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Mechanical Behaviour of Solution Heat Treated LM4 Alloy

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Abstract

LM4 alloy is a general engineering alloy containing majorly Aluminum, Silicon and Copper as the alloying elements. The alloy possesses good castability, low material cost and it is regularly used for many engineering applications where its moderate mechanical properties are desirable. While many investigations have been carried out on the alloy, only few studies have reported investigations on mechanical behavior of LM4 alloy processed at low temperatures. Therefore, this study investigated mechanical behavior of LM4 alloy material solution heat treated at 100ºC. LM4 alloy material was prepared in the laboratory and cast into rods of 15 mm diameter and 200 mm length. A sample of the cast rods was solution heat treated at 100ºC for 24 hours, while another untreated sample which served as control was also prepared. The samples were evaluated for mechanical behaviours on a Universal testing machine. Results showed that the solution heat treated LM4 alloy material exhibits superior mechanical behavior as compared to the untreated LM4 material. Microstructure of the solution heat treated alloy show some modified structure, however with decreased elongation. Solution heat treatment of LM4 alloy material at 100ºC for 24 hours, can be used to improve the mechanical properties of the alloy material. In general, solution heat treatment can induce a large number of submicroscopic particles with non-equilibrium transition structure which may strain the matrix of the alloy material to increase strength.
Keywords: Solutionizing; Tensile strength; Fracture energy; Elongation.

1. Introduction

LM4 alloy is a general engineering alloy containing majorly Aluminum, Silicon and Copper as the alloying elements. The range of elements in the alloy is given as: Al; 4.0-6.0Si; 2.0-4.0Cu; 0.15Mg; 0.8Fe; 0.-0.7Mn; 0.3Ni; 0.5Zn; 0.1Pb; 0.05Sn; 0.2Ti. Elements Fe, Mn, Ni, Zn, Pb, Sn and Ti are considered impurity elements in the alloy [1-3]. The alloy possesses good castability, low material cost and used as piston alloy. It is also regularly used in junction boxes, gearboxes, tooling, gearboxes and electrical fittings where its moderate mechanical properties are desirable. LM4 is produced from the non-heat treatable Al-Si alloy by addition of copper to make the alloy thermally treatable.

While the alloy have been noted to possess attractive good engineering properties, however, various investigations have been carried out on the alloy to broaden the scope of areas where they can be usefully applied. Particularly, research efforts have been made to study influence of thixoprocessing on mechanical properties of LM4 [4], and the influence of Zirconium oxides reinforcement on the mechanical properties of the alloy was carried out by Ravichandra and Kumar [5]. Koushik, *et al.* [6] investigated the effects of soda glass reinforment on mechanical behavior of LM4; also Mannurkar and Raikar [7] studied dry sliding wear behaviour of LM4 using Taguchi approach. They found out that increased percentage of silicon in the alloy does not favour improved wear resistance. It was also observed that heat treatment tempering process has significant effect on tribological characteristics of the alloy.

Normally, LM4 is fully heat treated by heating for 6-16 hours at 505-520°C, and quenched in hot water and heat for 6-18 hours at 150-170°C before air cooled [8]. While the processing of LM4 by heat treating at 505-520°C for 6-16 hours and at 150-170°C for 6-18 hours is well documented, processing LM4 directly at temperatures below 150-170°C has not been reported in the literature. Davies [9], however suggested that heat treatments processing for longer times at lower temperatures give higher peak strength values. Therefore, this present study seeks to mechanically characterize solution heat treated LM4 alloy. The influence of solution heat treatment at 100ºC for 24 hours on mechanical characteristics of the LM4 alloy is investigated. Generally, understanding mechanical properties of materials is very important [10-13] to provide knowledge which is vital and useful for design and many other important engineering applications.

2. Materials and Experimental Procedure

The LM4 metallurgy alloy material used for the study was produced by melting together and casting aluminum-silicon master alloy, aluminum – copper master alloy and aluminum scrap. Two kilograms (2.25 kg) of Al-Si master alloy, 1.75 kg of Al-Cu master alloy were melted at a temperature of 720˚C with 3 kg of aluminum scrap in a lift-out electric crucible furnace (see Table 1). A total of 7 kg of LM4 was produced by casting into cylindrical rods of

15mm diameter and 200mm length in sand molds. The quantitative chemical analysis of the essential elements in the produced LM4 was carried out using Atomic Absorption Spectrophotometer (AAS) while the silicon content was determined by gravimetric analysis. Produced cast rods were machined into rods of 10mm diameter, and a rod was solution heat treated at a temperature of 100ºC for 24 hours, after which the sample was removed from the furnace and quickly quenched in water maintained at a temperature of 10ºC, before the rod was machined on a lathe machine into ASTM standard tensile test pieces for evaluation of mechanical behavior on the Universal Testing Machine. One rod was kept untreated, and was also machined into standard tensile test piece to be evaluated for mechanical behavior. This untreated sample served as control specimen. Both treated and untreated specimens were then evaluated for mechanical behavior on Universal Testing Machine. The result from the Universal Testing Machine produced the tensile strength, maximum fracture energy, Young's Modulus, and elongation values of the tested samples. The stress-strain graphs of the tested samples were also produced by the Universal Testing Machine, and these plots were obtained for further analysis. Micro-examination of the samples by optical microscopy was also carried out.

Table.1. Proportion of materials charged for the production of LM4 alloy

Material	Weight	
	Kg	%
Al-Si	2.25	32
Al-Cu	1.75	25
Al Scrap	3	43
Total	7	100

3. Results and Discussions

The results of the study are presented in Table 2; and Figures 1 2 3 4 5 6 7 8. Table 1 presents the results of the elemental chemical analysis of the produced LM4 alloy. Figures 1 and 3 show the stress-strain curves for the untreated and the treated samples respectively. The microstructures of the untreated and the treated samples are presented in Figures 2 and 4 respectively. In Figures 5 6 7 8, the test results for tensile strength, maximum fracture energy, Young's Modulus, and elongation values are presented respectively.

Table 2 showed that the percentage of the major alloying elements in the prepared alloy compared well with chemical composition of standard LM4 alloy. The stress-strain curve of the untreated sample presented in Figure 1 showed type-S stress-strain curve [12]. Ordinarily, materials with S-shaped stress-strain curves are particularly susceptible to elastic instabilities [13]. The S-type stress-strain curve indicates three distinct regions of the stress/strain curve. These regions are: (1) the toe region, (2) the linear region, and (3) the yield and failure/fracture region. For this curve, the toe region is about 67% of the total deformation, and includes all areas where low flow stresses bring about relatively large extensions. In this initial part of the curve, the material presents low stiffness to increasing load. Although toe region presents nonlinear stress/strain curve, because the slope of the toe region is not linear, the material will return to its original length when unloaded, therefore this portion is elastic and reversible and the slope of the curve represents an elastic modulus [11]. At about 0.0075 to 0.010 mm/mm, there is heel area within the toe region where there is onset of increased stiffness to applied load. At 0.010mm/mm strain, the deformation enters the linear region of the stress-strain curve. The linear region is about 17% of the entire deformation. The region is an area of higher modulus indicating stiffer material. The tested material offered higher stiffness to increased loading of the material. The stress strain curve presents a linear relationship of the stress and strain in this region. This shows that the deformation in the region is elastic, and the material will return to original shape/length when loading is removed. There is the onset of yield and failure/fracture region at around 0.012 mm/mm strain where stress of about 60.92 MPa was applied. The yield and failure/fracture region constitutes about 13% of the total deformation before failure. The microstructure of the untreated sample reveals primary aluminum with some strands of acicular silicon.

Table-2. Chemical composition of essential elements in the prepared alloy

Elements	Average (wt%)
Si	5.80
Cu	3.83
Mg	0.41
Fe	0.23
Mn	0.02
Al	Rest

Figure-1. Stress-Strain curve for untreated sample

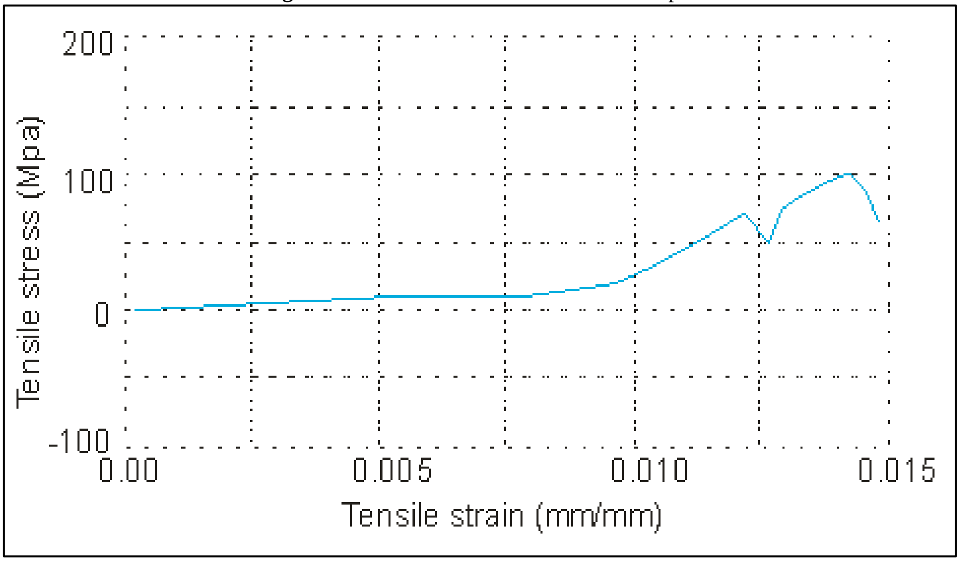
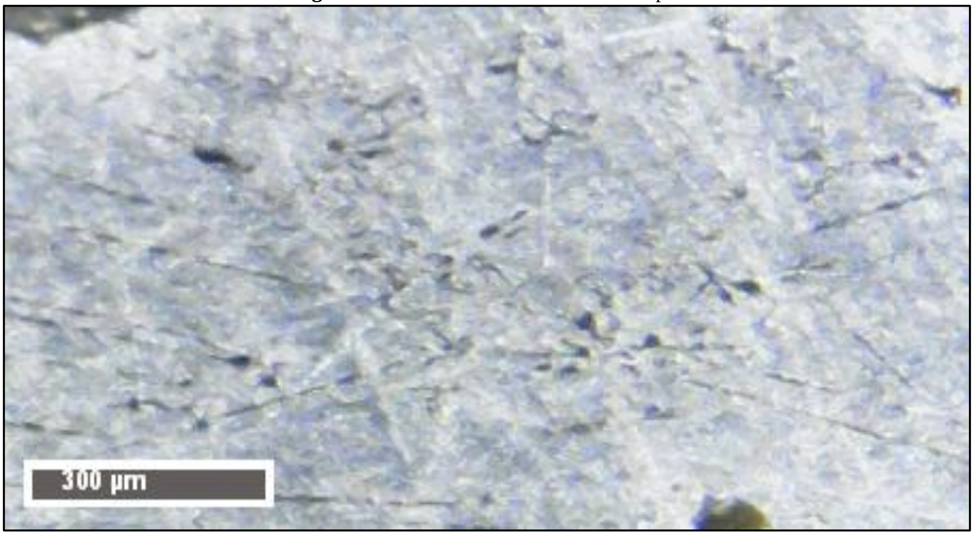


Figure-2. Microstructure of untreated sample



In Figure 3, the stress-strain curve of the treated sample is presented. Similarly the stress/strain curve manifests the three distinct regions:: (1) the toe region, (2) the linear region, and (3) the yield and failure/fracture region. In the treated sample, the toe is significantly reduced with the absence of heel region. The toe is about 14.3% of the entire deformation before fracture. Normally, the toe represents areas of low flow stress where low stresses bring about relatively large extension. This shows that the tested material offered low stiffness to applied stress at this stage.

Figure-3. Stress-Strain curve for treated sample

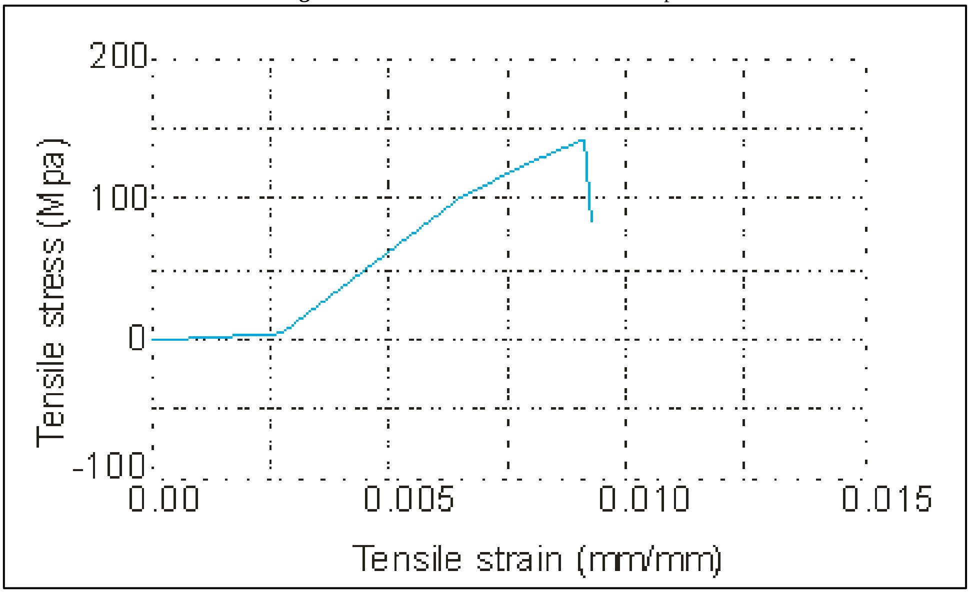
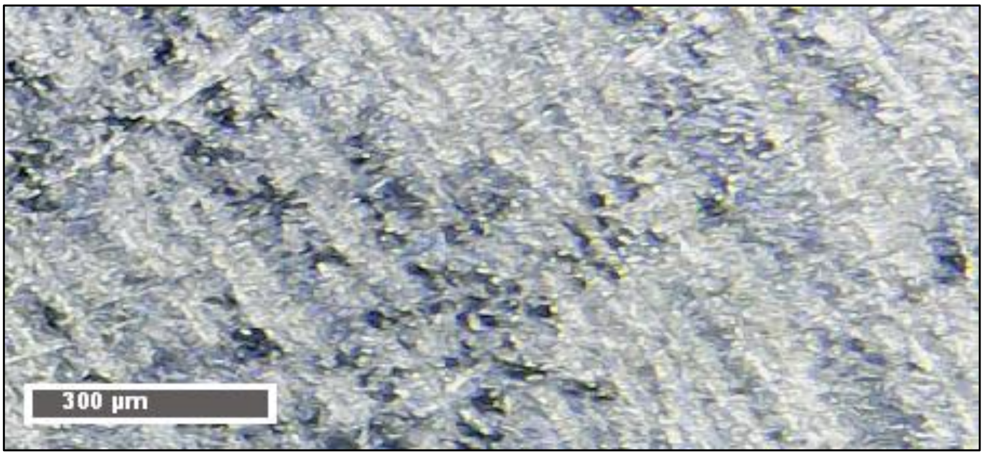


Figure-4. Microstructure of treated sample



Comparing the toe regions of the untreated and the treated samples, this reveals that treated material offered higher stiffness than the untreated material. This implies that the solution heat treatment applied to the LM4 has improved the stiffness of the LM4 matrix. At other times, during solution heat treatment, a large number of submicroscopic particles with non-equilibrum transition structure may form [10]. These particles strain the matrix so that they may increase the strength of the matrix. Microstructure of the treated sample presented in Figure 4 revealed coarsening of precipitate, confirming formation of precipitates during solution heat treatment. The results of tensile strength, maximum fracture energy, Young's Modulus, and elongation values presented in Figures 5 6 7 8 show that the tensile strength fracture energy and Young's modulus increased during the solution heat treatment, where as elongation decreased. Elongation decreased because of the straining of the matrix of the treated LM4 by formation of precipitates during the solution heat treatment.

Figure-5. Tensile strength values for the samples

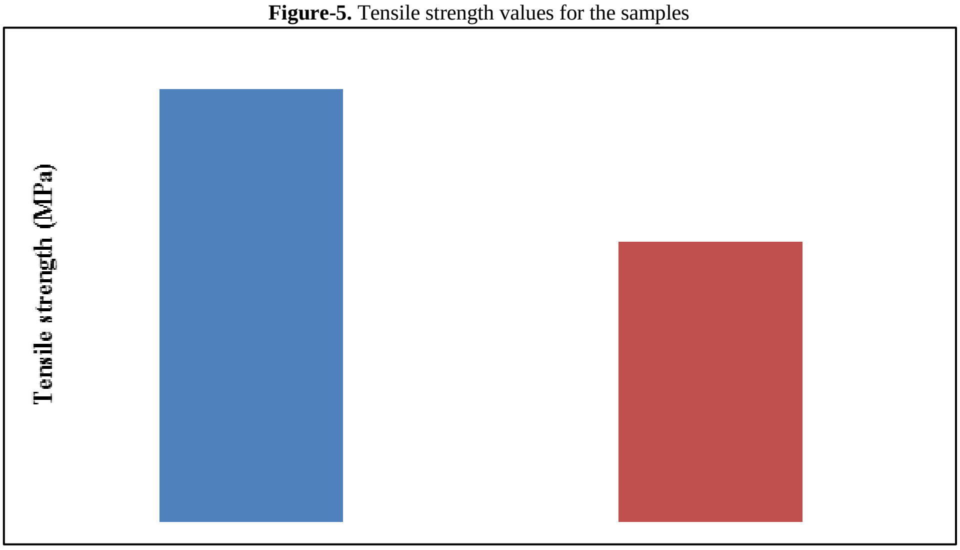


Figure-6. Fracture energy values for the samples

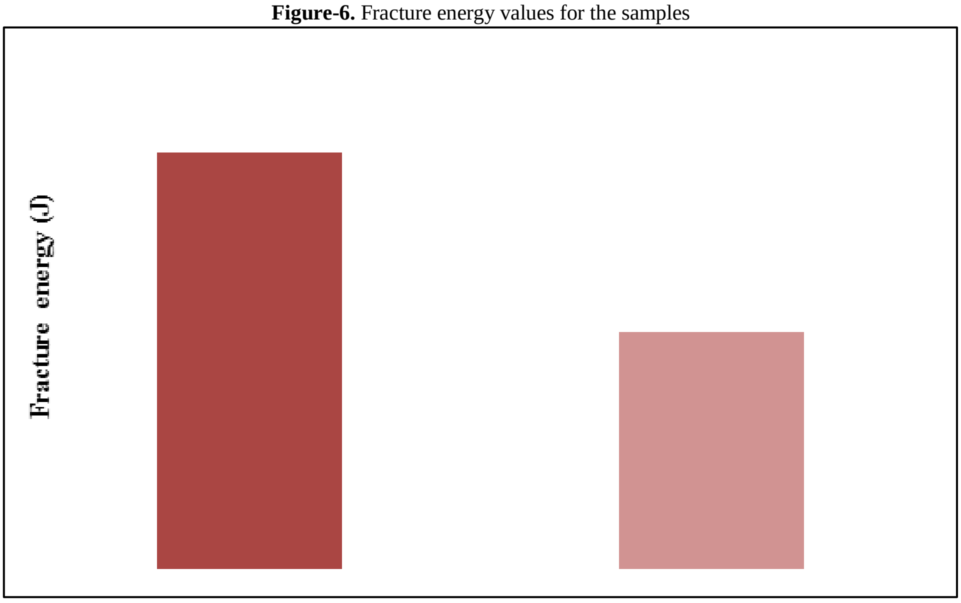


Figure-7. Youngs Modulus values for the samples

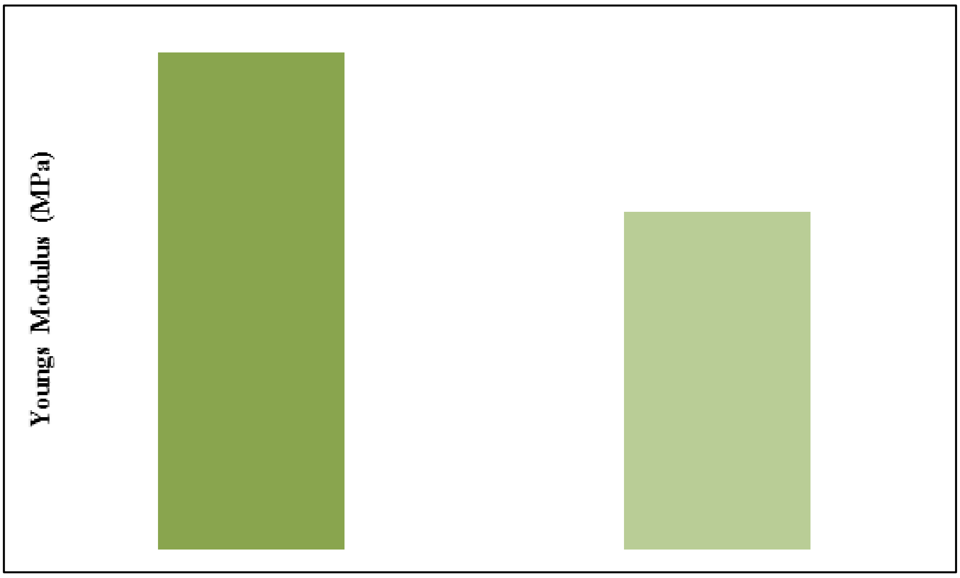
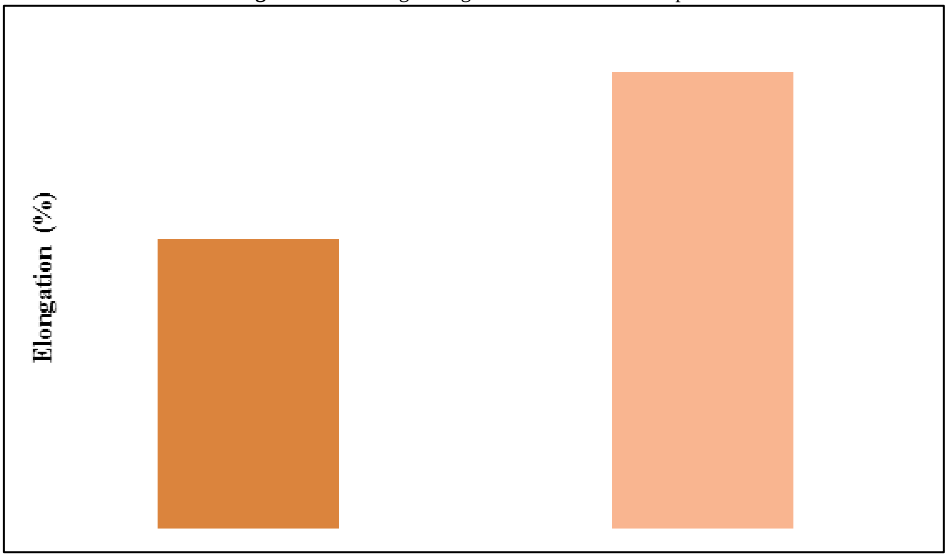


Figure-8. Percentage elongation values for the samples



4. Conclusion

The result of the investigation showed that LM4 alloy material solution heat treated has improved strength of about 145MPa. The fracture energy and Young's Modulus values for the treated alloy are equally improved to values of 0.198 J and 24788 MPa respectively during solution heat treatment. The alloy in as cast condition can be solution heat treated for improved mechanical performance. Generally, solution heat treatment can induce a large number of submicroscopic particles with non-equilibrium transition structure which may strain the matrix of the alloy material to increase strength.

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