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Experimental analysis of microstructure and mechanical properties of Al-8011 by variation of copper content

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Abstract

In this work, the effect of Copper (Cu) in the aluminum alloy Al 8011 at different concentration on the microstructure and mechanical properties of Al-8011 alloy were evaluated. For experimental studies, four different alloy having concentration of Cu (2,4,6,8%) were prepared through casting process in the form of rectangular bar having dimension of 200x25x13 mm. The bar were homogeneous and cooled in the atmospheric temperature and tensile test specimen were prepared from the homogeneous rectangular bar. The test specimen were characterized by scanning electron microscope (SEM), hardness measure and tensile test. The phase which were formed in the microstructure for different amount of copper were examined. The result indicate that the tensile strength and hardness of the alloy increase with increasing Cu concentration.

Keywords: Aluminum alloy, Copper, Tensile strength, microstructure

1. Introduction

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 improving of strength is one of the most used processes in the industry.

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. Strength of aluminum alloys after aging can be considerably increased by addition of copper, silicon and magnesium. The mechanism of the strength increase cannot be easily explained by addition of various alloying elements and phase transformations alone. A good combination of mechanical properties can be achieved when all these hardener precipitates are present [1]. 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 [2-5]. Copper was found to be the most effective alloying addition towards improving mechanical and tribological properties of these alloys [6-11]. 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

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Al as compared to other synthetic fibers like GFRP [12, 13]. Copper also increases heat treatability of the alloy. Addition of copper decreases significantly the melting point and eutectic temperature of the alloy. Therefore, the copper increases the solidification range of the alloy [14–17]. Addition of copper to Al–Si alloys causes to form $CuAl_2$ phases and other intermetallic compounds, which increase strength of casting parts [18-20]. 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 [21-22]. The quality of the microstructure of aluminum parts depends on chemical composition, melting process, casting process and solidification rate [23-25]. Solidification begins with the development of primary aluminum dendrite network in majority of aluminum casting alloys. The secondary dendrite arm spacing depends on chemical composition of the alloy, cooling rate, local solidification time and temperature gradient [26-27]. A variety of methods have been used to make high-strength copper alloys. 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 [28]. A high tensile strength of 600 MPa was reported in 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 CueZn alloys [29]. The addition of 0.6% Cu to the 6082Al–Mg–Si alloy clearly increases the peak hardness and reduces the time to reach the peak hardness. The hardness value of the alloy with 0.6% Cu was always distinctly higher than that of the alloy without Cu during isothermal treatment at 250^0C [30]. The ultimate tensile strength and hardness of steel 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 [31-35]. The addition of Cu (0.1 wt. %) results in refinement of needle-shaped precipitates and may also increase the density of precipitates amount [36]. Also demonstrate that low Cu and Ag additions enhance the hardness and kinetically accelerate the formation of Mg2Si precipitates, which is the main hardening phase in Al-Mg-Si alloys [37]. The 6351 aluminum alloy as well as 6082 and 6005A alloys contains a superior amount of Mg2Si than 6063 and 6061 alloys with a substantial silicon excess. A 0.2% Si excess increases the strength of an alloy containing 0.8% of Mg2Si in about 70 MPa [38]. 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, in addition of substantial refinement of precipitate structure. The amount of silicon in 6351 aluminum alloy has shown influence on cutting force. Smaller values of cutting force were obtained with 1.2% silicon content [39].

2. Experimental Procedure

2.1 Material and Processing

Four new Aluminum alloy were prepared by variation of copper concentration in Al-8011. Pure copper are melted in a furnace in clay graphite crucible at 1050^0C. Pre weighted Al-8011 quantity pieces were added and the same temperature is maintained until aluminum alloy melt completely

2.2 Specimen dimensions

Tensile test was conducted using ASTM-E8 standard specimen to check the mechanical properties of parent material Al-8011 and new Al-alloy by variation of copper concentration.

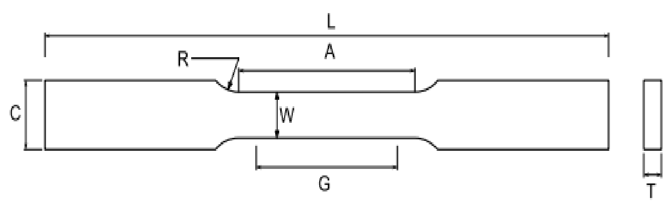


Figure 1: ASTM E8 standard test specimen

Table 1: Tensile test specimen dimension

All dimensions in (mm)	
Gauge length (G)	25.4
Width (W)	6.35
Radius of fillet (R)	6.35
Overall length (L)	101.6
Length of reduced parallel section(A)	31.75
Width of grip section (C)	9.53

Figure 2: Tensile test specimen after tensile test

2.3 Chemical Composition

Chemical composition of Al-8011 and Mechanical properties of Al-8011are given in table 2 and 3 respectively

Table 2: Chemical composition of Al-8011

Element %	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Al-8011	0.4-0.8	0.7	0.1-0.4	0.15	0.8-1.2	0.04-0.35	0.25	0.15	Bal

2.4 Mechanical and physical properties

Mechanical and physical properties of Al-8011 are given in table 3.

Table 3:- Mechanical and physical properties of Al-8011

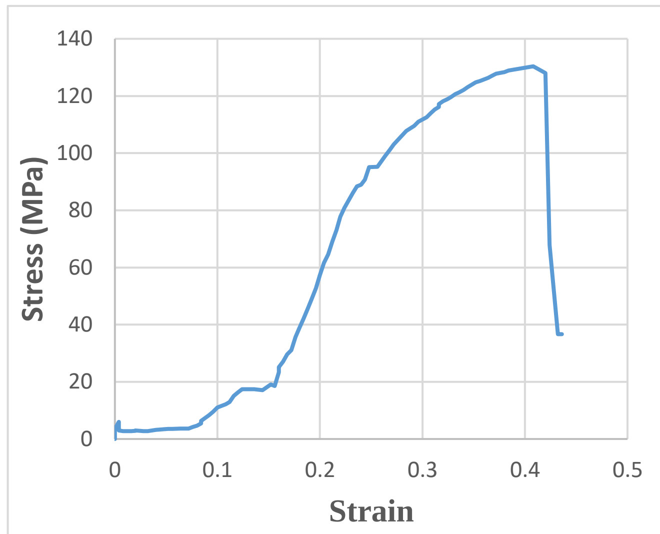
Al-Alloy	Tensile strength (MPa)	Elastic modulus (GPa)	Thermal conductivity (W/m-K)	Density (g/cm^3)	Elongation (%)
8011	124-180	68.9	151-200	2.7	12-25

3. Result and Discussion

In table 4 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 4: 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-8011	1	121.52	123.81
	2	126.10	
Copper 2%	1	131.25	130.88
	2	130.52	
Copper 4%	1	137.2	138.72
	2	139.74	
Copper 6%	1	146.8	145.15
	2	143.5	
Copper 8%	1	157.04	158.34



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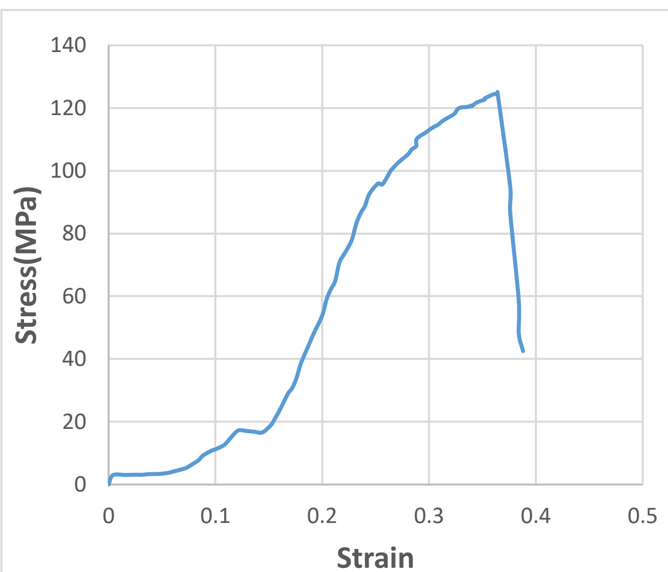

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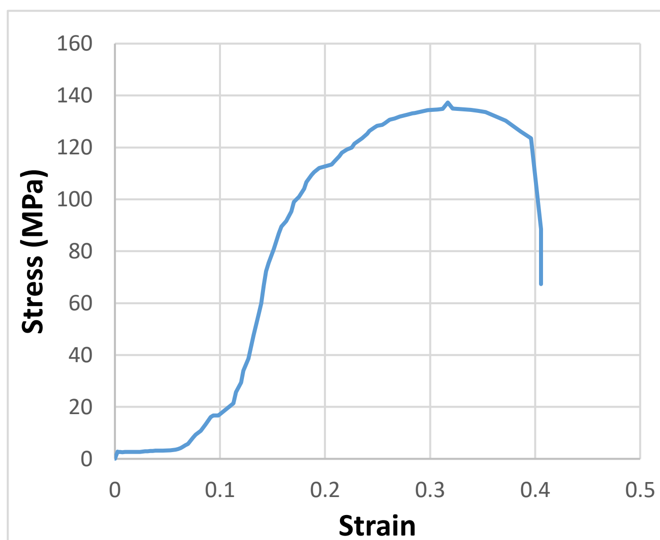

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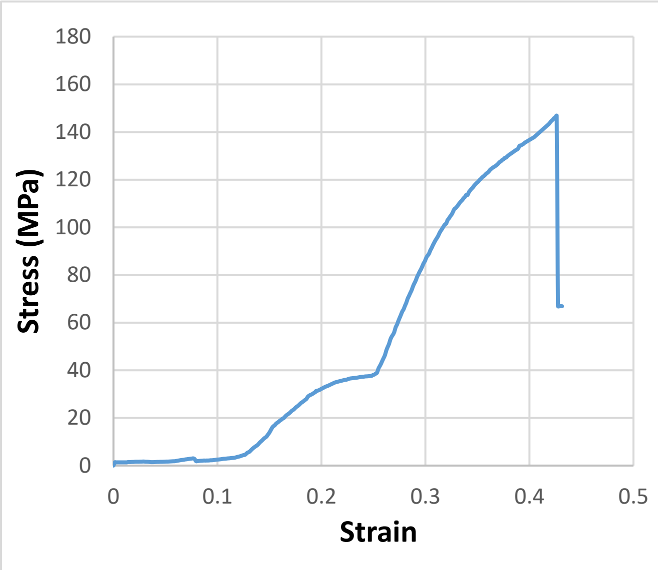

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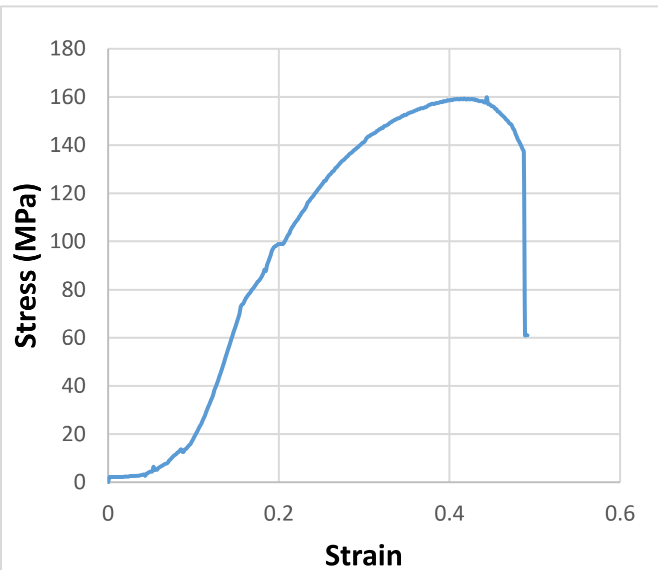


(e)

Figure: 3: Average Stress strain diagram for aluminum alloy at (a) Cu- 2%, (b) Cu-4%, (c) Cu-6%, (d) Cu-8%

Tensile test specimen was prepared by guideline of ASTM E8 standard to evaluate the tensile properties of test specimen by universal testing machine (UTM) at room temperate. Three specimen were tested for each case and average value was taken. Fig. 3, shows the stress strain diagram of Aluminum alloy Al-8011 and new Aluminum alloy by variation of Cu content (2, 4, 6, 8). Mechanical properties like ultimate tensile strength and ductility (measured in terms of elongation were determine from the curves. The numerical data have been presented in table 4.

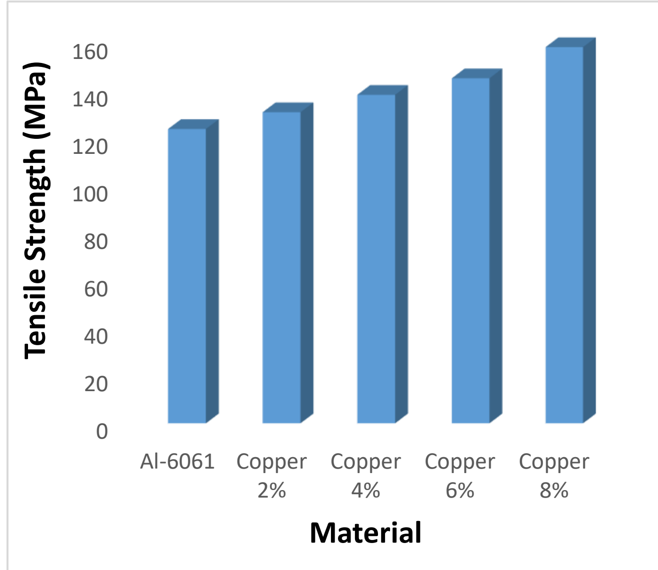
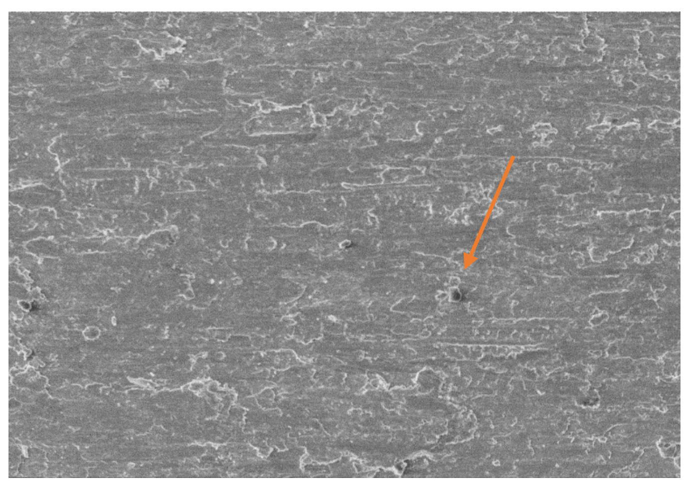
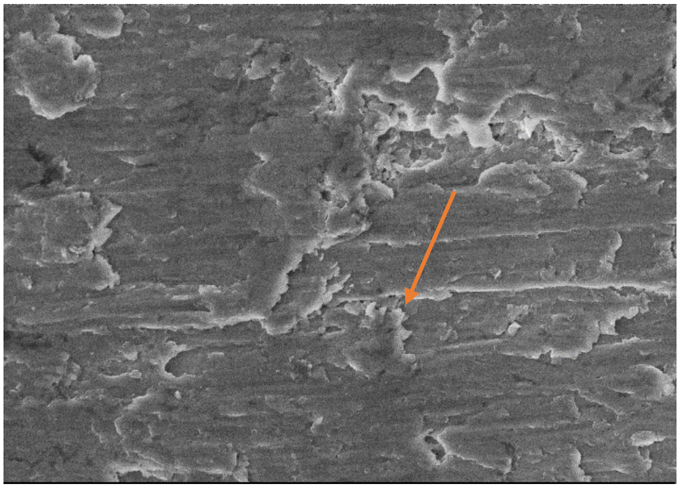


Figure 4: Variation of tensile strength of aluminum alloy 8011 by variation of copper concentration.

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 (2%) obtained minimum ultimate strength after fracture whereas higher concentrations of copper (up to 8%) 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].



(a)



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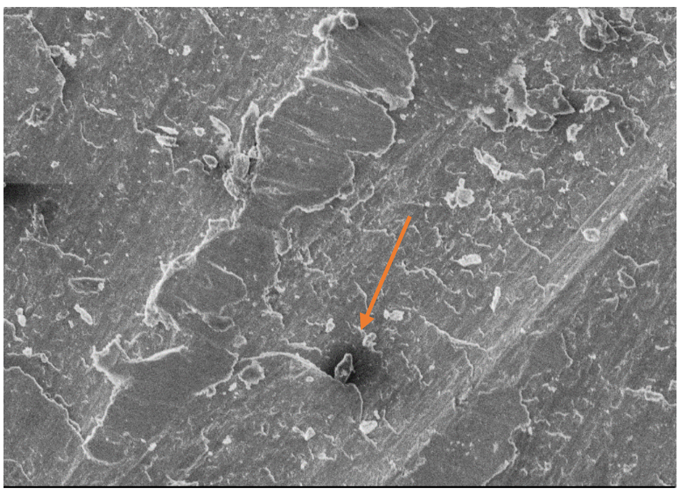

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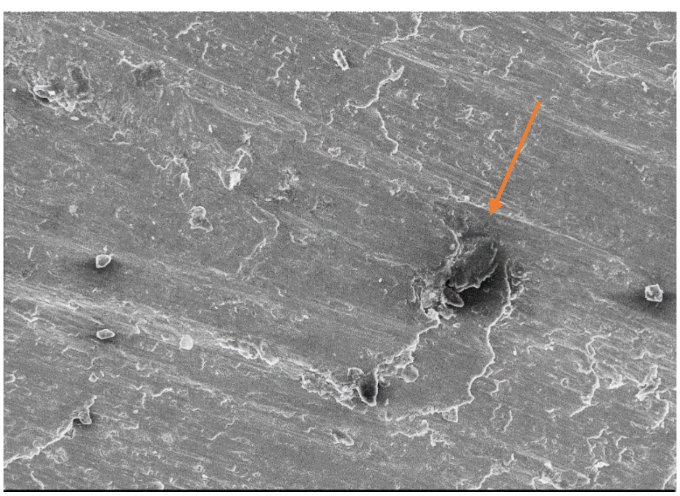

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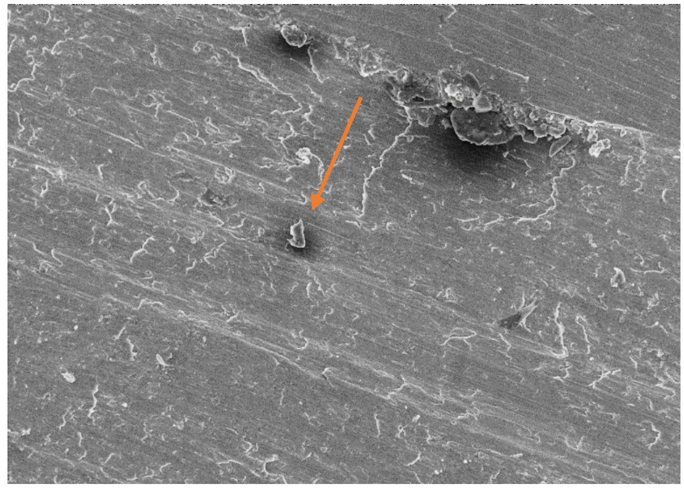

(e)

Figure 5: SEM Microstructures of the8011aluminum alloy samples with different copper concentration (a) Al-8011, (b) Al- 8011 with 2 % Cu, (c) Al- 8011 with 4 % Cu, (d) Al- 8011 with 6 % Cu, (e) Al- 8011 with 8 % Cu)

In Fig.5 are shown the (SEM) microstructures of the four samples of Al-8011 aluminum alloy with different contents of copper (2, 4, 6, 8 %) with 400x magnification. Porosity in aluminum alloys comprised of massive shrinkage cavities, and occurs in long-freezing range alloys, caused by failure to compensate for solidification shrinkage, and distributed more or less homogeneously, due to the failure to feed interdendritic regions, and the precipitation of dissolved gases (i.e., gas porosity). In all aluminum alloys samples investigated was observed the porosity like marked in orange arrows in Fig. 5.

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 158.34 MPa at 8% of copper content whereas minimum value of ultimate tensile strength wasa obtained 123.81 MPa at base material i.e. Al-8011.

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