Optimizing the Synthesis of Alumina Inserts Using Hot Isostatic Pressing (HIP)

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Abstract.
Alumina or Aluminium Oxide (Al_2O_3) is well known for its high strength and hardness. Its low heat retention and low specific heat characteristics make it attractive to be used widely as a cutting tool for grinding, milling and turning processes. Various synthesis methods have been used for the purpose of enhancing the properties of the alumina inserts. However, the optimization process using Hot Isostatic Pressing (HIP) has not been performed. This research aims in finding the optimum parameters in synthesizing the alumina inserts ($98Al_2O_3$ $1.6ZrO_2$ 0.4MgO, $93Al_2O_3$ $6.4ZrO_2$ 0.6MgO and $85Al_2O_3$ $14.5ZrO_2$ 0.5MgO) using HIP at different temperatures (1200, 1250 and 1300°C) and sintering time (10, 30 and 60 minutes). Hardness, density, shrinkage and microstructure using SEM were analysed. The optimum sintering condition for the alumina insert was found in $98Al_2O_3$ $1.6ZrO_2$ 0.4MgO sintered at 1300°C for 60 minutes for it exhibited the highest values of hardness (1917HV), density (3.95g/cm^3), shrinkage (9.6%).

1. Introduction

Various types of cutting inserts are available in machining industry and used widely in milling, turning, grinding and threading. A good cutting insert is used to achieve good performance. The performance of machined components can be seen through dimensional accuracy and surface roughness. The quality of the product is influenced by the cutting insert itself. Ceramic inserts exhibit excellent hardness, toughness and thermal conductivity. The synthesis of ceramic inserts are typically prepared by powder metallurgy technique and can be manufactured further to near net finish [1], [2].

One of the most potential cutting inserts is made from Al_2O_3 based materials which are popularly known to be chemically inert, possess high hardness, abundant and relatively cheap. Alumina is used as raw material for a broad range of advanced ceramic product and as an active agent in chemical processing [3], [4]. Zirconium dioxide (ZrO_2) is added to enhance the strength and toughness of the alumina, while magnesium oxide (MgO) is added to enhance the hardness of alumina [5], [6], [7].

Hot Isostatic Pressing (HIP) is a process commonly used for densification enhancement in powder metallurgy. The uniform heat and pressure applied to all surfaces enhances the mechanical properties of the part. The open pores in Al_2O_3 decreases linearly with increasing bulk density [8]. Various methods and compositions are used in the development of Al_2O_3 tool inserts. This paper aims in

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producing an optimum composition with optimum conditions in the synthesis of Al_2O_3 tool inserts using HIP.

2. Experimental procedure

Three different compositions of Al_2O_3 tool inserts were prepared (98wt%Al_2O_3 1.6wt%ZrO_2 0.4wt%MgO, 93wt%Al_2O_3 6.4wt%ZrO_2 0.6wt%MgO and 85wt%Al_2O_3 14.5wt%ZrO_2 0.5wt%MgO). These powders were weighed (Table 1) using a weighing scale (CP 224 S Sartorius Scale) and mixed accordingly in a ball mill (FRITSCH-pulverisette 5) using 23 steel balls with diameter of 8.89 mm. The powders were compacted using the VT manual hand press (MP-15T). A pressure of 200 kg/cm^2 was applied with a holding time of 5 minutes. 6 samples from each composition were produced. The samples were placed in the HIP machine (American-HP 630) at a temperature of 1300°C for 60 minutes. This part was first performed to identify the optimum composition.

Then, once the best composition was selected, another 6 samples were prepared. Optimum sintering temperature was selected by placing the samples into the HIP for 60 minutes at 1200, 1250 and 1300°C. Once the optimum temperature was selected, then the optimum sintering time had to be found. Experiment was repeated by preparing another 6 samples and placing them into the HIP at 1300C for 10, 30 and 60 minutes.

For every part of the experiment, the hardness (Micro-Vickers 401 MVA), density (GK-300) and the shrinkage were determined. Readings were repeated 3 times for each test. Results were plotted into graphs and charts. SEM images were obtained to analyze the microstructure and porosity (JEOL JSM-5600).

Table 1. Mass of powder used for each composition1ol inserts

Compositions	Al_2O_3 (g)	ZrO_2 (g)	MgO (g)
98Al_2O_3 1.6ZrO_2 0.4MgO	4.508	0.0736	0.0184
93Al_2O_3 6.4ZrO_2 0.6MgO	4.278	0.2944	0.0276
85Al_2O_3 14.5ZrO_2 0.5MgO	3.91	0.667	0.023

3. Results and Discussion

3.1 Determining the optimum composition

Figure 1 shows the result of Vickers hardness. The hardest sample is 98Al_2O_3 1.6ZrO_2 0.4MgO (1917HV), followed by 93Al_2O_3 6.4ZrO_2 0.6MgO (1825 HV) and 85Al_2O_3 14.5ZrO_2 0.5MgO (1686 HV). Higher percentage of Al_2O_3 has exhibited better hardness. Increasing the percentage of ZrO_2 did not show any improvements in the overall hardness of the alumina insert.

The density and shrinkage values of the alumina inserts are shown in Figure 2. Density for 98Al_2O_3, 93Al_2O_3 and 85Al_2O_3 are 3.89, 3.87 and 3.86 g/cm^3 respectively. The densities were found to be quite similar to each other for the 3 different compositions despite exhibiting different hardness values. The reduction in the densities are very insignificant with the reduction in the percentage of alumina. Nevertheless, the percentage of shrinkage has shown to increase 0.74% and 3.12% with the reduction in the densities for the 93 and 85wt% of Al_2O_3 respectively (Figure 2). Larger shrinkage values relate to larger porosities inside the compact.

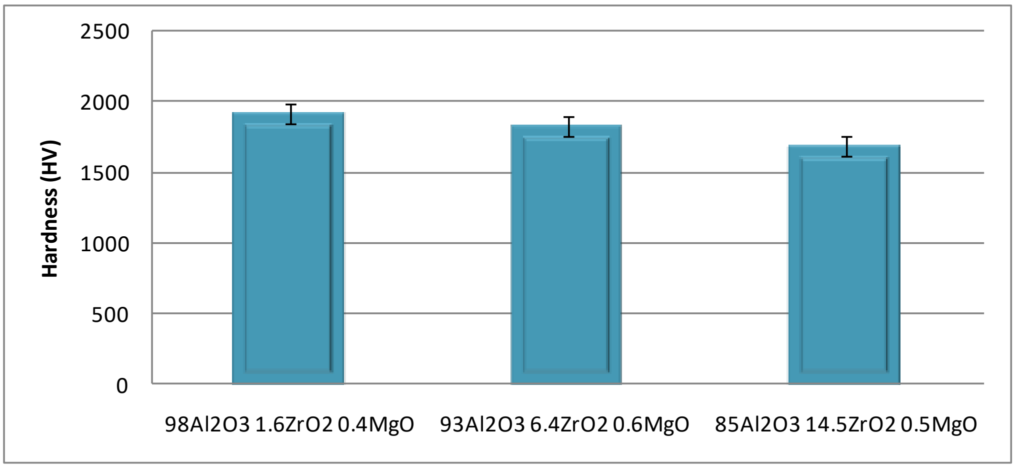

Figure 1. Hardness values for the 3 different compositions of alumina inserts

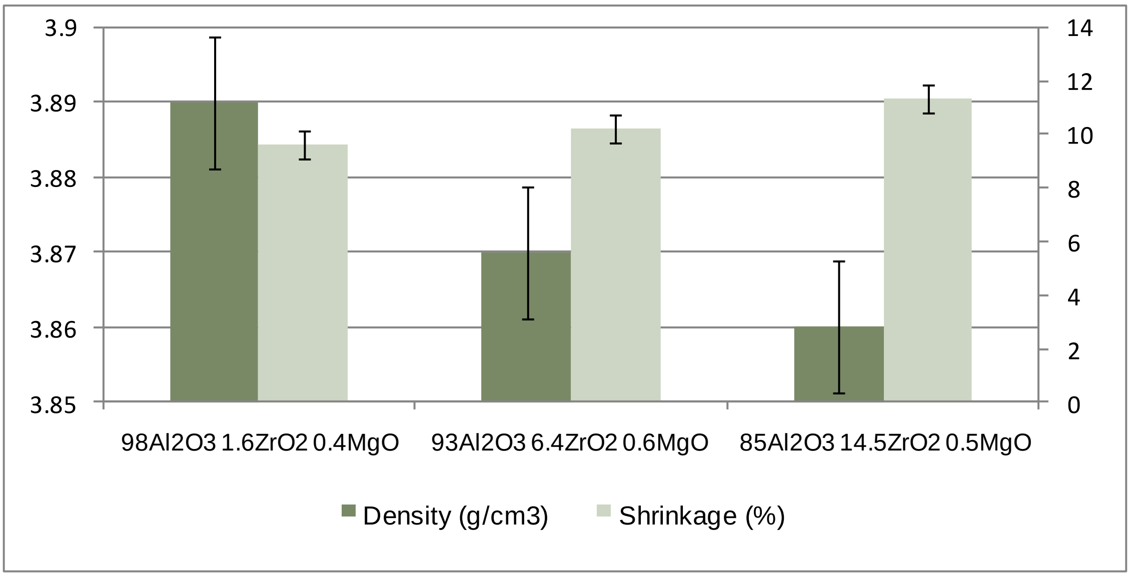

Figure 2. Density and shrinkage values for the 3 different compositions of alumina inserts

SEM images of the alumina inserts after HIP are shown in Figure 3. It can be seen that the surface of samples for $98Al_2O_3$ Figure 3(a) has less porosity when compared to $93Al_2O_3$ and $85Al_2O_3$ Figure 3 (b) and (c) respectively. This relates with the hardness and density values which decreases as the weight percentage of Al_2O_3 reduces from 98% to 85%. Full diffusion and densification can be seen in $98Al_2O_3$. Similar observation is also noticed in the commercialized insert (Sandvik Coromant) in Figure 3(d). $85Al_2O_3$ in Figure 3(c) indicates that less percentage of alumina resulted in larger porosity and lesser densification.

Since $98Al_2O_3$ has exhibited highest values of hardness, density and the lowest shrinkage, for the rest of the experiments, $98Al_2O_3$ $1.6ZrO_2$ 0.4MgO composition was selected. This appears to be the optimum composition to work on.

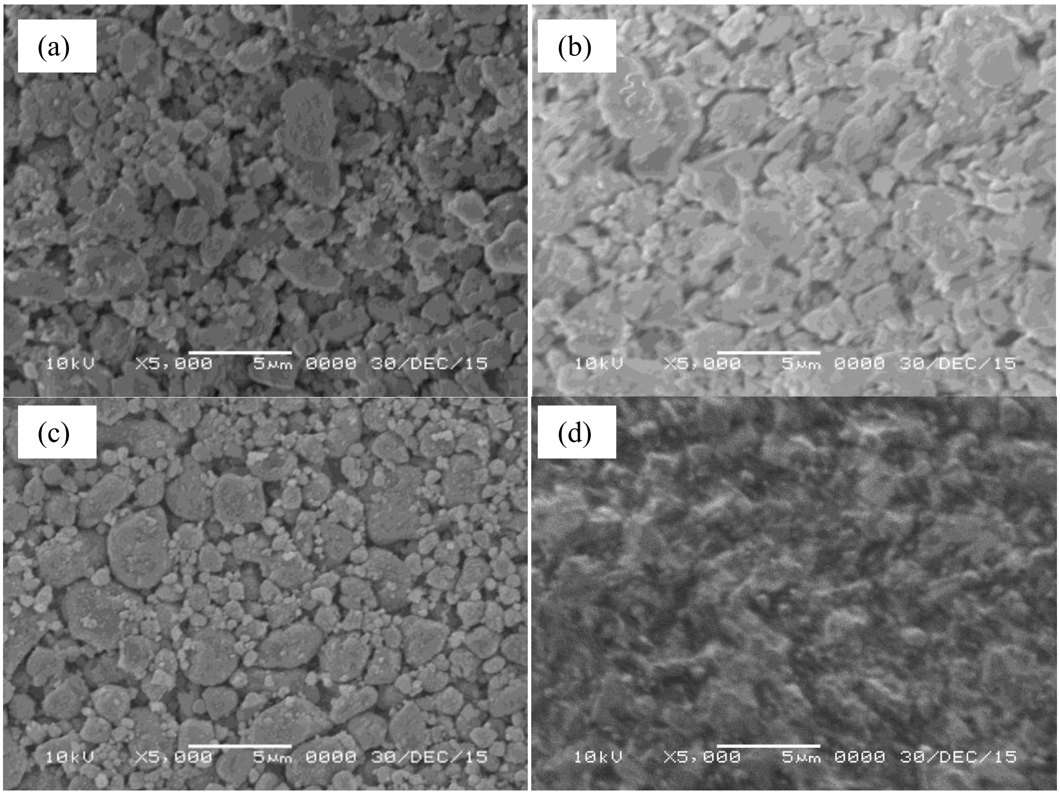

Figure 3. SEM image with 5000 X magnification (a) $98Al_2O_3$ (b) $93Al_2O_3$ (c) $85Al_2O_3$ (d) Sandvik Coromant (commercialized alumina insert)

3.2 Determining the optimum sintering temperature

$98Al_2O_3$ $1.6ZrO_2$ $0.4MgO$ is used in determining the optimum sintering temperature in HIP. Figure 4 shows graph of the hardness values obtained for the three different sintering temperatures (1200, 1250 and 1300°C). The highest hardness value (1917 HV) obtained is at the highest temperature 1300°C. There has been an increase in hardness by 57% when the sintering temperature increased from 1200°C to 1300°C. This is a significant increment. However, it only increased by 8% when sintered from 1250°C to 1300°C. Higher sintering temperature densifies the structure further, diffuses more completely and reduces porosity.

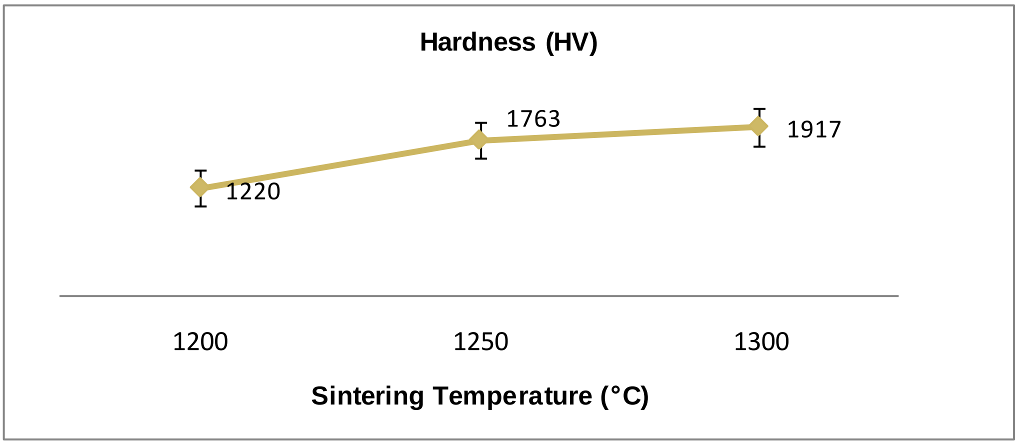

Figure 4. Hardness values for the $98Al_2O_3$ $1.6ZrO_2$ $0.4MgO$ Alumina Inserts sintered for 60 minutes

Figure 5 shows the density and shrinkage values for three different sintering temperatures obtained from the $98Al_2O_3$ $1.6ZrO_2$ 0.4MgO Alumina Inserts when sintered for 60 minutes. The values show that the highest density (3.89 g/cm^3) is achieved when the alumina insert is sintered at the highest temperature (1300°C). This is in line with the reduction in porosity where the highest shrinkage value (8.25%) obtained is also at this temperature.

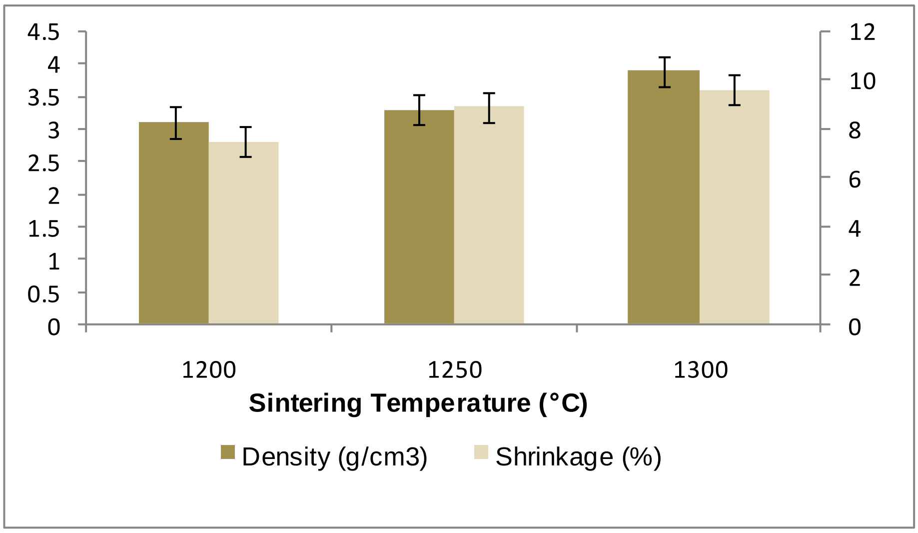

Figure 5. Density and Shrinkage for $98Al_2O_3$ $1.6ZrO_2$ 0.4MgO Alumina Inserts sintered for 60 minutes

3.3 Determining the optimum sintering time

98Al2O3 1.6ZrO2 0.4MgO sintered at 1300°C in HIP is used in determining the optimum sintering time in HIP. Figure 6 shows the graph of the hardness values obtained for the three different sintering time used in HIP (10, 30 and 60 mins). The highest hardness value (1917 HV) obtained is at the longest time (60 mins). There has been an increase in hardness by 37% when the sintering time increased from 10 to 30 minutes. This is a significant increment. Nevertheless, it has increased by 97% when sintered from 30 to 60 minutes. Longer sintering time has resulted in a more densified structure, enhanced diffusion and reduced porosity.

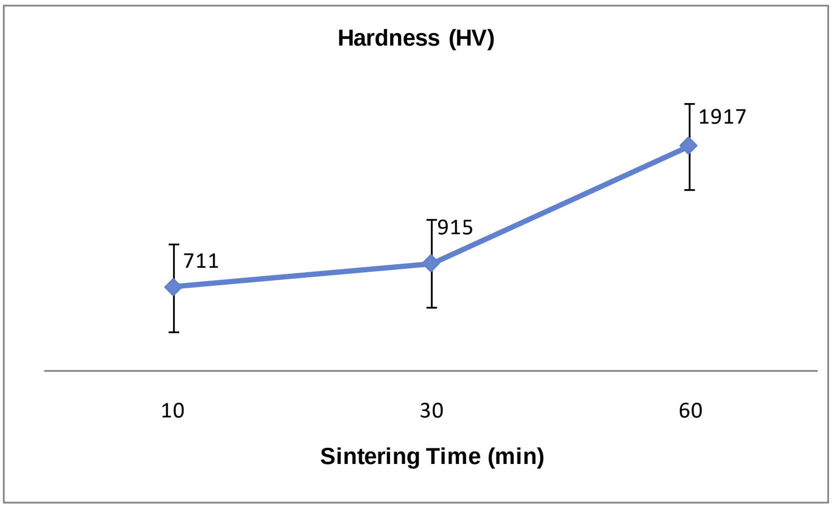

Figure 6. Hardness values for the 98Al2O3 1.6ZrO2 0.4MgO Alumina Inserts sintered at 1300°C

Figure 7 shows the density and shrinkage values for three different sintering time obtained from the $98Al_2O_3$ $1.6ZrO_2$ 0.4MgO Alumina Inserts when sintered at 1300°C. The values show that the highest density (3.95 g/cm^3) is achieved when the alumina insert is sintered for the longest time (60 mins). This is in line with the reduction in porosity where the highest shrinkage value (9.6%) obtained is also at this time.

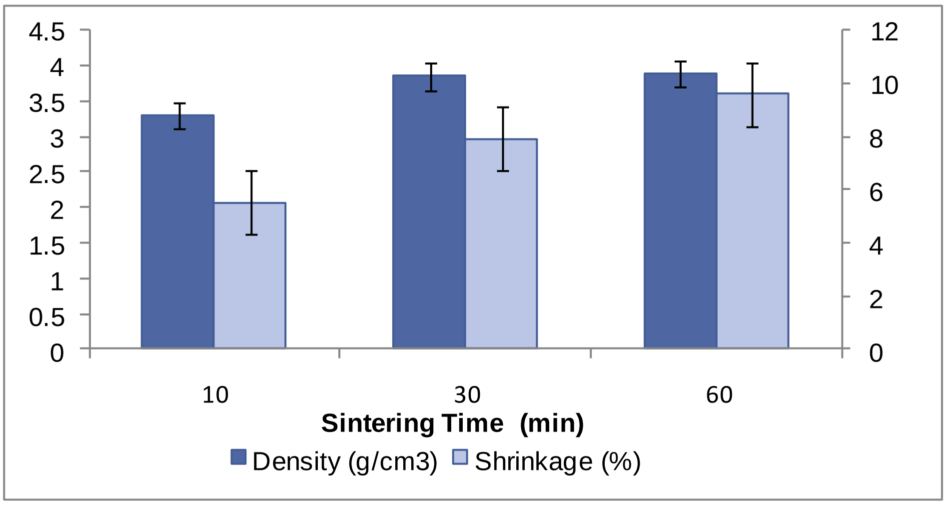

Figure 7. Density and Shrinkage for $98Al_2O_3$ $1.6ZrO_2$ 0.4MgO Alumina Inserts sintered at 1300°C

4. Conclusion

The optimum sintering composition for the alumina insert using HIP was found in $98Al_2O_3$ $1.6ZrO_2$ 0.4MgO sintered at 1300°C for 60 minutes for it exhibited the highest values of hardness (1917HV), density (3.95g/cm^3) and shrinkage (9.6%). The hardness of the synthesized alumina inserts using HIP may not be as high as the commercialised inserts (2400-2600 HV). However, further experiments in machining and tool wear analysis would enhance the findings, since hardness alone is not enough to justify longer tool life .

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