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Influence of Ageing Processes on the Microstructure, Mechanical Properties and Corrosion Behavior of Aluminum-Silicon Cast Alloys "Al- 6%Si-3%Cu"

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ABSTRACT:

The present work describes the influence of age hardening behaviour on mechanical properties and corrosion response on cast Al-Si-Cu alloy. These alloys were subjected to heat-treatment at 450^0C with holding time 1hour and water quenching at room temperature. The aging characteristics were done at different temperatures 170^0C, 180^0C and 190^0C with holding time 1, 3, 6, 9, 12 hrs. From the microstructures two phases has been identified, that Al_2Cu precipitated out in an Al matrix with dissolved Si. At high aging temperatures and high aging times the precipitated Al_2Cu became coarser. Hardness values that obtained in this process are optimum. At 170^0C & 190^0C rate of corrosion rates are increased as aging time and temperature increases, excepting at 180^0C.

Keywords: Cast aluminium alloys, Heat Treatment, Solution Treatment, Artificial Ageing, Rockwell Hardness, Microstructure

1. INTRODCUTION:

Aluminum and its alloys represent an important category of materials due to their high technological value and wide range of industrial applications, especially in automotive applications [1]. This is mainly because of their high strength to weight ratio, good corrosion resistance, formability. Al-Si alloys systems are popular for many engineering casting applications. The trend of the Al-Si alloys are extensively used in automotive industry goes toward the construction of light weight high-powered, comfortable, economical, ecological and safe vehicles [2]. Mainly these alloys containing Si and Cu are heat treatable in cast condition due to precipitation mechanisms to achieve high strengths. Current study considers the cast Al-Si-Cu cast alloy. However this alloy heat treatment follows T6 condition, i.e. three stages involved solution treatment, quenching and aging process [3]. For better mechanical properties spheroidal Si precipitates are necessary, these formed at high temperatures for longer time periods [4]. The heat-treatable alloy undergoes precipitation hardening, fine precipitates will dissolve completely in saturated matrix to achieve high strength in material. The super-saturated solid solution undergoes aging treatment; a large amount of small and uniformly distributed precipitants will appear thus the mechanical properties of material can be improved. Numerous studies have been undertaken on evolution of microstructure, and hardness values of precipitation hardened Al-alloy [5]. Aluminum is a reactive metal, but it develops an aluminum oxide coating or film that protects it from corrosion in many environments. This film is quite stable in neutral and many acid solutions but is attacked by alkalis. This oxide film forms in many environments, but it can be artificially produced by passage of electric current [6-8]. The engineering applications for aluminium and alloys are limited due to poor surface properties, and low abrasion resistance [9]. It is possible that adding alloying elements affects the wear properties for Al-Si-Cu, as it strengthens them through solid solution and hardening precipitation [10, 11]. In this work an attempt has been made to study the effect corrosion rate in mechanical and electrochemical properties of Al-6Si-3 Cu alloy using potentio dynamic techniques

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2. EXPERIMENTAL PROCEDURE:

The chemical composition of the alloy is indicated in **Table 1.**

Si	Cu	Al
6	3	91

Table 1 : Chemical composition of the Al-Si-Cu alloy, %wt

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2.1HEAT TREATMENT:

Samples were cut in the cylindrical shape with diameter of 2 cm and a thickness of 2.5 cm. Later, the samples were polished by using rough polishing belt grinder (120 grid) and with 1/0, 2/0, 3/0 and 4/0 emery papers to obtain smooth surface of the specimen. Microstructures are taken in an optical microscope after etching (HF). In the heat treatment process, involves three stages i.e. solution treatment, water quenching and aging. Here T6 condition is followed i.e. artificial aging. High temperature oxidation furnace (range 1050^0C) and tubular horizontal furnace (range 1350^0C) are used to carry out heat treatment process. Temperatures and holding time has to be programmed in the furnace itself as per requirements. Precipitation hardening consists of solution treatment at 450^0C with holding time 1 hour, water quenching, and artificial aging by different temperature 170^0C, 180^0C, 190^0C with different holding time 1, 3, 6, 9, 12 hours. Precipitation hardening samples were subjected for mechanical test (Hardness test) and Metallographic observations. The samples polished and etched by using HF. These etched samples subjected for optical analysis and microstructures are observed. Hardness measurement was performed by a Rockwell hardness tester with a load of 100kg using 1/16'' hard steel ball diameters.

2.2 CORROSION TECHNIQUES:

2.2.1Corrosion Weight-Loss experiment

To determine corrosion rate, all the samples are immersed in 0.1N HCl for 90 mins. Before and after sample weights are taken from that corrosion rate was determined.

Corrosion Rate: 534ΔW/DAT

Where ΔW is weight difference in milligrams, D is density in g/cc, A is area in cm^2, T is time in hours.

2.2.2 Potentiodynamic Polarization Curves:

A typical three-electrode electrochemical corrosion cell was used in this experiment. A saturated calomel electrode (SCE) was used as reference. All measured potentials were referred to this electrode. A platinum foil was used as the counter electrode. The Aluminium, copper, brass and SS were used as working electrodes [12]. All experiments were carried out using IVIUM potentiostat controlled by a personal computer to obtain the potentiodynamic polarization curves. Before each experiment, the open circuit potential (OCP) was recorded for at least 1 hour. Polarization curves were obtained potentiodynamically; the linear

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potential sweep was performed at a -0.9250 to 1.8V potential window around the measured OCP, from the cathodic to the anodic side, at scan rates of 1mV/s.

3. RESULTS AND DISCUSSION:

The heat treated samples were subjected to optical microscopy at magnifications of 4x, 10x and 40x before etching and after etching for analysis.

3.1 METALLOGRAPHIC OBSERVATIONS:

Figure 1, shows the as received sample microstructure, here Al matrix containing Cu and Si in alloyed form. The inter-metallic precipitates can't be distinguished. Figure 2 to 7 shows the microstructures at different aging temperatures and at different holding times. From above all these, the observation is that Si is dissolved in Al matrix and inter metallic Al_2Cu precipitates are precipitated out of the matrix. At lower temperatures and lower holding times of solution treatment does not completely dissolve the Si and hence formation Si precipitation is not occurs. From the quantitative analysis of Figure 2, two phases are present phase1 is 60.829, phase 2 is 39.76. Figure 3, 4, 7, represents the heat treated Al-Si-Cu alloy at aging temperature 170^0C, 180^0C, 190^0C and at aging time 1h, 3h, 1h. At this temperature Al_2Cu precipitated out of the Al matrix. At this lower aging time Si still in the Al matrix itself. Here mechanical properties are fairly good from hardness tests. Figure 5, 6, 8, are heat treated Al-Si-Cu alloy at aging temperature 170^0C, 180^0C, 190^0C and at aging time 12h, 9h, 12h. At this temperature Al2Cu precipitates are became coarser in the Al matrix when aging time is increased. Here mechanical properties are decreasing.

3.2 HARDNESS TEST MEASUREMENTS:

Hardness test analysis for original sample:

The theoretical hardness value for aluminium alloy 3xx.x-T6 is 109HV. The hardness value of test specimen is 108.5HV.

*3.2.*1 Hardness test analysis for samples ageing at 170^0C*:*

Table 2 shows that the hardness of the alloy increased gradually from under aged region to peak region. However, it decreased over aged region. It shows a small decrement of hardness from 81HV to 76HV at 3 hours of ageing. In contrast rapid hardening occurred in extending ageing time to 6 hours has brought aluminium alloy to reach optimum hardness which was 87HV. The hardness started to decrease to 77HV at 9 hours of ageing. However there was a small increment in hardness to 82 HV at 12 hours of ageing. Thus, if longer time is given, the hardness might still be able to increase a little to reach its highest strength.

3.2.2 Hardness test analysis for samples ageing at 180^{0}C:

From table 2, the hardness of the alloy increased gradually from under aged region to peak region. At 1 hour of ageing the hardness of the sample is 86HV. Extended ageing of artificial aged alloys at 180^{0}C eventually led to the increment of hardness up to a peak value of 103HV at 6 hours of ageing time. It dropped to 88HVat 12 hours.

3.2.3 Hardness test analysis for samples ageing at 190^{0}C:

After the heat treatment, the hardness of aluminium alloy was increased significantly after 1 hour which reached the optimum hardness of 105HV. Subsequently, the hardness began to fall constantly from 83Hv at 3 hours ageing until 80HV of 6 hours ageing time. It shows clearly that ageing of alloy which exceeded 1 hour would come to over aged region.

3.3 CORROSION TECHNIQUES

Increased corrosion along grain boundaries was unavoidable in alloys due to segregation of alloying elements to the grain boundaries. Aluminum is surprisingly resistant to corrosion by considering its low electrode potential. The standard electrode potential is - 1.68V3. A metal with a more electronegative potential is easier to oxidize but the potential depends on the system. Aluminum has an oxide layer Al_2O_3 on the surface, which will strongly influence its electrochemical behavior. The oxide is spontaneously formed in oxidizing media, so Aluminum is naturally passivated by water and oxygen in the air.At higher aging temperatures and times, high corrosion rates are observed for Al-6Si-3Cu alloy. At 170^{0}C on increasing aging time corrosion rates also increased whereas 180^{0}C on increasing aging time corrosion rates are decreased. At 190^{0}C high corrosion rates are obtained from both weight loss and potentio dynamic experiments. The mass loss gives a hint of the corrosion rate of the material as the corrosion process includes metal oxidized into ions. Since these ions leave the al surface to the surrounding electrolyte, the corrosion process involves the mass loss from the metal.

4. CONCLUSIONS:

From the above observation the three peak aged condition were compared i.e. occurred

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during 6 hours of ageing at 170^0C and 180^0C and 1 hour of ageing at 190^0C, it can be concluded that peak aged condition can be achieved at a shorter ageing time by using higher ageing temperature. The highest strength was generally achieved when a large amount of closely spaced, small and round precipitates are coherently dispersed throughout an alloy.

In this current study mechanical properties are optimum at this 450^0C solution treatment temperature and 1h holding time.

From corrosion studies, at 170^0C & 190^0C rate of corrosion rates are increased as aging time and temperature increases, excepting at 180^0C. Hence at this temperatures the mechanical properties and corrosion behaviour of Al-6Si-3Cu alloy are seem to be better.

6. ACKNOWLEDGEMENTS:

We would like to express our sincere gratitude to Prof. Raja Kumar, Vice chancellor, Rajiv Gandhi University of knowledge technologies and Prof. Ibrahim Khan, Director RGUKT Nuzvid for their unconditional support to carry out this work.

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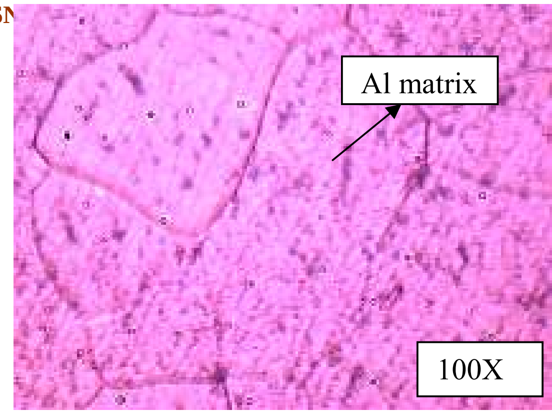

Figure 1: Microstructure for before heat treatment

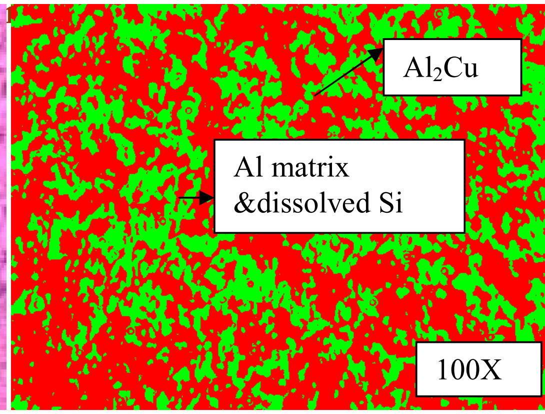

Figure 2: Phase segregation

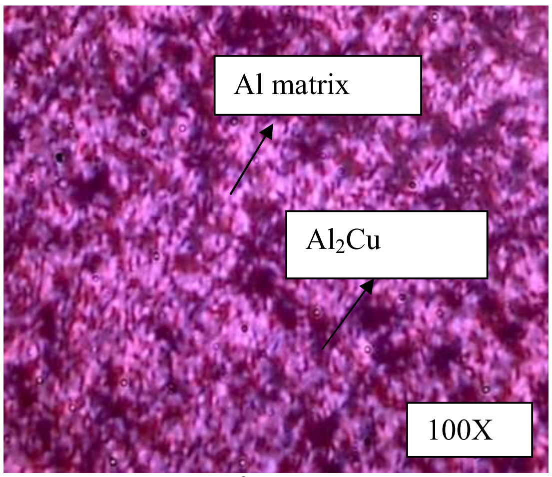

Figure 3: At 170^{o}C ageing for 1h

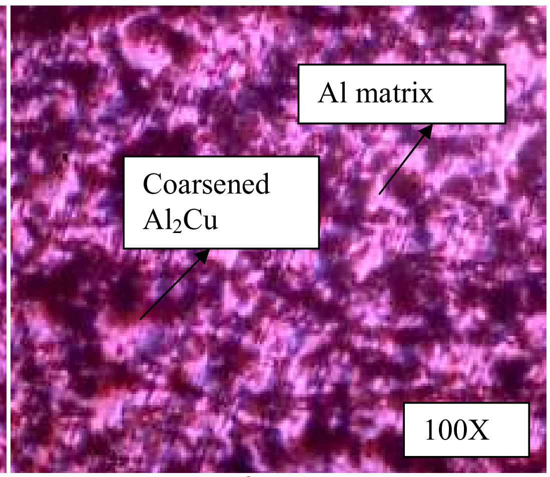

Figure 4: At 170^{o}C ageing for 12h

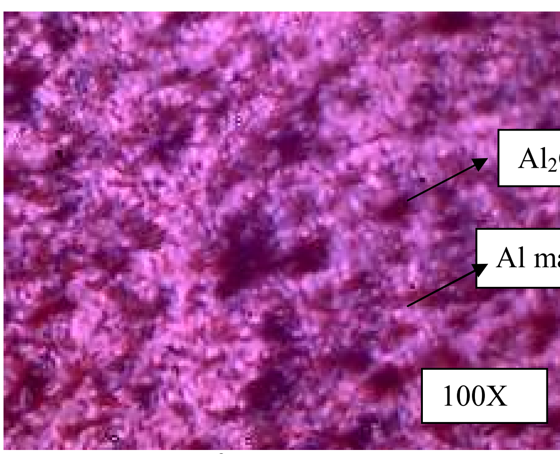

Figure 5: At 180^{o}C ageing for 3h

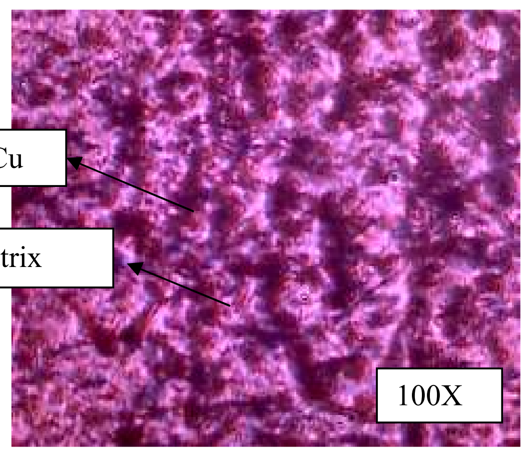

Figure 6: At 180^{o}C ageing for 12h

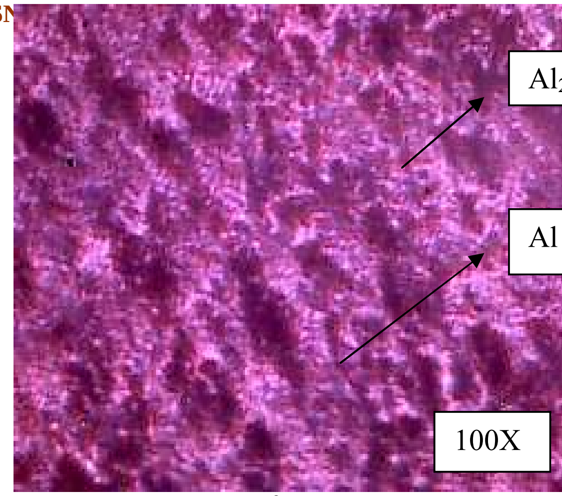

Figure 7: At 190°C ageing for 1h

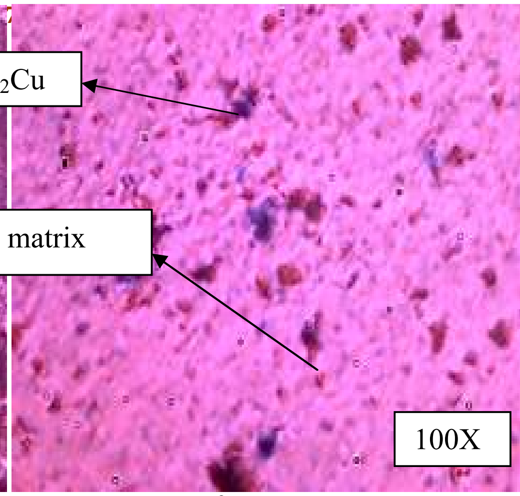

Figure 8: At 190°C ageing for 9h

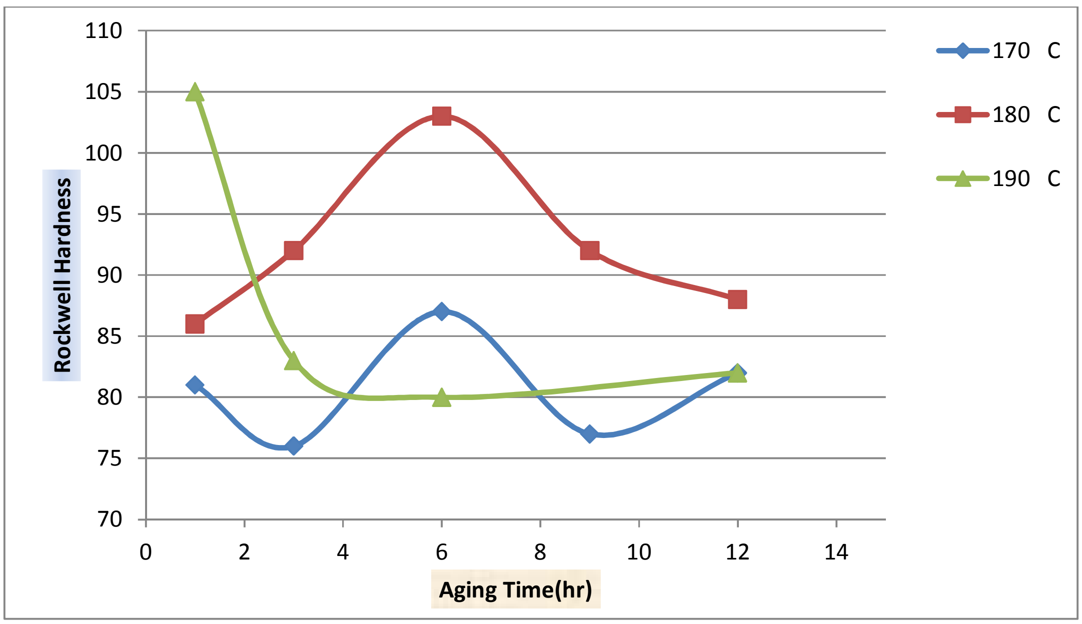

Figure 9: hardness verses ageing time at different temperatures for the heat treated Al alloy

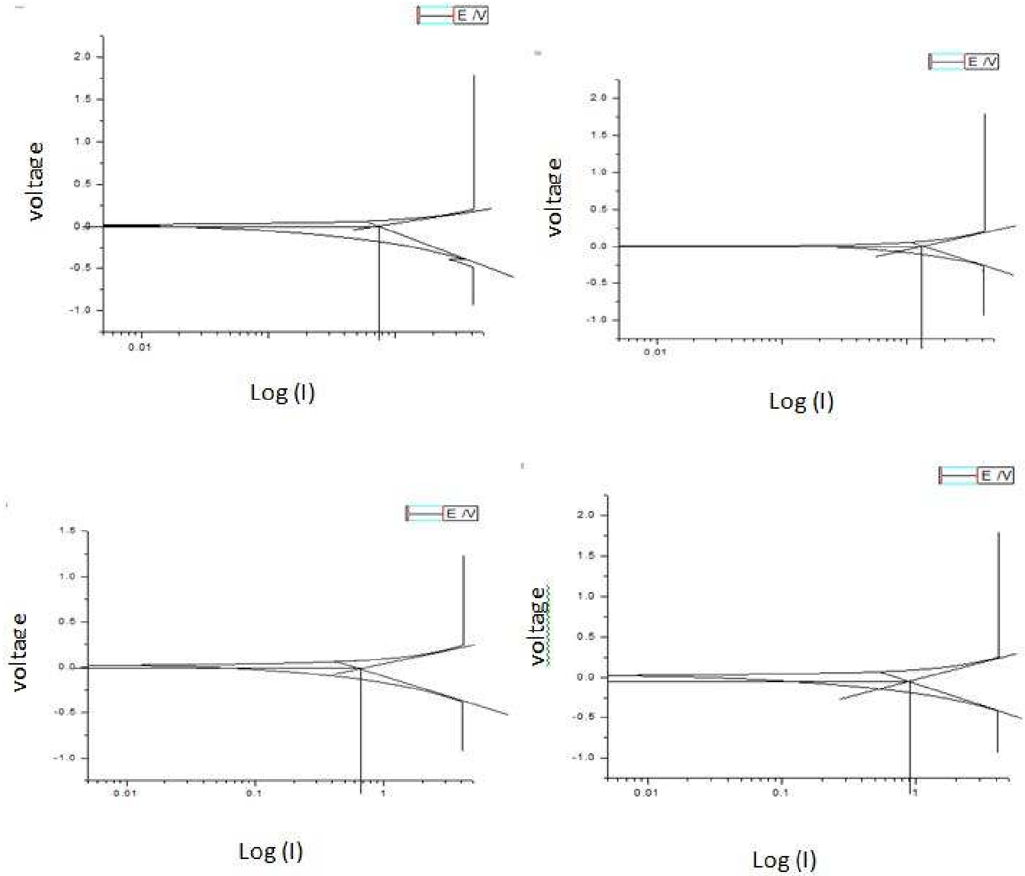

Figure 10: Potentio dynamic graphs are plotted between E Vs log (i) using origin software

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Table 2: Rockwell hardness values at different ageing temperatures with ageing times

Ageing time (in hrs)	HV (at ageing Temperature 170°C)	HV (at ageing Temperature 180°C)	HV (at ageing Temperature 190°C)
1	81	86	105
3	76	92	83
6	87	103	80
9	77	92	--
12	82	88	82

Table 3: Weight loss experimental data

Ageing time (in hrs)	CR (at ageing Temperature 170°C)	CR (at ageing Temperature 180°C)	CR (at ageing Temperature 190°C)
1	5.62	11.63	12.54
3	7.89	9.635	12.32
6	6.30	12.08	11.64
9	10.10	7.060	--
12	14.34	7.690	16.86

Table 4: Corrosion rate from potentio dynamic curves

Ageing time(in hrs)	Ageing temperature 170°C		Ageing temperature 180°C		Ageing temperature 190°C	
	$I_{orrosion}$	CR	$I_{orrosion}$	CR	$I_{corrosion}$	CR
1	3.08760	33.42	-------	-------	3.05344	33.05
3	2.13150	23.07	1.94210	21.02	3.6102	82.30
6	4.41610	47.80	2.97070	32.15	--------	------
9	---------	-------	2.47690	26.81	--------	------
12	3.68700	39.90	1.79170	19.39	3.5630	38.56