International Journal of Research in Engineering, Science and Management
Volume-3, Issue-12, December-2020
https://www.ijresm.com | ISSN (Online): 2581-5792

Experimental Study of Surface Characteristics in Grinding Ti-6Al-4V Using 4% MWCNT Incorporated CBN Grinding Wheel

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***Abstract*: In the following report, the experiment was discussed in detail, which is about the experimental learning and observational study of the surface characteristics of grade 5 Titanium (Ti-6Al-4V) using the Cubic Boron Nitride (CBN) grinding wheel and with 4% Multiwall Carbon Nano Tube (CNT) reinforced CBN grinding wheel. After the completion of the experiment, parameters of the Titanium work pieces were measured and compared between both the wheels. It was found out that the surface roughness parameters are not better for the 4% CNT wheel (wheel B) when compared to the CBN grinding wheel (wheel A). Whereas, the Material Removal Rate (MRR) of the wheel A is lesser than that of wheel B. For a better assessment, each wheel is used to grind 7 cubes of Ti-6Al-4V of which 4 sides are used. This gives a total of 28 surfaces.**

***Keywords*: Surface characteristics, Grinding.**

1. Introduction

A. Grinding

Grinding is the process of removing excess material using abrasive material on the grinding wheel, in this case, it is CBN. Grinding is a technique that is used in various sectors of manufacturing. This process is a quicker and more suitable method of surface finishing that can be used as compared to other machining practices. It can be applied in the process like reducing shaft diameter, smoother edges on harder metals, also making very shallow cuts it can reduce the thickness as less as thousands of an inch.

1) Surface grinding

The method of surface grinding is accomplished by the process of using an abrasive wheel. Here we use, CBN as abrasive in the grinding wheel. Very high precision can be obtained close to 2 ± 10^{-4} for flat surfaces whereas a parallel surface can have a tolerance of 3 ± 10^{-4}. A surface grinder incorporates the use of a chuck: either a vacuum or electromagnetic, reciprocating table, abrasive wheel, and a work piece holder. Grinding is commonly used for machining the surfaces of hard materials like cast iron alloy, Ti-6Al-4V and different kinds of steel. Usually, this is held by electromagnetic chuck so that there is no melting into the wheel or clogging it or preventing it from cutting. Materials that are not used commonly for grinding are aluminum, stainless steel and plastics. These materials are not suitable for the process as they may result in many complications such as clogging the wheel, plunging the performance and accuracy.

B. Grinding Wheel

Grinding wheel is a tool that is used in machining in which a wheel with a base material and a coating of abrasive material. They are usually used in a grinding machine which can be either manual or automatic. The wheel is mostly made up of abrasive material or has a base of a heavier metal that is used in the case of the CBN wheel. This is to be able to take the impact of the wheel hitting the workpiece. The wheel is made of abrasive which is coarse material that is bonded by cementing material called the bonding matrix. This forms a circular structure that is tested generally for its circularity using the CMM machine. The profile of the grinding wheel can vary depending upon the required material that has to be machined. The production of the wheel is a very detailed and carefully controlled process because of the safety involved with using it if any irregularity present in the workpiece then there is a high chance for it to explode due to impact with workpiece. Grinding wheel is consumable and its lifetime may vary from days to years. As the wheel is used for cutting it losses abrasive material which makes the wheel dull after its said lifetime. This is because of increased drag that wears down the wheel pulling out the abrasive from the bond from the base or compound. When a new cycle is started new abrasive material is brought out by this process making them usable even after one use. This rate of wear gives the performance rates of the wheel.

1) Factors affecting the surface finishing

Factors affecting surface finishing is as follows:

1. Cutting speed
2. Feed rate
3. Depth of cut

These are the major factors affecting the surface finishing of the workpiece. The increase or decrease in the following parameters results in better or worse surface finishing. Cutting speed reduced causes better surface finish. The increased feed rate causes lower quality of surface finish. The input of coolant causes a reduction in the temperature of the workpiece causing less deviation in the volume of the workpiece hence expanding or contracting the surface of the workpiece causing the decrease in quality of surface roughness. Temperature higher than optimal temperature may cause unevenness of the surface.

C. Introduction to CNT

Carbon Nanotubes (CNTs) are allotropes of carbon with a special type of cylindrical nanostructure. These cylindrical carbon molecules have various different properties, which can be used in wide range of applications for nanotechnology, electronics optics and other fields of material science and technology. Also Due to the materials exceptional strength and stiffness, these nanotubes can be manufactured created with length to diameter ratio of up to 132000000:1, expressively greater than for any other material. In addition, due to their astonishing thermal conductivity, mechanical and electrical properties, Carbon Nanotubes are a great importance as additives to various structural materials. For example, nanotubes can form a portion of the material in some (primarily carbon fiber) baseball bats, golf clubs, car parts and Damascus steel.

D. Introduction to Ti-6Al-4V

Ti-6Al-4V is also sometimes called TC4 or Ti64, is an alpha-beta titanium alloy with a high strength-to-weight ratio and outstanding corrosion resistance. It is also one of the most frequently used titanium alloys and is widely used within an extensive range of applications

E. Problem Statement

The challenge in machining hard materials like Titanium where they resist the penetration of abrasive grains and cause them to dull quickly, it has to be trued frequently resulting in loss of tool surface and this also decreases the life of the tool.

The surface finish obtained on the metal is not very smooth and the material removal rate is not too high. In order to obtain good surface finish, we have decided to incorporate CNT (Carbon Nanotubes) with the conventional Cubic Boron Nitride (CBN) matrix. i.e., we can increase the tool life, surface roughness and the material removal rate.

2. Experiment

A. Manufacturing of Grinding Wheel

In this project, the requirement of the wheels to be manufactured was accomplished by the help of a professional wheel manufacturer. The two wheels required are as follows: the first wheel is the CBN grinding wheel, used in manufacturing processes and the second one was the manufacturing of the CNT wheel. This was accomplished by buying carbon nanotube from an authentic certified dealer which was then provided to the manufacturer.

Fig. 1. CBN grinding wheel

B. Pre Experiment Setup

The main pre experiment setup is to purchase the work piece (Ti-6Al-4v alloy) from a certified dealer and to manufacture the CBN and the 4% CNT incorporated CBN grinding wheel from a wheel manufacturer.

Table 1
Specification of the work piece

Material of work piece: Titanium
Grade of titanium: GRADE 5
Dimensions of material purchased: 203.2mmX38.1mmX25.4m
Dimensions of workpiece required: (25.4mm*25.4mm*25.4m)
Method used for cutting: EDM wire cutting method

1) Workpiece cutting process

An 8*1.5*1-inch Titanium alloy work piece is used. Work piece is cut into seven equal parts by EDM Wire cutting process. Electrical Discharge machining also is known as Spark eroding wire erosion, is a method of cutting in which the desired shape is obtained by electrical discharge (spark). The material is removed due to the dielectric fluid flowing through it due to the distance between the two electrodes. The electrode that is the copper wire is known as a tool and the other electrode is the workpiece. The machining process happens due to no actual contact of the two electrodes. Wire EDM machining is basically done by producing an electrical discharge between the wire or the electrode and the work piece. As soon as the spark appears across the gap, material is then removed from the work piece and the electrode. Due to the characteristic properties of the process, Wire EDM can be used to machine complex parts and precision components out of hard conductive materials.

C. Free Vibration Test on the Grinding Wheel

Free vibration test for CBN wheel was carried out. The test was carried out to check whether the grinding wheel could produce a constant frequency wave for the varieties of load applied on it. The NI Signal Express 2015 software was used for the test. The instrument used to conduct the test was National Instrument.

The load is applied on the wheel initially and is allowed to vibrating. Natural frequencies obtained after conducting the experiment are given below. The material is subjected to different loads.

Fig. 2. Free vibration test using NI SIGNAL EXPRESS software

1) Graph obtained from free vibration test

The configuration is set up in such a way that spectrum type is set to power, Peak connection is set to RMS, Magnitude scale is set to linear and spectral density is set off. The configuration is same for all.

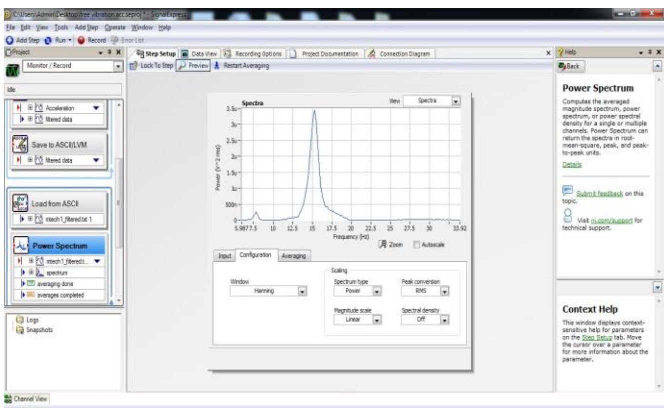

Fig. 3. Graph obtained from free vibration test of CBN wheel with small load

In this graph a small load up to power of 3.5u (V^2 rms) is applied on the wheel and the natural frequency is in the range of 15Hz as observed using NI Signal express software.

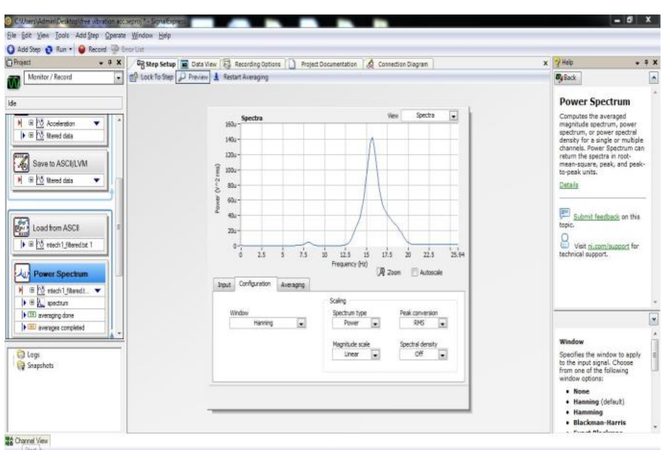

Fig. 4. Graph obtained from free vibration test of CBN Wheel with high load

In this graph the load is further increased to a higher load up to the power of 140u (V^2 rms) and the natural frequency is observed at a range of 15Hz as observed using NI Signal Express Software. Since the natural frequency is constant in various loads applied, the free vibration test is performed successfully and the material is fit for use.

D. Experimental Setup

The experimental setup consists of the surface grinding machine, CBN grinding wheel, 7 workpieces of Ti-6Al4V with dimension 25.4X25.4X25.4 mm^3. Four out six surfaces of 7 workpieces will be ground at different parameters for both the wheels separately. The grinding machine consists of machine vice that holds the work piece, the chuck that holds and rotates the CBN grinding wheel, a reciprocating table that moves the work piece as per requirement. An autotransformer that changes the speed of the grinding wheel is added to vary wheel speeds. The tangential and normal forces are found out using a dynamometer. The work piece holding table or the reciprocating table is run by hydraulics.

Fig. 5. Surface grinding machine

Fig. 6. Dynamometer

E. Grinding Process

Grinding is a manufacturing process which removes the material from the work piece and generates surface finish. Work pieces are fed to the rotating abrasive wheel, due to friction between the abrasive particles and work piece material is removed. The seven cut blocks of work pieces were ground using a CBN grinding wheel. It is ground until smooth surface appears and after the process these work pieces are checked for their surface roughness and MRR. Grinding is done by varying the parameters. The parameters are speed, feed rate and depth of cut.

Table 2
Input parameters

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

Varying the above parameters we got 27 grounded surfaces. Weights of the work pieces are taken before and after grinding so as to find the material removal rate. During grinding temperature values of the wheel and the work piece is taken using FLUKE Thermal Imager TiS45. It has a manual focus camera with 160*120 resolution and captures images from close to 0.15m. Offers a temperature measurement range from -20C to 350C. While observing the thermal image, during grinding, we observed that the initial temperature was high and gradually reduced along the process. The thermal images of some grounded surfaces are given below.

F. Finding the surface roughness of the specimen

After the surfaces was machined, the pieces were taken into the metrology laboratory where the surfaces of the work pieces were checked for its surface roughness, since each of the settings were different. The surface roughness of each of the work pieces were taken thrice for average roughness of the work-piece. This was done using the Surfcom-surface roughness measuring machine. This gave us the value of Ra, and R_q. Roughness Average, R_a, is the arithmetic mean of the complete values determined by profile heights over the estimation of length. RMS Roughness, R_q, is the root mean square average of the profile heights over the evaluation length Average Maximum Height of the Profile. This was done by the diamond probe that measured 3 mm of the surface and gave the reading of R_a and R_q these values were noted and the rough average for all the surfaces was noted.

G. Microstructure of grinded surface

We took the microstructures based on temperature. Microstructure of high temperature, low temperature and average temperature was taken. Steps involved in taking microstructure are, Rough polishing using emery paper. Six grades of emery paper were used 220, 600, 1000, 1200, 1500, 2000.Disc polishing was done on the selected rough polished surfaces. Diamond paste and Hiffin spray was used while disc polishing. Etching was done for the disc polished surface. Etchant was used as Al based alloy. It was then rotated 90 degrees and the procedure were carried on as usual. It was then treated with a suitable etchant and the surface was polished using diamond paste and a satin wheel to get a more smooth finish with very less scratches. The image was magnified at 50X, 100X, 200X and 500X.Microstructure was then observed from the microscope.

Fig. 7. Workpiece after etching process

Fig. 8. Workpiece after applying coolant

Fig. 9. Microstructure being observed under microscope

International Journal of Research in Engineering, Science and Management
Volume-3, Issue-12, December-2020
https://www.ijresm.com | ISSN (Online): 2581-5792

1) Microstructure of CBN grinded surfaces

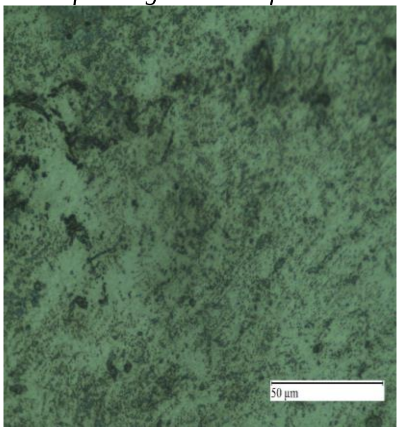

Fig. 10. Lowest temperature surface (A1a) at 32.2° C

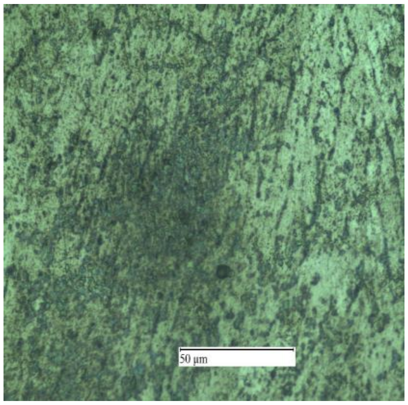

Fig. 11. Average lowest temperature Surface (A4a) at 40° C

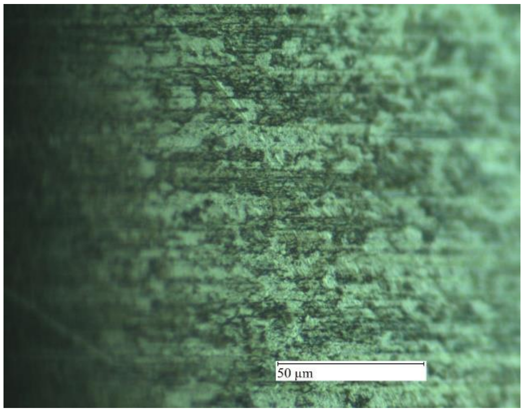

Fig. 12. High temperature Surface (A4d) at 52.2° C

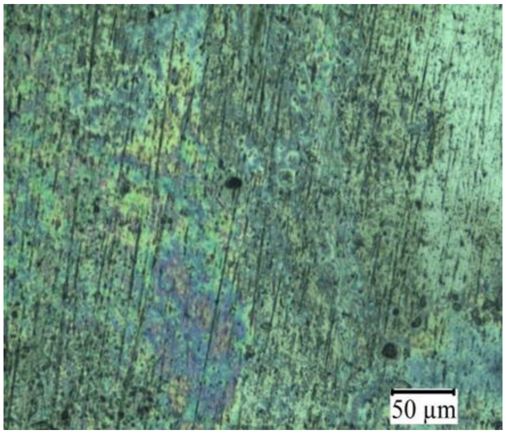

Fig. 13. Average temperature (A2c) at 49.6° C

Table 3
CBN ground surfaces

Surface Number	Weight Before (gm)	Weight After (gm)	Time Taken (sec)	MRR (gm/sec)	R_a (µm)	R_q (µm)	Normal Force Fn (N)	Tangential Force Ft (N)	Surface Temperature °C
A1a	65.5246	65.3869	54.43	0.0025	1.2479	1.7188	11.49	4.0475	33.2
A2a	69.0889	68.662	52.32	0.0081	0.9236	1.1716	12.83	-14.1365	56.7
A3a	74.174	74.057	51.27	0.0022	0.8302	0.9581	16.72	21.378	45
A4a	72.9532	72.8837	52.08	0.0013	1.1778	1.5154	14.34	11.547	40
A5a	63.526	63.4158	52.3	0.00210	0.8486	1.0106	14.47	33.7855	45.9
A6a	74.92	74.7276	53.55	0.0035	0.7876	0.8888	16.22	9.5914	58.2
A7a	70.337	69.9236	57.66	0.0071	0.9075	1.1569	0.361	10.0322	43.7
A1b	65.3869	65.0857	51.55	0.0058	0.9017	1.2890	9.631	9.9042	62.3
A2b	68.662	68.4704	51.97	0.0036	1.0869	1.4262	16.63	13.5671	59.1
A3b	74.057	73.8326	53.94	0.0041	0.9396	1.2679	8.407	10.5665	39.9
A4b	72.8837	72.5358	58.32	0.0059	0.7833	1.1006	17.09	7.8680	49.5
A5b	63.4158	63.1493	58.88	0.0045	0.9031	1.2956	16.14	9.1760	59.4
A5b	74.7276	74.536	52.65	0.0036	0.6891	0.9094	15.42	4.6010	53.3
A7b	69.9236	69.5652	54.16	0.0066	0.8457	1.1051	13.97	9.1590	57.6
A1c	65.0857	64.7650	51.97	0.0061	0.9838	1.3759	15.25	6.4190	59.6
A2c	68.4704	68.3052	52.06	0.0031	0.7215	1.0658	10.97	9.8052	49.6
A3c	73.8326	73.5366	53.34	0.0055	0.60133	0.8534	16.25	11.6300	56.6
A4c	72.5358	72.2980	52.8	0.0045	0.8808	1.2343	14.93	9.1081	58.2
A5c	63.1493	62.8581	51.17	0.0056	0.8309	1.2271	-9.754	-6.2580	51.9
A6c	74.536	74.1279	54.09	0.0075	0.6846	0.9124	11.44	9.0660	55.3
A7c	69.5652	69.3420	50.25	0.0044	0.5861	0.9119	15.91	8.7120	57.2
A1d	64.765	64.4765	51.77	0.0055	1.1158	1.6311	13.59	-2.6871	51.6
A2d	68.3052	67.9402	51.63	0.0070	1.3552	1.9585	17.93	7.3990	56.6
A3d	73.5366	73.2157	53.16	0.0060	0.7822	1.0908	14.25	9.8920	58.6
A4d	72.298	71.8873	51.88	0.0079	1.0798	1.5745	15.34	10.450	52.2
A5d	62.8581	62.576	50.22	0.00561	1.2537	1.6439	16.41	9.1070	56.8
A6d	74.1279	73.8565	59.03	0.0051	1.0781	1.4010	11.94	44.8900	58.3

3. Tabulation Work and Calculation

A. CBN Ground Surfaces

The table 3, shows the CBN ground surfaces.

B. CBN Ground Surfaces

The table 4, shows the CNT surface grinding values.

C. Material Removal Rate Calculation

Material removal rate = (Weight before (g) subtracted from weight after (g))/Time Taken (in sec)

D. Taguchi Analysis: MRR, Temp. vs. Speed, Feed Rate and Depth of Cut

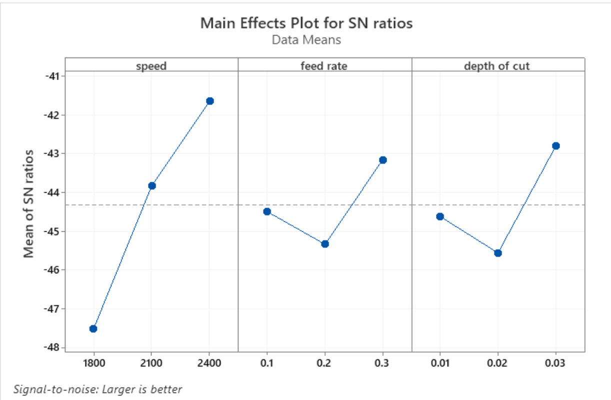

Fig. 14. Graph for S/N ratio obtained for CBN wheel

In these results it shows that the main effects plot for S/N ratio indicates that Speed has the largest effect on the signal to noise ratio and how temperature and MRR is greatly affected by it.

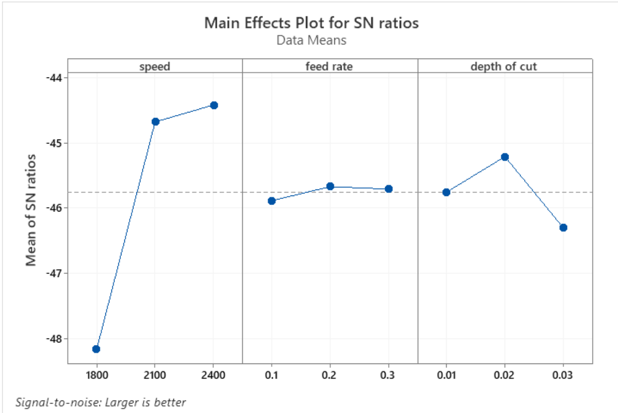

Fig. 15. Graph for S/N ratio obtained for CNT wheel

In these results it shows that the main effects plot for S/N ratio indicates that Speed has the largest effect on the signal to noise ratio and how temperature and MRR is greatly affected by it and feed rate is least affecting it.

4. Results

A. CBN Wheel Result

The table 5, shows the CBN wheel result.

B. CNT Wheel Result

The table 6, shows the CNT wheel result.

C. Comparison

The Material Removal Rate of 4%CNT-CBN wheel is better than that of CBN wheel, which is evident from the table. But it

Table 4
CNT ground surfaces

S.no.	Surface Number	Weight before (gm)	Weight after (gm)	Time (sec)	MRR (gm/sec)	Surface Roughness (µm)	Temp. °C
1	B1a	74.0404	73.8355	54.43	0.0029	0.5439	33.2
2	B2a	73.9935	73.7069	52.32	0.0035	0.4219	56.7
3	B3a	73.9159	73.7165	51.27	0.0024	0.4766	45
4	B4a	73.9094	73.6904	52.08	0.0024	0.5333	40
5	B5a	73.6799	73.4318	52.3	0.0027	0.3381	45.9
6	B6a	72.977	72.4371	53.55	0.0050	0.4082	58.2
7	B7a	73.7279	73.501	57.66	0.0022	0.3792	43.7
8	B1b	73.7165	73.453	51.55	0.0034	0.6093	62.3
9	B2b	73.6904	73.5094	51.97	0.0022	0.61085	59.1
10	B3b	73.7165	73.408	53.94	0.0040	0.4784	39.9
11	B4b	73.6904	73.325	58.32	0.0046	0.4924	49.5
12	B5b	73.4318	73.1298	58.88	0.0038	0.6761	54.4
13	B6b	72.4371	72.0398	52.65	0.0044	0.4157	53.3
14	B7b	73.501	73.2027	54.16	0.0031	0.3985	57.6
15	B1c	73.453	72.9817	51.97	0.0063	0.5143	59.6
16	B2c	73.5094	73.2558	52.06	0.0034	0.6153	49.6
17	B3c	73.408	72.9563	53.34	0.0050	0.5140	56.6
18	B4c	73.325	72.9577	52.8	0.0043	0.4885	58.2
19	B5c	73.1298	72.8436	51.17	0.0037	0.7378	51.9
20	B6c	72.0398	71.7675	54.09	0.0037	0.4870	55.3
21	B7c	73.2027	72.8625	50.25	0.0043	0.6287	57.2
22	B1d	72.9817	72.46	51.77	0.0069	0.486	51.6
23	B2d	73.2558	73.091	51.63	0.0028	0.5235	56.6
24	B3d	72.9563	72.5589	53.16	0.0053	0.7039	58.6
26	B4d	72.9577	72.5867	51.88	0.0045	0.4132	52.2
26	B5d	72.8436	72.5227	50.22	0.0043	0.8681	56.8
27	B6d	71.7675	71.2869	53.09	0.0056	0.4914	58.3

is noted that the surface roughness parameters of the CBN wheel is much better than that of the CNT wheel.

Table 5
CBN result

Surface name	Surface roughness	MRR
A1a	1.247933	0.0025299
A2a	0.9236	0.0081594
A3a	0.830267	0.002282
A4a	1.177833	0.0013345
A5a	0.848667	0.0021071
A6a	0.787667	0.0035929
A7a	0.9075	0.0071696
A1b	0.9017	0.0058429
A2b	1.086933	0.0036867
A3b	0.939667	0.0041602
A4b	0.783333	0.0059654
A5b	0.9031	0.0045262
A5b	0.68	0.0036391
A7b	0.8457	0.0066174
A1c	0.9838	0.0061709
A2c	0.721533	0.0031733
A3c	0.601333	0.0055493
A4c	0.8808	0.0045038
A5c	0.830967	0.0056908
A6c	0.684667	0.0075448
A7c	0.5861	0.0044816
A1d	1.1158	0.0055727
A2d	1.3552	0.0070695
A3d	0.782233	0.0060365
A4d	1.079867	0.0079163
A5d	1.253767	0.0056173
A6d	1.078167	0.0051121

Table 6
CNT result

Surface Number	Surface Roughness	MRR
B1a	0.5439165	0.002932
B2a	0.4219665	0.003509
B3a	0.4766665	0.002418
B4a	0.53335	0.002433
B5a	0.3381	0.002727
B6a	0.4082835	0.005064
B7a	0.3792	0.002274
B1b	0.6093665	0.003407
B2b	0.61085	0.002235
B3b	0.4784335	0.004091
B4b	0.49245	0.004607
B5b	0.6761335	0.003837
B6b	0.4157835	0.004431
B7b	0.3985665	0.003114
B1c	0.5143665	0.006393
B2c	0.6153165	0.003448
B3c	0.5140165	0.005042
B4c	0.4885335	0.004376
B5c	0.7378335	0.003769
B6c	0.48705	0.003737
B7c	0.6287	0.004333
B1d	0.486	0.006979
B2d	0.5235165	0.002857
B3d	0.70395	0.005386
B4d	0.4132335	0.00454
B5d	0.8681335	0.004385
B6d	0.4914215	0.005625

5. Conclusion

Grinding all the pieces of Titanium Grade 5 specimens, using CBN grinding wheel and by extrapolating the values of the 4% CNT-CBN wheel from the research papers of 2% and 3% CNT-CBN wheel, it is predicted that the surface finishing of the 4% CNT-CBN grinding wheel is much better than that of the CBN grinding wheel. 4% CNT incorporated CBN grinding wheel it is concluded that the Surface finishing of the 4% CNT-CBN grinding wheel is much better than that of CBN grinding wheel.

The material removal rate of the 4% CNT-CBN grinding wheel is predicted to grind the surface more efficiently than that of the CBN wheel.

So it is concluded by stating that the percentage of CNT incorporated in CBN grinding wheel greatly affects the surface roughness and MRR of the work piece. Hence it is a great idea to incorporate CNT in standard CBN wheel can achieve better surface characteristics.

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