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Full Length Research Paper

The effect of aging on the machinability of AA7075 aluminium alloy

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In this study, machinability tests were performed on aged AA7075 aluminium (Al) alloy through single point turning method. Before the machinability tests, AA7075 Al alloy samples were aged at 180°C for 1, 6, 12 and 24 h. The machinability tests were carried out at various cutting speeds and the resulting sample surface roughness, cutting forces and thermal changes occurring on the cutting tool were analysed depending on the cutting speed when machining the aged AA7075 alloy samples. An unaged sample was also subjected to machinability tests for comparison purposes. The hardness measurements taken from the aged samples showed that aging treatment increased the hardness between the intervals of 102 to 211 (HV), depending on the aging time. The lowest surface roughness values were measured on the samples aged for 6 h. Different types of chips were observed with thermal camera during machining of the unaged and aged samples. Temperatures of the chips were found to vary between 52 to 92°C.

Key words: AA7075, machinability, aging, heat treatment, hardness, surface roughness.

INTRODUCTION

Due to their high density/strength properties, aluminium (Al) alloys have considerably broad application areas in the aerospace industry (Zhao and Jiang, 2008). In the studies that have been performed in recent years, it is indicated that strength of AA7075 Al alloy could be increased to a considerable extent by means of aging heat treatment (Demir and Gündüz, 2009; Li et al., 2008). Besides, another important property of this alloy is that its mechanical properties can be estimated beforehand. Therefore, it is a reason of preference in the air frames and applications in the aerospace industry (Clark et al., 2005; ASM, 1990). AA7075 alloy contains about 5.6% zinc (Zn) and 2.5% magnesium (Mg). These two alloying elements lead to increase in the strength of this alloy through formation of $MgZn_2$ intermetallic phase within the structure as the result of aging heat treatment (Du et al., 2006). On the other hand, elements such as cupper (Cu), silicon (Si) and iron (Fe) that exist within the structure of the alloy at lower rates also increase its strength through formation of some other intermetallic constitutions. T6 temper heat is regarded to be the optimal temperature behaviour for AA7075 alloys. Ideal aging process for the AA7075 alloy is taken into the solution at 480°C for 1 h. After the implementation of the solution, rapidly cooled in water and finally the aging hardening is done for various periods of the time (Enbury and Deschamps, 2003). Usually, shaping and other various forming processes are requires machinability working in obtaining the product ready for use. Machinability in this sense helps to achieve the final product.

Machinability shall be considered as a system property that includes both the process and the material (Seker et al., 2002). Various factors such as the hardness, ductility, surface tensions, alloying elements within the structure and heat treatment to which the material is exposed have influence on the machinability of a material. As well as the mechanical properties of the material, the machining parameters such as the cutting speed and cutting edge geometry are also effective upon supplying the ideal

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Table 1. Chemical composition of AA7075 alloy.

Element	weight (%)
Al	89.6
Si	0.403
Fe	0.549
Mn	0.014
Cu	1.568
Mg	2.596
Zn	5.480
Cr	0.0125
Zr	0.0305

machining process properties (ASM, 1967; Ozcatalbas and Aydın, 2006). It is especially used for the cutting tool in determining the tool life, surface roughness of the machined component, cutting speed and optimum cutting force. Surface properties constitute a significant measure for the finished component quality. However these properties like friction coefficient, wear and appearance (Vakondios et al., 2012; Groover, 2004). The procurement of the chip removal processes under ideal conditions has an impact on the cutting speeds of the material, geometries and mechanical properties of the cutting tool (Fang and Wu, 2009). In this study the influences of hardness and cutting speeds on surface roughness, cutting force, tool wear and chip types were aimed to be examined.

MATERIALS AND METHODS

In this study, commercial AA7075 Al alloy rods in diameter of 50 mm and length of 150 mm were used as the samples. The chemical composition of the AA7075 Al alloy is given in Table 1.

Except for the one sample, all the other samples were initially homogenised and then left cooling in furnace. After this process the homogenized samples were then solution treated at 480°C for 1 h and subsequently quenched in water at room temperature. The aging heat treatments were performed at 180°C for 1, 6, 12 and 24 h. Hardness measurements were carried out on these aged samples. The machinability tests of the aged and unaged samples were performed through single point turning operation at cutting speed of 42, 66, 104, 137, 220 and 314 m/min. Cemented carbide cutting tools were branded Böhler and a geometry of CCGT 120408-270 were used for the machinability tests. The depth of cut was chosen as 1.2 mm and the feed rate was chosen as 0.2 mm/rev as a constant for each sample. During the machining tests a Flir branded thermal camera capable of measuring between 0 to 200°C was used to determine the temperature within the cutting region. Average surface roughness (Ra) measurements were performed on each machined surface. For each cutting condition, five surface roughness measurements were taken. The Ra values of the machined surfaces were measured using a Mahr/Marsurf PS1 surface roughness measurement device. BSA class and CAS model load cell unit and Esit branded TR3AV model signal amplifier were used in order to measure the cutting forces. The cutting force data were transferred to a personal computer (PC) via a National Instrument USB-6009 data acquisition card and Labwiew software. The measurements were performed during machining of 50 mm length on the samples. Hardness measurement tests were performed for the purpose of determining the hardness values of the aged and unaged samples. Hardness values were measured as Vickers hardness (HV2).

RESULTS

Hardness measurement

Hardness measurements were determined in Department of Machine Education's Laboratory at Kocaeli University. Hardness values were measured as Vickers hardness (HV2) in Buehler Lake Bluff testing machine. Samples were separated into two pieces for hardness measurements and standard test method (ASTM) E-92 standardization on load applied 2 kgf. Measurement ranges between indentations has been taken as quadruple of diagonal indentation length. Each hardness value was determined as the average of five measurements. The hardness values of the unaged and aged samples are given in Figure 1. While the hardness value of the unaged 7075 Al alloy was measured as 102 HV, the hardness value of the sample aged for 1 h was measured as 211 HV. When the aging time was increased, hardness values of 207, 209 and 208 HV were obtained for 6, 12 and 24 h aging times, respectively.

Cutting forces

The effect of cutting speeds and cutting forces on the machinability was examined. The cutting forces obtained during machining process of the samples are given in Figure 2. The cutting force values for the aged samples increased accordingly the increase in the cutting speed. For the unaged samples, the cutting force values show almost 60% increase with the increasing cutting speed up to 150 m/min. However, a decrease in the cutting forces is seen up to the cutting speed of 220 m/min above 150 m/min. Further increase beyond 220 m/min cutting speed again increases the forces. In the aged samples, the cutting force values depending on the cutting speed are very close to each other. A cutting force of 225 N was obtained at the cutting speed between 137 of 220 m/min. This value is approximately 175 m/min as investigated (Figure 2).

During the machining of unaged and aged samples built–up edge (BUE) occurred on the cutting tool (Figure 3). In the experiment the cutting force increases up to the cutting speed of 150 m/min, the increase of the cutting speed beyond 150 m/min the cutting forces.

Some changes also occur in cutting forces. However, these changes are considerably less. But a significant amount of difference was measured for the unaged samples at lower cutting speeds. This condition is

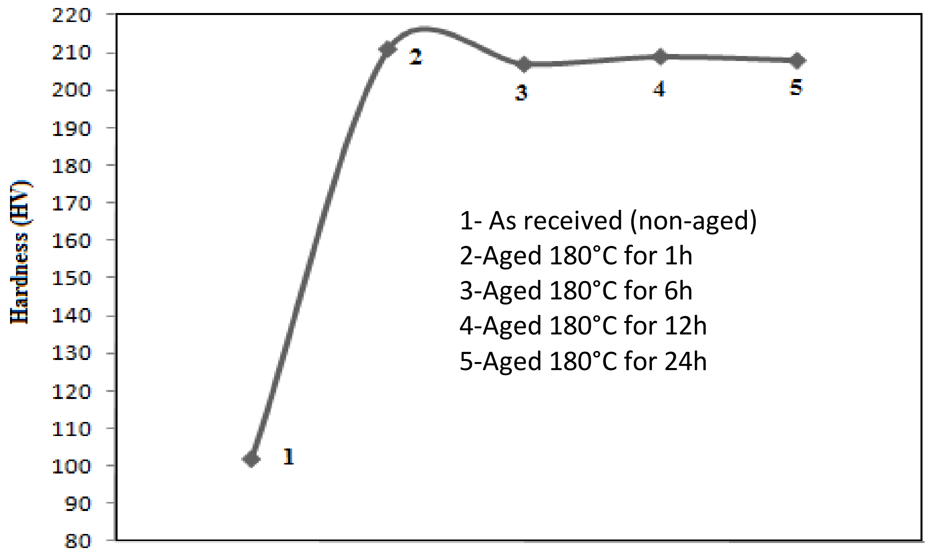

Figure 1. Hardness values of the As-received and aged samples.

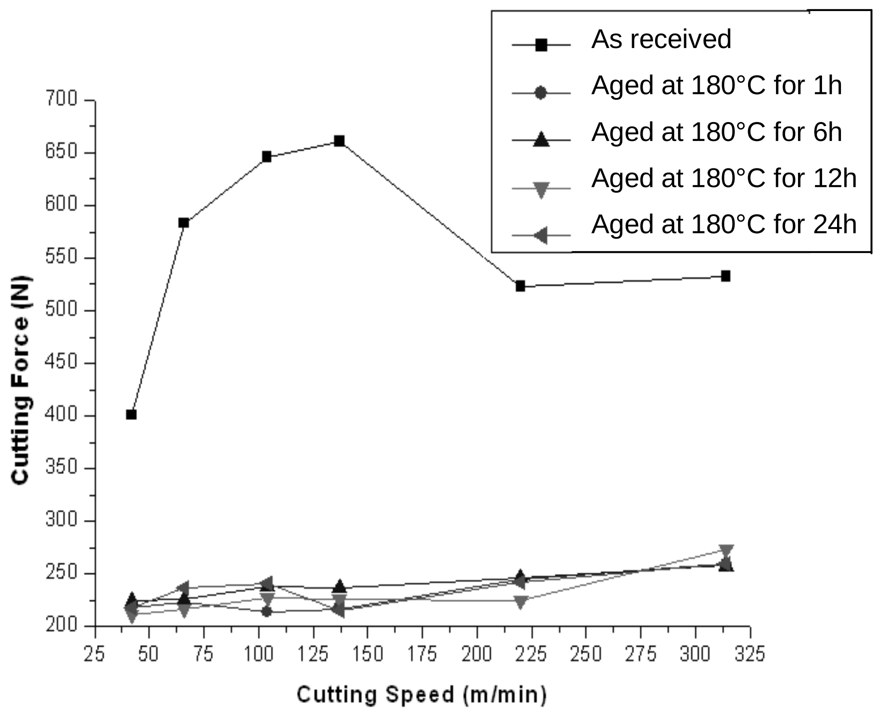

Figure 2. The effect of different conditions and cutting speeds on cutting forces of 7075 Al alloy.

thought to be caused under the influence of the smearing that occur by force of the BUE on the surface of the cutting tool that is used during the machining processing of the unaged sample, as is seen in Figure 2.

Normally, cutting forces increase with material hardness increasing. This is not true for the cases as shown in Figures 1 and 2. In these cases, the hardness of the unaged sample is much lower than aged samples. However, the cutting forces for unaged samples are much greater than aged for all cutting speeds. Since aluminum get ductile while homogenized during the dry cutting operation, aluminum has stick property on the

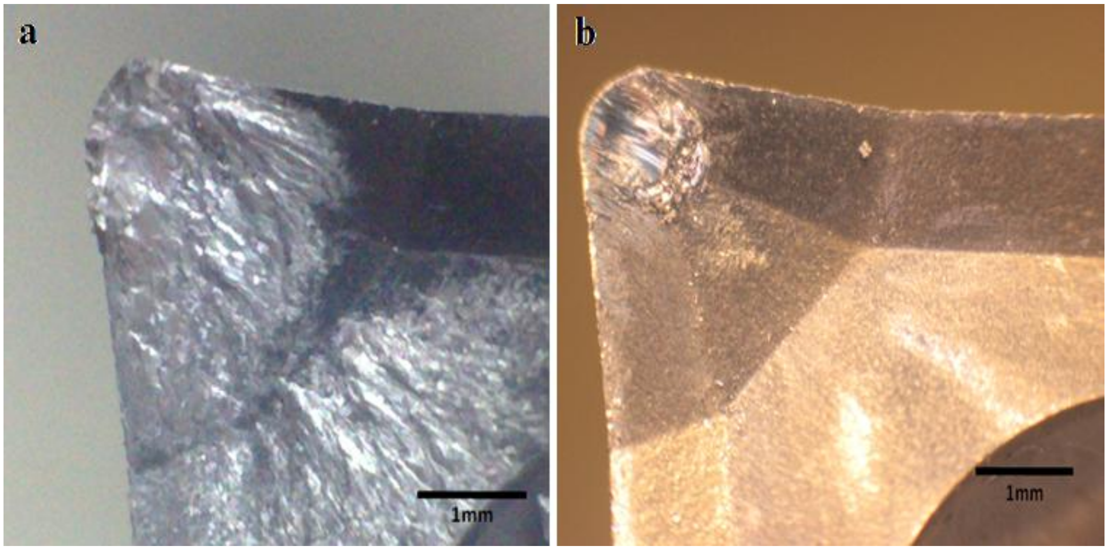

Figure 3. The effect of BUE (built up edge) on cutting tools a- As-Received and b- Aged at 180°C for 1 h.

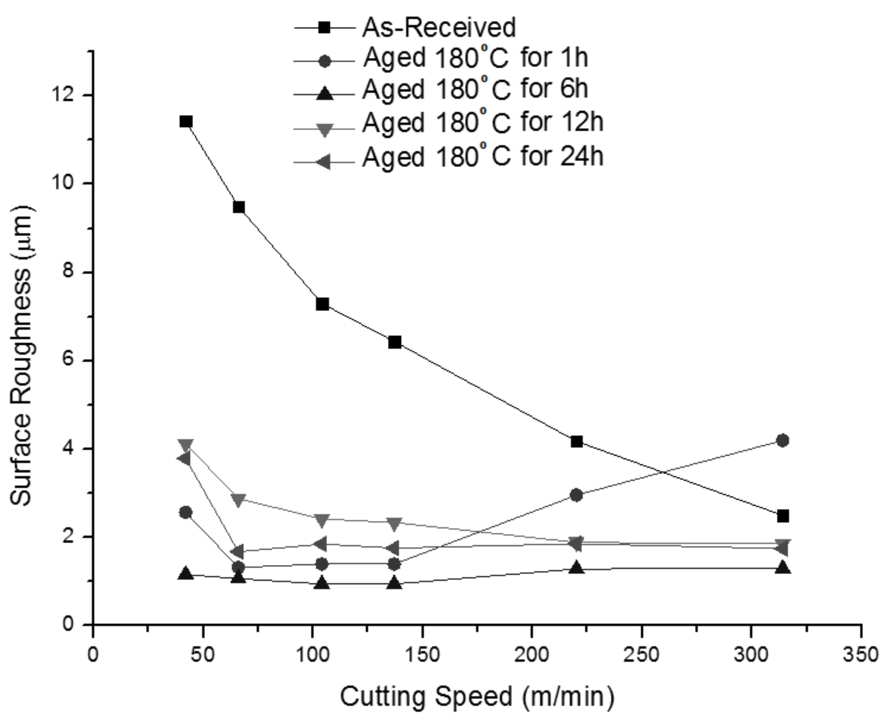

Figure 4. The influence of cutting speeds and aging time on the machined test sample surface roughness values.

cutting tools. Hence cutting forces have been obtained higher than unaged (soft) aluminum. Aged AA7075 harder than unaged AA7075 depending on aging time. Aged aluminum is more brittle and it has less stick properties so BUE could not see on the cutting tool. Therefore the cutting forces obtained less than unaged samples.

Surface roughness

On samples that are aged for different times, the effect of different cutting speeds upon the surface roughness (Ra) is given in Figure 4. Ra values were determined by calculating the mean of five measurements for each cutting speed parameter.

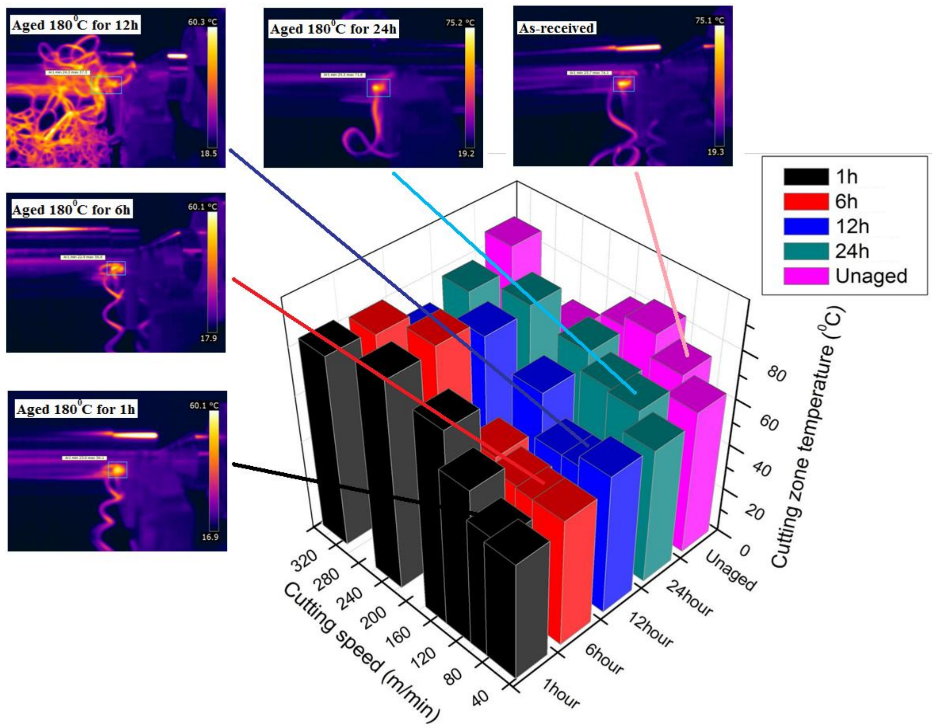

Figure 5. The effects of aging parameters on cutting heat treatment at the cutting speed of 66 m/min.

As is seen from Figure 4, while the surface roughness value decreases at the cutting speed of the interval of 50 to 125 m/min, it shows an increase after 125 m/min. While a decrease in surface roughness is observed at the cutting speeds of 42 to 66 m/min, it is determined that the decrease continues for the samples that were aged for 6 and 12 h and very small increases were observed for the other samples.

Thermal analysis

During the machinability tests, depending on the aging process performed on the materials, the different temperature values at the cutting zone were observed using the thermal camera. As a result of the observations, the temperature differences between the samples that were unaged and aged for different times were examined in accordance with the changes of the diameter and cutting speeds. From the thermal camera images given in Figure 5, the cutting zone temperatures were observed as 74, 56, 56, 57 and 71°C for the unaged and aged samples for 1, 6, 12 and 24 h aging times, respectively.

DISCUSSION

In this study, machinability tests through single point turning method were performed on the AA7075 alloy samples which were subjected to aging heat treatment for different times. The hardness values differences, because of aging processes, temperature variations during the machining, surface roughness values of the machined surfaces and cutting forces of the unaged and aged samples were examined.

According to the hardness results of the 7075 Al alloy, it was found that there was a great difference between the hardness values of the unaged and aged samples. Almost, a two-fold difference was observed. In the literature, the reason for the increase in hardness value of 7xxx series Al-Zn-Mg alloys, after from dissolution heat treatment and quenching process can be explained as applied to precipitation strength together with aging phase (Zhao et al., 2004; Amjad, 2011; Deschamps and Bre´chet, 1998). This increase in the hardness value occurs as the result of the second phase precipitations that occur during the process of aging performed on the AA7075 Al-Zn-Mg alloys. The sequential structure that occurs during the aging heat treatments is as follows; super saturated solid solution → GP zones → η'($MgZn_2$) → η($MgZn_2$) (Somoza and Dupasquier, 2003; Waterloo et al., 2001). The guinier-preston (GP) zones that have low interfacial energies and therefore can be produced at lower temperatures are compatible with the matrix and they are round-shaped. It is indicated in some of the previous studies that the material obtains higher strengths as a result of the heat treatment (Thomas and Nutting, 1959;

Gjonnes and Simensen, 1970; Chen et al., 2003; Chen and Huang, 2003; Huang et al., 2007; 2005). In their studies performed on the 7075 alloy, Campbell et al. (2006) indicate that as well as heat treatments, the cutting speed also contributes to the increase of the hardness through formation of deformation layers, in terms of hardening the samples.

It was found that increasing cutting speed up to 150 m/min was increasing the cutting forces for the unaged sample. But, further increase in the cutting speed resulted in considerable decrease in the cutting forces. The cutting speed did not lead to considerable differences in the cutting speed for the aged samples. This change could be explained through the strain rate effect of the AA7075 Al alloy. The results from obtained experimental studies between cutting speeds of 220 and 314 m/min show that the cutting forces increases a rate of 4% depending on the strain rate effect. These results correspond with Lee et al. (2000) experimental results and show that the strength of AA7075 is increased. The reason of the cutting force increment could be explained with effect of cutting heat and the toughness change. Increasing of the cutting forces could be explained by the relation between BUE and cutting speed. In the previous study, it was indicated that BUE occurred at low friction speed on soft materials (Bao and Stevensen, 1976). Hence cutting forces cause a sudden decrease of 20% after 150 m/min, due to the interaction with the cutting tool. The cutting forces obtained during machining process of the aged samples at various cutting speeds are very close to each other.

Increasing hardness due to the aging heat treatment significantly reduced the surface roughness values of the samples after the machining process. As shown in Figure 1, the hardness values of the unaged sample is lower than the aged samples. Therefore, the aged samples show a ductile behavior during the machining. As Trent and Wright (2000) indicate, the cutting forces depending on the cutting speed are very close to each other on the aged samples. In the study carried out by Boothroyd and Knight (2006), it is indicated that the decrease in the surface roughness values together with the increasing cutting speed could be explained through the decreasing BUE tendency with increasing cutting speed. Altıntas (2000) classified the complex, borer and cord formed chips as non-acceptable and helically formed chips as acceptable. As a result of the study performed on the 7075 Al alloys, it was observed that the chip forms of the aged materials have a better acceptability rate compared to the unaged material; the helical chip forms of the 6 h aged sample are more uniform. The effect of this condition was also observed on the surface roughness values. The Ra value of the 6 h aged sample was for measured as 1 µm and it was seen that this value shows a smooth surface quality 6 times higher than that of the unaged material and 2.5 times lower than those of the other aged materials. However, complex forms are obtained at cutting speeds of 220 and 314 m/min.

Except for the 1 h aged sample, it was found that while the cutting speeds were increasing, the surface roughness values for all of the other samples were decreasing. In other words, high cutting speeds were found to decrease the surface roughness values. The increase of the surface roughness value of the aged samples after a certain cutting speed is caused by the increase of the BUE tendency on the cutting edge. This deposition of the material on the cutting edge increases the surface roughness. This value exponentially decreases only for the unaged sample. Among the aged samples, the surface roughness decreases, even if just a bit, as the cutting speed increases only for the samples that were aged for 12 h. It shows that there is a relation between this result and the hardness values, as well. Ra value decreases together with increase cutting speed in unaged sample. However Ra values in aged samples after from 104 m/min cutting speed are decreases until to 1 µm. While the second-phase particles formed within structure of the samples due to aging increase the hardness, they decrease the surface roughness during the machining process.

The cutting zone temperature of 74°C was recorded by the thermal camera for the unaged sample. On the other hand, the mean temperature of the aged samples was found to be 60°C. The cutting speed of machining process was taken as 66 m/min for all the samples. While temperature differences are high because of BUE for unaged samples it can be explained as a function of cutting speed on the aged samples.

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