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Effect of thermal ageing treatment on the mechanical properties of antimony-modified A356.0-type Al-Si-Mg alloy

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Abstract
Studies have been made on the mechanical properties upon thermal ageing of a sand cast antimony-modified A356-type Al-Si-Mg alloy. The produced alloy was solution heat treated at 540^{o}C/1 h then subjected to thermal ageing treatment at 180^{o}C for 1-5 h. There mechanical properties; Tensile properties, Hardness and Impact strength were used as criterion. From the results, the tensile properties and hardness increased with thermal ageing treatment. While the impact energy and elongation decreased upon ageing. The tensile properties of antimony-modified Al-Si-Mg alloy improved with ageing time and that the microstructures indicate spherodization of the silicon flakes to fine structures, which account for the improved properties.

Keywords: Al-Si-Mg alloy, spherodization, ageing time, grain refinement

1. Introduction
Aluminium and its alloy found applications in many industries due to their excellent properties, such as high strength-to-weight ratios, high thermal conductivity, good corrosion properties and excellent workability [1-5]. The use of Al-Si-Mg alloys in particular for automotive industry is attractive due to light weight and reasonable strength after ageing treatment [6]. The A356-type Al-Si-Mg alloy offer hardening possibilities that leads to specific properties and applications in automobile, aerospace and marine industries. Since precipitation hardening remains one of the major treatments that are usually adopted for the purpose of increasing strength/hardness of aluminium alloys [7-10], method(s) for improving this treatment becomes necessary. Modification has been reported to alter the microstructure of aluminium alloy. Both sodium (Na) and strontium (Sr) has historically been used for modification of Al-Si alloys. The beneficial effect of modification is connected with a change in the shape of the silicon crystals [2,6]. In the normal untreated castings silicon is found as irregular plates while in the modified casting they are very small and worm shaped surrounded by ductile aluminium. The optimum Na or Sr content in a modified A356 is approximately 0.01% Na, or Sr and with less Na or Sr the modification is incomplete while with higher Na or Sr content large Si crystals are formed, besides the fine grained matrix [6]. Though many theories have

been put forward to explain the process, the most probable structure is a ternary eutectic mixture Al-Si-Na, or Sr (eutectic temperature is reduced by 10% with Na as modifier).

Through the development of technology for modifying the eutectic structure of silicon on Al-Si casting alloys, an overriding hypothesis has been that the mechanical properties of these alloys improve with changes in microstructure away from the acicular granular either to the lamellar refinement from antimony (Sb) addition or toward the fibrous structure from modification with Na and /or Sr. In the ageing process the temperature is controlled so that fine precipitates are dispersed from the SSSS. The temperature in the precipitation step must be before the metastable miscibility gap which is the GP-zone solvus line [11], When the SSSS undergoes ageing treatment, a large amount of small and uniformly distributed precipitants will appear thus the mechanical properties of the materials can be improved. Uniform and delicate Mg_2Si precipitants can be obtained in the matrix of a heat treatable Al-Si-Mg casting part with T6 treatment, leading to improvement in its tensile strength, hardness, elongation and toughness [8]. Consequently, the precipitation process in many alloy system is determined by the most efficient way to decompose the unstable supersaturated solid solution into the equilibrium two-phase matrix [12]. In this work, the effect of antimony as a modifier on the mechanical properties of A356.0-type Al-Si-Mg alloy was investigated.

2. Experimental procedures

2.1 Materials

The materials used for the production of Al-Si-Mg alloy systems includes high purity aluminum obtained from Northern Cable Company NOCACO Kaduna and elemental Si/Mg obtained from Chemical Shop in Zaria, Nigeria. The chemical composition of the cast alloy is 7%Si, 0.3%Mg and 92.7%Al. The alloys were sand cast into cylindrical bars of 22 mm diameter and 300 mm length and machined into standard specifications [13] for tensile, impact and hardness tests respectively. The binary phase diagram of Al-Si alloy is shown in Figure 1.

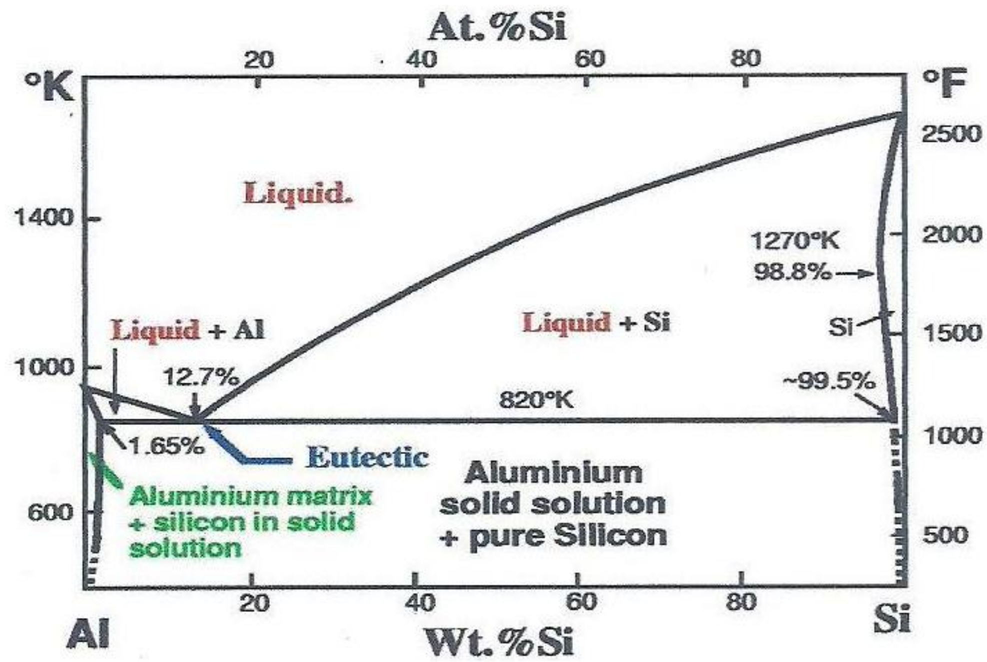

Figure 1: Al-Si cast alloy phase diagram [14]

2.2 Method

An A356-type Al-Si-Mg alloy was produced through sand casting technique. The composition was melted in Alumina crucible. The melting was done using a muffle resistance furnace. The pure aluminium wire were first melted which was allowed to heat to 750°C before the crucible was removed and other alloying elements; silicon and magnesium were added. Then the crucible was returned back to the furnace for further 30 minutes during which the furnace temperature was raised to 800^{0}C for superheat to occur then 0.01% antimony was added and stirred thoroughly before pouring into the mould. The cast samples were machined to standard tensile, hardness and impact test specimens. The machined samples were solution heat treated at temperature of 540^{0}C in an electric heat treatment furnace, soaked for 1 h at this temperature and then rapidly quenched in warm water. The quenched specimens were then aged at 180^{0}C, for 1-5 h before cooling in air. The specimens were then subjected to the various mechanical testing.

3. Results and discussion

3.1 Results

In Figure 2, the hardness, yield strength and ultimate tensile strength are presented with the ageing time. Figure 3 shows the variation of impact strength and percentage elongation with ageing time. The microstructures of the aged samples were shown in Figure 4(a-f).

3.2 Discussion

The hardness values of the aged samples increased with ageing time up to 3 h (40.40 HRA) also the hardness decreased sharply from 3-5 h ageing time, this shows that the antimony-modified Al-Si-Mg alloy has peak ageing time of 3 h. The reasons for this may be as a result of the fact that a decrease in the hardness is associated with an increase in the inter-particle spacing between precipitates, which makes dislocation bowing much easier [15,16]. Equally, the ultimate tensile strength (UTS) and yield strength (YS) increases with ageing time (Figure 2). The UTS of 48.49 N/mm^2 was obtained at 2 h ageing time then decreased similar to YS. From Figure 3, it can be observed that the impact energy of Al-Si-Mg alloys increased form 1-2 h ageing time and % elongation decreased with ageing time.

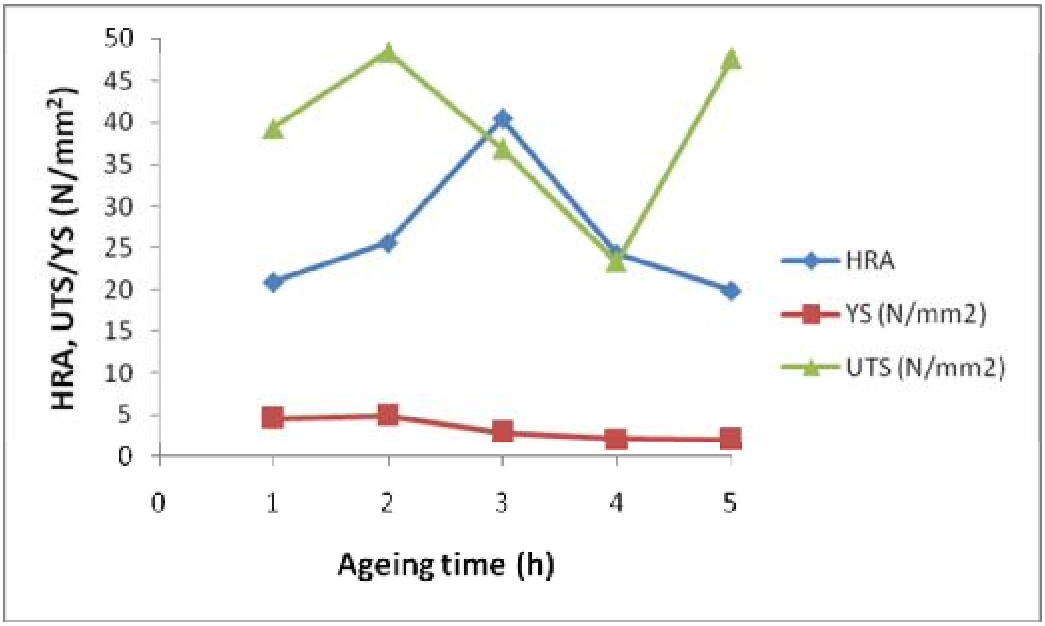

Figure 2: Variation of the hardness (HRA), yield strength (YS) and Ultimate Tensile Strength (UTS) with the ageing time

Form the results, between 1-2 h and 3-5 h are termed under ageing and over ageing time respectively for the hardness of the aluminium alloy. The result shows that the resistance of Al-Si-Mg alloy to plastic deformation by indentation increases from 1-3 h ageing time and also decreases from 3-5 h ageing time. Also the heat treated samples and quenched material show the significant increase in hardness. This is similar to the finding reported [17]. However, Figure 3 shows that the impact energy increases from 1-2 h ageing time and began to decrease after 2 h. In this case 2 h was the peak ageing time. Equally, the Figure 2 shows that the ultimate tensile strength for Al-Si-Mg alloys increases from 1-2 h ageing time, and begins to decrease from 2-4 h ageing time and suddenly rise after 4h.

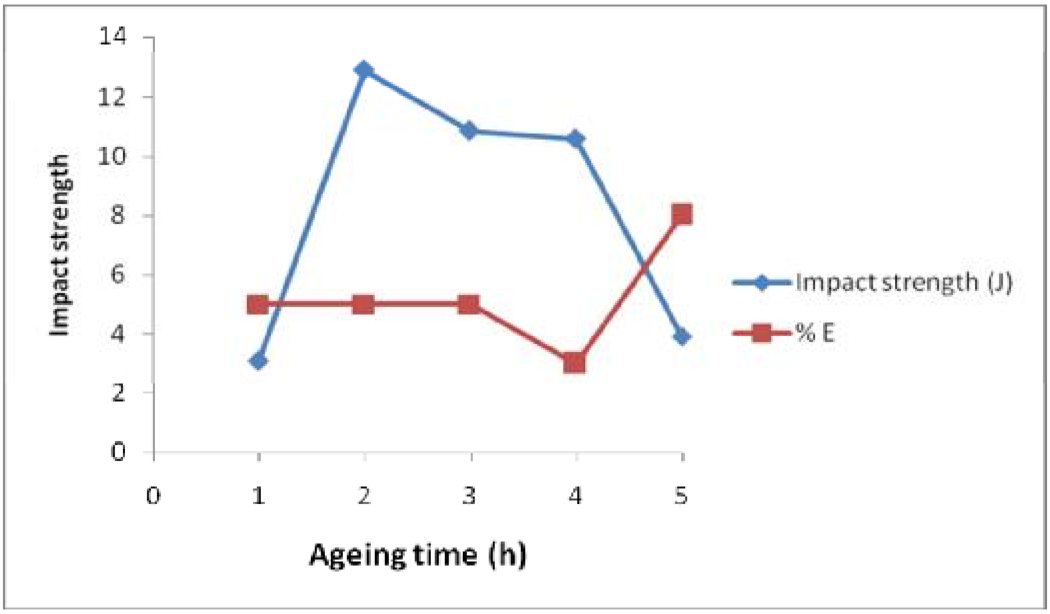

Figure 3: Variation of the impact strength (J) and percentage elongation (% E) with the ageing time

The result also demonstrates that, longer ageing times led to over ageing which may result to a decrease in the mechanical properties such as hardness and impact energy. Equally, Figure 3 shows that the Al-Si-Mg alloy has good and uniform % elongation between 1 to 3 h ageing period, which signified good mechanical properties and that the % elongation dropped from 3 to 4 h ageing time which shows that the mechanical properties of the materials decreased just after the peak ageing time. With the antimony modifier, it is expected that the eutectic temperature will shift down by 10% (see Figure 1), which will signify easy spherodization of silicon flakes in the matrix of aluminium solid solution.

Specifically, Figure 2 indicates that the yield strength of the Al-Si-Mg alloy increases from 1 to 2 h ageing time and decreased between 2 to 5 h ageing time, this shows that the mechanical properties increases from 1 to 2 h ageing time and start to decrease from 2 to 5 h ageing time.

The tensile properties of antimony-modified Al-Si-Mg alloy improved with ageing time and that the microstructures indicate spherodization of the silicon flakes to fine structures, which account for the improved properties. Generally, the tensile properties of Al-Si-Mg alloy improved with ageing time until it reached to the peak ageing time i.e. from 1-2 h and it dropped from 2-4 h ageing time. Thus the increment from 4-5 h ageing time, this show that there is a continuous increase in the breakdown (Figure 4) in the structure of Si eutectic network formed with grain refinement as the ageing continued, which implies a higher strength for the alloy.

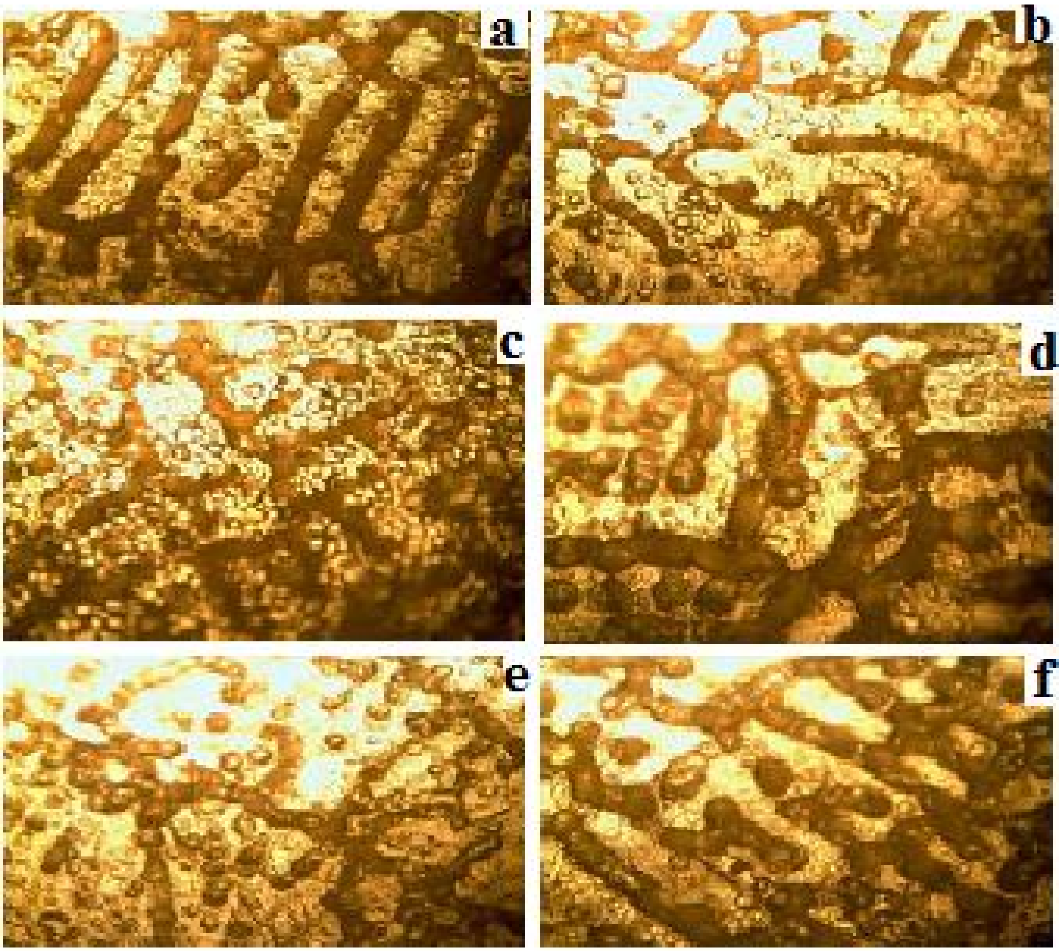

Figure 4: Microstructure of cast Al-Si-Mg alloy (a) solution heat treated at 540^0C/1 h (b) aged for 1 h (c) 2 h (d) 3 h (e) 4 h (f) 5 h x100

Conclusions

1. The hardness values of the cast antimony-modified Al-Si-Mg alloys improved by thermal ageing treatment and the results showed that higher hardness value for the alloy was achieved at the peak ageing time of 3 h.
2. The impact energy of Al-Si-Mg alloy increases as the ageing time increases until it reaches the peak ageing time.
3. Generally, the tensile properties of antimony-modified Al-Si-Mg alloy improved with ageing time and that the microstructures indicate spherodization of the silicon flakes to fine structures, which account for the improved properties.

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References

1. Chuang, Y. Lee, S. and Lin, H., *Materials Transactions*, 47(1) (2006) 106.
2. Abdulwahab**,** M. **,** Madugu, I. A., Yaro, S.A., Hassan, S. B., Popoola, A. P. I. Mater Des, 32(3) (2011) 1159.
3. Li, H. X., Rudnev, V. S., Zheng, X. H., Yarovaya, T. P., Song. R. G., *Journal of Alloys and Compounds*, 462 (2008) 99.
4. Rudman, K. B. Metal Casting Reference Book, Department of Materials Science and Engineering, Michigan Technical University, USA, pp 23-29, (2005).
5. Ding, H., Zhou, G.. and Hui, D., Frictional and wear performance of an aluminium alloy in artificial seawater. *Proceeding of the Institute of Mechanical Engineers (Proc. IMechE), Part J: Engineering Tribology*, 225: 43-49, (2011).
6. Thompson, S., Cockcroft, S. L., Wells, M. A., *J Mater Sci Techn*, 20 (2004) 194.
7. Miao, W. F., Laughlin, D. E., *Scripta Mater.*, 40(7) (1999) 873.
8. Juang, S. H., Wu, S-M, *J. Marine Sci. Tech.***,** 16(4) (2008) 271.
9. Birol, Y., *J alloys Compds*, 484 (2009) 164.
10. Ravi, C, Wolverton, C., *Acta Mater*, 52 (2004) 4213.
11. Zander, J., Sandstrom, R., *Mater Des.*, 28 (2008) 1540.
12. Hamani, M. S., Hamidane, F., Djouama, M. C., *Res. J. Appl. Sci.,* 2(1) (2007) 105.
13. John, V. B., Testing of Materials, an Introduction" 3rd Edition, Macmillan Education Limited, London, (1992).
14. Jacobs, M. Precipitation Hardening. TALAT Lecture:Interdisciplinary Research Centre in Materials The University of Birmingham, UK , 2-10. European Aluminium Association, (1999).
15. Risanti, D. D., Yin, M., Rivera Diazdel Castillo, P. E. J., Vau der Zwang, S. *Mater. Sci. and Eng.* A523 (2009) 99.
16. El Sebaie, O., Samuel, A. M., Samuel, F. H., Doty, H. W., *Mater. Sci. and Eng.* A480 (2008) 342.
17. Abdulwahab, M., *Australian Journal of Basic and Applied Sciences, 2(4)* (2008) *839*.