Evaluation of Energy Aspects in Machining Performance of Ti6Al4V in CNC turning using CBN Insert

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Abstract — Machinability is a term usually employed to describe the material removal capability with an accepted finish at a relatively low cost. The machinability study of titanium alloy has been increasing and is acquiring more significance as it can produce stress-free and high-quality surface. Machining of titanium alloy is an interest to the researchers to increase its usability in industrial parts. It is difficult to machine alloy due to its favorable characteristics like preventing heat to pass through them, forming atomic bonds with the cutting tool material and high tensile strength. Metal cutting scientists are working hard to overcome the difficulties and hence associated temperatures and stresses generated during machining. The chapter deals with the machining performance evaluation of Titanium Biomaterial Ti6Al4V in CNC cylindrical turning using CBN insert. The analysis of machining forces, surface roughness and tool wear is by taking into consideration the workpiece machining length and Acoustic Emission (AE) characteristics are correlated with the machining conditions to monitor the condition of the CBN tool insert. It was found that resultant cutting force values were low up to 60 mm cutting length. The lowest surface roughness value, Ra observed was 0.9 µm at 15 mm cutting length and the major flank wear on flank face, VB was observed 0.2 mm at 30 mm cutting length. The AE signals were correlated with the number of passes and it was found that there was reduction in AE energy and AE count after four number of passes.

Keywords: CNC Turning, CBN Insert

I. INTRODUCTION

The requirement for materials with higher machinability are less cutting power, faster rate of cutting and achieving a desired surface finish easily with less tool wear. The machinability is often degraded by the factors that usually improve the performance of the material. In this regard, the metal cutting scientist as well as manufacturing engineers are on the way to improve the material ability keeping the economy and productivity intact [1]. It may not be easy to predict machinability as it has many variables. The various aspects such as work material type and their physical properties, working conditions, cutting tool geometry and the machining control factors have influence on the machining performance [2]. Aerospace, biomedical and chemical industries employ the use of Titanium Biomaterial, Ti6Al4V due to its light weight and elevated temperature corrosion resistance. During machining, the heat generated is not able to dissipate quickly from the tool edge because of lower thermal diffusivity of these alloys. The CBN cutting inserts are nowadays increasingly being used for machining various components in high end industries. Recently, turning of titanium alloy was carried out using PCBN and PCD tools and better performance of PCD tools was reported [3]. However, the PCD tools are expensive. Therefore, CBN tools are preferred for machining to cut the cost. The main contents of CBN tools are boron and nitrogen. A relatively flexible and smooth hexagonal structure of Boron nitride (BN), like graphite appears which can be easily broken into small pieces. The conversion of hexagonal boron nitride (HBN) into CBN can be achieved using high temperatures and pressures, similar to the conversion of graphite into diamond. The CBN grains, once grown by breaking down unwanted foreign particles, are released and returned to a normal state for further processing. The multiple CBN crystals are bounded together by using ceramic bonds and a large mass of polycrystalline CBN is formed [4]. The PCBN, obtained by sintering process is an isotropic compound which consists of randomly oriented anisotropic crystals. In fact, there are two types of PCBN tools. The first one is known as high CBN content cutting tools and has 0.9 volume CBN content with metal connectors (e.g., cobalt). The second one is known as low volume CBN content tools [4] with 0.5-0.7% volume particles of CBN content having ceramic binders such as titanium nitride and titanium carbide. Additionally, the CBN inserts are coated with special coatings that make them possible to sustain sudden impact, resist wear due to rubbing and extreme heat. Some of the major advantages are increased productivity, extremely good capacity to absorb heat, high impact and wear resistance, increased tool life and high material removal rate. PCBN provides natural benefits by recycling unwanted chips and removing grinding swarf. Not only this, but the time required for machining can be reduced by being able to make metals machined in a solid state as an alternative to grinding.

II. LITERATURE REVIEW

It is revealed from the literature that factors like CBN percentage, cutting edge type, coating material, binder used, grain size of CBN, use of lubrication methods and cutting conditions have significant effect on the CBN cutting tool efficiency. Titanium Biomaterial, Ti6Al4V is researched by many authors in the recent past and still is a topic of importance of many researchers worldwide. Though studies are reported on machining of Titanium Biomaterial, Ti6Al4V using plain and coated carbide tools, however very few attempts are found using CBN cutting tools. Research on slot milling of Titanium Biomaterial, Ti6Al4V has been conducted by Zareena [5] using CBN, PCD and BCBN cutting tools. They observed that better performance was exhibited by CBN tools when the following cutting conditions are used as compared to other cutting tools: cutting speed (400 m/min), feed rate (0.05 mm/tooth) and depth of cut (0.05 mm). Hirosaki et al. [6] tried machining of vanadium free titanium alloy Ti-6Al-2Nb-1Ta with a binder-less PCBN tool. They found that low flank wear and retained sharp cutting edge was exhibited by PCBN tool under the application of a high-pressure coolant.

High speed slot milling was performed on Ti-6Al-4V by Wang et al. [7] using BCBN tools. The working and the wear pattern of the BCBN tool with respect to machining forces, tool life and tool wear has been studied. It is found that the uneven wear on the flank face dominated the wear behaviour of BCBN tools.

Wang et al. [8] in another study investigated that tool life at higher cutting speed is more than at low cutting speed. A diffusion bond was found at the tool-work interface and the welded work constituents to the tool flank face caused reduction in tool wear. Based on the energy dispersive X-Ray analysis of chips, the alloying elements of the tool diffused into the nearby region of the chip. This led to the development of diffusion activated dissolution wear mechanism for BCBN tools.

Ezugwu et al. [9] tested the machining performance of various grades of CBN in fine turning of Titanium Biomaterial Ti6Al4V at higher speed of 250 m/min with various coolants. They found that at higher cutting speed, low CBN content (50% CBN) tool shows reduction in tool life. A similar result with severe notching and cutting-edge chipping found when the higher CBN content (90% CBN) was used. It was also seen that there was accelerated notch wear rate at higher CBN content which diminished the tool life consequently for the cutting conditions which were investigated. Multi-layer coated inserts were evaluated by Ozel et al. [10] while investigating turning of Ti-6Al-4V. A new modified material model for Titanium Biomaterial Ti6Al4V titanium alloy is established where the softness (flow), hardness and temperature effects are combined. A serrated chip model using adiabatic shear phenomenon is applied to validate the model with elastoviscous plastic FE simulation while machining Titanium Biomaterial Ti6Al4V. Measured cutting forces and chip morphology are used to compare simulation predictions with orthogonal cutting test results. Bhaumik et al. [11] found that for machining titanium alloys, a composite tool of WBN-CBN can be used economically. The results showed that a steady state of flank wear is reached after machining time of 5 minutes. The magnitude of wear rate tend to increase after 50 minutes. Burhanuddin et al. [12] investigated critical factors which influenced tool life, tool flank wear rate and different modes of tool wear patterns of the CBN cutting tool while machining of Titanium Biomaterial Ti6Al4V. It was investigated that cutting speed and feed rate critically influenced the life of the tool. The thorough analysis on a worn-out tool by scanning electron microscopy found that the wear took place on the flank face and rake face of the tool cutting edge. The parameter such as feed rate influences the tool life most, in addition cutting speed, depth of cut used and CBN grades also affect much.

Zoya and Krishnamurthy [13] employed CBN tools for high-speed turning of titanium alloys and investigated their machining performance. They concluded that machining of titanium alloy is a thermally dominant process. The surface finish is highly influenced by the replication of the tool nose on the work surface during the turning operation.

Liang et al. [14] investigated surface topography and its deterioration resulting from tool wear evolution while dry turning of titanium alloy Ti-6Al-4V. They analysed that the amplitude and functional parameters increased with the increasing tool wear. The experiments were performed by Li et al. [15] demonstrating the effect of very high speed and found that the chip configuration rapidly varied at higher cutting speed. As a result, tool worn out at a rapid pace. Polini et al. [16] found that higher values of cutting forces were achieved and better surface quality was produced at higher cutting speed. This can also be obtained with an increase in radial depth of cut thus maintaining the cutting force value. Guo et al. [17] analysed the wear of the tool and found coating delamination and adhesion are the common tool wear failure which is observed when coated carbide tools were used. Tool wear mechanisms were analysed by Jaffery et al. [18] to improve coating on the cutting tool for machining of titanium alloys. It was recommended that life of the tool can be improved by employing materials having coatings with lower thermal diffusivity as compared to other material. Dorlin et al. [19] compared a proposed model with experimental data of cutting forces and confirmed that the increased cutting force causes rise in the nose radius of the tool. Celik et al. [20] analysed the tool wear and surface quality when turning was performed dry using PVD and CVD cutting tools. It was presumed that a common rise in tool wear in both types when machining factors became much difficult. This gave rise to worsen the surface finish. Highly satisfactory results were obtained when V_c value reached 300 – 400 m/min in high speed machining employing cubic boron nitride tools without binder (BCBN) [21]. Based on the literature review on past research work on machining of Titanium alloy using CBN insert in machining, the following summary is presented. The performance of CBN insert depends on cutting edge geometry, coating type, CBN content, type of binder, the grain size of CBN, use of cooling methods and variation in cutting parameters. Titanium alloy has low thermal conductivity and chemical reactivity with other materials. In recent years, the titanium alloy was turned using PCBN tools and PCD tools and better performance was reported using PCD tools. Cutting performance of CBN tools was relatively dull as compared to uncoated carbide tools with respect to tool life at a cutting speed of 250 m/min. Optimum cutting speed condition for machining of Titanium alloy with CBN insert is 185-225 m/min. The wear mechanisms like mechanical abrasion, adhesion, diffusion-dissolution and fracture were seen during machining of Titanium alloy with CBN insert. There are chances of better machinability by changing feed conditions and cutting-edge geometry of the insert.

Thus, it is revealed that none of the studies have reported use of AE signals to correlate the CBN tool insert for evaluating the machining performance of Ti-6Al-4V alloy. Besides, the effect of machining parameters on machinability is less understood. In this study, indigenously developed new CBN inserts were employed to assess the machinability of Ti-6Al-4V alloy in terms of cutting forces, tool wear and AE signal characteristics.

Therefore, the objectives of the current study are to:

1) Analyse the effect of low CBN content cutting tool on the machinability of Titanium alloy,
2) Decide the optimum cutting conditions for higher tool life and good surface finish, and

3) To explore the effect of cutting parameters with the AE signal characteristics during machining.

III. MATERIALS AND METHODS

The experimental plan involves selection of process parameters, response variables, experimental method and measurement performed to assess the machinability of Ti-6Al-4V Alloy. It also describes the plan of experimentation, machining facilities and equipment that are used.

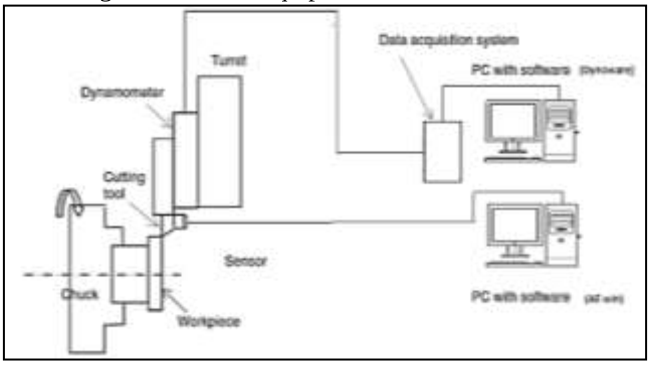


Fig. 1: Schematic of Experimental set-up

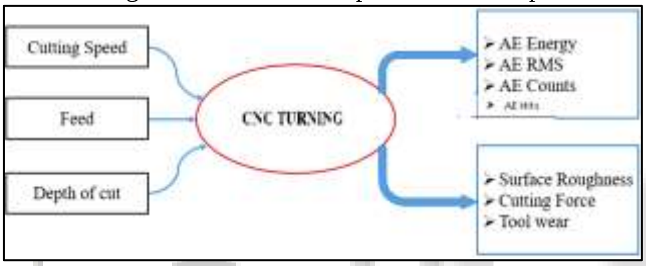


Fig. 2: p-diagram of CNC turning

The schematic of experimental setup and the p-diagram of parallel turning is depicted in Fig. 1 and Fig. 2 respectively.

IV. INPUT MACHINING PARAMETERS

A. *Cutting speed*

Cutting speed is the relative speed at which the tool passes through the work material and removes metal. It is normally expressed in meters per minute and is evaluated by equation (1) -

$$v = \frac{\pi dn}{1000} \quad (1)$$

Where, cutting speed (v) is in m/min, spindle speed (n) is in rpm and diameter of workpiece (d) is in mm.

B. *Depth of cut*

It is the thickness of the material removed in one pass when the tool penetrates into the workpiece (in mm).

C. *Feed*

It is the distance travelled by the cutting tool. In case of turning, it is given by feed per revolution stating the advancement of the tool during one workpiece revolution [22].

V. SELECTION OF RESPONSE VARIABLES

Machining performance of titanium alloy was assessed in terms of output variables which includes cutting forces, tool wear and acoustic emission signal characteristics. These are defined below.

A. *Cutting Forces*

One of the most promising techniques for evaluating the machinability involves the measurement of cutting forces. Cutting forces influence the dimensional accuracy and machining system stability and therefore chosen as one of the machinability parameters.

B. *Tool wear*

Cutting tools are subjected to an extremely severe rubbing process. Usually, it is a gradual process. Tool wear can be defined as progressive loss of material. The basic mechanism of wear that can be insisted for the formation of wear between sharp cutting tool edge and workpiece surface are due to abrasion and adhesion, diffusion, localized galvanic action, surface cracks, etc. It depends on various factors including tool and workpiece material, tool shape, cutting parameters and cutting fluid. Tool wear affects the machining performance in a number of ways. These include increased cutting forces, increased cutting temperature, decreased accuracy of produced parts, decreased tool life, poor surface finish and economics of machining.

C. *Acoustic Emission*

Acoustic emission (AE) is the phenomenon of radiating elastic waves for a short time interval by the rapid release of energy when a material undergoes deformation due to stresses. AE is one of the most significant indirect method to monitor tool wear and surface damages. AE signals are captured using AE sensor. AE monitors tool condition very precisely because the frequency range of the AE signal is quite higher than that of the machine tool vibrations and environmental noises [23].

The response variables selected are the cutting force components, surface roughness, tool life and acoustic emission parameters which include AE energy, counts, RMS and the AE hits. The machinability is assessed in terms of the above performance indicators also. These are elaborated below.

1) *Cutting Forces*

The three components of cutting forces are illustrated as follows -

The cutting or tangential force (F_t) acting in downward direction on the tool tip allowing the upward deflection of the workpiece. It delivers the energy needed for the turning process.

The axial or feed force (F_f) acting in the longitudinal direction. It is also known as feed force because it is parallel to the axis of the workpiece. The tool is being pushed away from the chuck due to this force.

The radial or thrust force (F_r) acting in the radial direction which tends to push the tool away from the workpiece.

2) *Surface Roughness*

Surface roughness is defined as the shorter frequency of real surfaces relative to the troughs. Surface roughness not only affects the appearance, but it also produces texture or tactile differences. Surface roughness is given as the arithmetic mean value for a randomly sampled area. Theoretical value of arithmetic mean surface roughness [24] is given by equation (2) as follows

$$R_a = f^2/8R_n \quad (2)$$

where f is the feed in mm/rev and R_n is the nose radius in mm.

3) Acoustic Emission Signal Variables

The electrical signal identified as an AE signal is generated by the elastic deformation and fracture. Therefore, AE signal variables are studied to get insight into the physical phenomena during machining [25]. The AE parameters are defined graphically as shown in Fig. 3.

Hit: It a signal exceeding the limit which makes the channel suitable for data collection. This usually shows the AE function by calculated time (average). In Fig. 3, a single waveform is corresponding to one “hit”.

Count: When the AE signal crosses the pre-set limit within an interval, it is called as count. It is a function of amount of work done and threshold value.

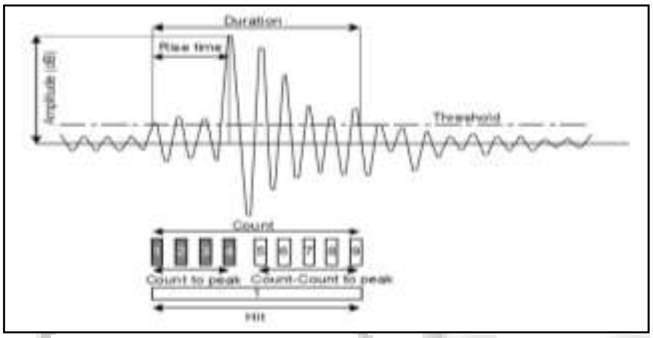


Fig. 3: Acoustic emissions parameters [26]

Often, the counts in between the trigger time above threshold value as well as peak amplitude is known as counts to peak (see Fig. 3).

Energy: A rated area under the adjusted envelope of the signal. It is the value of source event power and is sensitive to the magnitude and length of time and is highly dependent on the frequency threshold of operating frequency.

RMS: A variable proportional to the square root of the energy carried by acoustic emission waves. It is the most widely used term to quantify the AE signals. It is determined from the rate of energy dissipation and the count rate.

VI. SELECTION OF WORKPIECE MATERIAL

Ti-6Al-4V (UNS designated R56400), also known as TC4, is an alpha-beta titanium alloy having high strength-to-weight ratio and excellent resistance to corrosion, was selected as work material for this research (See Fig. 4). It is one of the most widely used titanium alloys and is applied where low density and extremely good corrosion resistance are necessary like aircraft industries and biomedical applications (implants and prostheses).

Fig. 4: Ti-6Al-4V Workpiece

VII. TOOL MATERIAL

The cutting tools used for the experimental trials were CBN inserts. Table 1 is showing the chemical composition of CBN insert of Grade (2NK-CNGA120408) indigenously manufactured which is obtained from the EDAX results, performed with PHI 710 Scanning Auger Nanoprobe (High Performance Auger Electron Spectroscopy (AES)) at ICO Analytical lab at Worli, Mumbai (See Fig. 5).

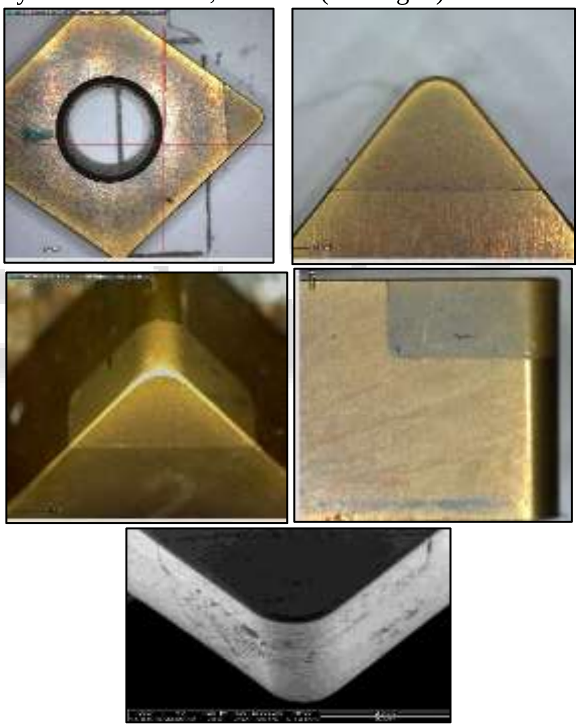


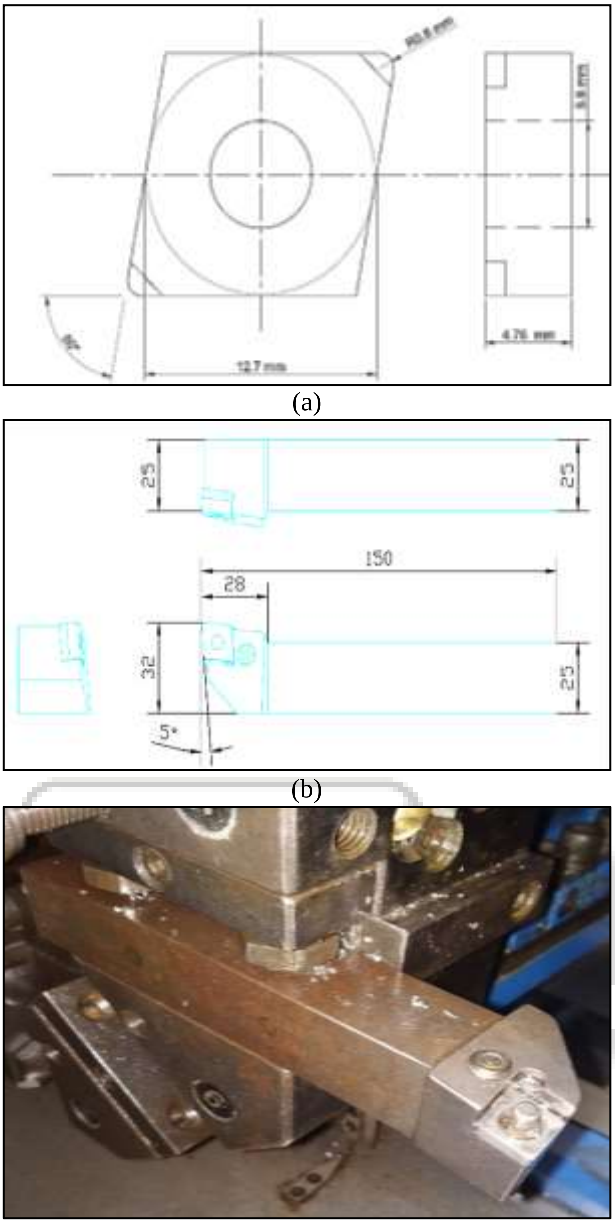
Fig. 5: Digital Microscope Images of CBN and SEM Image of CBN

Alloying Elements	C	Ti	N	O	Na	Al	Si	Cl
Weight (%)	10.7575	51.63	15.7125	11.76	1.1425	0.2225	8.545	0.2325

Table 1: Chemical Composition of CBN

A. Cutting Tool and Tool Holder

Cylindrical turning on Ti-6Al-4V workpiece was performed using CBN inserts (2NK-CNGA120408), as shown in Fig. 6(a). The typical insert-holder (PCLNL2525M12) combination is shown in the Fig. 6(b). It was a righthanded tool holder because the tool cutting edge points to the left when viewing the holder from the top as shown in Fig. 6(c).



(a)

(b)

(c)

Fig. 6: (a) CBN Insert (2NK-CNGA120408), (b) Tool holder geometry and (c) Tool holder used

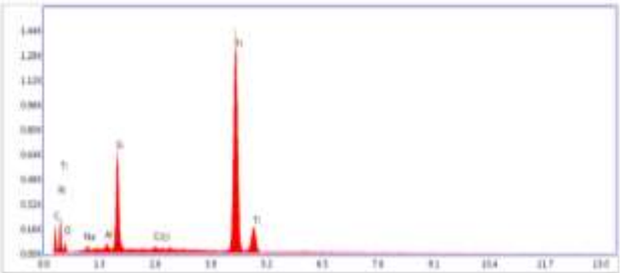


Fig. 7: Chemical composition of CBN and the EDAX profile

VIII. EXPERIMENTAL PROCEDURE

Experiments were performed using CBN insert (2NK-CNGA120408) with two cutting edges. The tool holder was PCLNL2525M12. The experiments were performed on a CNC Lathe (Micromatic – Ace, Jobber XL) with dry condition. A round bar of Ti-6Al-4V Biomaterial with hardness of 36 HRC was selected for the experiments. It was ϕ 65 mm x 150 mm long cylinder.

First set of experiment was performed for selection of the best set of cutting parameters to determine the minimum cutting forces and lower surface roughness and to correlate the AE signal characteristics with cutting parameters. This set of experiments were performed using first cutting edge of CBN insert. The optimum cutting parameters obtained from the first set of experiments were further used to assess the tool life. These optimum parameters were considered as the cutting parameters for the second set of experiments.

First set of experiment were conducted to measure the surface roughness, cutting forces and AE parameters. The following parameters are identified based on the literature review and the manufacturer's catalogue.

Cutting Speed – 150, 185, 200 and 220 m/min; Feed rate – 0.1 and 0.15 mm/rev; and

Depth of cut – 0.25 mm. The experimental parameter combinations are given in Table 2.

Experiment Number	Cutting Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
1	185	0.15	0.25
2	200	0.15	0.25
3	220	0.15	0.25
4	185	0.1	0.25
5	150	0.15	0.25

Table 2: Machining parameters for the First Set of Experiments

The second set of experiments were performed using second cutting edge of CBN insert. In the second set of experiments, during and after every run, output parameter was recorded. While machining, cutting force components as well as AE signals were recorded and after each run, the values for Surface roughness and Tool wear were recorded by Roughness tester and Digital microscope respectively. A second set of experiment was conducted to monitor tool life for the selected optimum cutting parameters based on the first set of experiments. The parameters used for these experiments are given below:

Cutting Speed – 200 m/min, Feed rate – 0.15 mm/rev, Depth of cut – 0.25 mm

For each experiment, the cutting length considered was 15 mm for analysing the effect of cutting length on cutting force components. These experiments were performed till the value of V_{Bavg} reached the critical value of 0.6 mm.

Machine tool and measuring instruments

A. CNC Lathe

All the experiments were performed on CNC lathe. The CNC Lathe is a Micromatic – Ace, model Jobber XL (see figure 8).

Fig. 8: CNC Lathe Machine with specification

Make and model	Micromatic – Ace, Jobber XL
Distance between centres	425 mm
Maximum turning diameter	270 mm
Maximum turning length	400 mm
Spindle motor rated power	5.5/7.5 Kw
Speed range	50– 5000 rpm

B. Cutting Force Dynamometer

Cutting force dynamometer records the following forces which are acting on the tool-workpiece interface while oblique machining.

1) F_t: Cutting force along the direction of the cutting velocity vector, known as tangential force component.
2) F_f: Feed force along the direction of the tool travel, known as axial force component.
3) F_r: Thrust force in the direction normal to the produced surface, known as radial force component.

Fig. 9: Set up of cutting force dynamometer with specifications

Make and Model	Kistler 5233A1
Manufacturer	Kistler, Switzerland
Operating Temperature Range	0 to 60˚C
Force Range	-5 to 5 kN for F_x and F_y -5 to 10 kN for F_z
Sensitivity	10 mV/N for F_x and F_y 5 mV/N for F_z

C. Surface Roughness Tester

The stylus of the roughness tester unit traces the minute irregularities of the machined surface. Surface roughness is determined from the vertical stylus displacement produced during the detector traversing over surface irregularities of workpiece material (see Fig. 10).

Fig. 10: Surface Roughness Tester with specifications

Parameters	*Ra, Rz*
Make	Mitutoyo
Measuring Range	Ra:0.05-10.0µm Rz:0.1-50.0µm
Accuracy	+/- 10٪ of actual value
Dimensions	125 x 73 x 26mm
Operating temperature	0°C - 40°C

D. Digital microscope

The most common instrument used for measuring tool wear, chip thickness and width is dino-lite digital microscope. This microscope helps in taking a photograph of tool wear, chip thickness and width and dino-lite software used for measurement of tool wear, chip thickness and width in photographs. For the selection of optimum cutting parameters which were to be selected for minimum cutting forces and lower surface roughness, the cutting force piezoelectric dynamometer and Surface Roughness tester were used.

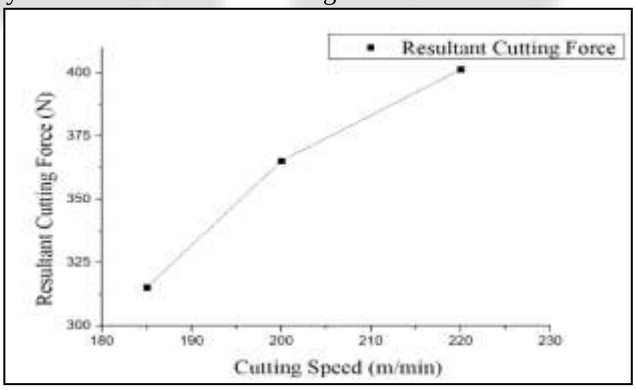


Fig. 11: Resultant Cutting Force v/s Cutting Speed

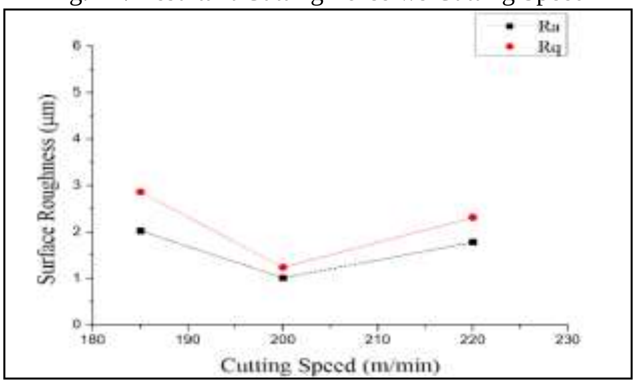


Fig. 12: Surface Roughness (R_a and R_q) v/s Cutting Speed

Expt No.	Cutting Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	F_t (N)	F_r (N)	F_f (N)	Resultant Cutting force (N)	R_a (µm)	R_q (µm)
1	185	0.15	0.25	162.73	269.83	10.5	315.2	2.02	2.86
2	200	0.15	0.25	109.53	348.11	12.5	365.1	1.01	1.24
3	220	0.15	0.25	104.02	387.27	14	401.2	1.78	2.31
4	185	0.1	0.25	107.5	376.66	14.4	391.9	1.12	1.41
5	150	0.15	0.25	115.66	328.67	9.3	348.5	2.88	3.787

Table 3: Cutting Force and Surface Roughness observations

IX. Results and Discussion

This deals with the analysis of experimental data i.e. cutting forces, surface roughness, tool wear and acoustic emission signal characteristics recorded during the second set of experiments.

A. *Cutting Force Analysis*

It is observed from the graph (see Fig. 14) that increasing trend is observed for all the force components with respect to cutting length. Radial force is found to be maximum than other two cutting forces. Initially the cutting edge is new and there is a point contact as seen in Fig. 14. Therefore, cutting forces are low which were constant till 60 mm cutting length. Abrasion, oxidation and adhesion wear mechanisms were observed at 60 mm cutting length. After that, the forces remain almost constant up to 210 mm. At 210 mm, severe nose radius wear and chipping were observed due to which cutting forces increased drastically.

As the cutting length increases, a steady rise in R_a values because of increase in tool flank wear was found. During machining, BUE forms which leads to increase in roughness values. Table 6 presents the magnitude of cutting force component during each pass of 15 mm.

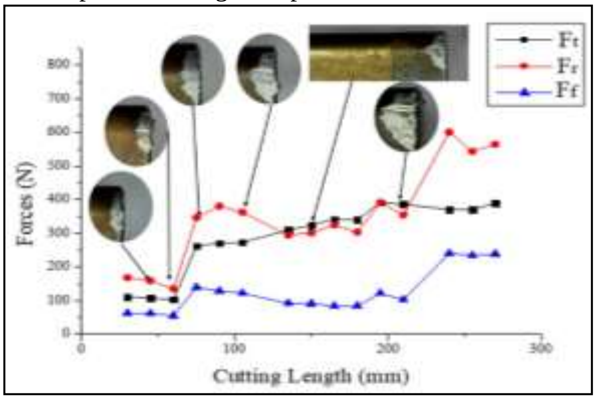


Fig. 13: Cutting force component v/s Cutting length

Expt No.	Cutting Length (mm)	F_t (N)	F_r (N)	F_f (N)	R_a (µm)	R_q (µm)
1	15	115.36	172.42	68.26	0.924	1.1445
2	30	109.67	167.8	62.1	0.8555	1.0605
3	45	107.73	158.76	61.82	1.2385	1.5185
4	60	102.43	135.2	54.76	1.559	1.919
5	75	262.01	346.47	139.62	1.786	2.196
6	90	270.51	380.75	128.23	1.6435	2.0555
7	105	272.94	362.42	121.75	1.922	2.341
8	120	278.17	332.43	98.28	1.6905	2.1065
9	135	309.4	294.34	91.14	1.7795	2.2065
10	150	324.37	301.4	90.64	1.8735	2.1965
11	165	342.22	324.56	83.25	1.714	2.0575
12	180	340.4	303.18	84.18	2.2765	2.7775
13	195	391.3	391.63	121.21	1.8365	2.157
14	210	386.23	354.56	102.26	1.895	2.2145
15	225	385.43	788.7	278.24	1.782	2.114
16	240	370.51	600.84	239.88	1.9335	2.1535
17	255	370.83	543.4	234.29	1.4895	1.8245
18	270	389.67	564.58	238.4	1.276	1.5685

Table 4: Values of Cutting Force components for varying cutting length

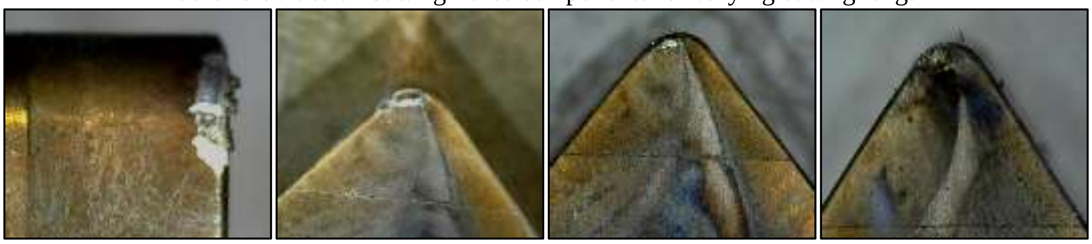

(a) Abrasion (b) Nose Wear (c) Oxidation (d) Nose Radius

Fig. 14: Wear Pattern and Wear Mechanism

B. Surface Roughness Analysis

The surface roughness in terms of R_a and R_q was measured for all the specimen and is presented in Table 6. From Fig. 16, the graph followed the same trend for surface roughness parameters R_a and R_q. It was observed that with an increase in cutting length, there was a slight increase in surface roughness at approximately 180 mm cutting length.

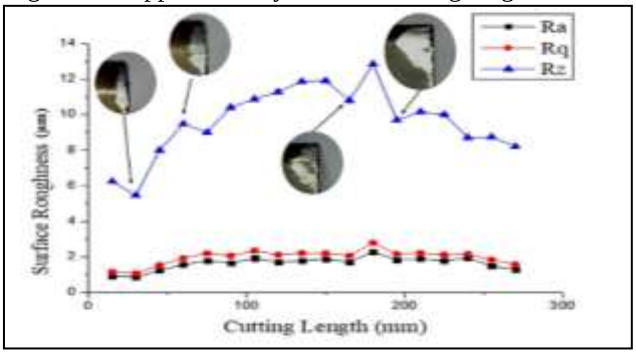


Fig. 15: Surface roughness vs Cutting length

C. Tool Wear Analysis

Tool wear was measured in terms of V_{Bmax} and V_{Bavg}, and its variation was shown with the cutting length. Fig. 17 shows the graphical variation of average values of flank wear of CBN tool with respect to increase in cutting length. The variation is normally classified into three categories: the accelerated beginning stage, intermediate stage and the rapid failure stage [12]. The tool worn out mostly due to adhesion, attrition, oxidation as shown in Fig. 18. The increase in wear rate tends to reduce when the turning is employed for more than 90 mm cutting length. The chip flowing on the tool rake face gets partially welded at the tool edge. This sticking or welding of chip is attributed to the adhesive wear on the rake face of the tool. Under dry cutting conditions, temperature increases quickly while turning at high rate of feed and/or high rate of cutting speed. This high temperature welds the work material to the tool and form the built-up-edge-like layer. The welded material causes the wear growth. The blunt tool as well as the built-up-edge increases the cutting force. Despite of the mechanism procedures outlined above, CBN tool was diagnosed with crater wear. The breakdown and dispersion phenomena took place at the interface of cutting tool and workpiece being welded.

D. Acoustic Emission Analysis

Analysis of acoustic emission parameter is done according to the number of passes. After every seven experiments, diameter of workpiece is decreased by 0.4 mm.

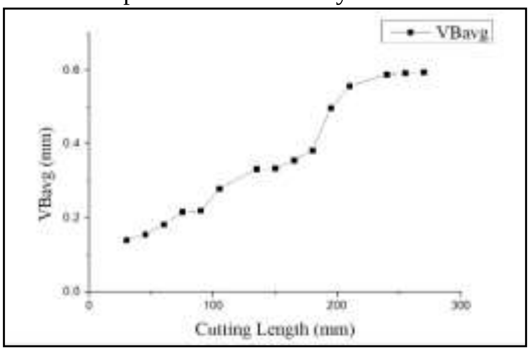


Fig. 16: V_{Bavg} v/s Cutting Length

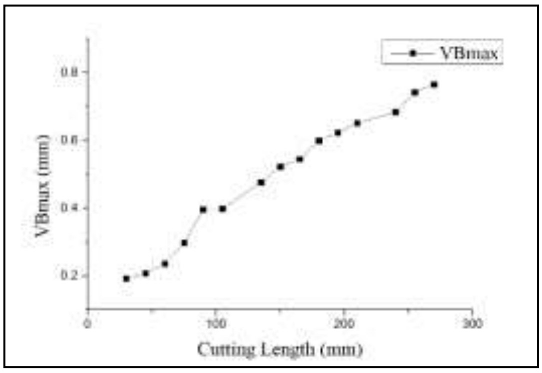


Fig. 17: V_{Bmax} v/s Cutting Length

It is observed that absolute energy increases with an increase in number of passes. However, after four passes, the absolute energy reduces because of severe tool wear. The similar trend is observed for AE counts also. From Figure, it is seen that RMS value increases steadily with number of passes. This may be attributed to the fact that RMS value increases with an increase in tool wear. However opposite trend is followed in AE hits from second pass to fourth pass.

X. CONCLUSIONS

The experimental research was done to analyze the effect of process parameters on machinability in turning of Ti-6Al-4V with CBN insert. In order to study the tool wear mechanism, variation of the cutting forces, AE signal trends and surface roughness has been observed with respect to cutting length. The following conclusions are drawn on the basis of exhaustive research work carried out –

1) Lower cutting forces (150-400 N) are observed at 200 m/min cutting speed and 0.15 mm/rev feed.
2) Thrust force is higher than the cutting force and feed force due to lower depth of cut, feed rate and negative rake angle (0.25mm).
3) Cutting force value increases drastically with nose radius wear, abrasion and chipping wear becomes severe.
4) Low cutting forces has been observed with CBN (2NK-CNGA120408). It is in accordance with the past researches related to the study of cutting forces during turning of Ti-6Al-4V using low CBN content.
5) As the thermal conductivity of Titanium alloy is low, temperature is concentrated at machining zone. Due to which sparks are seen during machining. Due to increase in temperature of workpiece material and after that cooling in atmosphere, it may get hardened and force values might have increases.
6) Lowest surface roughness (R_a – 0.9 µm) is observed. As tool wear progresses roughness values increases.
7) Due to higher nose radius (0.8 mm), surface roughness values are low.
8) With an increase in number of passes, AE absolute energy increases. However after four passes, absolute energy reduces due to rise in tool wear.
9) AE RMS value increases with an increase in tool wear.
10) With the increase in cutting length, BUE formation has been observed and it may cause to increase in roughness value up to 1.6 µm R_a.

11) Since there is no chip breaker geometry, chips get accumulated in the machining zone as the tool progresses and may damage the machined surface.
12) 0.6 mm V_{Bavg} criteria is considered for experimentation for that tool life is 1.628 min.
13) Abrasion, nose radius wear, oxidation, adhesion and flank wear are observed during the study.
14) Tool wear progression curve divides into three categories: the accelerated beginning stage, the intermediate stage and the rapid failure stage.

XI. FUTURE SCOPE

The present investigation was carried out with certain limited resources. However it has a scope in future so as to enhance the understanding of machining characteristics of the Titanium alloy with CBN insert.

In this context, the following aspects will be useful.

1) All these experiments are performed in dry machining conditions. Therefore, other cutting environment like MQL conditions with different lubricant can be explored.
2) Different CBN tool geometry like round cutting edge and different nose radius can be studied.
3) Characterisation like SEM and EDAX of tool wear can be explored to get more understanding of wear mechanism.
4) Modelling of Machining forces, Roughness parameter R_a and Tool flank wear can be studied.
5) In depth correlation of process parameters with AE signals can also be done.

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