International Journal of Scientific & Engineering Research, Volume 3, Issue 1, January-2012
ISSN 2229-5518

Parametric influence on cutting parameters characteristics in precision machining of ceramic coating materials

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Abstract— Ceramic coated components have the advantage features of both metal and ceramics, i.e. good toughness, high hardness and wear resistance. Despite their outstanding characteristics, ceramic materials are not used in many cases due to high cost of machining. A major draw back to engineering applications of ceramic is due to their brittleness and fracture toughness, which makes them difficult and costly to machine.

In order to study the precision machining processes of ceramics like grinding and lapping, experiments were conducted to find out the influence of various cutting parameters on surface quality production as well as grinding and lapping performance.

Surface grinding of ceramic coating materials was done on samples specimens coated with Alumina (Al2O3), Alumina- Titania (Al2O3-TiO2) and Partially stabilized zirconia (PSZ)using diamond and CBN (cubic boron nitride) grinding wheels. Based on the experimental results, the influence of cutting parameters, namely, cutting force, surface roughness and bearing area characteristics were evaluated and optimum machining conditions have been suggested for better performance in precision machining of ceramic coating materials.

Index Terms— Bearing Area Characteristics, Cutting force, Diamond and CBN grinding wheel, Grinding and Lapping, Optimizations of Cutting parameters, Precision Machining Processes Surface roughness.

1 INTRODUCTION

WITH the projected wide spread applications of ceramic coating materials, it is necessary to develop an appropriate technology for their efficient and cost effective machining processes[5],[7], [9] and [11]. Grinding of ceramics is a difficult task, as it is generally associated with cracking, splintering and delamination of surfaces. Conventional processes and tools are not generally suited for the machining of ceramics. Standard machining tools can be used with optimization of machining parameters in operating conditions [13-14]. Various precision machining techniques that could be adopted for efficient machining of ceramic materials, namely grinding and lapping processes are studied in detail for the parametric influence of various cutting parameters of precision machining of ceramic coating materials.

Ceramic coated components used in industrial applications, generally require post treatments like heat treatment and surface finishing by precision machining [1-8]. Good surface finish and high efficiency in machining to meet the demands of tight tolerances are generally achieved by grinding, lapping and polishing like precision machining processes [3].

Grinding of ceramics is a difficult task, as it is generally associated with cracking of surface. In order to study the effect of precision measuring processes [15], experiments were conducted to check the machining parameters like surface quality, grinding forces etc. on ceramic coated components for different machining conditions.

The main object of this study is to evaluate the behavior of A, AT, PSZ, Super-Z alloy and ZTA ceramic coating materials subjected to different grinding conditions. The performance was evaluated by machining grinding force [20-22], surface finish [17] and bearing area characteristics [18] and also oil film retainability characteristics [15].

2 EXPERIMENTAL PROCEDURE

Three different commercially available ceramic coating powder materials namely, Alumina (Al_2O_3), Alumina-Titania (Al_2O_3-TiO_2), Partially Stabilized Zirconia (PSZ) were used for the preparation of coatings [10-14]. A 40 KW Sulzer, Metco plasma spray system with 7MB gun is used for this plasma spraying of coatings. Mild steel plates of 50x50x6 mm were used as substrate to spray the ceramic oxides. They were grit blasted, degreased and spray coated with a 50 to 100 microns Ni Cr Al bond coat. The above ceramic materials were then plasma sprayed using optimum spray parameters.

2.1 Precision Machining of Ceramic Coating

Grinding: Using diamond and CBN grinding wheels [20] with the surface grinding trials were conducted with the grinding conditions mentioned below in table 1. Machining trials were conducted on different ceramic coated specimens (A, AT and PSZ ceramic coatings).

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Table1. Grinding specifications

Type of grinding	Surface grinding
Grinding wheel used	Diamond of 185 grit size CBN of 120 grit size
Wheel speed used	5 to 30m/sec
Depth of grinding	10 to 40µm
Work feed	0.5 mm/sec

The main object of this study is to evaluate the behavior of A, AT and PSZ ceramic coatings subjected to different grinding conditions. The performance [18] was evaluated by measuring

1. Grinding force (Normal and Tangential force)
2. Surface finish produced which also includes the bearing area characteristics
3. Oil retainability characteristics.

2.2 Force Measurement

The normal grinding force (Fn) and the tangential force (Ft) were measured using grinding dynamometer [17] and [21].The ground samples were measured for different surface finish parameters such as R_a, R_t, and t_p using Taylor Hobson's stylus tracing profilometer.

2.3 Lapping

A circular disc of 200 mm in diameter made of bright steel and a pin of 6mm diameter were coated with NiCrAlumel bond coat of thickness 75µm and subsequently coated with different coaing materials namely, Alumina (A), Alumina-Titania (AT), Partial Stabilized Zirconia (PSZ), Super-Z alloy and ZTA [19-20].

Table2. Lapping specifications

Type of Machine	Flat surface hand lapping
Lapping medium	Abrasive and diamond compound paste.
Diamond size	2-10 µ m
Lapping speed	0.2 m/sec
Lapping pressure	0.5 MPa
Lapping time duration	25 minutes

Samples were initially ground to achieve pre lapping finish and then further lapped under the conditions mentioned above in table 2. The process variables were lapping time (ranging 5 to 25 minutes) and size of the diamond abrasives in lapping [18].

The lapped discs were thoroughly cleaned and measurement in respect of surface finish was made using Taylor Hobson's surface finish profilometer.

2.4 Oil retainability test

The oil retainability of ceramic coated surfaces was estimated using SAE 120 lubricating oil. In order to explain the oil retain ability of ceramic coated surfaces, the coated plates (specimens) were ground and lapped to half the area of the plate and the rest half left as it is. Oil droplets were then put on these two parts of the specimen and left untouched for 3 hours. The specimens with the oil droplets were then observed further increase in diameter using a travelling microscope and oil spreadability on ground and lapped surfaces were studied.

3 Results and Discussion

3.1 Results of Grinding

It has been noticed that, during the grinding of ceramic coatings, grinding forces were found to be varying considerably with increasing grinding speed. Also, it is observed that, with CBN wheels grinding force components (Ft and Fn) were found to be higher when compared to diamond grinding wheel as shown in figures1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 30, 31, 32 and 33. Besides, it is noticed that, the increase in the depth of grinding, generally improved the surface finish. During trials on grinding of ceramic coatings, grinding velocity, a range of 10 – 15 m/sec and depth of grinding 30µm were assessed to be more critical. It is also observed grinding of Alumina-Titania (AT) and Partially stabilized zirconia (PSZ) ceramic coatings with diamond wheel gave better surface finish.

3.2 Results of Lapping

It is concluded that, surface finish of lapped ceramic coatings, improved with lapping time and remains constant after 15 minutes of lapping time in case of AT and PSZ, whereas in case of Alumina (A), it attains saturation after 20 minutes of lapping time. It is also seen among the coatings that, AT could be lapped better than the other two.

Bearing area characteristics of sprayed and ceramic coatings with diamond wheels are shown in figures 36, 37, 38, 39, 40, 41, 42, 43, 44 and 45. It is observed there is no much variation in the bearing area characteristics of coated ceramic surfaces subjected to diamond wheel grinding, but AT exhibits faster tendency to attain cent percent t_p area. With CBN grinding, rapid improvement in bearing area characteristics of Alumina is observed due to improved grinding of brittle materials (like Alumina). This is due to grinding forces associated with CBN grinding wheels, CBN grains, cuts the ceramics relatively cooler (CBN is thermally more conductive) compared to diamond wheel. It is also seen that, diamond wheel is more sensitive to grinding condition and with CBN wheel it is possible to go for higher depth of grinding , because of better thermal properties of CBN.

3.3 Results of Oil Retainabilty Test

Ceramics find wider applications from bearings to critical components of I.C.Engines. Some of the applications require for porosity control to enhance the strength and also to provide adequate film and damping qualities. For evaluating oil retention capability and to find out the surface quality during precision machining, oil machining test have been carried out. It is seen that, as sprayed ceramic surface could not retain more oil on the surface (because of its layer surface porosity) and hence the oil film thickness was found to be less, but thickness of oil film on ground and lapped surface was larger compared with the as sprayed ceramic surface. This may be due to the closure of pores in surface grinding. It is seen that, closure of pores and surface asperities take place on the surfaces of AT and PSZ coating than with Alumina coatings. Lapping further improved surface finish of ceramic coatings by reducing porosity and oil film thickness on the lapped surface was correspondingly higher. The oil retainability of the different coated plates after machining to 10µm depth of cut on the basis of three hours observation is shown table 3.

Table 3. Results of oil speadability in diameter

Condition	**Alumina**	**Alumina-Titania**	**Partial stabilized zirconia**
As sprayed	2 times	2 times	2 times
Grinding	3 times	1.25times	2.5times
Lapping	3.5 times	1 time	2.75 times

The occurrence of early bearing area improvement for AT and PSZ coating by grinding and lapping can be visualized in the marginal difference in film thickness.

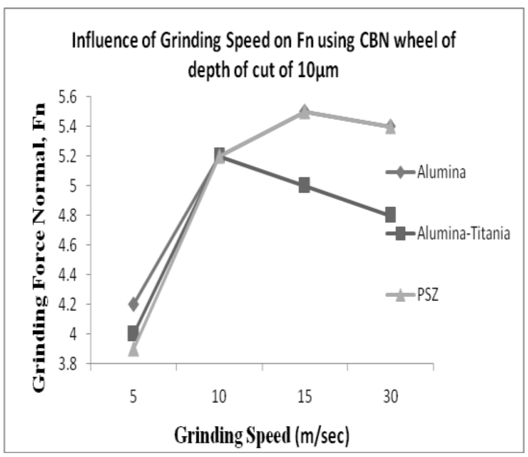

Fig.1. Normal force v/s grinding speed using CBN wheel and depth of cut 10µm.

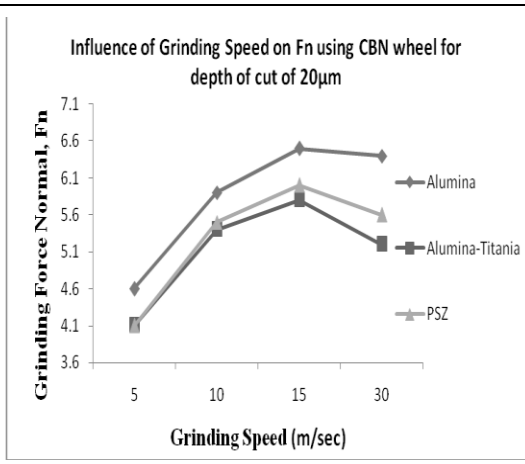

Fig. 2. Normal force v/s grinding speed using CBN wheel and depth of cut 20µm.

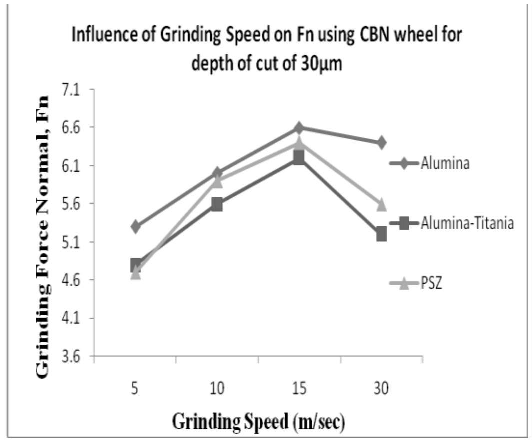

Fig. 3. Normal force v/s grinding speed using CBN wheel and depth of cut 30µm.

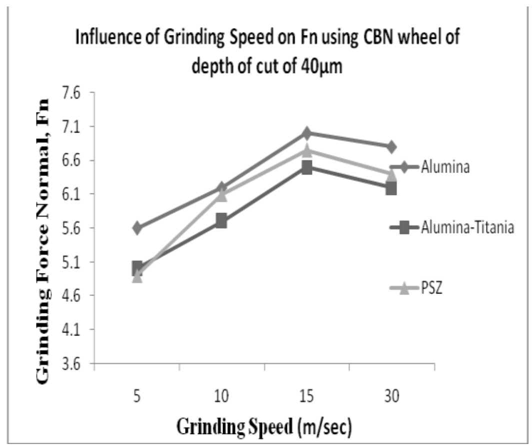

Fig. 4. Normal force v/s grinding speed using CBN wheel and depth of cut 40µm.

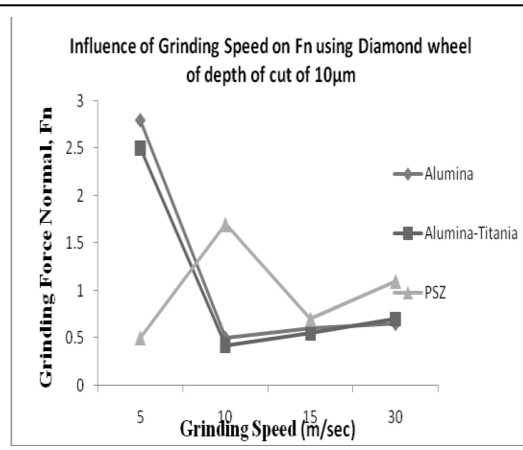

Fig. 5. Normal force v/s grinding speed using Diamond wheel and depth of cut 10µm

ISSN 2229-5518

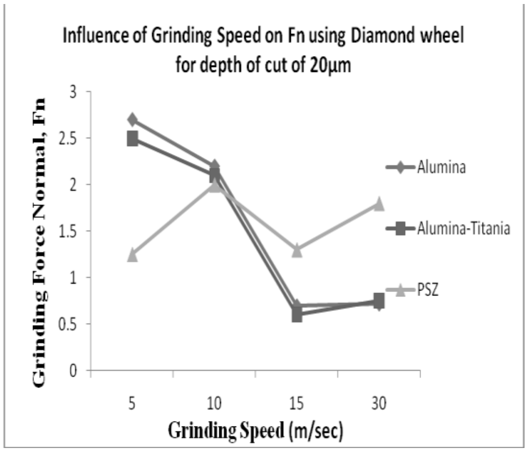

Fig. 6. Normal force v/s grinding speed using Diamond wheel and depth of cut 20µm.

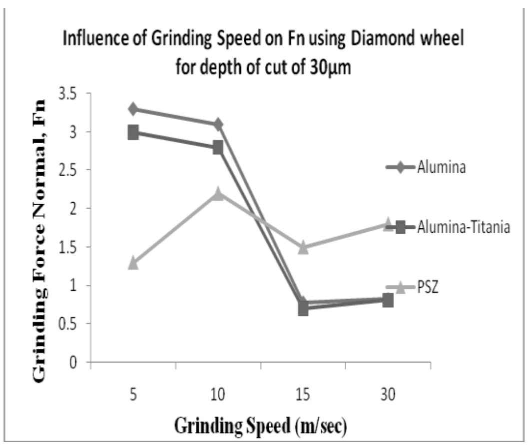

Fig. 7. Normal force v/s grinding speed using Diamond wheel and depth of cut 30µm.

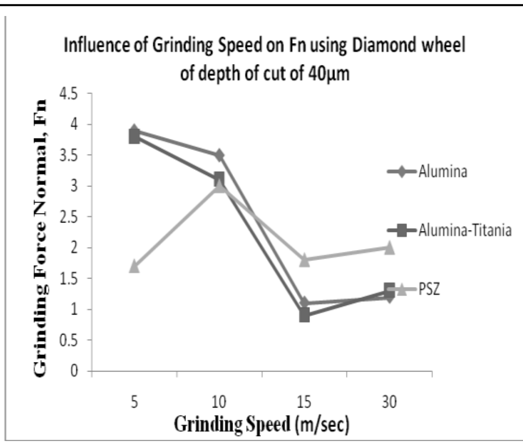

Fig. 8. Normal force v/s grinding speed using Diamond wheel and depth of cut 40µm

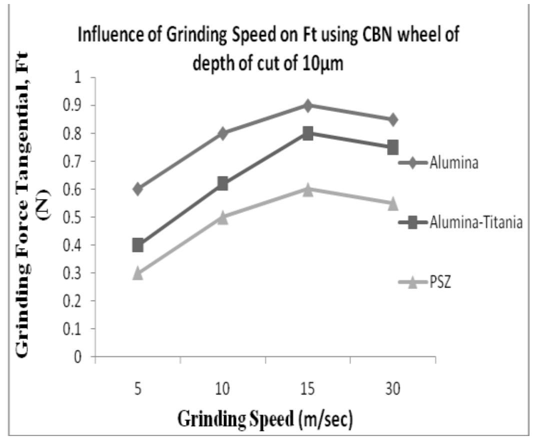

Fig. 9. Tangential force v/s grinding speed using CBN wheel and depth of cut 10µm.

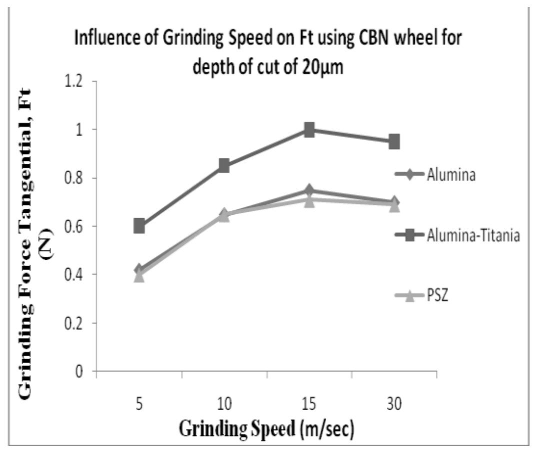

Fig. 10. Tangential force v/s grinding speed using CBN wheel and depth of cut 20µm.

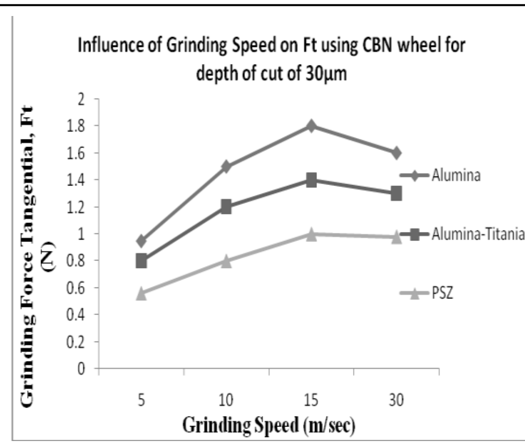

Fig. 11. Tangential force v/s grinding speed using CBN wheel and depth of cut 30µm.

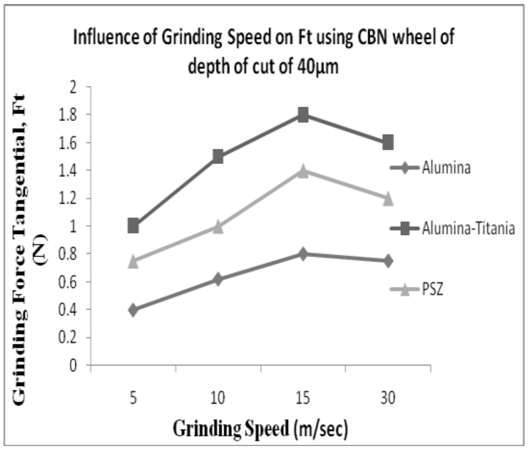

Fig. 12. Tangential force v/s grinding speed using CBN wheel and depth of cut 40µm.

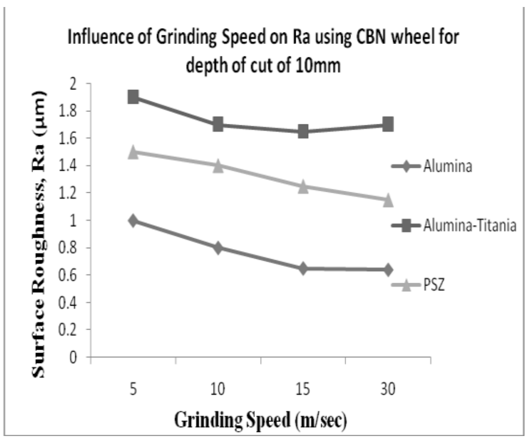

Fig. 13. Surface roughness (Ra) v/s grinding speed using CBN wheel and depth of cut 10µm.

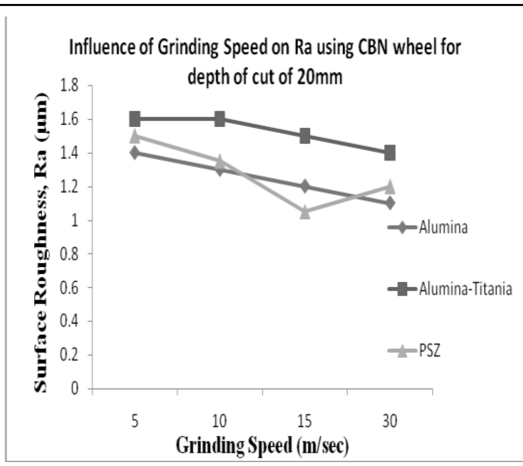

Fig. 14. Surface roughness (Ra) v/s grinding speed using CBN wheel and depth of cut 10µm.

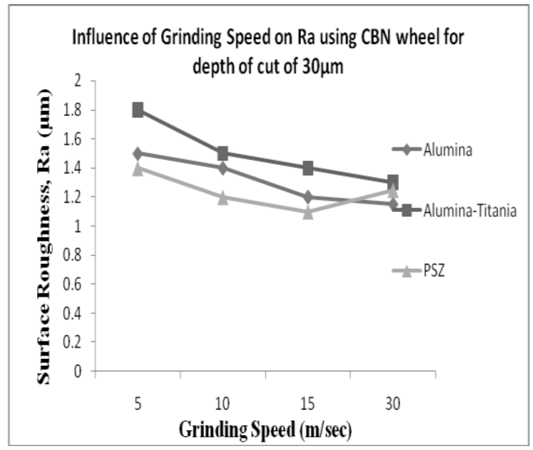

Fig. 15. Surface roughness (Ra) v/s grinding speed using CBN wheel and depth of cut 30µm.

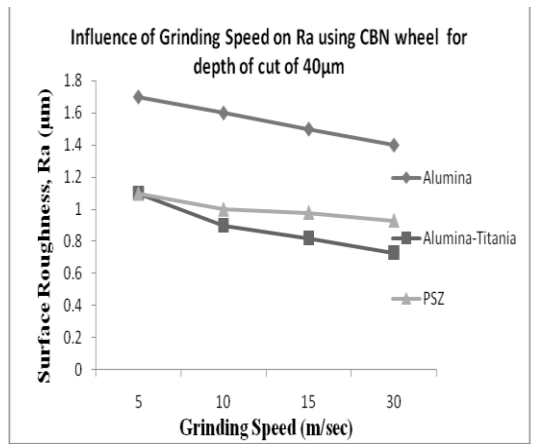

Fig. 16. Surface roughness (Ra) v/s grinding speed using CBN wheel and depth of cut 40µm.

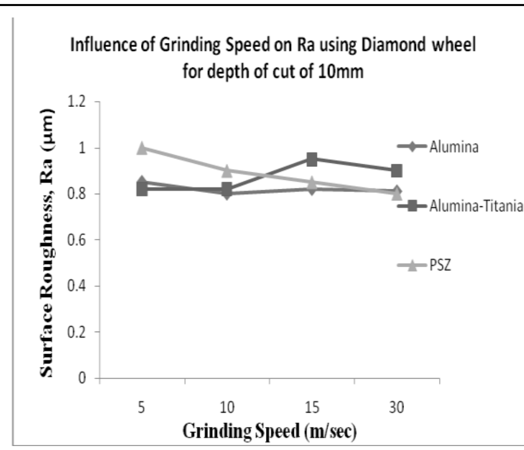

Fig. 17. Surface roughness (Ra) v/s grinding speed using Diamond wheel and depth of cut 10µm.

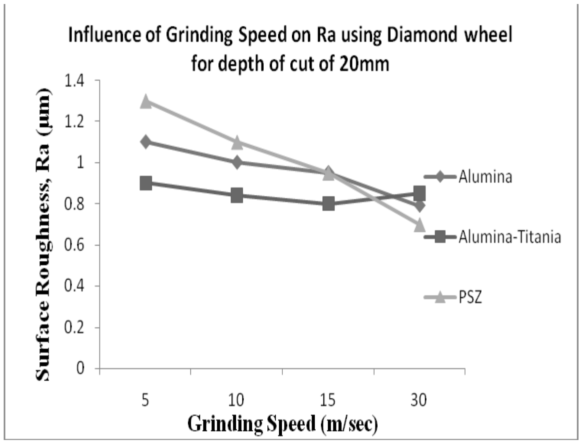

Fig. 18. Surface roughness (Ra) v/s grinding speed using Diamond wheel and depth of cut 20µm.

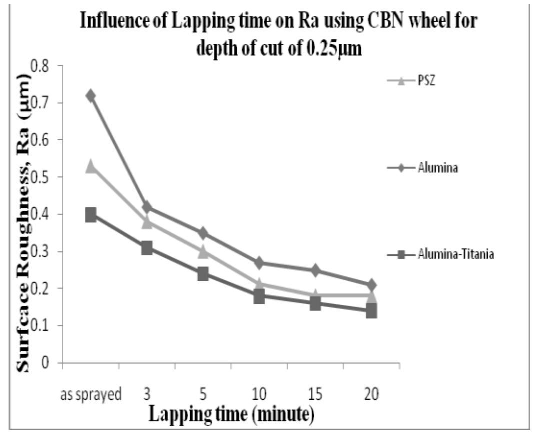

Fig. 21. Surface roughness (Ra) v/s lapping time using CBN wheel and depth of cut 0.25µm.

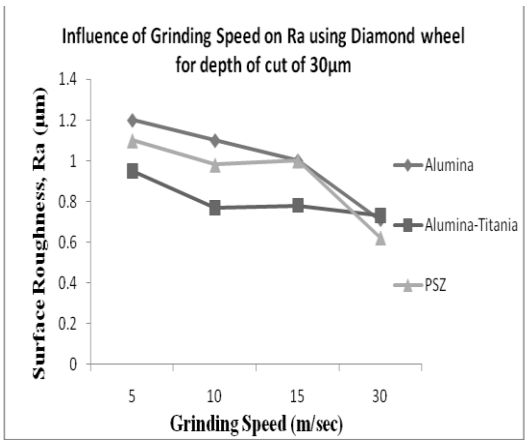

Fig. 19. Surface roughness (Ra) v/s grinding speed using Diamond wheel and depth of cut 30µm.

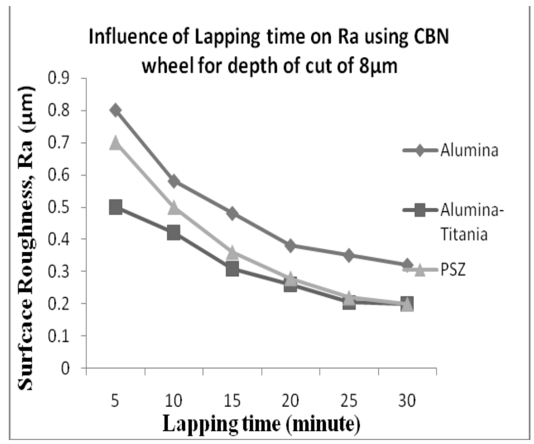

Fig. 22. Surface roughness (Ra) v/s lapping time using CBN wheel and depth of cut 8µm.

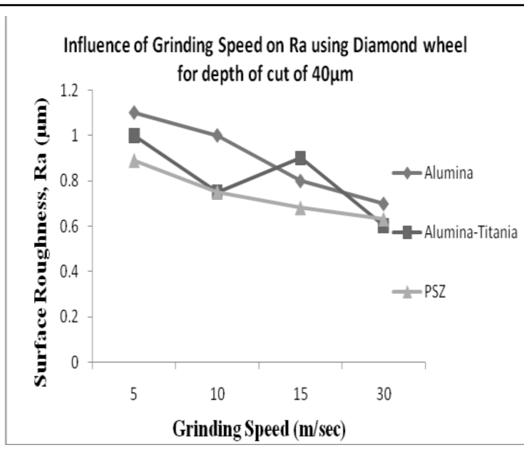

Fig. 20. Surface roughness (Ra) v/s grinding speed using Diamond wheel and depth of cut 40µm.

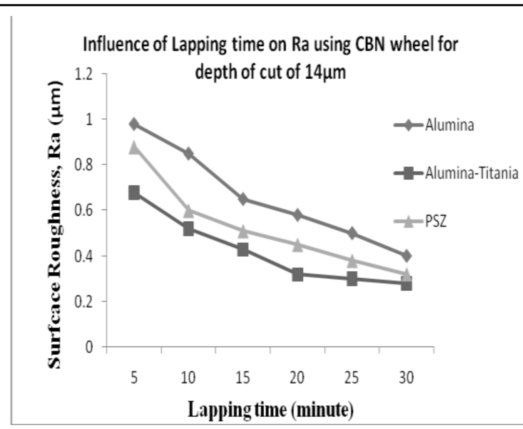

Fig. 23. Surface roughness (Ra) v/s lapping time using CBN wheel and depth of cut 14µm.

ISSN 2229-5518

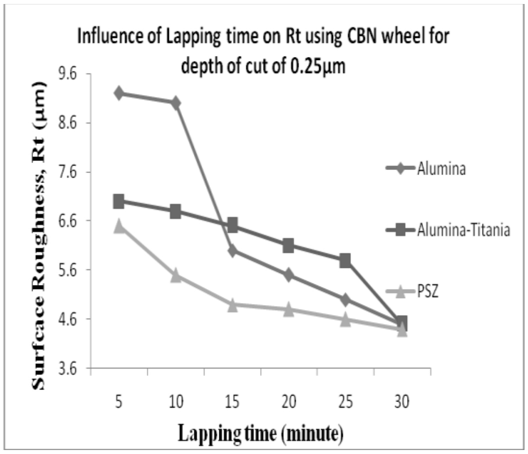

Fig. 24. Surface roughness(Ra) v/s lapping time using Diamond wheel and depth of cut 0.25µm.

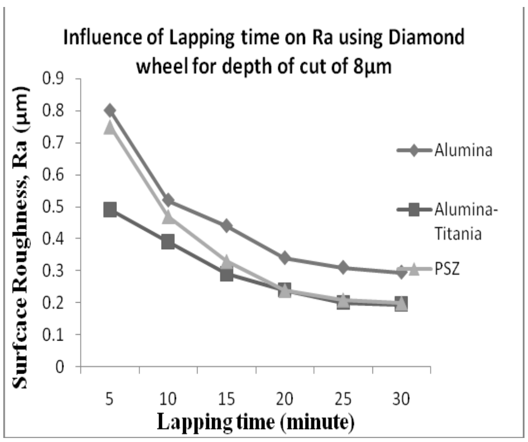

Fig. 25. Surface roughness(Ra) v/s lapping time using Diamond wheel and depth of cut 8µm.

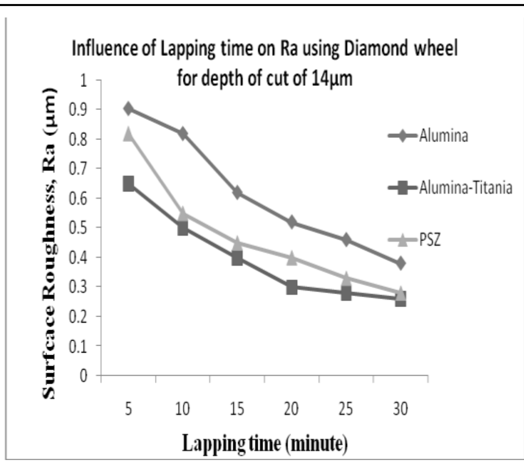

Fig. 26. Surface roughness(Ra) v/s lapping time using Diamond wheel and depth of cut 14µm.

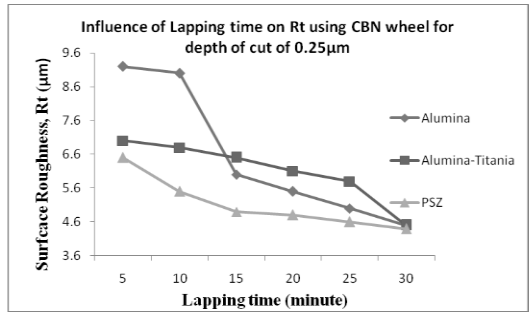

Fig. 27. Surface roughness (Rt) v/s lapping time using CBN wheel and depth of cut 0.25µm.

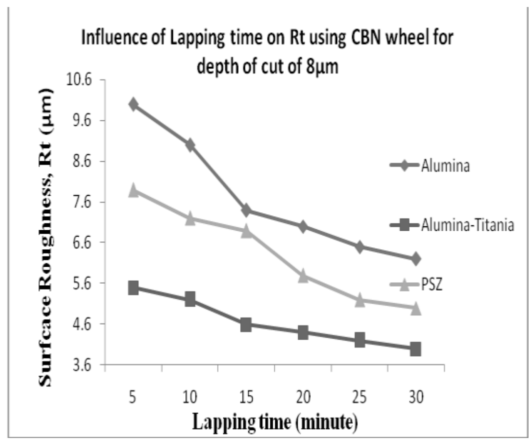

Fig. 28. Surface roughness (Rt) v/s lapping time using CBN wheel and depth of cut 8 µm.

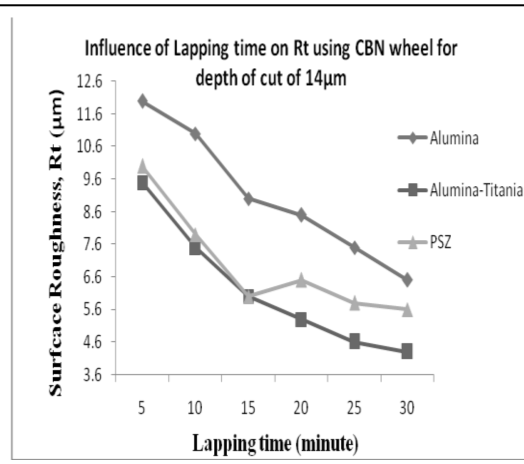

Fig. 29. Surface roughness (Rt) v/s lapping time using CBN wheel and depth of cut 14 µm.

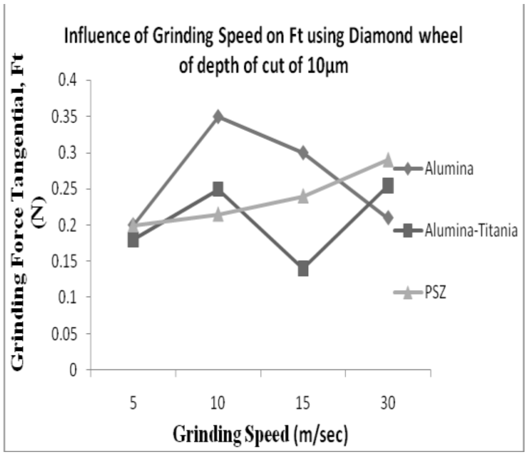

Fig. 30. Tangential force v/s grinding speed using Diamond wheel and depth of cut 10µm.

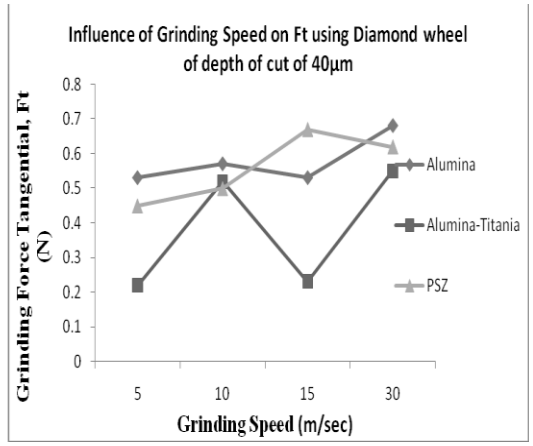

Fig. 33. Tangential force v/s grinding speed using Diamond wheel and depth of cut 40µm.

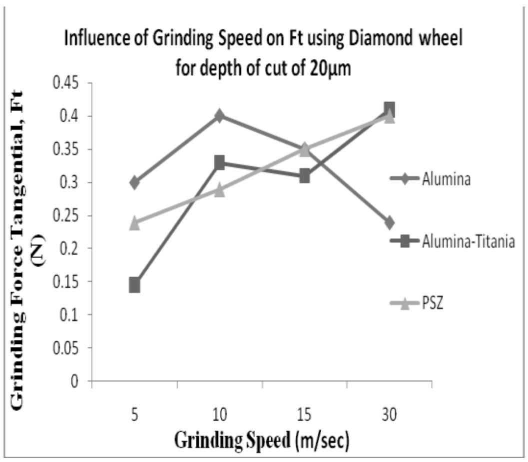

Fig. 31. Tangential force v/s grinding speed using Diamond wheel and depth of cut 20µm.

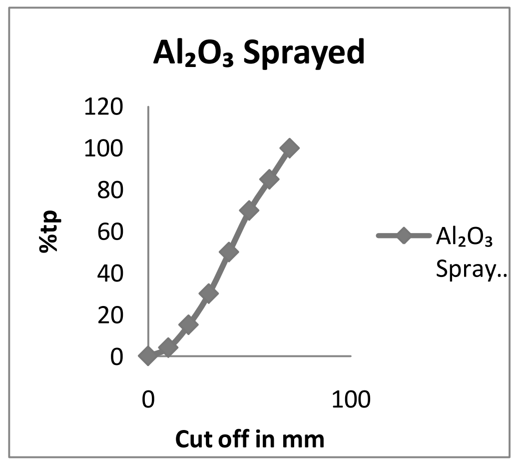

Fig. 34. % Bearing area(tp) v/s cutoff for as sprayed Alumina.

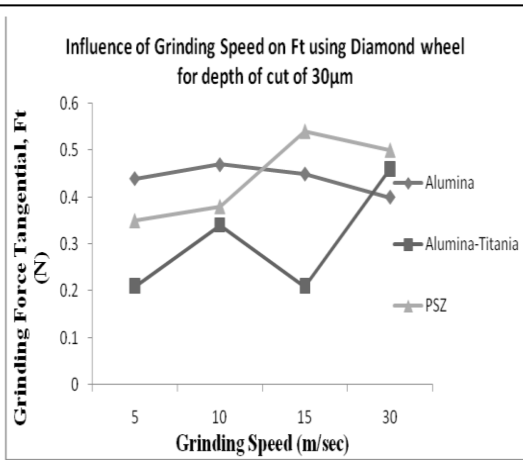

Fig. 32. Tangential force v/s grinding speed using Diamond wheel and depth of cut 30µm.

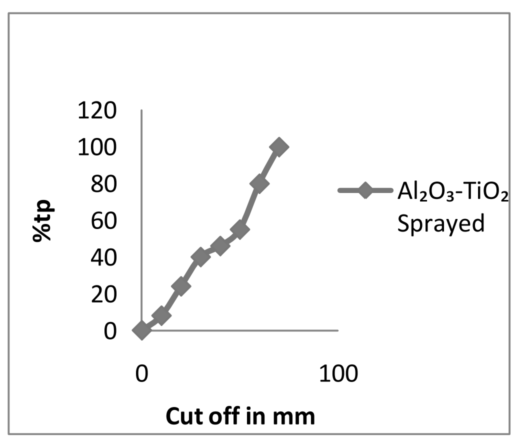

Fig. 35. % Bearing area(tp) v/s cutoff for as sprayed Alumina-Titania (AT).

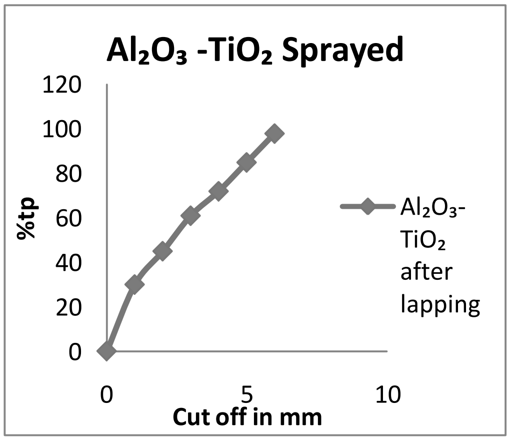

Fig. 36. % Bearing area (tp) v/s cutoff after lapping surface of Alumina-Titania (AT).

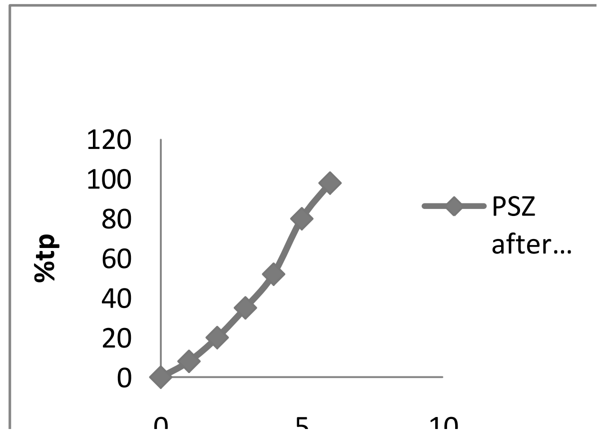

Fig. 39. % Bearing area (tp) v/s cutoff after lapping surface of PSZ.

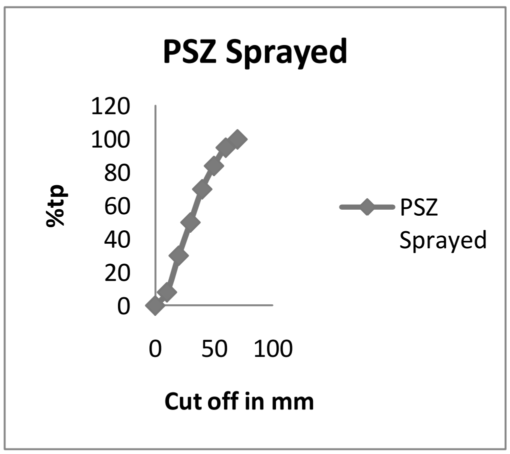

Fig. 37. % Bearing area (tp) v/s cutoff for as sprayed PSZ.

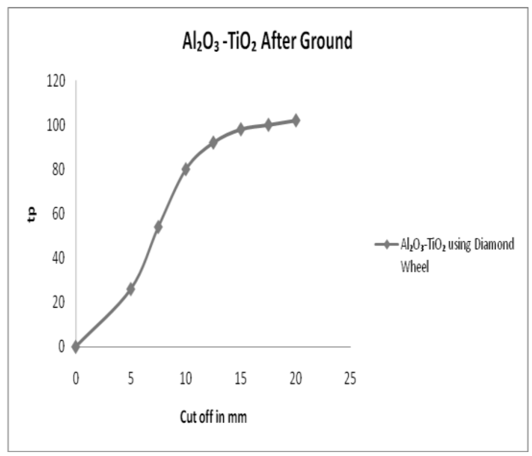

Fig. 40. % Bearing area (tp) v/s cutoff, ground with diamond wheel for Alumina-Titania (AT).

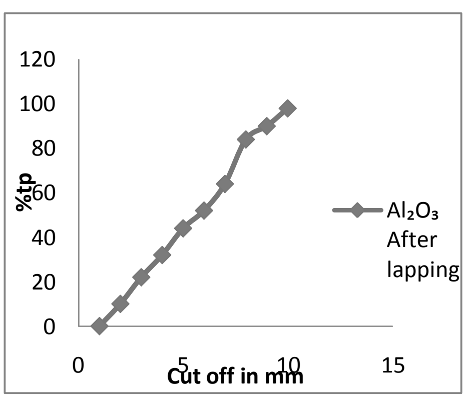

Fig. 38. % Bearing area (tp) v/s cutoff after lapping the surface of (A).

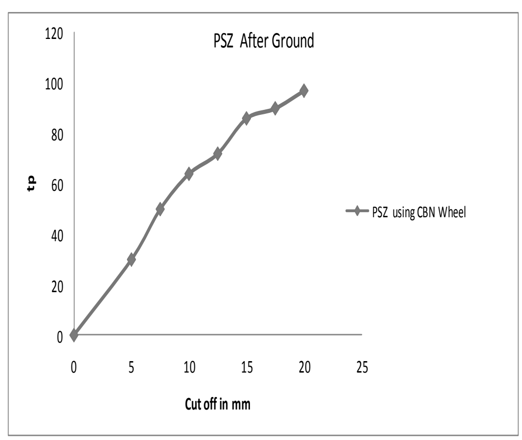

Fig. 41 % Bearing area (tp) v/s cutoff, ground with CBN wheel for PSZ.

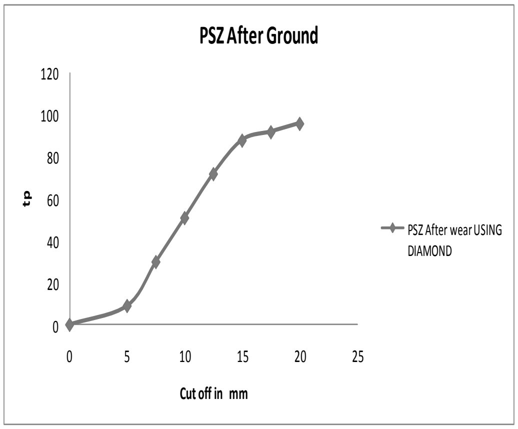

Fig. 42. % Bearing area (tp) v/s cutoff, ground with diamond wheel for PSZ.

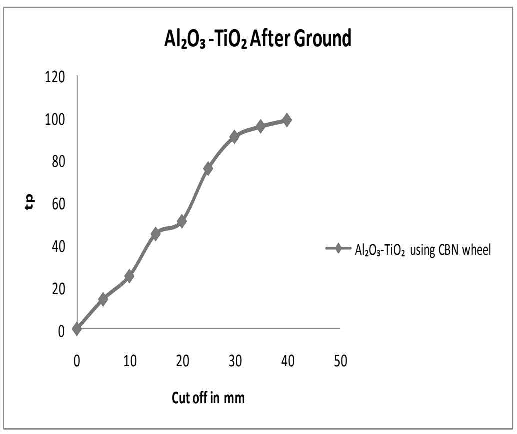

Fig. 43 % Bearing area (tp) v/s cutoff, ground with CBN wheel for AT.

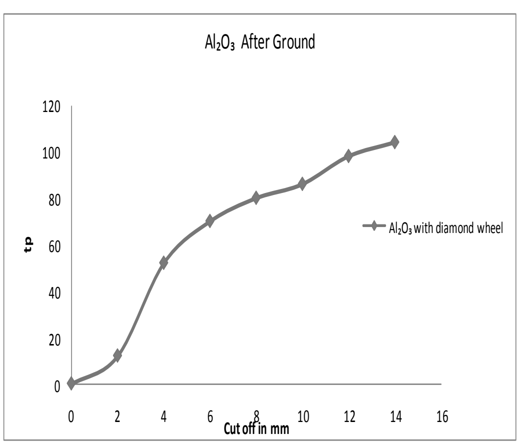

Fig. 44 % Bearing area (tp) v/s cutoff, ground with Diamond wheel for Alumina (A)

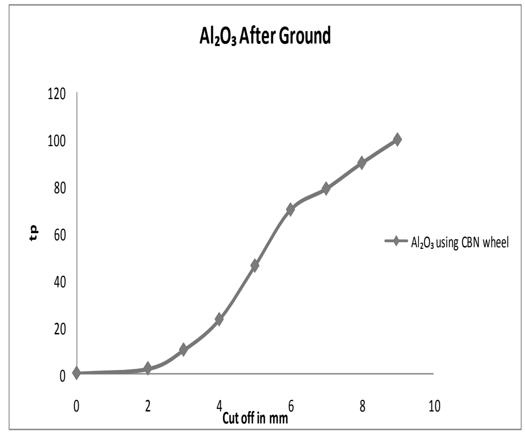

Fig. 45 % Bearing area (tp) v/s cutoff, ground with CBN wheel for Alumina (A)

4 CONCLUSION

Oxide ceramics such as Alumina (A), Alumina-Titania (AT) and Partial stablized zirconia (PSZ), Zirconia Toughened Alumina (ZTA) and Super-Z alloy have been widely used for many industrial applications by deposition of thick film of hard materials on a relatively softer substrate of the engineering components. Before deciding on particular type of coatings, it is essential to look into its characteristics which includes machinability for control of size and shape of end products. Hence it has become objective of the present work to characterise and machine for precision and to identify the optimal conditions for the development of oxide ceramic coatings. Based on the trials on grinding and lapping of ceramic coatings the following conclusions are made.

1. With CBN grinding wheels, grinding force components (Ft and Fn) were found be higher when compared to diamond grinding wheel[20].
2. It is noticed that, increase in depth of grinding, generally the surface finish is improved.
3. During grinding of ceramic coatings, grinding velocity range 10 – 15m/sec and depth of grinding 30µm were found to be more critical.
4. Grinding of AT and PSZ ceramic coatings generally give better surface finish with diamond wheel.
5. From the data obtained by lapping of ceramic coatings, it is observed that, surface finish increases with lapping time and saturation of surface finish takes place after 15 minutes of lapping time in the three ceramic coating materials mentioned.
6. AT could be lapped better than the other two (Ra=0.25 µm and Rt= 4.2µm).
7. Surface texture details show that, AT exhibits faster tendency to attain cent percentage tp area (bearing area characteristic).

8. With CBN wheels, it is possible to go for higher depth of grinding than using Diamond grinding wheel because of better thermal properties of CBN wheels.
9. The oil retainability test reveals the thickness of oil film on ground and lapped surfaces were larger compared with as sprayed ceramic surfaces, which is due to closure of pores and surface irregularities taking place on machined surfaces. Which ishelpful from the point of view of oil film lubrication between parts having relative motion.

The above work has taken as product and development of ceramic coated surfaces are having immense value for industrial applications.

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