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Study Of Machinability Of Titanium Alloy (Ti-6Al-4V) In High Speed Turning Process Using Steam As A Coolant

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Abstract **— In this paper we proposed The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of dimensional accuracy, surface finish, high production rate and cost saving, with a reduced environmental impact. Such goals are strongly affected by several elements among one of them is the cooling lubricant. Many authors have investigated the machinability with coolant in machining with flood coolant, MQL and cryogenic cooling and it is observed that surface finish, cutting forces, chip formation and tool wear are all affected with the type of coolant, cutting speed, feed rate and depth of cut. Very little investigation in water vapor as coolant is available in the literature hence the water vapor as a coolant has been selected to explore the machinability of titanium alloy with the introduction of this environmental friendly coolant.**

Keywords – Flood coolant, Cryogenic cooling, and Environmental friendly coolant

I .Introduction

In view of this, an attempt is made to investigate the machinability of titanium alloy using water vapor as a coolant system. The experimental study revealed that at higher cutting speed the chips become more ductile and show continuous morphology with serrated tooth because of increased temperature of shear zone and concentrated shear in the deformation zone. It is observed that chip thickness ratio and cross sectional area of the chip is increased with increase in feed rate for all cutting speeds. Good surface finish is obtained when snarled and ribbon type chips are formed. Pitch of the chip is decreased as speed is increased for all feed levels. Chip segmentation frequency is higher at the higher speed of 180m/min for feed rates of 0.08 and 0.32 mm/rev. It is observed that the machined surface produced at 60 m/min cutting speed has higher values of surface roughness. However further increase in the cutting speed to 120 m/min and again at 180 m/min causes little reduction in the surface roughness. The above trend might be due to the increase in the machining temperature, which leads to thermal softening and consequent restructuring of the machined surface layer. Thus the machined surface shows lower roughness due to less flaws/alterations on the surface. The effect of feedrate on surface roughness shows that at 0.08 mm/rev feed rate, surface roughness is less and it increases with an increase in the feedrate. This might be due to higher cross sectional area that involves in deformation and thus surfaces show more alterations and higher surface roughness is due to higher deformation of the machined surface layer. Feedmarks are visible at all cutting speeds from 60 m/min to 180 m/min. They are severe at 60 m/min and reduce at higher cutting speed of 180 m/min. This might be due to the increase in cutting speed that causes thermal softening of the work material. It is observed from the SEM analysis that the microparticles in larger size are visible at cutting speed of 60 m/min and comparatively smaller particles are visible at a cutting speed 120 m/min. The size of the particles was more at feedrate of 0.08 mm/rev and less at 0.32 mm/rev. At higher cutting speed of 180 m/min and feed rate of 0.32 m/min grooves are not appeared on the surface. Besides, plastic deformation on the top layer of machined surface is visible due to severe cutting conditions used during machining of Ti-6Al-4V alloy at 120 m/min and 180 m/min cutting speed.

In high-speed turning process, the quality of the machined surface depends on the process, workpiece and tool related parameters such as - cutting speed, feedrate, depth of cut and cutting fluid used while machining. These parameters significantly influence the performance measures such as chip formation mechanism (chip thickness ratio and chip segmentation frequency), surface roughness and surface damage. If there are multiple response variables, for the same conditions of independent variables, design of experiments provides separate optimum parametric conditions for each response variable. These conditions could be significantly different from each other, say for example, in machining, optimum condition for maximizing chip thickness ratio need not be the same as for minimizing surface roughness or chip segmentation frequency. In such circumstances, obtaining a solution that gives the best possible surface finish, at the highest possible chip thickness ratio is necessary. Therefore, design of experiments alone is not appropriate for such problems. On the other hand, grey relational analysis ranks the experiments based on the increasing order of their grey relational grade (GRG) and this GRG can be used to identify the most influencing factors affecting the response variables. The present investigation is focused on the improvement of surface topography in high-speed turning process. As the chip formation mechanism plays a major role in generation of machined surface. The mechanism of chip curl, chip thickness, frequency of chip segmentation affects the mechanism of surface generation and hence the resultant machined surface topography to considerable extent. Surface topography in turning process can be measured in terms of output variables such as surface roughness, chip thickness ratio and chip segmentation frequency. Each of these variables has different measurement unit that quantify the performance of the process individually. Thus comparison of the above output variables is not possible considering individual measurement unit. Hence, the multi-objective problem is converted into a single objective using grey relational principle.

II. Normalization of response variables

A normalization of the response variables was performed to prepare raw data for analysis where the original sequence is transferred to a comparable sequence. Linear normalization is usually required since the range and unit in one data sequence may differ from the others. As the original sequence of surface roughness is a problem of 'smaller-the-better' type. Hence 'the smaller-the-better' normalization formula was used to transfer original sequence to comparable sequence and is given below.

$$x_i^*(k) = \frac{\max x_i^{(o)}(k) - x_i^{(o)}(k)}{\max x_i^{(o)}(k) - \min x_i^{(o)}(k)} \quad (1)$$

Similarly for the chip thickness ratio the original sequence is a problem of 'larger the better' type. Hence the 'larger the better' type normalization formula is used to transfer original sequence to comparable sequence and is given below.

$$x_i^*(k) = \frac{x_i^{(o)}(k) - \min x_i^{(o)}(k)}{\max x_i^{(o)}(k) - \min x_i^{(o)}(k)} \quad (2)$$

For the chip segmentation frequency the original sequence is a problem of 'smaller the better' type. Hence the 'smaller the better' type normalization formula is used to transfer original sequence to comparable sequence. The values of normalization ($x_i*(k)$)of nine experimental runs are shown in Table 2. for surface roughness, chip thickness ratio and chip segmentation frequency. Table 1.Values of Ra, r.

Expt	Surface roughness (R_a)	Chip thickness ratio (r_c)	Chip segmentation frequency
1	0.328	0.568	9.31
2	0.933	0.604	21.99
3	2.634	0.654	15.18
4	0.399	0.561	14.20
5	0.863	0.729	27.68
6	2.244	0.517	13.47
7	0.432	0.469	24.79
8	0.936	0.607	11.26
9	2.034	0.810	29.51

$x_i*(k)$ values of surface roughness, chip thickness ratio, and chip segmentation frequency

Table 2.

Expt	Surface roughness $x_i*(k)$	Chip thickness ratio $x_i*(k)$	Chip segmentation frequency $x_i*(k)$
1	1	0.292	1
2	0.7376	0.395	0.372375
3	0	0.543	0.709296
4	0.9692	0.270	0.757854
5	0.7680	0.763	0.090756
6	0.1691	0.142	0.793922
7	0.9549	0.000	0.233576
8	0.7363	0.404	0.903594
9	0.2602	1.000	0

A. Determination of Deviation Sequences, $\Delta 0_i$ (k)

The deviation sequence, $\Delta 0_i$ (k) is the absolute difference between the reference sequence $x_0*(k)$ and the comparability sequence $x_i*(k)$ after normalization. The value of $x_0*(k)$ was considered as 1. It is determined using Eq. 3 as given below. The values of deviation sequences for surface roughness, chip thickness ratio and chip segmentation frequency for all nine experimental runs are shown in Table 3.

$$\Delta 0_i(k) = |x_0*(k) - x_i*(k)| \qquad (3)$$

$\Delta 0_i$(k)values of surface roughness, chip thickness ratio, and chip segmentation frequency ,

Table 3.

Expt.	Surface roughness $\Delta 0_i$ (k)	Chip thickness ratio $\Delta 0_i$ (k)	Chip segmentation frequency $\Delta 0_i$ (k)
1	0	0.708	0
2	0.2624	0.605	0.627625
3	1	0.457	0.290704
4	0.0308	0.730	0.242146
5	0.2320	0.237	0.909244
6	0.8309	0.858	0.206078
7	0.0451	1.000	0.766424
8	0.2637	0.596	0.096406
9	0.7398	0.000	1

III. CALCULATION OF GREY RELATIONAL COEFFICIENT, GRC

Grey relational coefficients (GRC) for all the sequences express the relationship between the ideal (best) and actual normalized response variables. If the two sequences agree at all points, then their grey relational coefficient is 1. The grey relational coefficient $\gamma(x_0(k), x_i(k))$ can be expressed by

$$\gamma(x_0(k), x_i(k)) = \frac{\Delta \min + \zeta \Delta \max}{\Delta_{0i}(k) + \zeta \Delta \max} \qquad (4)$$

where $\Delta \min$ is the smallest value of $\Delta 0_i(k)$ $= \min_i \min_k |x_0*(k) - x_i*(k)|$ and $\Delta \max$ is the largest value of $\Delta 0_i(k)$ $= \max_i \max_k |x_0*(k) - x_i*(k)|$, $x_0^*(k)$ is the ideal normalized S/N ratio, $x_i^*(k)$ is the normalized comparability sequence and ζ is the distinguishing coefficient. The value of (ζ) is taken as 0.5 for all response variables and is substituted in Eq. 4. The GRC for all the experimental runs are calculated.

Grey relational coefficient for the response variables Table 4.

Sample	GRC for Surface roughness	GRC for chip thickness ratio	GRC for chip segmentation frequency
1	1.0000	0.4138	1.0000
2	0.6558	0.4526	0.4434
3	0.3333	0.5226	0.6323
4	0.9419	0.4066	0.6737
5	0.683	0.6786	0.3548
6	0.3757	0.3681	0.7081
7	0.9172	0.3333	0.3948
8	0.6547	0.4561	0.8384
9	0.4033	1.0000	0.3333

The overall assessment of the multiple performance characteristics is based on the grey relational grade. The grey relational grade is an average sum of the grey relational coefficient, which is defined as follows:

$$\gamma(x_0, x_i) = \frac{1}{m} \sum_{i=1}^{m} \gamma(x_0(k), x_i(k)) \qquad (5)$$

Where $\gamma(x_0, x_i)$ is the grey relational grade for the j^{th} experiment and m is the number of performance characteristics.

The grey relational grade $\gamma(x_0, x_i)$ represents the level of correlation between the reference sequence and the comparability sequence. If the two sequences agree at all points, then their grey relational coefficient is 1 everywhere, and therefore, their grey relational grade is equal to 1. The grey relational grade was determined by Eq. 5 and is shown in Table 5. A higher grey relational grade in Table 5 indicates that the corresponding condition is optimum. It is observed that the experiment #1 has the highest grey relational grade.

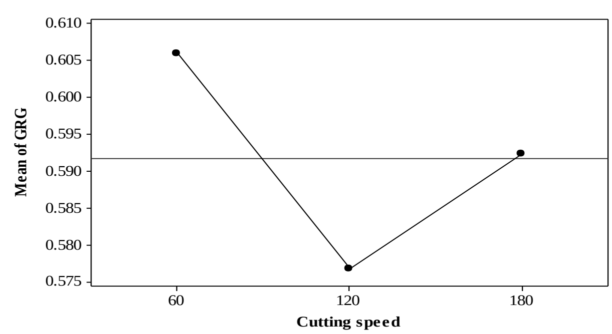
GRG of the multiple performance characteristics
Table 5

Expt	GRG
1	**0.8046**
2	0.5173
3	0.4961
4	0.6741
5	0.5721
6	0.4840
7	0.5484
8	0.6497
9	0.5789

Condition one is optimum i. e *V*= 60 m/min and *f* = 0.08 mm/rev

A. Effect of Cutting Speed on GRG

It observed from the mean effects plot that as cutting speed increases from 60 m/min to 120 m/min the grey relational grade decreases. Further increase in the cutting speed to 180 m/min causes increase in the grey relational grade. As the cutting speed increases chip thickness ratio decreases and chip segmentation frequency increases Fig.1 Effect of cutting speed



B. Effect of Feedrate on GRG

The effect of feed rate on grey relational grade shows that the feedrate has linear relationship with gray relational grade. It is observed that the gray relational grade decreases with an increase in the feed rate during machining. Fig. 2

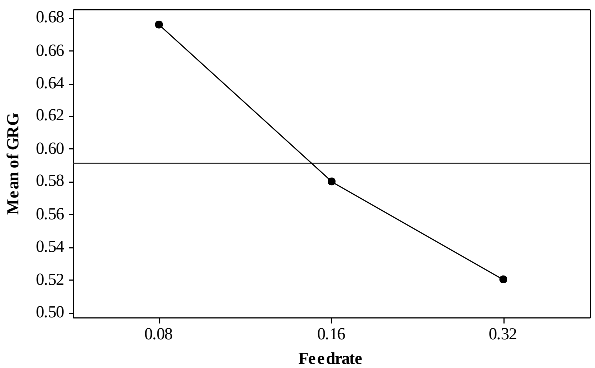


Fig. 2 Main effects plot for feederate.

C. Interaction between Cutting Speed and Feedrate

The effect of cutting speed and feedrate is shown in the Fig 3. It is seen from interaction plot that at highest feedrate the change in the value of grey relational grade is less when cutting speed changes from 60 m/min to 120 m/min. However it is found that the grey relational grade value decreases when feedrate changes from 0.08 mm/rev to 0.32 mm/rev at cutting speed of 60 m/min and 120 m/min, while it reaches for highest values at feedrate of 0.08 m/min and cutting speed 60 m/min.

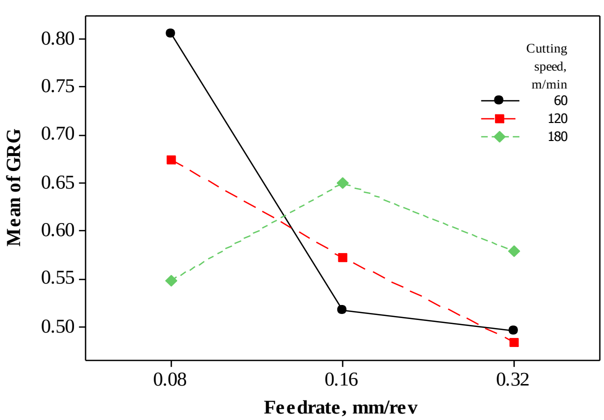


Fig. 3 Interaction between cutting speed and federate.

Analysis of Variance (ANOVA) for Gray Relational Grade

It is observed from the ANOVA Table that the feedrate influences the grey relational grade when compared to cutting speed.

Table 6 ANOVA for grey relational grade

Source	DF	SOS	MS	F - ratio	P - value
Cutting speed (V_c)	2	0.00129	0.00064	0.06	0.946
Feedrate f	2	0.03717	0.01858	1.63	0.304
Error	4	0.04572	0.01143		
Total	8	0.08418			
R-Sq = 45.68%					

IV CONCLUSION –

- It is observed that the feedrate and interaction between the cutting speed and feedrate shows significant influence on the chip thickness ratio.
- It is found that the cutting speed influences the chip thickness ratio, which in turn governs the chip morphology. It is observed that at lower and medium cutting speed of 60 m/min and 120 m/min respectively the chip thickness ratio follows the decreasing trend, however at higher cutting speed of 180 m/min, the trend is reversed. In this case, the chip thickness ratio increases and chips produced are of broken coiled and washer type. This might be due to the change in chip formation mechanism at higher cutting speed due to material deformation characteristics. It is further seen that the chips break frequently due to increase in the chip sliding velocity which might supersede the cutting velocity.
- The effect of feed rate on chip thickness ratio shows that the feed rate has almost linear relationship with chip thickness ratio. It is

observed that the chip thickness ratio increases with an increase in the feed rate during machining. At 0.08 mm/rev, the chip thickness ratio is less, and chip cross sectional area is also less. Chip shows tendency of snarled ribbon type morphology. The breaking of chips is more due to higher feed rates in this case. Further with an increase in the feedrate from 0.08 mm/rev to 0.16 mm/rev chip thickness ratio increases significantly. This might be due to increase in the undeformed chip thickness. Morphology of chip is snarled washer type. Further, increase in the feedrate from 0.16 mm/rev to 0.32 mm/rev causes increase in the chip thickness ratio and chip cross sectional area too.

- It is observed that the higher chip width and chip thickness ratio are produced when feed (0.32 mm/rev) and cutting speed (180 m/min) both are higher. However, lower value of chip thickness ratio was observed when the feedrate was lowest (0.08 mm/rev) level and the cutting speed (180 m/min) at the highest level.

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