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AA7xxx Alloy Tensile and Wear Behaviour of Precipitation Hardening

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Abstract

In the present study, tensile and wear behaviour of AA 7xxx alloy were studied. Casting process was used to produce AA 7xxx alloy. AA 7xxx alloy reveals distribution of fine precipitates and intermetallic compounds in the α-aluminium matrix. In order to improve the mechanical properties and condition the microstructural features, precipitation hardening treatment was carried out by keeping temperature and time as variables. Ageing treatment was carried out at 120°C with varying time interval. Tensile and hardness studies were carried out on the aged alloys. There is a greater increment in strength and hardness at precipitation alloy. Wear behavior of the alloy was studied using the pin-on-disc technique with varying load and keeping sliding speed and time as constant. Precipitation hardened alloy shows better wear resistance than that of cast and solutionized alloy.

Keywords: AA 7xxx alloys, Precipitation Hardening, Micro structure correlation, and SEM analysis and wear behaviour.

1. Introduction

Aluminum (Al) alloys are widely used for various structural applications due to their good combination of formability, corrosion resistance, weldability and mechanical properties. The demand for higher strength, toughness and strength to weight ratio of Al alloys for structural applications is ever growing owing to the increasing importance of achieving longer life time and cost effectiveness of the materials. Automotive and aerospace industries are looking for light weight structural alloys for better fuel consumption and cost saving. In current industrial practice, the use of 7xxx series alloys plays a vital role. It is due to their superior mechanical properties, corrosion resistance, weldability and good wear resistance etc. In the present investigation, the alloying elements such as Zn, Mg, Cu had been increased and suitable thermal treatments, precipitation hardening treatment (T6), was carried out to improve the mechanical properties. It was observed formation of complex intermetallic compounds in aluminum alloy by increasing alloying content [1-5]. Precipitation hardening treatment is intensely used in industry for a variety of heat treatable Al alloys to increase their strength by fine tuning coherent / semi-coherent precipitates such as $MgZn_2$, Al_2Cu, etc. [6]. Addition of 2 wt.% Al–5Ti–1B master alloy to Al–12Zn–3Mg–2.5Cu alloy showed the reduction its grain size and subsequently increased in strength and hardness by T6 heat treatment [7]. Wear and tear of engineering components is the big issue in industries such as automotive, etc. Wear studies of aluminum alloys and composites were widely studied many researchers. It was reported that composites and alloy with hard dispersoids exhibited better wear resistance than that of base alloys. Ammar J. Khaleel et al reported that the effects of zinc addition in aluminum to resist dry sliding wear. The results showed that the wear rate decreases with increasing the Zinc proportion for the test samples [8]. AA7075 alloy reinforced with SiC via powder metallurgy method had resulted increasing wear resistance. Formation of mechanically mixed layer (MML) during wear test increased the wear resistance [9]. M. Alipour et al reported dry sliding wear performance of the Al–12Zn–3Mg–2.5Cu in normal atmospheric conditions. The T6 treated aluminium alloy showed considerably improved wear resistance to the dry sliding wear [10].

2. Experimental procedure

AA7xxx alloy was prepared by metal casting with controlled process parameters. In order to understand the precipitation hardening (T6) behavior, the alloy was solution treated at 450°C for 2 hrs followed by water quenching. Ageing treatment was carried out at 120°C with varying time interval. Mechanical properties such as hardness and tensile studies were conducted on cast and precipitation hardened AA7xxx alloy. Tensile and hardness tests were conducted using (Model: H50 KS) tensile machine and Wilson hardness, respectively. Dry sliding wear tests were conducted using a conventional pin-on-disc testing machine to appraise room temperature wear behaviour of the AA 7xxx aluminium alloy. Wear test samples were prepared as per ASTM G99 standards. The specimen (cylindrical pin) size is 6 mm diameter and 12 mm length. The rotating disc was made up of EN-32 steel with hardness of 65HRC. Weight loss was determined from the final and initial weight with the help of precision electronic balance accuracy of 0.001g. The tests were conducted with varying load (10N to 40N) and constant speed 2000m. The following equations were used to determine wear rate.

Parameters taken constant during sliding wear test

Parameters taken constant during sliding wear test: Distance between centre of disc and centre of sample (r) as 21.8mm; Diameter (d) as 43.6mm; Velocity (V) as 1.2 m/s. From these parameters, rotational speed (N) is calculated based on the equation V = πdN/60 and time is calculated based on the equation Displacement / Velocity.

Distance between centre of disc and centre of sample (r) = 21.8mm

Diameter (d) = 43.6mm

Velocity (V) = πdN/60

$1.2 = \pi \times (43.6 \times 10^{-3}) \times N/60$

N = 526rpm

Time (t) = Displacement / Velocity = 2000/1.2 = 1666.67s

Wear calculation

Wear rate = Volume loss / Sliding distance

Volume loss = mass loss/ density

Wear resistance = 1/ Wear rate

Specific wear rate = Wear rate/load

Wight loss = 0.1g for as cast material on 40n load

Volume = (mass/density) = 0.1/2.8

$= 35.71 \mathrm{X}\ 10^{-3}\ \mathrm{cm}^3 = 35.71\ \mathrm{mm}^3$

Wear rate = $35.71/2000 = 1.785 \mathrm{X} 10^{-5}\ (\mathrm{mm}^3/\mathrm{m})$

3. Results and Discussion

Figure 1 shows the optical micrographs of AA7xxx alloy in three different conditions cast, solutionized and aged. Cast AA7xxx alloy reveals α-Al matrix and complex intermetallics by non-equilibrium solidification. The intermetallic compounds are predominantly segregated along the grain boundaries. The soluble compounds are dissolved in α-aluminium matrix during solutionizing treatment shows Fig. 2. However, there are some undissloved compounds in the matrix. The microstructure of peak aged alloy shows fine grain structure and undissloved compounds and optically unresolvable fine precipitates.

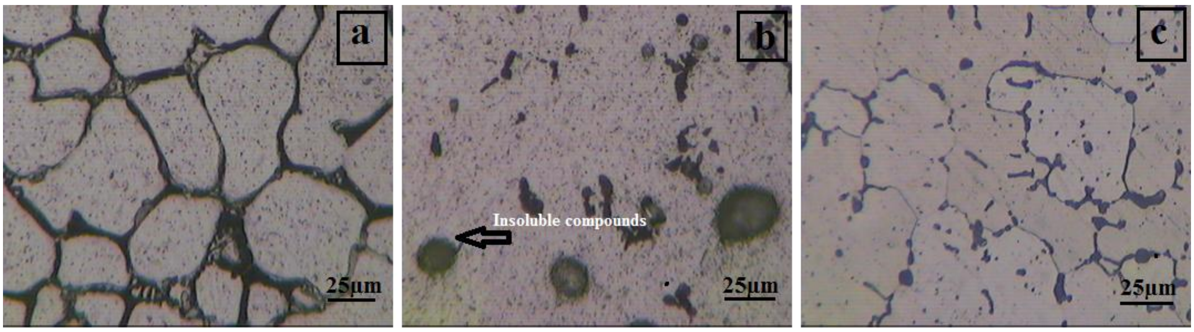


Fig. 1 Microstructure of AA7xxx alloy with different processing conditions (a) Cast, (b) Solutionized and (c) Aged.

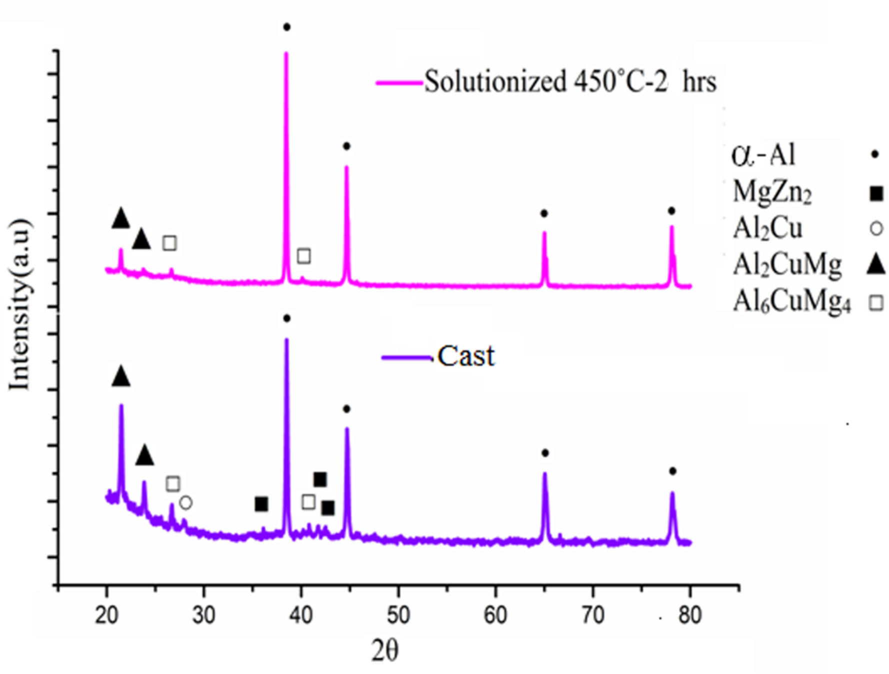


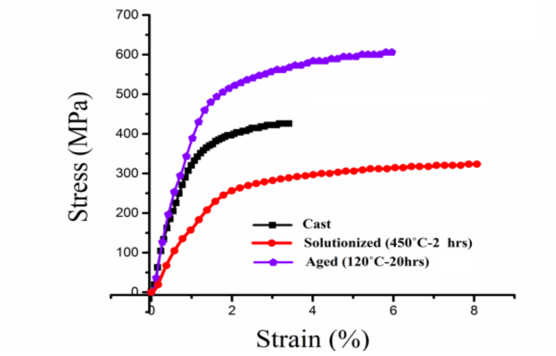
Fig. 2 X-ray diffraction patterns of AA 7xxx alloy

Hardness values of the alloy with different processes are given in Table 1.The hardness values of cast and solutionized conditions are 152Hv and 108Hv, respectively. Solutionized alloy results lower hardness than that of cast alloy, which is due to dissolution harder precipitates in the matrix. The undissloved precipitates such as Al_6CuMg_4 and Al_2CuMg are coarser in size and their contribution is minimal in enhancing hardness. The peak hardness is obtained at ageing temperature, 184Hv for 20hrs at 120°C, respectively. After attaining peak hardness, the hardness is getting reduced by over-ageing. The peak hardness values of aged alloy are much higher than conventional AA7xxx alloy. This is attributed by both incoherent insoluble compounds and coherent soluble compounds provide synergetic hardening effect.

Table1.Hardness values of AA7xxx alloy with different conditions

Conditions	Hardness Values (Hv)
As Cast	152±4
Solutionized(450°C+2hrs)	108±5
Ageing Time (hrs)	Hardness Values (Hv)
	120°C
4	114 ±3
8	122±3
12	148±3
16	162±3
20	184±3
24	198±5
28	175±5

Stress – strain curves of AA7xxx alloy with different conditions are shown in fig. 3. The ultimate tensile strength (UTS) of cast, solutionized and aged alloy is 404MPa, 316MPa and 593MPa and the elongation is 3%, 8% and 6%, respectively (Table 2). Age hardened aluminium alloy exhibits approximately increment in UTS than that of cast alloy with ductility. The increment in strength and ductility after ageing are attributed by combined effect of solid solution, precipitation hardening and dispersion hardening.



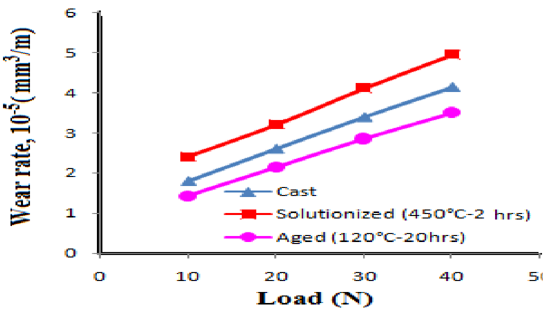


Fig. 3 Stress-strain curves of AA7xxx alloy at different conditions.

Fig. 4 Wear rate of different loads on AA7xxx alloy a) As cast b) Solutionized and c) Aged (120˚C-20hrs) conditions.

Table 2.Tensile properties of AA 7xxx alloy at different conditions

Conditions	Yield strength (MPa)	UTS (MPa)	%Elongation
As cast	326±8	404±10	3.4±1
Solutionized	212±8	316±10	7.8±2
Aged-(120˚C-20hrs)	421±8	593±10	6.2±2

Wear data obtained for AA7xxx alloy at different conditions are tabulated (Table 3). Figure 4 relates the wear rate with increasing load. Wear rate of cast (4.11x$10^{-5}$$mm^3$/m) condition is more than aged (3.21x$10^{-5}$$mm^3$/m). Wear rate of cast is 20% more than that of aged conditions. Wear rate increases with increase in supplied load from 1.8x$10^{-5}$$mm^3$/m for 10N to 4.11x$10^{-5}$$mm^3$/m for 40N load with an increase of 55%. Coefficient of friction almost remains constant for all the time of wear test. Coefficient of friction increases from 0.43 for 10N load to 0.54 for 40N load causing overall increase of 55%.

Table 3.Wear data obtained for AA7xxx alloy at different conditions

Conditions	Mass loss (g)	Volume (mm^3)	Wear rate (mm^3/m)	COF
Cast				
10N	0.100	35.71	1.78 x 10^{-5}	0.43
20N	0.145	51.78	2.60 x 10^{-5}	0.48
30N	0.190	67.85	3.40 x 10^{-5}	0.52
40N	0.230	82.14	4.11 x 10^{-5}	0.54
Solutionized (450°C-2hrs)				
10N	0.135	48.21	2.41 x 10^{-5}	0.32
20N	0.180	64.28	3.21 x 10^{-5}	0.36
30N	0.230	82.14	4.10 x 10^{-5}	0.39
40N	0.280	100	5.00 x 10^{-5}	0.41
Aged (120°C-20hrs)				
10N	0.080	28.57	1.428 x 10^{-5}	0.52
20N	0.120	42.85	2.142 x 10^{-5}	0.54
30N	0.160	57.14	2.857 x 10^{-5}	0.59
40N	0.200	71.42	3.214 x 10^{-5}	0.68

Figure 5 shows the worn surface of AA7xxx alloy at different conditions cast, solutionized and aged. Figure 5a shows the worn surfaces of the cast alloy and it can be observed that the alloys at low velocity mild oxidation wear marks are visible. Figure 5b and 5c show the worn surface of solutionized alloy and Aged (120˚C-20hrs). The worn surface has mainly oxidation marks and debris particle due to delamination.

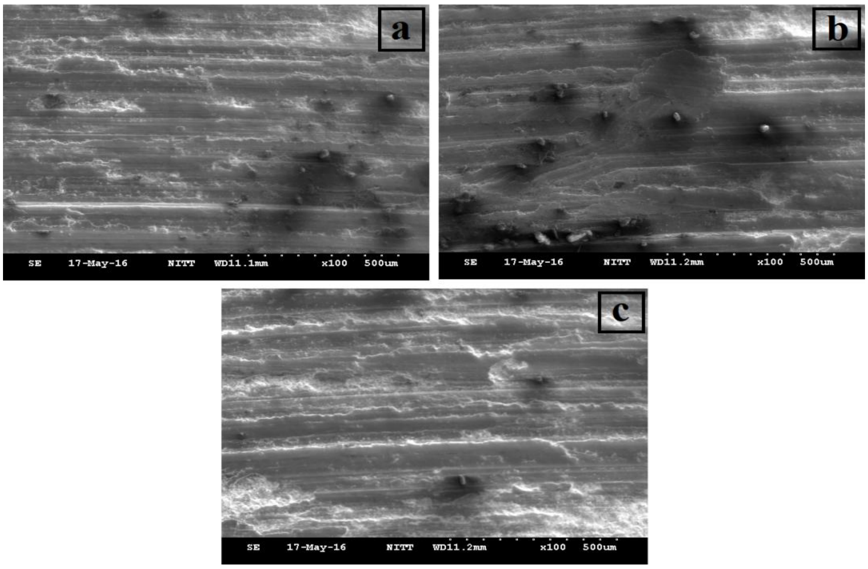
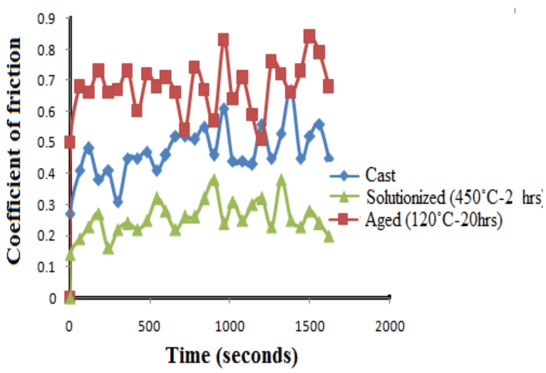


Fig. 5 SEM micrograph wear track surface of AA 7xxx alloy after T6 treated at 120˚C for 20hrs in different conditions a) As cast b) Solutionized and c) Aged (120˚C-20hrs) conditions.

The relation between sliding distance and coefficient of friction of alloy is expressed in fig. 6. Before attaining the stable region, A running-in period is observed before attaining the stable region. It is noticed the stable value of coefficient of friction followed by strong fluctuation in the friction coefficient in cast, solutionized and aged conditions.



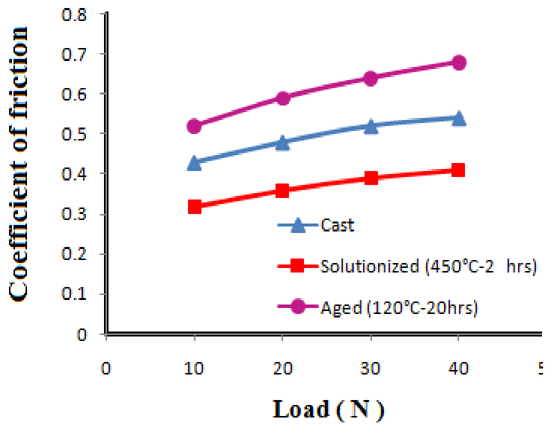


Fig. 6 Coefficient of friction comparing time of wear on load at 40N, AA7xxx alloy a) As cast b) Solutionized and c) Aged (120˚C-20hrs) conditions.

Fig. 7 Coefficient of friction comparing different loads on AA7xxx alloy a) As cast b) Solutionized and c) Aged (120˚C-20hrs).

Figure 7 shows the friction coefficient of the AA7xxx aluminium alloy under the load of 10N–40N, respectively. The friction coefficient is increased at the starting of sliding with increasing load. Solutionized condition shows lower friction coefficient than that of cast condition because of plastic nature of solutionized alloy. Aged condition at 120°C-20hrs shows higher friction coefficient than that of conventional AA 7xxx alloy because of effect of precipitation hardening.

4. Conclusions

AA 7xxx, wt.% alloy contains coarse intermetallic compounds, homogeneously distributed throughout the matrix and grain boundaries. The ultimate tensile strength (UTS) of cast, and aged alloy is 404MPa, and 593MPa and the elongation is 3.4%, and 6.2% respectively. Precipitation hardening results increment in UTS than that of cast alloy with ductility. Precipitation hardened alloy shows exhibits higher wear resistance than that of cast and solutionized alloy. However, the co-efficient of friction is low.

5. References

[1] M. Alipour, B.G. Aghdam, H. Ebrahimi Rahnoma, M Emamya.Investigation of the effect of Al–5Ti–1B grain refiner on dry sliding wear behaviour of an Al–Zn–Mg–Cu alloy formed by strain-induced melt activation process.Materials and Design, 2013, 46: 766–775.

[2] G. Chen, J. Jiang, DU. Zhiming, QI Cao, XIN Zhang. Formation of Fine Spheroidal Microstructure of Semi-Solid AleZneMgeCu Alloy by Hyperthermally and Subsequent Isothermally Reheating. Materials Science and Technology, 2013, 29(10): 979-982.

[3] M. Dixit, R.S. Mishra, K.K Sankaran. Structure–property correlations in Al 7050 and Al 7055high-strength aluminum alloys. Materials Science and Engineering A, 2008, 478: 163–172.

[4] M.F. Ibrahim, A.M. Samuel, F.H. Samuel. A preliminary study on optimizing the heat treatment of high strength Al–Cu–Mg–Zn alloys. Materials and Design, 2014, 57: 342–350.

[5] R. Ranganatha, V. Anilkumar, S. Vaishaki Nandi, R.R. Bhat, B.K. Muralidhar. Multi-stage heat treatment of aluminium alloy AA7049. Transactions of Nonferrous Metals Society of China, 2013, 23: 1570-1575.

[6] L.J.Yang. The effect of casting temperature on the properties of squeeze cast aluminium and zinc alloys. Journal of Materials Processing Technology, 2003, 140: 391–396.

[7] M. Alipour, M. Emamy. Effects of Al-5Ti-1B on the structure and hardness of a super high strength aluminum alloy produced by a strain-induced melt activation process. Materials and Design, 2011, 32: 4485–4492.

[8] Ammar J. Khaleel, Adel M. Bash. Study the effect of Zinc addition on dry sliding wear rate of pure aluminum. Academic Research International. Vol 4 no-5, 2013. 234-243.

[9] B Venkataraman, G Sundararajan. Correlation between the characteristics of the mechanically mixed layer and wear behaviour of aluminium, Al-7075 alloy and Al-MMCs. Wear, 245(1-2) (2000), 22-38.

[10] M. Alipour, M. Azarbarmas, F. Heydari, M. Hoghoughi, M. Alidoost, M. Emamy. The effect of Al–8B grain refiner and heat treatment conditions on the microstructure, mechanical properties and dry sliding wear behavior of an Al–12Zn–3Mg–2.5Cu aluminum alloy. Materials and Desig