



AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com



Enhancing Tool life of Silicon Nitride Inserts Via Hybrid Microwave Post Sintering

¹Tasnim Firdaus Ariff, ²Husna Izzati Ibrahim, ³Noor Sheila Roselley, ⁴Mohammad Iqbal, ⁵Irfan Hilmy and ⁶Suryanto

¹⁻⁶International Islamic University Malaysia, Manufacturing & Materials Engineering Department, Faculty of Engineering, P.O. Box 10, 50728 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:

Received 15 September 2014

Accepted 5 October 2014

Available online 25 October 2014

Key words:

silicon nitride; post sintering; hybrid microwave energy; conventional heating; tool life; wear resistance

ABSTRACT

Silicon nitride (Si_3N_4) is widely used as a cutting tool material due to its high fracture toughness and high strength at elevated temperatures compared with the properties of other ceramics materials. This research aims to study the effects of hybrid microwave energy on the tool life of Si_3N_4 cutting tool by using post-sintering technique at 600°C for 15 minutes. Results were compared with post-sintering using conventional heating with the same conditions. Dry machining was performed on a T6061 Aluminium alloy rod for wear measurement analysis. Hybrid microwave post-sintered Si_3N_4 insert resulted in a longer tool life (48-94 %) compared with the conventionally post sintered Si_3N_4 insert (11-21%). This is due to the increase in wear resistance resulting from the improvements in the mechanical properties such as density and hardness.

© 2014 AENSI Publisher All rights reserved.

ToCite This Article: T.F. Ariff, H.I. Ibrahim, N.S. Roselley, M. Iqbal, I. Hilmy and Suryanto, Enhancing Tool life of Silicon Nitride Inserts Via Hybrid Microwave Post Sintering. *Aust. J. Basic & Appl. Sci.*, 8(15): 80-85, 2014

INTRODUCTION

Silicon nitride is in the group of hard covalent materials (Homberg and Matthews, 1994) and often has amorphous structures with the atomic bonding which are formed with very high cohesive forces (Grzesik, 2008) that can withstand high temperatures, higher resistance to abrasive wear and improved oxidation and chemical resistance (Kalpakjian, 2013). Tool wear is undeniably a problem that will occur regardless how fascinating and magnificent the tool properties are. Tool wear is an important parameter that must be controlled so that the tool life will be prolonged. The properties in Silicon Nitride (Si_3N_4) are knowingly outstanding. However, the wear will be influenced with the type of work material, machining parameters and processing time. So if tool wear is high, replacement of tools will become faster and eventually result in increasing machining cost. A new technique using post sintering via hybrid microwave energy is developed for minimizing tool wear as well as increasing tool life.

In microwave sintering, it involves energy conversion which is different from the conventional sintering that involves energy transfer. In microwave sintering, the heat is generated internally within the material instead of originating from external sources like in conventional heating. In the process of microwave heating, the materials absorb microwave energy themselves and then transform it into heat within the sample volume (Sorescu *et al.*, 2007). The energy is directly transferred to the material through the interaction of electromagnetic waves with molecules leading to heating (Ebadzadeh and Valefi, 2007). Higher heating rates from hybrid microwave energy result in a more uniform heating; i.e volumetric heating, which reduces the total processing time and overall energy consumption (Ariff and Gabbitas, 2008).

According to Feng and Hattori (2000), aluminium and its alloys are considered to be the most critical materials with regards to dry machining; since it possesses a high thermal conductivity, the workpiece absorbs considerable amount of heat from the machining process and may cause deformation due to its higher thermal expansion capabilities. Aluminium alloys also may cause problem related to chip formation due to its high ductility. T6061 Aluminium alloy has a wide range of mechanical and corrosion resistance properties as well as having most of the good qualities of aluminum. It is used in many applications from aircraft structures, yacht construction, truck bodies, bicycle frames to screw machine parts. However, Ariff *et al.* (2013) have successfully dry machined T6061 aluminium alloy using Si_3N_4 with insignificant rise in temperature compared to traditional wet machining. Nevertheless, the tool life cannot be maintained even though there is only a slight decrease (1-10%) when compared to wet machining.

Corresponding Author: Tasnim Firdaus Ariff, International Islamic University Malaysia, Manufacturing & Materials Engineering, Engineering Faculty, P.O Box 10, Kuala Lumpur, Malaysia. Telephone: (603) 61965728

Therefore, research investigates the possibilities of enhancing tool life of Si₃N₄ inserts by post sintering via hybrid microwave energy and the results are to be compared with post sintering via conventional heating. Tool life analysis is conducted by dry machining T6061 aluminium alloy at three different cutting speeds.

MATERIALS AND METHODS

Preparation of Si₃N₄ inserts:

Silicon Nitride (Si₃N₄) inserts from Sandvik Coromant with diameter of 12.69 mm and thickness of 7.96 mm were used (Fig. 1). There were two types of Si₃N₄ inserts that were examined in this study. The triangular inserts (TNGA 332 T0820-6190) were used for machining purpose for tool life analysis and the circular inserts (RNG 45 T0820-6190) were used for mechanical and micro structural analysis. Three sets of experiments were prepared with three sets of inserts. First, is the commercially available tool as it is with no heat treatment performed (unpost sintered). The second, is the post sintered Si₃N₄ via hybrid microwave energy. The third, is the post-sintered Si₃N₄ via conventional heating.

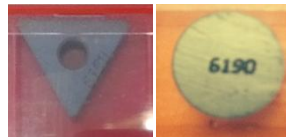


Fig. 1: Si₃N₄ inserts used

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 600°C for 15 minutes of holding time. The Si₃N₄ insert was placed on top of a ceramic tile which was then placed into the furnace.

Post Sintering Via Hybrid Microwave Energy:

Post sintering was done by using the modified domestic microwave oven (Panasonic ST 55M). The Si₃N₄ 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). This is to avoid direct contact of the Si₃N₄ insert with the graphite powder which acts as a susceptor to aid in speeding up the heating process. Susceptors have the capability of absorbing microwave energy, since they comprise a particulate substrate which is substantially non-reflective of microwave energy. Finally, the crucible is placed inside a ceramic fiber insulator box which is then placed inside the microwave furnace. The Si₃N₄ 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.

Mechanical Testing:

The three samples of Si₃N₄ 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,

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

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.

Tool life Analysis:

Dry machining of T6061 aluminium alloy rod with a diameter 100 mm and was performed using three different cutting speeds; 215, 314 and 393 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 life curves for the three types of Si₃N₄ inserts were analyzed.

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. Phosphoric acid (H_3PO_4) was used as an etchant with an etching time of 30 – 60 seconds.

RESULTS AND DISCUSSION**Density Measurement:**

Fig. 2 presents the results obtained from the density measurement of Si_3N_4 inserts based on the type of post sintering method. It is clearly obvious that post sintering for 15 minutes at $600^\circ C$ using conventional heating and hybrid microwave energy have not significantly changed the density measurements. Percentage increase for the former is only 0.4 % while the latter has increased by 0.8 % when compared with the unpost-sintered inserts. This increase is too small to be even considered an improvement. Results appeared to be quite similar due to the post sintering conditions which was only done for 15 minutes at $600^\circ C$. Furthermore, the Si_3N_4 inserts itself 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.

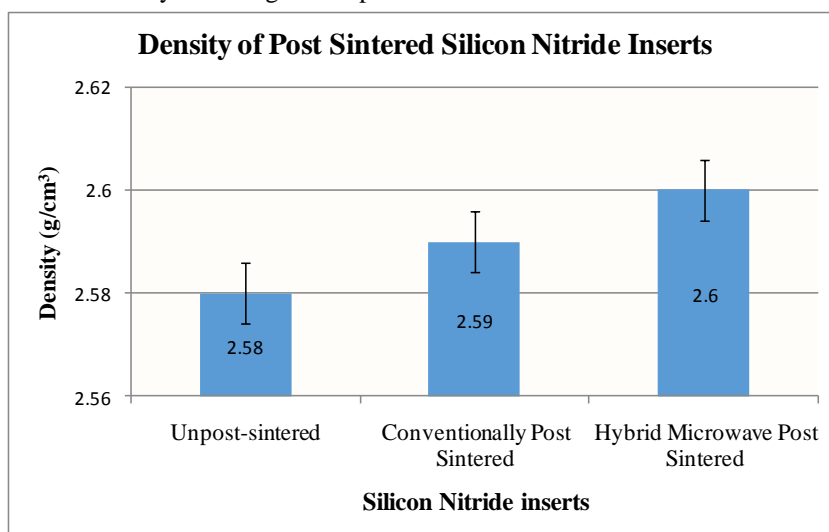


Fig. 2: Density measurements of the Si_3N_4 inserts

Hardness:

Fig. 3 shows the results of the hardness test obtained for all the three types of silicon nitride inserts. Conventionally post sintered inserts have shown to have an increase in hardness by 14% while the hardness for the hybrid microwave post sintered inserts have increased by 31% 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.

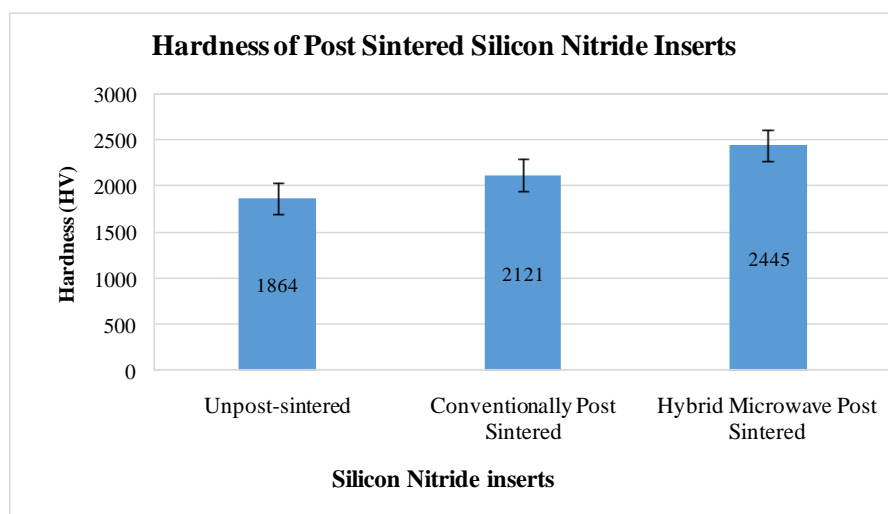


Fig. 3: Hardness measurements of the Si_3N_4 inserts

Strength:

The compressive strength and tensile stress values for all the three types of Si_3N_4 inserts can be seen in Fig. 4. The conventionally post sintered Si_3N_4 inserts reduced its compressive strength by 16% 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 22%) when compared with the original unpost-sintered inserts. This shows that the hybrid microwave sintered inserts absorbed lesser energy (590 MPa) to fracture compared with the unpost-sintered (615 MPa) and the conventionally post sintered (564 MPa) inserts. No doubt, brittle materials exhibit this characteristic whereby it has high hardness but lower ability to absorb energy for fracture. Silicon Nitride is a ceramic tool and post sintering for 15 minutes via conventional heating and hybrid microwave heating has enhanced its brittleness further.

Tool Life:

Flank wear measurements of the Si_3N_4 inserts were obtained (Fig. 5) and compared for three different cutting speeds (215, 314 and 393 m/min). From here, 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. 6) based on the Taylor's tool life equation (Eq. 2),

$$VT^n = C \quad (2)$$

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 Si_3N_4 inserts were found to be around 0.7 (which corresponds to ceramic tool); 0.71, 0.73 and 0.74 for the unpost-sintered, conventionally post-sintered and the hybrid microwave post-sintered inserts respectively.

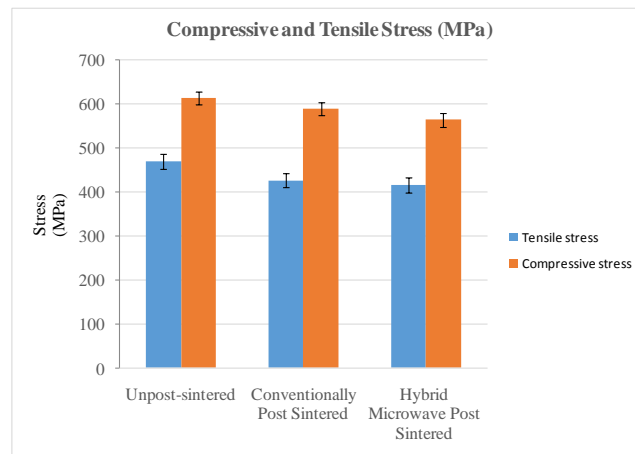


Fig. 4: Compressive and Tensile stress values for the Si_3N_4 inserts

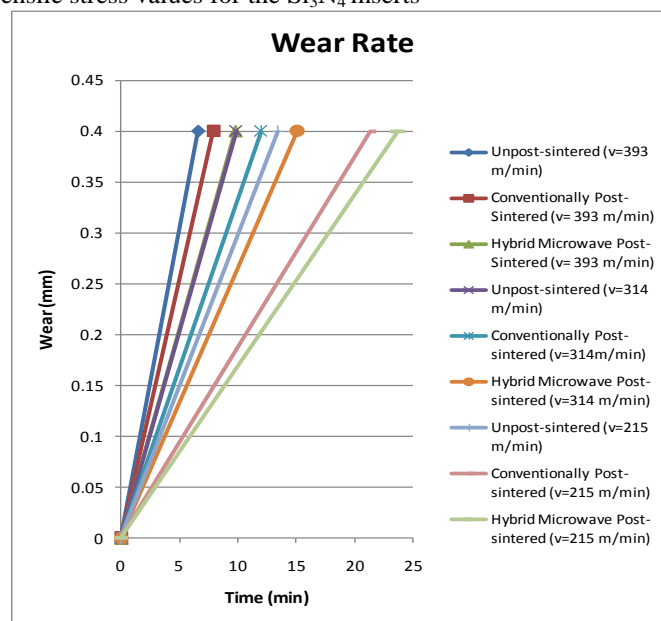


Fig. 5: Wear rate curves for the Si_3N_4 inserts at three different cutting speeds

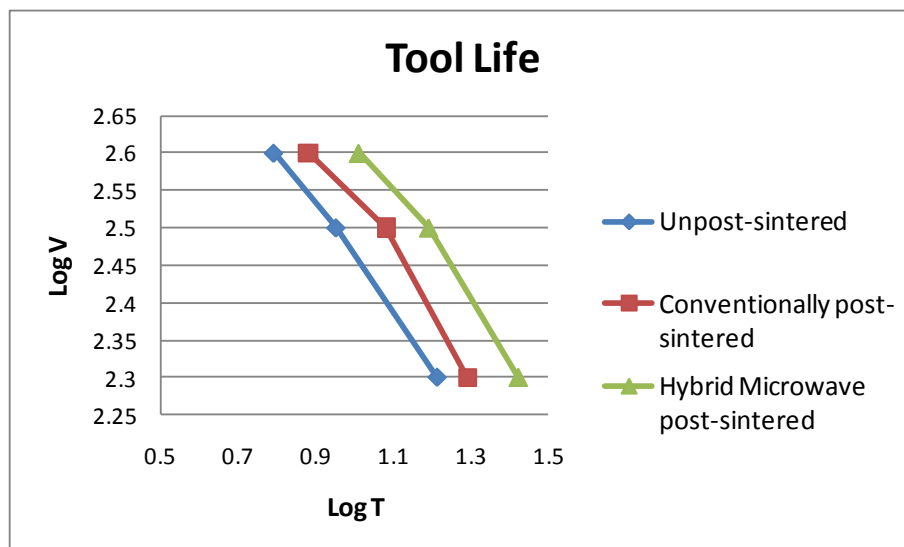


Fig. 6: Tool Life curves for the three types of Si_3N_4 inserts

For the same constant value of C , the larger the value of n , the longer the tool life. Therefore, post-sintering has increased the level of n from 0.71 for the commercial untreated Si_3N_4 insert to 0.73 (conventionally post-sintered) and 0.74 (hybrid microwave post-sintered). Percentage of increase in tool life for the conventional and hybrid microwave post-sintering is shown in Table 1. The tool life of the conventionally post-sintered Si_3N_4 inserts increased by 11, 21 and 20 % for the cutting speed of 215, 314 and 393 m/min respectively. Meanwhile, post-sintering using the hybrid microwave energy resulted in a longer tool life; 94, 53 and 48% for 215, 314 and 393 m/min respectively.

Table 1: Percentage Increase in Tool Life

Type of Post-Sintering	Cutting Speed, V (m/min)	% Increase in Tool Life
Conventional	215	11
Hybrid Microwave		94
Conventional	314	21
Hybrid Microwave		53
Conventional	393	20
Hybrid Microwave		48

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, the tool life and the wear resistance of the Si_3N_4 inserts.

Micro Structural Analysis:

Micro structural images shown in Fig. 7 appear to be quite similar with no significant difference for all the three types of Si_3N_4 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.

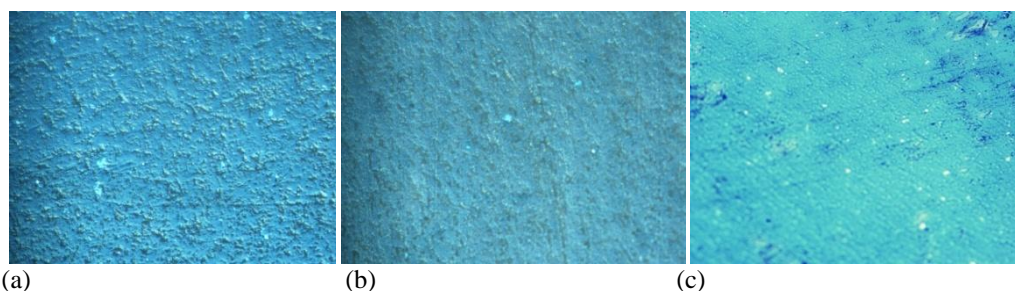


Fig. 7: Polarized SEM image at 100X magnification (a) Un-post-sintered (b) Conventionally post-sintered (c) Hybrid microwave post-sintered Si_3N_4 inserts

Conclusions:

Post sintering using conventional heating and hybrid microwave heating has resulted in the increase of tool life of Si_3N_4 inserts. Hybrid microwave energy prolonged the tool life by 48 – 94%, while conventional heating only managed to increase tool life by 11 -21%. 15 minutes of rapid heating has also improved wear resistance in the Si_3N_4 inserts. Wear resistance has improved even though there are no improvements in the density or strength. Hybrid microwave post-sintering has enabled to release residual stresses from the tool insert that were accumulated from the HIP process.

ACKNOWLEDGEMENTS

Great appreciation goes to the Ministry of Higher Education Malaysia for funding this research project through Research Acculturation Grant Scheme (RAGS).

REFERENCES

- Ariff, T.F. and B. Gabbitas, 2008. Effect Of Microwave Sintering On The Mechanical And Structural Properties Of Pewter Alloy. *Research Journal in Transactions of Material Science*, 8: 65-71.
- Ariff, T.F., N.S. Shafie and Z.M. Zahir, 2013. Wear Analysis Of Silicon Nitride (Si_3N_4) Cutting Tool In Dry Machining Of T6061 Aluminium Alloy. *Applied Mechanics and Materials*, 268: 563-567.
- Ebadzadeh, T. and M. Valefi, 2007. Microwave -Assisted Sintering Of Zircon. *Journal of Alloys and Compounds*, 11: 1-4.
- Feng, S. and M. Hattori, 2000. Cost And Process Information Modeling For Dry Machining. In: *Proceedings of the International Workshop on Environment and Manufacturing*.
- Grzesik, W., J. Malecka, D. Kowalczyk and P. Kiszka, 2011. Wear Behaviour Of Nitride Ceramic Cutting Tools In The Machining Of Nodular Cast Iron. *Advanced Manufacturing Science and Technology*, 35: 6-10.
- Homlberg, K. and A. Matthews, 1994. *Coating Tribology, Properties, Techniques and Applications in Surface Engineering*, Elsevier, Amsterdam.
- Kalpakjian, S. and S.R. Schmid, 2013. *Manufacturing Engineering and Technology*, seventh ed. Pearson, Singapore, pp: 198-199.
- Sorescu, M., L. Diamandescu, R. Peelamedu, R. Roy, A. Daly and Z. Bruno, 2007. Evidence For Microwave-Induced Recrystallization In NiZn Ferrites, *Materials Chemistry and Physics*, 101: 410-414.