Mechanical and Tribological Behaviour of Artificially Aged (T6) Al-Zn-Mg-Cu Alloy

Akhilesh Soni, R K Mandloi

***Abstract:** The present work deals with the effect of aging on the mechanical and tribological properties Al-Zn-Mg-Cu (AA7068) alloy. The mechanical properties such as tensile strength, compressive strength, hardness and sliding wear of the alloy in as cast and heat treated condition were examined in order to achieve the maximum properties. Microstructural examination of the alloy in as cast and heat treated condition was carried out to observe the effect of aging. SEM study was also done to observe the worn surfaces and the mechanism of material removal. It is observed that there is a substantial improvement in the mechanical and tribological properties of the alloy due to heat treatment as compared to the as cast alloy. The microstructural study of the cast alloy shows primary dendrites of aluminium and intermetallic phases around the inter-dendrites regions. Due to the heat treatment, the identity of the dendritic structure is lost, because of uniform distribution of precipitates, wherein intermetallic phases were seen dispersed within the grains and the grain boundaries. Results show that the tensile strength of the heat treated alloy at 210^{o}C aging temperature has increased by 155% as compared to as cast alloy. The compressive strength and hardness of the alloy at 210^{o}C aging temperature shows improvement of 41% and 54% respectively as compared to as cast alloy. Wear loss of the heat treated alloy at 210^{o}C aging temperature has decreased at an applied load of 20, 40, 60 and 80 N in both 1.57m/s and 3.00m/s sliding speed.*

***Keywords:** AA7068 alloy; aging ; tensile strength; compressive strength; harness; sliding wear.*

I. INTRODUCTION

The intended requirement of aluminium is growing, as it executes a unique set of characteristic, which leads the most adaptable material for engineering application [1]-[4]. In general AA 7068 alloy is a precipitation-hardened alloy in which Zn, Mg and Copper are the major alloying elements. Properties of the Aluminium alloys can be altered by adding alloying elements and heat treatment processes. The heat treatment process is also term as artificial aging, which allows developing hard precipitates or solid impurities inside the grain boundary, which restricts the dislocation motion under the mechanical loading. The size of precipitates is a function of aging duration and temperature, which results in higher mechanical properties when subjected to mechanical loading [5]. Zinc is the primary alloying component in 7××× series aluminium alloys. These alloys are heat-treatable alloys and the Al– Zn– Mg based alloys, with some amount of Cu, including the most widely recognized aluminium alloys utilized in aviation, military, marine, car, and development businesses. This alloy offers the best combination of higher mechanical and tribological quality compared to some other to aluminium alloys [6]. The heat treatment process ensures the development of precipitates in the alloy which alters the alloy characteristics. Precipitation sequence is as followed [10],[11].

$$\text{Supersaturated solid solution} \rightarrow \text{GP zones} \rightarrow \text{metastable phase } (\eta') \rightarrow \text{equilibrium phase } (\eta).$$

Aluminium Alloy 7068 executes the highest strength in longitudinal and transverse direction among the zinc alloys. Also, it is the strongest commercially produced aluminium [14]. The objective of this work is to evaluate the precipitation kinetics to improve the mechanical and tribological properties under different aging temperature i.e. pre aging, under aging, optimum aging and over aging. Then the testing results of as-cast material and heat-treated material are compared.

II. EXPERIMENTAL PROCEDURE

A. Materials and methods

The present work Aluminium alloy 7068 is selected as base material, chemical composition and physical property of the procured aluminium alloy are shown in Table 1 and Table 2 respectively. Aluminium alloy 7068 (AA7068) is procured in the form of ingots from parshwamani metals, Mumbai, India. The chemical composition test was conducted at Varsh Bullion & Element Analab, M. H. dharamkanta, Mumbai, India. Liquid metallurgical route was opted to fabricated circular and rectangular bars for the tensile and wear test specimens. The small rectangular pieces are cut down from AA7068 ingot to accommodate inside the graphite crucible of 3 litres capacity and placed inside a programmable electric furnace. The furnaces temperature was set to 740^{o}C. When AA7068 meltdown, 15-20 g Coveral 11 is mixed in the melt to remove the impurities, which is taken out from the melt. Then mechanical stirring is done with 45^{o} blade angle stirrer at 500 rpm for 10-15 minute along with dry nitrogen atmosphere. The setup used for stir casting is situated in Nanocomposite Laboratory of Mechanical Department in MANIT Bhopal, the fabrication setup is shown in Fig. 1. The melt was poured into pre-heated graphite coated dies at 450^{o}C and left to solidify gradually at room temperature i.e. 30^{o}C. Tensile and compressive specimens are made according to the ASTM E8 and ASTM E9 standard respectively (shown in Fig. 2) and wear specimens are made according to ASTM G99.

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Table 1: Chemical Composition of AA7068

Elements	% Ratio
Zn	8.30
Mg	3.03
Cu	2.42
Fe	0.192
Mn	0.034
Ti	0.05
Si	0.142
Cr	0.05
Ni	0.0075
Al	85.51

Table 2: Physical properties of AA7068 [Basavaraj S]

Properties	Values
Density	2.85 g/cc^3
Melting Point	476-635^{o}C
Modulus of Elasticity	73.1 GPa
Poisson's Ratio	0.23

B. Heat treatment (T6)

The specimens of alloy were heat treated in a programmable furnace to compare the properties in as cast and aged condition. There were three stages involved in the heat treatment.

i) Solutionising: The specimens were heated to a temperature of 495 ± 5 ^{o}C for 8 hours until the alloy solute elements are completely dissolved in the Al solid solution.

ii) Quenching: The solution treated specimens were rapidly cooled into oil (at room temperature).

iii) Artificial aging: To improve the strength and hardness of the material the specimens were aged at 180^{o}C /195^{o}C /210^{o}C /225^{o}C for 6 hours each and then allowed to cool in the still air.

C. Testing

Wear test

Wear test specimens were machined from the casting according to ASTM G-99 standard. The test was carried out at room temperature on a computerized (DUCOM made) pin-on-disc Material Testing Laboratory, MSME Department, MANIT, Bhopal, M.P, India. EN31 Steel disc 160 mm diameter and 8 mm thick is used as a counter surface having the hardness of HRC 62, the track diameter for specimen was kept as 100 mm. The surface roughness of steel disc was 1µm. The specimens were made flat before the test to have a uniform horizontal surface. The counter surface was cleaned with acetone solution after performing each test. The tests were conducted at 300 (1.57 m/s), 575 (3.00 m/s) and 800 (4.18 m/s) rpm with 20, 40, 60 and 80 N applied load for a sliding distance of 5000 m. To evaluate the wear loss, specimens are weighed before and after each test with the help of electronic weighing balance.

Tensile test

Tensile test specimens were machined from the casting according to ASTM E-8 standard. The test was carried out at room temperature on a computerized universal testing machine (Mech.CS.UTE, 40T, Mechatronic Control System, India) in Material Testing Laboratory, MSME Department, MANIT, Bhopal, M.P, India. Ultimate tensile strength (UTS) values were calculated and reported in the Table 3.

Compressive test

Ultimate compressive strength was determined as per ASTM E-9 standard, the test was performed at room temperature at a strain rate of 3 mm/minute on universal testing machine in Material Testing Laboratory, MSME Department, MANIT, Bhopal, M.P, India.

Hardness test

Vickers hardness test was performed as per ASTM E-92 standard in MANIT Bhopal on optical Vickers testing machine (model: VM 50, FIE). Three tests were conducted at different locations on the same surface.

II. RESULT AND DISCUSSION

A. Tribological behaviour

The wear behaviour of extended aged AA7068 is examined experimentally using a pin-on-disc apparatus. The comparative data of as-cast and heat-treated specimens are shown in results. In this section, the effect of load and sliding speed on the wear loss are discussed followed by worn surface analysis.

Significance of load on the wear loss

Figure 3 (a-c) graphs are representing the behaviour of wear loss of heat-treated and as-castAA7068. The wear loss behaviour is shown in the graph under the variation of applied load i.e. 20, 40, 60 and 80 N. The effect of sliding speed can also be observed through the graph. The applied load plays a significant role in wear loss, as the load increases the wear loss increases. The test was conducted for a constant sliding distance i.e. 5000 m, while the other parameters are kept varying such as applied load and sliding speed. The wear loss of the heat-treated specimen is less than the as-cast specimen, as the artificial aging transforms the GP zone in the precipitates [22] that is harder as compared to the base material, due to which wear loss deficit. The specimen, which is heat-treated at 210 ^{o}C for 6 hours, shows the least wear loss compared to other heat-treated specimens. This trend is observed in all the load condition as well as heat-treated condition as compared to as-cast. It is also observed that the increment in sliding speed results decrements in wear loss.

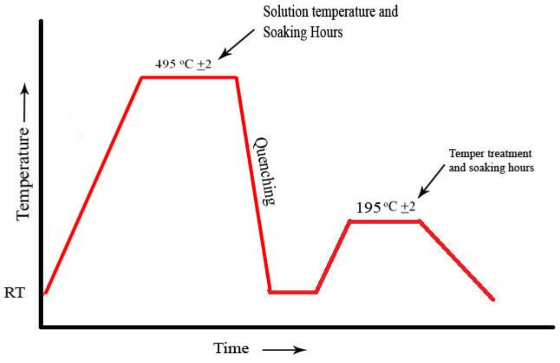

Fig. 3: Heat treatment schemes

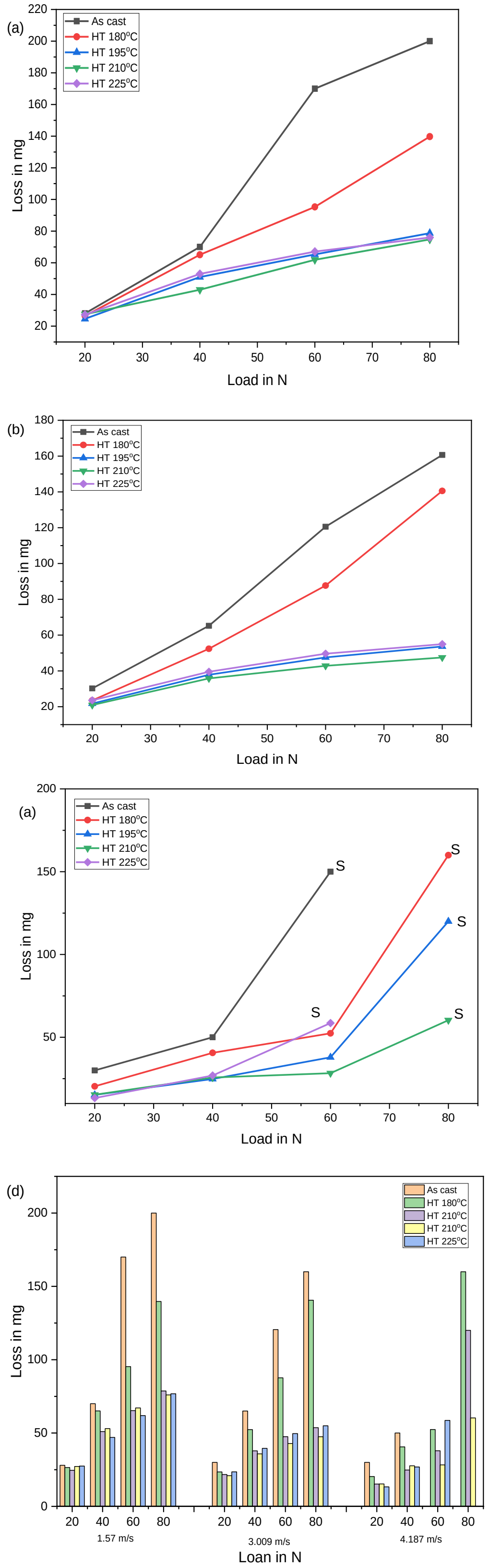

Fig. 4: Wear loss at a different load of as-cast and heat-treated AA7068 at different sliding speed (a) at 1.57m/s, (b) at 3.00 m/s, (c) at 4.18 m/s and (d) shows comparative wear loss at different load and sliding speed.

The graph a, b and c are observed while the sliding speed between the pin surface and rotating disc are kept at 1.57m/s, 3.00 m/s and 4.18m/s respectively. It is observed in Figure 4 (c), seizure of the specimen were prompt to initiated, which is represented by letter "S" in the figure.

Worn surface analysis

SEM maps are shown in Fig. 5 (a-d). Worn surface analysis is generally based on the type of wear, which is broadly categories in three regimes i.e. low wear, mild wear and severe wear [23]. The wear regimes are the function of load.

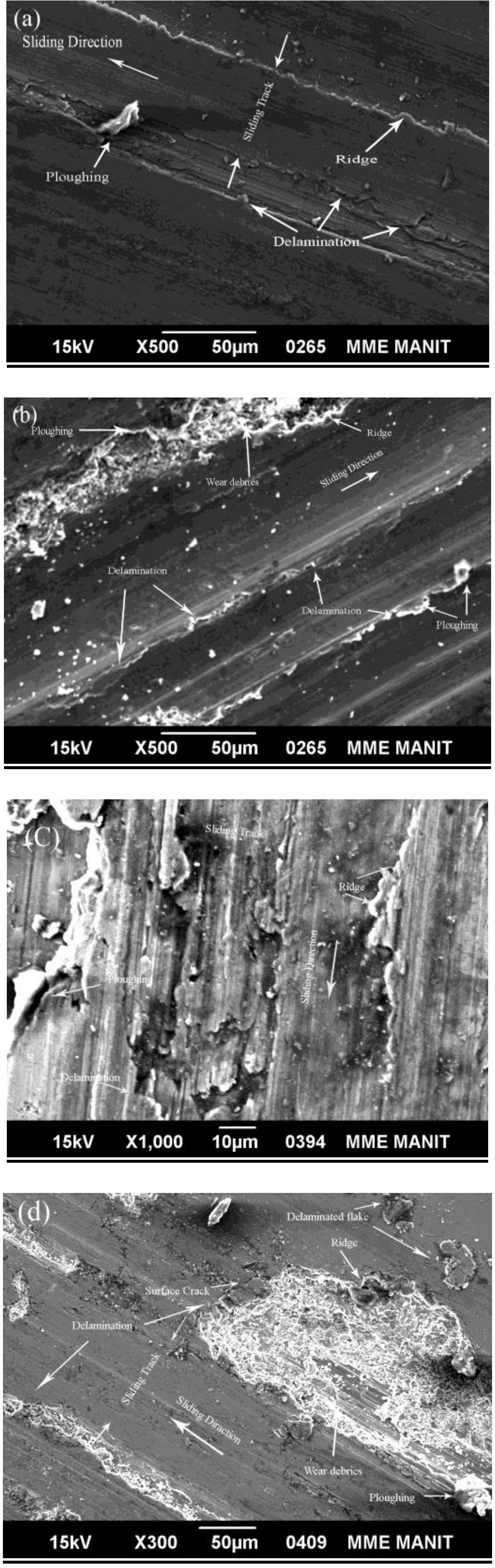

Figure 5. Wear transition map, SEM analysis of worn surfaces. (a) & (b) at 20 N load, As-cast and heat-treated, (c) & (d) at 80 N load, As-cast and heat-treated.

The mild wear occurs at low load, which is characterized by iron-rich compacted debris layer [24]. Whereas delamination type of wear mechanism dominates in severe wear. Which is caused by sub-surface deformation and cracking. This delamination wear theory resulting in high wear loss and lead to bigger particles of abrasive dust. The ultra-severe wear occurs when the high temperature reduces the shear strength of the subsurface layer, which promotes material transfer into the hardened counter face from wearing alloy.

B. Tensile Properties

Tensile test results are showing in Table 3; the result shows that an increment in tensile strength is observed, while the specimens are subjected to artificial aging. Shown in Fig 6. As the grain size is the function of artificial aging, which enhances the strength of material [18]. The grain refinement and solutes are furnishing of Al-Mg and Al-Zn. In the literature, it has been observed that a large number of grain boundaries are available in fine-grain material, which leads to higher strength as compared to non-tempered material, which has coarse grain and deficit grain boundaries [19],[20]. Since a large number of grain boundaries of a tempered specimen than as-cast, are more rigid to dislocation to motion, while subjected to mechanical deformation. As it results in high mechanical strength [21]. With the microstructure analysis, it can be explained that the enhancement in ultimate tensile strength and yield strength are the cause of grain size. The microstructure is shown Fig. 7 and 8 to represent the microstructure of grain boundaries of as-cast and heat-treated at 210 ^{o}C. During the dislocation or plastic deformation, the movement passes through the grain boundaries. As this polycrystalline grain has different orientation at the boundaries, due to which dislocation has to change its orientation at each boundary, which results in higher ultimate and yield strength [8]. Age hardening techniques increases the number of solid impurities (precipitates) inside the grain boundary, which resists the dislocation, either by cutting or bowing. It can be stats that artificial aging duration influence the size and the number of precipitates inside the grain boundaries as show in microstructure.

Table 3: Ultimate tensile strength of as-cast and heat-treated samples.

No of Test Material	Test 1	Test 2	Test 3	Average
AA 7068 As cast	122	111.5	126.5	120
AA 7068 HT180	172.56	173	197.5	182
AA 7068 HT195	212	195.5	222	210
AA 7068 HT210	300	298	320	306
AA 7068 HT225	285.5	256	290	278

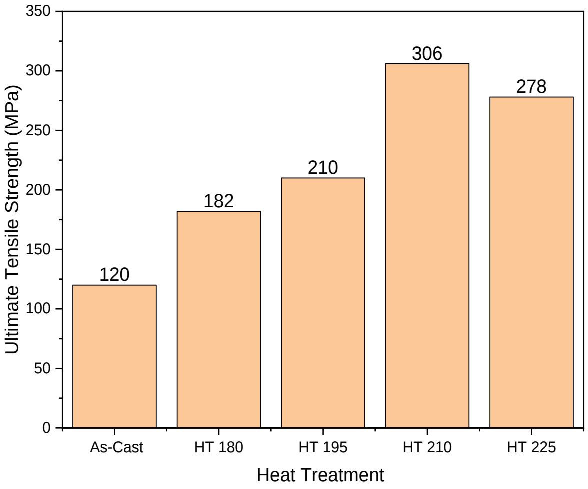

Fig. 6: Ultimate tensile strength of AA7068 heat-treated and as-cast.

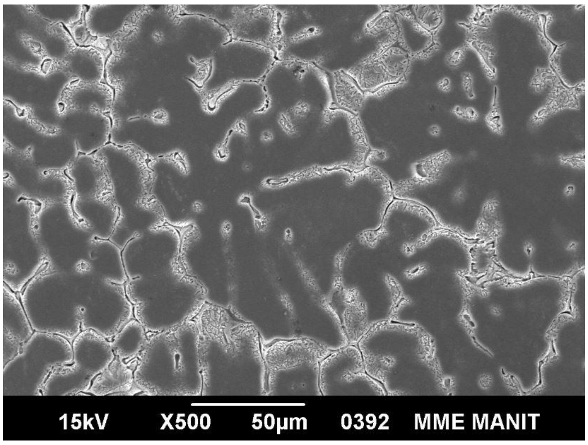

Figure 7. The micrograph of as-cast material showing dendrite structure of Aluminium.

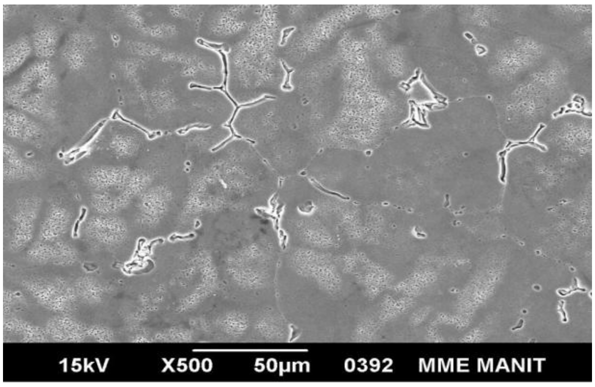

Figure 8. The micrograph of artificially aged shows the intermetallic phases at 210 ^{o}C for 6 hours.

C. Compressive strength

Ultimate compressive strength results are represented with the help of bar graph, shown in Fig 9. The result shows that an increment in ultimate compressive strength is observed, while the specimens are subjected to artificial aged at 210 ^{o}C for 6 hours. The increment in the strength is a cause of modified grain size of the material, which is the function of artificial aging, which enhances the strength of material [18].

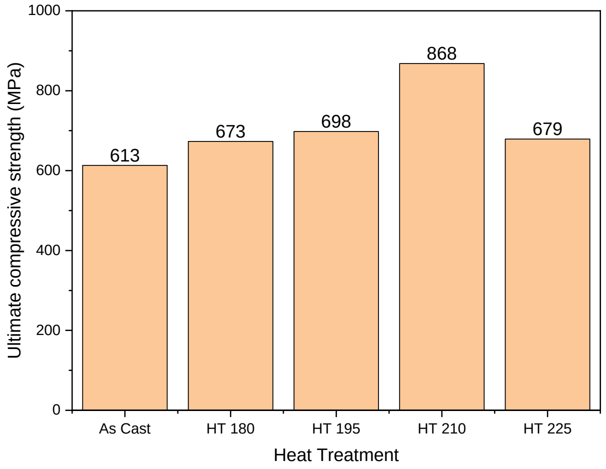

Fig. 9: Ultimate compressive strength of AA7068 heat-treated and as-cast.

D. Hardness

The Vickers hardness test results of AA7068 as-cast and heat-treated were represented with the help of bar graph and showing the relationship between the effect of artificial aging and hardness value in Fig. 10. The increment is observed in VHN value, when material is subjected to an artificially aged. The highest value of hardness is observed, when the AA7068 is artificially aged at 210 °C for 6 hours. The higher value of hardness is due to the precipitation formation and refining of grain boundaries due to artificially aging.

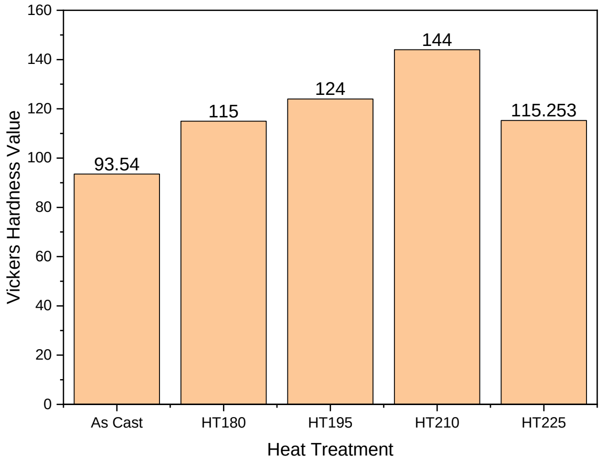

Fig. 10: Vickers harness of AA7068 heat-treated and as-cast.

III. CONCLUSION

The mechanical and tribological characteristic of heat-treated and as-cast AA7068 at different parameters are examined. With the experimental data following results can be summarized.

- Heat treatment of material shows an intense effect on mechanical and tribological properties of AA7068.
- The specimen heat-treated to 210 °C for 6-hour duration executes highest ultimate (Tensile and compressive) strength, high hardness value along with lowest wear loss in all load conditions.
- The ultimate tensile strength of heat treated specimen is increased by 155% as compared to as-cast alloy.
- The ultimate compressive strength of heat treated specimen is increased by 41% as compared to as-cast alloy.
- The hardness value of heat treated alloy is 54 % higher as compared to as-cast alloy.
- Increase in sliding speed reduces the wear loss in as-cast as well as in artificially aged condition.
- The lowest wear rate is achieved, when the specimen (artificially aged at 210 °C) is subjected to 20 N load and 1.57 m/s sliding speed.
- Wear loss of the heat treated alloy at 210°C aging temperature has decreased by 1.78%, 38.5%, 63.5% and 62.6% at an applied load of 20, 40, 60 and 80 N respectively at 1.57m/s sliding speed.
- Wear loss of the heat treated alloy at 210°C aging temperature has decreased by 30%, 44.89%, 64% and 70.3% at an applied load of 20, 40, 60 and 80 N respectively at 3.00m/s sliding speed.

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