JJMIE

Volume 10 Number 1, March.2016
ISSN 1995-6665
Pages 19- 26

Jordan Journal of Mechanical and Industrial Engineering

The Effect of Adding Different Percentages of Manganese (Mn) and Copper (Cu) on the Mechanical Behavior of Aluminum

Lina M. Shehadeh[1] , Issam S. Jalham[2 *]

[1] MSc student Industrial Engineering Dept, University of Jordan, Amman 11942 Jordan
[2] Professor in the Industrial Engineering Dept, University of Jordan, Amman 11942 Jordan.

Received 11 May 2015 Accepted 1 Oct 2015

Abstract

In the present investigation, aluminum cast alloys were produced, age hardened, and tested after adding a varying manganese content (from 0.1to 0.5%) and Cu content from (1.5-7%) with constant Mg-Si-Fe composition and Al as the dominant constituent. Results showed that the addition of Mn to the alloy increased the tensile properties and hardness up to 0.6 percent for both the as-cast and age-hardened conditions, while their impact energies decreased. On the other hand, the addition of Cu to the alloy increased the tensile and hardness properties and decreased the impact energy.

© 2016 Jordan Journal of Mechanical and Industrial Engineering. All rights reserved

Keywords: *Hardness, Artificial Hardening, Impact, Toughness, Tensile*.

1. Introduction

Aluminum alloys are widely used in the production of automotive components, buildings and constructions, containers and packaging, marine, aviation, aerospace and electrical industries because of their light weights, corrosion resistance in most environments or combination of these properties. Aluminum based alloys also have a high thermal conductivity and a low coefficient of linear expansion values, and, based on these two properties, they can be forged to the desired shapes at elevated temperatures and then solution treated and aged hardened to obtain desired microstructures and excellent mechanical properties [1,2]. All alloying elements that are used for aluminum alloy design can be classified into three principal groups: basic alloying elements, ancillary additions (or dopants), and impurities. Depending on the nature of an alloy, the same elements could play different roles. The widely used elements to improve the properties of Aluminum alloys are magnesium, zinc, copper; and silicon. These chemical elements are called “basic’’, or “principal’’, because they are introduced into aluminum alloys in (relatively) large amounts and define their microstructure and properties. When added to Al–Mg alloys, Mn generally combines with Al, Si (and Fe) during ingot preheating or homogenization to form sub-micron sized, semi-coherent or incoherent dispersions. The level of Mn also affects the type, size and volume fraction of the coarse constituent, Fe-containing, particles. Additions of Fe and Si also affect the type, size and volume fraction of the coarse constituent particles, and increasing levels of both elements were shown to be detrimental to O-temper sheet formability, through their effect on increasing the size and volume fraction of these particles [3].

Copper is added to Al mainly to increase strength. As the Cu content increases, there is a continuous increase in hardness, but strength and especially ductility depend on how the Cu is distributed. Manganese is added to most commercial Al-Cu alloys. It forms $Al_{20}\,Cu_2\,Mn_3$ dispersion particles which provide some dispersion strengthening, and also serve to nucleate precipitates during aging on dislocations which emanate from the particle matrix interface during quenching. Si increases fluidability and resistance to hot cracking during casting, even though Fe reduces hot cracking in Al-Cu alloys. But both Fe and Si can form constituent phases (e.g., Al_7Cu_2Fe and Mg_2Si) which reduce fracture toughness [4].

A lot of studies were conducted on aluminum and its alloys. Most of the studies aimed at discovering its mechanical, and other, properties. The change of the composition was one of the areas which were taken into consideration. Many researchers concentrated on the change of manganese content on the properties of Al alloys or on the change of the content of copper or other elements. The interaction of the change of the percentages of these two elements (Mn and Cu) together on the properties of Al was not considered. As these elements have a considerable effect on the properties of Al alloys, it was decided to study the influence of adding different percentages of Mn and Cu together on the mechanical properties of Aluminum to bring a clear picture of the effect of the interaction of different percentages of Mn and Cu on the mechanical properties of Aluminum.

* Corresponding author e-mail: jalham@ju.edu.jo.

2. Literature Review

In this section, some of the research contribution will be discussed. The main focus of this survey will be the mechanical properties of aluminum such as tensile, hardness and impact properties.

Various alloying elements are added to aluminum to enhance its mechanical properties. Copper has been the most common alloying element almost since the beginning of the aluminum industry, and a variety of alloys in which copper is the major addition were developed. Magnesium (Mg) used to strengthen and harden aluminum castings. Nafsin N. and Rashed H. M. M. A. [5] emphasized the establishment of a relationship between microstructureand cold deformation behavior of aluminum-copper magnesium alloys. Aluminum-copper-magnesium alloys with varying Cu% and Mg% were casted and their chemical compositions were determined using Optical Emission Spectroscopy (OES). These alloys underwent cold deformation after homogenization and their microstructures were examined using optical microscope. Finally, the effects of deformations were studied by measuring the hardness of those alloys. The microstructure and mechanical properties of Al–14.5 Si – 0.5 Mg alloy by the addition of different percentages of Cu, mainly 4.65 wt.% and 0.52 wt.% were studied by Chih-Ting Wu *et al* [6]. After examining the microstructure, they concluded that an acicular Al_5FeSi was found in the high-Cu content alloy while in the low-Cu content alloy, $Al_8Mg_3FeSi_6$ was found in the Fe-bearing phase. Furthermore, tensile testing indicated that the low-Cu alloy containing $Al_8Mg_3FeSi_6$ had higher Ultimate Tensile Strength (UTS) and elongation than the high-Cu alloy containing the acicular Al_5FeSi. On the other hand, it was believed that the presence of the acicular_Al_5FeSi in the high-Cu alloy is responsible for the increased number of crack initiators and brittleness of the alloy. This also indicated that the hardness of the high-Cu alloy exceeded that of low-Cu alloy.

Nine Al–(1–3)Mg–(0–0.4)Cu–0.15Si–0.25Mn (in wt.%) alloys with potential applications in both packaging and automotive industries were investigated by Zhu *et al.* [7]. The results of their tensile testing showed that the solution strengthening is, in good approximation, linearly proportional to the Mg content. Mechanical testing and microstructural examinations of aged samples indicate that Mg_2Si phase precipitates contribute to age hardening of Cu-free alloys whilst both Mg_2Si phase and (Al_2CuMg) phases contribute to that of Cu-containing alloys. The age hardening capability is critically influenced by solution treatment temperature. Increasing the solution treatment temperature from 500 to 550°C results in a marked increase in rate of hardening for Cu-containing alloys and solution treatment at about 550°C or higher is needed to allow Mg_2Si phase precipitation during ageing in Cu-free alloys with Mg content of about 2% or higher.

Yield strength of an Al–3.7Cu–1.5Li–0.50Zn–0.37Mg–0.30Mn–0.14Zr alloy aged at 165°C as a function of time was examined by Hongying Li *et al*. [8]. Existing phases in this alloy were identified by selected area electron diffraction analysis and the microstructural evolution was examined by Transmission Electron Microscopy (TEM). It was found that the peak ageing time determined is 50 h leads to a yield strength of 453 MPa. The strength of the alloy increases rapidly during the 24 h of ageing and an additional strengthening was obtained for further ageing up to 50 h due to evolution of T1 and plates.

Mechanical properties of age-hardened Al alloys consisting of a varying manganese content with a constant Si-Fe composition were studied by Abdulwahab [1]. He concluded that the addition of Mn to the alloy increased the tensile properties and the hardness subject to 0.4 percent for both the as-cast and age-hardened conditions. Moreover, he concluded that the addition of Mn to the alloy decreases the impact energies for the age-hardened samples. On the other hand, Hwang *et al*. [9] studied the effect of Mn (Mn content is increased up to 0.65 wt%) on the microstructure and mechanical properties of Type 319 (Al–7wt.%Si–3.8wt.%Cu–0.5wt.%Fe) aluminum casting alloys. They found that the plate-like inter-metallic phase is completely converted to the Chinese script phase resulting in improved tensile properties. Excess amounts of Mn, however, deteriorate the mechanical properties by increasing the total amount of iron-containing inter-metallic phases. The porosity and volume percent of inter-metallic phases are correlated with the tensile properties in order to determine the role of Mn on Type 319 casting alloys.

The effects of individual and combined additions of Be, Mn, Ca and Sr on the solidification, structure and mechanical properties of Al–7Si–0.3Mg–0.8Fe alloy were investigated by Kumari *et al*. [10]. Their thermal analysis revealed that all additions, except for Be, show a peak corresponding to β-Fe intermetallic phase formation and the eutectic temperature decreased after the addition of Ca and Sr by 6.6 and 8.7 K, respectively, compared to the untreated alloy and lead to modification of eutectic Si from platelet to fibrous form. The peak corresponding to Be–Fe phase has been identified by DTA. Mn (0.4%) and Be (0.2%) additions to Al–7Si–0.3Mg–0.8Fe alloy change the morphology of platelet β-phase to script form leading to significant improvement in tensile . In another work, Ma *et al*. [11] studied the effect of-iron intermetallics and porosity on the tensile properties in cast Al–Si–Cu and Al–Si–Mg alloys. The results showed that the alloy ductility and UTS were subject to deterioration as a result of an increase in the size of iron intermetallics. An increase in the size of the porosity was also deleterious to alloy ductility and UTS. The co-addition of Re, Mn and Fe proves to be an effective method to enhance the high-temperature strength of A390. The high-temperature strength of A390 is increased by 25% in this article using this method. Moreover, they investigated the effects of the cooling rate, heat treatment as well as additions of Mn and Sr on hardness and hardening characteristics in Al–11Si–2.5Cu–Mg alloys. The results of scanning electron microscopy reveal that the age-hardening behavior is related to the precipitation sequence of alloy. An energy dispersive spectroscopy analysis was used to identify the precipitated phases. The results also show that the hardness of the solution heat-treated samples is higher in air-cooled alloys than in furnace cooled ones. Furthermore, the hardness observed in solution heat-treated samples is higher than in those of the cast samples for air-cooled alloys, with the highest hardness level in the non-modified alloys. The highest hardness levels, among the artificially aged samples, were observed in the non-modified, air-cooled alloys. These levels occur after aging for longer times at lower temperatures (e.g., 30 h at 155°C). The alloys studied did not display any softening after 44 h at 155° C, whereas at 180°C, softening was noted to occur after 10–15 h. At short aging times of 5–10 h, high hardness values may be obtained by aging at180°C. At aging temperatures of 200°C, 220° C and 240°C, softening began after 2 h had elapsed.

The influence of Cu content on the ageing behavior of Al–8Si–0.4Mg–xCu alloys was investigated by Zhang *et al.* [12]. They conducted hardness measurement, Differential Scanning Calorimeter (DSC) and Transmission Electron Microscopy (TEM) analysis for Al–8Si–0.4Mg–xCu alloys with 1 wt%Cu, 2 wt%Cu, 3 wt%Cu, and 4 wt%Cu produced in permanent molds. Hardness has been estimated for ageing times varying from 1 h to 100 h. The results indicate that the maximum hardness increases clearly with the increase of Cu content, but the total increase in hardness during ageing (DHVmax) decreases with the addition of 1 wt%Cu and has a little increase with Cu content from 1 wt% to 4 wt%. In other words, the addition of Cu decreases the age hardening rate.

The addition of Cu to Al alloys were also investigated. For example, Basavakumar *et al.* [13] studied the microstructures and impact toughness of Al–7Si and Al–7Si–2-5Cu cast alloys after various melt treatments like grain refinement and modification. The results indicate that the combined grain refined and modified Al–7Si–2 5Cu alloys have microstructures consisting of uniformly distributed -Al grains, interdendritic network of fine eutectic silicon and fine $CuAl_2$ particles in the interdendritic region. These alloys exhibited an improved impact toughness as cast condition when compared to those treated by individual addition of grain refiner or modifier. The improved impact toughness of Al–7Si–2 5Cu alloys are related to breakage of the large aluminum grains and uniform distribution of eutectic silicon and fine $CuAl_2$ particles in the interdendritic region resulting from combined refinement and modification. The present paper attempts to investigate the influence of microstructural changes in the Al–7Si and Al–7Si–2 5Cu cast alloys by grain refinement, modification and combined action of both on the impact toughness.

The effect of copper and silicon content on the mechanical properties in Al–Cu–Si–Mg alloys was studied by Muzaffer Zeren [14]. Al–Cu–Si–Mg alloys with 1, 3, 4.5, 6% Cu and 0, 5, 7, 12, 18% Si were utilized for this purpose. After melting and Na modification, alloys were cast in metal molds at 780°C and solidified. They were solution treated at 490°C for 4 h and then quenched. Samples were aged at 180°C for 5, 10, 15, 20 h to observe the effect of aging on mechanical properties. While in their work [15], Muzaffer and others studied the influence of Cu content on the microstructure and hardness of near-eutectic Al-Si-*x*Cu (x = 2%, 3%, 4% and 5%). After melting Al-based alloys with different Cu contents, alloys were cast in green sand molds at 690°C and solidified. The solution treatment was performed at 500°C for 7 h and then the specimens were cooled by water quenching. The samples were respectively aged at 190°C for 5, 10 and 15 h to observe the effect of aging time on the hardness of matrix. Also differential thermal analysis was used to obtain the transition temperature of the equilibrium phases at cooling rate of 30 K/min and to determine the effect of Cu content on the formation of quaternary eutectic phases and the melting point of α(Al) + Si. The results showed that as Cu content in the alloy increases, the hardness of matrix increases due to precipitation hardening. On the other hand, factors necessary to obtain an optimal heat treatment that influence the hardness and resistivity of Al-6Si-0.5Mg casting alloys with Cu or/and Ni additions were investigated by Hossain A. *et al*. [16]. The alloys were homogenized (24hr at 500°C), solutionized (2hr at 540°C) and artificially ageing at various times and temperatures. The alloys were aged isochronally for 60 minutes at temperatures up to 400°C and isothermally at 150, 175, 200, 225, 250 & 300°C for different periods in the range 15 to 360 minutes. The hardness and electrical resistivity of the alloys were measured for various artificial ageing times and temperatures. From the isochronal ageing treatment, hardness found maximum ageing at 225°C. And from the isothermal ageing treatment, hardness found maximum for 60 minutes at 225°C. So the optimal heat treatment consists of 60 minutes ageing at 225°C. It is worth mentioning that Nurul Razliana Abdul Razak *et al.* [17] studied Effect of Aluminum Addition on Microstructure and Microhardness of Sn-0.7 Cu-xAl Lead-free Alloy. They found that the microhardness was improved by 19% as the weight percentage of Al particls was increased up to 1.0%.

Unlike the works mentioned above, the present investigation differs in that it studies the effect of the interaction of different percentages of Mn and Cu on the mechanical properties of Aluminum.

3. Materials, Equipments and Experimental Procedure

3.1. Materials

Materials that are used in the present investigation are: commercially pure Aluminum (its composition is shown in Table 1), pure Copper and pure Manganese as a master alloy, and etching agent of the following composition: (0.5% HF, 2.5%HCL, 1.5%HNO_3).

Table 1. Chemical compositions of commercially pure aluminum

Elements	Al	Mg	Si	Fe
Percentage (%)	94.45	1.06	1.2	3.29

The composition of alloys which were manufactured and tested in the present study is shown in Table 2.

3.2. Equipment

Equipment used in the present study are: Electrical Resistance Furnace of EAFt Type, graphite crucible, permanent brass mold in the form of cylindrical castings (size: 15mm in diameter, 150 mm long), BUEHLER Type grinder/Polisher machine to prepare the samples to microstructural examination, MEIJI Type optical microscope to reveal the microstructure, Aleitz-Amr 1000 Type scanning electron microscope to determine the chemical composition of the alloys, computerized SHIMADZU Type electro hydraulic servo universal testing machine to determine the tensile properties, digital

An MVK-11, MITUTOYO Type micro hardness Vickers tester to determine the hardness properties, and PIT-C Metal Type pendulum Charpy Impact Testing Machine to determine the impact properties.

Table 2. Chemical compositions of manufactured Al-base alloys.

Alloy No.	Elements (wt. %)		
	Cu	Mn	Al
1	1.5	0.2	Balance
2	1.5	0.4	Balance
3	1.5	0.6	Balance
4	1.5	0.8	Balance
5	1.5	1	Balance
6	3	0.2	Balance
7	3	0.4	Balance
8	3	0.6	Balance
9	3	0.8	Balance
10	3	1	Balance
11	4.5	0.2	Balance
12	4.5	0.4	Balance
13	4.5	0.6	Balance
14	4.5	0.8	Balance
15	4.5	1	Balance
16	6	0.2	Balance
17	6	0.4	Balance
18	6	0.6	Balance
19	6	0.8	Balance
20	6	1	Balance
21	7.5	0.2	Balance
22	7.5	0.4	Balance
23	7.5	0.6	Balance
24	7.5	0.8	Balance
25	7.5	1	Balance

3.3. Experimental Procedure

The experimental procedure used in the present project comprises three stages: manufacturing, microstructural examination, and testing. In the manufacturing stage, twenty five alloys were prepared by melting commercially pure aluminum in an electrical resistance furnace using a graphite crucible. Copper with a range between (1.5-7%), and Mn with a range between (0.2-1%) were sequentially added to the melt to produce alloys with the compositions shown in Table (2) above. Then the melt was poured into permanent brass mold.

Specimens with Cu percentages less than 6 %, which were numbered (1-15), were solution heat treated at 488°C for 8 h, quenched into warm water (70°C) and then aged to a T6 condition at 193°C for 8 h (artificial age-hardening).

To conduct the microstructural examination, samples were ground and polished by using grinder/polisher machine. The polished samples were etched using etching agent of (0.5% HF, 2.5% HCL, 1.5 % HNO_3) composition. The etched alloys were examined by using optical microscope at different magnification and scanning electron microscope.

Tensile, hardness, and impact tests were also conducted using the UTM and pendulum type Charpy testing machine. To accomplish the tensile test, specimens with 15 mm diameter, 45 mm length were prepared and subjected to the test to get the stress strain behavior.

To perform Vickers hardness test, specimens with 15 mm diameter, 15mm length were prepared, ground and polished. At least 5 impressions were made to determine the mean value of the hardness at different locations.

At the end, Charpy impact test was conducted using a standard V-notch impact samples having the dimensions of 10x10x55 mm which are prepared according to ASTM E 23 by using the Charpy impact testing machine.

4. Results and Discussions

4.1. Microstructural Observations

In this section, the influence of the addition of Mn and Cu to the microstructure of Aluminum is investigated. The microstructure of the tested samples was revealed using optical microscope and scanning electron microscope. It was found that α-Al solid solution is the predominant phase in the microstructure of these alloys (Figure 1). It forms dendritic network, and also precipitate in several multiphase eutectic reactions. This in agreement with Muzaffer *et al.* [16].

During the solution heat treatment, most of eutectic Al_2Cu and intermetallic particles dissolve into the Al matrix in the low- Cu alloy. So Al_2Cu was not observed clearly by using optical microscope but the EDS detector on SEM identifies the presence of this phase. This can be seen by the EDS detector spectra analysis (shown in Table 3).

The addition of Mn with percentage between 0.1&0.6 transforms the β- Al_5FeSi into α- Al_5FeSi, increasing the amount of Mn to (0.8 &1)% results in the formation of polyhedral α-Al_5FeSi, as shown in Figure 2. These results are in agreement with J.Y. Hwang H.W [?]. The increase in Mn and Cu content affects the size of the dendritic arm spacing (SDAS). The size of SDAS was calculated by measuring the distance between adjacent side branches on the longitudinal section of primary dendritic as a function of distance from the dendritic tip, following the method described by Muzaffer Z. [15]. Figure (3) shows the results of these calculated values. It is clear from the figure that the size of SDAS decreases until 0.6% µm and start increasing after that; this is explained in Figure 2.

In non-heat treated alloys, optical microscope reveals all phases clearly for specimens contain a high percentage of Cu. EDS results, shown in Table 4, supports these results.

The addition of Mn with percentage between 0.1&0.6 transforms the β- Al_5FeSi into α- Al_5FeSi, increasing the amount of Mn to (0.8 &1)% results in the formation of polyhedral α-Al_5FeSi Figure 4. These results are in agreement with Hwang [13]. The increase in Mn and Cu content affects the size of the dendritic arm spacing (SDAS). The size of SDAS was calculated by measuring the distance between adjacent side branches on the longitudinal section of primary dendritic as a function of distance from the dendritic tip, following the method described by Muzaffer Z. [15]. Figure 5 shows the results of these calculated values. It is clear from the figure that the size of SDAS decreases until 0.6% µm and start increasing after that; this can be explained by Figure 4.

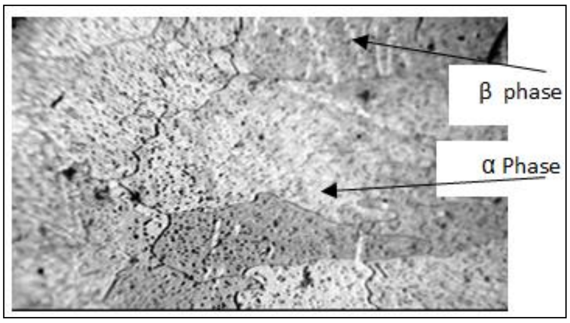
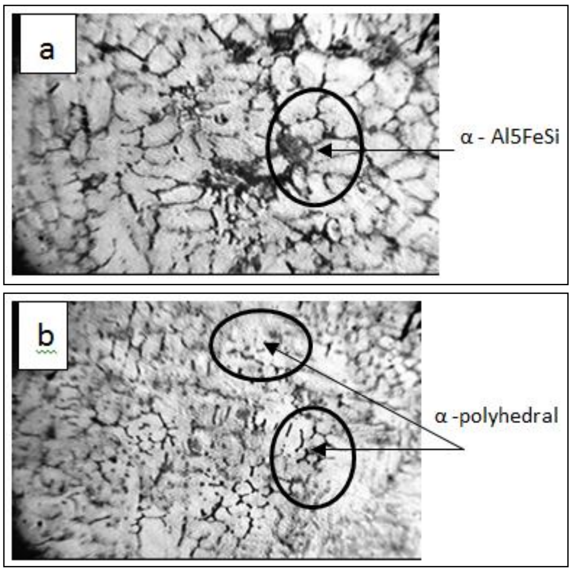


Figure 1. Optical microstructures observed in Al sample before addition Mn and Cu at magnification 250x



(a) Optical microstructures observed in samples (14) at magnification 400x

(b) Optical microstructures observed in samples (15) at magnification 400x

Figure 2.

Table 3: Results of EDS analysis of alloy 15.

Element	Weight%	AT%	K-Value
Al	85.993	92.262	0.75941
Si	1.988	2.050	0.00649
Mn	2.972	1.566	0.03240
Cu	9.047	4.122	0.09918

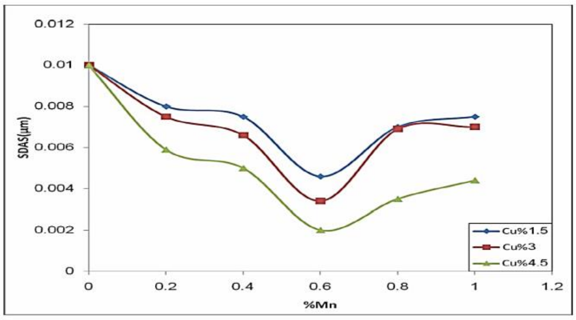


Figure (4.4): values SDAS for heat treated alloys at different Mn percentages

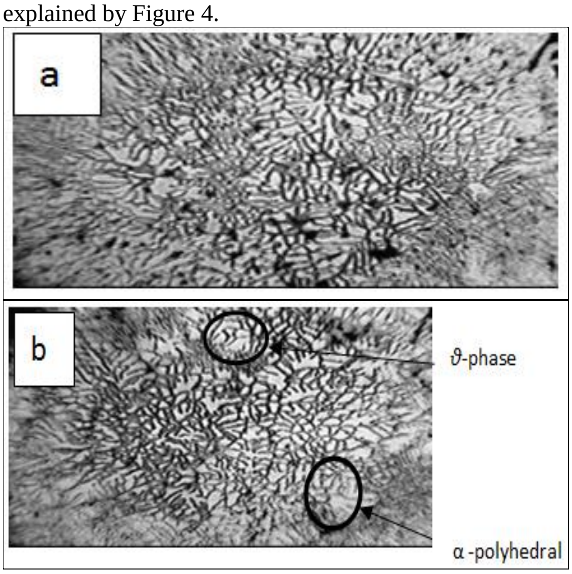
Figure 3. Values SDAS for heat treated alloys at different Mn percentages

Table 4. Results of EDS analysis of alloy 24.

Element	Weight%	AT%	K-Value
Mg	0.958	1.161	0.00441
Al	83.560	91.207	0.42480
Mn	1.043	0.559	0.00698
Fe	5.960	3.143	0.02972
Cu	8.479	3.930	0.05619

In non-heat treated alloys optical microscope reveals all phases clearly for specimens contain a high percentage of Cu. EDS results, shown in Table 4, supports this result. The addition of Mn with percentage between 0.1&0.6 transforms the β- Al_5FeSi into α- Al_5FeSi, increasing the amount of Mn to (0.8 &1)% results in the formation of polyhedral α-Al_5FeSi (Figure 4). These results are in agreement with Hwang *et al.* [13]. The increase in Mn and Cu content affects the size of the dendritic arm spacing SDAS. The size of SDAS was calculated by measuring the distance between adjacent side branches on the longitudinal section of primary dendritic as a function of distance from the dendritic tip, following the method described by Muzaffer Zeren [15].

Figure 5 shows the results of these calculated values. It is clear from the figure that the size of SDAS decreases until 0.6% µm and start increasing after that. This can be explained by Figure 4.



(a): Optical microstructures observed in samples (23) at magnification 250x

(b): Optical microstructures observed in samples (24) at magnification 250x

Figure 4. Results in the formation of polyhedral α-Al5FeSi

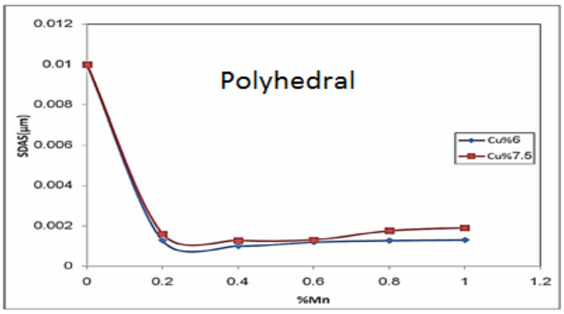


Figure 5. The values of SDAS for non-heat treated alloys at different Mn percentages

4.2. Tensile tests

True stress-strain diagram of Al alloy before adding Cu and Mn is shown in Figure 6. It is clear that the magnitude of ultimate tensile stress (UTS) of Al equal 143 Mpa.

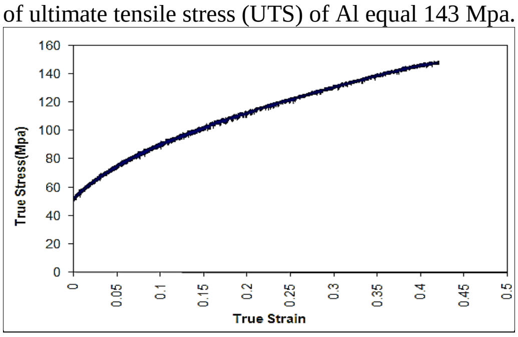


Figure 6. True stress strain diagram for pure Al

It is known that the UTM gives a load-displacement data. After getting these data, manipulation of them is needed to get the true stre;ss-true strain data. The following formula will help in this matter:

True stress $\sigma_T = P/A$ (1)

True strain $\varepsilon_T = \ln(\delta / l_0) = \ln[(l_f - l_0) / l_0]$ (2)

where, σ -Engineering stress, σ_T –True stress, and δ is the Change in length or difference between final (l_f) and initial length (l_0).

In the present study, UTS and elongation increased with Mn content up to 0.6 wt.%. The β phase completely converted to the Chinese script α phase by adding 0.6 wt.% Mn in sample alloys, which results in decreasing the value of UTS, as shown in Figures 7 and 8. The reason refers to the presence of the polyhedral phase (Figure 4). This result is in agreement with Hwang H.Y. *et al.* [13]. It can also be observed that the size of SDAS decreases at 0.6%Mn, and then starts increasing at (0.8 & 1)%, which leads to the increase of the UTS at 0.6% Mn and then start to decrease at 0.8 and 1 % Mn.

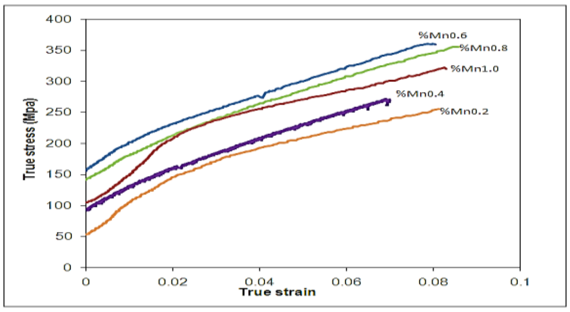


Figure 7. True stress strain diagram for alloys from (16-20) at 6wt.%Cu

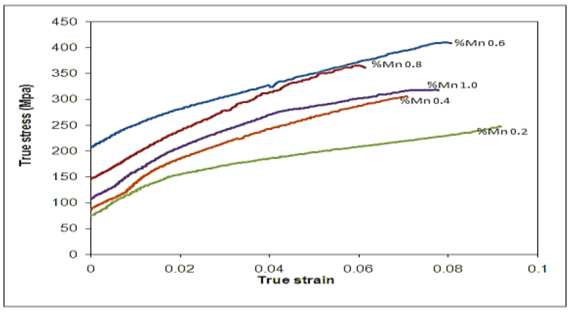


Figure 8. True stress strain diagram for alloys from (21-25) at 7.5wt.%Cu

In heat treated alloys, the tensile strength (UTS) and elongation of the 4.5% Cu alloys that contains high percentage of precipitates of dendritic structures are higher than the alloys contain a low percentages (Figures 9 to 11). The reason behind this is the solution heat treatment which resulted in dissolving back of some particles into Al matrix, yielding to solid-solution strengthening. The degree of solid-solution strengthening depends on the number of solute atoms in the Al matrix. This is in agreement with Chih-Ting [6]. Moreover, the size of SDAS decreases at 0.6%Mn, and then starts increasing at (0.8 & 1)%, which leads to increasing the UTS at 0.6% Mn and then starts to decrease at 0.8 and 1 % Mn.

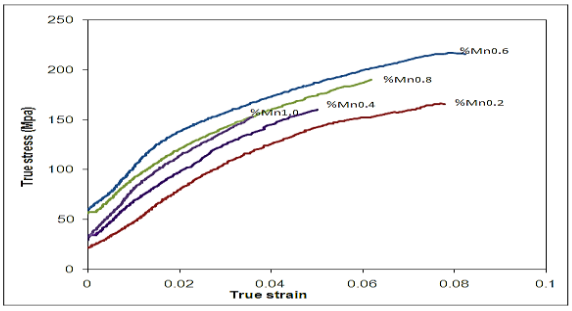


Figure 9. True stress strain diagram for alloys from (1-5) at 1.5wt.%Cu

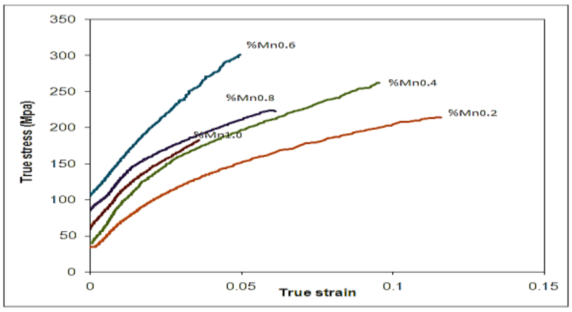


Figure 10. True stress strain diagram for alloys from (6-10) at 3wt.%Cu

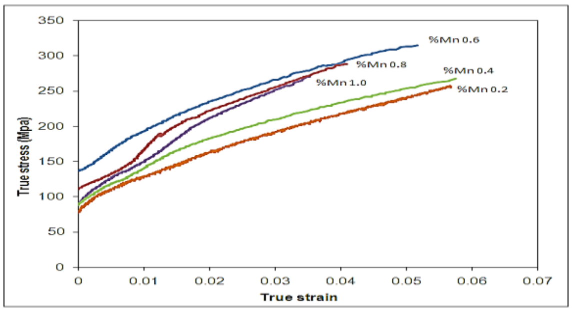


Figure 11. True stress strain diagram for alloys from (11-15) at 4.5wt.%Cu

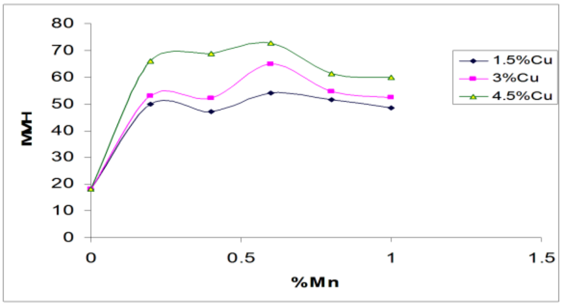


Figure 12. The relationship between the vickers hardness and % of Mn for alloy from (1-15)

4.3. Hardness test

Hardness measurements were performed on all heat-treated specimens and not heat treated alloys. The highest hardness number may be observed to correspond to highest Cu –0.6%Mn conditions. The hardening of Al-%Cu alloy is attributed to the formation of (Al_2Cu) zones, and this zone shows a higher fraction at alloy (7% Cu and 0.6% Mn). At the same time, the amount of the iron content influences the size and amount of the Chinese script α-Al15(Fe,Mn)3Si2 phase appear in the same alloy.

For the composition of 0.8 and 1 % Mn, the value of VH begins to decrease due to the presence of polyhedral α-phase. This polyhedral α phase has been described as "sludge" and has been shown to have a detrimental effect on mechanical properties. The results can be seen in Figures 12, 13 and 14.

4.4. Impact test

It has been found that Mn and Cu does not improve the impact properties at all, as shown in Figures 15, 16 and 17. This may be due to the presence of both acicular eutectic silicon and hard Mn–Fe intermetallic phases in the Mn added alloy and the distortion of the lattice during the precipitation hardening which lead to brittleness in the Cu added alloy. This result is in agreement with Kumari *et al.* [10].

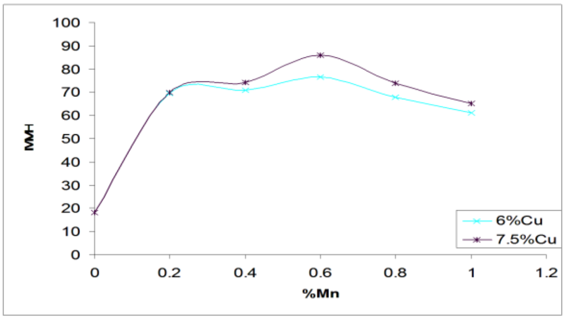


Figure 13. The relationship between the Vickers hardness and % of Mn for alloy from (16-25)

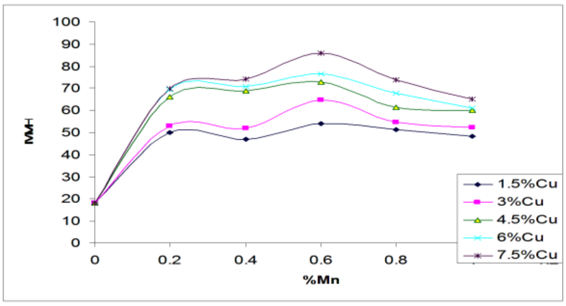


Figure 14. The relationship between the Vickers hardness and % of Mn for all alloy

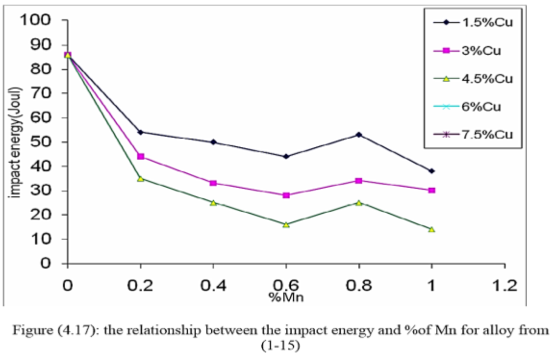


Figure 15. The relationship between the impact energy and % of Mn for alloy from (1-15)

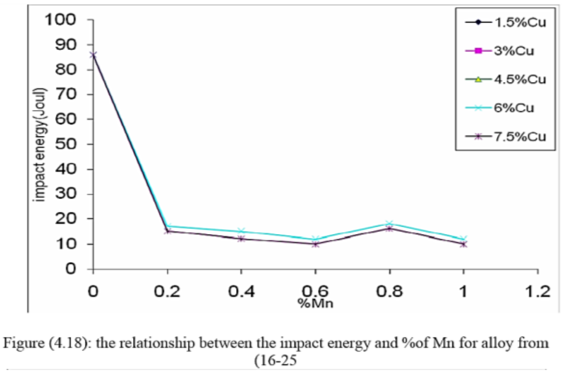


Figure 16. The relationship between the impact energy and % of Mn for alloy from (16-25)

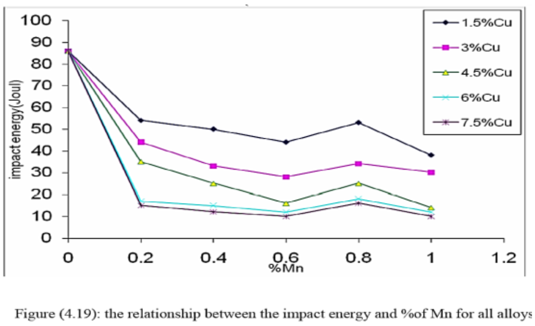


Figure 17. The relationship between the impact energy and % of Mn for all alloys

 © 2016 Jordan Journal of Mechanical and Industrial Engineering. All rights reserved - Volume 10, Number 1 (ISSN 1995-6665)

5. Conclusions

Referring to the results and the discussion above, the following can be concluded:

- The effect of addition of Mn on the microstructure is changing the morphology of platelet iron phase to script form at percentages from (0.2-0.6) %, and decreases the SDAS then transforms to polyhedral form at percentages (0.8-1) %, and SDAS begins to increase.
- The effect of the addition of Cu on the microstructure is the formation of Al_2Cu as a colony, and the percentage of Al_2Cu increases as the Cu content increases.
- The tensile strength (UTS) increased with the increase in Mn percentages from (0.2 to 0.6) then started decreasing after 0.6% for the heat treated alloys.
- The tensile strength (UTS) increased with the increase in Mn percentages from (0.2 to 0.6) then started decreasing after 0.6% for the non-heat treated alloys.
- The tensile strength (UTS) increased with the increase in Cu percentages for the heat treated alloys.
- The tensile strength (UTS) increased with the increase in Cu percentages for the non-heat treated alloys.
- The hardness properties (MVH) increased with the increase in Mn percentages from (0.2 to 0.6) then started decreasing after 0.6% for the heat treated alloys.
- The hardness properties (MVH) increased with the increase in Mn percentages from (0.2 to 0.6) then started decreasing after 0.6% for the non-heat treated alloys.
- The hardness properties (MVH) increased with the increase in Cu percentage for the heat treated alloys.
- The hardness properties (MVH) increased with the increase in Cu percentage for the non-heat treated alloys.
- The impact properties decreased with the increase in Mn and Cu percentages for the heat treated alloys.
- The impact properties decreased with the increase in Mn and Cu percentages for the non-heat treated alloys.

References

[1] M. Abdulwahab "Studies of the Mechanical Properties of Age-hardened Al-Si-Fe-Mn Alloy", Australian Journal of Basic and Applied Sciences, Vol. 2 (2008), No.4, 839-843.

[2] R. S. Rana; Rajesh Purohit, and S Das, "Reviews on the Influences of Alloying elements on the Microstructure and Mechanical Properties of Aluminum Alloys and Aluminum Alloy Composites", International Journal of Scientific and Research Publications, Vol. 2, (2012), No. 6, 3145-3153.

[3] D. J. Lloyd; S. A. Court, Influence of grain size on tensile properties of Al-Mg alloys, Materials Science and Technology Vol. 19, (2003), No. 10 ,1349-1354.

[4] E. *George* Totten, D. Scott MacKenzie, "*Handbook of Aluminum*: Vol. 2: Alloy Production and Materials Manufacturing", (2003).

[5] N. Nafsin and H. M. M. A. Rashed ,"Effects of Copper and Magnesium on Microstructure and Hardness of Al-Cu-Mg Alloys,International Journal of Engineering and Advanced Technology (IJEAT)", Vol. 2 (2013), No.5, 547-533.

[6] Chih-Ting Wu, Sheng-Long Lee, Meng-Hsiung Hsieh, and Jing-Chie Lin, "Effects of Cu content on microstructure and mechanical properties of Al–14.5Si–0.5Mg alloy", Materials characterization, Vol. 61 (2010), 1074–1079.

[7] Z. Zhu, M.J. Starink, " Solution strengthening and age hardening capability of Al–Mg–Mn alloys with small additions of Cu", Materials Science and Engineering A 488, (2007), 125–133.

[8] Li. Hongying ,Y i Tang, Zaide Zeng , Ziqiao Zheng , Feng Zheng, "Effect of ageing time on strength and microstructures of an Al–Cu–Li–Zn–Mg–Mn–Zr alloy", Materials Science and Engineering A ,498 , (2008), 314–320.

[9] J. Y. Hwang, H.W. Doty, M. J. Kaufman, "The effects of Mn additions on the microstructure and mechanical properties of Al–Si–Cu casting alloys", Materials Science and Engineering A 488, (2007), 496–504.

[10] S.S. Kumari, "Effects of individual and combined additions of Be, Mn, Ca and Sr on the solidification behaviour, structure and mechanical properties of Al–7Si–0.3Mg–0.8Fe alloy", Materials Science and Engineering: A, Vol. 460-461, (2007), 561-573.

[11] Z. Ma, A.M. Samuel, F.H. Samuel, H. W. Doty, S. Valtierra, "A study of tensile properties in Al–Si–Cu and Al–Si–Mg alloys: Effect of-iron intermetallics and porosity", Materials Science and Engineering A 490, (2008), 36–51.

[12] G.J. Zhang, R. H. Wang, S.P. Yuan, G. L. Scudino, J.Chen K. H. Sun, "Influence of constituents on the ductile fracture of Al–Cu–Mg alloys: Modulated by the aging treatment", Materials Science and Engineering A 526, (2009),171–176.

[13] K. G. Basavakumar, P. G. Mukunda And M. Chakraborty, "Effect of melt treatment on microstructure and impact properties of Al–7Si and Al–7Si–25Cu cast alloys", Bull. Mater. Sci., Vol. 30 (2007), No. 5, 439–445.

[14] Z. Muzaffer, "Effect of copper and silicon content on mechanical properties in Al–Cu–Si–Mg alloys", Journal of Materials Processing Technology Vol. 169 (2005), 292–298.

[15] Z. Muzaffer, Karakulak Erdem, GÜMÜŞ Serap, "Influence of Cu addition on microstructure and hardness of near-eutectic Al-Si-*x*Cu-alloys", Trans. Nonferrous Met. Soc. China vol. 21, (2011), 1698-1702.

[16] Hossain, A. S. W. Kurny, "Optimization of Artificial Ageing Time and Temperature on Evaluation of Hardness and Resistivity of Al-Si-Mg (Cu or/& Ni) Alloys", International Journal of Chemical, Materials Science and Engineering, Vol. 8 (2014), No: 4, 291-296.

[17] Nurul Razliana Abdul Razak, Nisrin Adli, Norainiza Saud, and Sayyaidah Amnah Musa, "Effect of Aluminum Addition on Microstructure and Microhardness of Sn-0.7 Cu-xAl Lead-free Solder Alloy", Applied mechanics and Materials, Vol. 754-755 (2015), 166-170.