IOP Conf. Series: Materials Science and Engineering **377** (2018) 012025 doi:10.1088/1757-899X/377/1/012025

Study on Influence of Heat Treatment on Mechanical Properties and Machinability during CNC Turning of AA6061 Alloy

N Naga Krishna*, M Praveen and Venu Mangam

Department of Mechanical Engineering, Vishnu Institute of Technology, Vishnupur, Bhimavaram-534202, Andhra Pradesh, India.

*Email: nagakrishna.n@vishnu.edu.in

Abstract. The present work identifies the effect of heat treatment processes on the mechanical properties and machinability of 6061 Al alloy. The heat treatment processes involved are solution heat treatment and precipitation hardening. Aging at 175°C for different times affected the surface roughness of workpieces considerably. Test pieces aged at 6 h and 8 h exhibited lower surface roughness values and this is due to their higher hardness values. Chip morphology was also studied using tool maker's microscope and similar observations were made. For samples aged for 6 h and 8 h, along the width of the chip, the edges were discontinuous, indicating poor ductile behaviour of the samples and this is due to their high hardness values.

1. Introduction

Aluminium and its alloys owing to their high strength-to-weight ratio and corrosion resistance, finds applications in many industries such as aerospace, automotive and food packaging. In particular, Aluminium-Magnesium-Silicon (Al-Mg-Si) alloys denoted as 6XXX series alloys have been widely studied because of their benefits such as medium strength, excellent formability, corrosion resistance and economical, compared to other aluminium alloys [1]. Mg and Si are the major solutes and the strength of these alloys can be enhanced by precipitation hardening. Parson *et al.*[2] reported that there has been a considerable industrial interest in these alloys, because, two-thirds of all extruded products are made of aluminium and 90% of those are made from 6XXX series alloys. AA6061 is one of the most widely used alloys in this series.

The properties of various aluminium alloys can be varied by specific heat treatment. One of the common methods of enhancing the strength of AA6061 alloy is the T6 treatment which contains solution heat treatment and subsequent artificial aging and quenching [3]. This consists of heating the alloy to a temperature of 530°C to obtain the supersaturated α-solid solution. Artificial aging is obtained by heating to about 175°C for different time durations and results in precipitation of various phases.

Literature till date reveals that little or no work has been carried on machining of aluminium alloys aged at different times. This study investigated the effect of different aging times at 175°C on the hardness, surface roughness and chip morphology when turning solutionized 6061 Al-alloy workpieces under solution heat treated (SHT) and solution heat treated and aged (SHTA) conditions.

IOP Conf. Series: Materials Science and Engineering **377** (2018) 012025 doi:10.1088/1757-899X/377/1/012025

2. Materials and Methods

Commercial AA6061 alloy in the T6 condition in the form of rods of 20 mm diameter was used in this study. Its chemical composition in weight percentage is 1.0 Mg, 0.6 Si, 0.27 Cu, 0.11 Mn, 0.5 Fe, 0.21 Cr, 0.18 Zn and remaining Al. All the 6061 Al-alloy workpieces were solution heat treated at 530°C for 100 min followed by quenching in chilled water. Chilled water is used to preserve the alloy in supersaturated solid solution state.

Following the solution heat treatment, the workpieces were artificially age hardened at 175°C for a period of 0.5, 1, 2, 4, 6 and 8 h in a furnace and subsequently cooled in air. Machining tests were performed by single point continuous turning of the SHT and SHTA workpieces in cylindrical form on a CNC turning centre with a spindle speed of 1500 rpm, feed rate and depth of cut were fixed at 60 mm/rev and 0.4 mm, respectively. The workpieces were 150 mm long and 20 mm in Ø. Surface roughness measurement was carried out on the machined surfaces using a Mitutoyo (Surftest 211) instrument. Microhardness measurements were carried out using a Vickers hardness tester with 100 g load and a dwell time of 10 s. The hardness values reported are an average of ten readings. Chip morphology was also studied using tool maker's microscope.

3. Results and Discussion

3.1 Hardness Test

Heat treatment is one of the significant controlling factors used to enhance the mechanical properties and machinability of Al-Mg-Si alloys. Among the most important metallurgical parameters, hardness is one parameter that controls the alloy machinability. Jorstad [4] reported that aluminium alloys differ from many other metals, in that, machinability of aluminium generally improves as the hardness increases.

Table 1 Microhardness values of Al-Mg-Si alloy in different aged conditions

Aging Time (h)	Hardness ($HV_{0.1}$)
Solutionized	107 ± 3
0.5	106 ± 3
1	96 ± 3
2	111 ± 6
4	119 ± 10
6	135 ± 10
8	135 ± 9

Table 1 shows the microhardness values of 6061 Al-alloy in different aged conditions. The hardness of 6061 Al-alloy, immediately after solutionizing is 107 HV. It can be observed from Table 1 that, the hardness values decrease up to an aging time of 1 h. This decrease in hardness can be attributed to the decrease in the number of dislocations due to the thermal energy provided during aging. From there on, with an increase in aging time, the hardness values increased and achieved maximum hardness when aged for 8 h. These results are similar to the findings of Demir *et al.*[3], who reported that the increase in hardness is due to diffusion assisted mechanism and also by hinderance of dislocations by impurity atoms. Siddiqui *et al.*[5] showed that as aging time increases, the density of Guiner Preston (GP) zones will also increase. Hence, the degree of irregularity in the lattices will cause an increase in mechanical properties of the Al-alloy. 6061 Al-alloy used in the present investigation contains 1.0 wt. % Mg and 0.27 wt.% Cu. Hence, an increase in hardness after aging at 175°C for different aging times could be due to mutual precipitation of Al_2Cu and Mg_2Si phase particles.

IOP Conf. Series: Materials Science and Engineering **377** (2018) 012025 doi:10.1088/1757-899X/377/1/012025

3.2 Surface Roughness

For parameters such as dimensional accuracy, workpiece appearance, reflectivity and corrosion resistance, the surface quality of a workpiece is very crucial. After turning operation, the mean arithmetic surface roughness R_a (μm) is commonly used for describing the surface quality [6].

Table 2 Surface roughness values of Al-Mg-Si alloy in different aged conditions

Aging Time (h)	Surface Roughness (μm)
Solutionized	0.661 ± 0.064
0.5	0.850 ± 0.132
1	1.289 ± 0.116
2	0.773 ± 0.034
4	0.713 ± 0.075
6	0.807 ± 0.044
8	0.730 ± 0.092

Table 2 shows the surface roughness values of Al-Mg-Si alloy in different aged conditions. Five locations have been randomly chosen for surface roughness testing and an average value was reported in Table 2. Asl *et al.* [6] reported that surface roughness is solely related to the influence of machining conditions. They have reported that materials with a lower hardness give rise to higher surface roughness values than those offered by workpieces with higher hardness. It can be observed from Table 2 that, 6061 Al-alloy samples aged for 30 min and 1 h showed higher surface roughness values. With an increase in aging time, the samples exhibited higher hardness values with a simultaneous reduction in surface roughness values.

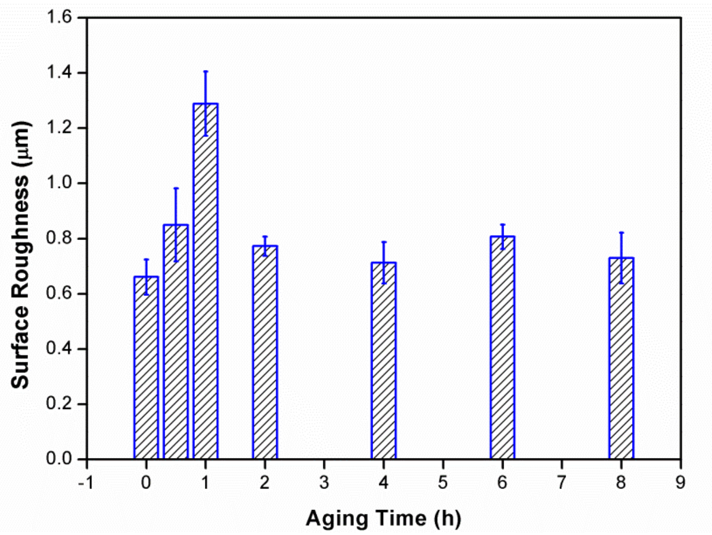

Fig. 1 Column chart representing surface roughness values of aged specimens

Figure 1 shows column chart representing the surface roughness values of aged specimens. The lower surface roughness of workpieces with higher hardness is due to their easier chip disposal during machining. However, with workpieces that possess lower hardness, the chips formed during machining were found to concentrate around the machined workpiece and the cutting tool, causing a poor surface finish by scratching the newly machined workpiece surface. Similar results were reported by Demir *et al.*[3], in which 6061 Al-alloy aged at 180°C for 11 h showed lower surface roughness values and this was due to its superior hardness values as a result of aging and easy disposal of chip during machining. It was also reported that, while machining workpieces which had lower hardness

IOP Conf. Series: Materials Science and Engineering **377** (2018) 012025 doi:10.1088/1757-899X/377/1/012025

values, the chips formed during machining entangled around the machined workpiece and cutting tool [3]. These entangled chips scratches the newly machined workpiece surface and results in poor surface finish. Thus, one of the main problems encountered during machining of ductile materials is the chip disposal.

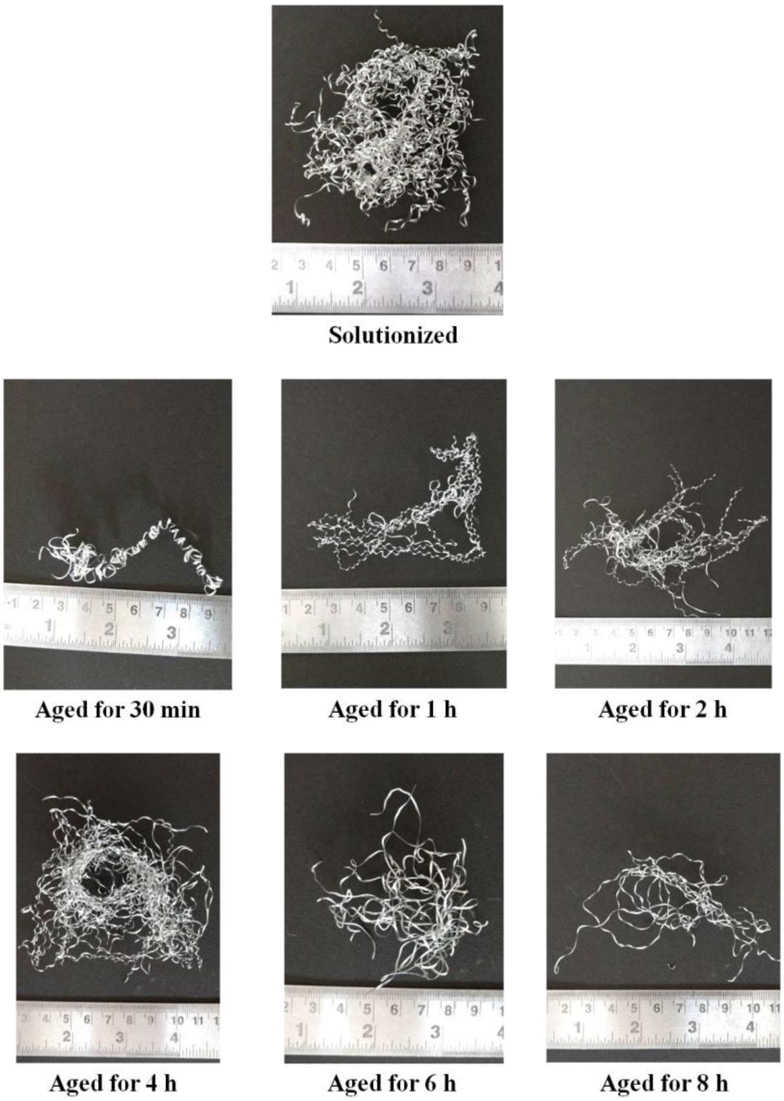

Fig. 2 Chip images of 6061 Al-alloy at different aging times

3.3 Chip Morphology

Analysis of chip images revealed that, in solutionized condition, continuous chips were produced and chip entanglement occurred. However, the sample aged for 30 min exhibited chip curling, as observed from figure 2. With an increase in aging time to 1 h, chip curling occurred and the width of the chip generated was more than the sample aged for 30 min. The sample aged for 4 h exhibited chip entanglement similar to that of solutionized sample and the chip entanglement of the sample aged for 4 h was more when compared to the sample aged for 2 h. Figure 2 also revealed that, with an increase in aging time (6 h and 8 h), the tendency of chip entanglement reduced and the length of the chip generated was also minimum. This was due to the high hardness of the samples aged at 6 h and 8 h as evidenced from Table 1.

IOP Conf. Series: Materials Science and Engineering **377** (2018) 012025 doi:10.1088/1757-899X/377/1/012025

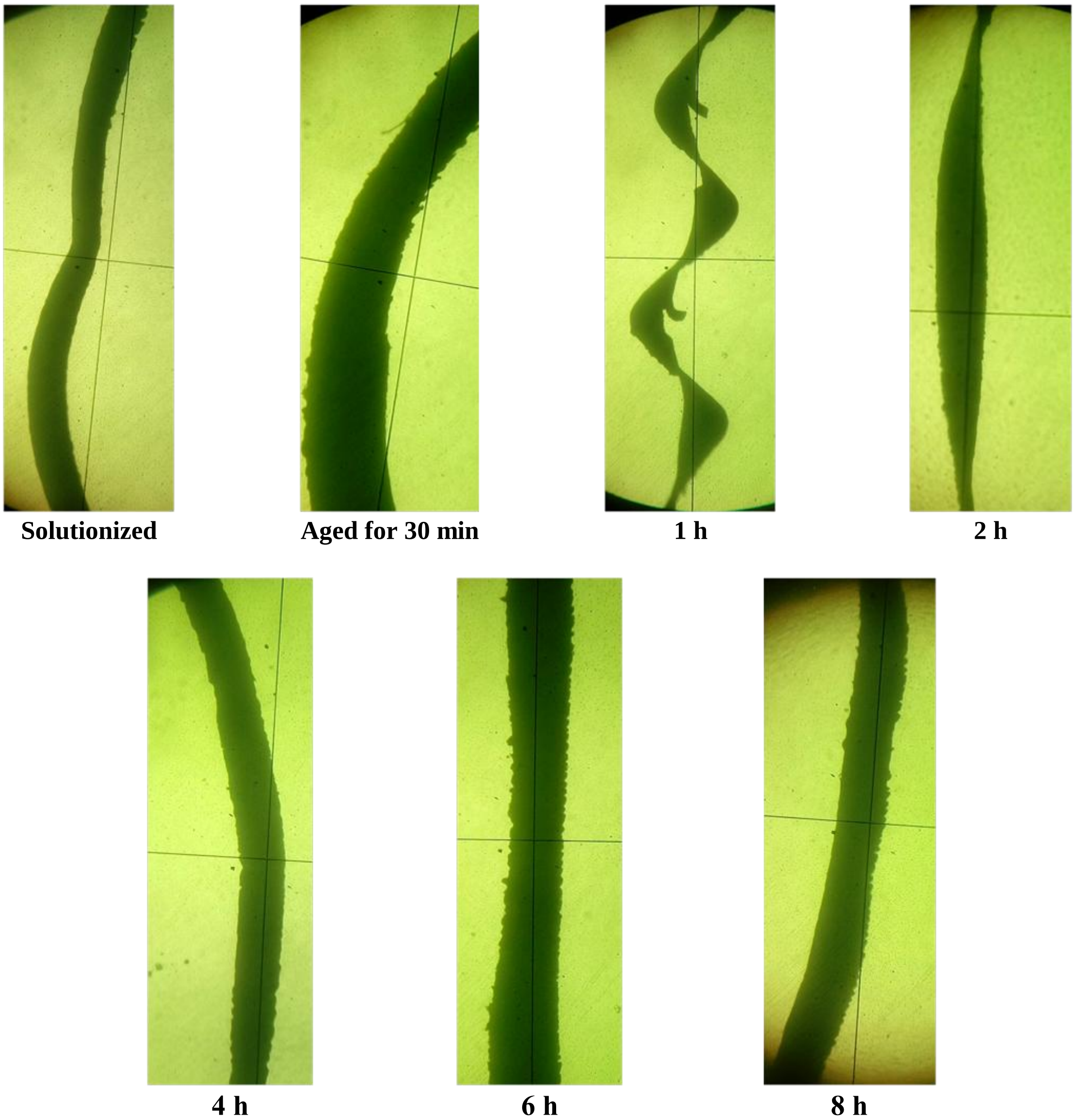

Fig. 3 Chip morphology of AA 6061 alloy in different conditions as observed in Tool Maker's Microscope (30 ×)

The above discussion is in good agreement with the profile of the chips observed through tool maker's microscope (at 30 ×). From figure 3, chip curling is clearly visible for the sample aged for 1 h. Also, for the samples aged for 6 h and 8 h, along the width of the chip, the edges were discontinuous, indicating poor ductile behaviour of the samples and this is due to their higher hardness values.

4. Conclusions

In the present investigation, 6061 Al-alloy was solutionized and then aged at 175°C for different time periods. The effect of aging time on hardness and machinability during CNC turning was determined.

Following conclusions were made –

1. With an increase in aging time, the samples exhibited higher hardness and this is due to the result of interference of the precipitates formed during age hardening with the motion of dislocations.

2. Aging for different times at 175°C affected surface roughness of workpieces considerably. Test pieces aged at 6 h and 8 h showed lower surface roughness values and this is due to their higher hardness values.

3. Chip morphology was also studied through tool maker's microscope and similar observations were made. For the samples aged for 6 h and 8 h, along the width of the chip, the edges were discontinuous, exhibiting brittle behaviour of the samples and this is attributed to their higher hardness values.

Acknowledgements
The authors thank Vignan Foundation for Science, Technology and Research (VFSTR), Guntur, for extending the microhardness testing facility. The first author also thank Leela Krishna Teja D, Vinod Kumar Varma K, Sai Ram Ch and Srinivasa Varma KLP, for their contribution in preparation and testing of specimens.

References

[1] Altenpohl DG. *Aluminum, technology, applications, and environment, a profile of a modern metal*. 6th ed. WILEY, 1998.
[2] Parson NC and Yiu HL. 1989 In: Campbell PG, editor. *Light metals.* Warrendale (PA,USA): TMS.
[3] Demir H and Gunduz S 2009 *The effects of aging on machinability of 6061 aluminium alloy.* Materials and Design, 30, 1480-1483.
[4] Jorstad J. 1980 *Influence of aluminum casting alloy metallurgical factors on machinability.* In: Society of Automotive Engineers Technical Paper 800486, doi:10.4271/800486.
[5] Siddiqui R A, Abdullah H Aand Al-Belushi K R 2000 *Influence of aging parameters on the mechanical properties of 6063 Al alloy.* Journal of Materials Processing Technology, 102, 234-240.
[6] Asl Y B, Meratian M, Emamikhah A, Homami R M and Abbasi A 2015 *Mechanical properties and machinability of 6061 aluminium alloy produced by equal-channel angular pressing.* Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 229, 1302-1313.