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The Roughness Characteristic of AA6061-F, AA6061-O and AA6061-T6 after Machining Process

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Abstract. Generally, the aims of the machining process are to produce a smooth surface according to a specific standard. To get a good surface quality can be implied by improving the machinability of the raw material. In addition, the selection of machining methods and machining parameters is also an important factor. This study aims to obtain a relationship between heat treatment and surface quality of AA6061 alloy after machining. Heat treatment is expected to improve the machinability of the AA6061 alloy to produce a surface with low roughness. The study was conducted using two heat treatment methods, namely AA6061-T6 and AA6061-O and comparing it with AA6061-F. After the heat treatment process, the AA6061 alloy was machined using a lathe with 1500 rpm spindle speed, 0.05 mm/rev of feed rate and 2 mm depth of cut. The condition of the turning process was varied with and without lubrication. The effect of heat treatment on the surface quality after machining is in terms of surface roughness, microstructure, hardness value, and chip shape. From the results, it was found that Al6061-O has the best surface quality with lowest hardness and lowest surface roughness.

1. Introduction

Product quality is the goal of each manufacturing process. The machining process is one of the commonly used process in manufacturing processes. Machining process works by removing part of the work pieces by cutting using the appropriate tool and doing it on the machining equipment's. Machining quality can be seen from the accuracy of the product dimensions, the level of surface roughness and conformity with the desired shape. The stages of surface finishing in each machining process are very important to note.

The quality of surface finishing is influenced by many factors including machining parameters such as cutting speed, feed rate, and cutting depth. The choice of tools and use of cooling fluid is also one of the main considerations. However, another factor that is not less important is the machinability of the raw materials. Improving the machinability is often an option if there is no other material can be choose. The machining process plays a large portion in the manufacture of metal products. Machining is generally carried out after the main manufacturing process. The aim is to provide a good surface quality and dimensional accuracy. The importance of the machining process in making metal products makes machining topics are attractive to explore. This is to get the most appropriate combination of the many machining parameters involved to produce high quality products.

Aluminum is a metal that has the best combination of properties for applications. Its strength can be improved, the metal is lightweight, has excellent corrosion resistance, adequate thermal and electrical conductivity. This is the main reason why an aluminum is so widely used in every field and application. Many components are made from aluminum as machined parts. Aluminum has a weakness in strength but is overcome by the ability of aluminum to obtain microstructural modifications. The strength of aluminum alloy can be increased by heat treatment, work hardening and the addition of alloying element.



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The historical treatment of aluminum as a raw material certainly affects the behaviour during the machining process. The problem is to find the most appropriate manufacturing route for aluminum alloy with typical micro structure condition in manufacturing process to meet the desired product requirements.

Improving the machinability is one of the way to get best surface quality in machining. Machinability is related to tool life, surface roughness, cutting force, machining power and type of chips obtained. There are so many studies on aluminum alloys that are related to heat treatment and machining processes. Good quality of machined surface will increase fatigue strength of material, corrosion resistance and lower friction [1]. Demir et al has investigated about the effect of heat treatment (SHS) and SHTA on machinability of material AA6061. They found that differences in aging time and cutting speed significantly affected the value of surface roughness. However, the SHTA treatment did not significantly affect the cutting force except for SHT which resulted low hardness [2]. However, F. Frost et al found that reducing the processing time during the heat treatment stages had little effect on the mechanical properties that obtained [3].

Similar research was also conducted by Kaya et al studied effect of aging on machinability of AA7075 materials with variations in aging time (1, 6, 12, and 24 hours at a temperature of 180°C) and machining conditions. Changes in tool temperature were examined to see the effect on chips resulted. The results of the study showed that the condition of aging 6 hours had the best machinability with the lowest surface roughness value [4].

Another study was carried out by Rashad et al with five variations of heat treatment namely natural aging, artificial aging, annealed and artificial aging with superimposed free forging and as received. The effect of heat treatment on the machinability of alloy 7116 was focused on the value of surface roughness. By varying the cutting parameters such as cutting conditions, cutting speed, feeding, and cutting depth it was found that artificial aging conditions with superimposed free forging have the best machinability [5].

Imhade et al conducted study of the relationship between machining parameters using the end milling process on AA6061 alloys. Sequentially it was found that the most influential on surface roughness was spindle rotation speed, feed rate and depth of cut [6]. The combination of spindle rotation variations and feed rate also produces an effective influence on the level of surface roughness. Similar research is also carried out by [7], the presence of burrs defects and surface quality during the milling process in AA6061-T6 alloys can be reduced by controlling the feed per tooth whereas the cutting speed gives minimal effect. Another study was conducted by Adnan, he examined various cutting techniques in pure Aluminum alloys and 6061 then proposed cutting with water jet cutting techniques as the best method, the reason was that this technique did not produce significant changes in microstructure and there was no significant decrease in hardness after the cutting process [8]. However, it is still necessary to conduct an in-depth study of the relationship between heat treatment and machining conditions in the AA6061 alloy on machining quality, hardness and the shape of the chips produced

2. Materials and Method

AA6061 cylinder was used as specimen which is dimension 150 mm length and 32 mm diameter. Specimens were divided in three categories, namely AA6061-F, AA6061-O and AA6061-T6. Figure 1 shows the heat treatment mode for AA 6061-O and AA6061-T6. The first specimen, AA 6061-O was heated to 440°C and then hold for 2 hours, after that the sample was cooling down to the room temperature with slow cooling. The second specimen, AA6061-T6 was heated to 550°C and hold it for 2 hours and then rapid cooling to 29 °C then artificial aging for 8 hours at 176 °C. The third specimen of AA6061 was as fabricated (AA6061-F). After heat treatment process, the specimen was machined in turning lathe using GEDEE WEILER LZ-330 G with HSS as a tool steel, see figure 2. There were two type of turning condition without cooling media and with cooling media.

The hardness test was conducted after heat treatment process using hardness leeb portable instrument before machining process. The machining variable was set up in 1500 rpm spindle speed, 0.05 mm/rev feed rate and 2 mm of depth of cut for 80 mm length. For microstructural observation, the specimen was etched using *Keller reagent* consist of 25 ml aquades, 5 ml HF, 7.5 ml HCL and 12.5 HNO₃ for 30

second. The microstructure was evaluated using Optical Microscope. The surface roughness was measure by using *surface roughness tester* Mitutoyo SJ-310.

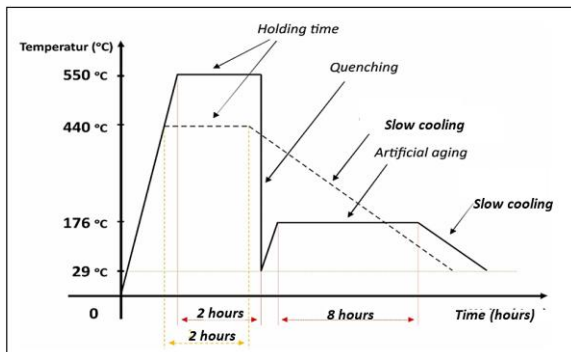


Figure 1. The schema of heat treatment process for AA6061-O (dashed line) and AA6061-T6 (bold line)



Figure 2. Machine lathe, Gede Weiler LZ-330 G

3. Result and Discussion

Figure 3 shows the hardness value of each specimen. AA6061-T6 has the highest hardness (412.6 HL) and the lowest hardness value is AA6061-O (337 HL). AA6061-T6 has increases in hardness due to microstructural change during heat treatment process. The changes on microstructure of AA6061 during aging is the causes of increases hardness mainly due to the presence of precipitate state. Similar result was obtained by Ozturk et al, where variations in strength of AA6061 occurred with different levels of aging process. This variation in mechanical strength is caused by structural evolution during the aging process [9]. In the other hand for AA6061-O has solution heat treatment where the hardness was decreased compare to AA6061-F. The decreases of AA6061-O hardness because of softening in microstructure during solution treatment, the same result with SHT treatment conduct by Demir et al. [2].

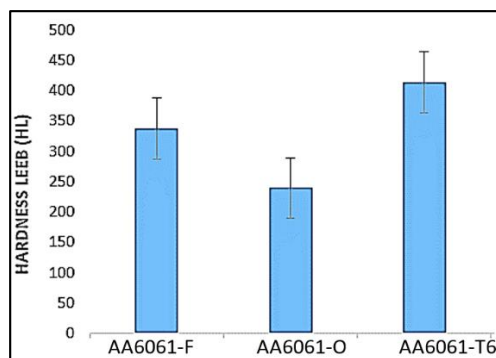


Figure 3. Hardness value of AA6061-F, AA6061-O and AA6061-T6

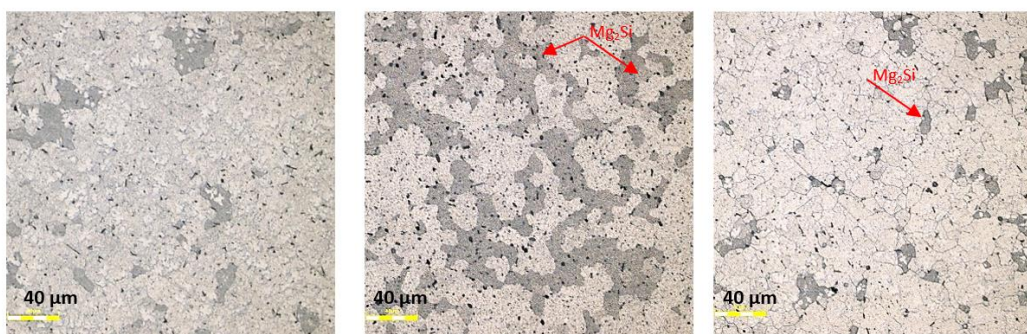


Figure 4. Microstructure of AA6061-F, AA6061-O and AA6061-T6

Figure 4 shows the different of microstructure of each specimen AA6061-F, AA6061-O and AA6061-T6. Figure 4a show typical microstructure of AA6061 consist of α -Al matrix with unclear of grain boundary. Figure 4b show large area of Mg_2Si surrounding by α -Al matrix and then 4c shows that large of Mg_2Si precipitate dissoluble in aluminum matrix. Three different type of microstructure causing different value of hardness, which is AA6061-T6 give the highest hardness.

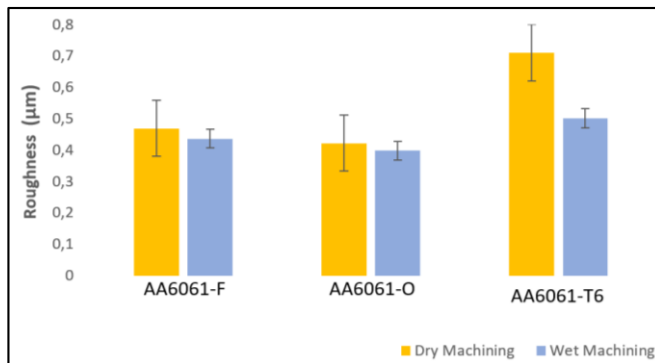


Figure 5. Roughness value of AA6061-F, AA6061-O and AA6061-T6 after turning process.

Figure 5 shows the roughness value for each type of specimen after turning process using lathe with 1500 rpm spindle speed and 0.05 mm/rev of feed rate. For each type of aluminum specimen, the roughness measurement was repeated five times, and it was found that the lower roughness was 0.396 μm for AA6061-O with wet machining and in the other hand the highest roughness was 0.710 μm for AA6061-T6 with no lubrication (dry machining). AA6061-T6 show a significant roughness decreases by using wet machining condition, from figure 5 also show that in overall, wet machining effectively stabilize the value of roughness for each specimen. The uses of lubricant will be reduced energy consumption during cutting process and as result the chip temperature decreases and also better improve in a controlled surface [10]. Moreover, according to Sreejith, that machining with minimal lubrication conditions can actually improve the characteristics of the machine's ability so that the use of flooded can be reduced [11]

However, from roughness measurement it seems that AA6061-O has the best quality of surface indicated by low surface roughness which also has lower hardness. The different result was obtained by Sevim et al, where the quality of surface roughness was improved by increasing the specimen hardness due to presence of precipitate. The presence of soluble precipitate in AA6061-T6 play important role to increase hardness [12], however this precipitate also probably produce distortion and deflection during shear deformation in cutting process and produce bad quality of surface roughness. Walid et al mentioned that if the interaction between surface hardness and cutting speed produce built-up edge chip condition then the surface quality became undesired [13].

The other reason can be explained by residual stress, AA6061 specimen was relatively free of residual stress due to softening, Assini et al stated that the residual stress will give unpredictable machining behaviour, especially for large work piece [14]. As mentioned that work piece hardness has significant effect to the surface finish quality [1], but the effect of the hardness on the surface quality could be play different mechanism and different result. As reported by Kaya et al that workpiece with high hardness tend to produce BUE chip condition and it is insufficient to meet a better quality of surface [4]. Khamer et al has different explanation, he stated that material with high resist of plasticity will be difficult to facilitate material flow during cutting or machining process and then surface finish will improved.

Figure 6 shows the chips produced for each type of specimen by turning process. The result shows that the chips have different type such as continued spiral chip, continued chip, discontinued spiral chip and discontinued chip. For dry machining condition, AA6061-F and AA6061-O has continued chips, otherwise AA6061-T6 has discontinued chips. However, for wet machining each type of specimen produce discontinued chips. As mentioned above that for AA6061-F and AA6061-O both has continued chips but AA6061-F produce continued spiral chips for dry machining condition. AA6061-O with the lowest hardness produce relatively straight continued chip but AA6061-T6 with the highest hardness

produce discontinued chip. It is implied that the hardness of specimen also influence the form and type of chips produced. Straight continued chips indicated good surface finish and steady cutting force. From figure 6 also shows that for AA6061-F and AA6061-O, the lubrication had significant effect to the chips form. In dry machining, the chips tend to be continuous form but in wet machining the chips tend to be discontinued.

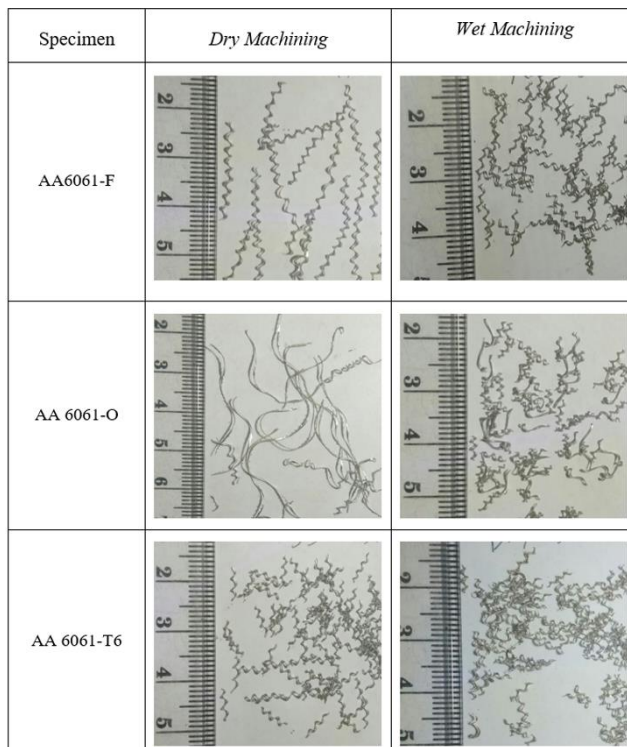


Figure 6. The chips produced for each type of specimen by turning process with and without cooling media

According to Kaya et al, that chips temperature during cutting for AA7075 is in the range 52°C-92°C [4]. So that, the energy consumption due to cutting process is transferred as heat on the tool tip and chips. Wet machining condition influence cutting energy consumption and gives effect to the chip temperature. The cutting energy consumption has decreased by using cooling media and ultimately improve machined surfaces [15]. For discontinued chips is resulted from fluctuating cutting force, and may also cause vibration and chatter so that surface roughness increases. Chip grain size is also a function of cutting conditions and gives an effect on chip temperature which affects the microstructure of the chip during the machining process [15].

4. Conclusion

This study presents the experimental results of the roughness characteristic for AA6061-F, AA6061-O and AA6061-T6 after turning process. Experimental results show that AA6061-O has the lowest value of roughness and AA6061 has the highest value of roughness. Based on results obtained in hardness test, AA6061-O also has the lowest hardness due to softening process during heat treatment. It is indicated that AA6061-O has good machinability compare to AA6061-T6 and AA6061-F. The presence of precipitate on AA6061-T6 may cause distortion and vibration as the reason of high roughness. The effect of lubrication significantly decrease the roughness value of AA-6061-T6, but not for AA6061-F and AA6061-O. For Specimen AA6061-O, the form of chips is continued and relatively straight, however for AA6061-T6 produce discontinued spiral chips type.

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