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Improvement of the Mechanical Properties of Titania stabilized Alumina Ceramic Cutting tool.

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Abstract

In this work an attempt was taken to improve the mechanical properties of the Al_2O_3 ceramic cutting tool which is continuation of the previous work. In this work, (100-x)% TiO_2 – x% Al_2O_3 (x=98,95 and 92) were prepared using solid state route and pressed into pallets under 175-180MPa load and sintered at three different sintering temperatures 1350ºC, 1400ºC and 1450ºC for 2 hours. Then hardness, wear rate and cutting properties were measured and analyzed with previously measured results of microstructure and densities. It was found that with the increase of % TiO_2 the hardness of the ceramic cutting tools were increased, the wear rate decreased and cutting property got improved. The maximum hardness was found 22 GPa and the minimum weight loss $0.06x10^{-4}$ gm/min was found at 8% TiO_2 stabilized Al_2O_3 ceramic cutting tool. It was also found that 8% TiO_2 stabilized Al_2O_3 showed the best cutting property.

Keywords: Hardness, Wear, Cutting property, Ceramic tools

1. Introduction

For many years, people are searching for a suitable material to produce cutting tools that can sustain higher temperature. There were many pathways taken to select specific materials as cutting tool which can survive at higher temperature. Ceramic materials, due to their better mechanical properties and higher chemical stabilities at high temperature, outperformed other materials and found as the best suited cutting tools materials for high temperature applications. Carbides are one of the most popular choices in making ceramic cutting tool in the industries. However, in recent days, Alumina ceramics has become a prominent material for cutting tools because of their high hardness, chemical inertness and wear resistance [1]. This ceramic is also retaining a high hardness at high temperature when compared to other cutting tools materials. Major limitations on using Alumina ceramic for cutting tools are its low toughness and low thermal shock resistance. Mechanical properties of Al_2O_3 based ceramics have been improved by incorporating reinforcing phases such as TiC, TiN, ZrO_2, WC, TiO_2 etc [2]. In this research work, addition of TiO_2 in Al_2O_3 ceramic has thoroughly investigated.
When alumina is doped with TiO_2 to a certain level, the densifications temperature reduces and makes the mechanical properties like hardness, wear resistance and cutting property much more prominent. It has already been found that the addition of TiO_2 in Al_2O_3 reduces the sintering temperature and retards the grain growth[3] The working paper aims to highlight some improved mechanical properties like hardness, wear and cutting rate of TiO_2 stabilized Al_2O_3 Ceramic Cutting tools and to evaluate the structure-property relationship.

2. Experimental

In this research work, conventional solid state ceramic processing technique was followed. Samples were prepared from commercial alpha Al_2O_3 with the addition of 2, 5 & 8 wt % of TiO_2.The alumina powders used in this work were of 99.87% purity with particle size of around 40nm while, the TiO_2 powders were of 99.9% purity with particle size around 40nm. First, the raw materials were ball-milled at 150 rpm for 18~20 hours in acetone medium. After proper mixing, the powders were extracted with the help of acetone. Then the wet powders were dried at 110-120^oC for 24 hours. After drying, 5~8% PVA (Polyvinyl alcohol) binder was mixed with the powder before compaction. Then, the samples were prepared by using 175-180MPa pressure for 2 minutes holding with a uniaxial hydraulic press. The prepared samples were around 13 mm in diameter and 2 mm thick. These green samples were then dried for one day at 110^{0}C. Finally, the samples were sintered at different sintering temperature. Single stage sintering were carried out for all the sintering cycles where at the first step of sintering the binder was removed by holding the samples at temperature 500^{o}C for 1 hr. After binder removal, at the second step of sintering the samples were fired at 1350^{o}C, 1400^{o}C and at 1450^{o}C for 2 hours (Fig. 1, 2 and 3). With 3 composition and 3 temperature variations, total 9 sets of samples were prepared. The final sintered samples were around 11 mm in diameter and 1.5 mm thick. Finally after sintering, percent theoretical density, grain size, mechanical properties such as hardness, wear and cutting properties were measured and compared with the help of the microstructure of the respected samples, obtained from Scanning Electron Microscope (SEM).

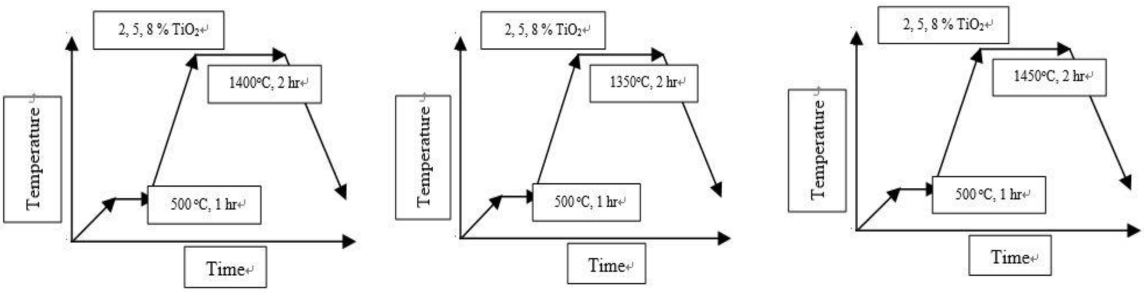

Fig. 1. Single stage sintering cycle for different composition of TiO_2 in Al_2O_3 with increasing temperature

The hardness values of the samples were measured using Vickers Micro hardness Testing Machine **(Fig.2.)** The indentations were made on the specimens using 1 kg load for 30 seconds. The diagonal of the indentations were measured in SEM.
The hardness was calculated using the following formula:

$$H.V. = \frac{1.854Pg}{d} \tag{1}$$

Where,
P = Applied load, kg
d = Mean diagonal of indentation, (m)
g = gravitational acceleration, (9.8m/s^2)
H.V. = Vickers hardness, (GPa)

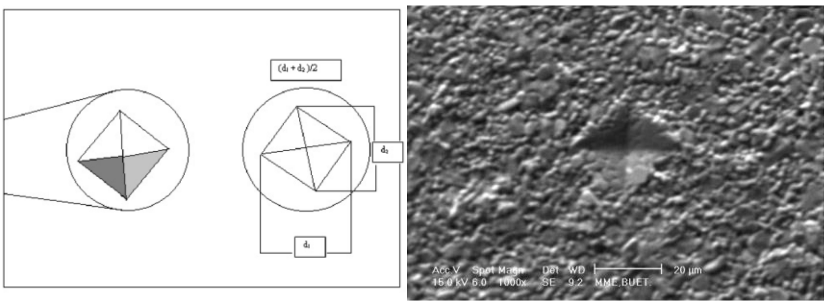

Fig. 2. Indentation of the pyramid cone of Vickers hardness test

Wears of the samples were measured by a wear-testing machine where the samples were placed on a moving disc (Pin and Disk Method). The discs used in the test were made of hardened steel. First the weights of the ceramic sample tools were measured and marked accordingly. Then the samples were placed in the holder and set in the machine **(Fig. 3.)**. After the test the weight of the tools were again taken for the data calculation and result.

The cutting properties of the ceramic tools were tested by cutting a mild steel specimen in the lathe machine. The tools were used to cut mild steel back. Cutting was done for 2 minutes using cutting speed 465 rpm and depth of cut roughly 0.2 mm. First, the weights of the tools were taken. Then the metal removal was measured by weighing out the chips in every cut. The tools after cutting mild steel were weighed again and by the difference of its initial weight and final weight the cutting rate was determined.

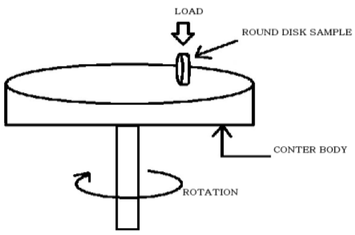

Fig. 3. Wear test (Pin on disk method)

3. Results and discussions

At higher sintering temperature and higher % of TiO_2 content high degree of densification has been achieved. The maximum value of % theoretical density was achieved 95.18% for 8% TiO_2 stabilized alumina cutting tool sintered at 1450ºC[3]. The hardness, wear test and cutting properties were discussed in the following sections.

3.1 Hardness

Theoretically, with increase of sintering temperature densification rate as well as the hardness also increases. This is because denser the samples, more difficult will be the penetration of indenter and higher will be the hardness [5]. From the **Fig. 4** it can be seen that with increase in sintering temperature for 2% TiO_2 stabilized Al_2O_3, the hardness of cutting tools increases from 1350^{0}C to1400^{0}C. But at higher temperature of 1450^{0}C the hardness drops. It is due to grain coarsening at elevated temperature, density drops [3] slightly and so does the hardness.

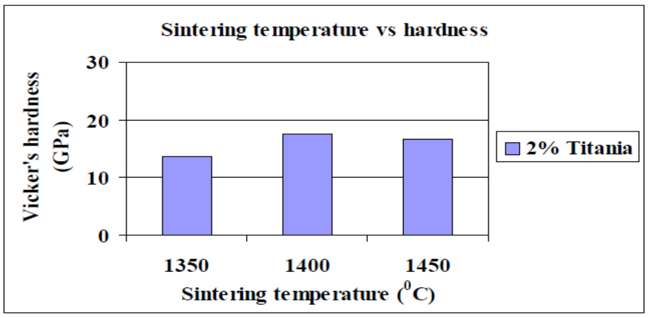

Fig. 4. Sintering temperature versus hardness of 2% TiO_2 stabilized Al_2O_3

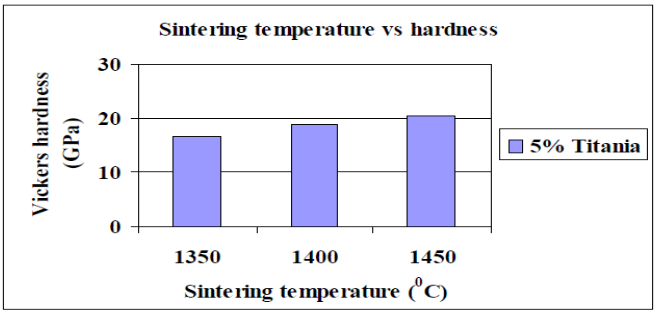

Fig. 5. Sintering temperature versus hardness of 5% TiO_2 stabilized Al_2O_3

From **Fig. 5** and **Fig. 6** a gradual increase in hardness with increase in sintering temperature can be found for

5% TiO_2 and 8% TiO_2 stabilized alumina in the temperature range 1350^{0}C to 1450^{0}C. Maximum value of Vickers's hardness of 22 GPa was obtained for 8% TiO_2-92% Al_2O_3 composition, sintered at 1450^{0}C. The reason behind this is that with higher percentage of TiO_2 it can provide the pinning effect and retards the grain growth [3] of Al_2O_3. For 2% TiO_2 stabilized Al_2O_3 the amount of TiO_2 is very small, that's why it could not provide sufficient pinning effect [3] on Al_2O_3 grains and at higher temperature exaggerated grain growth of Al_2O_3 occurred which can also be seen from the microstructures [3]. For this reason, even at higher temperature we have obtained fine grain dense microstructure with high hardness.

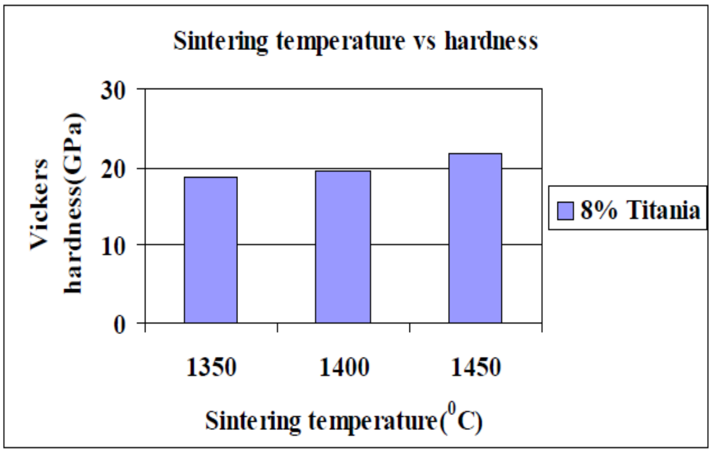

Fig. 6. Sintering temperature versus hardness of 8% TiO_2 stabilized Al_2O_3

So the hardness can be increased at low temperature by increasing % TiO_2 and higher hardness can be achieved with increasing both temperature along with % TiO_2.

3.2 Wear

Theoretically, with increase in density and hardness, the wear rate decreases. From **Fig. 7, Fig. 8** and **Fig. 9** we can see that, for all the samples with increase of %TiO_2 in the compositions, wear rate gradually decreases. On the contrary, for the same composition, increasing temperature in the cases of 2% TiO_2 and 5% TiO_2 wear rate gradually decreased up to 1400 ºC and then slightly increased at 1450ºC. This is due to the grain coarsening [3] occurs at higher temperature which reduces hardness. According to Hall-Patch relationship, we know that coarser the grain, inferior will be the mechanical properties like hardness, wear resistance etc. [4]. As the amount of TiO_2 is very small it could not provide sufficient pinning effect to hinder grain growth of Al_2O_3 grains. That is why excessive, grain growth has occurred at 1450ºC, which is clearly visible in the microstructure [3].

Minimum wear rate of $8*10^{-6}$ gm/min was found for 8% TiO_2 sintered at 1450ºC. This is because the sample containing 8% TiO_2 sintered at 1450ºC has the highest density [3], finer grain and high hardness [3] which is already told in the previous part of the paper.

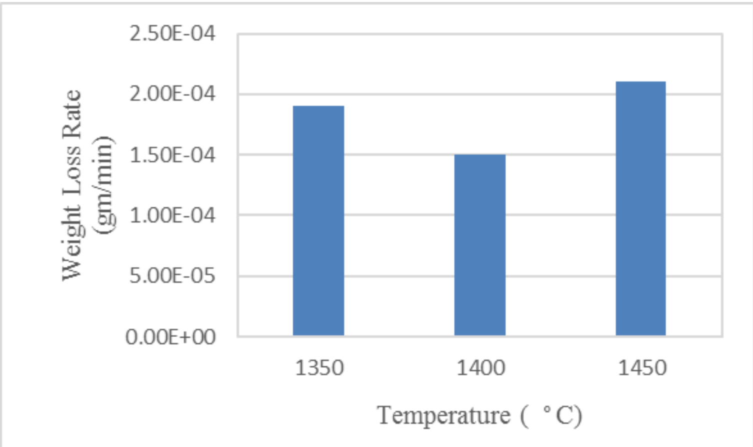

Fig. 7. Sintering temperature vs wear rate of 2% TiO_2 stabilized Al_2O_3

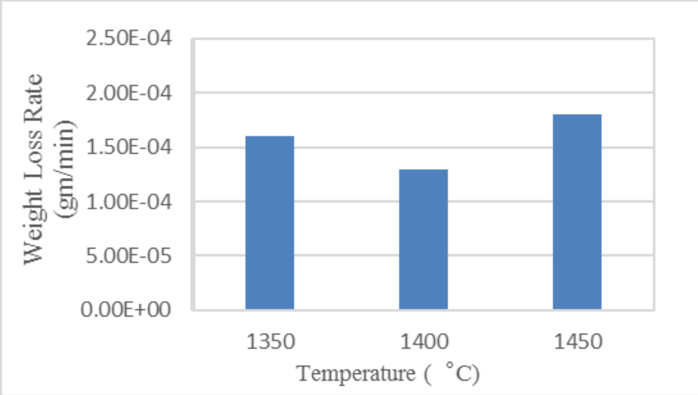

Fig. 8. Sintering temperature versus wear rate of 5% TiO_2 stabilized Al_2O_3

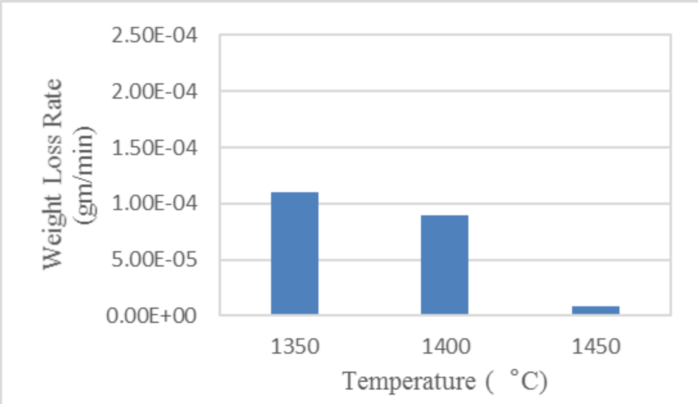

Fig. 9. Sintering temperature versus wear rate of 8% TiO_2 stabilized Al_2O_3

3.3 Cutting

Theoretically with the increase of density and hardness cutting rate also increases. With the increase of TiO_2 in composition, for the same temperature, cutting property gradually improved, which is clearly visible from **Fig. 11 to Fig. 12.** However, in the cases of 2% and 5% TiO_2 cutting property gradually improved up to 1400ºC but then deteriorated at 1450^0C and also samples had failed during cutting operation. This was happened due to grain coarsening occurred at higher temperature. So same thing can be said again with respect to pinning effect occurred at high % TiO_2 which inhibits the grain growth. And it was found that highest cutting rate of 0.95 gm/min was obtained in the sample containing 8% TiO_2 sintered at 1450ºC. This is already discussed as we know the 8% TiO_2 sintered at 1450ºC has the highest density [3], finer grain and high hardness [3].

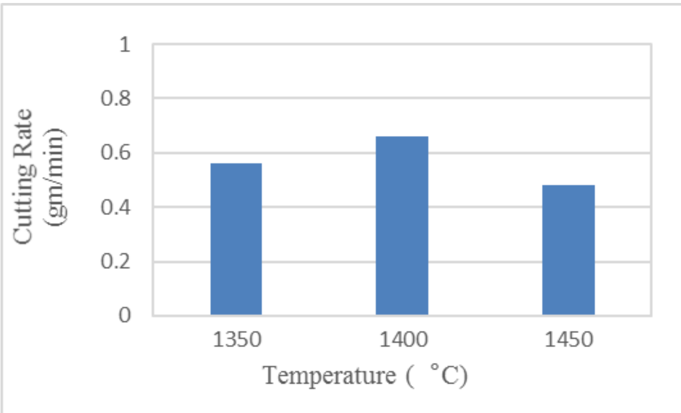

Fig. 10. Sintering temperature versus cutting rate of 2% TiO_2 stabilized Al_2O_3

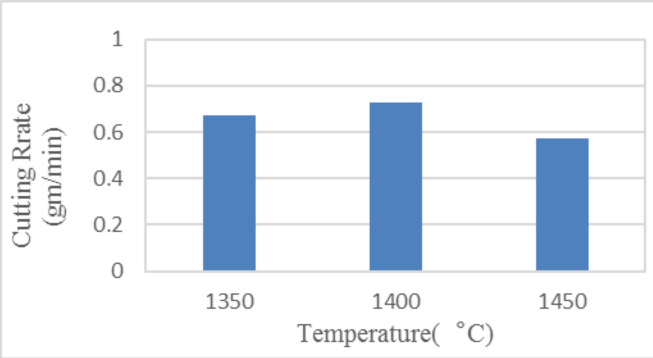

Fig. 11. Sintering temperature versus cutting rate of 5% TiO_2 stabilized Al_2O_3

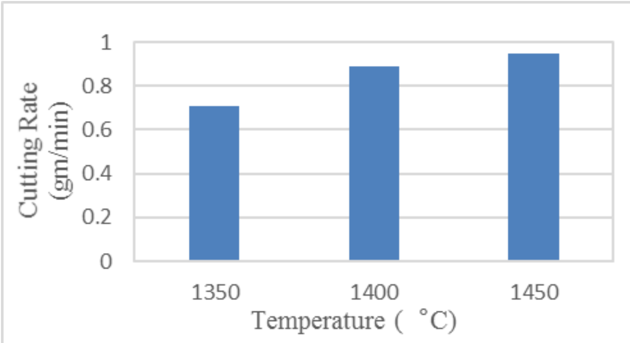

Fig. 12. Sintering temperature versus cutting rate of 8% TiO_2 stabilized Al_2O_3

4. Conclusion

The main focus of this research work was to find out the optimum conditions at which the mechanical properties of the Al_2O_3 Ceramic Cutting tools begins to improve. In this research, it was found that 8% TiO_2 stabilized Al_2O_3 sintered at 1450^0C showed the maximum hardness. It was also found that, wear rate was also the minimum for the same condition, which is around $8*10^{-6}$ gm/min. Finally, it was observed that for the same condition the cutting rate was also maximum which 0.95 gm/min was. The reason behind the continuous improvement mechanical behavior was the addition of the TiO_2 in Al_2O_3 to a certain extent. Lower % TiO_2 didn't not showed any prominent result at low temperatures. But at higher % of TiO_2 with higher temperature sintering showed better mechanical properties of the tools. This is because, lower TiO_2 addition does not provide any adequate pinning effect and with increasing of temperature densification occurred along with grain coarsening. As a result mechanical properties were not up to the mark. Moreover, when the % of TiO_2 increased from 2% to 8%, TiO_2 able to give sufficient pinning effect and inhibits grain coarsening and densification increases with smaller grains. As a result good mechanical properties were observed.

5. Acknowledgement

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