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Improved Performance in Aluminium Oxide Tool Inserts Via Post Sintering Using Hybrid Microwave Energy

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ABSTRACT

This research investigates the effect of hybrid microwave energy toward the enhancement of tool life in Al_2O_3 inserts. Post sintering was done using conventional and hybrid microwave sintering at 600°C for 15 mins and compared the findings with the original available commercial inserts. Mechanical testing such as density, hardness and compression strength were performed together with the micro structural analysis using Scanning Electron Microscope (SEM) was done. Tool life of these Al_2O_3 inserts were analysed through dry machining using three different cutting speeds (245, 305 and 381 m/min) at the feed rate of 0.2 mm/rev and depth of cut of 0.2 mm. Two different workpieces were used in this research; T6061 Aluminium Alloy and AISI 01 Cold Worked Tool Steel. Results have shown that the density and hardness remain quite similar with or without the post sintering effect. However, the material became slightly more brittle upon post sintering where conventional sintering produced compression strength of 0.07 MPa while the hybrid microwave sintering produced compression strength of 0.21 MPa. Tool life of Al_2O_3 inserts in dry machining of T6061 Aluminium alloy and AISI 01 Cold Worked Tool Steel has increased by 27-40 % and 31-40 % respectively for the hybrid microwave post sintering.

Keywords: Aluminium oxide, Post sintering, Hybrid microwave energy, Conventional heating, Tool life, Wear resistance.

1. Introduction

Ceramic materials are inorganic, non-metallic materials made from compounds of metal and non-metal. Ceramic materials might be crystalline or partly crystalline. They are formed by the action of heat and subsequent cooling. Clay was one of the earliest materials used to produce ceramics as pottery, but many different ceramic materials are now used in domestic, industrial and building product. Ceramic materials tend to be strong, stiff, brittle, chemically inert and non-conductor heat and electricity. But in term of their properties vary widely. As example, porcelain is widely used to make electrical insulators but some ceramic compounds are superconductors. Ceramic materials are brittle, hard and strong in compression but weak at shearing and tension. Ceramic, in general would be able to withstand very high temperature such as temperature that ranges from 1000 ˚C to 1600˚C (Groover, 2010).

At present, there is a growing interest in applying microwave heating for the process of sintering ceramics and metals. The process of sintering is carried out using conventional heating such as pressureless sintering and hot pressing. However, with the introduction and development of the microwave technology, there has been considerable interest in microwaves heating for the synthesis and processing of materials. The sintering process can be done either using conventional sintering or microwave sintering as the alternative. Microwave heating and sintering is fundamentally different from the conventional sintering, which involves radiant/resistance heating followed by transfer of thermal energy via conduction to the inside of the body being processed (Menzes and Kiminami, 2008).

The use of microwaves allows transfer of energy directly into the materials to take place, where it is converted into heat through absorption mechanisms, such as ionic conduction, dipole relaxation, and photon-phonon interactions. In this context of microwave heating each constituent unit of the crystal lattice raises a certain constant amplitude vibration, which results in a highly uniform distribution of heat in the ceramic body (Cheng et al., 2000; Upadhyaya et al., 2001)

The use of microwave energy for materials processing has major potential and real advantages over conventional heating. These include time and energy savings, rapid heating rates, reduced processing time and temperature, finer microstructures and hence improved mechanical properties, better product performance and lower environmental impact (Figiel et al., 2011). Microwave heating is a volumetric heating involving conversion of electromagnetic energy into thermal energy, which is instantaneous, rapid and highly efficient.

Compared to other ceramic, Alumina (Al_2O_3) commonly been used as tool whether for the lathe machining process. It is due to considerable price and widely available in the market, the quality of machining using this tool is considerably good. Nevertheless, wear is a common phenomenon that al machining industries will have to face. Al_2O_3 generally is known to have a long tool life with good wear resistance. However, if these inserts can last a little bit longer, may have an impact on the tool cost and frequency of changing the tool itself. This research focuses on post heat treatment through post sintering via hybrid microwave energy to enhance tool life of Al_2O_3 inserts.

2. Methodology

2.1. Preparation of Al_2O_3 inserts

Aluminium Oxide (Al_2O_3) inserts from Sandvik Coromant were used (Fig. 1). There were two types of Al_2O_3 inserts that were examined in this study. The triangular inserts (TNGA 333 T0320-620) were used for machining purpose for tool life analysis and the circular inserts (RNG 45 T0820-620) with diameter of 12.69 mm and thickness of 7.96 mm were used for mechanical and micro structural analysis. Three sets of experiments were prepared with three sets of inserts. The first set of tool inserts was the commercially available tool with no heat treatment performed (unpost sintered). The second set of tool inserts was the post-sintered Al_2O_3 via conventional heating. The third set of tool inserts was the post sintered Al_2O_3 via hybrid microwave energy.

(a) (b) (c)

Fig-1. Al_2O_3 inserts (a) Sandvik Coromant (TNGA 333 T0320-620) (b) Sandvik Coromant RNG 45 T0820-620 (c) Insert placed inside the crucible with graphite powder

2.2. Post Sintering Via Conventional Heating

In order to perform post sintering using conventional furnace, the heating conditions with the hybrid microwave sintering were used. The conventional furnace (Nabertherm N81) was set to 600ºC for 15 minutes of holding time. The Al_2O_3 insert was placed on top of a ceramic tile which was then placed into the furnace.

2.3. Post Sintering Via Hybrid Microwave Energy

A modified domestic microwave oven (Panasonic ST 55M) was used to perform the post-sintering. The Al_2O_3 insert was placed inside an alumina crucible which was placed inside another larger crucible and then filled with 3 g of graphite powder (Alfa Aesar -300 mesh) as shown in Fig. 1 (c). This is to avoid direct contact of the Al_2O_3 insert with the graphite powder which acts as a susceptor to aid in speeding up the heating process. Susceptors were used because of its capability in absorbing microwave energy, since they comprise a particulate substrate which is substantially non-reflective of microwave energy. Finally, the crucible was placed inside a ceramic fiber insulator box which was then placed inside the microwave furnace. The Al_2O_3 insert was post sintered for 15 minutes and a gun type infrared pyrometer (SENTRY-ST671) was used to record the temperature. The temperature reading showed 600°C.

2.4. Mechanical Testing

The three samples of Al_2O_3 inserts from each category; unpost sintered, conventionally sintered and microwave sintered, were mechanically tested for its density, hardness, compression strength and wear. Density was measured using Electronic Densimeter (Rillins Sains MD 2005). Hardness test was performed using MicroVickers Hardness Tester (Mitutoyo MVK-H2) with 20 seconds of dwell time. The compression test was conducted using the Universal Testing Machine (Shimadzu 250 kN). The solid cylindrical insert (disk) was compressed between two flat dies. Tensile stresses were developed perpendicular to the vertical centerline along the disk during compression. Fracture begins and the disk splits into half vertically. The tensile stress (σ) of the insert from the compression test is uniform along the centerline and can be calculated from Eq.1,

$$\sigma = 2P/(\pi dt) \qquad (1)$$

where *P* is the load at fracture, *d* is the diameter of the disk and *t* is the thickness. In order to avoid premature failure at the contact points, thin strips of soft metal were placed between the disk and the two platens; these strips also protect the platens from being damaged during the test.

2.5. Tool Life Analysis

Dry machining of T6061 Aluminium Alloy and AISI 01 Cold Worked Tool Steel rods with a diameter 100 mm and was performed using three different cutting speeds; 245, 305 and 381 m/min, at a depth of cut (d) 0.2 mm and a feed rate (f) of 0.4 mm/rev. Wear measurements were found by using an Optical Microscope (Nikon MM-400). Data were extrapolated (up to maximum flank wear of 0.4 mm), graphs were plotted and tool lives for the three types of Al_2O_3 inserts were analyzed.

2.6. Micro Structural Analysis

Samples for microstructural analysis using Scanning Electron Microscopy (SEM) (JEOL-JSM 5600) were polished (Metapol-2 polisher) with alumina solution till most of the surface scratches were removed. Ceramic Etchant A was used as an etchant with an etching time of 30 – 60 seconds. The inserts were coated prior to taking the SEM images using JEOL JFC-1600 Auto Fine Coater Machine.

3. Results and Discussion

3.1. Density Measurement

Fig. 2 presents the results obtained from the density measurement of Al_2O_3 inserts based on the type of post sintering method. The density has increased marginally (~0.6%) with the post sintering for 15 minutes at 600°C for both conventional heating and hybrid microwave energy. Results appeared to be quite similar due to the post sintering conditions which was only done for 15 minutes at 600°C. Furthermore, the Al_2O_3 inserts are already very dense and there would not have been any more increase in density even if it was post sintered for a longer duration of time or at a very much higher temperature.

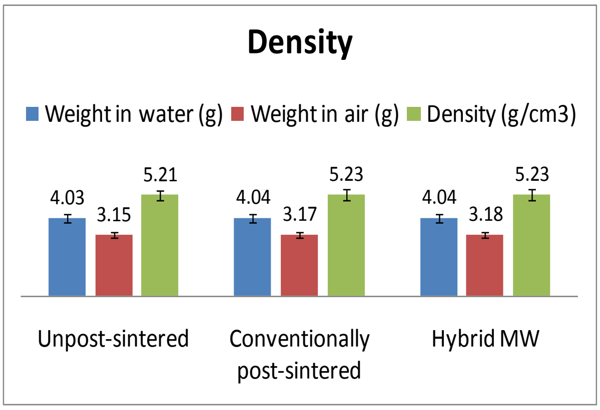


Fig-2. Density measurements for the Al_2O_3 inserts

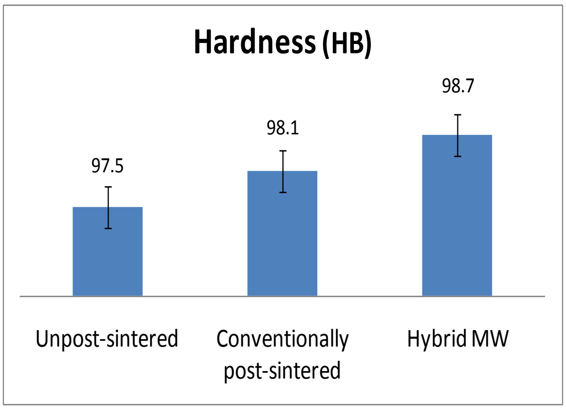


Fig-3. Density measurements for the Al_2O_3 inserts

3.2. Hardness

Fig. 3 shows the results of the hardness test obtained for all the three types of Al_2O_3 inserts. Conventionally post-sintered inserts have shown to have an increase in hardness by 0.6% while the hardness for the hybrid microwave post sintered inserts have increased by 1.23% when compared with the unpost-sintered inserts. Post sintering has increased the hardness of the material even though the density only showed a marginal increase.

3.3. Strength

The compressive strength and tensile stress values for all the three types of Al_2O_3 inserts can be seen in Fig. 4. The conventionally post sintered Al_2O_3 inserts reduced its compressive strength by 10% when compared with the original unpost-sintered inserts. The hybrid microwave post sintering on the other hand, exhibited even a lower compressive strength (decreased by 17%) when compared with the original unpost-sintered inserts. This shows that the hybrid microwave sintered inserts absorbed lesser energy (425 MPa) to fracture compared with the unpost-sintered (510 MPa) and the conventionally post sintered (460 MPa) inserts. No doubt, brittle materials exhibit this characteristic whereby it has high hardness but lower ability to absorb energy for fracture. Al_2O_3 is a ceramic tool and post sintering for 15 minutes via conventional heating and hybrid microwave heating has reduced its ductility.

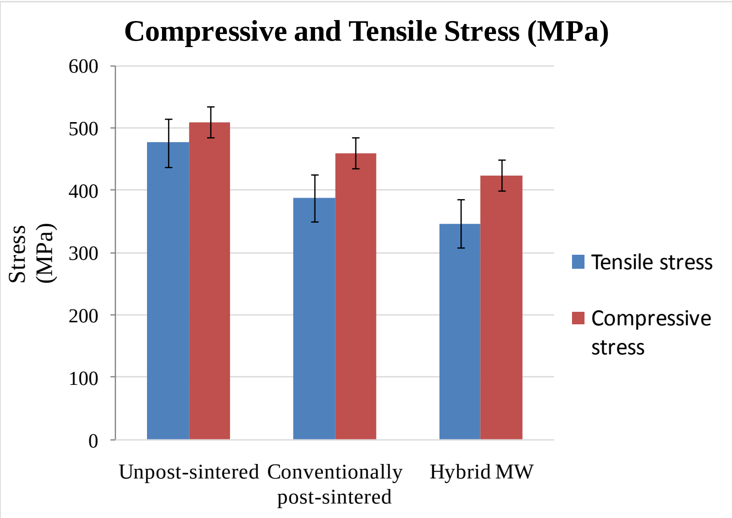


Fig-4. Compressive and tensile stress values for Al_2O_3 inserts

3.4. Tool Life

Flank wear measurements of the Al_2O_3 inserts were obtained (Table 1) and compared for three different cutting speeds (245, 305 and 381 m/min). Using the data obtained, the wear rates were calculated for each type of tool insert used from machining T6061 Aluminium Alloy and AISI 01 Cold

Table-1. Wear Measurements for Al_2O_3 inserts

Cutting Speed (m/min)	Section	Wear (mm)					
		T6061 Aluminium Alloy			AISI 01 Cold Worked Steel		
		Unpost-sintered	Conventionally post-sintered	Hybrid MW post-sintered	Unpost-sintered	Conventionally post-sintered	Hybrid MW post-sintered
245	1	0.025	0.018	0.010	0.032	0.030	0.018
	2	0.027	0.021	0.011	0.037	0.031	0.021
	3	0.028	0.023	0.013	0.038	0.033	0.023
	4	0.031	0.023	0.015	0.041	0.034	0.024
	5	0.033	0.024	0.017	0.042	0.036	0.025
305	1	0.023	0.013	0.009	0.025	0.024	0.016
	2	0.025	0.015	0.011	0.029	0.026	0.018
	3	0.025	0.017	0.013	0.031	0.030	0.022
	4	0.027	0.018	0.013	0.034	0.031	0.024
	5	0.029	0.021	0.014	0.036	0.033	0.025
381	1	0.021	0.013	0.006	0.018	0.016	0.011
	2	0.023	0.014	0.007	0.020	0.021	0.017
	3	0.023	0.016	0.010	0.021	0.027	0.019
	4	0.025	0.017	0.012	0.024	0.029	0.020
	5	0.027	0.020	0.012	0.030	0.032	0.023

Worked Tool Steel as shown in Table 2. Hybrid Microwave post–sintered tool has shown to have the smallest wear rates in machining T6061 Aluminium Alloy (0.001-0.002 mm/min) and AISI 01 Cold Worked Tool Steel (0.007-0.01), followed by conventionally post-sintered inserts and finally the unpost-sintered inserts. This is clearly because the Al_2O_3 inserts have increased in hardness and hence, improved in performance. Smaller wear rates is a clear indication of longer tool life.

Table-2. Wear Rates and Tool Life for Al_2O_3 inserts

Cutting Speed (m/min)	T6061 Aluminium Alloy			AISI 01 Cold Worked Steel		
	Wear rate (mm/min)					
	Unpost-sintered	Conventionally post-sintered	Hybrid MW post-sintered	Unpost-sintered	Conventionally post-sintered	Hybrid MW post-sintered
245	0.007	0.004	0.002	0.012	0.009	0.007
305	0.006	0.003	0.002	0.013	0.012	0.009
381	0.007	0.004	0.001	0.013	0.016	0.010
	Tool Life (min)					
245	22	30	42	17	20.5	29
305	21	27	39	15.75	17	22
381	17	21	31	15.84	13	19

The tool life values were obtained for the untreated insert, the conventionally post-sintered and the hybrid microwave post sintered inserts. The exponential values (*n*) were found from the slopes of the tool life curves (Fig. 5) based on the Taylor's tool life equation (Eq. 2),

$$V T^{n} = C \tag{2}$$

where V is the cutting speed, T is the tool life (minutes) and C is the constant value. The *n* values for all the three types of Al_2O_3 inserts were found to be around 0.5-0.7 which corresponds to ceramic tool (Kalpakjian, 2014).

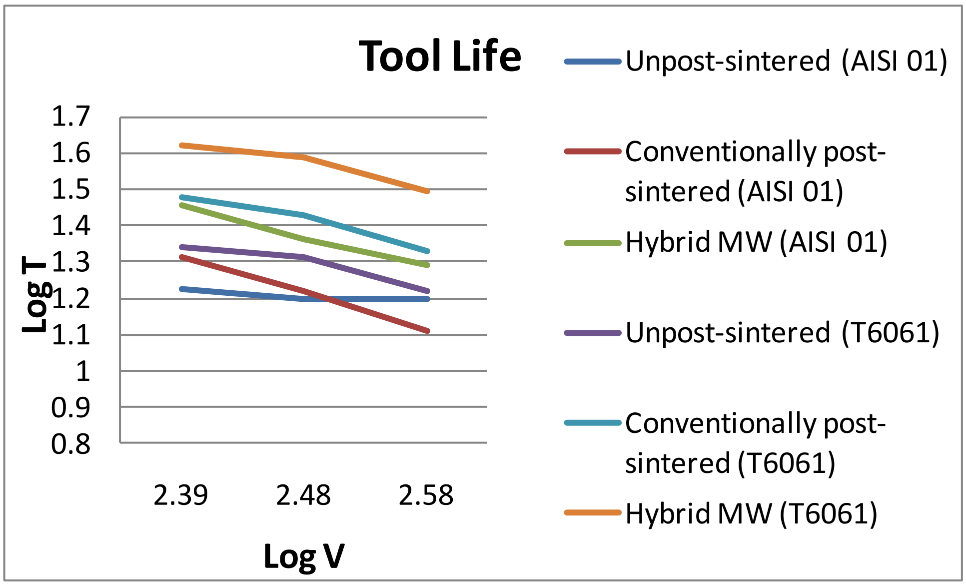
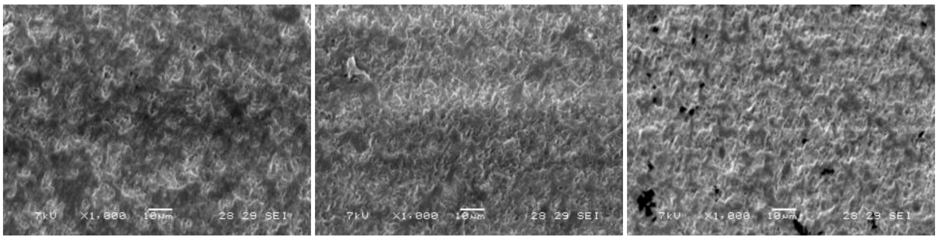


Fig-5. Tool life curves for three types of Al_2O_3 inserts

There is a significant increase in the tool life from the post-sintering effect using hybrid microwave energy. This is the resultant of the rapid heating or high heating rate encountered from the microwave energy. Post-sintering has a positive effect on the cutting tool inserts where it functions as a heat treatment to release stresses accumulated from the Hot Isostatic Pressing (HIP). Therefore, this post-sintering (heat treatment) has enhanced the hardness, tool life and wear resistance of the Al_2O_3 inserts.

3.5. Micro Structural Analysis

Micro structural images shown in Fig. 6 appear to be quite similar with no significant difference for all the three types of Al_2O_3 inserts. Considering the nature of the tool itself which is of very hard, dense and strong material, it is unlikely to observe any changes in the microstructure of the material. Furthermore, it is a heat treatment process rather than a sintering process.



(a) (b) (c)

Fig-6. Polarized SEM image at 1000X magnification (a) Un-post-sintered (b) Conventionally post-sintered (c) Hybrid microwave post-sintered Al_2O_3 inserts

4. Conclusion

The mechanical properties such as density (5.20-5.23 g/cm^3) and hardness (97.5-98.7 HB) remained similar for all the three conditions of inserts. However, the compression strength for the hybrid microwave post-sintered inserts exhibited in decreased ductility. No significant difference was noticed in the grain structure for all the three conditions. Tool life of alumina inserts increased in dry machining of T6061 Aluminium Alloys (27- 40%) and AISI 01 Cold Worked Tool Steel (31- 40%).

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References

Cheng J., D. Agrawal, R. Roy, P.S. Jayan, 2000. Continuous microwave sintering of alumina abrasive grits, Journal of Materials Processing Technology 108: 26-29.

Figiel P., M. Rozmus, B. Smuk, 2011. Properties Of Alumina Ceramics Obtained By Conventional And Non-Conventional Methods For Sintering Ceramics, Journal of Achievement in Material and Manufacturing Engineering, 48 (1): 29-34.

Groover M.P., 2010. Fundamentals of Modern Manufacturing, 4th Edition, John Wiley & Sons, Inc., Asia, 129-136.

Kalpakjian, S. and S.R. Schmid, 2014. Manufacturing Engineering and Technology, 7th Edition, Pearson Education, Singapore, 583-585.

Menzes R.R. and R.H.G.A. Kiminami, 2008. Microwave sintering of alumina-zirconia nanocomposites. Journal of Materials Processing Technology 203: 513-517.

Upadhyaya D.D., A. Ghosh, G.K. Dey, R. Prasad, A.K. Suri, 2001. Microwave sintering of zirconia ceramics, Journal of Materials Science 36: 4707-4710.