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Study of the Effects of Ageing Temperature and Ageing Time on the Microstructure and Some Mechanical Properties of Sand Cast Al-Si-Mg Alloys

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ABSTRACT: This research work studied the effect of heat treatment on some mechanical properties of locally produced sand cast Al-Si-Mg alloys. The T6 heat treatment method was used for the heat treatment. The results show that solution heat treatment of Al-14%Si-0.288Mg at 530 ^{0}C for 6 hours resulted in an ultimate tensile strength of (120.00±0.70 MPa) with impact energy of (20.00±2.65 J) and the as cast ultimate tensile strength was (122.00±0.70 MPa) with impact energy of (12.33±0.58 J).The peak ultimate tensile strength was (228.32±0.93 MPa) with impact energy (14.00±0.58 J) when artificially aged at 170 ^{0}C for 5 hours. The peak strength at 160 ^{0}C for 7 hours was (200.40±0.98 MPa) with impact energy (13.67±0.58 J). These values obtained for the ultimate tensile strength were within the European standards for the ultimate tensile strength of sand cast Al-Si-Mg alloys (ISO Al Si7Mg, ISO AlSi10Mg and ISO Al Si12Cu in the T6 conditions are 260, 260 and 170 MPa) respectively. Also Al-Si-Mg alloy responded to the heat treatment very well.

KEYWORDS: Solution Treatment, Ageing Time, Ageing Temperature, Intermetallic Phases.

1 INTRODUCTION

The exceptional and excellent specific strength and the combination of properties provided by aluminium and its alloys make it one of the most attractive metallic materials for industrial applications [5]. Aluminium and its alloys have gained several applications in the aerospace, automotive, building, marine, sports and exercise, rail, energy distribution, packaging and mechanical industry. As designers seek to design light weight vehicles and aircrafts with improved fuel efficiency and reduced carbon footprint [10].

The Al-Si-Mg alloy is very useful in the automotive industry due to its good wear resistance, low thermal expansion, light weight and strength after ageing treatment [7]. Magnesium additions of 0.25–0.5% Mg allow Al–Si alloys to be hardened by heat treatment, improving mechanical properties through the precipitation of Mg_2Si in a finely dispersed form [1], [7]. The T6 ageing treatment of heat treatable Al-Si-Mg alloys consists of solution heat treatment, quenching and ageing. The strengthening phase (Mg_2Si) precipitates out of solution and grows into large incoherent phase within the matrix during casting. This is due to the slow cooling rate of the samples in the mould. The large, incoherent (Mg_2Si) phases do little to increase the strength of the alloy. To obtain finely dispersed Mg_2Si particles, the alloy is solution heat treated to a temperature of 540 ^{0}C to dissolve the Mg_2Si back into solution in the aluminium matrix [2]. Quenching is where the alloy quickly cools from solution, locking the strengthening elements in the aluminium matrix. At this point the alloy is meta-stable due to entrapment of silicon and magnesium crystals wanting to precipitate but at this room temperature they lack enough energy to fully precipitate out of the matrix. Aging is where the alloy is raised to a temperature high enough to initiate the precipitation of the Mg_2Si particles. During the aging process, the Mg_2Si particles precipitates out as finely dispersed particles, which anchor the matrix and impede the movement of dislocation in the matrix and in effect this strengthens the alloy significantly [2], [11]. The successive precipitation sequence in Al-Si alloys which contain magnesium is represented by β_{SSS} → GP zones (β”) → β’ → β Mg_2Si. The precipitation sequence for Al–Si–Mg alloys starts with the formation of spherical GP zones consisting of an enrichment of Mg and Si atoms. The zones elongate and develop into a needle shaped coherent β” phase. The needles grow to become semi-coherent rods (β’ phase) and finally non-coherent platelets (stable β phase) [11].

The aim of this research is to investigate the effects of ageing temperature and ageing time on the microstructure and the mechanical properties of Al-Si-Mg alloys.

2 EXPERIMENTAL PROCEDURES

High purity aluminium 99.80%, high purity magnesium 99.80%, and Silicon were obtained from Valco Ghana limited and used for the work. The chemical composition of the aluminium alloy is given in Table 1. in the as-cast condition.

Table 1.Chemical compositions for the Al-Si-Mg alloy sample (weight. %)

Al	Si	Fe	Cu	Mn	Mg	Zn	Ni	Ti	Li	Sr	V
80.889	14.400	0.102	0.010	0.003	0.288	0.007	0.5233	0.002	0.000	0.008	0.014
B	Ca	Pb	Cr	GA	Sn	Zr	Be	Bi	Na	Cd	P
0.000	0.001	0.000	0.000	0.008	0.000	0.001	0.000	0.000	0.000	0.000	3.749

Some quantities each of the aluminium, magnesium and silicon were melted in a diesel fired crucible furnace and then cast into cylindrical rods of diameter 20 mm and length 370 mm in a sand mould. After solidification of the cast samples, the samples were machined into the standard test size for both tensile test and impact test and microstructural specimen. 24 test samples were prepared for each of the tensile test and impact test 70 samples were cast in all. All samples were solution treated at temperature of 530 ^{o}C to prevent melting of the Mg_2Si, which melts at 550 ^{o}C. The solution treatment time was 6 hours. After the solution heat treatment all the samples were quenched in water of temperature 28 ^{o}C.

The samples were then divided into groups for the tensile, impact and microstructural tests. Samples were artificially aged at two different temperatures of 160 ^{0}C/1Hr, 160^{0}C/2Hrs, 160^{0}C/3Hrs, 160^{0}C/4Hrs, 160^{0}C/5Hrs, 160^{0}C/6Hrs, 160^{0}C/7Hrs and 160^{0}C/8Hrs. Also 170 ^{0}C/1Hr, 170 ^{0}C/ 2Hrs, 170 ^{0}C/3 Hrs, 170 ^{0}C/4Hrs, 170 ^{0}C/5Hrs, 170 ^{0}C/6Hrs, 170 ^{0}C/7Hrs and 170 ^{0}C/8Hrs. Three samples were tested for each time and temperature.

2.1 TENSILE TEST

Tensile test was performed on the various samples using the Control tensile testing machine from the Ghana Standards Authority. The load to fracture and diameter at point of fracture as well as the final gauge length was noted. The initial gauge length and diameter was noted before the uniaxial load. The ultimate tensile strength and the percentage elongation were calculated from the data gathered both before and after the tests. Figure 1 below shows the schematic of the tensile test sample according to ASTM E8 standards.

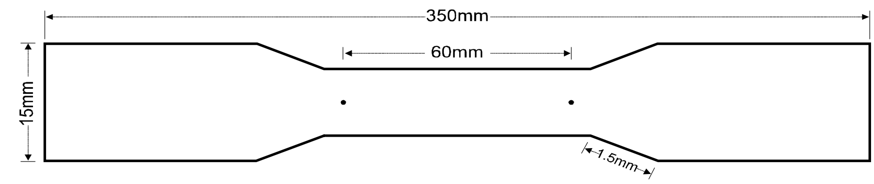

Figure 1 Schematic diagram of tensile test sample

2.2 IMPACT TEST

Impact test were performed on the various samples to determine the impact strength by using the Tinius Oslen impact testing machine. The dimensions of the square prism as given by the American Society for Testing and Materials (ASTM): B 108 Standards are 10 mm x 10 mm x 55 mm. A V-notch of depth 2 mm and base radius 0.25 mm and angle opening of 45 ^{o}C were cut in the mid-section of the length of the samples. The v notched sample in the form of square prism was clamped in the impact testing machine. The hammer was then released from a preset height to come and strike the sample on the opposite side to the notch. After the sample was broken the pendulum hammer swung on and the energy used in breaking the sample was read off a scale on the machine in joules. Figure 2 below shows the schematic of the sizes of samples used for the test.

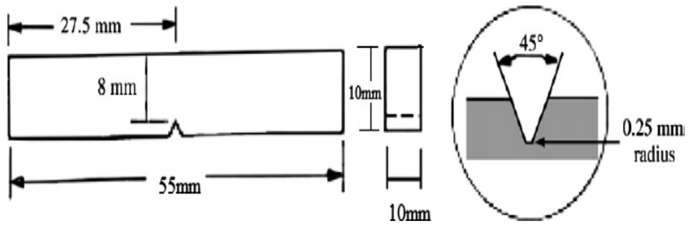

Figure 2 Schematic of impact test sample

2.3 MICROSTRUCTURE EXAMINATION

A Leica microscope with a computer interphase was used for the microstructural examination. The sample were section, grinded and polished using SiC water proof abrasive papers of grits, 240, 400, 600 and 1000 in succession on electrically powered grinding wheels. The samples were each mounted on the stage of the microscope (Leica DM 2500 M optical microscope) which is capable of producing magnification of (100X to 1000X). The specimen surface was perpendicular to the optical axis.

3 RESULTS AND DISCUSSION

Table 2 Tensile properties of Al-14%Si-0.288Mg as cast, SHT, Peaked aged at 160 °C and 170 °C respectively.

Alloy	Condition	Time(hrs)	UTS(MPa)
Al-14Si-0.288Mg	As cast		122.00
	SHT(530 °C)	6	120.00
	Peak aged 160 °C	7	200.40
	Peak aged 170 °C	5	228.32

Table 2 above depicts the variations in the ultimate tensile strength of Al-14%Si-0.288Mg under various conditions such as, as-cast, SHT, Peak-aged at 160 °C and 170 °C respectively. The ultimate tensile strength of the as-cast alloy was (122±0.70 MPa) and (120±0.70 MPa) when the alloy was solution treated at 530 °C for 6 hours in the furnace, the percentage reduction in strength was 1.67%. Decrease in ultimate tensile strength was attributed to slow cooling rate during quenching of the sample which caused particles to precipitates heterogeneously at grain boundaries or at the dislocations; resulting in a decrease in the super saturation of solute atoms and resulting in reduction in ultimate tensile strength [8]. As expected, there was 63.6% and 66.31% increase in strength from the as cast and the solution treated samples when aged at 160 °C, that is (122±0.70) to (200.40±0.98 MPa) and (120±0.70 MPa) to (200.40±0.98 MPa). There was also an increase in strength of 86.4% from the as cast structure when the samples were peak aged at 170 °C, that is from (122±0.70 MPa) to (228.32±0.93 MPa). It can also be seen that the peak ageing time was 5 hours for the 170 °C temperature and 7 hours for 160 °C temperatures. This shows that increase in temperature, increased the ultimate tensile strength of Al-14%Si-0.288Mg alloys.

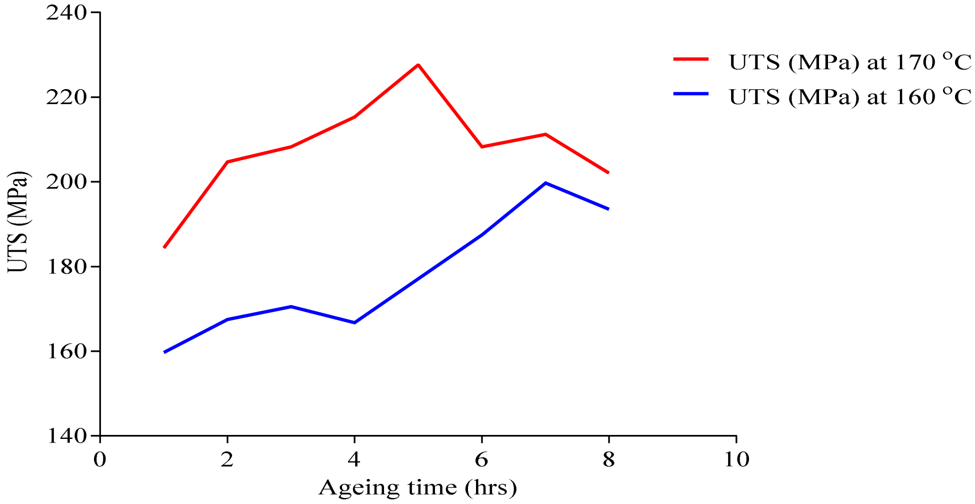

Figure 3 Composite curves for Al-14%Si-0.288Mg at 160 °C and 170 °C for 8 hours

Figure 3 show that as the ageing time is increased, the UTS value also increased up to (171±0.70 MPa) at 3 hours and drops slowly at time 4 hours. After this time, the UTS value increased up to (200.40±0.98 MPa) at 7 hours which is the peak and drops, as indicated in Figure 3 for the alloy studied at 160 °C. The reasons for this drop may be as a result of the fact that a decrease in ultimate tensile strength is associated with an increase in inter-particle spacing between precipitates which makes dislocation bowing very easier [3].

The increase in ultimate tensile strength at 170 °C was quick at 3 hours with a value of (208.60±0.42 MPa). This value further increased to (228.32±0.93 MPa) which is the peak UTS. At this temperature the microstructure has been refined by the heat treatment into finely dispersed Mg_2Si, AlFeSi, $Al_{12}Mg_2Si$ and $Al_8Mg_3FeSi_6$ particles or precipitates. With the strengthening phase β" which is coherent together with the semi-coherent β-Mg_2Si [6]. The alloy at this time and temperature produces UTS which is due to the accelerated production of Mg_2Si and other strengthening phases. Clusters are formed which impede the movement of dislocations therefore high UTS is recorded [1]. This UTS was within the European standards for the ultimate tensile strength of sand and chill cast aluminium alloys (ISO Al Si7Mg, ISO Al Si10Mg and ISO Al Si12Cu in the T6 conditions are 260, 260 and 170 Mp) respectively [4].

Figure 3 compares the two temperatures 160 °C and 170 °C and the various UTS values recorded for their peaks. It could be seen that the UTS values for the temperature 170 °C were higher than that of 160 °C. This confirmed the fact that increasing ageing temperature increases the tensile strength of Al-Si-Mg alloys [9]. Figure 4 and Figure 5 shows that Al-Si-Mg has uniform and good percent elongation from 1 hour to their peak ageing periods, which showed good mechanical properties and these mechanical decreased after their peak ageing times that was 7 hours and 5 hours for Al-Si-Mg alloy at ageing temperatures 160 °C and 170 °C.

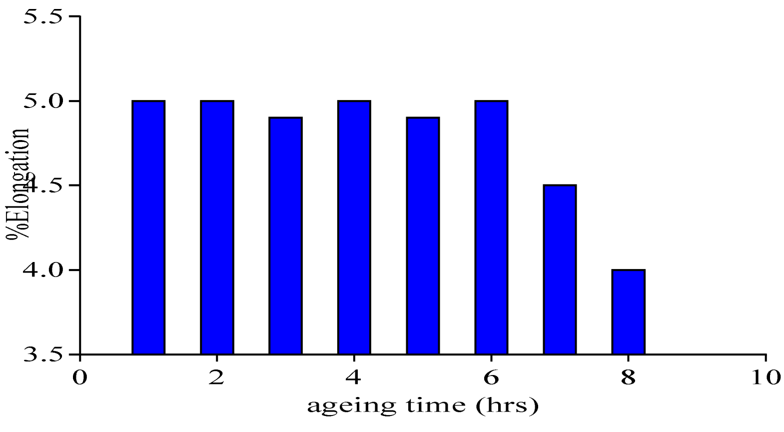

Figure 4 Effects of ageing time on the ductility of samples 160 °C

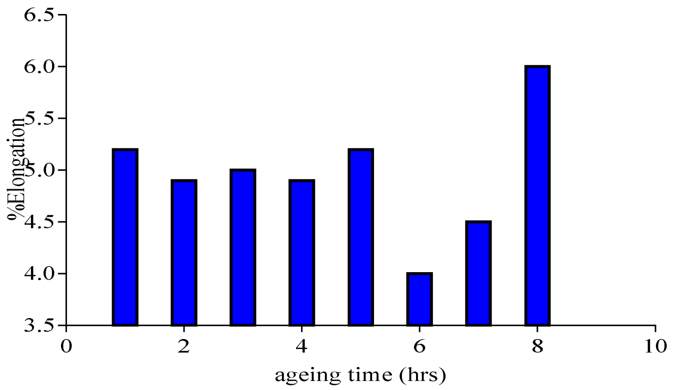

Figure 5 Effects of ageing time on the ductility of samples at 170 ^{0}C

3.1 IMPACT PROPERTIES OF SAMPLES

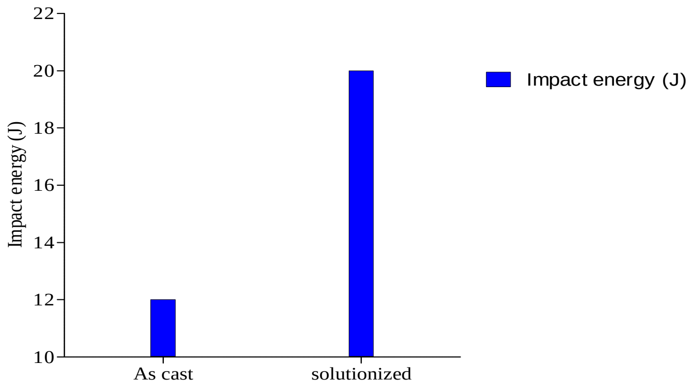

Figure 6 Impact energy of as-cast and solution treated sample

The observation made from Figure 6 was that the impact energy of the solution heat treated sample was greater than the as cast sample. The impact energy increased from (12.33±0.58 joules) to (20±2.65 joules) respectively. This means the heat treatment had a positive effect on the impact toughness of the sample. This increase in impact toughness was due to the coarsening and increases in size and shapes of the silicon particles and spacing between intermetallic particles that were formed which made dislocation movement much easier. This confirmed the observations made by [12].

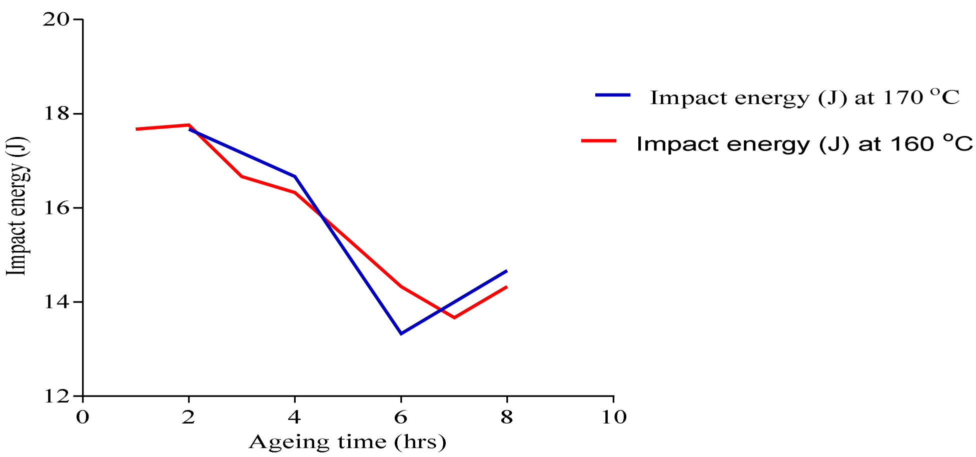

Figure 7 Composite curves of impact energies at 160 ^{o}C and 170 ^{o}C for Al-Si-Mg alloy

Figure 7, shows composite curves of impact energy at 160 °C and 170 °C for Al-Si-Mg alloy. At temperature 170 °C, there was a reduction in impact from 2 hours up to 6 hours. After 6 hours the impact energy started to increases again. The reduction in impact energy was due to the microstructure being refined by the heat treatment into finely dispersed Mg_2Si, AlFeSi, $Al_{12}Mg_2Si$ and $Al_8Mg_3FeSi_6$ particles or precipitates. The strengthening phase β" is coherent together with the semi-coherent β-Mg_2Si [6]. Clusters are formed which impede the movement of dislocations [1]. The increase in impact toughness after 6 hours was due to the coarsening and increases in size and shapes of the silicon particles and spacing between intermetallic particles that were formed which made dislocation movement much easier. Temperature 160 °C showed same decrease in impact energy up to 7 hours and increase in the impact energy after 7 hours, Figure 7 also showed the effect of ageing temperature on the impact energy of the samples. The ageing time had a negative effect on the impact toughness because of the reduction in the impact toughness as time progressed.

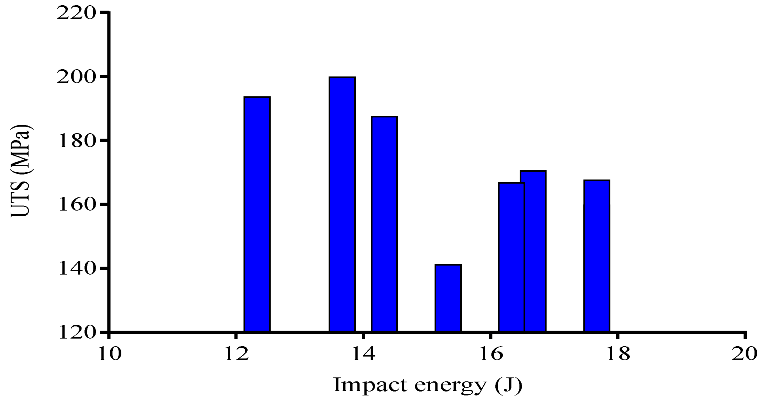

Figure 8 Bar charts of UTS against impact energies at ageing at 160 °C (Al-Si-Mg alloys)

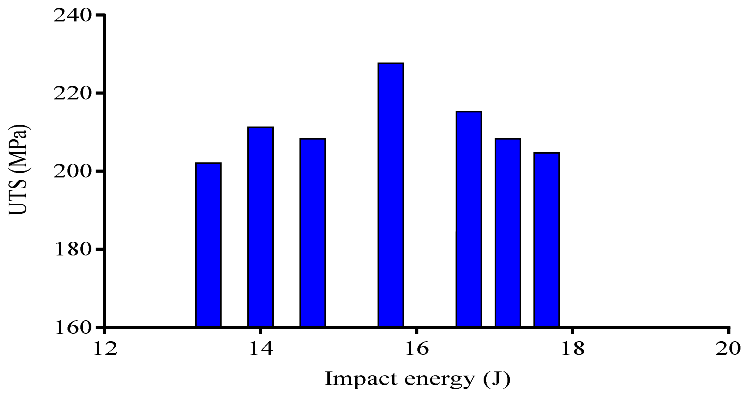

Figure 9 Bar charts of UTS against impact energies at ageing temperature of 170 °C (Al-Si-Mg alloys)

3.2 MICROSTRUCTURES

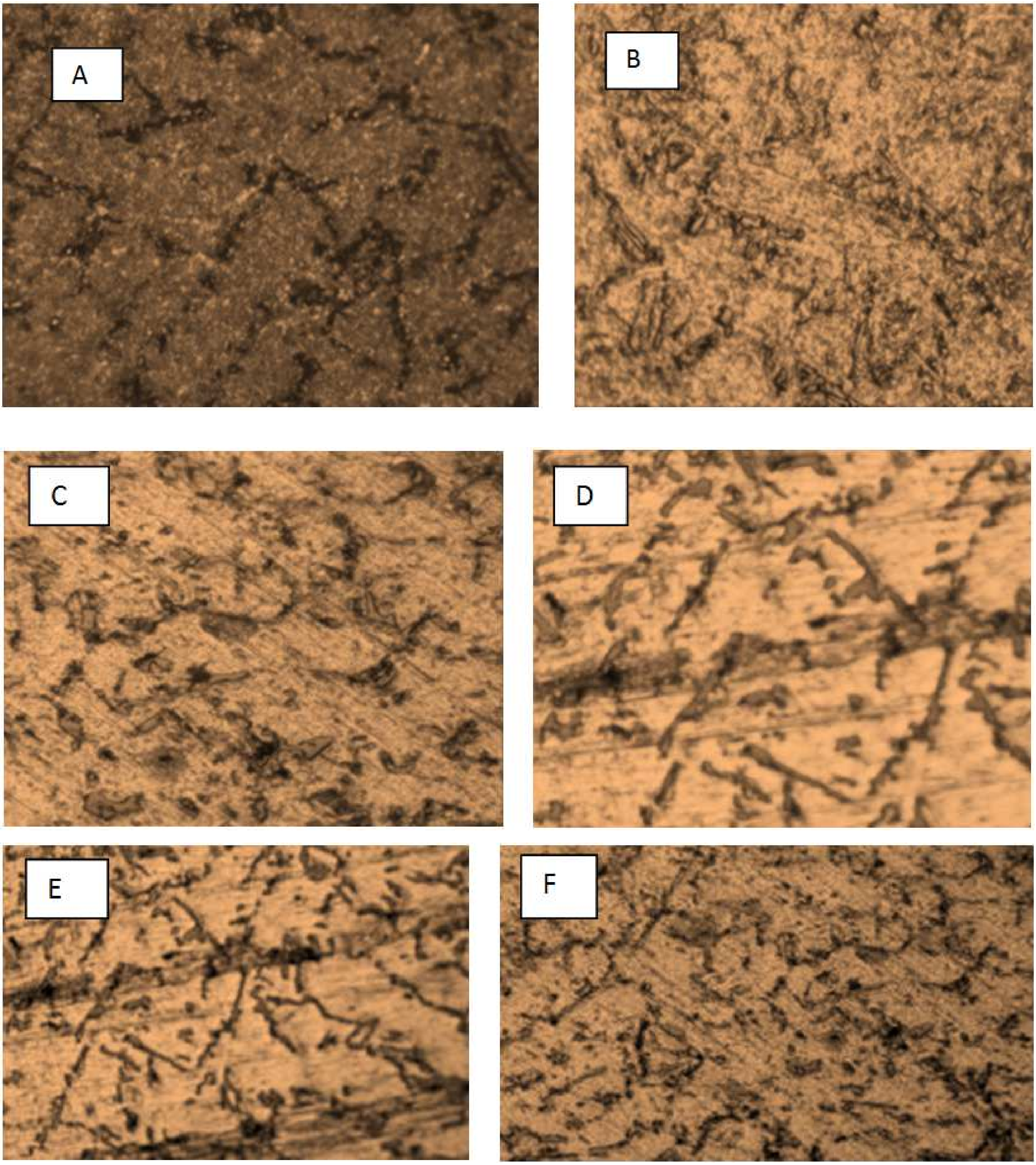

Figure 10 Optical microstructures of Al-Si-Mg (a) as cast (b) SHT for 6 hours (c) aged 5 hours (d) aged 7 hours at 170 ^{o}C, (E) aged 6 hours and (F) aged 7 hours at 160 ^{o}C (x200).

The microstructures in Figure (10) show how heat treatment changes the microstructure of Al-Si-Mg alloys used in this research work. Figure 10 (a) shows the as-cast microstructure which is made up of α-Al dendrites. Figure 10 (b) shows a supersaturated alloy microstructure with trapped solid solutes after solution heat treatment. Figure 10 (c) shows precipitates forming after age hardening for 2 hours. Figure 10 (d) shows more precipitates forming after 3 hours of ageing. The Mg_2Si is the principal hardening phase and precipitates of this structure in the microstructure results in increase in tensile and yield strength of the alloy as well as hardness [6]. This precipitates impede dislocation movements [1].

4 CONCLUSIONS

The study of the effects of heat treatment on locally produced sand cast Al-14%-Si-0.288Mg alloy has been conducted and the tensile, percentage elongation and impact strengths were measured and correlated to the microstructures. The following conclusions have been made from the research. Al-Si-Mg alloys respond very well to heat treatment. Increasing temperature increases both rate of precipitation and the Ultimate tensile strength (UTS) of Al-Si-Mg alloys.

The lower the ageing temperature, the longer the time required to obtain peak strength and the higher the temperature the shorter the time needed to attain peak strength. The ultimate tensile strength (UTS) recorded for the Al-Si-Mg alloy were within the European standards for sand and chill cast aluminium alloys (ISO Al Si7Mg, ISO Al Si10Mg and ISO Al Si12Cu in the T6 conditions are 260, 260 and 170 MPa) respectively. Increasing the ageing time reduced the impact strength of the alloy.

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