tool wear was found at a lower speed and the feed rate was found to be the most significant parameters to influence the surface roughness of grade -5 materials in turning process.

Keywords: Titanium, Taguchi optimization technique; Turning; Cutting force; Surface roughness;

1. Introduction
In the present scenario, the productivity is a key strategy’s for the manufacturing industries to compete in the competitive world or in the global markets. The main aim to achieve increase the productivity with the availability of the raw materials and some of the very good high precession technologies and maintenance system used in the world-class industries. In industries, the maintenance and production cost are rapidly increases in from past few years. The production cost is increased due to the improper planning system, overtime costs, improper method of usage of work order system and improper preventive maintenance system etc... The production quality is majority influenced by different machining parameters. The cutting tool wears due to the lower quality of the product. The metal cutting industries need to increase the quality of the products and reduce the cost of production, wastage effectively. The many variables which affect the quality and manufacturing costs, tool geometry, coating technology used in inserts, parameters of the cutting systems, lubrication system used in machining operations.

The titanium grade-5 (Ti-6Al-4V) material or alloy most widely used in the titanium grade. It is an alpha+beta two-phase alloy, aluminum as an alpha and vanadium as a beta stabilizer. The alloy significantly stronger than any other titanium, the alloy which has high strength at a temperature about 427°C in an annealed condition. It has very good resistance to corrosion and a good choice for offshore gas and fuel operations where the sea water is concern. Titanium is produced by melting by vacuum arc process. This has a good corrosion resistance, high strength, excellent fatigue resistance and nonmagnetic but low thermal expansion.
The optimization system is used to controllable variables make to consider to contribute to solving the problems which the manufacturing industries facing to get an optimal solution the above facing problem by using the Taguchi's method and it will help to reduce the number of tests to conduct and to run the trial and error methods. Which help to reducing the manufacturing cost significantly and time loss will be minimized. Now a day’s the Taguchi's methods are applied in both companies and academics. The main goal is to increase the manufacturing product quality with the minimal operating system at good efficiency.

The main aim of this experiments work is to the investigation of the effects of different cutting parameters on the titanium grade-5 workpiece surface roughness and tool inserts wear by Taguchi's method. The effect of machining parameters on the surface roughness of the turning titanium grade-5 by PVD coated carbide inserts was investigated. For optimizing machine condition like cutting speed, cutting feed and depth of cut for the minimum surface roughness and tool wear. The L9 array was used for conducting the test. The Taguchi signal to noise ratio was used to analyses predict the measured values by the linear regression. Finally, the model was tested by the confirmation test.

2. Literature review

Literature survey is required to understand the specific objective of the research work. The previous research which gives clear contain and clear ideas about the work. Dong Gao [1] et al, are the major contributor of TCM, they have defined Tool condition monitoring by statistical processing as an innovative approach to wear monitoring that optimizes quality of the work piece and tool life by operators through day-to-day activities involving the total workforce Alan Hase et al [2] has investigated systemic study of the cutting parameters which affect the materials and tool optimized by taguchi’s methods. Valerie G. Cook et al [3] have studied about the machining behavior of cutting operation by using the PVD coated carbide tools using orthogonal array system in turning operation and find the cutting temperatures which influence the surface roughness of the materials. Satyanarayana Kosaraju [4] et al have applied the optimal technique like taguchi’s to find optimum solution at minimum experiments. J. Bhaskaran et al[5] have investigate the Anova regression model analysis to optimize the machinability of the materials using L16 array taguchi’s method for different stages they used different response system to minimize the optimization the experimental values gives the 4% error in machining characteristic’s and feed rate and depth of cut influence on the materials more. Feng Ding. et al [6] have evaluate the machining parameters using the vibration analysis to find the wear rate of tools at different cutting conditions the feed rate is more influence on the surface of the materials by the vibration signal analysis. Ahmet Cakan et al [7] have used the taguchi’s method and regression equation to evaluate the machinability of the materials was using PVD and CVD inserts. The performance of the machinability parameters on the surface roughness and flank wear to optimize by using taguchi’s techniques to get minimum values of surface roughness the feed rate is dominate the major role in the surface roughness. X. Q. Chen et al [8] have optimized the surface roughness in the machinability of the AISI 4140 alloy steel by the taguchi’s L24 array technique evaluated the feed rate and depth of cut which dominate the major role with the help of S/N ratio significated on the surface roughness of the materials Xiaozhi Chen. et al. [9] have studied the experiments were conducted on the lathe machine, and find out the effect of depth of cut, speed and feed rate on surface roughness as well as tangential cutting forces which acting on cutting tool while turning. Feed and speed which more influence factor which affected on the surface roughness of the materials. P Kulandaivelu [10] have performed the Machine turning operations on the mild steel bar materials under the dry condition by using the taguchi’s L9 array technique they characterized the different machinability condition to find the tool wear and surface roughness by using PVD inserts for the better performance compare to CVD inserts hence the feed rate cause surface roughness of the materials. The several researches are focus on the hard machinability materials like titanium alloy for different charteristics by using statically techniques to get more reliability of the models under different cutting conditions.
3. Experimental details

3.1 Workpiece Materials
The specimen used in the experiment was Titanium grade-5 (Ti-6Al-4V) in the form of round bar having length 150mm and diameter 60mm. Titanium grade-5 (Ti-6Al-4V) was selected due to its very high range of application like military application, spacecraft & aircraft application, medical devices, premium sports equipment’s, sports cars and highly stressed components like connecting rods, torsion springs etc. the chemical composition of titanium grade-5 (Ti-6Al-4V) alloy is given in the table.

|    | Al  | Fe  | Mn  | No | V   | Ti  |
|----|-----|-----|-----|----|-----|-----|
|    | 6.32| 0.50| 0.05| 1  | 4.12| 87.96|

3.2 Cutting Inserts
This turning experiments were conducted by using coated carbide inserts. PVD-coated insets having ISO-Designation of CNMG120408 (80° Diamond shaped insert) without chip breaker geometry. The cutting inserts are bolted to a right-hand tool holder having the ISO designation PCLNR 2525 M12.

![Figure 1. CNMG120408 insert (PVD) with Tool holder PCLNR 2525 M12](image1.png)

3.3 Surface Roughness Measurements
The surface roughness (Ra) of the Titanium grade-5 workpiece was measured by a portable type of surface tester. Surface roughness was measured in three different parts of workpiece immediately after turning the workpiece.

![Figure 2. Surface roughness measurements](image2.png)

3.4 Experimental Procedure
The experiments are carried out on the panter lathe under Dry condition. The lathe which having the maximum spindle speed of 1250rpm. With the help of tailstock to support the workpiece. The main
aim of the test was to analyze the cutting parameters effects on tool wear and surface temperature and roughness of titanium grade-5 alloy. The experimental design was by using the Taguchi's L9 array which helps in reducing the experiments. With the help of the array identify the cutting parameters like speed, depth of cut and feed rate.

![Experimental setup](image)

4. Results and discussions
The experimental test was conducted on the basis of the Taguchi's L9 orthogonal array system with the help of Minitab soft wear. The table which shows the different cutting input parameters for machining of Titanium grade-5 material with PVD coated carbide inserts. The output response which obtained from the turning operations of titanium bar is tabulated in the table with corresponding S/N ratio.

| Levels | Cutting Speed | Feed Rate | Depth of cut |
|--------|---------------|-----------|-------------|
|        | Vc (m/min)    | f (mm/rev)| a_p (mm)    |
| 1      | 30            | 0.046     | 0.1         |
| 2      | 40            | 0.093     | 0.15        |
| 3      | 50            | 0.125     | 0.2         |

4.1 Analysis of S/N ratio
Signal to noise ratio is to measure used in the engineering system. That compares the level of the desired signal to the noise ratio. The Taguchi's orthogonal array techniques are used to measure the input values for the optimum solutions and signal to noise ratio is to be larger values. There will be three characteristics like i) smaller the better, ii) larger the better and iii) nominal is better. In this experiments, cutting force, surface roughness are mapped by using quality characteristics like smaller the better.
Where \( y \) is the measured value and \( n \) is the number experimental test conducted in which input parameters having high signal to noise ratio which gives the least variance and quality of the system.

| Sl No | \( a_p \) | \( V_c \) | \( f \) | Output Response | \( S/N \) Ratios |
|-------|---------|---------|------|----------------|----------------|
| 1     | 0.1     | 30      | 0.046| 2.53           | 164.85         |
| 2     | 0.1     | 40      | 0.093| 3.26           | 173.01         |
| 3     | 0.1     | 50      | 0.125| 4.77           | 186.15         |
| 4     | 0.15    | 30      | 0.046| 2.77           | 368.68         |
| 5     | 0.15    | 40      | 0.093| 3.06           | 296.66         |
| 6     | 0.15    | 50      | 0.125| 4.09           | 153.66         |
| 7     | 0.2     | 30      | 0.046| 2.69           | 283.8          |
| 8     | 0.2     | 40      | 0.093| 3.88           | 153.24         |
| 9     | 0.2     | 50      | 0.125| 4.99           | 220.8          |

4.2 Analysis of Variance (ANOVA)

The individual process parameters will be determined by using ANOVA Minitab software. ANOVA is techniques which investigate the effect of machining process parameters and in taguchi’s technique cannot trust for determine the effect of individual process parameters will be in percentage contribution and some of the factors influence the design model. The ANOVA table is consists of sum squares (SS), mean squares (MS), degree of freedom (DOF), P-value, F-value and percentage contribution.

4.3 Analyses of Variance (ANOVA) for coated tool insert machining with titanium grade-5

| Source | DF | SS  | MS  | \( F \) | P  | \%  |
|--------|----|-----|-----|--------|----|-----|
| \( a_p \) | 2  | 2.1824 | 1.092 | 1.22   | 0.45 | 5.7 |
| \( V_c \) | 2  | 34.063 | 17.0315 | 19.06 | 0.05 | 88.92 |
| \( f \) | 2  | 0.2748 | 0.1374 | 0.15   | 0.867 | 0.72 |
| Error  | 2  | 1.7871 | 0.8935 |        |      | 4.67 |
| Total  | 8  | 38.3072 |       |        |      | 100 |

| Source | DF | Adj SS | Adj MS | F-Value | P-Value | \% Cont |
|--------|----|--------|--------|---------|---------|---------|
| \( a_p \) | 2  | 16.701 | 8.350  | 8.32    | 0.107   | 26.47   |
| \( V_c \) | 2  | 14.034 | 7.017  | 6.99    | 0.125   | 22.25   |
| \( f \) | 2  | 30.346 | 15.173 | 15.11   | 0.062   | 48.1    |
| Error  | 2  | 2.008  | 1.004  |         | 3.18    |         |
| Total  | 8  | 63.09  |        |         |         | 100     |
From the ANOVA table, from the table no 5 the speed which contribute the 88.92% which is the most significant cutting parameters which influence on the surface roughness and followed by the depth of cut at 5.7%. However the feed rate at least efficacy of 0.72% which controlling the surface roughness of the materials and it is also not statistically significant to influence.

From the ANOVA table no 6 shows that the P-value of feed rate is 0.062 which are very less than the 0.1. It shows that depth of cut which influence significantly on the cutting force on tool. The depth of cut and cutting speed which has been contribute more on the tool are 26.47% and 22.25% but the biggest contribution came from the feed rate is about 48.1 % which is not significant. The contribution of error is 4.67% and 3.18% for surface roughness and cutting force respectively.

4.4 Mean Effect Plots
For the analysis the data to study the amount of cutting parameters and the main effect plots on the surface roughness were analyzed. With the help of Minitab soft wear shows the variation of individual response with three machining parameters separately. In the plots X-axis indicates the values of cutting machining parameters and Y-axis denotes the response value. The plots are used to find the design condition for surface roughness.

![Main Effect Plots](image)

Figure 4. Main effect plots for surface roughness for PVD coated carbide Insert

Figure 4 shows that the MEP for surface roughness, the graph shows that increase the depth of cut significantly roughness also increases in smaller rate, but when the speed increases there will be continuous increases in surface roughness. A feed rate increases there is decrease the surface roughness.

![Surface Roughness based on the S/N Ratio](image)

Figure 5. Surface Roughness based on the S/N Ratio for PVD coated carbide tool
Figure 5 shows that the S/N Ration for surface roughness, the graph shows that increase the depth of cut significantly roughness also decreases, but when the speed increases there will be continuous fall down in surface roughness. A feed rate increases there is increases the surface roughness.

![Main effect plots](image)

**Figure 6.** Main effect plots (a) and S/N ratio (b) for cutting force for PVD coated carbide Insert

Figure 6 shows that the MEP for cutting force, the graph shows that increase the depth of cut significantly cutting force also decreases, but when the speed increases there will be continuous decreases in cutting force. A feed rate increases there are increases the cutting force. Figure 6 shows that the S/N Ration for cutting force, the graph shows that increase the depth of cut significantly force also increases, when the speed increases there will be continuous increases in force. A feed rate an increase there is decreases the surface roughness.

**Table 7.** Optimal Conditions

| Optimal parameters for coated inserts | \(a_p\) | \(V_c\) | \(f\) |
|--------------------------------------|--------|--------|------|
| \(R_a\)                             | 0.15   | 30     | 0.046|
| \(F_z\)                             | 0.1    | 50     | 0.046|

**Table 8.** Response table for S/N ratio for Surface roughness Smaller the best

| Level | \(a_p\) (depth of cut) | \(V_c\) (speed) | \(f\) (feed rate) |
|-------|------------------------|-----------------|------------------|
| 1     | -10.632                | -8.502          | -10.691          |
| 2     | -10.266                | -10.585         | -11.025          |
| 3     | -11.445                | -13.256         | -10.627          |
| Delta | 1.178                  | 4.753           | 0.399            |
| Rank  | 2                      | 1                | 3                |

**Table 9.** Response table for S/N ratio for cutting force Smaller the best

| Level | \(a_p\) (depth of cut) | \(V_c\) (speed) | \(f\) (feed rate) |
|-------|------------------------|-----------------|------------------|
| 1     | -44.83                 | -48.25          | -43.93           |
| 2     | -48.17                 | -45.97          | -47.66           |
| 3     | -46.55                 | -45.34          | -47.97           |
| Delta | 3.34                   | 2.91            | 4.04             |
| Rank  | 2                      | 3               | 1                |
The table no 8 and 9 shows the response for the signal to noise ration of different cutting condition for smaller is better. The response table no 8 shows that the speed rate is significantly dominate the machining performance whereas compare to given different higher values. The table no 9 S/N ratio indicates that feed rate is significantly contributing more of the machining performance in the cutting fore condition and followed by the Depth of cut and speed.

4.5 Confirmation Test

After the experimental tests, applying the Taguchi’s method with ANOVA successfully. It is found that the optimum condition from the taguchi’s L9 array obtained the values, based the optimum values the conformation test was conducted and to validate the results in table 10. The predicated experimental values gives less error and it found to be good.

| Sl No | ap | Vc | f   | Ra   | Fz   | Ra   | Fz   |
|-------|----|----|-----|------|------|------|------|
| 1     | 0.15 | 30  | 0.046 | 2.56 | 186.45 | -0.26 | -48.17 |

5. Conclusions

In this experimental study the taguchi’s array method is used to determine the optimal cutting parameters in the turning of Titanium grade-5 with PVD coated carbide inserts. With the help of ANOVA the experimental test results are evaluated.

- According to experimental results the taguchi’s technique determines the optimum machining cutting condition acheives the low surface roughness and low cutting speed.
- According to the test the percentage contribution of speed (88.92%), depth of cut (5.7%) which the larger value affect the surface roughness of materials and the feed rate is 0.72% is smaller value.
- In the cutting force the significant parameters of work piece were feed rate which contributes 48.1%, depth of cut 26.47% and speed 22.25% respectively. These parameters influence the cutting force.
- According to the confirmation experimental test results, the measured values shows the minimum values of the surface roughness and cutting speed.

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