

THE EFFECT OF THE COPPER 2 – 8 % ON THE CORROSION OF Al – Cu CASTING ALLOYS

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Abstract: Since aluminium's relative density is only about one – third of that of steel or of a copper-base alloy, it is widely used in automotive, constructional engineering, electrical applications and mechanical equipment as in the forms of alloys containing small amounts of other elements. The main aim in the present work is to investigate the effect of copper addition at 2 % intervals starting from 2 % to 8 % on the corrosion resistance and hardness of Al – Cu alloys. It can be concluded from the results of the present work that the corrosion resistance of Al-Cu alloys was observed to show great variety depending on corrosion media. The copper addition was found to play a vital role in influencing the microstructure and improving the hardness of both heat treatable and 60 % rolled alloys.

Keywords: Corrosion, Casting, Al-Cu Alloys

1 INTRODUCTION

Aluminium is a widely consumed metal because of its properties such as low density, high thermal conductivity, cold workability and high brightness. Besides these properties, aluminium has a high corrosion resistance owing to passive aluminium oxide (Al_2O_3) films forming on the surface, very good casting and workability features which make it to be widely used in the fields of constructional and manufacture engineering, metal industry, food and chemical industry, automotive sector, communication and electrical applications and aircraft industry [1].

The addition of alloying elements is made principally to improve mechanical properties such as tensile strength, hardness, rigidity and machineability and sometimes to improve fluidity and other casting properties. Copper is one of the most beneficial alloying element added in improving the characteristic properties of aluminium Al-Cu alloys are preferred in design and manufacturing process due to the contribution of copper to the properties of these alloys in casting practices and favouring mechanical properties. Al-Cu alloys were at one time widely used for gearboxes, and other automobile castings, switch gear, household and industrial fittings, etc.[2,3].

Thus the effect of copper addition to aluminium attracts the attention of many researchers. The main aim in this work is to collect the results of the metallographical and accelerated corrosion experiments on Al-Cu and derive simple solutions to obtain better hardness and corrosion resistance whenever possible. In the Al-Cu binary system, the experimental investigation was concentrated on the alloys with copper content in the range of from 2 to 8 % respectively.

2 EXPERIMENTAL PROCEDURE

Pure copper and pure aluminium are used to prepare Al-Cu alloys having various weight ratios. The purity of copper is 99.9999 % and that of aluminium is 99.825 % as presented in Table 1.

Table 1. Chemical composition of pure aluminium

Elements (wt.%)					
Al	Fe	Si	Ti	Mg	Mn
99.825	0.130	0.004	0.001	0.002	0.002

In this work; alloying operation was performed by adding copper in the ratio of 2 % to 8 % into aluminium and melting in graphite ladle in an induction furnace under atmospheric conditions. Four alloy groups with different copper contents were chosen to determine the effect of copper addition to Al-Cu alloy. Alloys were casted into a preheated permanent mould with a 35 mm diameter and 180 mm length. Before casting process permanent moulds were heated to 300 °C [4]. Cast alloys were chemically analysed with an Analytical Optical emission spectrometer.

To determine corrosion behaviours and hardness of Al-Cu test alloys, the cast rods were investigated in two parts. One part of the rods was subjected to precipitation hardening process and the other was rolled by 60 % reducing ratio. The samples were heat treated followed by quenching in water at room temperature and kept at this temperature for three days to be exposed to natural ageing.

Al-2 %Cu and Al-4%Cu alloys were subjected to precipitation hardening process and solution heat treatment temperatures of these alloys were determined from Al-Cu binary equilibrium diagram [5,6,7]. Al-Cu alloy rods were rolled into square profiles and cut into the form of 25x25 mm profile samples. They were heated for 2 hours at 450 °C for homogenous annealing and were rolled by 60 % reducing ratio [8].

To study on the corrosion behaviour and the Brinell hardness of the alloy, several samples, have 3 mm height, were taken from the centre of as-cast alloy rods and some of these were used precipitation hardening process. The rolled alloy rods were cut into profile pieces having 5-mm thickness. The surfaces of samples were ground with emery papers of numbers 60, 120, 280, 320, 400, 500, 600 in an order. Their surfaces were polished with chrome oxide (Cr₂O₃) and aluminium oxide (Al₂O₃), respectively and were washed with cleaning solution of a mixture of 50% methyl alcohol and 50% di-isopropyl ether. Diameters and thickness' of the samples were measured by Mitutoya 500-151 UCD 15 Digimatic Calliper Compass with an accuracy of 0.0001 mm. Then rinsed with acetone, dried at room temperature and kept until corrosion and Brinell Hardness tests. Some of the samples which were prepared for the recent process were subjected to accelerated corrosion tests at 25 ± 1° C; in (a) 2%, 3.5%, 5% NaCl and 2%, 3.5% H₂SO₄ solutions for 100 hours, (b) EXCO (Exfoliation Corrosion) solution which was prepared in accordance with ASTM G 34 for 48 hours [9,10,11].

Immersion and weight loss methods were chosen as in agreement with the test procedure. Before corrosion tests, samples were weighted by 0.0001 g in sensitive scale. Three samples of each of the as cast, precipitated and hardened, and rolled alloys were immersed into 3 different corrosion solutions of various concentrations. The required quantity of the solution was to be min.40 ml./cm³. To clean corrosion layers of sample surfaces after taking the samples from NaCl and H₂SO₄ solutions, they were put into cleaning solution which was prepared by mixing 450 ml of H₂SO₄ 98% and 50 ml of distilled water for three minutes. Then they were rinsed with acetone and dried at room temperature. For the same aim after taking EXCO solutions, samples were put into solution, which was prepared according to ASTM G1. Then their weight losses were calculated by weighing samples before and after the corrosion tests. Thus, corrosion rates of samples were determined by using the following equation. (1)

$$\text{Corrosion rate} = \frac{K.W}{S.T} \quad (1)$$

Where:

- W : constant depending on alloy
- K : weight loss (g)
- T : time (h)
- S : surface area (m²)

The density of alloys was determined and shown in Table 2. Then constant, depending on alloy, was calculated by following equation. (2)

$$K=10^4.d \quad (2)$$

Where:

- K : constant depending on alloy
- d : density of alloy (g/cm³)

Table 2 .The density of alloys

Alloy	Al-2%Cu	Al-4%Cu	Al-6%Cu	Al-8%Cu
Density (g./cm ³)	2.716	2.774	2.790	2.801

The microstructures of Al-Cu alloys were examined before the corrosion tests [11].

The investigation of the effect of copper addition on hardness, samples were prepared according to the standards for Brinell Hardness tests separately from as-cast, precipitation hardened, rolled alloy rods. They were tested by Brinell Hardness tests [10]. The hardness were measured and shown in Table 3.

Table 3. The hardness of Al-Cu alloy

Alloys	As-Cast (HB)	Precipitation Hardening (HB)	60 %Rolled (HB)
Al-2%Cu	37	46	47
Al-4%Cu	47	52	59
Al-6%Cu	55	----	62
Al-8%Cu	58	----	71

3 RESULTS AND DISCUSSION

In the Al-Cu binary system the experimental investigations were focused on the alloys to search their corrosion behaviours and Brinell hardness values with copper content changing from 2 % to 8 %, respectively. In this work 2%, 3.5%, 5% NaCl, 2%, 3.5% H₂SO₄ and EXCO solutions were chosen as a corrosion solution after searching the literature.

General results obtained from the corrosion and Brinell Hardness tests are as follows:

As-Cast Condition: The corrosion rates of Al-2%Cu and Al-4%Cu alloys in NaCl solutions were found to be 2.9927 g/m²h and 4.2930 g/m²h, respectively. When the copper content was increased to 8%, corrosion rate was to be 7.2456g/m²h. The corrosion rates of these alloys in 3.5 NaCl solutions were determined 2.701 g/m²h and 7.2233g/m²h. When the raise of the copper content was to the value of 8%, corrosion rate increased to 38.9390 g/m²h. In 5% NaCl solution corrosion rates of Al-2%Cu and Al-4%Cu alloys were measured as 4.7344 g/m²h and 26.0163 g/m²h. As changing the copper ratio from 2% to 8%, corrosion rate was determined 45.9050 g/m²h. The macrostructural changes of Al-Cu alloys in 2%, 3.5%, 5% NaCl solutions are shown in Figures 1-4.

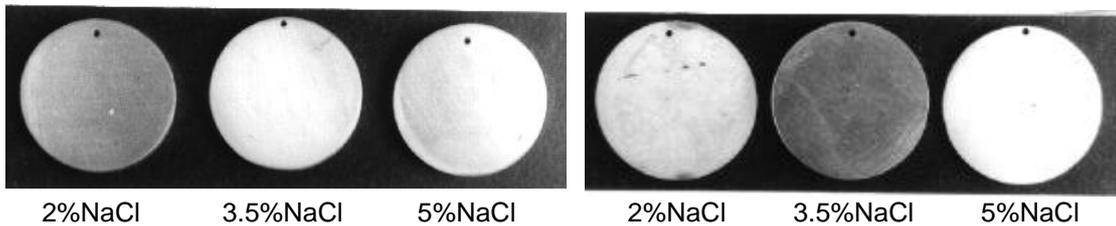


Figure 1. Al-2%Cu Alloy

Figure 2. Al-4%Cu Alloy

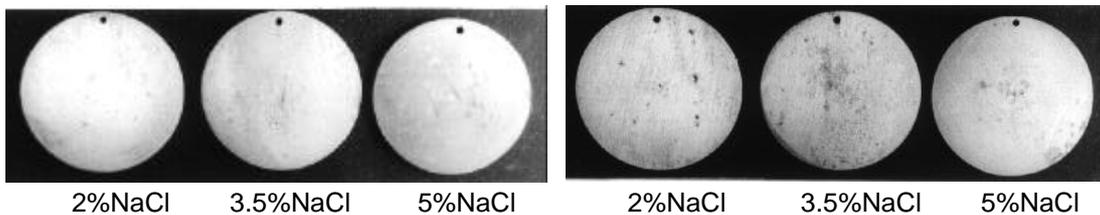


Figure 3. Al-6%Cu Alloy

Figure 4. Al-8%Cu Alloy

The corrosion rates of Al-2%Cu and Al-4%Cu alloys in 2% H₂SO₄ solution were found to be 74.8515 g/m²h and 59.7984 g/m²h. The corrosion rate of Al-8% Cu increased to 145.4763 g/m²h. The corrosion rates of these alloys in 3.5 % H₂SO₄ solution were determined 78.8859 g/m²h and 112.5544 g/m²h, respectively. Changing copper in ratio from 2% to 8%, corrosion inclined to 126.2669 g/m²h. In EXCO solution, the corrosion rates of Al-2%Cu and Al-4%Cu were obtained as 59.640 g/m²h and 89.1991 g/m²h. Changing copper ratio from 2% to 8%, corrosion rate raised to 126.2669 g/m²h. The macrostructures of Al-Cu alloys in 2%, 3.5 H₂SO₄ and EXCO solutions are given in Figures 5-8.

Precipitation Hardened Condition: The corrosion rate of Al-2%Cu alloy in 2% NaCl solution was found to be 4.6583 g/m²h. When the copper content was 4%, corrosion rate increased to 13.6940 g/m²h. As the corrosion rate of Al-2%Cu in 3.5% NaCl was determined 4.3891 g/m²h, the corrosion

rate of Al-4%Cu in the same solution was found to be 18.1169 g/m²h. The corrosion rates of Al-2%Cu and Al-4%Cu alloys in 5% NaCl were found to be 5.0248 g/m²h and 24.5758 g/m²h, respectively. The macrostructures of Al-2%Cu and Al-4%Cu alloys in 2%, 3.5%, 5% NaCl solutions are shown in Figures 9-10.

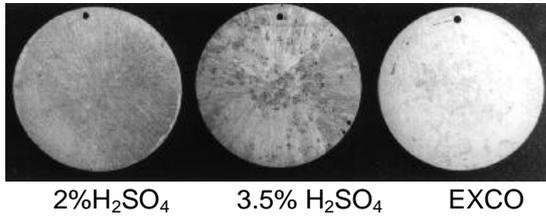


Figure 5. Al-2%Cu Alloy

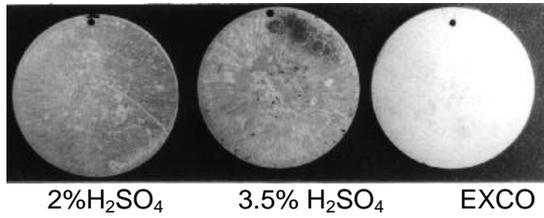


Figure 6. Al-4%Cu Alloy

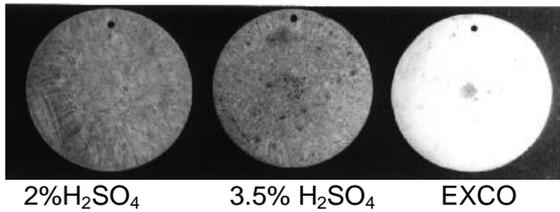


Figure 7. Al-6%Cu Alloy

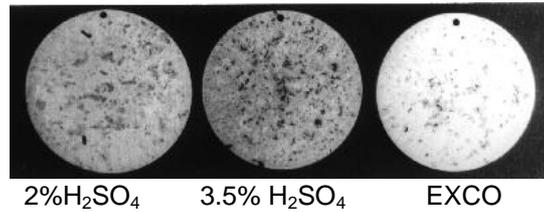


Figure 8. Al-8%Cu Alloy

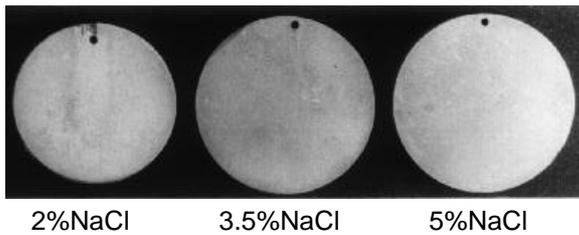


Figure 9. Al-2%Cu Alloy

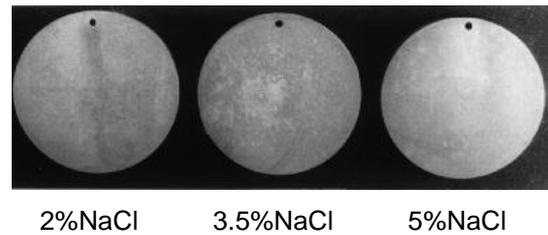


Figure 10. Al-4%Cu Alloy

In 2% H₂SO₄ solution, the corrosion rates of Al-2%Cu and Al-4%Cu alloys were determined 102.1478 g/m²h and 147.5610 g/m²h. Changing corrosion rates of these alloys in 3.5% H₂SO₄ solution were determined as 148.2873 g/m²h and 147.5610 g/m²h. The corrosion rates of these alloys in EXCO solution were found to be 78.007 g/m²h, 94.3472 g/m²h, respectively. The macrostructural changes of Al-2%Cu and Al-4%Cu alloys in 2%, 3.5% H₂SO₄ and EXCO solutions are given in Figures 11,12.

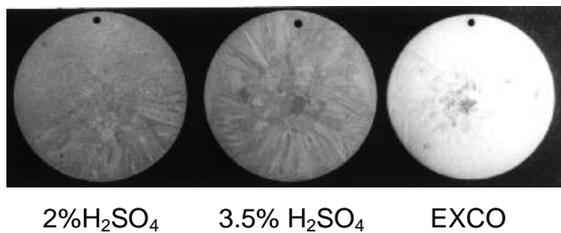


Figure 11. Al-2%Cu Alloy

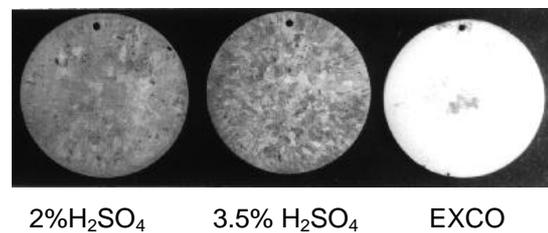


Figure 12. Al-4%Cu Alloy

60% Rolled Condition: The corrosion rates of Al-2%Cu and Al-4%Cu alloys in 2% NaCl solution were found to be 3.9602 g/m²h and 7.4063 g/m²h. When the increase of the copper ratio was to 8%, corrosion rate increased to 13.7907 g/m²h. The corrosion rates of these alloys in 3.5% NaCl were determined 7.4490 g/m²h and 11.1095 g/m²h. Corrosion rate increased to 15.1504 g/m²h by changing copper ratio from 2% to 8%. In 5% NaCl solution, the corrosion rates of these alloys were obtained as 8.1090 g/m²h and 12.4056 g/m²h, respectively. When the copper ratio was increased to 8%, corrosion

rate was found to be $16.1215 \text{ g/m}^2\text{h}$. The macrostructures of Al-Cu alloys in 2%, 3.5%, and 5% NaCl solutions are shown in Figures 13-16.

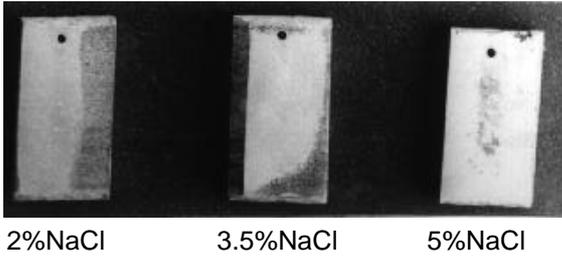


Figure 13. Al-2%Cu Alloy

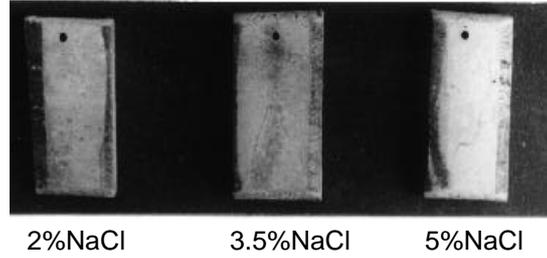


Figure 14. Al-4%Cu Alloy

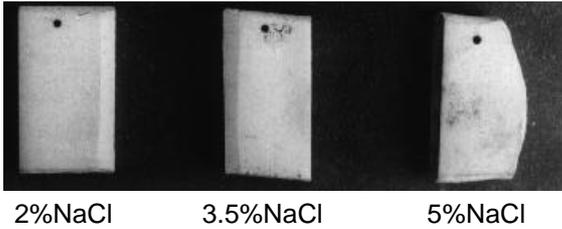


Figure 15. Al-6%Cu Alloy

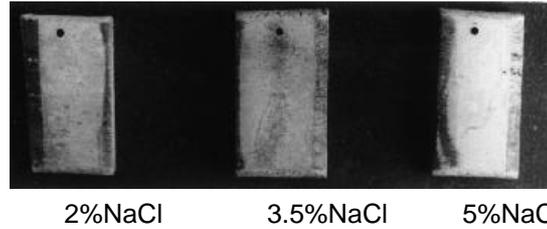


Figure 16. Al-8%Cu Alloy

The corrosion rates of Al-2%Cu and Al-4%Cu alloys in 2% H_2SO_4 were found to be $41.2366 \text{ g/m}^2\text{h}$ and $50.0544 \text{ g/m}^2\text{h}$, the corrosion rate of Al-8%Cu was determined as $120.8147 \text{ g/m}^2\text{h}$. The corrosion rates of these alloys in 3.5% H_2SO_4 solution were found to be $59.9333 \text{ g/m}^2\text{h}$ and $74.3102 \text{ g/m}^2\text{h}$. When the copper ratio was increased to 8%, the corrosion rate value was $164.2588 \text{ g/m}^2\text{h}$. In EXCO solution, the corrosion rates of these alloys were obtained as $3.8088 \text{ g/m}^2\text{h}$, $57.0904 \text{ g/m}^2\text{h}$ and $137.8535 \text{ g/m}^2\text{h}$, respectively. The macrostructural changes of Al-Cu alloys in 2%, 3.5% H_2SO_4 and EXCO solutions are given in Figures 17-20.

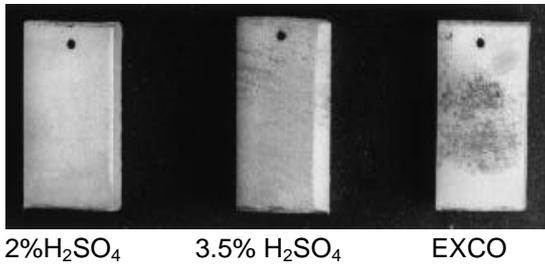


Figure 17. Al-2%Cu Alloy

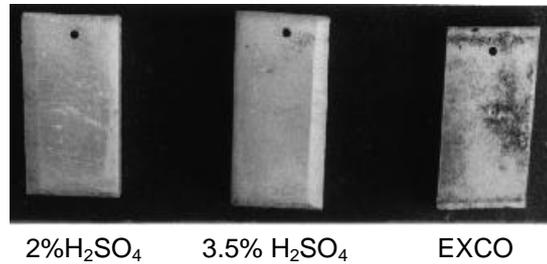


Figure 18. Al-4%Cu Alloy

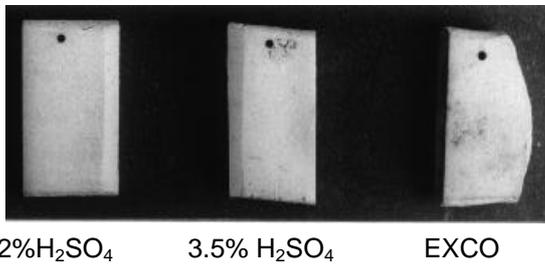


Figure 19. Al-6%Cu Alloy

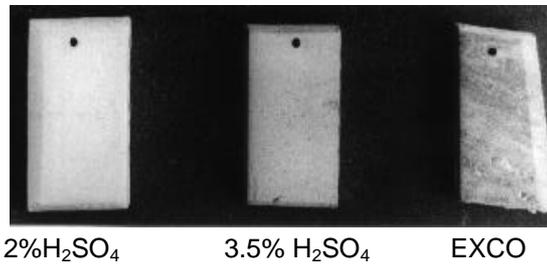


Figure 20. Al-8%Cu Alloy

As a result of the observations of macrophotographs of sample surfaces, in NaCl solutions; surfaces of as-cast and rolled specimens were observed as having smooth surface in Figures (1,2,3,4,13,14,15,16) but precipitation hardened samples were observed as small pits in Figure .9,10. Precipitation hardened samples were observed as more intergranular pittings locally in H_2SO_4 compared to as-cast sample surfaces in Fig.5,6,7,8,11,12. On the rolled sample surfaces less pitting were observed (Figures. 18, 19, 20). The yellow layer was formed on all the corrosion sample

surfaces and these samples were observed as intergranular corrosion in macrolevel in EXCO solutions, but on the other hand no pittings on these surfaces were observed in the same solutions. As a result of the investigations of the microphotographs of Al-Cu alloys, the increase in copper content from 2 % to 8 % caused more CuAl_2 intermetallic compound to precipitate on intergranulars and played a bad role to decrease corrosion resistance in all corrosion solutions.

The Brinell Hardness of Al-Cu alloys depended on the increased copper ratio from 2% to 8%, as-cast, precipitation hardened and rolled conditions as well. Measured hardness of these alloys are given as graphics in Figure 21.

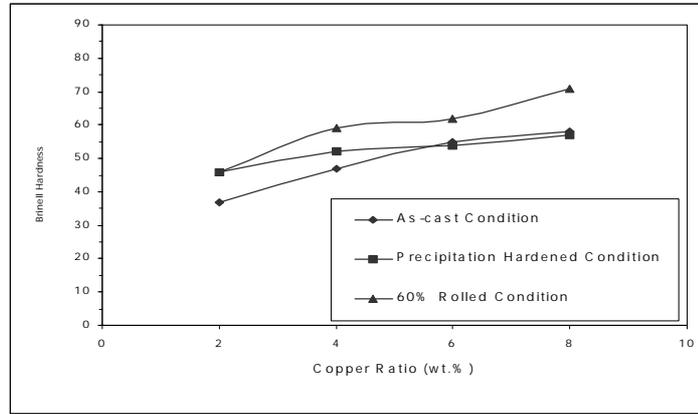


Figure 21. The Brinell Hardness of Al-Cu alloys

4 CONCLUSION

It was observed that the corrosion resistances of as-cast, precipitated hardened and rolled specimens, which have been prepared from Al-Cu alloys, show great variety depend on corrosion solutions.

The precipitation hardening process was found to play a vital role for decreasing the corrosion resistance of Al-Cu alloys.

Higher corrosion resistance was obtained with Al-2 %Cu cast specimens in 2%, 3.5% and 5% NaCl solutions compared to the other Al-Cu alloy specimens.

It was also obtained that rolled specimens which were prepared from Al-2 %Cu alloy give a better corrosion resistance in EXCO solutions than the as-cast and precipitation hardened specimens.

The low corrosion rates for Al-2%Cu and Al-4%Cu rolled specimens were obtained in 2% and 3.5% H_2SO_4 solutions.

It was found that by adding copper, the Brinell Hardness of rolled samples was more than as-cast and precipitated and hardened sample values.

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