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Synthesis and Characterization of Al-Cu-Mg Aluminium Alloys and Study the Effect of Deformation and Aging on their Properties

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Abstract: The binary alloy of Al-Cu and ternary alloys of Al-Cu-Mg was developed. The effect of magnesium content on microstructure and mechanical properties of Aluminium-copper-magnesium alloys was examined for different weight % of Magnesium. Rolling and Full annealing of Al-Cu-Mg Aluminium alloys was carried out. Comparison of microstructures and mechanical properties with different deformation rates and aging time was also done and its effect on properties of Al-Cu-Mg Aluminium alloys was analyzed. These properties were then compared with the properties of AlCu5 alloy which underwent the most optimum heat treatment cycle.

Keywords: Al-Cu-Mg alloys, heat treatment, cold-working, aging, strength, hardness

I. INTRODUCTION

Aluminium alloys find extensive use in the aeronautical, aerospace and automotive industries for making Aircraft structure, rivets, truck wheels, screw and others. These alloys have high levels of ductility, hardness, tensile strength, corrosion resistance etc. Although they have high specific strength, they have been used only as a substitute of iron-based materials for structural parts in the transportation industry.

However, several technical compositions are presently standardized and new alloys based on mentioned metallic system are now being considered and developed. In the binary aluminium-copper system, the aluminium-rich terminal solid solution is in equilibrium with the intermetallic phase Al_2Cu, although some solid solubility exists. Magnesium has been found to improve these properties when added in small amounts. The addition of Mg allows the formation of more intermetallic compounds such as Al_2CuMg, AlCuMg etc. Magnesium increases the strength and hardness of the alloys, but, especially in castings, this is accompanied by a decrease in ductility and impact resistance.

Al-Cu-Mg alloys find extensive use in industries like Aeronautical, Automobile, Railways, Shipbuilding, Construction, High pressure containers etc. due to their high strength to weight ratio. Also, they possess high durability with great ductility, good machinability and weldability. Their electrical-thermal conductivity is high, making them feasible for use in the electrical industry. Moreover, as these alloys are easily fabricated the cost to use these alloys is generally low.

Moreover, different heat treatment techniques have been employed to improve these properties but due to a large number of permutations and combinations left unexplored, the advances in this field are relatively slow. B. Zlaticanin et.al, studied the effect of Mg and Ti on Al-Cu alloys and found Ti to be an effective grain refiner whereas in their study Sani A. Salihu et. al. found both strength, ductility and hardness to decrease in Al-Cu alloys beyond 1.5% Mg. D.H. Xiao et. al. studied about the Effect of Cu content on the mechanical properties of an Al–Cu–Mg–Ag alloy. They concluded upon the fact that Cu improves tensile strength and hardness due to precipitation hardening. With increasing Cu content, fracture mode changed from transgranular fracture to intergranular crack. Biljana Zlaticanin et. al. performed Thermo analysis technique on Al-Cu-Mg alloys. According to them with increased amounts of magnesium for the same content of titanium in the alloy, the average values of the dendrite arm spacing and grain size are decreased.

D.H. Xiao et.al. found that tensile strength of the alloys increased with the titanium content up to 0.6 wt% at all test temperatures up to 350°C. Effect of Deformation and Aging on Properties of Al-4.1%Cu-1.4% Mg Aluminum Alloy was studied by Hao Wang et. al. They concluded that with increasing deformation rate, uniform distribution of grains is obtained with smaller grain size and mechanical properties of alloys aged at 190^0C are better than at 180^0C and 200^0C. A.N. Petrova et.al. and E.D Khafizova et.al. have studied the influence of megaplastic deformation and severe plastic deformation on the properties of Al alloys respectively. They have found that after certain true shear strain, the hardness of the A2024 alloy showed a positive increment when subjected to aging mechanism and for higher strain rates, ultrafine grains were obtained. With deformation temperature lower or equal to the temperature of aging,

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the resulting grain size was smaller that contributed to the accumulation of a higher dislocation density. S. P. Ringer et.al. Studied the Effects of cold work on precipitation in AlCuMg(Ag) alloys and found that Cold work prior to precipitation reduces the response during natural aging in most alloys. Prior cold work was found to slow down the rate of precipitation hardening in AlCuMg(Ag) alloys [1-9].

The objective of present study was to examine the effect of cold-working followed by aging of AlCuMg alloys at high temperature. Heat treatment can be done at varied temperatures and for varied times. One such method for AlCuMg alloys is to treat them in the range of 180-220°C for different time periods. An analysis of different combinations of temperature and time would give us the most optimum combination for heat treating AlCuMg alloys. But such data is not available for values of Mg above 2%. This is where the gap is.

II. EXPERIMENTAL WORK

The binary alloy of ratio 95:5 of Aluminium and Copper was developed. Thereafter ternary alloys of Al-Cu-Mg of various concentrations were made. The effect of increasing Mg content (1-5wt. %) on the Microstructure and Mechanical properties of the alloys was determined. The alloys with Mg conc. 1, 3 and 5 % were selected. These samples were annealed at 430°C for 1.5 hours. Further, the same degree of cold-working (Rolling) measured by the same reduction in width (33%) of identical samples, was performed on all samples. The alloys were then aged at 180, 190 and 200°C for 2, 4 and 6 hours. For this, 9 samples each of composition (1, 3, 5 wt. %) were cut. These 9 parts corresponded to each combination of the temperature and time. A particular combination of temperature and time was selected at one time and samples of each composition were heat treated at that temperature. The most optimum temperature and time combination was inferred from the hardness/Tensile strength readings obtained. Following this, conclusions were made on the most optimal aging mechanism for AlCuMg alloys and their final properties were compared to AlCu sample which underwent the most optimum heat treatment cycle (180,190,200°C for 6 hours).

III. RESULTS AND DISCUSSION

The mechanical properties of the binary alloy of Al-Cu and the microstructures are shown in Table I and Fig.1 respectively. The microstructure shows precipitate of Al_2Cu in solid solution of Copper in Aluminium. Rolling leads to increase in the hardness and ultimate tensile strength of the alloy.

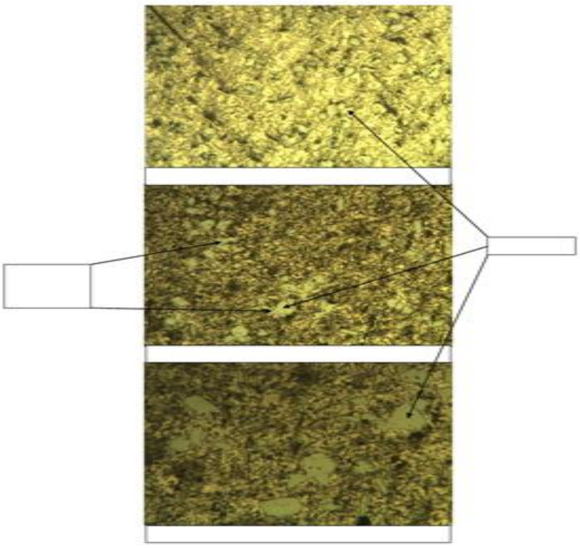

Fig. 1: Microstructure of as-cast, rolled and heat treated alloy with Al_2Cu precipitates (geometric shapes)

Table I: Variation in Tensile Strength and Brinell hardness numbers of as cast alloys and rolled alloys:

Alloy Composition (wt. %Mg)	Hardness (BHN)		Ultimate Tensile strength (MPa)	
	Before Rolling	After Rolling	Before Rolling	After Rolling
0 i.e. Al-Cu	89.0	96.1	126.7	161.8
1	95.2	107.4	143.5	383.9
3	97.3	109.6	200.5	398.2
5	98.6	111.3	236.3	405.1

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The effect of increasing Mg content on the Microstructure and Mechanical properties of the alloys was determined (Table II). The alloys with Mg conc. 1, 3 and 5 % were selected. These samples were annealed at 430°C for 1.5 hours. Further, the same degree of cold-working (Rolling) measured by the same reduction in width (33%) of identical samples, was performed on all samples. The microstructure of Al-5%Cu-5%Mg as cast, rolled and heat treated alloy (Fig.2) shows the formation of AlCuMg and Al_2CuMg at the grain boundaries of Al_2Cu.

Table II: Effect of Mg content on properties of Ternary alloys

Magnesium Content (wt. %)	Type of alloy	Tensile strength of as- cast alloy (MPa)	Yield strength of as-cast alloy (MPa)	Hardness of as-cast alloy (BHN)
1%	AlCu5Mg	143.56	120.60	95.2
2%	AlCu5Mg	178.72	145.45	95.9
3%	AlCu5Mg	200.54	167.86	97.3
4%	AlCu5Mg	220.85	186.51	97.8
5%	AlCu5Mg	236.38	201.96	98.6

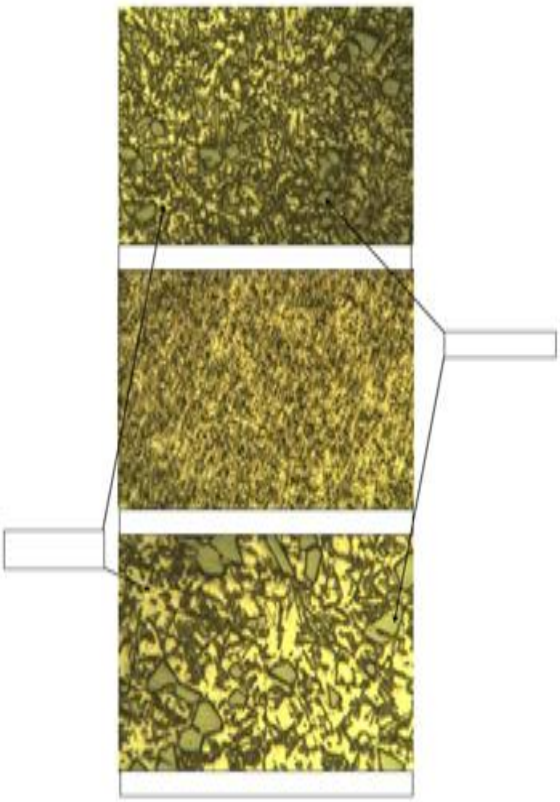

Figure 2: Microstructure of as cast, rolled and heat treated AlCuMg Alloy [5% Copper, 5% Magnesium] with Alpha solid solution (Yellow matrix) and **AlCuMg/Al_2CuMg (geometric shapes)**

The alloys were then aged at 180, 190 and 200°C for 2, 4 and 6 hours. For this, 9 samples each of composition (1, 3, 5 wt%) were cut. These 9 parts corresponded to each combination of the temperature and time. A particular combination of temperature and time was selected at one time and samples of each composition were heat treated at that temperature (Table III).

Table IIIa: Variation in Tensile Strength and Brinell hardness numbers of AlCu5 alloys after Aging

Alloy	Aging Temperature (^oC)	Holding time (in Hrs.)	Hardness (BHN)	Ultimate Tensile strength (MPa)
AlCu5	180	6	115.7	420.8
AlCu5	190	6	120.4	432.5
AlCu5	200	6	118.7	426.8

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Table IIIb: Variation in Tensile Strength and Brinell hardness numbers of AlCu5Mg1 alloys after Aging

Alloy Composition (wt. %Mg)	Aging Temperature (°C)	Holding time (in Hrs.)	Hardness (BHN)	Ultimate Tensile strength(MPa)
1	180°C	2	116.2	401.3
1		4	116.5	403.4
1		6	116.9	408.6
1	190°C	2	118.1	415
1		4	117.2	411.8
1		6	121.1	435.8
	200°C	2	117	410.9
1		4	117.9	414.8
1		6	118.8	422.1

Table IIIc: **Variation in Tensile Strength and Brinell hardness numbers of AlCu5Mg3 alloys after Aging**

Alloy Composition (wt. %Mg)	Aging Temperature (°C)	Holding time (in Hrs.)	Hardness (BHN)	Ultimate Tensile strength(MPa)
3	180°C	2	126.2	449.6
3		4	126.9	453.8
3		6	127.3	458.3
3	190°C	2	128.2	464.4
3		4	129.7	472.6
3		6	133.9	495.5
3	200°C	2	129.2	469.1
3		4	130.5	475.7
3		6	131.3	480.8

Table IIId: Variation in Tensile Strength and Brinell hardness numbers of AlCu5Mg5 alloys after Aging

Alloy Composition (wt. %Mg)	Aging Temperature (°C)	Holding time (in Hrs.)	Hardness (BHN)	Ultimate Tensile strength(MPa)
5	180°C	2	133.8	494.6
5		4	134.5	497.8
5		6	135.2	502.3
5	190°C	2	135.8	505.4
5		4	138.3	513.6
5		6	140.1	525.5
5	200°C	2	137.8	509.1
5		4	138.5	515.7
5		6	139.7	521.8

Following this, conclusions were made on the most optimal aging mechanism for AlCuMg alloys and their final properties were compared to AlCu sample which underwent the most optimum heat treatment cycle (180,190,200°C for 6 hours).

After the different tests conducted on the as cast, rolled and heat treated alloys, these conclusions were deduced: The hardness of the alloys increased linearly with the increase in Mg content. The tensile strength and yield strength of the alloys was also found to increase linearly with the increase in Mg content. The hardness of AlCu alloys even after the heat treatment cycle is much lower than the AlCuMg alloys. During rolling of alloys, it was found that AlCu5 alloys possessed significantly lower ductility than that of AlCu5Mg alloys.

In the range of Magnesium additions tried, the sample containing 5% and heated at 190°C for 6 hours seems to be the most favourable alloy in terms of tensile strength and hardness. It was observed that the alloy AlCu5Mg undergoes new phase precipitation during heat treatment the degree of which increases with time. A peak aging time can thus, be calculated by performing experiments for even longer time ranges. The heat treatment cycles not only reduce internal stresses in the matrix, but also increase the hardness of the alloy due to new phase precipitation.

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