# Experimental Investigation of Machining Parameters in Drilling Operation Using Conventional and CNC Machines on Titanium Alloy

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**Abstract—Titanium alloy is one of the newer materials in manufacturing industries due to its high strength to weight ratio and corrosion resistance properties. Making a hole on this component is very difficult task due to its poor machinability. Hence, the machining parameter investigation on titanium alloy material is very important for predicting the drilling performance characteristics. In addition, the modern manufacturing industries are used the conventional drilling machine and CNC drilling machines for making a hole. In the sense, the main aim of this work is to investigate the machining parameters on vibration, thrust force, torque, machining time, burr dimension, tool wear and surface roughness occurrences when drilling titanium alloy with conventional and CNC machines. The effects of spindle speed and feed rate on these responses were reported.**

**Keyword-**Drilling operation, titanium alloy, conventional drilling machine, CNC drilling machine, wear rate, surface roughness

## I. Introduction

Titanium and its alloys have wide range of applications in aerospace, chemical plant, power generation and other major industries due to its reliable performance. The high strength to low weight ratio and outstanding corrosion resistance are the inherent properties of titanium alloy. However, Ti is one of the difficult to machining material due to poor thermal conductivity, strong affinity to tool material and retains its hardness and strength at high temperatures. Hence Ti machining typically meets the troubles of tool failure and low productivity. Amongst all the machining processes like milling, turning, grinding and drilling, drilling is very significant and it is used to make a hole on component face. This process has considerable economical value because it is generally plays a role among final steps in machining of components [3]. The extensive research work was carried out in drilling operation with different responses for different tool and work piece combinations [4-14]. In spite of the fact, the exploration of machining parameters on drilling operation is very essential for Ti work piece material. Further Ti drilling has been widely utilized in industry, research publications are still limited [1].

### *A. Problem description*

This work concentrated about seven different responses for hole making process. Drilling operation is one of vital machining processes than any other machining processes like turning, milling and grinding. In that the machine tool vibration plays a important task in manufacturing industries for good surface finish. Vibration of machine tool is known as the relative movement between the work piece and the cutting tool. It affects the cutting surface and tool life. However vibration is commonly known as chatter, are essentially self-induced oscillations in a machining process, such as metal cutting, milling, or drilling. Chatter can be responsible for machine or work piece damage, and it can lower the productivity and the precision in the process. The correlation of vibration signal features to cutting tool wear are in a metal cutting operation. So the vibration analysis is effective for use in cutting tool-wear monitoring and wear qualification [15]. According to machining parameters, the spindle speed increases, the overall vibration of tool-tip tends to more stable condition which leads to the results of the best machined surface [16]. In response to that the analysis of vibration is significant for drilling operation to calculate the tool wear and surface roughness.

Subsequently the key response is the burr dimension. Burrs can be formed on the feed mark ridges and the edges of the machined parts in machining operations. These burrs are undesirable in terms of the surface quality, the precise dimensioning of the machined parts and the safety of operators [23]. It may increases the battle neck due to deburring operation and hole quality deviation in manufacturing industries. It increases the production cost in engineering firms. So the burr dimension is "the entry and exit perimeter of a hole diameter as burred if it has an extend beyond greater than boundary of hole faces” [17]. The drilling process creates the burrs. The burr formation in drilling primarily depends upon the cutting parameters and work piece materials [18]. These are the quality variation and affect the efficiency of the assembled parts. Reducing the burr is very important in drilling process, because of the deburring cost and assembling tolerance. The burr formation is the result of a combination of larger forces and less resistance in the work piece material with plastic deformation fracture [19]. The burr size is a performance indicator of the drilling process that decided the quality of the finished product [20].

Additional important response is thrust force and torque; since thrust force is the resistance against the tool penetration into the work piece material. It acts in the longitudinal direction, and also called as the feed force because it is in the feed direction of the tool. The longitudinal force is performed to push the tool away from the work piece. The 80% of the total moment of the resistance to cutting is accounted for by the lips, 8% by the chisel edge, 12 % by the friction between tool and chip and hole and the margins [21]. The increment of feed rate is increased with the thrust force for all combinations of spindle speed. There is no variation in thrust force for increment of speed for all combinations of feed rate. The drill depth and feed rate are the significant factors for drilling torque. Next the cutting torque is increased with the drill depth over five times of the drill diameter. The increment of torque is induced the drill temperature at cutting zone, which increased the tool wear and risk of tool breakage [22].

## II. EXPERIMENTAL SETUP

The responses in this investigation are vibration, thrust force, torque, machining time, burr dimension, tool wear , surface roughness and drilling parameters of spindle speed and feed rate. A drill diameter 6mm was used with 118° point angle with two flutes.

### *B. Tool and Work piece material*

The solid carbide 6mm diameter drill bits were used for experimental runs. Each experimental run, separate drill bits were used. SB. 265 Titanium Grade-2 diameter 43 X 10mm thickness materials were used for drilling experiments. The chemical composition of the work piece material tested by wet analysis method and the same is tabulated in table 1.

### *C. Machines used*

Two different machines were selected that they are presently used in various major manufacturing industries. The machines are CNC controlled and conventional with power feed mechanism attached machines.

CNC Machine: Lead well make vertical machining center with FANUC controller, spindle speed range of 12 to 6000 rpm, work volume is 550 in X axis, 350 in Y axis and 300 in Z axis.

Conventional machine: ALTO make conventional vertical milling machine with auto feed mechanism, spindle speed range of 80 to 4540 rpm, feed rate ranges are 0.038, 0.076 and 0.203 mm/rev and table size is 1270 X 252 mm. For both machines; Work piece diameter 43 mm X thickness 11 mm was clamped on drill tool dynamometer, this setup was bolted with machine table T - slots.

### *D. Drilling tests.*

The experimental setup is shown in fig. 1. The experiments were conducted based on 2 factors with 3 levels that are 32 factorial designs. So that, totally 9 experiments with two replicates were carried out as shown in table 2. The average of two replicates was taken for experimental investigation.

TABLE 1
Chemical composition of SB. 265 Titanium Grade-2 material

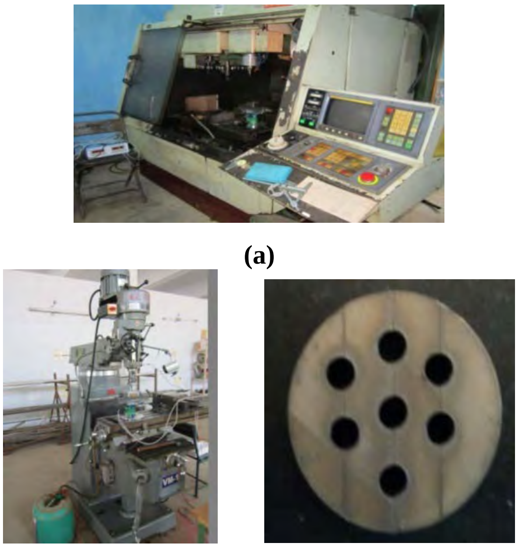
| **SB. 265 Titanium Gr.2** | | | | |
|---|---|---|---|---|
| **Elements** | C | Iron | Ti | |
| **Percentage** | 0.02 | 0.012 | 99.76 | |

TABLE 2
Experimental run details

| Experimental run | Spindle speed (rpm) | Feed rate (mm/rev) |
|---|---|---|
| 1 | 132 | 0.038 |
| 2 | | 0.076 |
| 3 | | 0.203 |
| 4 | 175 | 0.038 |
| 5 | | 0.076 |
| 6 | | 0.203 |
| 7 | 220 | 0.038 |
| 8 | | 0.076 |
| 9 | | 0.203 |

*E. Measurement of responses.*

The vibration was measured by piezo electric accelerometer located on the machine tool spindle. The vibration signal transferred and recorded in HTC instrument VB – 8205 with +/- 5% accuracy and +2 digits. The thrust force and torque was measured by armed wheel type strain gauge based drill tool dynamometer. The sensor resistance and accuracy of the equipment is 3500 ohms and +/- 1% of full scale. Machining time was measured from NC program running time. Machining time consists of tool approach point to entry of the hole to be drilled, cutting time and tool relieving time from exit of the hole. Burr height was measured by using mechanical comparator with 0.01 mm least count dial gauge and granite table. The V-block was used to locate the job on granite table. Burr thickness was measured by using Tool Maker's microscope with 30 X magnification, 8mm diameter field of view and working distance of 80 mm. The surface roughness of the job was measured by using the surface roughness tester of Mitutoyo make and SJP 210P.



**(a)**

**(b)** **(c)**

Fig. 1. Experimental setup. (a) CNC vertical machining center (b) conventional vertical milling machine, (c). work piece material after drilling

## III.RESULTS AND DISCUSSION

The experimentally measured vibration, thrust force, torque, machining time, burr dimensions, tool wear and surface roughness on conventional and CNC machines are compared. The evaluated results are established for identifying the effects of spindle speed and feed rate on different responses are discussed in sections A – F.

*A. Machine tool vibration*

The fig. 2 shows the comparison of vibrations on CNC and conventional machines. The machine tool vibration occurrence is more than in conventional machine as compared to CNC machine. The vibration is studied based on the frequency, velocity, acceleration and displacement. The vibration of the conventional and CNC machines at all three spindle speeds and feeds have the different effects. The fig 2 demonstrates that the effect of spindle speed and feed rate on vibration of frequency, velocity, acceleration and displacement. The frequency of vibration decreases with mid-level of spindle speed and feed rate in CNC drilling. However for conventional drilling the higher level of spindle speed with lower feed rate decreases the frequency of vibration. Similarly the effect of spindle speed and feed rate on velocity, acceleration and displacement of vibration are plotted. This may be attributed to the vibration is a function of spindle speed and feed rate.

The fig. 3 shows the relationship between machine tool frequency, velocity, acceleration and displacement. Frequency is the number of cycles that occur in one time period. Velocity measurement measures the how fast an object is moving from zero-to-peak. Displacement is the measure of how far an object is moving from peak to peak. Acceleration measures the rate of change of velocity from zero-to-peak. The velocity plot shows the lower frequencies generate high level of velocity and higher frequencies generate low levels of velocity. The lower and higher frequencies generate low acceleration. The displacement range remains relatively constant over a occurred range of frequency.

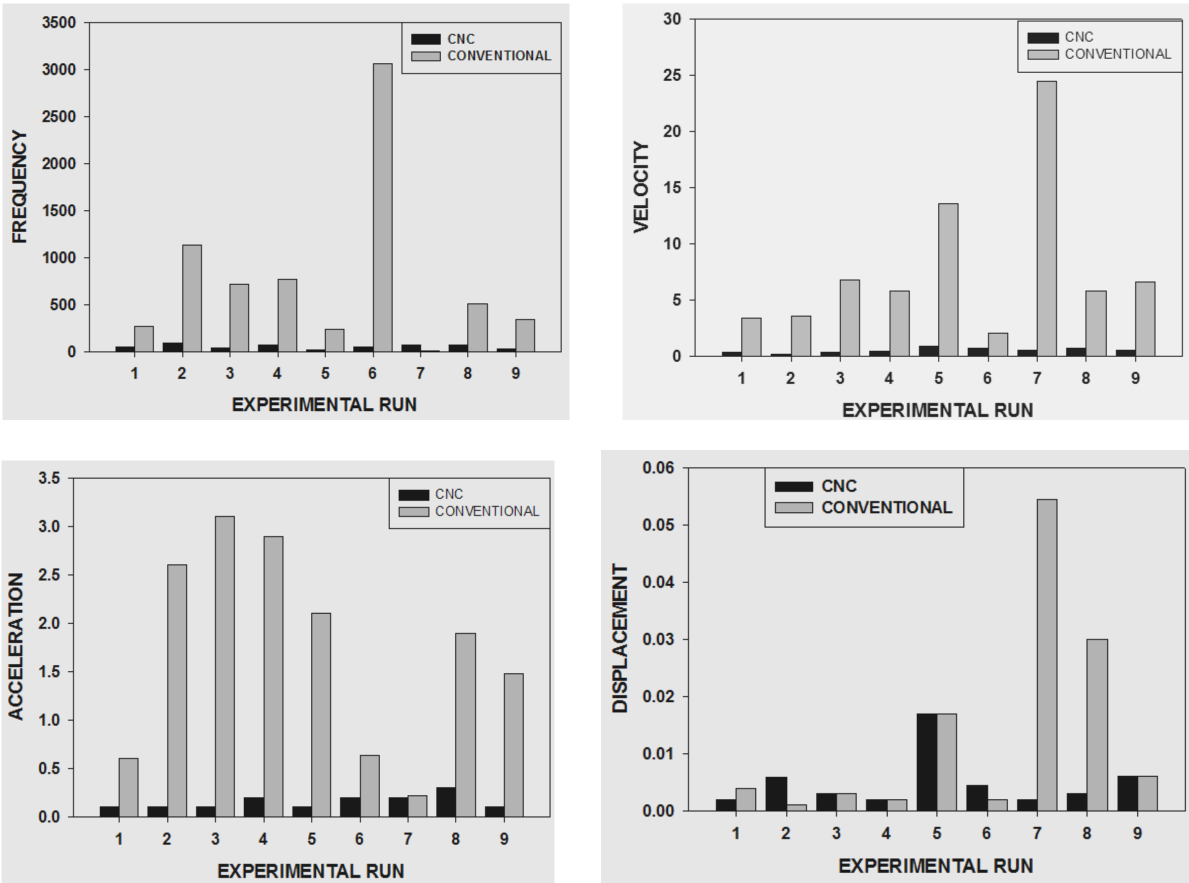



Fig. 2 Effect of machining parameters comparison for CNC and conventional drilling for vibration analysis.

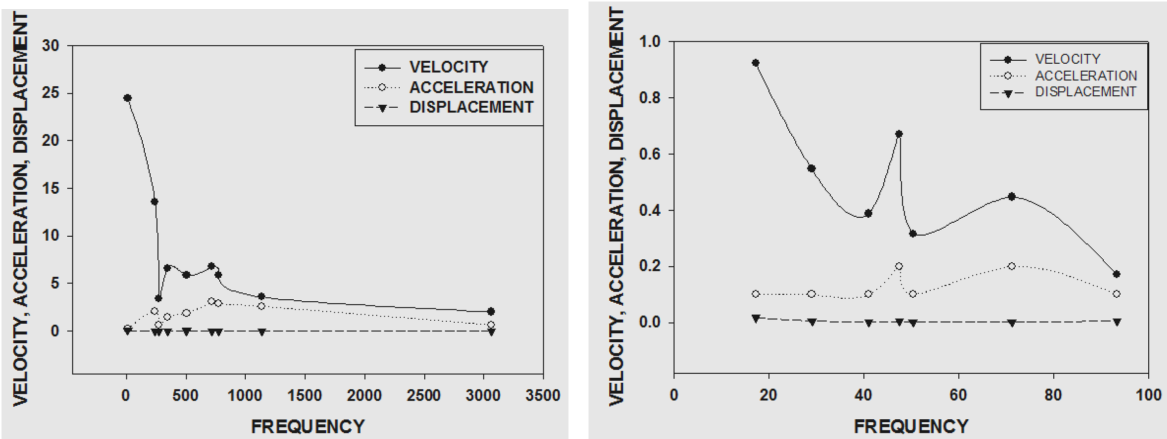



Fig. 3 Relationship between machine tool frequency, velocity, acceleration and displacement

*B. Thrust Force and Torque.*

The fig 4 shows thrust force and torque measured in different machines at three different spindle speed and feed rates. According to thrust force, the lower spindle speed with higher feed rate increases the thrust force in both machines. CNC machines produces the more thrust force than conventional drilling machines at higher feed rates with the the combinations of all the three spindle speeds. In conventional the lower feed rate with the all combinations of spindle speed produces higher thrust force.

Similarly for considering the torque, higher feed rates with all the combinations of spindle speed increases the torque on both machines. But higher torque value attained in CNC dilling operation. The lower feed rates produces lesser torque on both machines. If feed rate increases the torque will be higher on both machines for all combinations of spindle speed. So the feed rate is the most significant factor in titanium drilling for thrust force and torque responses.

*C. Machining time.*

The machining time is measured in conventional machine with the aid of stop watch. The depth of the tool travel controlled by lock nut provided by the machine tool manufacturer on machine spindle. The machining time measurement starts while the power feed mechanism lever engaged with the gear box of machine tool. But in CNC machine the machining time measured by CNC programme cycle time. However the machining time for both machines were measured by addition of tool approach time, tool engagement with work piece and tool relieving time from hole exit. The figure 5 shows that the higher spindle speed and higher feed rate reduces the machining time for both machines. However the CNC machine produced the holes with minimum time.

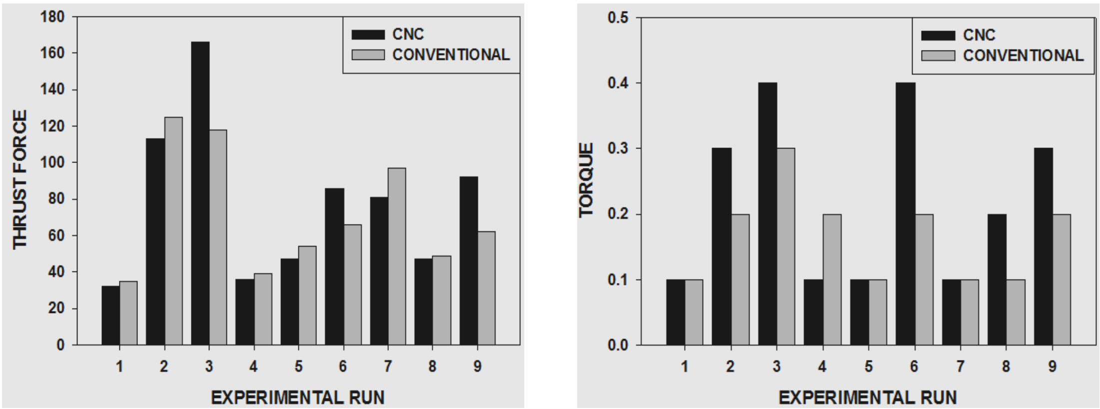



Fig. 4 Effect of machining parameters comparison of thrust force and torque in CNC and conventional machines

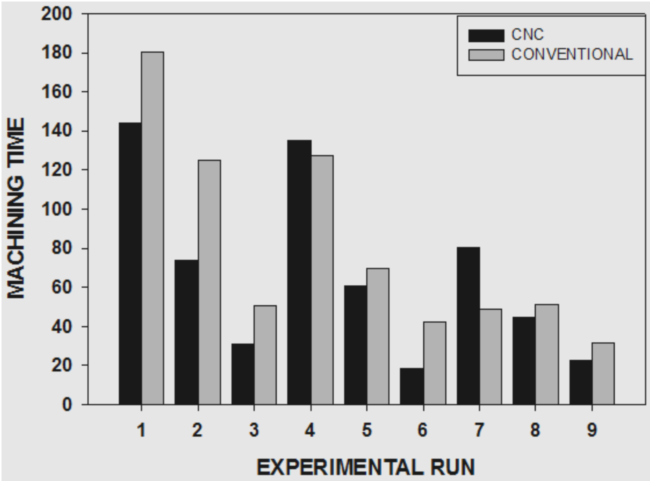
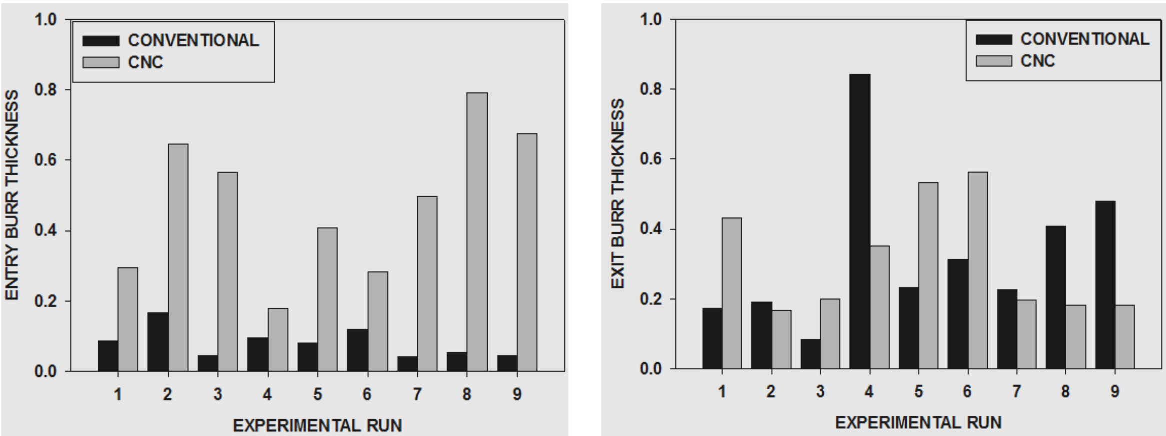


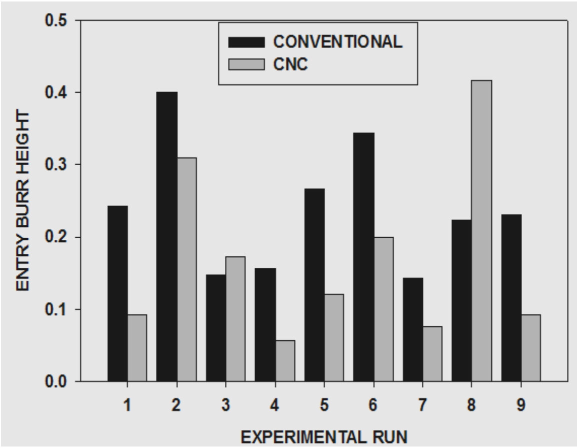

Fig. 5 Effect of machining parameters comparison of machining time for conventional and CNC machines

*D. Burr dimension.*

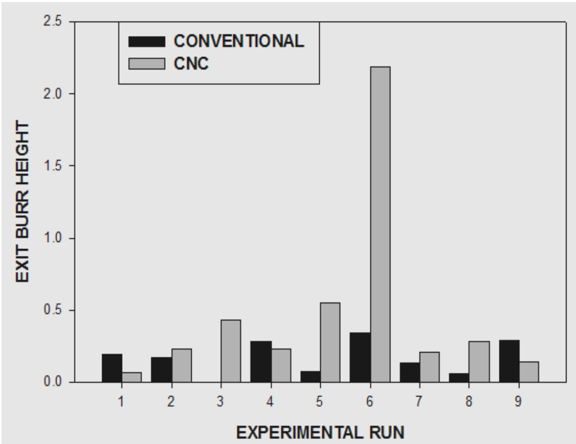
Generally burr dimensions are classified into four types; that are entry burr height and entry burr thickness, these are the burr dimensions at entry of the hole. Similarly the exit burr height and exit burr thickness are the exit burr dimensions. In this work, these dimensions are measured for both CNC and conventional machine's components. As per fig 6 (a) CNC machine produces higher entry burr thickness than conventional machine. In conventional machine the highest spindle speed with lower feed rate produces smaller burr thickness at the same spindle speed with mid level of feed rate produces the highest burr thickness. In CNC, the lowest spindle speed with higher feed rate produces the smallest entry burr thickness. Fig 6 (b) shows the exit burr thickness, it is more in conventional drilling machine than CNC machine. Exit burr dimension is higher at mid level of spindle speed with lowest feed rate. The lowest spindle speed with higher feed rate produces smaller exit burr thickness in conventional machine. Subsequently in CNC the lower spindle speed with mid level of feed rate produces smaller exit burr thickness. From fig 6 (c) entry burr height occurences is similar to both machines. For conventional machine the higher spindle speed with lower feed rate produces the lowest entry burr height. But in CNC the midlevel of spindle speed with lowest feed rate produces low entry burr height. Comparatively exit burr height is higher dimension than entry burr height. Lowest spindle speed with higher feed rate produces very fine exit burr height in conventional machine. Although in CNC machines lowest spindle speed and feed rate produces minimum exit burr height.




(a) (b)




(c)




(d)

Fig 6 Effect of machining parameters comparison of burr dimension in CNC and conventional machine Wear rate (a) Entry burr thickness (b) Exit burr thickness (c) Entry burr height (d) Exit burr height .

Wear rate is calculated from tool weight. The weight carried out before and after drilling. Each experiment uses individual drill bit. Then the weight difference of drill bit between before and after drilling is calculated. The calculated weight difference then divided by machining time. Therefore the wear rate is calculated by using following formula 1.

$$wear\ rate = \frac{weight\ before\ drilling\ (grams) - weight\ after\ drilling\ (grams)}{machining\ time\ (\sec)} \qquad (1)$$

The fig 7 shows the comparison of wear rate in conventional and CNC machines. Relatively conventional machines produce the higher wear rate than CNC machines. Mid level of feed rate with mid-level of spindle speed produces the lesser wear in conventional machine. Similarly the CNC machine also produces the tool wear.

*E. Surface roughness.*

Surface roughness is measured at entry, middle and exit of the drilled hole and the average value of surface roughness is considered for the investigation. Fig 8 shows the Lowest spindle speed with mid-level of feed rate reflects the lower surface roughness in conventional machine. Highest spindle speed with higher feed rate produces lowest surface roughness in CNC drilling machine. Comparatively CNC machine produces the lowest surface roughness than conventional machines.

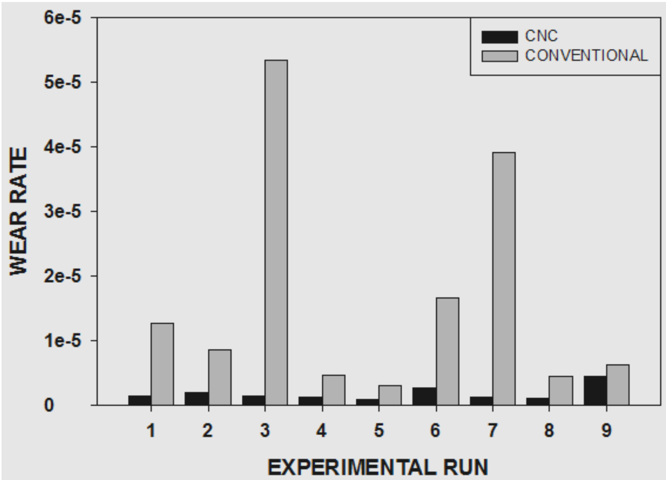



Fig 7 Effect of machining parameters comparison of wear rate in conventional and CNC

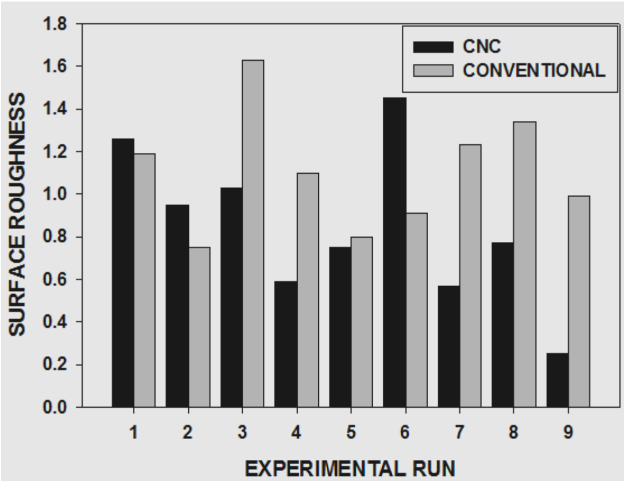



Fig 8 Effect of machining parameters comparison of surface roughness in CNC and conventional machine

## IV. CONCLUSIONS

This experimental work reveals the following conclusions on drilling operation by using CNC and conventional machines on titanium alloy

The conventional drilling machine produces higher vibrations than CNC machines. The higher spindle speed with lower feed rate generates lower frequency in conventional drilling machine. But in CNC the higher spindle speed with higher feed rate produces the lower frequency.

Comparatively CNC machine create higher thrust force and torque due to its strength and stiffness. Conventional machines acquire higher machining time at lower spindle speed with lower feed rate than CNC machine. Similarly CNC machines consume higher machining time at higher spindle speed with lower feed rate.

For considering burr dimensions, conventional machine creates higher entry burr thickness and exit burr height than CNC machine. The higher feed rate generates maximum burr thickness in conventional drilling process. The higher feed rate reduces the entry burr height in CNC machine.

Wear rate higher in conventional machines than CNC machines. However the low spindle speed with higher feed rate increases the tool wear rate in conventional machines.

The better surface roughness is occurred in CNC machines. However, Surface roughness is better in CNC machines at higher spindle speed with higher feed rates. In conventional the lower spindle speed with higher feed rate produces the poor surface finish.

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