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To cite this article: Nur Amalina Sabuan *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **342** 012106

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The development of Zirconia and Copper toughened Alumina ceramic insert

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Abstract. Ceramic cutting tools have been utilized in industry for over a century for its productivity and efficiency in machine tools and cutting tool material. However, due to the brittleness property the application has been limited. In order to manufacture high strength ceramic cutting tools, there is a need for suitable reinforcement to improve its toughness. In this case, copper (Cu) and zirconia (ZrO₂) powders were added to investigate the hardness and physical properties of the developed composite insert. A uniaxial pre-forming process of the mix powder was done prior to densification by sintering at 1000 and 1300°C. The effect of the composition of the reinforcement on the hardness, density, shrinkage and microstructure of the inserts was investigated. It was found that an optimum density of 3.26 % and hardness 1385HV was obtained for composite of 10wt % zirconia and 10wt% copper at temperature 1000 °C.

1. Introduction

The first attempt in using ceramic as cutting tools was made in early 1930's for turning of gray cast iron. High wear resistance, compressive strength, and its chemical inertness of ceramics promised success. Initially, only Al₂O₃ was used as cutting tools but in early 1970's, ceramic composite cutting tools containing alumina/titanium carbide was discovered [1, 2]. Aluminum oxide/alumina (Al₂O₃) composite cutting tools are entirely used as indexable insert. Lower bending strength and toughness of this material compared to carbide made it rarely used. There are doubts rising in using ceramic as insert cutting tools since ceramic exhibit properties of high brittleness and lower strength that cause low tool life performance. In fact, ceramics can resist a temperature exceed 2000°C vs 870°C compared to insert made from carbide powder. Apart from that, this high temperature helps in softening of the work piece material which allows deeper and cleaner cuts. These advantages cannot be achieved by using carbide material since cobalt binder has lower melting point [3]. Through last few years, remarkable improvements had been done in strength and toughness of Al₂O₃ ceramic composites [4-6].



A.K.Dutta [7] studied on Al_2O_3 incorporated with 5vol% of silver as insert cutting tool. The Al_2O_3 /silver (ASC) composite was successfully produced as cutting tool insert with higher toughness compared to monolithic alumina. The hardness of ASC compared to zirconia toughened alumina (ZTA) were found to be 6.5 GPa higher, while the fracture toughness measured was found to be 7.05MPa m^{1/2}. Addition of yttrium also showed improvement in alumina based composite [8]. Effects of yttrium on the mechanical property and the cutting performance of $\text{Al}_2\text{O}_3/\text{Ti}(\text{C},\text{N})$ composite ceramic tool material have been studied and the results showed that by adding certain amount of yttrium the mechanical properties of the composite material can be improved. As the result, flexural strength and fracture toughness value was 1010MPa and 6.1MPa m^{1/2}, respectively. The developed ceramic tools also showed higher fracture resistance when machining hardened C45 steel which improved by 20% compared to ceramic composite without yttrium. Jef Vleugels [9] reported on fabrication, wear and performance of ceramic cutting tools listed on requirements for cutting tools materials that includes cutting speed, cooling conditions and thermal properties of two contact materials that determine the temperature at cutting edge. The observation showed that zirconia (ZrO_2) composites were suitable for turning of DIN 42 CrMo₄ steel at 300 and 500 m/min with additional of 40vol% of TiCN. Dong Wang [10] reported on fabrication and cutting performance of $\text{Al}_2\text{O}_3/\text{TiC}/\text{TiCN}$ ceramic cutting tool of an ultra-high-strength steel and discovered that, under condition with sintering temperature of 1650 °C, holding time of 15mins and sintering pressure of 35MPa, tool material of AT10N20 exhibit the best comprehensive mechanical properties with hardness, flexural strength and fracture toughness measured was 20.8GPa, 881.4MPa, and 7.8MPa respectively. In this work copper (Cu) and zirconia (ZrO_2) powders were added to investigate the preliminary values of hardness and physical properties of the developed composite insert.

2. Experimental

The raw materials for this experiment are readily prepared from supplier: Alumina powder (Al_2O_3), Zirconia powder (Zr_2O), copper (Cu) powder, polyvinyl alcohol (PVA) as a binder and polyethyl glycol (PEG) as a plasticizer. During mixing, few drops of binder and plasticizer were added and mixed thoroughly before undergo drying process. Binders surrounds the ceramics particles and provide lubricants during compacting and act as a temporary bonds after pressing since it will be decomposed at high temperature which was during sintering process which required temperature over 1000°C. Plasticizer was added into the binders to improve the flexibility and functionality of the green compact since the plasticizer had brittle properties at room temperature and was not conducive for further processing steps. Conventional mixing is practiced in developing the composite. Al_2O_3 powder is added with Zr_2O to help toughened the Al_2O_3 . Different composition of Cu 10 (wt%) and 20 (wt%) is added in the mixture before PVA and PEG is added. The mixture is mixed thoroughly before drying at 200°C for 3 hours and left in vacuum condition for overnight to stabilize the mixture.

A diamond shaped green compact was produced by uniaxial compaction of 500MPa with holding time of 10 minutes per sample. The mould and the green compact is shown in Figure 1. The green compact was then sintered under two different sintering temperature: 1000°C and 1300°C. The hardness value of the sintered inserts was measured using Vickers hardness for a three samples of each and the average values were recorded. The density was also measured for each respective sample. The microstructure of the sintered samples was observed using optical microscope.

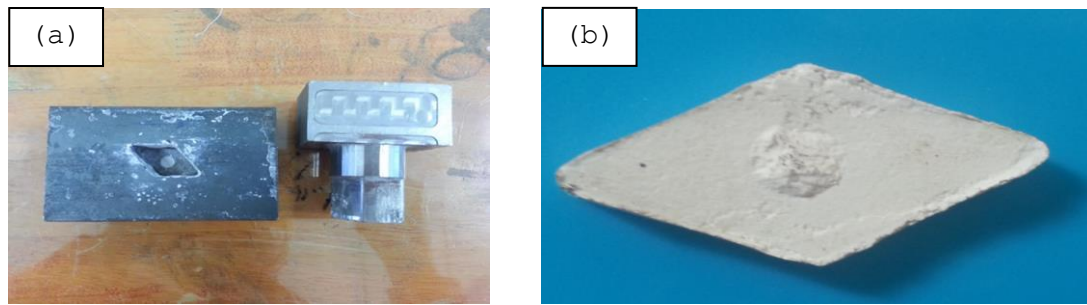


Figure 1. (a) The mould for the green compact of the ceramic insert (b) green compact .

Table 1. Parameters for sample preparation.

Parameters	Condition
Powder content (mixing)	90wt% Al ₂ O ₃ , 10wt% ZrO ₂ (90AlZr) 80wt% Al ₂ O ₃ , 10wt% ZrO ₂ , 10wt% Cu (80AlZr10Cu) 70wt% Al ₂ O ₃ , 10% wtZrO ₂ , 20wt% Cu (70AlZr20Cu)
Drying	200°C for 3 hours
Compaction	500MPa
Sintering	1000°C and 1300°C

3. Result and Discussion

Three different ceramic inserts as shown on the Table 1 was subjected to 1000°C and 1300 °C sintering temperature and each sintered composite inserts were investigated for hardness, density and microstructure. The hardness value of the three compositions is shown in Figure 2. It was observed that the average hardness at temperature 1000 °C for 90AlZr was 1089 HV0.5N and a slightly increase to about 1385 HV0.5N for 80AlZr10Cu and decrease to a value 1207 HV0.5N for 70AlZr20Cu was observed. However, the hardness value at sintering temperature 1300°C was observed decreasing as the composition of copper powder was increasing. At temperature 1300 °C the hardness was higher for 90AlZr compared to 1000 °C. Generally higher sintering temperature gave high hardness value for ceramic reinforced alumina composites where the sintering may not be effective at 1000 °C. However, it was generally observed that the hardness values were seen decreasing as the copper composition was increasing at each sintering temperatures. This may be due to the low melting temperature of copper which may be a case for the liquid phase sintering that lowers the hardness of the composites. The addition of copper and zirconia played a great role for increasing the toughness of the insert which consequently decrease the hardness value [11].

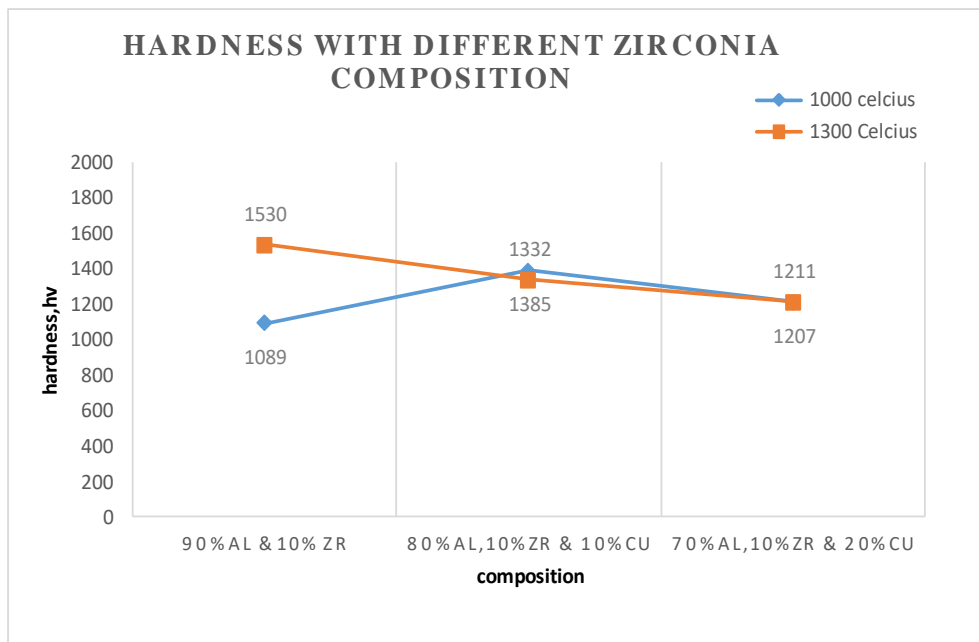


Figure 2. Hardness of samples with different composition and sintering temperature.

The results of the density after sintering were given in Figure 3. It was observed that density at 1000°C for 90AlZr showed the lowest value which is 2.95 g/cm³ and increased dramatically for 80AlZr10Cu which was 3.26 g/cm³ but then as the copper percentage by weight increased to 20%, the density value was measured to 3.14 g/cm³. At temperature 1300°C, all compositions of the inserts show lower density than the at 1000 °C sintering temperature. This may be due to the high sintering temperature which the copper particle may thermodynamically have changed to non-solid state which resulted into some porosity inside the samples.

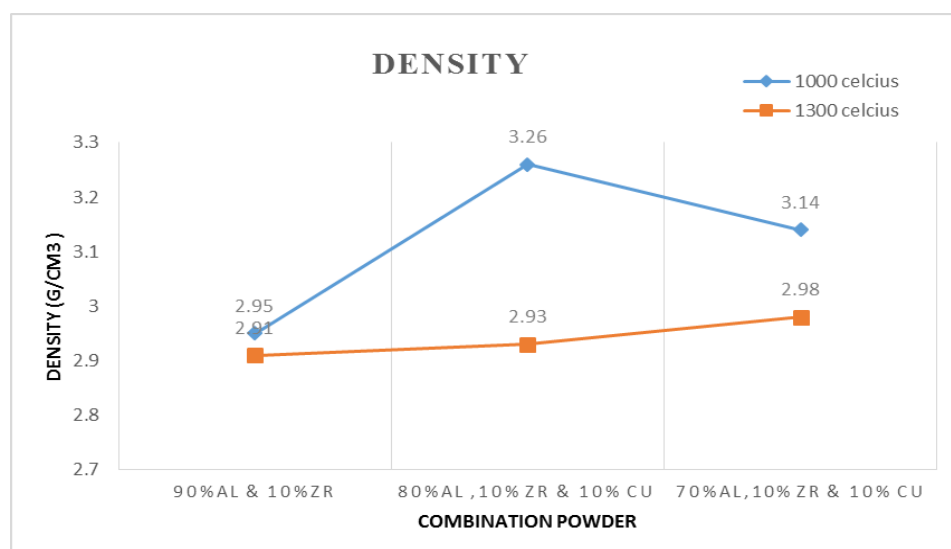


Figure 3. Density of sample at different sintering temperature and Cu composition.

Shrinkage was significantly observed when Cu was incorporated in Al₂O₃ matrix during the sintering cycle. Figure 4 shows the shrinkage value increases as the weight percentage of the

composition of Cu goes from 10% by weight to 20 % by weight. This may be due to the presence of the Cu liquid which helps the grain boundaries slide and create more adhesion as a result volumetric size decreased.

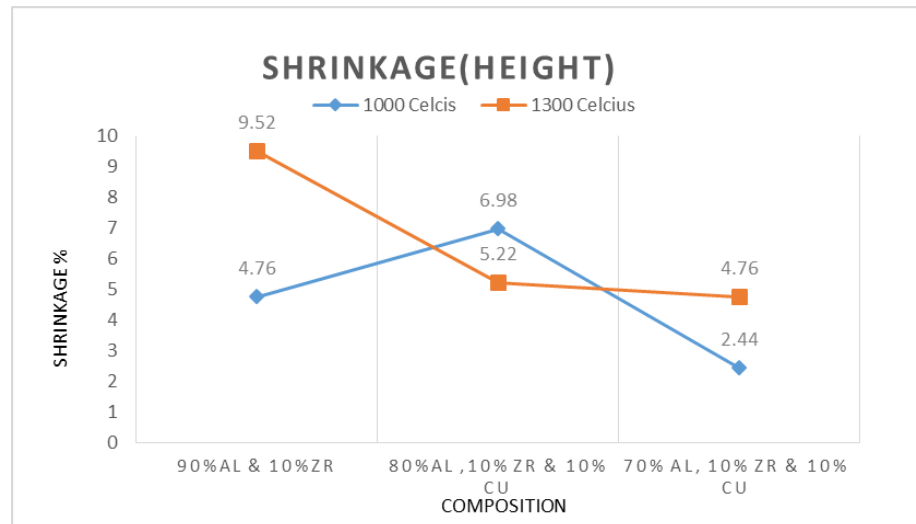


Figure 4. Shrinkage of sample at different sintering temperature and Cu composition.

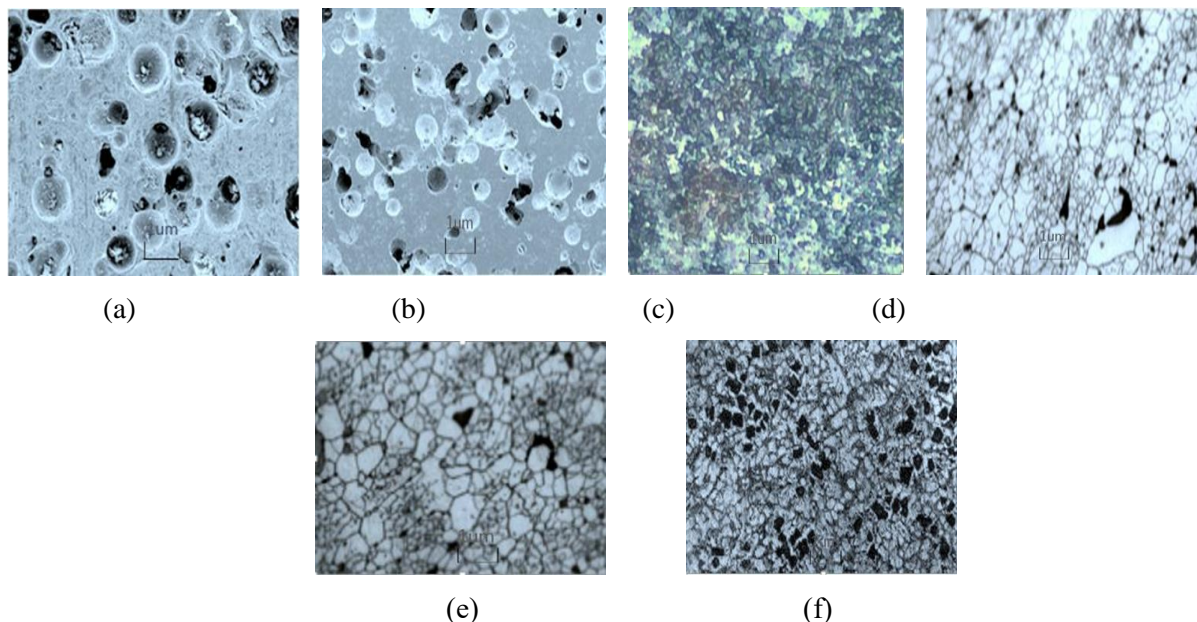


Figure 5. Microstructural changes for **90AlZr** at a) 1000°C b) 1300°C, **80AlZr10Cu** at c) 1000°C d) 1300°C and **70AlZr20Cu** at e) 1000°C and f) 1300°C.

Figure 5 a) and b) shows the presence of Al_2O_3 with ZrO_2 particle using optical microscope. The microstructure shows that the zirconia phase was dissolved in the alumina matrix uniformly in all cases, while the Cu were within the interface of the grain boundary to

form an interface solid solution. This showed that Cu assisted in the liquid phase sintering of the sintered composite. Alumina matrix is expected to be toughened by the zirconia particle. From the observation high number of porosity is seen at 1300 °C compared at 1000 °C due to the melting of the copper particles. Observations of the surface using the optical microscope show relatively good bonding between Al_2O_3 and Cu of the insert 70AlZr20Cu at 1000 °C than at 1300 °C. High number of porous was seen at the higher sintering temperature due to phase change of the copper particle as can show with dark regions between alumina. This phenomenon is especially seen in the regions of clusters of alumina and zirconia phases when liquid Cu has no possibility to infiltrate the porous structure. However these observations should be more studied with controlled experiment and high resolution microstructural study.

4. Conclusion

A preliminary experimental study was performed to develop alumina matrix insert reinforced with zirconia and copper. From this study, hardness, density and microstructural properties were investigated. It was shown that increasing Cu content generally improves the density at sintering temperature of 1000 °C. However, the density of samples sintered at temperature of 1300 °C was decreasing when Cu content increases. This was due to the melting temperature of the Cu is much lower than the Al_2O_3 which led to phase changes which is not favourable for the good property the sintered inserts produced. It was also found that an optimum density of 3.26% and hardness 1385HV was obtained for composite of 10wt % zirconia and 10wt% copper at temperature 1000°C.

Acknowledgement

This research was supported by research grant **RDU150121** from Ministry of Higher Education of Malaysia and **RDU1703193** of Universiti Malaysia Pahang.

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