Investigation of mechanical properties of pure aluminum by variation of copper content

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Abstract - *Aluminum alloys are widely used in automotive industries. This is particularly due to the real need to weight saving for more reduction of fuel consumption. The typical alloying elements are copper, magnesium, manganese, silicon, and zinc. Aluminum alloy is one of the metallic materials most used in metal working industry and its use has greatly increased in the aeronautics and automotive areas. Low weight/strength ratio, good electric and thermal conductivity, mechanical strength and good machinability are some of the properties that improved their market share. The aluminum due to its excellent qualities has taken important place in engineering applications, making it the most produced non-ferrous metal in the metallurgical industry. Copper is the only material that is having greatest impact of all alloying elements on the strength and hardness of aluminum cast alloys. Cu improves the machinability of aluminum alloys by increasing the hardness, making it easier to generate small cutting chips and fine machined finishes. On the other side, copper generally reduces the corrosion resistance of aluminum and, in certain alloys and tempers, it increases the stress corrosion susceptibility. Copper is generally used to increase the tensile strength and hardness through heat treatment. It also reduces the resistance to corrosion and hot cracking, or hot tearing.*

In this work, emphasis is given on the influences of copper in aluminum. A total four alloy were made with variation of copper in the composition of 1.62, 6.86, 12.54 and 17.31% using die casting process and their mechanical properties were calculated and analyzed. Tensile test bar was tested at room temperature. The addition of copper resulted in a linear increase in tensile strength. The maximum ultimate tensile strength was obtained in 121.98MPa at 17.31% of copper content.

Key Words: Aluminum, Copper, Ultimate tensile strength

1. INTRODUCTION

Aluminum is one of the metallic materials most used in metalworking industry and its use has greatly increased in the aeronautics and automotive areas. Low weight/strength ratio, good electric and thermal conductivity, mechanical strength and good machinability are some of the properties that improved their market share. The aluminum due to its excellent qualities has taken important place in engineering applications, making it the most produced non-ferrous metal in the metallurgical industry.

Due to the wide use of aluminum alloys, mainly in automotive and aeronautic industry, and their large participation in the market, the producers need more knowledge about the alloys behavior in manufacturing process to provide more technical data for his clients. In this scenario the machining is one of the most used processes in the industry.

The aluminum-copper alloys typically contain between 2 to 10% copper, with smaller additions of other elements. The copper provides substantial increases in strength and facilitates precipitation hardening. The introduction of copper to aluminum can also reduce ductility and corrosion resistance. The susceptibility to solidification cracking of aluminum-copper alloys is increased; consequently, some of these alloys can be the most challenging aluminum alloys to weld. These alloys include some of the highest strength heat treatable aluminum alloys. The most common applications for the 2xxx series alloys are aerospace, military vehicles and rocket fins. The addition of alloying elements including copper, silicon, magnesium and nickel can improve the mechanical and tribological properties of zinc-aluminum alloys [1-4]. Copper was found to be the most effective alloying addition towards improving mechanical and tribological properties of these alloys [5-10]. The mechanical properties of aluminum, nylon, GFRP, aluminum-GFRP composite & aluminum-nylon composite were found by using experimental method, The deflection of aluminum composite beams is less than that of pure material beams, the natural frequencies of pure materials (GFRP & Nylon) are larger than those of composite beams made by them if nylon is taken as synthetic fiber with Al, but if GFRP is taken then its deflection is found to be increased when compared to pure GFRP. So, nylon suits good to make composite beam with Al as compared to other synthetic fibers like GFRP [11, 12]. However, the effects of copper content on friction and wear properties of these alloys have not been fully established. It is therefore the purpose of this work to investigate the effect of copper on the friction and wear properties of monotectoid-based zinc-aluminum-copper alloys and to determine the optimum copper content. Copper alloys, including bronzes, are currently employed in a wide range of engineering applications because of their high ductility, high corrosion resistance, non-magnetic properties, excellent machinability, and high hardness [13]. Copper is used for electric wiring and in heat exchangers, pumps, tubing, and several other products, while aluminum bronze and high-strength brass are found in marine applications, for example in propellers and propeller shafts

[14]. Furthermore, shiny brass is widely employed for coins and for musical instruments. However, in spite of their excellent material characteristics, there is still scope for technical improvements to increase the strength and ductility of these alloys. To achieve improvements in mechanical strength, several copper alloys with high dislocation density and fine microstructure, containing solid solutions, have been proposed. The mechanical strength of ultrafine-grained or nano crystalline Cu-Al of pure material beams, the natural frequencies of pure materials (GFRP & Nylon) are larger than those of composite beams made by them if nylon is taken as synthetic fiber with Al, but if GFRP is taken then its deflection is found to be increased when compared to pure GFRP. So, nylon suits good to make composite beam with Al as compared to other synthetic fibers like GFRP [11, 12]. However, the effects of copper content on friction and wear properties of these alloys have not been fully established. It is therefore the purpose of this work to investigate the effect of copper on the friction and wear properties of monotectoid-based zinc-aluminum-copper alloys and to determine the optimum copper content. Copper alloys, including bronzes, are currently employed in a wide range of engineering applications because of their high ductility, high corrosion resistance, non-magnetic properties, excellent machinability, and high hardness [13]. Copper is used for electric wiring and in heat exchangers, pumps, tubing, and several other products, while aluminum bronze and high-strength brass are found in marine applications, for example in propellers and propeller shafts [14]. Furthermore, shiny brass is widely employed for coins and for musical instruments. However, in spite of their excellent material characteristics, there is still scope for technical improvements to increase the strength and ductility of these alloys. To achieve improvements in mechanical strength, several copper alloys with high dislocation density and fine microstructure, containing solid solutions, have been proposed. The mechanical strength of ultrafine-grained or nanocrystalline Cu-Al alloys, prepared by equal-channel angular pressing (ECAP), has been investigated, and the strength and uniform elongation of these alloys have been simultaneously improved by lowering the stacking fault energy [15]. The hardness of even nanocrystalline copper with grain size as small as 10 nm still follows the Halle Petch relation [16]. A variety of methods have been used to make high-strength copper alloys. A attempted to create a higher-strength Cu-Mg alloy through a solid-solution hardening effect, in which supersaturation with Mg increases the strength compared with that of a representative solid-solution Cu-Sn alloy [17]. A high tensile strength of 600 MPa was reported, who produced a Cu-Al alloy with ultrafine-grained microstructure and very fine annealing twins by cryorolling and annealing at 523 K for 15 min. The higher strength of this Cu-Al alloy was interpreted in terms of the enhanced solid-solution strengthening effect of Al, which is about 1.7 times higher than the corresponding effect in Cu-Zn alloys [18]. When copper (Cu) is added to Al-Si-Mg aluminum alloys, the Al-Cu-Mg-Si alloys family is formed with several properties and applications. The aging response of these alloys is often complex due the occurrence of many intermediate phases. Large strength increases can be achieved adding Cu in Al-Si-Mg alloys. Increasing the copper content of 1 to 6%, the tensile strength increases from 152 to 402 MPa and the hardness increases from 45 to 118 HB [19]. Aluminium alloys with silicon as a major alloying element are a class of alloys, which are the basis of many manufactured castings. This is mainly due to the outstanding effect of silicon in the improvement of casting characteristics, combined with other physical properties, such as mechanical properties and corrosion resistance [20].

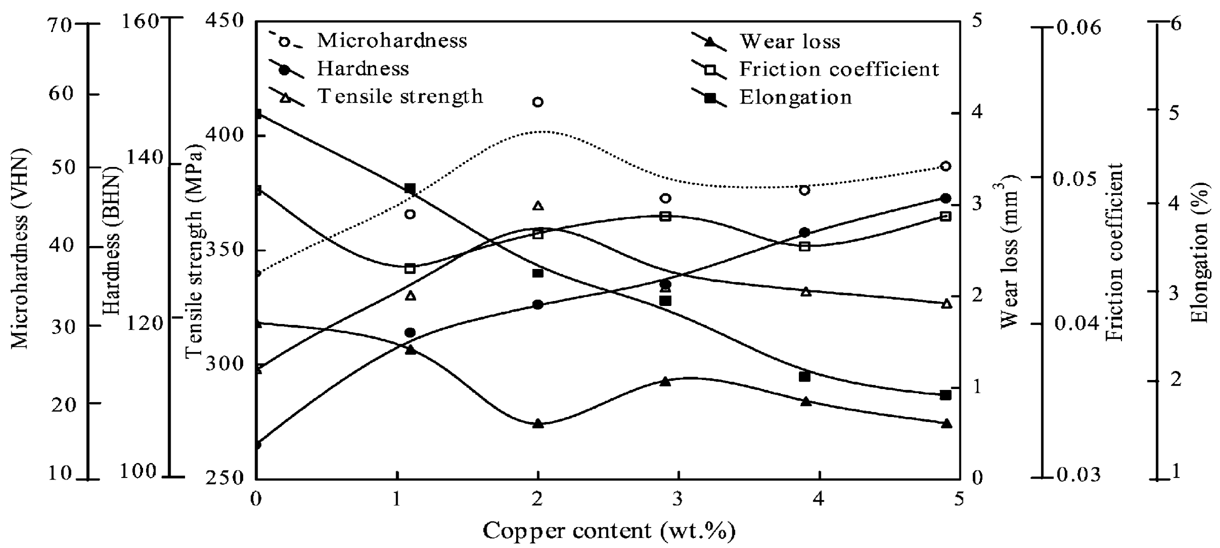


Figure: 1 Effect of copper content on the hardness, tensile strength, percentage elongation, friction coefficient and wear loss of monotectoid-based Zn-Al-Cu alloy [29]

Silicon is present as a uniformly distributed fine particle in the structure. However, when the primary silicon appears as coarse polyhedral particles, the strength properties decrease with increasing silicon content, but the hardness goes on increasing because of the increase in the number of silicon particles [21]. Ultimate tensile strength of the alloy improved as compared to LM 12, the solidifications temperature for Al-Alloy reduces and this is an important factor to consider which temperature the heat treatment not should exceed. When increase the silicon content then the melting point of aluminium alloy is decreases whereas fluidity was increases [22, 23].

The ultimate tensile strength and hardness of bimetallic weld joint increases by increasing the pre-stress, and ductility was decreases when thermal loading increases. For preventing brittle failure behavior of carbon steel the value of pre-stress and thermal stress should be low as possible [24-28].

The hardness of the alloys increased almost continuously with increasing copper content up to 5% (Fig. 1). However their tensile strength increased with increasing copper content only up to 2% above which the property decreased as the copper content increased (Fig. 1). The increase obtained in both hardness and tensile strength of the alloys results from the solid solution strengthening. However the decrease observed in the tensile strength of the alloys containing more than 2% Cu. The tensile strength of the alloys increased, but their volume loss due to wear decreased with increasing copper content up to 2%. Above this level, the tensile strength decreased but the volume loss showed an increase. However the hardness of these alloys continuously increased with increasing copper content (Fig. 1) [29].

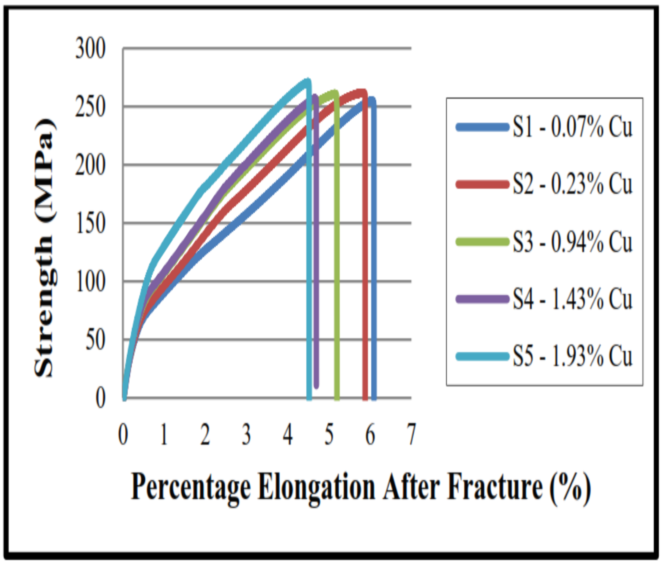


Figure 2: Strength versus percentage elongation after fracture of 6351 aluminum alloy samples [30]

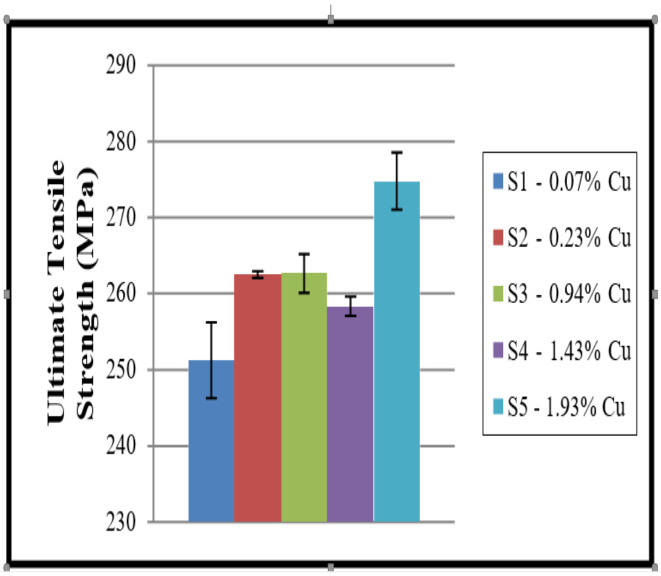


Figure 3: Ultimate tensile strength of 6351 aluminum alloy samples [30]

The average values of ultimate tensile strength and its standard deviation are shown in Fig. 3. It can be seen that the sample S1 with the lowest amount of copper (0.07%) was the one with the lowest average ultimate tensile strength (251.3 MPa) among the tested samples. In turn, the sample S5 with higher copper content (1.93%) showed ultimate tensile strength of 274.8 MPa. Comparing samples S1 and S5, which are the extremes with respect to copper content, the increase in copper content of 0.07% up to 1.93% meant an increase in strength by about 9%. In contrast, samples S2, S3 and S4 with intermediate levels of up to 1.43% copper showed intermediate values of mechanical resistance in the range of 258 MPa to 262 MPa, but as the standard deviation of these samples overlap is not possible to say that there is a real difference between the mean values of resistance shown by these samples [30].

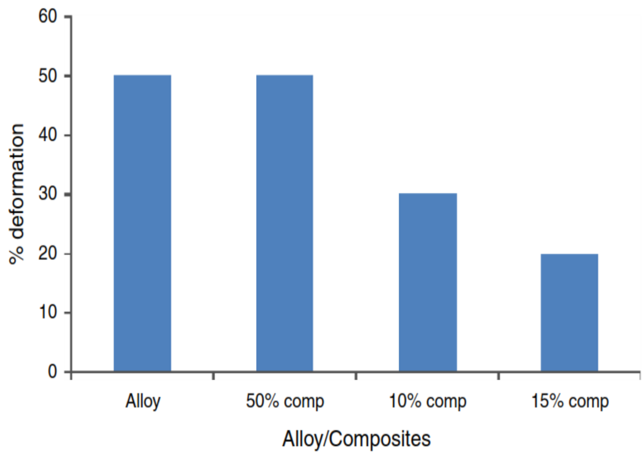


Figure 4.Effect of copper content on deformation, alloy and composites [31].

Figure: 5.Clustering of particulates Al–15%Cu composite,100× [31]

The thorough deformation of the alloy is self-explanatory as it consists of a solid solution of aluminum and inter metallics CuAl. The composite having similar composition does consist of a lean aluminum–copper alloy matrix and the copper particulates as reinforcements with an interface, comprising a series of alloys from the matrix to the reinforcement, aluminum rich alloys to copper rich alloys, respectively.

The voids present cause the decrease in strength. Secondly, there is always a chance of agglomeration of particles with an increased reinforcement content. This leads to the formation of voids and this effect accumulates further during deformation. The agglomeration of particulates multiply the effect of the drop in strength as shown in (Fig.5) Composites with higher concentrations (10% and 15%) of reinforcement have failed at 30% and 20%, respectively (Fig. 4). The reason for the early failure is due to the fast addition of the reinforcements in short times (30 s), leading to agglomeration/clustering (Fig.5). During deformation, agglomerates result in homogeneous deformation cause void generation between the particulates (Figs. 6 and 7) [31].

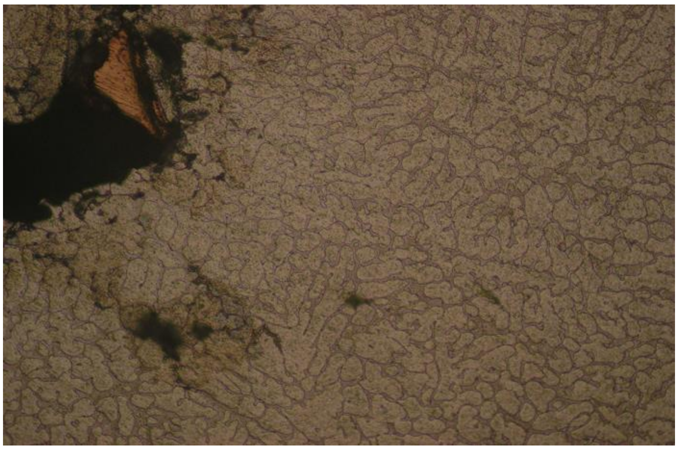


Figure 6: Microstructure showing presence of void in composite, 100×. [31]

The amount of alloy content has gone beyond 5%, which has become stronger than the Reinforcement causing the void formation due to the lack of compatibility between the matrix, interface and the reinforcement. Figs. 6-7 show the microstructures of the composite, with 15% reinforcement.

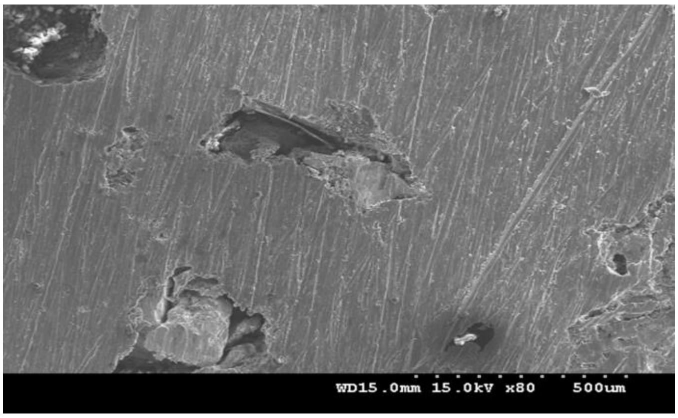


Figure 7: Presence of voids in composite [31]

2. EXPERIMENTAL PROCEDURE

Cut ingots of pure copper are melted in a furnace in clay graphite crucible at 1050^{0}C. Pure aluminum pre weighted quantity pieces were added and the same temperature is maintained until aluminum melt completely

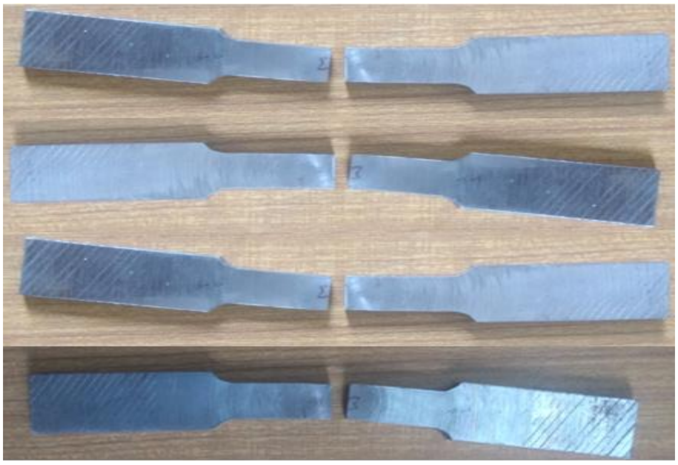
(a)

(b)

Figure: 8 (a) Pouring of molten metal into mould cavity, (b) Casted product

The surface finish obtained in castings is generally poor (dimensionally inaccurate), and hence in many cases, the cast product is subjected to machining processes like turning or grinding in order to improve the surface finish. The test specimens were made according ASTM code D638-02 as shown in table 1 and the figure of the same as shown in fig. 9a. The tensile strength, and elongation of the specimen were performed on a universal testing machine having capacity of maximum 10 ton and loaded at the rate as per the ASTM guidelines and the figure of broken tensile specimens is show in fig.9 (b).

(a)



(b)

Figure: 9 (a) Tensile Test specimen, (b) Broken specimen

Specification of Specimen

All the specimens are made with the help of ASTM code D638-02 and have the characteristics show in the Table 1.

Specimen 1: Aluminum (Type-I)
Specimen 2: Aluminum (Type-II).
Specimen 3: Aluminum (Type-III)

Similarly all the three specimens are made by Type-I, Type-II and Type-III for aluminum alloys and their individual material.

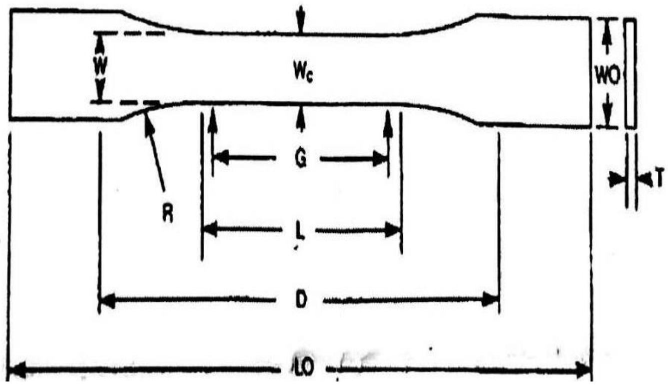


Figure 10: Drawing of Test Specimen [22]

Four specimen with different levels of copper (1.62, 6.86, 12.54 and 17.31%) concentration were casted for this work. Samples of aluminum were produced. The specimen were prepared with dimension as per ASTM D638-02 code as shown in table 1.

Specimen Dimensions in mm			
Dimension (See Drawing)	Thickness 7 mm or less		Over 7 to 14 mm
	Type-I (mm)	Type-II (mm)	Type-III (mm)
W- Width of Narrow Section	13	6	19
L-Length of narrow section	57	57	57
WO-Width over all	19	19	29
LO-Length over all	165	183	246
G- Gage length	50	50	50
D-Distance between grips	115	135	115

Table: 1 Dimension of test specimen [22]

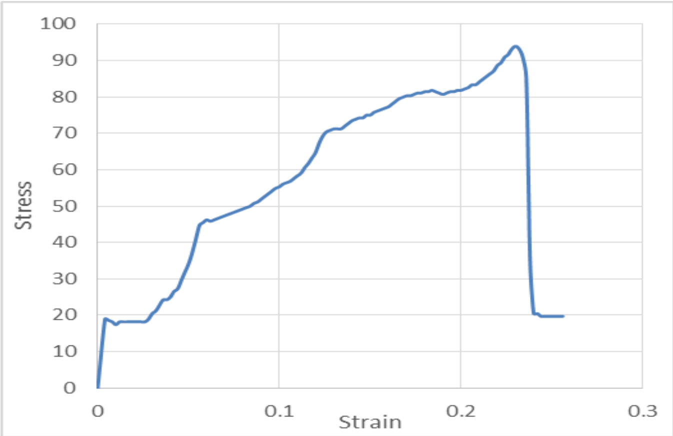
3. RESULT AND DISCUSSION

In table 2 are presented the average values of the mechanical properties obtained in the tensile tests carried out on aluminum with different amount of copper concentration.

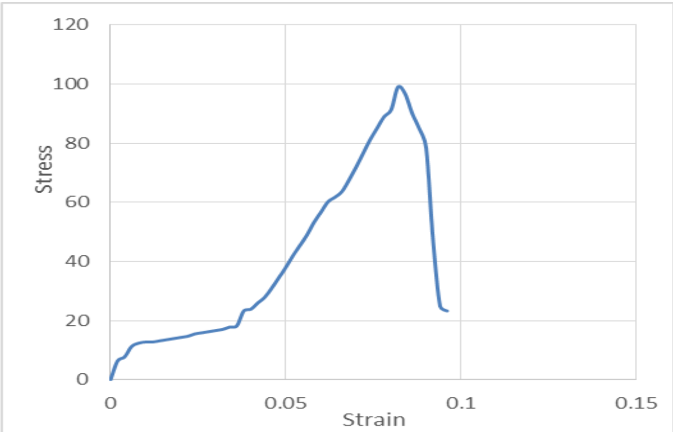
Table: 2 Average value of Mechanical Properties obtained in tensile strength for different copper concentration

Material	Specimen	Ultimate strength (N/mm^2)	Mean ultimate strength (N/mm^2)
Al	1	70	70
	2	70	
	1	90.08	

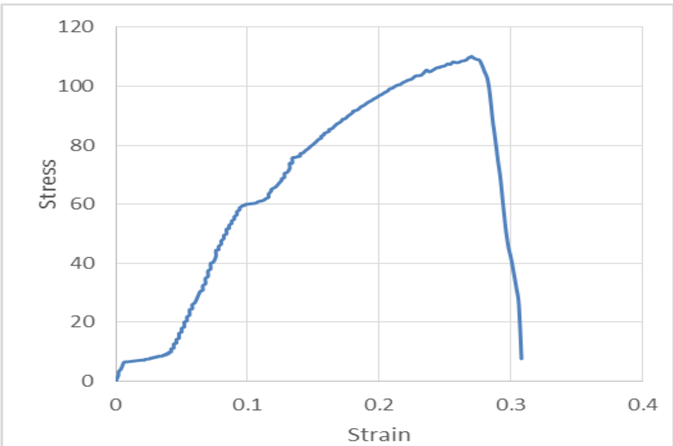
Copper 1.62%	2	93.95	92.01
Copper 6.86%	1	102.51	100.79
	2	99.08	
Copper 12.54%	1	110.20	111.41
	2	112.63	
Copper 17.31%	1	119.73	121.85
	2	123.98	



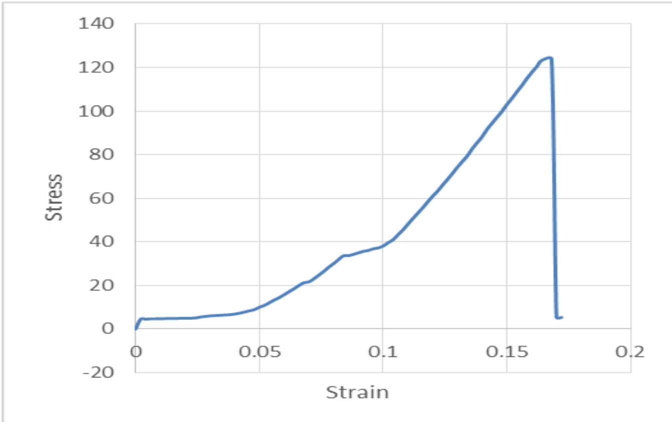
(a)



(b)



(c)



(d)

Figure: 11: Average Stress strain diagram for aluminum alloy at (a) Cu- 1.62%, (b) Cu-6.86%, (c) Cu-12.54%, (d) Cu-17.31%

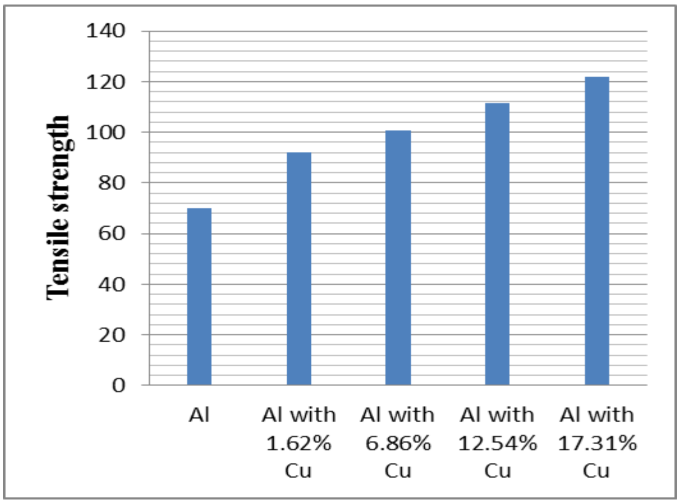


Figure: 12: Comparison of Tensile strength by variation of copper percentages

The density of the aluminum alloys increased with the increasing content of copper [20]. The average values of ultimate tensile strength after fracture with its standard deviation for the five samples tested are present in above fig. 12. The lowest concentration of copper (1.62%) obtained minimum ultimate strength after fracture whereas higher concentrations of copper (up to 17.31%) had the highest ultimate tensile strength after fracture, because the presence of copper leads to the formation of aluminum-copper particles, which refined and dispersed improve machinability by causing a decrease in plasticity and ultimately result in chip embrittlement [21].

4. CONCLUSION

The investigation of mechanical properties of pure aluminum with different levels of copper concentration has led to some important conclusion are listed below.

Increasing the copper content in a pure aluminum increase the precipitation hardening through the stabilization of hardening phase, thus the sample of pure aluminum with highest copper content showed the highest hardness and ultimate tensile value. The highest value of ultimate tensile strength was obtained 121.98 MPa at 17.31% of copper content whereas minimum value of ultimate tensile strength wasa obtained 92.01 MPa at 1.62% of copper content,

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BIOGRAPHIES

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