Selection of optimal controllable factors for surface roughness in turning of titanium alloy using eco friendly cutting fluids

M.Venkata Ramana
Department of Automobile Engineering
VNR Vignana Jyothi Institute of Engineering & Technology, Hyderabad, India
mandalavenki@gmail.com

Abstract: Surface finish plays a vital role in service components, to ensure a great reliability of sensitive aeronautical components, surface integrity of titanium alloys should be satisfied. Therefore, it is required to optimize process parameters like cutting speed, feed and depth of cut while machining of titanium components for better surface finish.

In this study, the optimization and effect of machining parameters on surface roughness in a turning operation is investigated by using the Taguchi’s robust design methodology. The experimental studies are conducted under varying cutting speeds, feed rates and depths of cut. An orthogonal array, analysis of mean (AOM) and the analysis of variance (ANOVA) are employed to study the performance characteristics in the turning of commercial Ti-6Al-4V alloy using uncoated carbide cutting tool with karanja and rice bran oils as coolants. The results observed that the feed rate is the most influential factor on the surface roughness for both karanja and rice bran oils. The minimal surface roughness value is observed for karanja oil than that of rice bran oil. The optimum process parameters found for karanja oil at a cutting speed of higher level, feed rate of lower level and depth of cut is of moderate level. Similarly, the optimum process parameters found for rice bran oil at a cutting speed of higher level, feed rate of lower level and depth of cut of higher level.

1. Introduction
Titanium and its alloys are useful materials but rarely used till 1940s. These are alloyed with manganese, molybdenum, aluminum and iron. By its weight, the strongest readily available material for extensive range of practical applications. Mostly, titanium alloys used where weight and strength is an issue. Automobile, aerospace, structural components, medical, surgical instruments and bicycle frames are some of the examples. Titanium alloys are commonly used due to its resistance to corrosion. Titanium alloys are being used in variety of manufacturing areas, however complicatedness is facing during metal cutting because of its large chemical reactivity and less thermal conductivity. Uncoated carbide tips are mostly used for Titanium and its alloys machining.

The alpha - phase Titanium alloys are more ductile and beta - phase Titanium alloys are stronger yet low ductile. The alpha - beta phase Titanium alloys are having mechanical properties in between both α and β phases. Titanium grade 5, also known as Ti6Al4V is the mostly used alloy. It consists of 6% Aluminium, 4% Vanadium and the remainder is Titanium.
Cutting fluids are applied during the machining process and this leads to consumption of energy and ecological harms due to dissociation of chemical in cutting fluid at elevated cutting temperature and skin irritations to the operators. Researchers are trying to replace conventional cutting fluids with biological oils in the recent years. Biological cutting fluids have some superior features as compared to the mineral based cutting fluids. These fluids reduced consumption of fluids due to high viscosity, minimized health hazardous to operators and reduced bio-contamination.

Surface finish is a significant parameter of product feature since it significantly controls the performance of mechanical components and price. Surface finish influences the useful features of components like friction, wear, electrical conductivity, heat transmission, lubrication, etc. Some of parameters which influence the surface finish are machining parameters such as depth of cut, feed rate, cutting speed and the geometry of tool like side cutting edge angle, rake angle, and nose radius. The surface roughness also depends on cutting tool and job material arrangement, quality of the machine tool, their mechanical properties and cutting fluid applied. There are various roughness factors in use, but average surface roughness (Ra) is the most general.

Venugopal et al. [1] have done the investigation on tool life and wear of uncoated carbide inserts in machining of Ti6Al4V alloy with cryogenic, dry and wet surroundings. A significant enhancement in life of the tool was observed with cryogenic medium as compared to flooded and dry machining. Samir et al. [2] have used coated tungsten carbide tools and experiential wear manners of the coated tools with flooded and dry machining. Dry cutting is better than wet machining of Ti6Al4V with coated inserts under high cutting speed. Hari et al. [3] observed the effect of controllable factors on tool wear. It is found that, the chosen factors significantly influenced on tool wear. These results are validated within the meticulous range of parameters and for the specific combination of tool and work material. Bermingham et al [4] researched on the effectiveness of cryogenic coolant during turning of Ti6Al4V with constant speed and different combinations of feed rate and depth of cut. Sulaiman et al [5] conducted dry machining with different combinations of cutting speed and feed rate. The cutting speeds and feed rates were chosen for the experiments and depth of cut was fixed at 0.5 mm. The wear of the tool was observed with microscope and the values of flank wear were noted. The results specified that the flank wear increased by raising feed and cutting speed. Nikhil et al [6] examined the wear profile of uncoated tools with dry, cryogenic and flooded environmental circumstances in turning C60 steel. The results were contrasted with flooded and dry machining. These results of the work indicated that considerable decrease in wear, which enhanced the life of the tool, surface finish and accuracy.

Dhar et al [7] studied the function of cryogenic coolant on surface finish, dimensional accuracy, tool wear and surface roughness in turning of AISI 4140 steel. The cryogenic coolant enabled considerable decrease in cutting temperature and good tool - chip interaction. This significantly decreased flank wear, improved life of the tool, dimensional accuracy and surface finish. Nambi et al [8] examined the influence of cutting fluid on machinability of titanium alloy in terms of tool wear with ceramic insert in machining of Ti6Al4V alloy at modest cutting speed without and with the use of servo cut 'S' water soluble coolant. The results tend to decrease wear and reduce adhesion of the work substance on the tool and as well improve the surface profile.

After thorough literature review, it proposed to carry out the work on turning of Ti6Al4V. It is proposed to optimize process parameters, analyze the effect of process factors on quality characteristics and compare surface roughness obtained by using karanja and rice bran oils as coolants.

2. Methodology

Taguchi's methodology can be employed for improving surface quality of the components at low cost. Dr. Taguchi build on the work of Plackett and Burman by combining statistics and engineering to achieve rapid improvements in product designs and manufacturing processes. His efforts led to a subset of
selecting experiments commonly referred to the Taguchi Method. Taguchi calls common cause variation the “noise”. Taguchi’s approach is not to eliminate or ignore the noise factors; Taguchi techniques aim to reduce the effect impact of the noise on the product quality. The Loss Function can help put the cost of deviation from target into perspective. The signal to noise ratio provides a measure of the impact of noise factors on performance. The larger the S/N, the more robust the product is against noise. Calculation of the S/N ratio depends on the experimental objective: Bigger-the-Better, Smaller-the-Bigger, Nominal-the-Better. Taguchi designs have been developed to study factors at two-levels, three-levels, four-levels and even with mixed levels. Types of Taguchi Designs include two-level designs the L4, L8, and L16 matrices. Taguchi screening designs for three levels exist. The L9 looks at 4 factors at 3 levels. An L27 can be used to study up to 13 factors at 3 levels and an L81 can evaluate up to 40 factors at 3 levels. The linear graph is a graphical tool that facilitates the assignment of factors and their interactions to the experimental matrix. Some experimenters find the interaction tables developed from the linear graphs to be easier to use. This methodology is based on the theory of optimization in which the goal function is defined in terms of Signal to Noise ratio this uses in arrival optimum factors at which the response is minimum responsive to various effects of the noise factors. In this work, Taguchi methodology is used to arrive the optimum parameters from chosen the process parameters. The Minitab 16.0 is employed to attain results for Analysis of Mean and Analysis of Variance.

3. Experimental design and setup
The idea of present work is to obtain the optimum values for the controllable parameters to enhance surface finish. Therefore, an effort is made in the present work to optimize process parameters viz. depth of cut, feed rate, cutting speed and also improve the machinability of Ti-6Al-4V alloy in turning using uncoated carbide inserts under various combinations of parameters with karanja oil and rice bran oil as coolants. The machining tests are carried on lathe TURNMASTER 35 as shown in figure 1. Original name of karanja oil is Pongamia oil. Karanja oil is derived from the seeds of the Millettia pinnata tree. It has been used as lamp oil, in leather tanning, in soap making and as a lubricant for thousands of years. Rice bran oil is the oil extracted from the hard outer brown layer of rice after chaff (rice husk). It is notable for its high smoke point of 232 °C (450 °F) and its mild flavor, making it suitable for high-temperature cooking methods such as stir frying and deep frying. It is popular as cooking oil. Rice bran oil is edible oil which is used in the preparation of vegetable ghee. Rice bran oil is a vegetable oil. It is highly viscous, non-toxic, non-hazardous, good thermal conductivity, oxidative stability and easily available. In this work, Taguchi method has been used to arrive best combination of the machining parameters to improve surface roughness.

Figure 1. Kirloskar lathe TURNMASTER35
3.1. Selection of controllable parameters and levels

The three controllable factors with three levels are selected as the control factors and the levels are adequately far part to cover wide range. The control parameters selected are cutting speed (A), feed rate (B) and depth of cut (C). The parameters and their levels are given in Table 1. Selection of specific orthogonal array (O.A) depends on the number of parameters, levels of each parameter and the total degrees of freedom. Stand on this, the necessary least number of experiments to be performed are seven, the closest O.A. satisfying this situation is $L_9$. This accommodates a three control factors each at three levels with nine experiments. The orthogonal array $L_9$ is given in Table 2.

| Table 1. Controllable factors and levels |
|----------------------------------------|
| Factors/Levels | Cutting Speed, $V$ (mpm) (A) | Feed rate, $F$ (mm/rev) (B) | Depth of cut, $D$ (mm) (C) |
|----------------|-------------------------------|-------------------------------|-------------------------------|
| 1              | 40                            | 0.18                          | 0.2                          |
| 2              | 70                            | 0.2                           | 0.6                          |
| 3              | 105                           | 0.25                          | 1.0                          |

3.2. Experimentation

The straight turning experiments are performed with various combinations of machining process parameters as per orthogonal array given in Table 2. The diameter and length of the workpiece used in this work is 30 mm and 100 mm respectively. The jobs used for the experimentation are shown in figure 2.

| Figure 2. Workpiece material |
|-----------------------------|

| Table 2. Standard $L_9$ orthogonal array |
|-----------------------------------------|
| Exp.no. | Column | $V$ (m/min) | $F$ (mm/rev) | $D$ (C) | (Ra) µm |
|------|-------------|-------------|-------------|--------|--------|
| 1    | 1 1 1       | 40          | 0.18        | 0.2    | 1.9995 | 2.4095 |
| 2    | 1 2 2       | 40          | 0.20        | 0.6    | 2.6325 | 3.4245 |
| 3    | 1 3 3       | 40          | 0.25        | 1.0    | 4.2520 | 3.6640 |
| 4    | 2 1 2       | 70          | 0.18        | 0.6    | 2.3125 | 2.2190 |
| 5    | 2 2 3       | 70          | 0.20        | 1.0    | 2.8025 | 2.3750 |
| 6    | 2 3 1       | 70          | 0.25        | 0.2    | 4.1520 | 4.0765 |
| 7    | 3 1 3       | 105         | 0.18        | 1.0    | 2.1025 | 2.1625 |
| 8    | 3 2 1       | 105         | 0.20        | 0.2    | 2.4415 | 2.5185 |
| 9    | 3 3 2       | 105         | 0.25        | 0.6    | 3.294  | 3.8105 |
The roughness of the surface (Ra) is measured with Mitutoyo make surftest SJ310 as shown in figure 3. It has good accuracy, quick measurement. The measured surface roughness using karanja and rice bran oils are given in Table 2.

4. Results and discussions
The aim of this work is to improve to surface roughness; therefore smaller the better type quality characteristic is chosen for the response.

4.1. Optimization of machining process parameters
Taguchi’s methodology is fruitfully employed to arrive the optimum machining factors from the selected controllable parameters in sort to reduce the surface roughness. Figure 4 and 5 represent the end result of analysis of mean response graph. In main effect plot for means, the level of factor with the lowest mean value is the optimal level. Analysis of data is performed using design experiments and optimum process parameters found are shown in Table 3. These optimum factor combinations are confirmed by performing confirmation test, these results are inside the selected range of foretell value and may be considered in the actual purposes.

![Figure 4. Main effects plots for Karanja oil](image)
![Figure 5. Main effects plot for rice bran oil](image)

### Table 3. Optimum process parameters for surface roughness

| Process Parameter | Karanja oil | Rice bran oil |
|-------------------|-------------|---------------|
| Cutting speed (m/min) | 105 | 105 |
| Feed rate (mm/rev) | 0.18 | 0.18 |
| Depth of cut (mm) | 0.6 | 1.0 |

Using optimum factors and additive model of Taguchi’s design, the predicted surface roughness can be found by using equation (1)

Additive model for prediction of surface roughness = \( Y + (\bar{A}_x - Y) + (\bar{B}_x - Y) + (\bar{C}_x - Y) \) (1)

where \( x \) is the optimum process parameter.

The predicted surface roughness for karanja oil is 1.724 μm. By using optimum process parameters the validation experiment is conducted and surface roughness is 1.78 μm. Similarly using equation 1, the predicted surface roughness for rice bran oil is 2.09 μm and result of validation experiment is 2.10 μm. The predicted and confirmation experiment values are contrasted for soundness of the optimum parameters. It is established that confirmation investigation is inside the limits of the foretell value and the aim is satisfied. Hence, these recommended optimum parameters can be implemented.
4.2. Influence of control parameters on surface roughness
The analysis of variance is conducted to discover the effect of machining factors on surface roughness as given in Table 4. It is experiential that the feed rate is controlling more (89.2%) on surface roughness followed by cutting speed and depth of cut for karanja oil. From ANOVA Table 5, it is found that the feed rate is controlling more (95.1%) on surface roughness followed by depth of cut and cutting speed for rice bran oil.

| Parameter | SS     | DoF | MSS   | F-ratio | % of contribution |
|-----------|--------|-----|-------|---------|-------------------|
| A         | 0.6484 | 2   | 0.3242| 11.83   | 6.0               |
| B         | 9.6211 | 2   | 4.8105| 175.55  | 89.2              |
| C         | 0.220  | 2   | 0.110 | 4.05    | 2.05              |
| Error     | 0.3014 | 11  | 0.0274|         | 2.79              |
| Total     | 10.7929| 17  |       |         | 100               |

| Parameter | SS     | DoF | MSS   | F-ratio | % of contribution |
|-----------|--------|-----|-------|---------|-------------------|
| A         | 0.0853 | 2   | 0.0426| 2.43    | 1.0               |
| B         | 8.0676 | 2   | 4.0338| 230.20  | 95.1              |
| C         | 0.1350 | 2   | 0.0675| 3.85    | 1.6               |
| Error     | 0.1928 | 11  | 0.0175|         | 2.27              |
| Total     | 8.4806 | 17  |       |         | 100               |

Where SS - Sum of Squares, DoF - Degrees of freedom, MSS – Mean Sum of Squares

4.3. Comparison of surface roughness between karanja oil and rice bran oil
The figure 6 shows that, surface roughness obtained by using karanja oil as coolant is less as compared to the rice bran oil for most of the experimental conditions. Hence from these results it is refined that, karanja is the superior choice as a coolant than that of rice bran oil due to excellent cooling, heat carrying and low coefficient of friction properties.

5. Conclusions
From these experimental investigations the subsequent conclusions are drawn
- The optimum process parameters found for karanja oil to minimize the surface roughness are cutting speed at 105 mpm, feed rate at 0.18 mm/rev and depth of cut at 0.6 mm. and the optimum surface roughness under these conditions is 1.78 µm.
The optimum process parameters found for rice bran oil to minimize the surface roughness are cutting speed at 105 m/min, feed rate at 0.18 mm/rev and depth of cut at 1.0 mm and the optimum surface roughness under these conditions is 2.10 µm.

Feed rate is more influencing factor on surface roughness for both karanja and rice bran oils.

The karanja oil as a coolant is a better choice than the rice bran oil to get minimum surface roughness.

6. References

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