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Experimental Study of Comparison of Surface Roughness in Grinding of Grade 5 Titanium(Ti-6Al-4V) with Different Percentages of MWCNT Incorporated CBN Wheels

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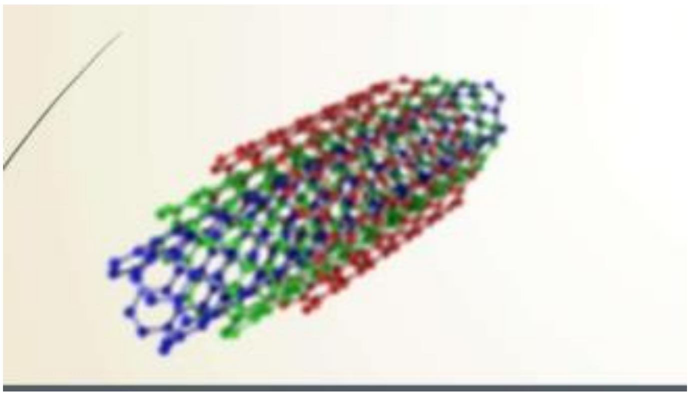
Abstract: The experiment is based on observational studies done on Multi Walled Carbon Nano Tube (MWCNT) incorporated Cubic Boron Nitride (CBN) wheels. Here we have compared the surface characteristics of grade 5 Titanium (Ti-6Al-4V) using CBN wheels which are reinforced with 3 percent and 5 percent multi wall Carbon Nano Tube (MWCNT) separately . After the completion of the experiment we have measured the Surface Hardness for each of the CBN wheels with CNT concentration 3% and 5%. The normal values when grinding without CNT is also compared for better understanding. Also assessment is done on 7 cubes of grade 5 Titanium (Ti-6Al-4V) which are grinded on 4 sides (totally 28 surfaces) with each wheel under different input parameters like depth of cut, feed rate and also the speed at which the wheels are operated for better precision and the results are found and tabulated.

Introduction

Grinding is an abrasive machining process which uses grinding wheel or grinder as the cutting tool .It can be considered as the subset of cutting as grinding is a true metal cutting process which is used to finish work pieces that must show high surface quality and high accuracy of shape and dimension. Traditional grinding process (without CNT) has lesser MRR and Rougher surfaces. Application of multi wall CNT can improve the MRR and help obtain better surface finish. These characteristics like surface finish impact the performance of the manufactured parts and improve their live span. Titanium Grade 5 is used owing to its mechanical properties of both high strength and less weight. Titanium metals are also hard to machine which makes them the perfect choice for this experiment.



Multiwalled Carbon Nano Tubes(MWCNT)

Literature Review

Even if majority of material identity is tied to its bulk property ,the surface property is also found to play many important roles. In some applications these surface properties are of immense significance. In this experiment we have used CNTs as cutting grains to improve machining where CNTs are epoxy bonded directly to the CBN wheel so it can withstand high temperatures and also high cutting forces and is made able to withstand the grinding process. No treatment is done on the CNTs as CNT without any kind of treatment shows better results in this experiment. Having stated the importance of surface grinding it has been a difficult journey to search for various ways to improve the grinding process of metals like Titanium which are hard to machine. Grade 5 titanium was considered as it have hard machinable properties coupled with low density which makes it suitable for this experiment. The grade 5 titanium has a composition of more than 90% Titanium ,6% vanadium and 4% Aluminium and its hardness is 360 BHN. Previously silcon carbide particles bonded with silicates were used for grinding purposes resulting in crack free surfaces but residual stresses and changes in micro structure were observed due to the high temperatures at the wheel work piece interface. Now a days CBN wheel are used to machine hard materials like Titanium. The machining of hard materials like Titanium continues to be a problem for surface integrity due to the huge amount of heat produced at the grinding wheel and work piece interface.In this paper we have compared two wheels of CNT inclusions of 3% and 4% and the properties and grinding effects of titanium wheels were comparatively monitored with different input parameters and L9 orthogonal array was used.

To better understand the use of CNT composites in grinding process the following studies were of great help:

1. Zhao et al .[1] performed Characterization of morphologies, like microstructure, pore structures and grain morphology. The grinding performance, force, force ratio, grinding temperature and a precise grinding energy and ground surface quality measurements were evaluated for both porous CBN wheels and a vitrified CBN wheel . Experimental results showed that porous CBN wheels exhibit controllable pore structures, porosity and promising better grinding performance. The results showed that a porous wheel out performed the vitrified wheel with better surface finish and also gave higher MRR values.

2. Nguyen et al. [2] addressed that grinding wheel wear adversely affects the performance of grinding wheel and also the grinding machine during machining process.Ti-6Al-4V alloy is very difficult to machine, because of its high adhesion, durability, and toughness combined with poor thermal conductivity and susceptibility to disabilities of the grinding details and causes fast wear of the grinding wheel. Therefore data about the grinding wheel wear and the surface roughness is of immense importance. The work focuses on a model for controlling grinding wheel wear conditions by using the grinding force signal and adaptive neural fuzzy inference system ,Gaussian regression and Taguchi analysis to predict the abrasive wear grinding process at various stages.

3. .Shen S. et al. the effect of carbon nanotube (CNT) orientation and the mechanical properties as well as fracture mechanisms of a vertically positioned CNT/C composite were studied. The results suggested stronger response of the composite while it was aligned parallelly to the CNT. Higher Young's modulus and hardness (≈34 GPa and ≈3.75 GPa) was observed in parallel direction compared to the perpendicular direction (≈19 GPa and ≈2.6 GPa).

4. Zhao et al. [4] The study is about the grinding aptitude of as-sintered aggregated cubic boron nitride (ACBN) grains. Single-grain grinding tests of Ti-6Al-4V titanium alloy were done to find out wear of ACBN grains and the MRR values .Micro-structure of ACBN grains and scratch morphologies was also performed and the grinding force ratio, material removal efficiency and also grain wear characteristics of ACBN abrasives were tabled. The results showed that ACBN grains feature a steadier and larger grinding force ratio, larger material removal volume along with higher material removal efficiency and longer steady-wear regions.

5. Li et al. [5] In this study the machining performance of particulate reinforced titanium matrix composites (PTMCs) in conventional speed grinding (CSG) and high speed grinding (HSG) using monolayer brazed CBN wheels were compared. It was discovered that the grinding forces in CSG were higher than those in HSG. However it was also found that grinding temperature was higher in HSG. The end results showed that machined surface obtained in HSG is smoother than that obtained in CSG.

6. Deresse et al. [6] There are many factors in machining that influence the MRR like cutting condition, tool and workpiece variables and the machine status. this study investigated the impact of process parameters in external CGP for EN45 steel material using the Taguchi analysis. The workpiece was heated slowly to 650–700 °C before reaching the final temperature of 870–930 °C . The experiment gave the optimal cutting condition and ANOVA table showed the impact level of the cutting depth (DOC) on MRR was 65.2% before heat treatment. Later after the heat treatment it was found to be 57.1%. Thus, the results are observed after having established the machining parameters for EN45 steel materials.

7. Mittal G. et al. [7] The paper reviews the production and characteristics of CNTs and also explores the possibility of utilization of graphene as a substitute instead of nanotubes as fillers. The review also focuses on problems which are related to the dispersion, processing and alignment of CNT inside the nanocomposites. A comparative investigation was done between graphene and carbon nanotubes and substantial changes in mechanical and electrical properties of matrix were tabulated.

8. Guru raj Udupa et al. [8] The study is on the use of CNT to improve functionally of graded composite material using powdered metallurgy technique. This paper talks about the characteristic method of manufacturing and basic concepts of graded composite material.

9. Jiali You et al. [9] passed out a study showing the capability of the CNT wheel as new alternative for the traditional cutting wheel. The studies were aimed to find the impact of different CNTs within the CNT wheels by using various measurement methods like roughness evaluation of workpiece surface, scanning electron microscopy and transmitting electronic microscopy and the results were compared with one another.

10. Harris et al. [10] carried out a study on the properties of carbon nanotubes and helped with the preparation and assets of carbon nanotube composites and the advantages for marketable exploitation of these materials.

11. William A Curtin et al. [11] This study will elaborate on the application of CNT on the Ceramic and metal matrices to produce composite structures with importance to the processing techniques and mechanical performance and the results show improved mechanical properties.

12. Zhong R et al. [12] talks about the advantages of SWNTs/Nano-Al composites produced by mixing Nano-Al particles and SWNTs, cold merging and hot- consolidation .The stiffness of the composites was found to be 2.89 GPa, which proved SWNTs can be used as reinforcements.

13. Coleman JN et al. [13] In this study mechanical properties when reinforcement nanaotubes were added were observed .The study discusses about the effectiveness of different processing methods and the results were compared and demonstrated which showed us using these nanotubes gave better results.

14. Laha T et al. [15] The work was done on carbon nanotube reinforced with aluminum composite. The Density and micro hardness measurements were taken to have a better understanding of the effect of carbon nanotube reinforcement on the mechanical properties of the composite. The results showed that the composite experienced higher relative micro hardness due to the presence of carbon nanotubes.

All the above literature helped us in understanding the applications and advantages that reinforced composites can have over traditional Grinding process. They clearly show the upperhand in MRR values and the Surface finish that CNTs infused wheels have over the grinding wheels without any reinforcements. These findings help us in understanding the comparison between the different CNT concentrations which impacts the MRR and the Surface Hardness values and understand the variation of results.

Methodology

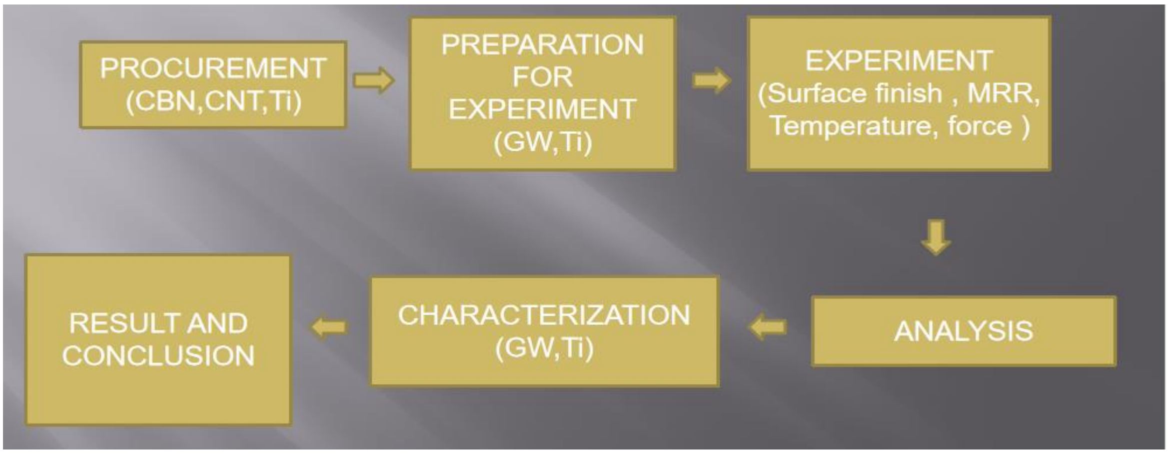


Fig taken from ref[1]

Experimental Setup

The setup for the experiment includes a hydraulic grinding machine(Avro, coimbatore) which has max speed of 2400 rpm.The table can be moved in horizontal directions(on x and y axis) the grinding wheel can be moved in vertical directions(on z axis) i.e it has upward and downward movement freedom. Depth of cut, feed and the speed of the setup is controlled manually. The titanium blocks are held in place using the specialized jigs and fixtures. A Kistler dynamometer is used to get the force readings from the experiment

The experimental setup of the grinding wheel and work piece(The fig was taken from ref[2])

Dynamometer(fig taken from ref[2])

The experiments were carried out in dry conditions without use of any coolants in order to prevent any coolant interactions with the readings obtained for detailed study on CNT. All the CBN wheels are of the same size as shown in the table below and the wheels were manufactured by the same manufacturer. This ensured that highest possible weight considerations were maintained in percentage weight composition of all wheels.

Table 1: Wheel Dimensions and characteristics

Dimension	**Values in mm**
Outer Diameter	250
Inner Diameter	76.2
Thickness	20

The titanium blocks were prepared by cutting a bigger block into 7 pieces for each wheel by electrical discharge machining (EDM) process. The block dimensions are 25.4 x 25.4 x 25.4

Titanium(Ti-6AL-4V) blocks marked and ready for the grinding process.

Experiment

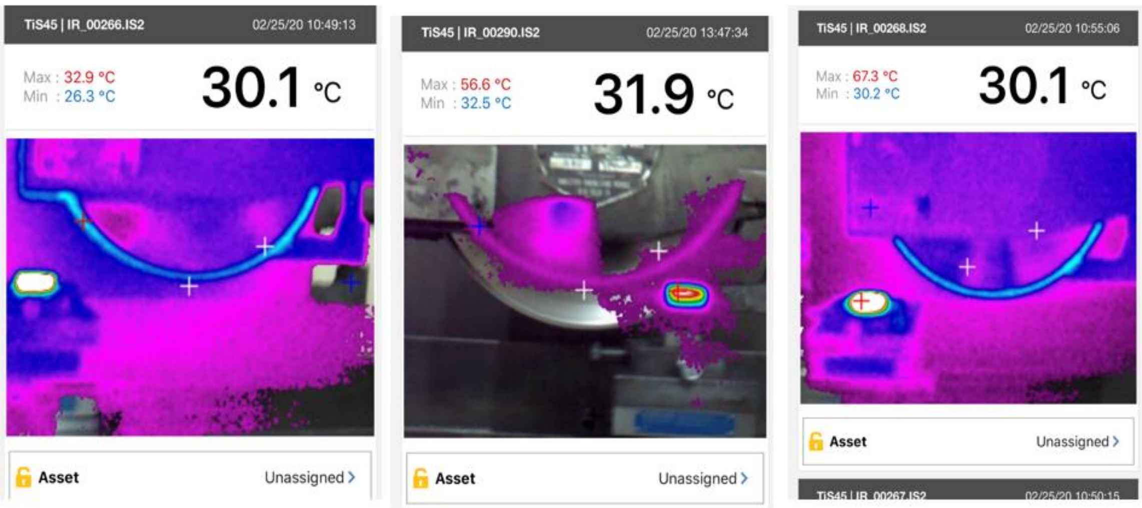
The wheel is fixed using special jigs and fixtures on to the hydraulic grinding machine turn by turn. The work pieces are exposed to the rotating abrasive wheel which causes friction and the materials start getting removed from the surface. All the blocks of Titanium are grinded using abrasive wheel with respect to the experimental needs. The process continues until each work piece shows a smooth surface and also the respective time is noted for each surface to be finished. Once we have finished grinding procedure then we move on to find the surface roughness and also the MRR of the blocks. Grinding for each wheel is done by varying the input parameters like the depth of cut, feed rate and also the speed of the wheel.

Table 2: Input Parameters

Speed	2400 RPM	2100 RPM	1800 RPM
Feed	0.1 mm/rev	0.2 mm/rev	0.3 mm/rev
Depth of Cut	0.01 mm	0.02 mm	0.03 mm

The grinding machine

After grinding the blocks are taken and weights are measured. The measured weight and the original weight before grinding are compared to get the MRR values. During the grinding process thermal images were taken using using FLUKE Thermal Imager TiS45.This imager is equipped with manual focus camera whose resolution is 160*120 and is capable of capturing images upto 0.15m and its temperature measurement range is from -20C to 350C.The noteworthy mention here is that at start of the experiment the temperature was high and at the end of the experiment the temperature dropped. The thermal images obtained are shown below



Thermal image scans

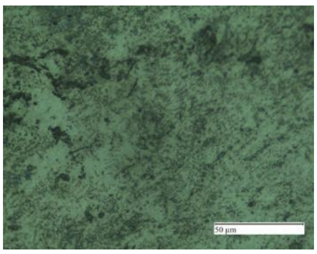
The standard CBN wheel used for the grinding process

Finding the surface roughness of the specimen

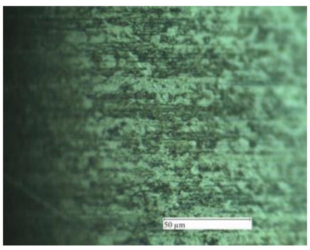
The blocks after grinding was then taken to the metrology lab for their surface hardness measurements of each block at different settings. Each surface reading was done 3 times and the average value was considered for further calculations. The machine used was surfcom- surface roughness measuring device. The machine gives us the values of Ra and Rq. Where Ra is the arithmetic average of absolute values of the profile height deviation from the mean line which is recorded within the evaluation length. Rq can be defined as the RMS roughness which is root mean squared value of profile heights over the evaluation lengths or put simply it is the average max height of the profile. The surfcom used a diamond probe that measured 3 mm of surface to get the values of Ra and Rq.

Microstructure of grounded surfaces

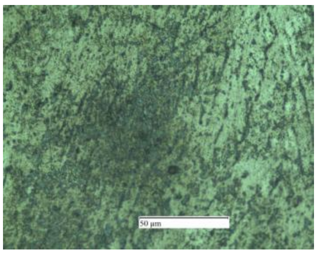
The microstructures were taken with respect to the temperature. The microstructure at high temperature, average temperature and also at the low temperature was observed. The process involved rough polishing using the emery paper of 6 grades. The grades of emery paper used were 220, 600, 1000, 1200, 1500 and 2000. Disc polishing was done on the selected rough surfaces. Diamond paste and Hiffin spray were used for disc polishing .The disc polished surface then was etched with an Al based alloy for better results. The surface was then rotated in a right angle(90 deg) and then these steps were repeated. At the end it was then treated with a suitable etchant and the surface was polished using diamond paste and a stain wheel to get best outcome with minimum scratches .The image was then zoomed under microscope to magnifications of 50x,100x, 200x and 500x . The microstructure was observed and recorded.



Lowest temp Surface

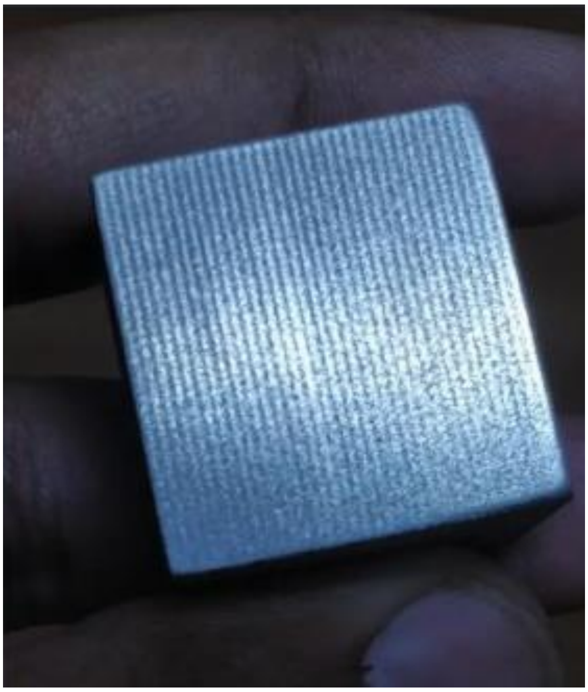


Highest temp Surface



Avg temp Surface

The microscope used for observing microstructure



The surface of the block ready for microscope to view.

The etching process

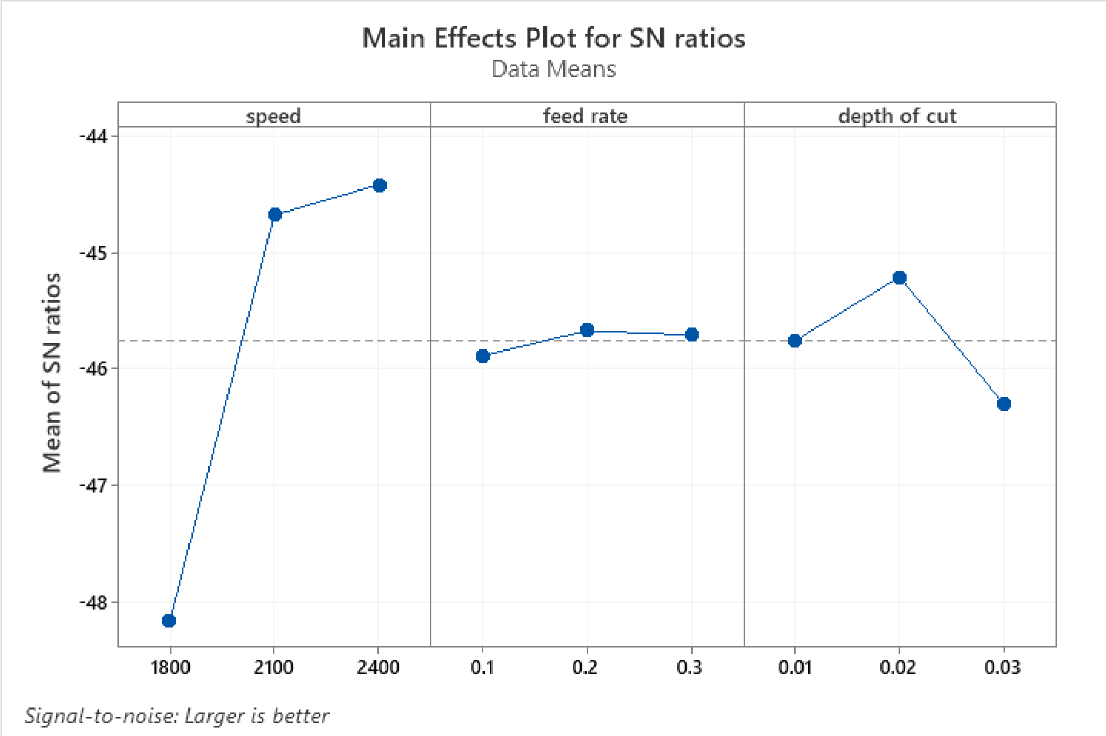
Tabulation work and Calculation

A) The comparative results of the experiment shows the variation in the Surface roughness with varying CNT percentage surface roughness for each CBN wheels were found.

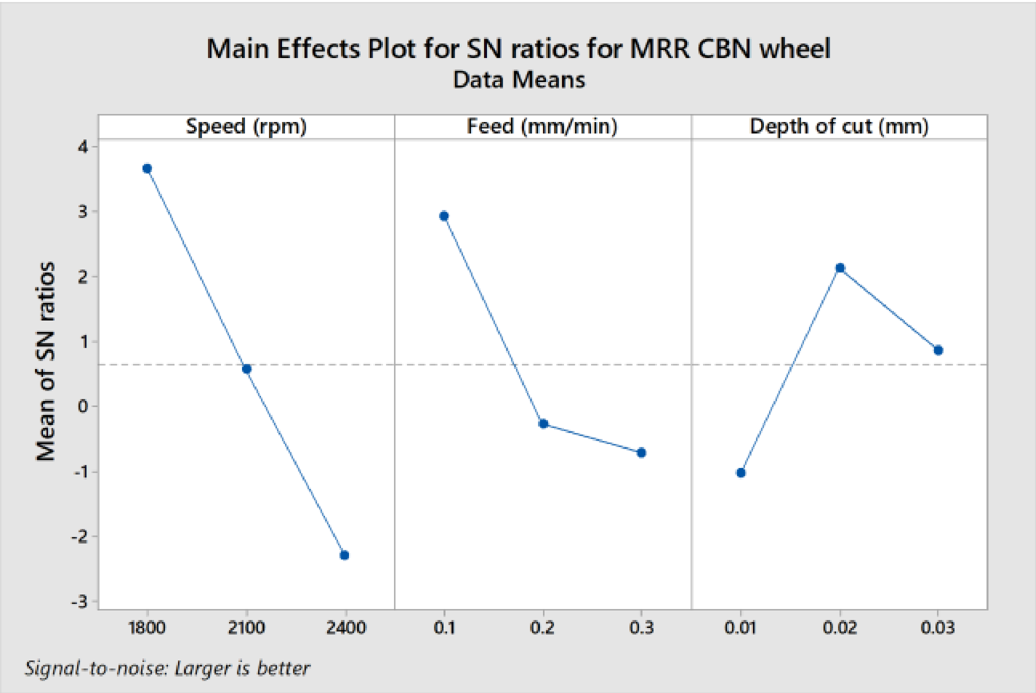
B) Taguchi Analysis for S/N ratio

Fig. 14. Graph for S/N ratio obtained for CBN wheel (data from ref[2])

We can see from the graphs that the results of S/N Taguchi analysis shows that speed has the largest effect.



Main factor effect plot of MRR for 4% CNT- CBN wheel.(data from ref[2])



Main factor effect plot of MRR for 3% CNT- CBN wheel.(data from ref[1])

Results

A) The comparisons of the CBN wheel, 3% CNT-CBN wheel and 4%CNT-CBN wheels are tabulated.

B) It is found that the Surface roughness values are much better for 3% CBN-CNT wheel as illustrated by the table.

C) Note the improvement in using the CBN-CNT reinforced wheel for improved surface roughness.

Table 3: The table shows the compared surface hardness values(Note: Data for these are from different experiments which are cited in reference section from ref[1] and ref[2])

				CBN	CBN-3%CNT	CBN-4%CNT
S.no	speed	feed	Depth of Cut	Ra	Ra	Ra
1	1800	0.1	0.01	0.8309	0.1123	0.7378
2	1800	0.2	0.02	1.3552	0.1377	0.5235
3	1800	0.3	0.03	1.0781	0.0538	0.4914
4	2100	0.1	0.02	0.7833	0.1438	0.4924
5	2100	0.2	0.03	0.9838	0.1996	0.5143
6	2100	0.3	0.01	0.7215	0.0838	0.6153
7	2400	0.1	0.03	0.8302	0.1087	0.4766
8	2400	0.2	0.01	1.1778	0.1339	0.5333
9	2400	0.3	0.02	0.9017	0.1848	0.6093

Conclusion

The results show that the CBN CNT wheel show better performance when compared to ordinary CBN wheel and there is much better surface finish obtained from the CBN-CNT wheels. Also we were able to show the effects of how the varying percentage of CNT effects the surface roughness of the Titanium and its observed under the above conditions 3% performed better than 4 percentage as per the above data set obtained from the experiments done under similar conditions. So it can be concluded that the surface roughness improves when using CNT composites and also the optimal CNT percentage was found to be 3 percent. Further research may be done and a better percentage composition found but in our limited scope for data we were able to observe how CNT percentages are affecting the grinding process and also this experiment gave me an incite to understand more about the grinding process and mechanisms involved.

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Disclaimer: The data from this experiment was used to compare the surface roughness values.

The link to the article is given below: https://www.researchgate.net/publication/344871222_Effects_of_grinding_a-b_Titanium_with_3_CNTs_in_CBN_grinding_wheel_An_Experimental_Study

[2] C Benjamin Jacob Experimental Study of Surface Characteristics in Grinding Ti-6Al-4V Using 4% MWCNT Incorporated CBN Grinding Wheel 2020.Disclaimer: The data from this experiment was used in this for comparative study.

Link to the original article is given below:

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