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To study the wear behavior of Al25Mg_2Si2Cu4Fe alloy at constant load, homogenized for 3 hour

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Abstract - *In the present work, wear behaviour of as cast aluminium (6xxx) alloy, which has been homogenized for 3hr with T6 Heat treatment is studied. The objective of the present study is to investigate the micro structural characteristics and wear behavior of T6 heat treated as cast Al25Mg_2Si with addition of Cu, Mg and Fe as alloys. This alloy has been synthesized by conventional casting, heat-treated by T6 method and aged at 210^{0}C for 3hr. The micro structural characterization has been studied by SEM (Scanning Electron Microscope).Copper forms Al_2Cu phase and other intermetallic compounds that increase strength. Due to copper addition melting point of the alloy decreases that increases the condition of porosity formation. From this study we have observed that the friction force values decrease with increase in the sliding speeds.Volumetric wear rate and interface temperature are directly proportional to the sliding speed.*

Key Words: Volumetric wear rate, Friction force, Coefficient of friction, Load, Interface temperature

1. INTRODUCTION

6000 series aluminium alloys are being used for applications in automotive industries for their light weight and strength. This strength comes mainly from their ablity to age artificially. Copper is added to these aluminium alloys in different proportions which leads to the formation of different phases as well as precipitates with unique properties. In case of Al-Mg-Si alloys the hardening phases are β' and β" whereas in case of Al-Mg-Si-Cu alloys more number of hardening phases appear that makes the response to the artificial aging process more complex.Among all the phases present in these alloys 'Q' phase is an important one which forms as an equilibrium phase.In this paper the thermodynamic stability of the 'Q'phase is discussed against other coexisting phases. A metastable type of this phase has been reported to exist at the peak age temper that may be useful in understanding the overall precipitation hardening mechanism.This phase is documented by using TEM micrographs and diffraction patterns which helps in differentiating this 'Q' phase from the β ' phase. As shown in figure 1 commercial aluminium alloys of Al-Mg-Si have terniary equilibrium phases such as θ, β and Si. When Cu is added Al and 'Q' phases which are common are formed alongwith θ, β and Si based phases.As seen in the figure 1 addition of silicon in the ternary Al-Cu-Mg alloys the three phase field consisting of Al, θ and Si expand into tetrahedran phase field consisting Al, θ, S and β phase at low silicon addition. At higher addition of silicon 'Q' phase replaces the 'S' phase. This replacement of 'S' phase with 'Q' phase results in abrupt changes in phase combinations [1].

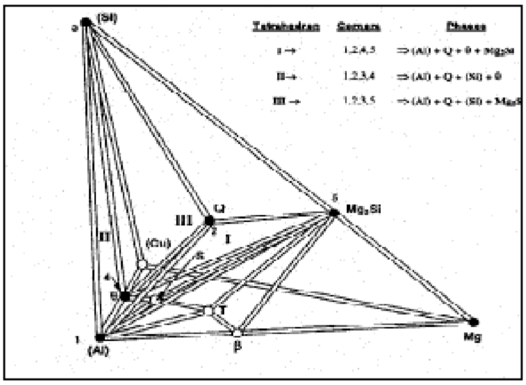


Fig -1: Line diagram of stable equilibrium phase fields in Al-Mg-Si-Cu system at normal aging temperatures

A recovery in elongation to fracture of Al-Si-Cu-Mg alloy on overaging is obtained for the finest microstructure, while the elongation remains low for the coarser microstructures. Difference between the finest and coarsest microstructure is 7 MPa for the peak aged condition.Concentration of Cu,Mg and Si in the α-Al were measured using wave length dispersive spectroscopy (WDS). The elongation to fracture depends strongly on the ability of Si particles in the Al-Si eutectic to stop the movement of dislocations [2].
The wear properties of A390 (Al-17Si-4.5Cu-0.5Mg wt%) hyperutectic Al-Si alloy was investigated after T6 treatment. A transformation of hard and coarse primary Si particles to fine MgSi particles with inferior hardness values occurs with increase in the Mg content.However, this transformation to fine Mg_2Si particles increased the wear resistance. Also, increasing Mg content contributed in refining the size and

morphology of the eutectic silicon that increased the wear resistance [3].

Al-Si eutectic alloy with copper and iron was investigated for microstructure and fracture using SEM and TEM. It is observed that Fe rich and Cu rich phases are solidified or precipitated in the form of chinese script or blocky α-Fe($Al_{15}(Fe,Mn)_3Si_2$) and θ-(Al_2Cu) at the grain boundaries of α-Al dendrites. The ultimate tensile strength and elongation of the alloy was found increased. Also, Al-Si alloy with Cu and Fe have mixed mode of fracture with quasi-cleavage and ductile fracture morphology. Tensile properties have improved. Tiny precipitates of Al_2Cu particles and α-iron dendrites are surrounded by dimples. Surrounding α-Al grains retard the propagation of micro-cracks more effectively than α-iron particles[4]. The influence of copper and iron on solidification charecteristics of 356 and 380 aluminium alloys has been investigated recording the thermal history during the solidification. Crystallization of Al_2Cu and Al_5FeSi is very sensitive to the copper and iron content respectively. Al_2Cu increases significantly when copper is added and similarly Al_5FeSi increases with increase in Fe. When copper and iron increases liquidus and eutectic temperature of 356 and 380 were suppressed [5].

Al-20Si-5Fe-2X (X=Cu, Ni, Cr) alloys produced by melt spinning and hot pressing were investigated for hardness and compressive strength at room temperature and elevated temperatures. The extended solid solution and formation of dispersed particles improve the strength, wear resistance and thermal stability of the aluminium alloys. Results of XRD,SEM and TEM showed formation of spherically shaped Si particles, ultrafine Si particles and iron containing intermetallic particles. Ni was found to be most effective in increasing the maximum sresss particularly at elevated temperatures [6].

2. EXPERIMENTAL DETAILS

2.1 Material selection

In the present investigation, the hypereutectic alloy such as Al-25Mg_2Si with Cu, Mg and Fe as alloying additions are used to represent the light weight heat treatable Al-Mg_2Si-Cu alloys. Table 1 summarizes the nominal compositions of all the selected alloys.

Table-1: Chemical composition (wt %) of Al25Mg_2Si2Cu4Fe alloys

Alloy	% Si	% Fe	% Cu	% Mg	% Al
Al-25Mg_2Si-2Cu-4Fe	13.68	5.01	2.61	13.2	Balance

The as-cast ingots of different compositions, listed in the Table 1, are obtained from FENFE Metallurgical, Bangalore, India. The chemical composition of all the alloys is analyzed by spark emission spectrometer [Make: PANalytical - XRD & XRF Instrumentation, Model QSN 750-II single or multi matrix system]. The alloy used in the present work is Al-25Mg_2Si-2Cu4Fe its chemical composition is as shown in Table1.

2.2 Heat treatment

2.2.1 Solutionizing and aging heat-treatment

The samples of as cast Al-Mg_2Si-2Cu-4Fe alloys are subjected to age hardening heat treatment. The age hardening treatment was accomplished following the procedures as per ASM handbook (ASM, 1997). Heat treatment was carried out in a muffle resistance furnace with a temperature accuracy of ±5^{0}C. The alloy is subjected to T6 heat treatment in a muffle heat treatment furnace.The samples are solutionized at 330 °C for 30 minutes and quenched in cold water. Ageing is carried out at 210 °C for 3 hr. The aged samples are cooled in air till room temperature is reached.

2.3 Wear test

2.3.1 Operating conditions

Table -2: Operating conditions

Sr. No	Sliding speed (m/s)	Load (Kg)
1	1	1
2	2	2
3	3	3
4	4	4

Note: Sliding distance is 2000 meters

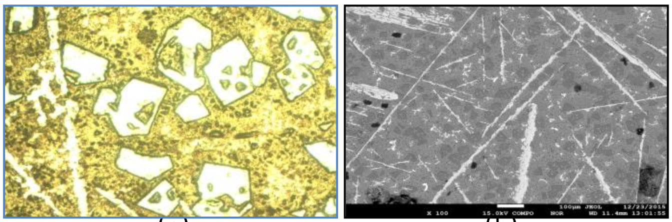
2.3.2 Dry sliding wear test

The wear test is carried out using a pin-on-disc type wear testing machine (DUCOM, Bangalore, India) according to ASTM: G99-05 (ASM, 1992) standard. The samples are cleaned prior to and after each interval of wear test with acetone. The wear rates of the alloys are calculated by measuring the difference in weight of the specimens measured before and after the tests (measured with an analytical balance Mettler AJ100, Hightstown, NJ of 0.1 mg precision). Wear specimen of size 30 mm length and 10 mm diameter are machined from differently processed samples. The contact surface of the specimen are polished up to 1200 mm grit size and tested against a rotating EN-32 steel wear disc with a hardness value of HRC 65. The wear tests are carried out at a sliding velocities for a fixed sliding distance of 2000m at different normal loads. The frictional force induced on the specimen is recorded constantly during the wear test by a load cell. The worn surfaces of pins after the test are examined using (SEM) Scanning Electron Microscope - EDAX tests. Wear tests will be conducted on all the alloy specimens on a pin-on-disc wear testing machine

(Model: TR-20, DUCOM) as per ASTM: G99 - 05. Wear specimens of size Ø10×30 mm are machined out from the alloys. The specimens are polished and then cleaned with acetone before conducting the wear test. The wear tests are conducted by varying the load from 1-4 kg at a sliding velocity of 1-4 m/s and a sliding distance of 2000 m. All the experiments are carried out under dry sliding conditions and data are recorded. The worn surfaces of the alloy after wear testing will be examined under Scanning Electron Microscope.

3. RESULTS AND DISCUSSIONS

3.1 Microstructure results:



(a) (b)

Fig-2: 3 hr homogenized (a) Optical 100X, (b) SEM 100X

Discussion: Figure 2(a) & Figure 2(b) shows 3 hr homogenized structure of Al25Mg_2Si2Cu4Fe alloy having complex intermetallic phases that originate from the casting stage in the form of ingot. Since iron is the omnipresent impurity having very low solubility in aluminium, iron rich phases are seen in aluminium alloys that adversely affect the ductility and castability. Presence of copper, manganese leads to the formation of $(Fe,Mn,Cu)_3SiAl_{12}$ phase [7]. Figure 2(a) shows 3 hr homogenized optical structure that consists of Mg_2Si intermetallic phase, blunted edge of Fe intermetallics and high volume of Al_2Cu phase. Fig 2(b) shows SEM 3 hr homogenized structure having rounded corners of Mg_2Si intermetallic blocks embedded with Fe in it due to the effect of 3 hour homogenizing. Needles of Al_5Fe Si intermetallic phase shows rounded edges. Increase in the Al_2Cu precipitates is also observed. Blocks of Mg_2Si particles act as heterogeneous sites for the nucleation of α-Al that lowers the interfacial energy. Therefore, all the Mg_2Si particles are surrounded by layer of α-Al. Mg_2Si is the other phase that easily dissolves during solutionizing and contribute to the precipitation hardening process. The type of intermetallic compounds formed depends on the presence of other alloying elements.We have added higher %Fe to increase wear resistance as well as resistance to temperature.Addition of copper leads to the formation of metastable phases and precipitates in the supersaturated solid solution such as β'(Mg_2Si), β''(Mg_2Si) alongwith 'Q' phase with specific properties [8]. Formation of complex intermetallic phases adversely affects the tensile strength of the alloy.These alloys contain Al, Mg and Si, however Cu is added to them to increase their ability to age harden so that their strength increases. This strength needs to be increased further to increase their performance at higher temperature. It is shown that increasing copper results in decrease in the equilibrium solidus from 540^{0}C to 505^{0}C. Iron is bound in the quarternary $Al_8FeMg_3Si_6$ phase in low iron alloys and in the ternary Al_9FeNi and Al_5FeSi phases in high iron alloys [9].

3.2 Wear test results

3.2.1 Wear Surface SEM

Discussion: As seen in figure 3, overall volumetric wear rate is observed to be lower at 3 hour homogenizing heat treatment compared to those unheat-treated samples. However, an increasing trend is observed for constant load with increase in the sliding speed.

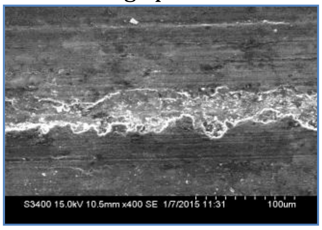
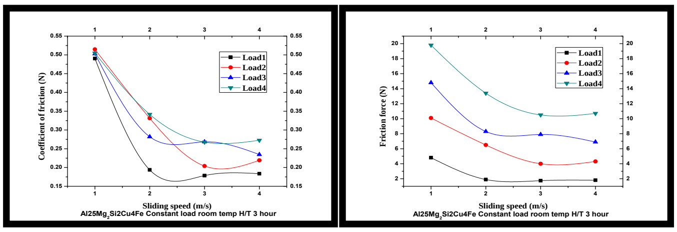


Fig-3: SEM for Speed 4m/s,4Kg load, H.T.3 Hr 100X

3.2.2 Speed v/s Friction coefficient and friction Force

Discussion: Figure 4(a) shows very high coefficient of friction values at 1 m/s sliding speed that decreases drastically to a minimum for all the loads with decrease in the sliding speeds. Figure 4(b) shows friction force is maximum at 1 m/s sliding speed across all the loads. Friction force decreases with increase in the sliding speeds across all the loads.



(a) (b)

Fig -4: Homogenized for 3 hr (a) Speed v/s Friction coefficient, (b) Speed v/s Friction Force

3.2.3 Speed v/s Volumetric wear rate (mm^3/m) & interface temperature homogenized for 3 hr

Discussion: As seen from the figure 5 (a) As seen from figure 5 (a) volumetric wear rate is unaffected for the low sliding speed. Whereas, for higer sliding speeds volumetric wear rate increases drastically and reaches peak value at 3 m/s sliding speed.

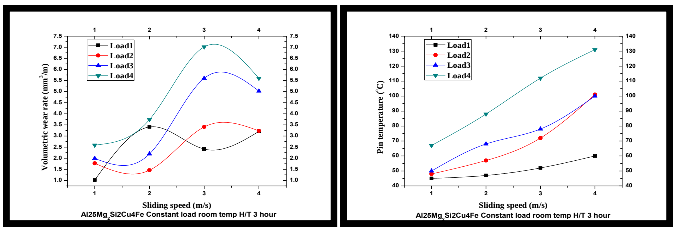


Fig -5: Homogenized for 3 hr, (a) Speed v/s Volumetric wear rate, (b) Speed v/s Interface temperature

As seen from the figure 5 (b) at higher loads higher interface temperature values are observed with increase in the sliding speeds.

4. CONCLUSION

1. Under constant load conditions coefficient of friction values decrease to a very low level with increase in the sliding speeds.

2. Friction force values decrease with increase in the sliding speeds.

3. Volumetric wear rate is directly proportional to the sliding speed.

4. Speed and temperature are directly proportional to each other.

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