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TRIBOLOGICAL AND TENSILE STRENGTH INVESTIGATION OF AA2014 ALLOY SUBJECTED TO AGE HARDENING

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ABSTRACT
AA2014 alloy, renowned for its superior mechanical properties, is being increasingly utilized in the aerospace and defense industries. This study explores the tribological behavior and tensile strength characteristics of AA2014 alloy after undergoing age-hardening treatment. Tensile tests were performed to evaluate the material's strength under axial loading, while tribological tests assessed its wear resistance against abrasive forces. The age-hardening process involved the precipitation of strengthening phases within the alloy matrix, influencing both its mechanical and tribological properties when subjected to T4 (artificial aging) condition and T6 (artificial aging) condition. AA2014 alloy was given a solution treatment at 500°C for 40 min and quenched in normal water. Then, one sample was aged naturally at room temperature 25°C for 48 hours and the remaining were artificially aged at three different temperatures such as 120°C, 170°C and 220°C for four different periods of time such as 4, 8, 12 and 16 hours. The ultimate tensile strength, yield strength and hardness of aged samples were measured by UTM machine and digital Rockwell Hardness testing machine respectively. Wear tests were carried out on the pin-on disc wear test apparatus under dry sliding condition. Results revealed enhancements in tensile strength and wear resistance following age hardening treatment, attributed the minimum wear rate and maximum friction coefficient.

Key words:
AA 2014 alloy, Age hardening, solution heat treatment, tensile strength, wear resistance

1. Introduction

AA2014 is a high-strength aluminium-copper alloy recognized for its outstanding mechanical properties and favourable strength-to-weight ratio. Predominantly utilized in aerospace and defence sectors, AA2014 is ideal for applications demanding robust performance and durability. This alloy effectively responds to heat treatment processes like age hardening, which significantly boosts its strength and hardness.

Aluminium alloys are increasingly replacing steel in applications requiring lower weight and reduced maintenance costs. Although it has moderate corrosion resistance, AA2014's excellent machinability and high tensile strength make it a preferred choice for critical structural components. The systematic study by Goncalves and Gavgalli [1,2] on the effect of homogenization treatment on the microstructure and hot workability of AA2014, under different heat treatment and cooling conditions (air, water, furnace), revealed that the hot workability of alloy AA2014 increases with increasing homogenization temperature and decreases with increasing cooling rate. However, at high temperatures, e.g., 510°C, the ductility tends to decrease due to hot brittleness caused by the secondary phase. The homogenization time has no significant effect on ductility, and ductility is generally high whenever the peak stress is low.

The early characterizations displayed that $CuAl_2$, AlMnCu, and AlMgCu were the primary particles observed in the α-Al matrix. A hardness of nearly 148 HB was obtained by solutionizing at 513°C and aging at 165°C for 12 hours, which was the optimum treatment for achieving peak hardness [3]. The microstructures evidently exposed the presence of $CuAl_2$ precipitate particles in the aluminium matrix. The measured hardness value of as received AA2014 alloy is 121 BHN. The solution heat-treated

AA2014 aluminium alloy has a hardness value of 94 BHN which is decreased compared to the as-received sample due to the single-phase solid solution. As aging time increases, the hardness values keep increasing up to 8 hrs of aging and thereafter these values decrease for aging of 10 hrs and 12 hrs. The highest hardness value 129 BHN is obtained after the aging of 8 hours [4]. Tensile tests and hardness measurements revealed that the mechanical properties of Aluminium Alloy 2024 were similar when the alloy was treated at different temperatures of 495°C, 505°C, and 515°C. Aging at 190°C and 208°C for short periods caused a slight decrease in the hardness of samples that were solid solution treated at 495°C and 505°C. Aging increased the strength of Aluminium Alloy 2024 but decreased its ductility [5]. The hardness of the second-phase precipitated samples was found to be higher than that of the as-cast samples, and it increased with higher solution temperatures and longer aging periods. The study also revealed that the wear rate and friction coefficient decreased with increasing solution temperatures and aging periods [6].

Previous studies on AA2014 Al have primarily focused on experimental approaches, which may align more closely with industrial applications. However, this research's objective was to explicitly examine the impact of age hardening on wear characteristics.

2. Material and Methods

A rod of AA 2014 alloy of 1 m length and 16 mm diameter is bought. Then it is cleaned thoroughly and cut down into 13 samples each 75 mm length and 16 mm diameter. The chemical composition of AA2014 alloy is shown in Table 1.

Table 1. Chemical composition of AA2014

Alloy series	Al	Cu	Si	Mg	Fe	Mn	Others
AA 2014	Balance	3.8-5.0	0.5-1.2	0.2-0.8	0.7	0.3-1.2	0.5

The samples were subjected to homogeneous treatment at 500 °C for 40 min in a muffle furnace and then quenched in normal water. One sample was aged at the T4 condition (natural aging) for 48 hours and the remaining samples were aged at the T6 condition (artificially aged) in a muffle furnace at three different temperatures such as 120°C, 170°C, and 220°C in four different time periods such as 04hr, 08hr, 12hr, and 16hr. The overall heat treatment process is shown on a time-temperature diagram, here temperature is taken on the X-axis and time is taken on the Y-axis as shown in Fig 1.

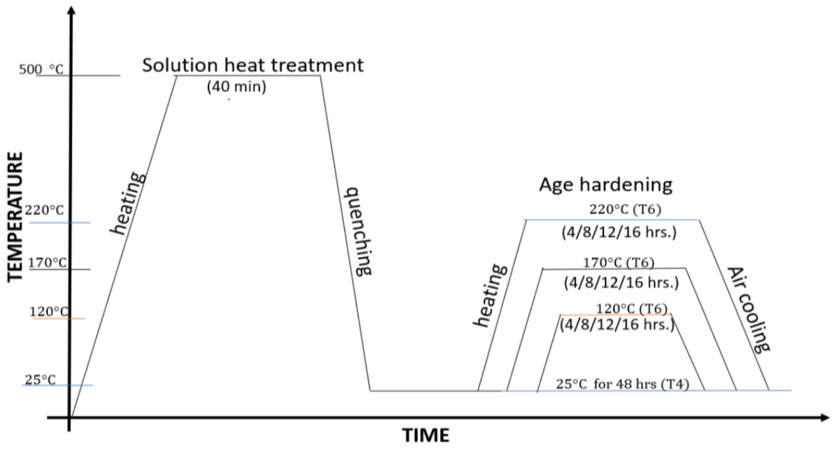

Figure 1: Time-temperature diagram of the heat treatment process

The mechanical properties like tensile strength and hardness are obtained from the UTM and hardness testing machines respectively and tribological characteristics are obtained from a pin-on-disc tribometer. The Tensile test was conducted on a Universal Testing Machine at room temperature as per ASTM E8 standard. As per ASTM E8 standard, the aged samples were prepared viz 70 mm in length, 8 mm in diameter, gauge length of 20 mm, and a diameter of 4 mm as shown in Fig. 2.

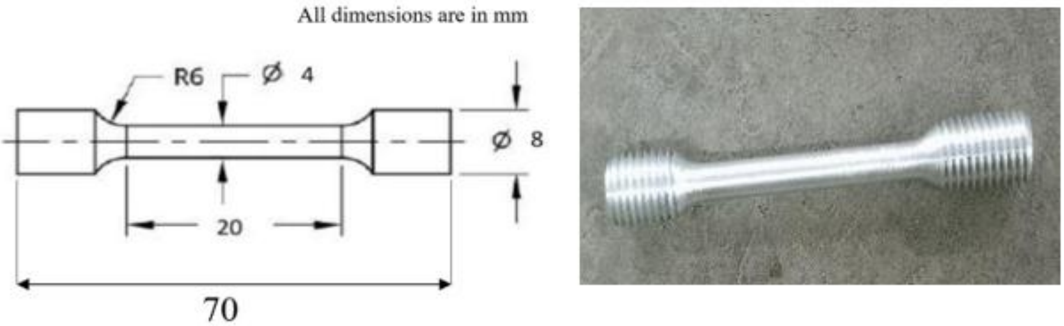

Figure 2: Tensile test specimen

Hardness was measured on four different locations on each sample by applying a load of 100 kgf indenter of 1/16 inch Steel ball indenter and then averaged for each sample. To plot the graph of hardness Vs aging time the integer value of hardness is taken.

A pin-on-disc tribometer features a stationary pin under an applied load in contact with a rotating disc. The pin can have various shapes to simulate specific contacts, but spherical tips are commonly used to simplify the contact geometry. The coefficient of friction is calculated as the ratio of the frictional force to the applied load on the pin. The test parameters used while conducting the pin-on-disc wear test are specimen diameter of 20 mm and length of 70 mm load applied on the specimen is 40 N and speed of the disc is 400 rpm and time 600 sec with a radial distance of 40 mm.

Figure 3: Setup of dry sliding wear test

3. Results and Discussion

In the hardness test, four tests (four trials for each specimen) are conducted and their average value is taken. To plot the graph of hardness versus aging time the integer value of hardness in Fig 7. The maximum hardness of 54 RHN is achieved at 120 °C for 12 hours. At 170 °C, no significant change in hardness is observed with increasing time, while at 220 °C, the hardness value increases with time. The natural aging condition (T4) shows the lowest hardness at 34 RHN. The optimal aging condition is 120 °C for 12 hours. At this point, precipitation is at its peak, with precipitates evenly distributed throughout the material. Prolonged aging causes nearby precipitates to merge into larger, unevenly dispersed ones, significantly weakening the material. Grain growth, influenced by both time and temperature, becomes a major concern. Peak aging results in the highest strength because the precipitates effectively hinder dislocation motion. However, in the overaged condition, larger precipitates act as stress concentration points, considerably weakening the material.

The tensile test results include measurements of ultimate tensile strength, yield strength, and percentage of gauge elongation under artificial aging conditions at three different temperatures over four time periods, as well as under natural aging conditions. The minimum percentage elongation was observed at 170 °C for 16 hours and 220 °C for 16 hours, with values of 15.65% and 15.85% respectively. The maximum percentage elongation was recorded at 170 °C for 4 hours, at 26.25%. The highest yield strength values were recorded at 120 °C for 12 hours and 220 °C for 16 hours, with values of 286 MPa and 284 MPa respectively. The T4 natural aging condition showed a yield strength of 240 MPa. No significant change in properties was observed with increasing time at the aging temperature of 170°C as shown in Fig 4.

Here the peak aging condition is 120 °C for 12 hours, At the point of peak aging, precipitation is at a maximum, and precipitates are relatively evenly distributed throughout the material. The peak aging condition yields the highest strength as precipitates help prevent dislocation motion. However, in the overaged condition, the large precipitates serve more as stress concentration points, making the material significantly weaker, here at 120 °C for 12 hours has maximum hardness so at this condition it has minimum wear volume and minimum Wear rate.

The wear rate decreases with an increase in aging time up to 12 hours and then it increases up to 16 hours, at artificial conditions, the minimum wear rate is seen at the aging temperature of 120 °C for 12 hours the maximum wear rate is seen at 120 °C for 4 hours and it is equal the wear rate the natural condition. To have a minimum wear rate choose the aging temperature of 120 °C and keep it there for 12 hours as shown in Table 2.

A coefficient of friction that is more than one just means that the frictional force is stronger than the normal force. From Fig 6, it is observed that the maximum coefficient of friction is seen at the aging condition of 120 °C for 12 hours, and the minimum coefficient of friction is seen at the natural aging condition.

Table 2: Values of Tensile test, Pin on Disc Wear Test, and hardness

Specimen condition	**wear volume (mm^3)**	**wear rate (mm^3/N m)**	**wear coefficient**	**Coefficient of friction**	**Hardness**	**Yield stress (MPa)**	**Elongation (%)**
120°C, 04hr	3.914591	9.7348×10^{-5}	3.5334×10^{-5}	0.39	37	210	18.95%
120°C, 08hr	2.846975	7.0799×10^{-5}	3.1254×10^{-5}	0.498	45	245	23.70%
120°C, 12hr	1.3879	3.4514×10^{-5}	1.7945×10^{-5}	0.592	53	286	22.65%
120°C, 16hr	1.850534	4.6019×10^{-5}	1.8960×10^{-5}	0.283	42	237	25.40%
170°C, 04hr	2.52669	6.2834×10^{-5}	2.2806×10^{-5}	0.314	37	207	26.25%
170°C, 08hr	1.708185	4.2479×10^{-5}	1.7919×10^{-5}	0.304	43	209	17.90%
170°C, 12hr	1.672598	4.1594×10^{-5}	1.9177×10^{-5}	0.453	47	220	24.90%
170°C, 16hr	2.313167	5.7524×10^{-5}	2.5958×10^{-5}	0.398	46	219	15.65%
220°C, 04hr	3.487544	8.6728×10^{-5}	3.31813×10^{-5}	0.421	39	252	16.75%
220°C, 08hr	3.309609	8.2303×10^{-5}	3.39106×10^{-5}	0.352	42	231	19.25%
220°C, 12hr	1.672598	4.1594×10^{-5}	1.79537×10^{-5}	0.439	44	215	18.30%
220°C, 16hr	2.491103	6.1949×10^{-5}	3.03858×10^{-5}	0.45	50	284	15.85%
(T4)Natural condition	3.66548	9.1153×10^{-5}	3.04032×10^{-5}	0.283	34	240	24.85%

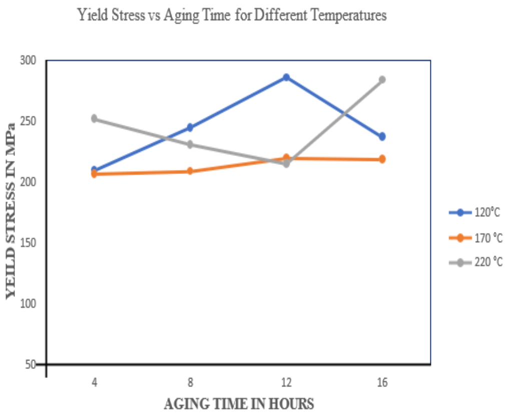

Figure 4: Effect of aging time at different aging temperature on yield strength

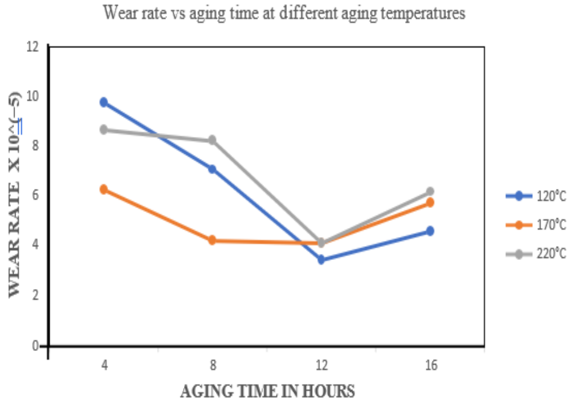

Figure 5: Effect of aging time at different aging temperature on wear rate

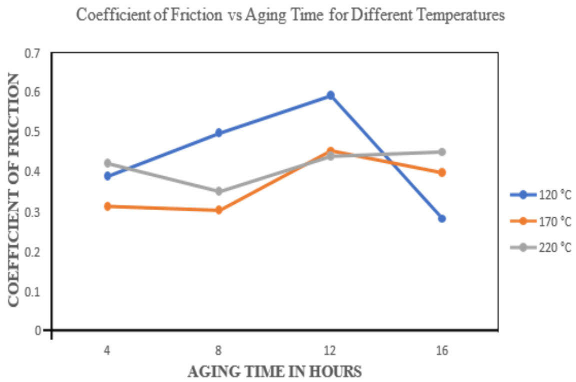

Figure 6: Effect of aging time at different aging temperature on coefficient friction

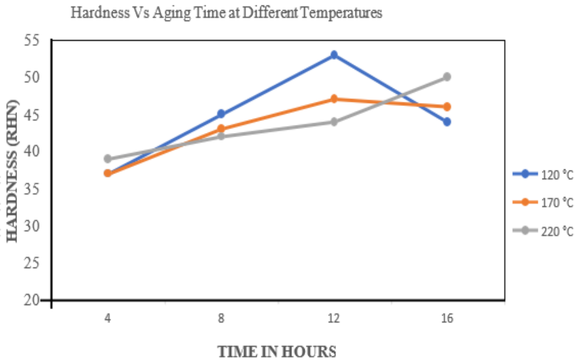

Figure 7: Effect of aging time at different aging temperature on hardness

4. Conclusions

From the experimental investigation on AA 2014 alloy subjected to heat treatment, the following remarks are concluded.

- The hardness value increases with an increase in time for different aging temperatures. Maximum value hardness 54 (RHN) was obtained at 120 °C for 12 hours condition.
- Maximum value of ultimate tensile strength 424 MPa is recorded at 120 °C for 12 hours condition and the minimum value of ultimate tensile strength is recorded at 220 °C for 12 hours condition its value is even less than natural T4 aging condition. In all the tensile test experiments, when time increases from 12 hours to 16 hours no significant change is observed. No significant increment or decrement in tensile strength is seen at 170 °C with an increase in time.
- Maximum value of yield strength is recorded at 120 °C for 12 hours condition with value of 286 MPa. T4 condition recorded yield strength of 240 MPa.
- Minimum percentage elongation (elongation of gauge length) observed at 170 °C for 16 hours and 220 °C, for 16 hours with percentages of 15.65% and 15.85 % respectively, and maximum percentage of elongation is observed at 170 °C, 04 hours condition having 26.25%.
- As aging time increases, the wear rate decreases up to 12 hours and then slightly increases when time increases to 16 hours. Minimum wear (wear volume) is recorded at 120 °C for 12 hours

having 1.0893 mm^3.

From this experimental investigation, it is clear that maximum hardness, maximum yield strength, maximum tensile strength, maximum coefficient of friction, and minimum wear loss are observed at 120 °C and 12-hour conditions. This aging condition is best suited to increase the properties of AA2014 alloy. No significant difference in properties is observed when time increases from 12 hours to 16 hours, so it is economical to take the aging time as 12 hours.

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