EFFECT OF MATERIAL PROPERTIES AND CUTTING PARAMETERS ON BURR FORMATION DURING MILLING OF PRE AND POST THERMALLY TREATED AA6061-T6 ALLOYS

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Abstract— **In this research, end milling was carried on pre and post thermally treated AA6061-T6 aluminum alloys. Heat treatment with aging time of 8 hours was used to vary the material properties (mechanical properties) of the AA6061-T6 alloy. The variation of material properties such us tensile strength, yield strength, hardness and ductility having significant effects on the burr formation. The burr formation was due to the transition of materials when the toll passes over the material. The materials with higher hardness and yield strength offer higher resistance to plastic deformation. Moreover the material transition in the lateral direction with higher cutting speed and depth of cut is negligible for materials with higher hardness and yield strength leading to reduced burr height. The burr height of post heat treated materials was lesser than the parent because of higher yield strength, hardness and lesser ductility..**

Index Terms— **End milling, Heat treatment, Aging, Analysis of variance, Yield strength, Hardness, Ductility.**

I. INTRODUCTION

Burr formation during machining is a common problem encountered in several industries such as marine, rail, aerospace and automobile sectors. Numerous studies have been conducted on the mechanisms of burr formation in the past years [1] and they have suggested integrated strategies for burr prevention and minimization [2]. In spite of all the improvements realized, there are still many challenges in understanding, modeling and optimizing burr formation during a machining operation.According to Hashimura et al [1] burr formation mechanism is affected by the mechanical properties of the work piece and cutting conditions. Gillespie [2] has enumerated the different types of machining burrs as Poisson burr, rollover burr, tear burr and cutoff bur. Azuddin and Abdullah [3] have done a study on surface roughness and burr formation of end milled Al6061aluminium alloy with different spindle speeds and feed rates using three different milling cutters. From this study it was observed that the milling tool with larger diameter results in higher burr formation. Pankul Goel and Zahid A. Khan [4] studied the influence of slab milling process parameters on surface integrity of HSLA. Their studies indicated that of all the four milling parameters analyzed the most significant was depth of cut followed by feed, cutting speed and the presence of cutting fluid. Luiz Roberto Muñoz Dias et al [5] investigated the differences in machinability between two gray cast irons belonging to the same class (GG25). The results showed that milling of the 100 % pearlitic alloy led to faster tool wear and higher cutting forces than in the 50 % ferritic alloy. Ceramic tools exhibited longer life than carbide tools. The observed wear mechanisms were diffusion, attrition, and thermal cracks. However, material microstructure was observed to be far more significant for tool life and cutting force than the other input variables (cutting speed and tool material). M. Santhanakrishnan et al [6] studied the effect of geometrical and machining parameters such as rake angle, nose radius, cutting speed, feed rate, and depth of cut on temperature rise during end milling operation. The experiments were conducted on Al 6351 with high-speed steel end mill cutter.From the literature it is identified that the principal factors governing milling burr formation are machined part (geometry, dimension, mechanical properties, etc.), cutting parameters (cutting speed, feed rate, depth of cut, etc.), cutting tool (material, shape, geometry, rake angle, lead angle, helix angle, etc.), machine tool (rotational speed, dynamic strength, etc.), manufacturing strategy (tool path, coolant, back cutting, lubrication, MQL, etc.) and machined part properties (e.g., chemical, mechanical properties) [7,8,9,10, 11 and12]. The dominant mechanical properties usually reported are hardness, ductility, yield strength and elongation [13]. In addition while machining ductile materials large burrs are formed particularly at higher levels of cutting speed and feed rate [14]. Burr formation can be reduced by limiting the plastic deformation of material during milling through localized mechanical process, hard machining, chemical and thermal treatments [15].Kareva et al [16] studied the mechanical properties, corrosion resistance and fracture behavior of precipitation-hardening aluminum alloys after a thermo mechanical treatment with deformation in a wide temperature range. The study showed a positive effect on the strength of the aluminum alloys with slight decrease in the ductility. F. Ozturk et al [17] studied that the mechanical properties of a commercially available AA6061 alloy aged to various levels were studied. Peak-aged conditions were reached in this particular alloy after a 2 h heat treatment at 200 o C. The variation of the yield stress, ultimate tensile strength, ductility and strain hardening rate with aging time is measured and discussed in relation to the micro structural changes induced by the heat treatment. Demir and Gunduz [18] investigated the effect of artificial aging on the machinability of AA6061 in as-received, solution heat treated and aged conditions. Their results revealed that aging at 180 o C for various times significantly affects the surface roughness of the work piece. Kim et al. [19] investigated the mechanical and tri-biological properties of rheo-formed AA6061 wrought alloy. Peak hardness and surface roughness were determined after a 530 o C solution heat treatment for 10 h. Surface roughness increases with the aging time. The solution heat treatment is first performed at 500oC to obtain the supersaturated α solid solution. Artificial aging is obtained by heating to about 200o C for various amounts of time and leads to precipitation of various phases (leading to the stable β phase). The hardness and strength are determined by the precipitate type, density and size [20]. Though several researches have been conducted on identifying the influence of thermal treatments on localized/entire material surface, and also on the optimization of milling parameters for enhanced surface quality; no study has been attempted on improving the surface quality during milling by limiting the plastic deformation. In this study AA6061-T6 material was subjected to thermal treatment viz., solution treatment with artificial aging of 8 hours.

II. EXPERIMENTAL DETAILS

A. AA6061-T6 Composition and Properties

AA6061-T6 aluminum alloy of nominal composition (wt %): Al- 0.76 Mg – 0.56 Si – 0.07 Mn – 0.06 Cu – 0.04 Ti – 0.03 Cr – 0.026 Zn – 0.008 Ni and dimensions 300 × 300 × 10 mm was chosen as starting material with the following mechanical properties: Tensile strength - 305 N/mm2, Yield strength - 179 N/mm2, Ductility - 14% and Hardness- 60.12 HRB.

B. Thermal Treatments

Solution heat treatment of parent material was done at 535°C for a period of 6 hours followed by quenching in water to room temperature. After solution treatment the alloy was artificially age-hardened at 175°C for 8 hours in a furnace and subsequently air cooled.

Rockwell hardness tests were carried out on the surface of the pre and post thermally treated AA6061-T6 alloy. The samples were subjected to a load of 100 kg using an indenter of diameter 25.4 mm. The tensile test for both pre and post thermally treated AA6061-T6 alloys were carried out as per the ASTM B209 -14 standards.

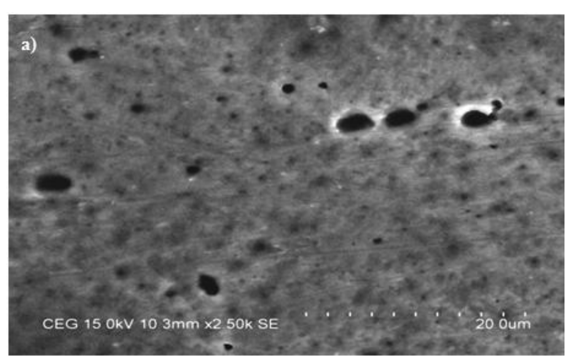
End milling was conducted on pre and post thermally treated AA6061-T6 aluminum alloy under dry cutting conditions using a CNC vertical machining center with a maximum spindle speed of 8000 rpm and cutting power of 25 kVA. Solid carbide K6 end mill tool with 6 mm diameter and three flutes were used for end milling. The cutting parameters used for milling are given in Table 1. Burr (poison burr) height of milled specimens was measured using tool maker's microscope along the length of the slot and average height was taken for analysis.

Table 1: End milling Cutting Parameters

Factors	Symbol	Unit	Levels		
			1	2	3
Cutting Speed	A	m/min	47.1	56.52	65.94
Feed	B	mm/min	100	150	200
Depth of cut	C	mm	1	1.5	2

C. SEM Images for pre and post thermally treated materials

Figure 1 shows the SEM images of pre and post thermally treated materials. The size of the microstructure of the parent material was bigger than heat treated and aged 8 hours material. The reduced size of microstructure after heat treatment increases the hardness, yield strength and reduces the ductility of the material. Figure 2 refers the average grain size of the pre and post thermally treated materials. The average grain size of parent material was higher than the grain size of heat treated with aging of 8 hours material.



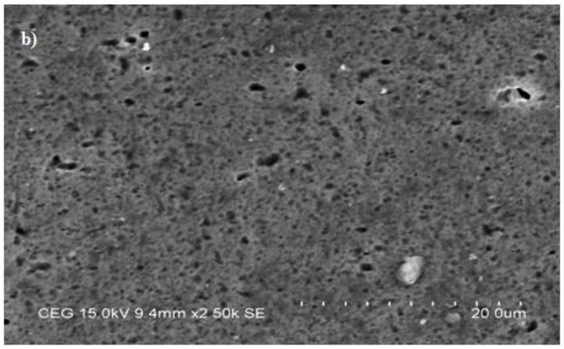


Fig. 1 SEM images of AA66061-T6 alloy (a) Parent material (b) Heat treated

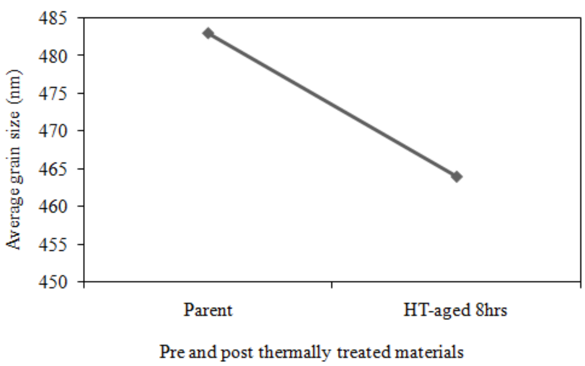


Figure 2: Average grain size of pre and pre thermally treated AA6061-T6 alloy

III. RESULTS AND DISCUSSION

During machining burr formation occurs due to the transition of material during multiple tool passes. It is well known that when material is deformed within the elastic limit it regains its original shape. However when the deformation exceeds the elastic limit, material flows in the longitudinal direction. When this movement is resisted by the side wall of the milling slot, metal surges over the wall of the milling slot and burr is formed. The burr height responses for various milling conditions of thermally treated and parent materials are showed in Table 2.

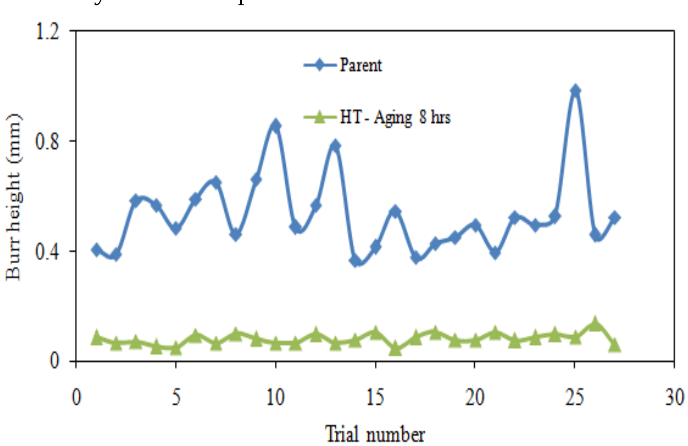


Fig 3: Variation of burr height for different conditions

Figure 3 displays the variation of burr height for different cutting conditions. In all the conditions the heat treated and aged materials displayed lowest burr height followed by the parent material.

Table 2: Cutting parameters and responses

Test no	Parameters			Burr height (mm)	
	Cutting Speed	Feed	Depth of Cut	Parent material	HT - Aging 8 hours
1	47.10	100	0.5	0.407	0.085
2	47.10	100	1.5	0.387	0.065
3	47.10	100	2.5	0.583	0.07
4	47.10	150	0.5	0.568	0.052
5	47.10	150	1.5	0.483	0.05
6	47.10	150	2.5	0.59	0.094
7	47.10	200	0.5	0.652	0.064
8	47.10	200	1.5	0.46	0.100
9	47.10	200	2.5	0.66	0.08
10	56.52	100	0.5	0.854	0.066
11	56.52	100	1.5	0.486	0.067
12	56.52	100	2.5	0.566	0.095
13	56.52	150	0.5	0.785	0.065
14	56.52	150	1.5	0.366	0.075
15	56.52	150	2.5	0.413	0.105
16	56.52	200	0.5	0.546	0.045
17	56.52	200	1.5	0.376	0.085
18	56.52	200	2.5	0.426	0.105
19	65.94	100	0.5	0.45	0.075
20	65.94	100	1.5	0.493	0.076
21	65.94	100	2.5	0.396	0.104
22	65.94	150	0.5	0.524	0.074
23	65.94	150	1.5	0.496	0.084
24	65.94	150	2.5	0.526	0.095
25	65.94	200	0.5	0.985	0.089
26	65.94	200	1.5	0.458	0.134
27	65.94	200	2.5	0.523	0.058

A. Burr height as a function of feed rate, cutting speed and work piece materials

Post milling burr height for thermally treated and parent materials at different feed rates are shown in Figure 4. It can be observed that burr height reduces with increasing milling feed rates. This can be attributed to the lower exposure time of the material to the milling tool at higher feed rates. On the other hand at low feed rates owing to the slow tool travel the material undergoes larger plastic deformations. This causes increased burr heights. In the present experimental range lower burr heights were obtained for all the materials at the feed rate of 200mm/min.

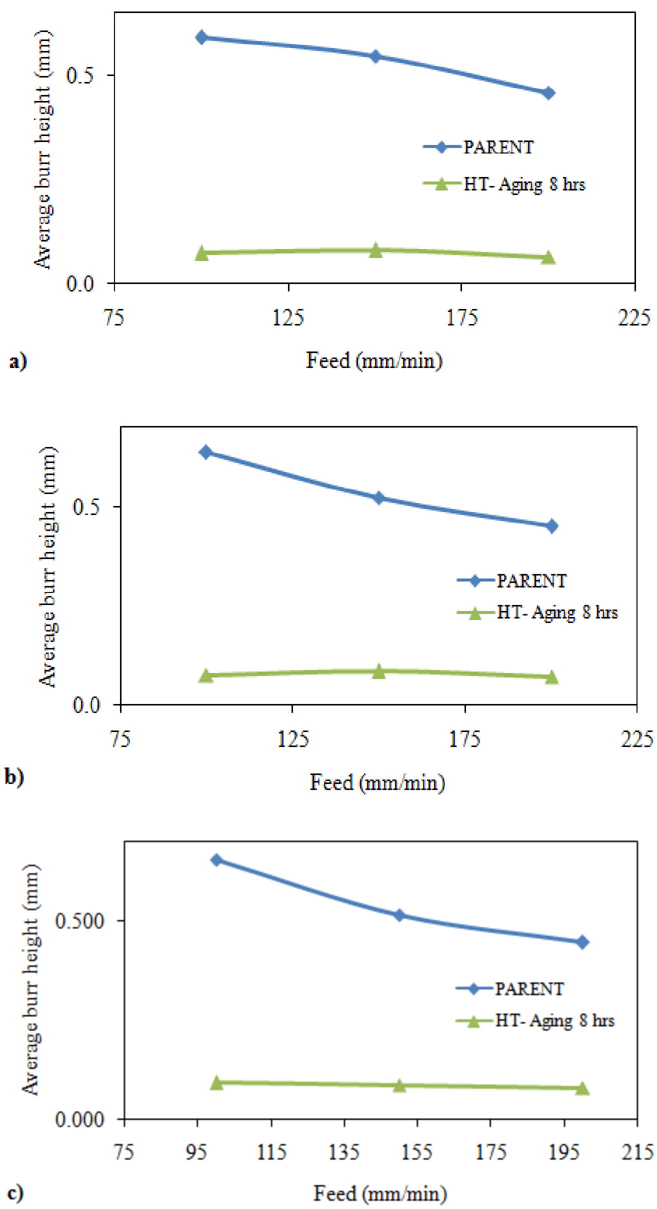


Fig 4: Variation of burr height with milling feed at Cutting speeds

a) 47.10m/min b) 56.52m/min c) 65.94m/min.

B. Burr height development as a function of depth of cut, cutting speed and work piece materials

Figure 5 shows the variation of burr height with depth of cut. It can be inferred that the influence of depth of cut as compared to milling cutting speed is insignificant. At lower cutting speeds the heat generated on the material is low and the value of burr height is also low irrespective of increasing depths of cut. In fact at lower cutting speed and higher depth of cut, burr height decreases or remains constant. At increasing cutting speeds higher thermal deformation of the material takes place due to higher temperature experienced by the work material [21]. At the same time with the increasing depth of cut, the total amount of material being displaced by the cutting edge raises proportionally with the cutting speed. However as the material is restricted to the flow mostly in the direction parallel to the cutting edge it results in higher burr heights. Therefore at higher cutting speeds and depth of cut, burr height increases.

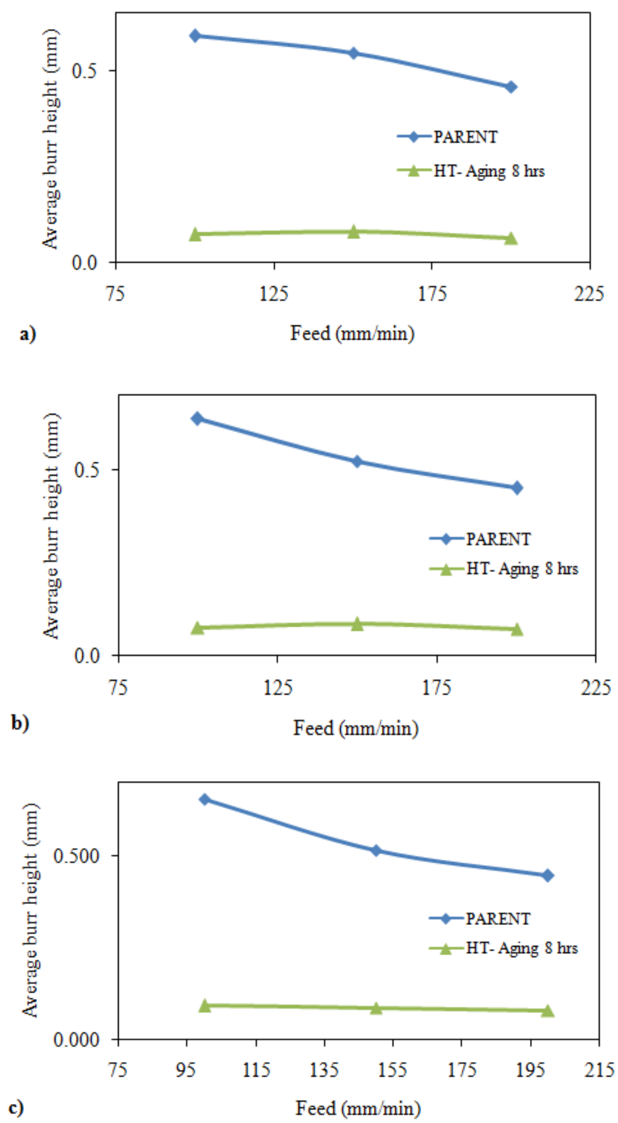


Fig 5: Variation of burr height with depth of cut at Cutting speeds
a) 47.10m/min b) 56.52m/min c) 65.94m/min

C. Effect of mechanical properties on burr formation

The mechanical properties of aluminum alloy AA6061-T6 such as tensile strength, yield strength, ductility and Rockwell hardness 'B' scale for parent and Post solution treated and artificially aged- 8 hrs are shown in Table 3. The yield strength, tensile strength and hardness of the solution treated and aged for 8 hours was higher than parent material.

The variation of mechanical properties of thermally treated and parent materials with the average burr height are shown in Figure 6. It can be observed that average burr height was high for materials with lower yield and tensile strength, lower hardness and higher ductility. This can be attributed to the reason that materials with higher hardness and yield strength offer higher resistance to plastic deformation. Moreover the material transition in the lateral direction with higher cutting speed and depth of cut is negligible for materials with higher hardness and yield strength leading to reduced burr height.

Table 3: Mechanical properties for various conditions

	Tensile strength N/mm^2	Yield strength N/mm^2	Hardness HRB	% Elongation
Parent	305	179	60.12	14
HT-Aging 8 hrs	314	311	77.66	8

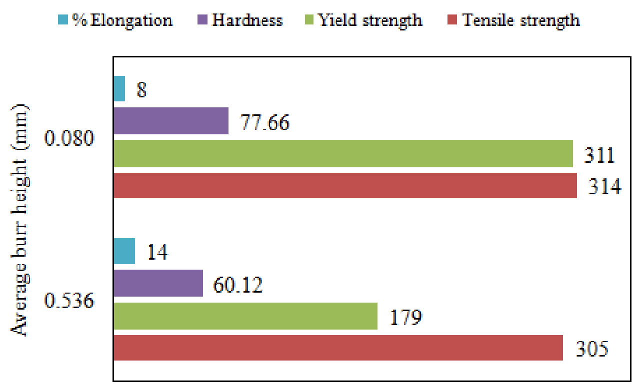
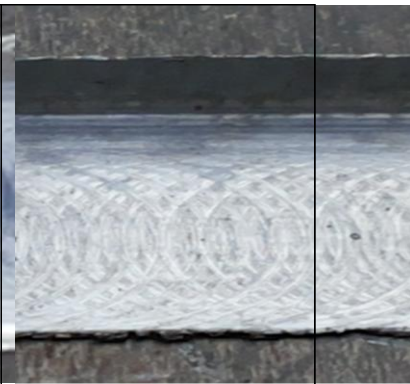
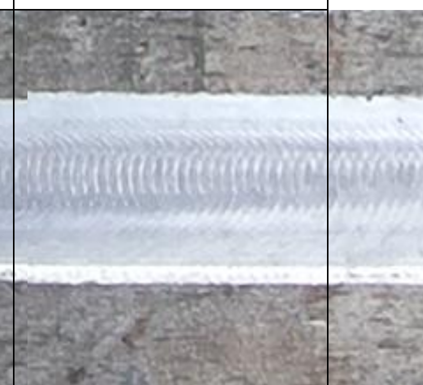


Fig 6: Variation of burr height for the mechanical properties

Alternatively materials with higher ductility give lower resistance to plastic deformation [22] though a complete failure takes a longer duration. Hence when the milling tool penetrates the ductile work piece, metal starts flowing in lateral and longitudinal directions giving rise to both side and exit burrs. In the present experiments heat treated materials showed least average burr height of 0.080mm owing to their high yield strength (311 N/mm2) and lower ductility (8%) compared with the parent material.

Table 4: Photographic view of burr formation under different conditions

	Maximum burr height	Minimum burr height
Parent material	 CS:65.94m/min,F:200 mm/min,DOC:0.5mm, BH: 0.985mm. Despite higher feed rate, burr height was higher due to elevated cutting speed.	 CS:56.52m/min,F:150mm /min, DOC: 1.5mm, BH: 0.366mm. Moderate feed and depth of cut leads to lower burr height
Aging time 8 hours	 CS:65.94m/min,F:200 mm/min, DOC: 1.5mm, BH: 0.134mm Higher burr height was achieved due to higher cutting speed and depth of cut	 CS:56.52m/min,F:200mm /min, DOC: 0.5mm, BH: 0.0458mm Burr height was lesser due to very low depth of cut and higher feed

IV. CONCLUSION

This study deals with the effect of mechanical properties and cutting parameters on the formation of burr during the milling of pre and post thermally treated materials.

- In all conditions materials subjected to heat treatment and aged for 8 hours displayed lowest burr height followed by the parent material.
- It was observed that burr height reduces with increasing feed. Lower burr height was obtained for the materials at the feed rate of 200 mm/min. At higher cutting speed and depth of cut, more amount of material was displaced along longitudinal direction which resulted in higher burr height.
- The least average burr height of 0.0458 mm was achieved for high yield strength (311 N/mm2) and lower ductility (8%) compared with parent material.

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