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Cost Analysis of Using Hybrid Microwave Post-Sintered Aluminium Oxide Inserts

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ABSTRACT

This research investigates the effect of heat treatment using hybrid microwave energy toward the enhancement of tool life in Aluminium Oxide (Al_2O_3) inserts. Al_2O_3 tool insert is known for its attractive properties including high fracture toughness, strength and wear resistance at elevated temperatures. Heat treatment was performed on these inserts by post-sintering them for 15 minutes at 600°C using conventional heating and hybrid microwave energy. Dry machining was performed on T6061 Aluminium alloy and AISI 01 Cold Worked Steel for tool life analysis at three different cutting speeds; 245, 305 and 381 m/min. Tool life for Al_2O_3 had increased by 87.5-92% and 22.7-70% for T6061 Aluminium alloy and AISI 01 Cold Worked Steel respectively. Cost analysis was performed on these post-sintered Al_2O_3 inserts and found that there are economical benefits in the tooling cost when compared with the untreated Al_2O_3 inserts.

Keywords: Aluminium oxide, Post sintering, Hybrid microwave energy, Conventional heating, Dry machining, Tool life, Cost analysis.

1. Introduction

The economics of using cutting fluids have changed dramatically over the past two decades with the implementation of dry machining. Purchasing, managing, and disposing of cutting fluids accounted for less than 3% of the cost of most machining jobs in the early 80's. The cost of the average job today has increased to 16% including the management and disposal of cutting fluids.

Cutting tools account for only about 4% of the total cost of a machining project, accepting a slightly shorter tool life for the chance to eliminate the cost and headaches of maintaining cutting fluids could be the less expensive choice (Graham et al., 2003).

Dry machining is possible because many of today's cutting tools use carbide inserts with advanced coatings that no longer need coolant to lower the temperature of the cutting edge and lubricate the cut area to prolong tool life. However, Al_2O_3 inserts on the other hand are mainly classified as plain oxide alumina ceramic cutting tool, mixed alumina ceramic cutting tool and whisker reinforced alumina ceramic cutting tool. When zirconium oxide is added to the aluminum oxide matrix, the resulting ceramic tools are called plain oxide ceramic cutting tools. The fracture toughness and thermal shock resistance of the Al_2O_3 inserts are increased by the addition of zirconia in alumina matrix (Kalpakjian and Schmid, 2014). It is used as it is in an uncoated form and widely used for machining hard materials such as cast irons having wide range of hardness, plain carbon steels and alloy steels having a hardness range of HRC 34 to HRC 66, stainless steels and high temperature alloys as they have high hot hardness and very good chemical stability (Choudhury and Bartarya, 2003).

Tool wear is a natural phenomenon that occurs as a result from machining; wet or dry. Tool wear rates are noted to be higher in dry machining compared to wet machining. It is impossible to totally eliminate tool wear; nevertheless, it can be reduced. Tool life can be prolonged by implementing suitable and effective heat treatment methods. Heat treatment has been used since ancient times for the purpose of improving mechanical properties and to relieve stresses accumulated upon value added activities. Traditional types of heat treatment include annealing, normalizing, tempering, hardening and stress relieving. These heat treatments are basically performed in a traditional furnace through convection. Rapid heating using microwave energy on the other hand has shown to have significant improvements in the mechanical properties of ceramics, metals and alloys (Menzes and Kiminami, 2008; Wong and Gupta, 2007; Ariff et al., 2009; Thauri et al., 2011).

Microwave heating is a volumetric heating involving conversion of electromagnetic energy into thermal energy, which is instantaneous, rapid and highly efficient. Conventional heating on the other hand involves energy transfer originating from external sources. Post-sintering on cutting tools is a new heat treatment process that is performed with the aim to increase wear resistance and prolong tool life in addition to the Hot Isostatic Pressing (HIP). In this research, Al_2O_3 tool inserts were experimented on using conventional heating and hybrid microwave energy and compared with the unpost-sintered insert. The economic benefits of implementing this method into the industry have also been analyzed.

2. Methodology

2.1. Preparation of Al_2O_3 inserts

Three triangular inserts (TNGA 333 T0320-620) were used in the machining for tool life analysis. Three sets of experiments were conducted with three inserts; untreated tool (no heat treatment performed), post-sintered Al_2O_3 via conventional heating (Nabertherm N81) and post-sintered Al_2O_3 via hybrid microwave energy using a modified domestic microwave oven (Panasonic ST 55M). Both post-sintering were performed at 600ºC for 15 minutes. For the microwave heat treatment, 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) with particle size 300 mesh.

2.2. Measuring Tool Life

Dry machining 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 on T6061 Aluminium Alloy and AISI 01 Cold Worked Tool Steel rods with a diameter of 100 mm and length of 600 mm. 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.

2.3. Cost Calculations

In determining cost effectiveness, several equations from Groover (2007) were used. Eqs. 1-3 were used to find the total cost per unit product for the operation cycle (C_c). First, the machining time (T_m) in a straight turning operation was found by;

$$T_m = \pi DL/vf \qquad (1)$$

where D= diameter of the work piece (mm), L = work piece length (mm), f = feed (mm/rev) and v = cutting speed (mm/min). Then, the number of pieces per tool (n_p), had to be determined;

$$n_p = T/T_m \qquad (2)$$

where T = tool life (min/tool) and T_m = machining time per part (min/piece). Finally, the total cost per unit product (C_c) for the machining cycle was obtained;

$$C_c = C_o\, T_h + C_o\, T_m + C_o\, T_t/n_p + C_t/n_p \qquad (3)$$

where C_o = the cost rate (RM/min), T_h = part handling time (min), T_t = tool change time (min) and C_t = cost per cutting edge (RM/tool life).

3. Analysis of Results

3.1. Tool Life Analysis

The tool life values were obtained for the unpost-sintered 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. 1) based on the Taylor’s tool life equation (Eq. 4),

$$V T^{n} = C \qquad (4)$$

where V is the cutting speed, T is the tool life (minutes) and *C* is the constant value. The corresponding values of *C* for T6061 Aluminium Alloy and AISI 01 Cold Worked Steel are listed in Table 1.

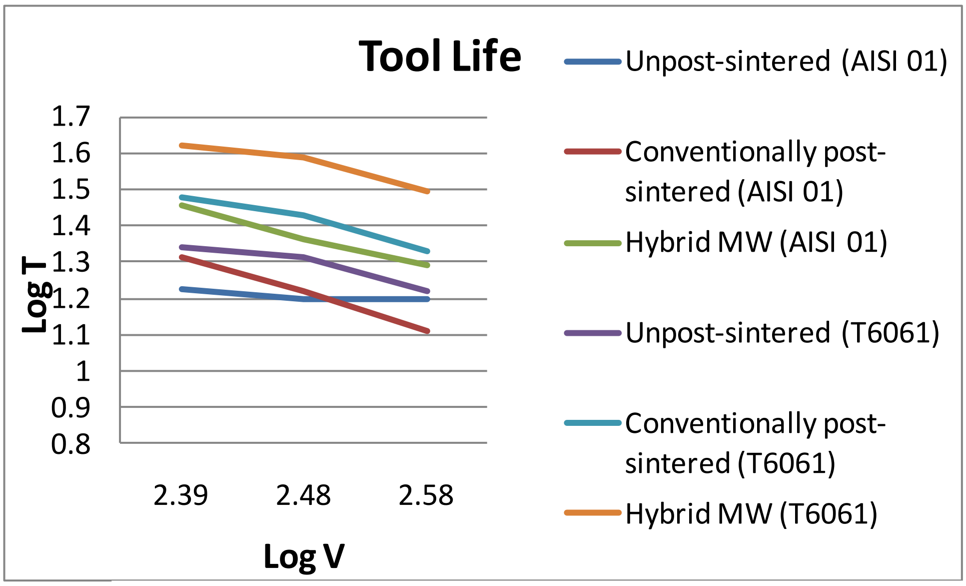

Fig-1. Tool life curves for three types of Al_2O_3 inserts

Table-1. Values of *n* and *C* for Al_2O_3 inserts

	T6061 Aluminium Alloy								
	Unpost-sintered			**Conventional**			**Hybrid MW**		
Speed	Tool Life (min)	n	C	Tool Life (min)	n	C	Tool Life (min)	n	C
245 m/min	21.84	0.55	1335.4	30.24	0.65	2246.7	42	0.6	2307.4
305 m/min	20.64	0.55	1612.1	26.66	0.65	2576.9	38.7	0.6	2734.8
381 m/min	16.65	0.55	1789.4	21.45	0.65	2794.8	31.35	0.6	3010.7
	AISI 01 Cold Worked Steel								
	Unpost-sintered			Conventional			Hybrid MW		
Cutting Speed (m/min)	Tool Life (min)	n	C	Tool Life (min)	n	C	Tool Life (min)	n	C
245	16.8	0.55	1156.3	20.52	0.65	1746	28.5	0.6	1828
305	15.75	0.55	1389.3	16.65	0.65	1898	23	0.6	1951
381	15.84	0.55	1740.9	16.96	0.65	2014	19.44	0.6	2260

The percentage of increase in tool life for the conventional and hybrid microwave post-sintering is shown in Fig. 2. The tool lives for both post-sintering processes have increased. However, the tool life of the conventionally post-sintered Al_2O_3 inserts increased by a smaller amount; 38.5, 28.9 and 28.8% from dry machining of T6061 Aluminium Alloy for the cutting speed of 245, 305 and 381 m/min respectively. Meanwhile, post-sintering using the hybrid microwave energy resulted in a longer tool life, with an increment of 92.3 %, 87.5% and 88.3% for 245, 305 and 381 m/min respectively. Dry machining of AISI 01 Cold Worked Steel on the other hand resulted in a lower increment; conventionally post-sintered inserts increased in tool life by 22.1, 5.7 and 7.1% while for the hybrid microwave post-sintered inserts increased in tool life by 69.6, 46.0 and 22.7% for the cutting speed of 245, 305 and 381 m/min respectively.

The tool life has significantly increased from the post-sintering effect using hybrid microwave energy. Rapid heating encountered from the hybrid microwave energy resulted in a very interactive molecular attraction with the electromagnetic waves which enhanced its wear resistance characteristics; thus, enhancing its machining performance. Post-sintering acts as a heat treatment process to release stresses accumulated from the Hot Isostatic Pressing (HIP). Therefore, this post-sintering (heat treatment) has successfully enhanced the tool life of the Al_2O_3 inserts.

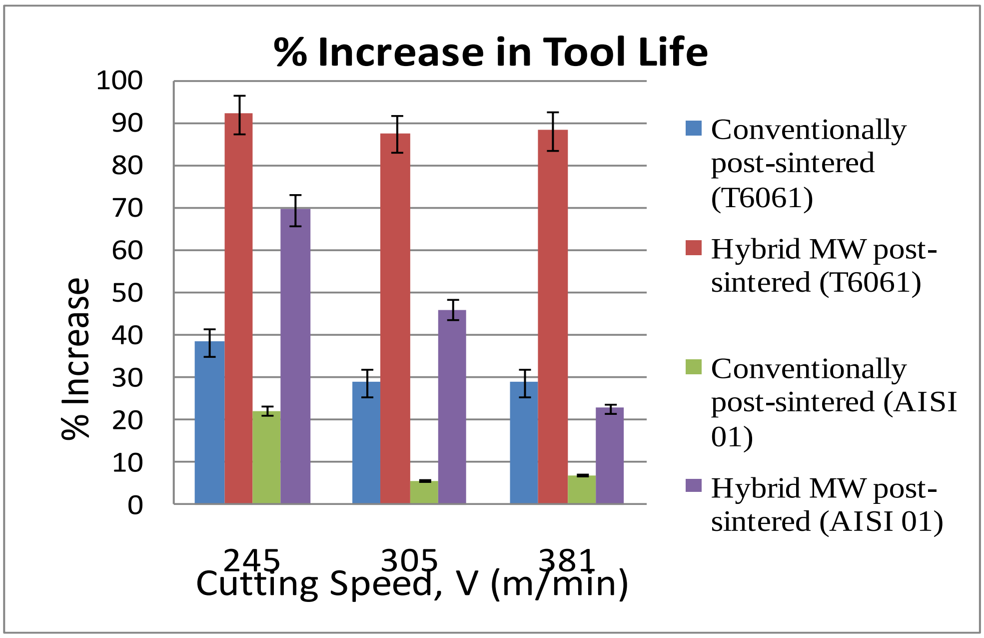

Fig-2. Percentage of tool life increment for Al_2O_3 inserts

3.2. Cost Analysis

Table 2 shows the data obtained from the cost calculations of using the post-sintered Al_2O_3 inserts. The number of pieces per tool (n_p) that can be machined using the three types of inserts are listed. Hybrid microwave post-sintering has the highest number of pieces to be machined until the tool wears off, followed by traditional conventional post-sintering and finally the untreated tool for the three respective cutting speeds; 245, 305 and 381 m/min. This shows that post-sintering has the ability of increasing the performance of the tool while increasing productivity by 21-31% from conventionally post-sintered inserts and 79-88% from hybrid microwave post-sintered inserts in dry machining of T6061 Aluminium Alloy. Dry machining of AISI 01 Cold Worked Steel on the other hand from using conventionally post-sintered and hybrid microwave post-sintered inserts, managed to reach an increment in productivity by 7-25% and 23-75% respectively.

Taking RM 30/hr for the machine and labor cost, tool handling time as 5 min, tool changing time as 2 min and RM 40.05 per insert (RM 6.675 per cutting edge), the average percentage of cost savings per product achieved from the hybrid microwave post-sintering is around 2.15 % (T6061 Aluminium Alloy) and 1.63% (AISI 01 Cold Worked Steel). The traditional conventional post-sintering technique resulted in only 0.84 % (T6061 Aluminium Alloy) and 0.6% (AISI 01 Cold Worked Steel) of savings (Fig. 3). Therefore, it can be said that with the prolonged tool life, the productivity increases because of the number of pieces that can be machined with one insert increases, hence, reduces tooling cost and is advantageous to the machining industry.

Table-2. Data of the cost calculations

	T6061 Aluminium Alloy							
	V (mm/min)	**Tm (min)**	**T (min/cutting edge)**	**T (min/tool)**	**np**	**Tt/np**	**Ct (RM)**	**Cc (RM)**
Untreated	24500	16.029	41.58	249.48	16	0.1285	6.675	11.01
	30500	12.875	39.69	238.14	19	0.1081	6.675	9.35
	38100	10.307	32.13	192.78	19	0.1069	6.675	8.06
Conventional	24500	16.029	56.7	340.2	21	0.0942	6.675	10.88
	30500	12.875	51.03	306.18	24	0.0841	6.675	9.26
	38100	10.307	39.69	238.14	23	0.0866	6.675	7.99
Hybrid MW	24500	16.029	79.38	476.28	30	0.0673	6.675	10.77
	30500	12.875	73.71	442.26	34	0.0582	6.675	9.16
	38100	10.307	58.59	351.54	34	0.0586	6.675	7.88
	AISI 01 Cold Worked Steel							
	V (mm/min)	Tm (min)	T (min/cutting edge)	T (min/tool)	np	Tt/np	Ct (RM)	Cc (RM)
Untreated	24500	16.029	32.13	192.78	12.0	0.1663	6.675	11.15
	30500	12.875	29.7675	178.605	14	0.1442	6.675	9.49
	38100	10.307	29.9376	179.6256	17	0.1148	6.675	8.09
Conventional	24500	16.029	38.745	232.47	15	0.1379	6.675	11.04
	30500	12.875	32.13	192.78	15	0.1336	6.675	9.45
	38100	10.307	24.57	147.42	19	0.1072	6.675	8.06
Hybrid MW	24500	16.029	54.81	328.86	21	0.0975	6.675	10.89
	30500	12.875	41.58	249.48	19	0.1032	6.675	9.33
	38100	10.307	35.91	215.46	21	0.0957	6.675	8.02

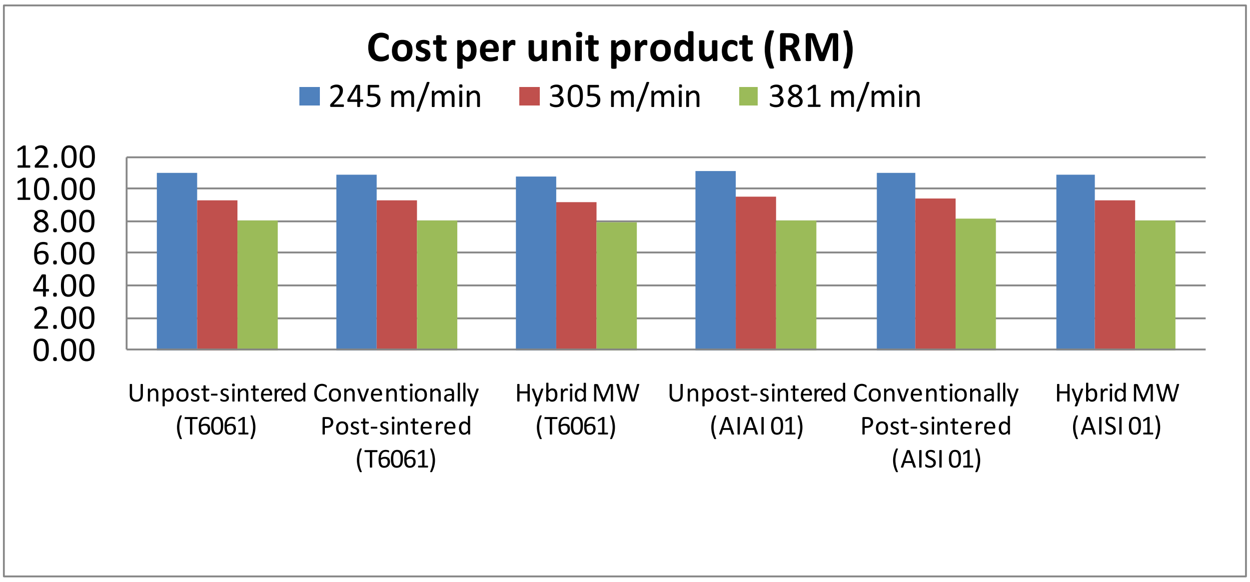

Fig-3. Cost per unit product for the three types of tools used in dry machining of T6061 Aluminium Alloy and AISI 01 Cold Worked Steel

4. Conclusions

Tool life of Al_2O_3 inserts using hybrid microwave post-sintering technique increased in the dry machining of T6061 Aluminium Alloys and AISI 01 Cold Worked Tool Steel by 27- 40% and 31- 40% respectively. Longer tool life increases the number of pieces that can be machined before it wears off. Compared to an untreated tool insert, using the hybrid microwave energy can produce 79-88% and 23-75% more machined pieces from dry machining T6061 Aluminium

Alloy and AISI 01 Cold Worked Steel respectively. Furthermore, it leads to larger tool cost savings. Therefore, total average cost savings per product that can be achieved by the hybrid microwave post-sintering is around 2.15 % for T6061 Aluminium Alloy and 1.63% for AISI 01 Cold Worked Steel. More promising and significant savings can be anticipated from mass production. Heat treatment of the tool inserts after the HIP can significantly help in reducing the accumulated stress built up and thus, further enhances its performance.

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