American Journal of Materials Science and Engineering, 2015, Vol. 3, No. 1, 1-6
Available online at http://pubs.sciepub.com/ajmse/3/1/1
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DOI:10.12691/ajmse-3-1-1

Evaluation of Aluminium Alloy for Plasticity Applications

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Received January 07, 2015; Revised January 17, 2015; Accepted January 22, 2015

Abstract An evaluation of aluminium alloy for plasticity applications was undertaken to bridge the gap in appraising the impact of variation of alloying elements such as magnesium (Mg) and copper (Cu) on plasticity as a mechanical property of the aluminium alloy. To this end, twenty seven (27) samples of aluminium alloys were produced with constituents drawn from 6 % zinc (Zn), 2.5 % - 3.5 % magnesium (Mg), 1.8 % - 3.0 % copper (Cu), 0.03 % manganese (Mn), 0.23 % chromium (Cr) and aluminium (Al) as balance in all cases. 0.1 gram of sulphur (S), which the same as the quantity of iron (Fe) in chromium (Cr) and manganese (Mn), was added to oxidize (eradicate) iron (Fe). Samples were subjected to hardness test; to measure the ability of the alloy to resist plastic deformation and percentage elongation (% e) to unveil the mechanical properties of the alloy. Maximum Vickers hardness (Hv) of 130.7 was displayed by an alloy of 6 % zinc (Zn), 2.5 % magnesium (Mg), 1.8 % copper (Cu), 0.03 % manganese (Mn), 0.23 % chromium (Cr) and aluminium, quenched in water at 490°C and soaked for five (5) hours. The same alloy, non-heat treated, displayed a least Hv of 91.5. Hardness increased from 91.5 Hv in an alloy of 2.5 percentage weight of magnesium to 120.3 Hv in an alloy of 3.5 percentage weight of magnesium. Maximum percentage elongation (% e) of 130.00 was recorded by an alloy of 3.5 % Mg and 2.5 % Cu. A least percentage elongation of 12.00 % was established in an alloy of 3.5 % Mg and 3.0 % Cu. The experiment observed that with increase in percentage weight of magnesium from 2.5 % - 3.0 % - 3.5 %, there was variation from 25.67-18.67- 130.00 respectively in percentage elongation. The alloy with 3.5 % Mg, 1.8 % Cu was recommended for plasticity (% elongation) applications. Investigation of the impacts of other constituents on this alloy may be considered.

Keywords: *magnesium, copper, mechanical properties, plasticity, hardness, aluminium, alloy*

Cite This Article: J.D. Amine, K. Abubakar, and L.T. Tuleun, “Evaluation of Aluminium Alloy for Plasticity Applications.” *American Journal of Materials Science and Engineering*, vol. 3, no. 1 (2015): 1-6. doi: 10.12691/ajmse-3-1-1.

1. Introduction

Aluminium comprises approximately 8 % of the earth’s crust, making it second only to Silicon (27.7 %). It can be alloyed with other elements to bring about changes in the properties as desired [15]. Mechanical properties are measures of reaction of a material to an applied load that determine the range of usefulness of a material and establish the service life expected, though it can be altered by heat treatment. Among twelve (12) basic elements added to aluminium, magnesium is frequently used. Four digits are used to describe both wrought and cast alloys, which are further, divided into solution heat treatable and non-solution heat treatable. Wrought alloys are generally used for further fabrication [11].

[16], studied on AA5182 solid solution of Mg in Al, with alloying elements drawn from Al -5.0 % Mg -0.3 % Mn -0.1 % Cu- 0.2 % Si -0.2 % Fe (w.t. %), rolled and annealed sheets. The author varied only the thickness of the samples from 1.5 mm to 2.0 mm. He added Mg to increase strength through solid solution and improve strain-hardening ability. [13] experiment dwelled on superplastic forming response in AA7075 aluminum at approximately 516 °C in a 5-mm thick aluminum alloy. [1] produced an alloy having 4 % zinc by weight and varied composition of Magnesium by weight, [3] experimented on three different Al-Cu alloys of 3,6 and 9 w.t.% Cu and tested both mechanically and chemically. [15] had suggested the need for appraisal of the impacts of these variations in copper and magnesium on hardness and plasticity. Hardness is a measure of a material’s resistance to localized plastic deformation or resistance of metal to plastic deformation, usually by indentation. The softer the material, the larger and deeper the indentation [14].

The intent of this research was to fill the knowledge gap in varying the percentage weight of two constituents; magnesium from 2.5-3.5 % and that of copper from1.8-2.5 % and evaluate the impact of the changes on hardness and percentage elongation aimed at determining the plasticity of the alloy as proposed by [15]. In section I, we present preliminary foundation for this investigation, section 2.0 discussed materials and experimental procedures, section 3.0 discussed the results of experiments and in section IV, we concluded on the evidences obtained from the experiment.

For the sake of simplicity and ease of presentation, we refer to an alloy of 6 % Zn, *2.5 % Mg, 3.0 % Cu*, 0.03 % Mn, 0.23 % Cr and Al balance as an alloy of *2.5 % Mg, 3.0 % Cu* since emphasis is on these two constituents, (Mg and Cu) and aluminium balances the alloy. In addition, the weights of other constituents in the alloys were assumed constant following the [15] investigation.

Plasticity allows components to be formed to required shape by applying pressure and/or tool movement within custom designed forming machines. It is also a measure of elasticity or softness of a metal, which is often measured by elongation and hardness of the material [9].

Hardness has been variously defined as resistance to local penetration, scratching, machining, wear or abrasion, and to yielding. The multiplicity of definitions, and corresponding multiplicity of hardness- measuring instruments, together with the lack of a fundamental definition, indicates that hardness may not be a fundamental property of a material but rather a composite one including plasticity, yield strength, work hardening, true tensile strength, modulus of elasticity, and others [9].

[7] viewed heat-treating as a group of industrial and metal working processes used to alter the physical and sometimes chemical properties of a material. The most common application is metallurgical. Heat treatment techniques include annealing, case hardening, precipitation strengthening, tempering and quenching.

In addition, [5] proclaimed that heat treating for aluminum alloys is frequently restricted to the specific operations employed to increase strength and hardness of the precipitation-hardenable wrought and cast alloys. These usually are referred to as the “heat-treatable” alloys to distinguish them from those alloys in which no significant strengthening can be achieved by heating and cooling. [2] concluded that heat treatments done to increase strength of aluminum alloys are usually a three-step process, viz: (i) solution heat treatment: dissolution of soluble phases; (ii) quenching: development of supersaturation; and (iii) age hardening: precipitation of solute atoms either at room temperature (natural aging) or elevated temperature (artificial aging or precipitation heat treatment).

The general requirement for precipitation strengthening of supersaturated solid involves the formation of finely dispersed precipitates during aging heat treatment (which may include either natural aging or artificial aging).

[2] and [10] made the roles of heat treatment clearer, by outlining the specific functions of heat treatment thus; improvement of ductility, relieving of internal stresses, refinement of grain size, increasing hardness or tensile strength, achieving changes in chemical composition of metals as in the case of case-hardening; modification of electrical conductivity; improvement of toughness; and development of recrystallized structure in cold-worked metal.

Plasticity is often measured in relation to elongation. The conventional measures of ductility are the engineering strain at fracture (usually called the elongation). Tensile tests are performed for several reasons, one been the measurement and determination of percentage elongation [14].

2. Materials and Methods

Materials used for this experiment include commercially available aluminum of 99.9 % purity in the form of bundles of wires, 99.5 % pure zinc and 99.5 % pure cupper in precipitate form, magnesium ligands, Ferro-Chromium (Fe-Cr) ferro- chromium an alloy of 23 % ferro and 77 % chromium in granular, Ferro-Manganese (Fe-Mn) 20 % ferro and 80 % manganese, and sulphur. Other materials include turker hitching solution, Vicker’s hardness test machine, digital weighing machine and photographic visual metallographic microscope following [15].

A permanent mould was designed to produce standard samples of alloy measuring 5 mm gauge diameter and 30 mm gauge length. Percentage weight of Mg and Cu were varied from 2.5 % - 3.5 % and 1.8 % - 3.0 % respectively, while Mn, Cr, and Zn were kept constant as aluminium completes the mixture in all cases. Table 1 shows the alloy configurations adopted for this experiment [15].

Table 1. PERCENTAGE WEIGHT OF CONSTITUENTS SHOWING VARIATION IN MG AND CU

S/N	Constituent	Percentage (% w.t)/ Weight(g)					
		%	g	%	g	%	g
1	Zn	6.00	24.00	6.00	24.00	6.00	24.00
2	Cr	0.23	0.20	0.23	0.20	0.23	0.20
3	Mn	0.03	0.12	0.03	0.12	0.03	0.12
4	Mg	2.50	10.00	3.00	12.00	3.50	14.00
5	Cu	1.80	7.20	2.50	10.00	3.00	12.00
6	Al	Balance					

A portable digital weighing machine was used in measuring the alloy constituents as in Table 1. After the measurement, the crucible was placed in the furnace to preheat it to a temperature of 200°C while eradicating moisture content and prepare it for the melting operation. The temperature was then adjusted to 450°C as requisite before introducing the metal. At this temperature, the refractory crucible containing the measured aluminium was introduced into the furnace in batches according to the variations in magnesium and copper. The temperature was raised progressively to 600°C followed by gradual increment of 50°C per hour to attain a temperature of 1050°C. However, the melting temperature of pure aluminium is about 660°C, but it is necessary to superheat to such a boiling point temperature to attain that closer to other constituents, such as chromium and for proper homogenization. The mixture was placed in the furnace for two (2) hours; it was then removed to introduce the remaining constituents earlier preheated. Zinc, having a melting point temperature of 420°C was charged. It readily melts since it was in granular form. An hour later, the furnace was turned off to reduce the temperature as a requisite to introducing magnesium. A pipe was used as guide to prevent magnesium from getting in contact with the atmospheric oxygen that makes it flammable [12].

Immediately after charging in the magnesium, there was illumination all over the foundry. Rigorous mixing using the ladle followed this. The mixture was totally liquefied, then copper and other constituents were charged one at a time. Since chromium exists as Fe-Cr, with about 67 % chromium and 33 % ferrous (iron) [6] this has reduced the melting point of chromium to about 900°C. The temperature was raised to 1700°C to accommodate

Fe-Mn. After 30 minutes of heating, ferro-manganese powder was introduced, followed by Sulphur to oxidize (eradicate) the Fe in Cr and Mn as the last constituent to be charged. Impurities were observed settled as slag.

Feeding operations was a continuous and speedy one to avoid the effect of oxygen that may cause external solidification on the alloy. Pouring was stopped just when metal was noticed at the risers and gate of the mould, an indication of well-filled cavity. The alloy was allowed for solidification and ejected from the mould after an hour. Then, a stainless steel spoon was used to scrape the cavity and prepare it for another casting operation. Heat treatments were performed as specified in Table 2.

Table 2. SPECIFICATION OF HEAT TREATMENTS CONDUCTED ON ALLOYS

No	Qty	Heat treatments	Soak time (Hrs)	Elements by % in weight
1	3	Hardened, quenched in water at 490°C	5	2.5 Mg, 1.8 Cu
2	3	Stress relief-annealed in oven at 420°C	3	2.5 Mg, 2.5 Cu
3	3	Aged at 200°C, annealed in oven at 430°C	2.5	2.5 Mg, 3.0 Cu
4	3	Solution treated in water at 490°C	5	3.0 Mg,1.8 Cu
5	3	stress relief-annealed in oven at 420°C	3	3.0 Mg, 2.5 Cu
6	3	Aged at 200°C, annealed in oven at 430°C	2.5	3.0 Mg, 3.0 Cu
7	3	Solution treated in water at 490°C	5	3.5 Mg, 1.8 Cu
8	3	stress relief-annealed in oven at 420°C	3	3.5 Mg, 2.5 Cu
9	3	Aged at 200°C, annealed in oven at 430°C	2.5	3.5 Mg, 3.0 Cu

Samples were taken from the alloys to conduct Vickers hardness test. Surface of samples were prepared for microstructure/metallographic investigations. A microhardness tester, which can accommodate sample of 100 x 100 mm with load ranging from 10-1,000 N, was used. The result of hardness is presented in Table 3 and Figure 1 and Figure 2 respectively. Percentage elongation was computed and presented in Figure 3 and Figure 4. Structures observed are presented in Figure 5- Figure 10.

3. Results and Discussion

3.1. Effect of Change in Percentage Weight of Magnesium on Hardness

From Table 3 and Figure 1, sample 4 is the alloy of 6 % Zn, 2.5 % Mg, 2.5 % Cu, 0.03 % Mn, 0.23 % Cr and Al balance according to the experimental design. Before heat treatment, it had a hardness value of 99.9 Hv as cast. The alloy was then heat to 300°C, stress relief-annealed in oven at 420°C. After the treatment, the hardness value increased to 107.70 Hv. The implication of this heat treatment on plasticity and hardness is that heat treatment improved on the hardness of this alloy. An alloy having a composition of 3.0 % w.t Mg and 1.8 % w.t Cu recorded a hardness of 122.6 Hv before heat treatment. The consequence is that an increase in % w.t. of Mg reciprocated increase in hardness. Comparison of the alloy of 3.0 % w.t Mg and 1.8 % w.t Cu and that of 2.5 % Mg, 2.5 % Cu shows an increase of 7.1 Hv in hardness value after heat treatment. It is also an indicator that 0.5 % w.t. increase in Mg produced 7.1 Hv. This result is a pointer that additional Mg increases the hardness of the alloy.

Table 3. HARDNESS TEST RESULT GENERATED TO COMPARE THE IMPACT OF HEAT TREATMENT ON THE ALLOYS

% w.t of Cu in alloy	% w.t of Mg in alloy	Hv before heat treatment	Hv after heat treatment
1.8	2.5	89.5	91.5
1.8	3.0	122.6	129.7
1.8	3.5	120	126
2.5	2.5	99.9	112.7
2.5	3.0	115.6	117.7
2.5	3.5	114.7	113.7
3.0	2.5	117.3	130.7
3.0	3.0	118	119
3.0	3.5	117.3	120.3

A general appraisal of Figure 1 revealed an increase in hardness of alloy, regardless of the % w.t. of alloying elements. It appears any increase in % w.t. of Mg may produce an increase in plasticity, since plasticity was linked to hardness by [9]. The micrograph also revealed a better bond of alloying constituents with increase in Mg. Notable from Figure 1 when placed side-by-side with Table 3 is the variation in hardness, which has remained less significant in samples 5 and 6, alloys of 3.0 and 3.5 % Mg by weight respectively.

In the same vein, an alloy comprising 3.5 % Mg has a hardness value of 120 Hv before heat treatment and 126 Hv after heat treatment. The increase in the percentage w.t of Mg and heat treatment may be responsible for the increase in hardness. This result established the findings of [8]. There was a continuous increment in hardness value in response to the increment of Mg.

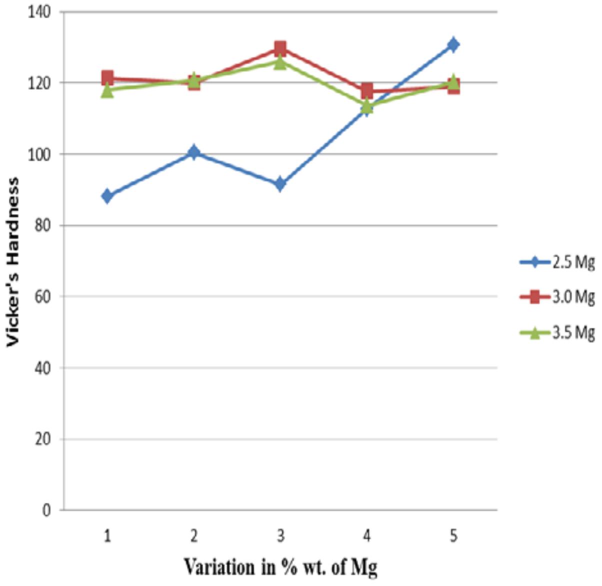

Figure 1. Curve of Vicker's hardness against variation in percentage weight of magnesium

Similarly, sample 6 with a composition of 88.51 % Al, 6 % Zn, 3.5 % Mg, 2.5 % Cu, 0.03 % Mn and 0.23 % Cr had a hardness value of 114.7 as-cast and 113.7 when exposed to stress relief, annealing process in oven with a soak temperature of 420°C and soak time of three (3) hours. In reaction to the heat treatment, an increase in the hardness value was expected, but it was on the contrary.

An alloy with a combination of 88.00 % Al, 6 % Zn, 2.5 % Mg, and 3.0 % Cu, represented on Figure 1 and Table 3 has 117.3 Hv before heat treatment. To drive home the roles played by Mg in hardness and plasticity properties of this alloy, on increment of Mg to 3.0 %, the hardness increased.

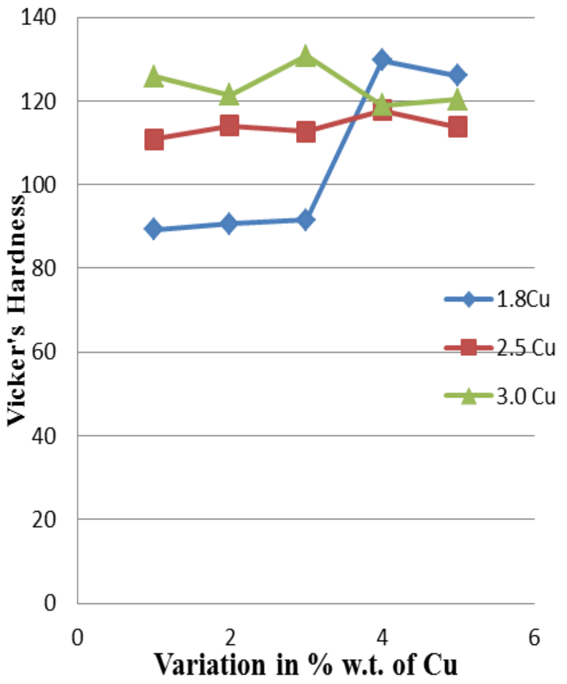

Figure 2. Curve of Vicker's hardness value against variation in percentage weight of copper

Despite this increase, worthy noting of is the uniformity in the result of the alloy. This result depicts the insignificance of changes in Mg on hardness and contradicted that obtained in [4]'s (2010) findings.

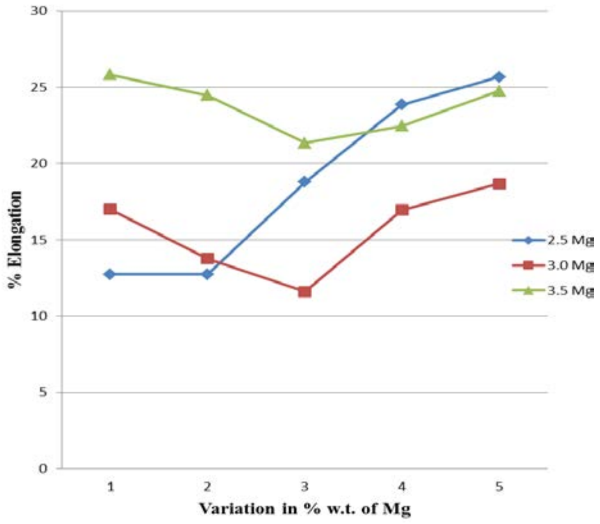

Figure 3. Curve of percentage elongation (% e) against variation in percentage weight of magnesium

3.2. Effect of Percentage Change in Copper on Hardness

Copper is a ductile material, [3]. The addition of Cu resulted in a linear increase of the microhardness. A study of Figure 2 brought to bear that an increase in percentage w.t. of Cu has an increasing potential on hardness with an alloy of 3.0 % Cu recording the highest hardness of 120.3 Hv. In another development, there was a decrease in hardness, when the 2.5 % w.t. Cu alloy recorded a drop from 117.7 to 113.7 Hv. There was however, an upward increase in sample 7; these fluctuations may be due to human error or because of the kind of heat treatment given to the alloy. The result predicts that an increase in percentage of Cu results in a corresponding increase of 13.4 Hv in the hardness values before and after heat treatment. From the forging, an alloy with a composition of 3.5 % Mg, 3.0 Cu, has a hardness value of 117.3 Hv as cast before heat treatment and this value increased to 120.3 Hv after heat treatment. The increment can be associated with the stress relief - annealing which the alloy went through where it was held at a temperature of 430 ^{o}C for two and a half (2.5) hours. The scenario of the increment in the hardness value is as shown in Figure 2. The connotation is that an increase in either % weight of Cu impacts a corresponding increase in plasticity and hardness. This result queues behind that of [1]. The alloy may not have improved corrosion resistance due to galvanic reaction with copper, but may be more plastic [4].

A study of the microstructure also revealed decrease in compaction level with increase in % w.t. of Cu along the grain. There are porous sites that may be corrosion inhibition sites, and may have a negative impact on the plasticity of the alloy.

3.3. Effect of Variation in Magnesium on Percentage Elongation and Microstructures of Aluminium Alloy

Figure 3 represents a curve of the percentage elongation against variation in percentage w.t. of Mg. The microstructures of alloys where percentage w.t. of Mg was varied from 2.5 % - 3.5 % are presented in Figure 5, Figure 6 and Figure 7 respectively. It may be observed that an alloy of 2.5 % w.t, recorded an average elongation of 25.67 %. The alloy with 3.0 % w.t. recorded an average % elongation of 18.67 %. The trend was maintained with an alloy of 3.5 % w.t. Mg recording an average of 130.00 % elongation as the longest elongation obtained in the experiment. This implies that the increase in Mg resulted in increase in elongation.

An interpretation of the micrographs revealed less compaction in the matrix of an alloy of 2.5 % w.t. Mg. With increase in compaction of the matrix at higher % w.t. of Mg. The implication is that an increase in % w.t of Mg increased the elongateability of the alloy which by extension improved on the plasticity of the alloy.

3.4. Effect of Variation in Copper on Percentage Elongation (% e) and Microstructures of Aluminium Alloy

Plasticity is often measured in relation to elongation. Tensile tests are performed for several reasons, one been the measurement and determination of percentage elongation [14]. The result as presented in Figure 4 shows an increase in percentage elongation recorded by an alloy of 1.8 %, 2.5 % and 3.0 % copper respectively. This increase by implication is an increase in plasticity of the alloy.

On another hand, a spontaneous increase in elongation was recorded in an alloy with 2.5 % Cu. There was a drop in this value, which may be due to human error or the type of heat treatment given to the alloy. An alloy of 3.0 % Cu was reported to improve on the elongation of the alloy. The implication is that the higher the % w.t. of Cu, the more ductile and elongateable the material.

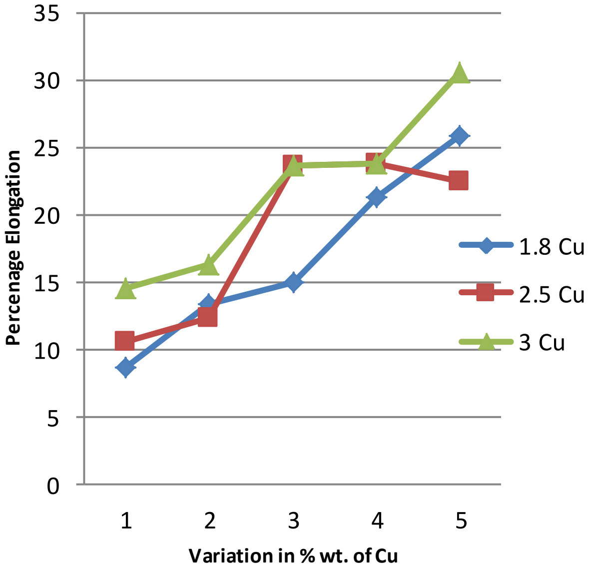

Figure 4. Curve of percentage elongation (% e) against variation in percentage weight of copper

This result aligns with that of [3] since Cu increases the flow rate of the alloy and makes it more plastic.

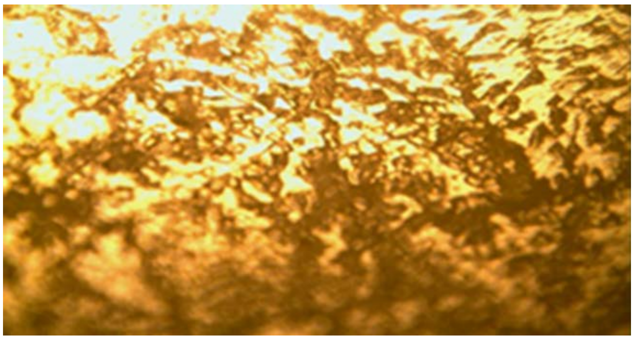

Figure 5. Microstructure of 2.5 % Mg alloy X 250

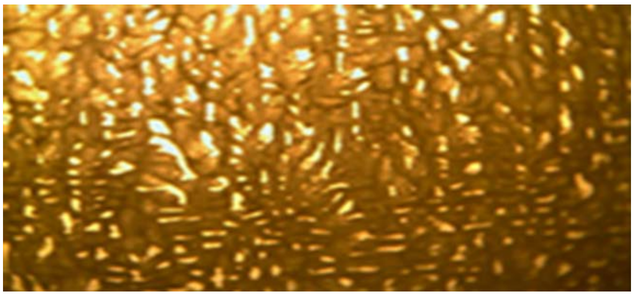

Figure 6. Microstructure of 3.0 % Mg alloy X 250

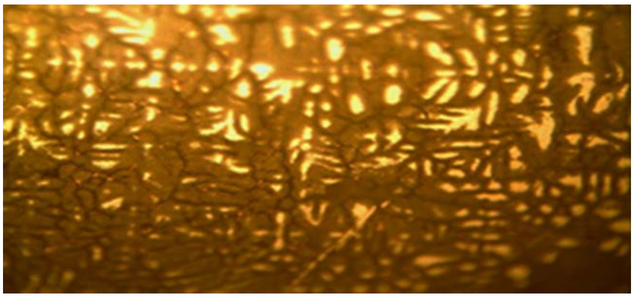

Figure 7. Microstructure of 3. 5 % Mg alloy X 250

The micrograph of an alloy with 89.41 % Al, 6 % Zn, 2.5 % Mg, 1.8 % Cu, 0.03 % Mn and 0.23 % Cr, quenched in water at 490°C, shows Al surrounded by Zn and other constituents that appeared to be scattered all through the alloy as presented in Figure 8, Figure 9 and Figure 10. This alloy also has an elongation of 10 % at a strain rate of 0.1 mm. Regarding the alloy with 3.0 % w.t. Cu, the increment in elongation is almost uniform and it outweighs those with 1.8 and 2.5 % w.t. Cu. This may be expected on the basis of the role of Cu in the alloy. Generally, an increase in the % w.t. of Cu will improve on the ductility, plasticity and by extension the elongation of the aluminium alloy.

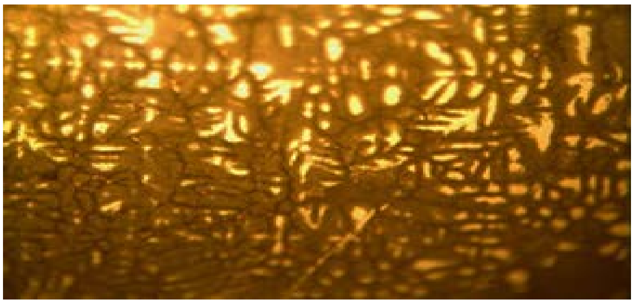

Figure 8. Microstructure of 1.8 % Cu alloy X250

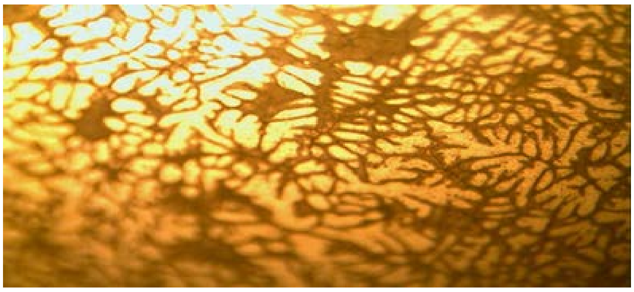

Figure 9. Microstructure of 2.5 % Cu alloy X250

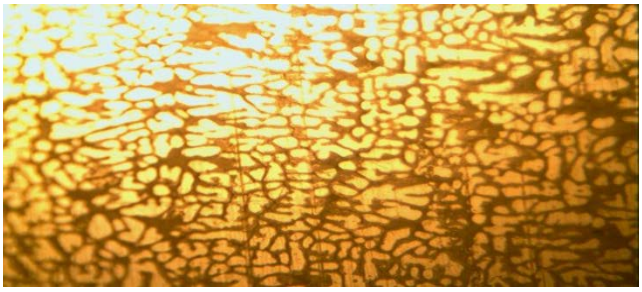

Figure 10. Microstructure of 3.0 % Cu alloy X250

4. Conclusion

Samples of aluminium alloys with compositions drawn from 6 % Zn, 2.5 % -3.5 % Mg, 1.8 %-3.0 % Cu, 0.03 % Mn, 0.23 % Cr and Al as balance in all cases were produced. The variation in 2.5 % -3.5 % Mg and 1.8 %-3.0 % Cu and evaluation these alloys for plasticity was the major achievement of this experiment. Plasticity was measured in terms of hardness and percentage elongation. An increase in percentage weight of Magnesium from 2.5 % -3.5 % increased the hardness of the alloy, but not as much as copper did. In the same vein, an increase in the percentage weight of copper from 2.5 - 3.0 % increased the hardness of the alloy from 119 to 120.30 Hv Plasticity of the alloys also increased with increase in either copper or magnesium.

An increase in percentage weight of magnesium induced corresponding increase in percentage elongation since an alloy of 3.5 % w.t. Mg configuration recorded a maximum of 130.00 % elongation and a decrease in the percentage weight reduced the % elongation of the alloy.

Mechanical properties of aluminium alloys depend not only on the content of alloying elements, but also on their relative chemistries with each other and heat treatments given to the alloy. The alloy of 3.5 % Mg, 1.8 % Cu may be recommended for high elongation applications on the basis of recording the maximum percentage elongation of 130 %.

References

[1] Agarwal, L., Rakesh, Y. and Abhishek, S. (2012). Effect of magnesium content on the mechanical properties of Al-Zn-Mg alloys. International Journal on Emerging Technologies 3(1): 137-140.

[2] Akii, A.O. (1997). Introduction to manufacturing technology, Ambik press, Nigeria. Pp 22-56.

[3] Al-Rawajfeh, A.E. and Al Qawabah, S.M.A. (2009). Investigation of copper addition on the mechanical properties and corrosion resistance of commercially pure aluminum. Emirates Journal for Engineering Research, 14 (1), 47-52.

[4] Aniruddha, M. (2010). Tensile test of aluminium at high temperature. National Institute of Technology Rourkela-769008 unpublished. Assessed online at http://ethesis.nitrkl.ac.in/1805/1/final_year_project_report_aniruddhameena.pdf on 22/1/2012.

[5] Budgen, N.F. (1933). The heat-treatment and annealing of aluminium and its alloy. Sherwood press Inc. Cleveland, Ohio. Pp 43-57.

[6] Dayan, A. D. and Paine, A. J. (2001). Mechanisms of chromium toxicity, carcinogenicity and allergenicity: Review of the literature from 1985 to 2000. Human and Experimental Toxicology 20 (9): 439-451.

[7] Dossett, J.L. and Boyer, H.E (2006). Practical heat treating. ASM International. Pp. 17-22.

[8] Islamgaliev, R.K., Yunusova, N.F., Nikitina, M.A. and Nesterov, K.M., (2010). The effect of alloying elements on superplasticity in an ultrafine-grained aluminum alloy. Advance Material Science. 25 (2010) 241-248.

[9] John, S., Vidosic, J. P., Harold, V. H. and Donald, D. D. (1996). Strength of Materials (Mechanical properties of materials). Pp 1-68.

[10] Keith, P. (2000). Process control applications for materials testing and characterization. Assessed online at http://www.industrialheating.com/articles/86135-process-control-applicatios-formaterialstesting-and-characterization on 6/7/ 2011.

[11] Lyle, J.P., Granger, D.A., and Sanders, R.E. (2005). Aluminium alloys. Assessed online at http://en.wikipedia.org/wiki/ullmann%27s_encyclopedia_of_industrial_chemistry/ww.v.engineering.de/pro.of.Al.pdf on 31/03/2011.

[12] Mohammed, S. (2010). A guide to alloying of non-ferrous metals. Unpublished, paper presented during an in-house seminar at the National Metallurgical Centre, Jos. Pp 1-15.

[13] Murray, M. (2002). Friction stir processing creates aluminum-alloy superplasticity. Assessed online at http://www.industrialheating.com/Articles/Cover_Story/192d4d11febb 7010VgnVCM100000f932a8c0 on 1/11/2011.

[14] Samsudi, S. (2011). Mechanical properties and testing lecture note on materials science (SSP 2412). Physics Dept. Faculty of Science, Universiti Teknologi Malaysia.

[15] Tuleun L.T., Amine, J.D. and Abubakar, K.,(2014). Effect of Variation in Magnesium and Copper on Mechanical Properties of X7475 Aluminium Alloy.” *American Journal of Materials Science and Engineering*, vol. 2, no. 4 (2014): 54-61.

[16] Zhenguo, C. (2010). Superplasticity of coarse grained aluminum alloys. Assessed online at http://www.materials.manchester.ac.uk/documents/research/epsrc/latest/Project%20Number%203%20%20Superplasticity%20of%20coarse%20grained%20aluminium%20alloys.pdf on 28/10/2010.