

**A comparative study of cutting forces with Ti-6Al-4V and Inconel 718 using coated carbide tool with dry and wet high speed machining**Shubhangi S. Shetake¹, Rohit V. Zende²¹Assistant Professor, Mechanical Department, AISSMS COE, Pune²Assistant Professor, Mechanical Department, RIT, Islampur

Abstract- Titanium alloy Ti-6Al-4V and Nickel based super alloy Inconel 718 have been widely used in modern manufacturing. Titanium alloy Ti-6Al-4V and Nickel based super alloy Inconel 718 are extensively used in aerospace application, gas turbine, rocket and biomedical application, etc. A comparative experimental study on cutting forces of Titanium alloy Ti-6Al-4V and Nickel based super alloy Inconel 718 with carbide coated tool were conducted using same machining setup. The experiments were carried out under dry and wet cutting condition. Experiments were conducted by Full Factorial design to find the effect of Process parameters such as Cutting speed, Feed and Depth of cut on Feed force, Thrust force and Tangential force. Statistical method are used to estimate relation between output parameters Feed force, Feed force and Tangential force with input parameters Cutting Speed, Feed and Depth of cut. Regression analysis is performed and empirical relation is formed for Feed force, Thrust force and Tangential force. It has been observed that wet cutting condition reduces the cutting forces. Comparative study between Titanium alloy Ti-6Al-4V and Nickel based super alloy Inconel 718 shows that Feed force, Thrust force and Tangential force of Ti alloy Ti-6Al-4V are less than Inconel 718 for considered input parameters speed, Feed and Depth of cut.

Keywords- Ti-6Al-4V, Inconel 718, High speed machining, Cutting force, Carbide coated tool

I. INTRODUCTION

High speed machining (HSM) widely used for effective and efficient manufacturing process. High speed machining (HSM) used for improve the product quality, quantity means improve production rate as well as reducing manufacturing cost. The cutting speed mostly depending on the work, tool material and tool life in High speed machining. HSM is often 2-50 times higher than those employed in traditional machining (4).

Titanium and its alloys often high strength, high toughness, lightweight, heat and corrosion resistant, making it a widely employed material for manufacturing of different parts. The machining of titanium and its alloys with conventional machining processes is very difficult because of their high toughness and low thermal conductivity of these alloy the heat generated during machining remains accumulated near the machining zone(5).

Inconel 718 is high tensile strength, high hardness, increased fatigue resistance, light weight and corrosion resistance and oxidation resistance in jet engine and gas turbine application.

Water soluble cutting oil used in wet machining process. It comprises of mineral oil or fat mixtures and emulsifiers added to water. It has milky appearance. Water soluble cutting oil has excellent lubricating properties. It available in low cost.

Cantalin Fetecau, Felicia Stan *et al.* [1] studied the effect of the cutting parameters and insert radius on the cutting force and surface roughness of PTFE composite using a polycrystalline diamond tool. Satish Chinchankar, S. K. Choudhury *et al.* [2] examined effect of cutting force, surface roughness and tool life on hardened AISI 4340 steel at different level of hardness. They reported that the cutting forces affected mostly by depth of cut followed by feed. Wassila b Bouzid *et al.* [3] investigated effect of tool life, roughness and cutting forces of AISI 4340 steel. Four types of Vapor chemical deposited (CVD) insets have been used in this study. Suleyman Yaldiz, Faruk Unsacar *et al.* [4] studied the strain gauge based dynamometer has been designed and developed for measuring the cutting forces. It was observed machining forces acting on the workpiece during the process and investigated the cutting speed, tool geometry and vibration amplitude. Hamdi Aouici, Mohamed Athmane Yallese, Kamel Chaoui, Tarek Mabrouki, Jean Francois Rigal *et al.* [5] studied the effect of cutting speed, feed, depth of cut and workpiece hardness on surface roughness and cutting force component in hard turning. For this experiment selected AISI H11 steel workpiece machined using cubic boron nitride which is essentially made 57% CBN and 35% TiCN. Durul Ulutan, Tugrul Ozal *et al.* [6] studied to investigate the effect of speed, feed, depth of cut and tool geometry on surface quality of titanium and nickel alloy. Experimental studies used analytical and Finite element modeling for better understanding machining induced surface integrity.

In this study to investigate comparison on cutting forces of Titanium alloy Ti-6Al-4V and Nickel based super alloy Inconel 718 with carbide coated tool. Two Full Factorial based statistical approach is employed to investigate the relationship between various machining parameters and their response.

II. EXPERIMENTAL SET-UP AND METHODS OF MEASUREMENT

2.1. Experimental set-up

The experiments were conducted on High speed machine as shown in Fig 1. High speed machining was performed in dry and wet machining condition using high power precision NH 22 (HMT India) lathe was used for experiments. These experiments were performed on two materials Ti alloy Ti-6Al-4V and Nickel alloy Inconel 718 bar of 40mm diameter and length 600mm were used. The chemical composition and physical properties of Ti-6Al-4V are given in Table 1 and 2 respectively and Inconel 718 are given in Table 3 and 4 respectively. Coated carbide insert DNMG 15 06 08 SM 11 05 (Sandvik Grade 11 05) were used in the experimental work with clamp type PDJNR 25 25 M 15 (Sandvik Coromant) tool holder. A right hand style tool holder designated by ISO as PDJNR 25 25 M 15 was used for mounting the insert.



Figure 1. High speed machine

Table 1. Chemical Composition of Ti-6Al-4V

Element	Content in %	Element	Content in %
Ti	89.2	Cu	<0.0020
Al	5.63	Cr	0.018
V	4.54	Mn	<0.0045
Fe	0.099	Mo	<0.015

Table 2. Mechanical Properties of Ti-6Al-4V

Properties	Values
Density	4.43 g/cm ³
Melting Point	1604- 1660°c
Ultimate Tensile strength (Rm)	1020MPa
Elongation	14%
Rockwell Hardness	33HRC
Modulus of elasticity	120 GPa

Table 3. Chemical Composition of Inconel 718

Element	Content in %	Element	Content in %
Ni	50.00 - 55.00	Mn	0.35
Al	0.2 - 0.8	Cu	0.3
Cr	17 - 21	Nb	4.75 - 5.5
C	0.08	C	0.08
Co	1.0	Fe	Balance
Mo	2.8 - 3.3		

Table 4. Mechanical Properties of Inconel 718

Properties	Values
Density	8.2g/cm ³
Melting Point	2300 - 2437°C
Elongation	12%
Hardness	80 HRC

2.2. Method of measurement

The cutting forces accurately measured with a Kistler dynamometer 92578 as shown in Fig 2 and 3. It has Piezo electric dynamometer with large range (-5KN to 5KN) of direct measurement. This dynamometer consist great rigidity and consequently a high natural frequency. High resolution enables the smallest dynamic changes in large forces to be measured. The three components of cutting forces - Feed force (Fx), Thrust force (Fy) and Tangential force (Fz) is measured in this study.



Figure 2. Kistler dynamometer



Figure 3. Kistler dynamometer Set-up

III. EXPERIMENTAL DESIGN

In present study Speed (N), Feed (mm/rev) and Depth of cut (mm) were considered as a input parameters and Feed force (Fx), Thrust force (Fy) and Tangential force (Fz) taken as output parameters. Full Factorial design with four center points was used to carry out total number of 12 experiments for each machining condition. Table 5 presents the design factors and their selected variation levels.

Table 5. Machining parameters and level selected

Factor Level	Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
1	1210	152	0.45
0	930	117	0.3
-1	420	52	0.15

IV. RESULTS AND DISCUSSIONS

4.1. Effect of Speed, Feed and Depth of cut on Feed Force in machining of Titanium alloy (Ti-6Al-4V) and Inconel 718

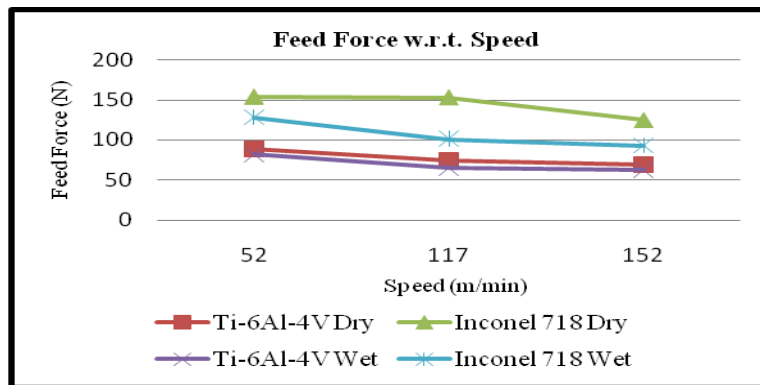


Figure 4. Effect of Speed on Feed Force for Dry and Wet Ti-6Al-4V and Inconel 718

Fig. 4 shows that F_x of Inconel 718 is increase as compared to Ti-6Al-4V. F_x with Inconel 718 machining in dry condition increases as compared to wet machining condition. F_x with Ti-6Al-4V machining in wet condition slightly decrease than dry machining condition. As the Speed increases, Feed force decreases.

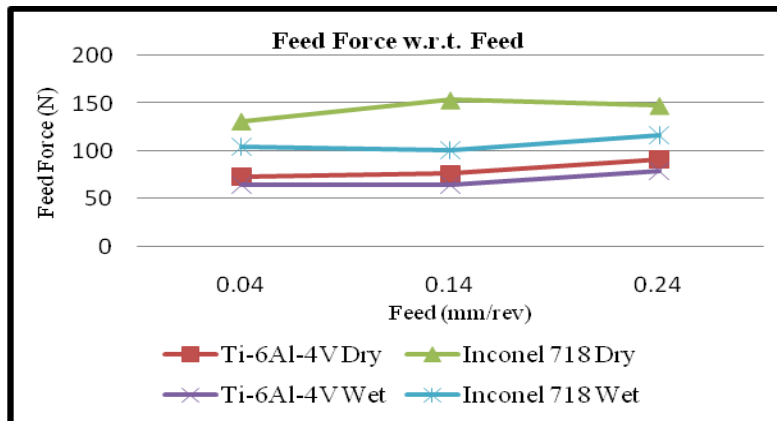


Figure 5. Effect of Feed on Feed Force for Dry and Wet Ti-6Al-4V and Inconel 718

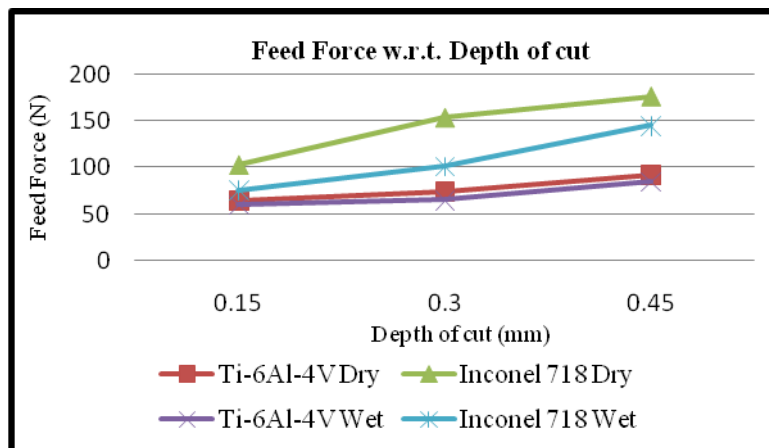


Figure 6. Effect of Depth of cut on Feed Force for Dry and Wet Ti-6Al-4V and Inconel 718

It is observed that the Fig. 5 & 6 as the Feed & Depth of cut increase there is increased in Feed Force with dry as well as wet machining. Feed force in dry machining condition for Inconel 718 higher than dry machining condition for Ti-6Al-4V.

4.2. Effect of Speed, Feed and Depth of cut on Thrust Force in machining of Titanium alloy (Ti-6Al-4V) and Inconel 718

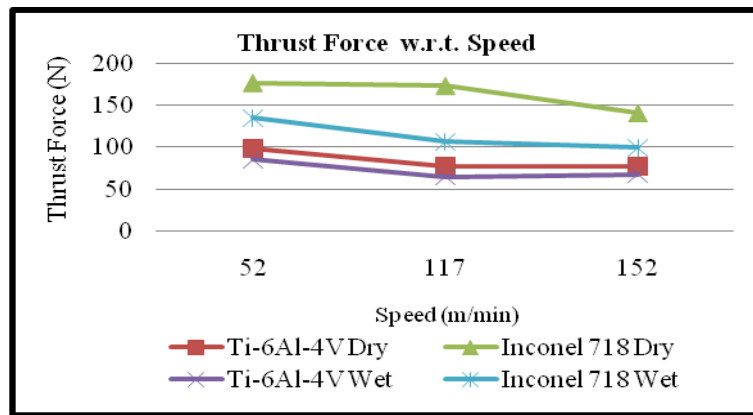


Figure 7. Effect of Speed on Thrust Force for Dry and Wet Ti-6Al-4V and Inconel 718

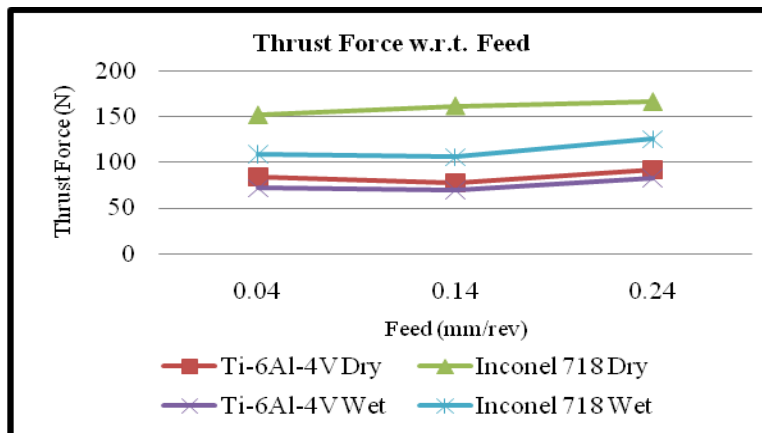


Figure 8. Effect of Feed on Thrust Force for Dry and Wet Ti-6Al-4V and Inconel 718

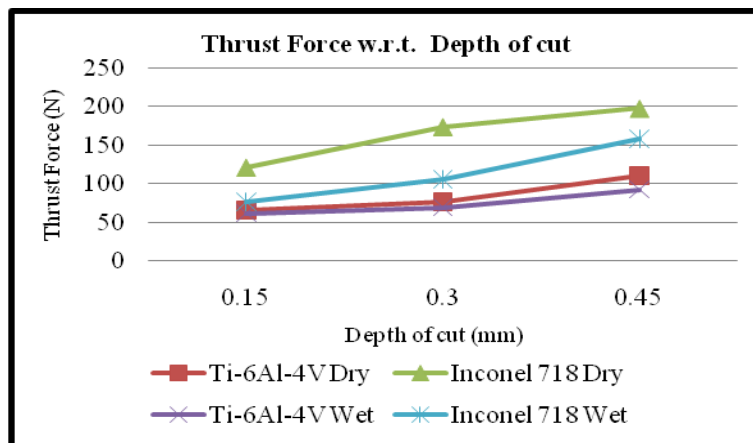


Figure 9. Effect of Depth of cut on Thrust Force for Dry and Wet Ti-6Al-4V and Inconel 718

As Speed increases, for both dry and wet conditions Thrust force decreases and with Feed & Depth of cut increases than start increases. Above figures shows that there is reduction in Thrust Force for Wet machining condition for Ti-6Al-4V and Inconel 718 compared to Dry machining condition for Ti-6Al-4V and Inconel 718.

4.3. Effect of Speed, Feed and Depth of cut on Tangential Force in machining of Titanium alloy (Ti-6Al-4V) and Inconel 718

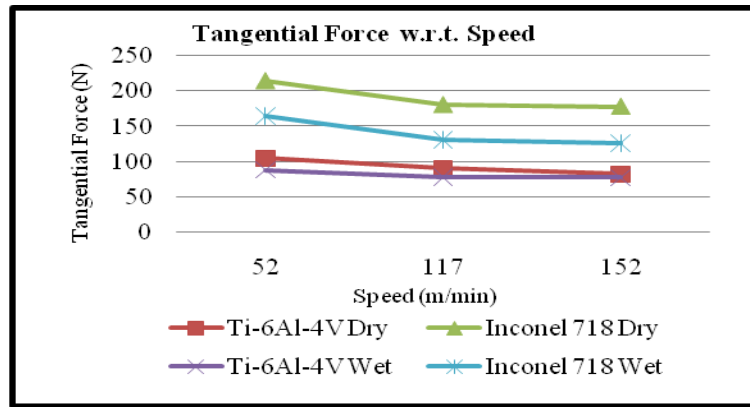


Figure 10. Effect of Speed on Tangential Force for Dry and Wet Ti-6Al-4V and Inconel 718

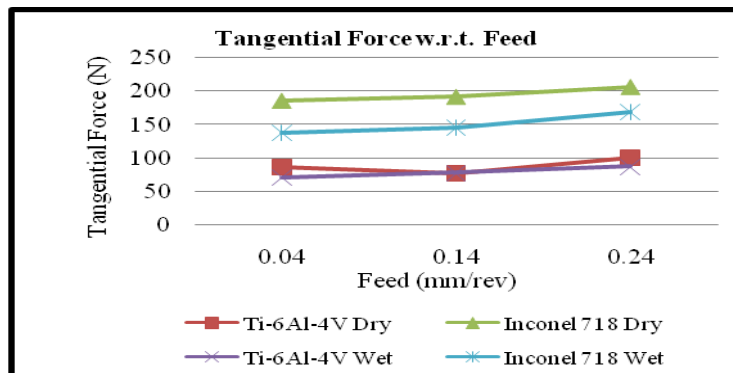


Figure 11. Effect of Feed on Tangential Force for Dry and Wet Ti-6Al-4V and Inconel 718

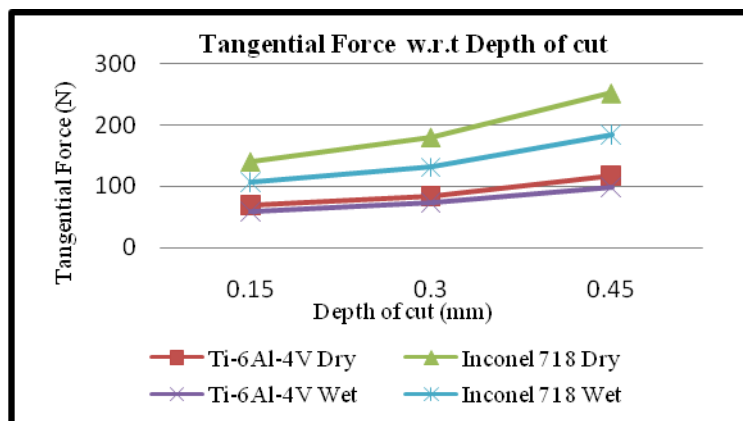


Figure 12. Effect of Depth of cut on Tangential Force for Dry and Wet Ti-6Al-4V and Inconel 718

According to the above Figures Tangential Force decreased as speed increases in case of Dry and Wet machining of Ti-6Al-4V and Inconel 718. As Feed and Depth of cut increases Tangential Force increases. Above figures shows that there is reduction in Tangential Force for Wet machining condition for Ti-6Al-4V and Inconel 718 compared to Dry machining condition for Ti-6Al-4V and Inconel 718.

V. EMPIRICAL REGRESSION RELATIONSHIP

The experimental data included in Figures 4 -12 was further used to generate regression equations of Feed force (F_x), Thrust force (F_y) and Tangential force (F_z). The generated regression equations are listed in the following paragraphs:

5.1. Material –Ti Alloy (Ti-6Al-4V) Dry Machining

$$F_x (N) = 65.3 - 0.0275 N + 54.8 f + 92.2 \text{ DOC} \dots\dots\dots(1)$$

$$F_y (N) = 58.7 - 0.0292 N + 40.2 f + 149 \text{ DOC} \dots\dots\dots(2)$$

$$F_z (N) = 56.3 - 0.0315N + 69.6 f + 163 \text{ DOC} \dots\dots\dots(3)$$

The R^2 (Coefficient of determination) values for equations 1 - 3 are 86.0, 87.7 and 86.4. R^2 indicates how much variation in the response is explained by the model. In general, the higher the R^2 , the better the model fits your data. Generally R^2 value should be more than 80 %.These equations represent reasonably good fits with the experimental data.

5.2. Material –Nickel Alloy (Inconel 718) Dry Machining

$$F_x (N) = 87.3 - 0.0328 N + 81.9 f + 245 \text{ DOC} \dots\dots\dots .(4)$$

$$F_y (N) = 112 - 0.0412 N + 71.6 f + 256 \text{ DOC} \dots\dots\dots .(5)$$

$$F_z (N) = 107 - 0.0490N + 103 f + 372 \text{ DOC} \dots\dots\dots (6)$$

The R^2 (Coefficient of determination) values for equations 4 - 6 are 87.7, 89.8 and 89.5. These equations represent reasonably good fits with the experimental data.

5.3. Material –Ti Alloy (Ti-6Al-4V) Wet Machining

$$F_x (N) = 57.5 - 0.0251 N + 67.8 f + 81.4 \text{ DOC} \dots\dots\dots .(7)$$

$$F_y (N) = 55.8 - 0.0229 N + 55.3 f + 101 \text{ DOC} \dots\dots\dots (8)$$

$$F_z (N) = 56.7 - 0.0141N + 46.3 f + 100 \text{ DOC} \dots\dots\dots (9)$$

The R^2 (Coefficient of determination) values for equations 7 - 9 are 85.4, 89.2 and 85.6. These equations represent reasonably good fits with the experimental data.

5.4. Material –Nickel Alloy (Inconel 718) Wet Machining

$$F_x (N) = 68.3 - 0.0451N + 59.6 f + 231 \text{ DOC} \dots\dots\dots (10)$$

$$F_y (N) = 60.8 - 0.0466 N + 81.2 f + 270 \text{ DOC} \dots\dots\dots (11)$$

$$F_z (N) = 95.5 - 0.0518N + 82.7 f + 259 \text{ DOC} \dots\dots\dots (12)$$

The R^2 (Coefficient of determination) values for equations 10 - 12 are 89.6, 89.8and 89.8. These equations represent reasonably good fits with the experimental data.

CONCLUSIONS

In this paper, High speed machining of Ti alloy (Ti-6Al-4V) and Nickel super alloy (Inconel 718) with DNMG 15 06 08 tool has been performed. Based on Full Factorial design has involved 3 levels of cutting speed, feed and depth of cut for dry and wet machining condition. Obtain regression equations for both the materials of Feed force (F_x), Thrust force (F_y) and Tangential force (F_z). The differences in machining the two material are summarized as follows:

- (1) Comparative study between Ti alloy (Ti-6Al-4V) and Nickel super alloy (Inconel 718) shows that, Feed force, Thrust force and Tangential force of Ti-6Al-4V are less than Inconel 718 for considered input parameter Speed, Feed and Depth of cut.
- (2) In case of Dry Machining and Wet Machining lubricant used water soluble cutting oil is showing more effective results. Since, it removes the debris effectively which reduced Feed force, Thrust force and Tangential force.
- (3) For both materials: as the cutting speed increases, the result all forces (Feed force, Thrust force and Tangential force) decreases.
- (4) For both materials: as the Feed and Depth of cut increases, the result all forces (Feed force, Thrust force and Tangential force) increases.

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