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Microstructure and Wear Behavior Of as Cast Al-25mg2si-2cu-2ni Alloy

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Abstract: The remarkable feature of the Aluminium is its low density and ability to withstand corrosion effect due to phenomenon of passivation. Structural components made from Aluminium and its alloys are vital to the aerospace industry and are important in other areas of transportation and structural materials. The oxides and sulphate are useful compounds of Aluminium based on its weight. In this work, an attempt has been made to utilize the combined effect of high cooling rate solidification, unique micro structural evolution mechanism of T6 heat treatment the advantages of hypereutectic Al-Si system alloyed with other elements such as Cu, Fe and Mg. In the present investigation, the binary alloys in the hypereutectic range viz. Al25Mg2Si has been selected as heat resistant Al-Si alloys. A systematic approach has been carried out to explore the micro structural features, mechanical and wear properties of as cast alloys.

Keywords – Aluminium, Passivation, Hyperutectic

I. Introduction

Aluminium (Al) has been at the center of various engineering applications since long. Aluminium and its alloys had become economic competitors in engineering applications because of their useful features, which include its lightweight with a density of approximately one third of that of steel, attractive appearance, fabric ability and excellent corrosion resistance, re-cycle ability, formability and conductivity. The main driving force for using Al-Si alloys by replacing iron based alloys in the automotive and aerospace industries is improved mechanical properties, lower production cost and greater strength to weight ratio which has also met the demand for reduced pollution and increased performance. [1] Alloying elements are selected based on their effect and Suitability. Silicon lowers the melting point and increase the fluidity (improve casting characteristics) of Aluminium. A moderate increase in strength is also provided by Silicon addition. Different alloying elements added to Al-Si alloy will improve its tribological properties. Some composites of Al-Si alloys are also improve its wear rates and friction properties. [2] Al2Cu and Al-Si-Cu-Mg phases are relatively stable below 150°C and Mg2Si phase will coarsen over 180°C giving rise to a sharp decrease in high temperature strength. [3] The microstructure of spray formed and hot pressed alloy consists of fine and uniform distribution of both primary and eutectic Si with fine needles of Q-Al12Si7Mg4Fe intermetallics and Chinese script like θ-Al2Cu precipitates in the Al matrix. Hot pressing has reduced the porosity from 10 to 1 % in spray formed alloy.

The objectives of the present study is to utilize the combined effects of high cooling rate solidification, unique micro structural evolution mechanism of T6 heat treatment and the advantages of hypereutectic Al-Si system alloyed with other elements such as Cu, Fe and Mg. In the present investigation, the binary alloys in the hypereutectic range viz. $Al25Mg_2Si$ has been selected as heat resistant Al-Si alloys. A systematic approach has been carried out to explore the micro structural features, mechanical and wear properties of as cast alloys.

II. Material and Methodology

A. Material selection

In the present investigation, the binary alloys in the hypereutectic have been $Al\text{-}25Mg_2Si\text{-}2Cu\text{-}4Fe\text{-}4Ni$ alloy is used to represent the light weight heat treatable $Al\text{-}Mg_2Si\text{-}Cu$ alloys. Table 1 summarizes the nominal compositions of all the selected alloys. The chemical composition of all the alloys is anlalysed by spark emission spectrometer.

Table.1 Chemical Composition of (wt %) $Al25Mg_2Si\text{-}2Cu\text{-}2Fe\text{-}2Ni$ alloy

Alloy	%Si	% Fe	% Cu	% Mg	%Ni	%Al
$Al\text{-}25Mg_2Si\text{-}2Cu\text{-}2Fe\text{-}2Ni$	11	1.86	2	14	1.96	Balance

B. Wear test

Dry sliding wear test

The wear test is carried out using a pin-on-disc type wear-testing machine .The samples are cleaned prior to and after each interval of wear test with acetone. The wear rates of the alloys found out 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 sliding velocities for a fixed sliding distance of 2000 m at different normal loads. The frictional force induced on the specimen is recorded constantly during the wear test by a load

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cell. The worn surfaces of pins after the test are examined using (SEM) Scanning Electron Microscope.

Fig.1 Pin-on-disc wear testing machine

A pin-on-disc wear testing machine as shown in the Fig.1 (Model: TR-20, DUCOM) as per ASTM:G99–05 is used to conduct the wear test for $Al25Mg_2Si$-2Cu-2Fe-2Ni. The corresponding disc was made of quenched and tempered EN-32 steel having a surface hardness of 65HRC. Wear specimens of size Ø10×30 mm were machined out from both the alloys. The specimens were polished and then cleaned with acetone before conducting the wear test. The wear tests were conducted by varying the load from 10 to 50 N at a sliding velocity of 1 to 3 m/s and a sliding distance of 1025 m. All the experiments were carried out under dry sliding conditions and data was recorded at room temperature. The worn surfaces of both the alloys after wear testing were examined under Scanning Electron Microscopy.

Fig .2Specimen from front view

C. Micro structural study

Metallographic specimen preparation

The samples from as cast, as cast hot pressed and as-cast alloys are machined from the center portion of the platform. The samples are prepared using standard metallographic techniques of grinding on emery paper with 1/0, 2/0, 3/0 and 4/0 specifications. Final polishing is done on a wheel cloth using brasso and kerosene. The polished samples are etched with Keller's reagent

Fig.9 Disc type cloth polishing machine

Optical microscopy

ZEISS Optical Microscope examines the microstructure of the sample alloying element. Optical micrograph of all experimental alloys have been taken using CCD camera attached to the microscope in order to estimate the size, shape and distribution of the primary and secondary phases present in the alloys. Here for the examination of microstructure, the as cast, spray deposited, hot pressed and heat treated alloys are cut from the billets and it is studied under optical microscope. Grain size measurement is carried out using image analysis following the procedure discussed in ASTM E-112-96

Scanning electron microscopy

The microstructures, fracture surface of the tensile specimens and worn surface of wear testing samples are examined on a field emission scanning electron microscope using secondary electron (SE) and backscattered electron (BSE) imaging modes, whereas chemical compositions of the constituent phases are examined using an energy dispersive X-ray micro-analyzer. The SEM is operated at an acceleration voltage of 10-30 kV.

III. Results and Tables

D. Wear test results

Table 2. Wear test of $Al25Mg_2$ 2Si-2Cu-2Fe-2Ni alloy at constant speed

Velocity	Speed	Load	Time	Friction Force	Coefficient of Friction	Initial Weight	Final Weight	Weight Loss	Volumetric Loss	Vol.Wear Rate
m/s	RPM	Kg	Min	N	µ	Gms	Gms	Gms	$(mm^3)\times10^{-7}$	$(mm^3/m)\times10^{5}$
1	212	1	33	4.7	0.479103	5.6192	5.6046	0.0146	6.360824	3.180412
1	212	2	33	5.8	0.2956167	5.5814	5.5718	0.0096	4.182459	2.091229
1	212	3	33	7.8	0.2650357	5.6018	5.5958	0.0060	2.61403	1.307018
1	2	4	33	11.5	0.2930683	5.7223	5.7105	0.0118	5.140943	2.570470
2	424	1	17	4.2	0.4281346	5.6735	5.6696	0.0039	1.699124	0.549562
2	424	2	17	5.6	0.2854236	5.6913	5.6889	0.0024	1.045614	0.522807
2	424	3	17	6.9	0.2344546	5.6779	5.6679	0.0100	4.356728	2.178364
2	424	4	17	9.86	0.2512742	5.7776	5.7699	0.0077	3.354681	1.677340
3	636	1	11	4.4	0.4485219	5.7231	5.7190	0.0041	1.786258	0.893129
3	636	2	11	5.5	0.2803262	5.6696	5.6566	0.0130	5.663747	2.831874
3	636	3	11	6.9	0.2344546	5.7956	5.7896	0.0060	2.614037	1.307018

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Table 3. Wear test of Al25Mg_2 2Si-2Cu-2Fe-2Ni alloy at constant load

Velocity	Speed	Load	Time	Friction Force	Coefficient of Friction	Initial Weight	Final Weight	Weight Loss	Volumetric Loss	Vol.Wear Rate
m/s	RPM	Kg	Min	N	µ	gms	Gms	gms	$(mm^3)\times10^{-7}$	$(mm^3/m)\times10^{3}$
1	212	1	33	210	0.2140673	5.7689	5.7312	0.0377	16.6865843	8.3432921
2	424	1	17	180	0.1834862	5.7725	5.7661	0.0064	2.8327358	1.4163679
3	636	1	11	150	0.1529052	5.6263	5.6032	0.0231	10.2244058	5.1122028
4	848	1	8	160	0.1630989	5.3261	5.3131	0.013	5.7539946	2.8769973
1	212	2	33	320	0.1630989	5.6869	5.6754	0.0115	5.09007215	2.5450360
2	424	2	17	290	0.1478084	5.6633	5.6533	0.0100	4.42614969	2.2130748
3	636	2	11	190	0.0968400	5.3233	5.3152	0.0081	3.58518125	1.7925906
4	848	2	8	198	0.1009174	5.6124	5.5964	0.016	7.08183951	3.5409197
1	212	3	33	263	0.0893646	5.3333	5.3125	0.0208	9.20639136	4.6031956
2	424	3	17	254	0.0863065	5.5254	5.5031	0.0223	9.87031381	4.9351569
3	636	3	11	222	0.0754332	5.3131	5.3001	0.013	5.7539946	2.8769973
4	848	3	8	214	0.0727149	5.1112	5.1036	0.0076	3.36387377	1.6819368
1	212	4	33	290	0.0739042	5.0033	5.0000	0.0033	1.4606294	0.7303146
2	424	4	17	280	0.0713558	5.6112	5.6023	0.0089	3.93927323	1.9696366
3	636	4	11	275	0.0700815	5.3212	5.3112	0.0100	4.42614969	2.2130748
4	848	4	8	200	0.0509684	5.3963	5.3855	0.0113	5.00154915	2.5007745

E. Experimental graphs of wear test

Figure.3 shows Graph For load 1 kg and speed 1 m/s, the coefficient of friction is maximum and with increase in the speed the coefficient of friction decreases slightly but remains steady at a low value.

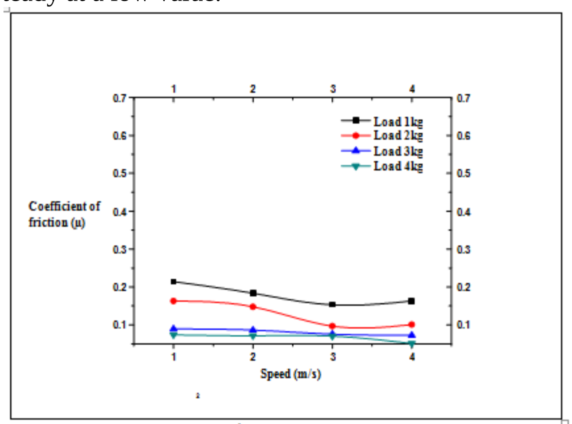

Fig 3. Speed v/s coefficient of friction

Figure.4 Shows graph for all the values of the load, Friction force remains steady in the lower range

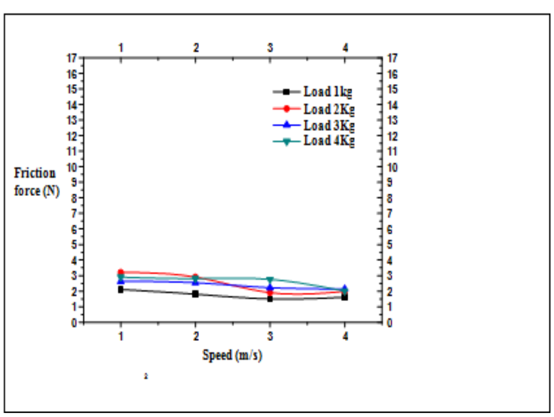

Fig .4 Speed v/s friction force at constant load

Figure.5 Except for the load 1 Kg, for all other load values the volumetric loss remains steady between 3 to 10 mm^3.

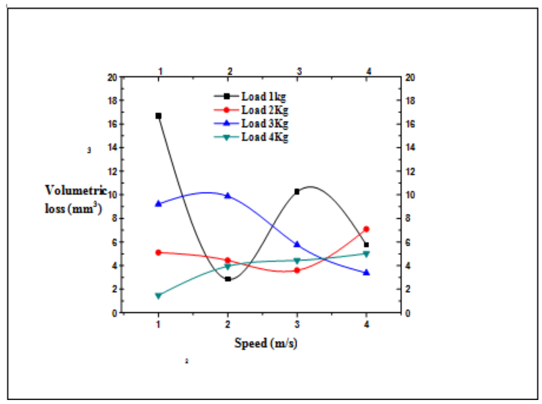

Fig.5 Speed v/s volumetric loss at constant load

Figure 6 shows that at lower values of load coefficient of friction is high and with increase in the load it decreases and comes to a steady state value.

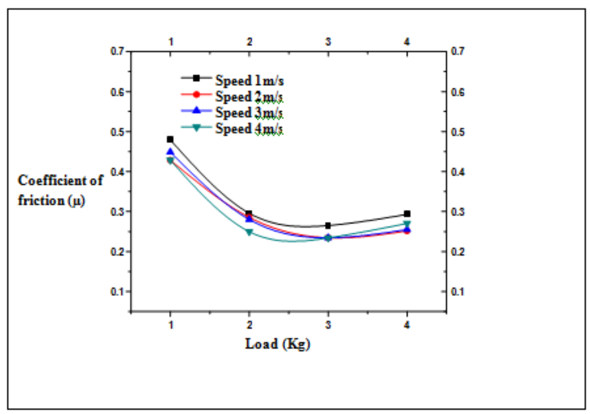

Fig.6 Speed v/s coefficient of friction at constant speed

Figure. 7 At lower value of load friction force is low and it increases with increase in the load.

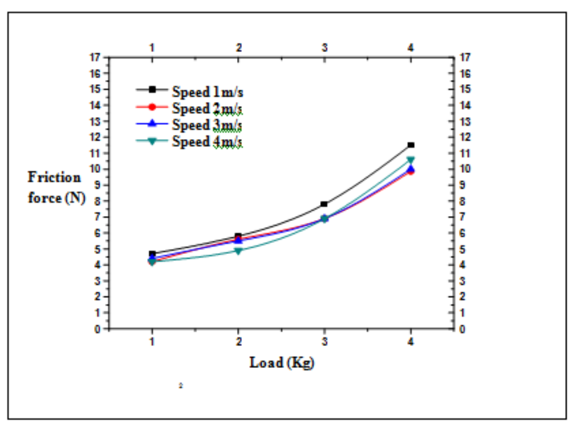

Fig.7 Speed v/s friction force at constant speed

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Figure.8 Shows that Volumetric loss remains high for low load value, whereas it is low initially and increases slightly at higher loads.

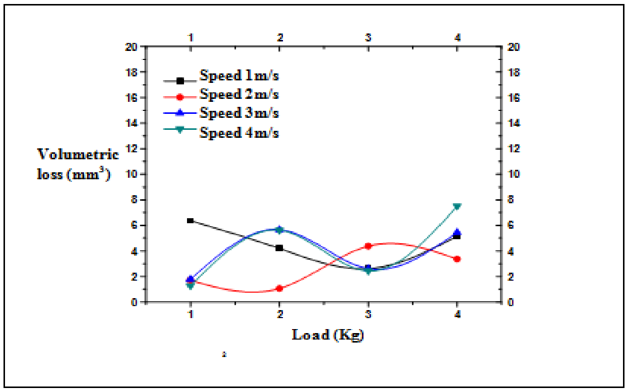

Fig.8 Load v/s volumetric loss at constant speed

Optical characterization

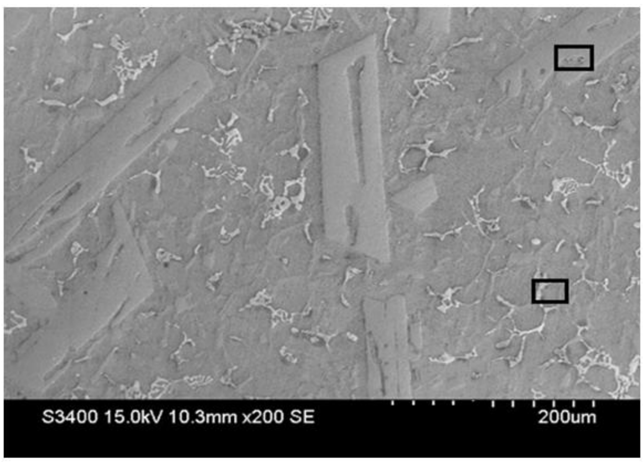

Fig 10 as cast structure $Al25Mg_2Si2Cu2Fe2Ni$

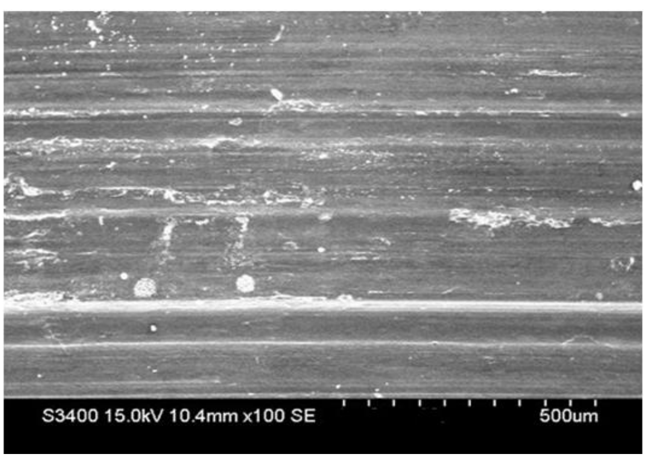

Fig 11 Wear sample

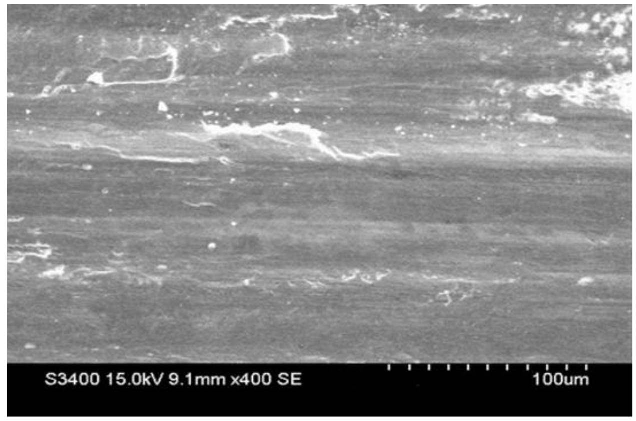

Fig 12 Wear sample

In general the Aluminium Silicon alloy differs from other eutectic alloys in the fact that there is no solubility of aluminium in silicon thus there is no formation of beta-phase. The microstructure primarily consists of a matrix of eutectic Aluminium and pure silicon. In this matrix there is a formation of Mg_2Si intermetallic (less in case of near eutectic and hypereutectic alloys) and silicon part. These flakes often make the material brittle as they become sites of stress. The microstructures reveal the presence of matrix along with microstructures. The microstructures show two distinct phases, which can be seen as contrasting hues of these phases, besides the matrix phase. This indicates the formation of multiple phases owing to the alloying elements added to the alloy during melting. As cast SEM structure of alloy shows major phases as primary beta-$Mg_2$2Si (dark contrast), theta-Al_2Cu (white colored) and Q-$Al_2Cu_2Mg_8Si_7$(grey in color) phase distributed randomly in Al matrix. It can be observed from the Figure.10 that beta-Mg_2Si phase exists in the form of vermiform.Chinese script form of theta-Al_2Cu and a true quaternary compound Q-$Al_2Cu_2Mg_2Si_7$ phase in the form of intertwined structure. These phases are randomly distributed in the Al matrix.

SEM characterization

The SEM micrograph of worn surface as cast alloy tested at elevated temperature sliding at the velocity of 3m/s at 4 kg load is shown in Figure.11The surface consists of continuous wide and deep grooves, crates and delaminated surfaces. It is concluded that the surface has gone through high wear rate. Figure.12 shows the SEM micrograph of the worn surface at the elevated temperature of 200^{o}C at the sliding speed of 1m/s and a load of 1 kg. The worn out surface consists of smooth and continuous grooves that are closer to each other indicating less wear. Due to the mutual solubility of Magnesium and Silicon in solid Aluminium, it leads to an important effect of precipitation hardening due to the development of metastable modifications of the Mg_2Si phase during aging.

IV. Conclusion

From the study of wear behaviour and microstructure of $Al25Mg_22Si$-2Cu-2Fe-2Ni tested at elevated temperature, following conclusions have been drawn.

- The microstructure primarily consists of a matrix of eutectic Aluminium and pure silicon. In this matrix there is a formation of Mg_2Si intermetallic and silicon part.
- As cast SEM structure of alloy shows major phases as primary beta-Mg_22Si (dark contrast), theta-Al_2Cu (white colour) and Q-$Al_2Cu_2Mg_8Si_7$ (grey in colour) phase distributed randomly in Al matrix.
- $Al25Mg_2Si2Cu2Fe2Ni$ alloy shows higher wear resistance even at elevated temperature of 200^0C.
- SEM micrographs show no coarsening of Mg_2Si intermetallic particles due to elevated temperature test.
- Wear resistance is better at lower loads and higher speeds

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