



Evolution of Thermo-mechanical Properties of Aluminium-Silicon Alloy (Al-1wt%Si)

Nursabah Sarikavakli^{1,*}, Syed Khalid Mustafa², Mohammad Ayaz Ahmad³

¹Department of Chemistry, Faculty of Sciences, and Arts, Adnan Menderes University, Aydın, Turkey

²Department of Chemistry, Faculty of Sciences, University of Tabuk, Tabuk, Kingdom of Saudi Arabia

³Physics Department, Faculty of Sciences, University of Tabuk, Tabuk, Kingdom of Saudi Arabia

Email address:

nsarikavakli@gmail.com (N. Sarikavakli), syedkhalid.mustafa938@gmail.com (S. K. Mustafa), mayaz.alig@gmail.com (M. Ayaz Ahmad)

*Corresponding author

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Abstract: In the present article, an attempt has been made for the study of thermo-mechanical properties of alloy sample (Al-1 wt%Si). The effect of this we find good results on the microstructure and hardness of our samples with an addition of 1-3 wt.% (Al-Si). The analyses by transmission electron microscopy (TEM) show that aging heat treatment promotes micro-structural changes in morphology, size, and spatial distribution of precipitates.

Keywords: Aluminium-Silicon (Al-Si) Alloys, Temperature, Structure, Transmission Electron Microscopy (TEM)

1. Introduction

The Aluminium-Silicon (Al-Si) alloys [1-3] are frequently utilized to play an important role in the automotive industry, due its excellent combination of strength and ductility; moreover, of their high strength/weight ratio, corrosion resistance, excellent thermal conductivity and high cast ability allows the casting of complex forms.

The 3XX alloy, an Al-Si-Cu system, is commonly used in engine blocks and cylinder heads normally with a T6 heat treatment to improve mechanical properties. Kinetically, time and temperature, are two important variables to control during solution heat treatment (SHT) as they are responsible for Si modification and dissolution of Cu and Mg enriched phases. In aluminum alloys, some transition metals like Ni and Fe, and some rare earths like Ce, which the main characteristic is their low solubility in Al e.g. maximum of 0.01% to 0.04%, are employed in Al-Cu and Al-Si alloys to improve strength and hardness at elevated temperature [4-7]. This is correlated mainly to impact its coefficient of thermal expansion.

In a quenched Al-Si alloy, the silicon precipitates nucleate on the vacancy clusters and dislocation loops [8]. The

precipitates of Si become visible after the disappearance of the formed dislocation loops. The nucleation of the precipitate of Si was enhanced by pre-ageing quenched specimens near the room temperature as a result of the existence of the dislocation loops formed by the condensation of the quenched alloy in vacancies [9]. Some other workers also carried out such properties of structure and mechanical properties of low silicon-aluminium alloys [7-10]. Both the strength and ductility of the alloy were functions of the size and distribution of the Si particles in the aluminium matrix [11].

In the Al-Si alloys, the solubility of Si in aluminum is negligible below 525 K [12], therefore separate phase exists. Above 525 K, the process of Si precipitation ceases and, consequently, a reduction in the micro-hardness of these alloys is observed above 575 K [13]. The ionizing radiation is known to be one of the major sources for altering the internal structure of crystalline metallic materials and consequently their properties, which are largely governed by lattice defects [11-14]. Therefore, attention is focused on irradiation effects to search for new materials that can withstand radiation damage [13, 14].

Finally, in this article, we studied the thermo-mechanical

properties of alloy sample (Al-1 wt%Si) and we find good results on the microstructure and hardness of our samples with an addition of 1-3 wt.% (Al-Si) as some other works already found it [14]. The analyses by transmission electron microscopy (TEM) show that aging heat treatment promotes micro-structural changes in morphology, size, and spatial distribution of precipitates.

2. Methodology for Experimental Work

2.1. Chemical Analysis

The present sample of the alloy (Al-1wt%Si) was prepared by melting 99.99% pure aluminum and 99.98% Silicon (Si) in a clean graphite crucible in a vacuum induction furnace. The cast ingot was homogenized at temperature of 825 K under the vacuum of 10^{-3} Torr, up to time limit 48 hours and then cold drawn to wires of 2 mm diameter. The wires were given intermediate annealing treatment at temperature of 775 K for 8 hours then the cold drawn in a diamond dies down to wires of 0.4 mm in diameter and 10 cm in length. All the specimens were solution treated for 3 hours at 825 K, then quenched into water kept at the room temperature (RT~300K) to get samples containing the α -solid solution phase. The samples were irradiated with different doses of gamma radiation up to 1.75 MGy. In the ^{60}Co gamma rays cell used, the dose rate was 1.58 KGy/min. Some other relevant information was given in references [15-18] for data samples preparations.

2.2. Analysis for Electron Micrographs

The samples for micro-structural analysis were cut from the TA test samples, close to the tips of the thermocouples. The cross-sections of the specimens were ground and polished on an automatic polisher using standard metallographic procedures. The final polish was carried out using commercial slurry (Struers OP-U). The samples were observed under a JEOL (1973 model JEM-100C) [15-18] by using magnifications between X100 and X5000. The qualitative and quantitative assessments of the chemical compositions of the sample of the alloy (Al-1wt%Si) were done with the Energy Dispersive Spectrometer (EDS) method. The obtained chemical compositions were then normalized to 100%.

3. Results and Discussions

The stress - strain tests were carried out with an average strain rate of $2 \times 10^{-2} \text{ s}^{-1}$ in the temperature range from 500 K to 600 K. The load applied to the sample was gradually increased by adding 300 grams, with 45 second between each two successive loadings and the elongation was immediately recorded before the next loading. The elongations were measured by a dial gauge to an accuracy of $\pm 10^{-5} \text{ m}$. The yield stress, σ_y is considered to be the stress corresponding to the first significant deviation from linearity in the starting part of the stress - strain curve.

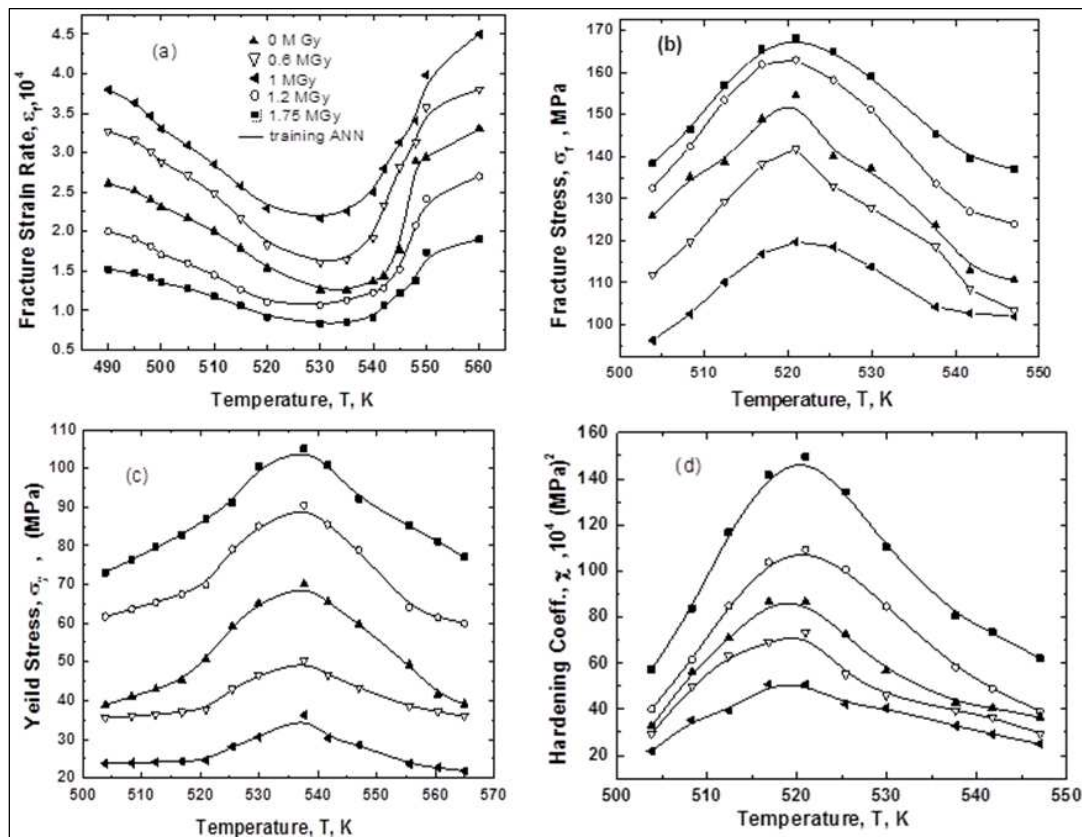


Figure 1. (a-d): The dependence of the temperature on the irradiated samples with the indicated doses: (a) fracture strain rate, ϵ_f ; (b) fracture stress, σ_f ; (c) yield stress, σ_y ; and (d) the hardening coefficient, χ .

For the Figure 1 (a-d), the maximum stress applied to the sample before fracture was taken as the fracture stress σ_f [10-17]. The microstructure of the alloy (Al-1wt% Si) was investigated by using an electron microscope, JEOL (1973 model JEM-100C) [15-18] working at an accelerating voltages 100 kV.

The stress-strain relations for the alloy samples (Al-1wt%Si) irradiated with different, γ -doses (0, 0.6, 1, 1.2 and 1.75 MGy) obtained at different working temperatures. The dependence of the temperature on the irradiated samples with

the indicated doses has been depicted in Figure 1 (a-d). In these figures the following parameters were found: 1(a) fracture strain rate ϵ_f , 1(b) fracture stress σ_f , 1(c) yield stress σ_y , and 1(d) the coefficient of work hardening, χ .

The electron micrographs showing Silicon precipitates in the alloy (Al-1wt%Si) heated for 3 h at various temperature 425, 525 and 625 K respectively were shown Figure 2 (a - c). It is clear from these figures that there exists a critical temperature (525 K) characterizing two opposite behaviors for the observed variations in the measured parameters.

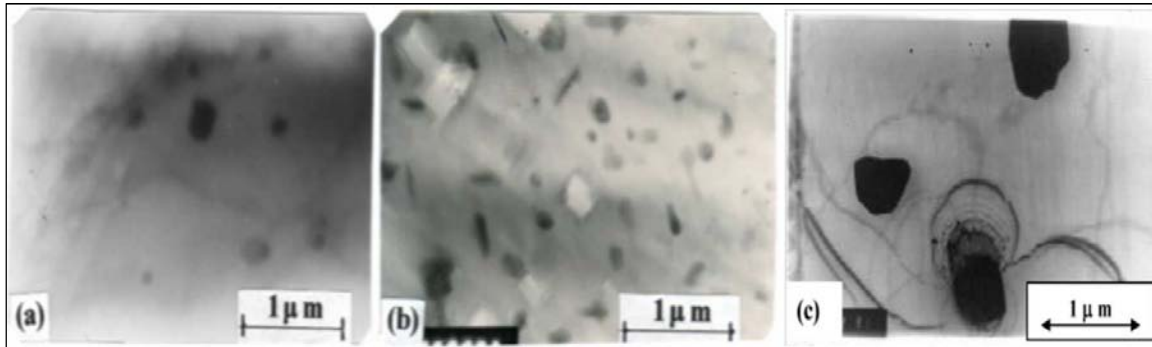


Figure 2. (a-c): The electron micrographs performance for Silicon precipitates in the alloy (Al-1wt%Si) sample heated up to 3 hours at various temperatures: (a) 425 K, (b) 525 K and (c) 625 K. respectively.

One can conclude from the above results that at relatively lower temperatures, below 525 K, heterogeneous precipitation may take place by the motion of vacancy-Silicon atom pairs. The Silicon concentration might reach its equilibrium value due to the saturation of the heterogeneous nucleation sites. Although this process makes the matrix of the alloy poor in Silicon atoms, yet Silicon concentration remains still higher than the equilibrium value. The remaining supersaturation of the matrix can thus be removed by homogeneous nucleation leading to zone formation responsible for the observed hardening for samples annealed at temperatures below 525 K. This hardening proves itself in Figure 1 as an increase in all the hardening parameters such as: σ_y , σ_f and χ reaching maxima at 525 K and a decrease in ϵ_f to minima at 523 K. This is supported by the TEM micrographs of Figure 2 (a, c) where the maximum hardness corresponds to the high precipitate density observed in Figure 2b.

The nucleation of precipitates in the alloys (Al-Si) was improved by pre-aging quenched specimens approx at the room temperature [15-18]. This enrichment can be attributed to dislocation loops formed by condensation of quenched - in vacancies. The present observations confirmed [9] that Silicon precipitates nucleated on vacancy clusters, but their formation and the subsequent nucleation took place within a few seconds after quenching.

Further, the working temperature exceeds 525 K, the regions may be rather unstable and they can easily transform to nuclei of precipitates if the Silicon concentration of the matrix is not too low and the temperature is relatively high. The Silicon atoms in these regions can disintegrate to form precipitates, with sizes on increasing the working

temperature (as it was found in Figure 2c). Therefore, it go ahead to a decrease in hardness. This decrease in hardness, or softening of the alloy, is reflected through the observed decrease in the hardening parameters σ_f , σ_y and χ and an increase in ϵ_f given in Figure 1. The thermally induced internal structure of the alloy in the tested temperature range which leads to the observed hardening behavior up to 525 K after which a softening behavior dominates, consists with previous studies [1-14].

Finally the irradiation damage caused by γ -rays creates ionizing type defects of densities depending on the radiation dose. The observed softening might be the result of the induced irradiation defects interaction with the existing quenching defects which leads to the annihilation of many defects at different sinks in the matrix. Also, the precipitating Si atoms on dislocations might be liberated and the pinned dislocations contribute to the density of mobile dislocations, which leads to the observed softening.

4. Conclusions and Final Remark

The tensile creep (TC) tests were carried out under constant suitable stress. All data and results discuss in view beast thermo-mechanical properties of alloys. Therefore, based on our present investigations on the study of thermo-mechanical properties of Aluminium-Silicon alloy (Al-1wt%Si), one can concludes the following final remarks:

The alloy samples favored the formation of intermetallic compounds containing Al-Si. Some changes were observed in the morphology, distribution, type, size and number density of the Al_2Si precipitates formed during aging heat treatment. Due to the relative scarcity of present available

experimental data there will be a requirement for more empirical measurements of this property, by means of existing methods, modifications to these and also entirely new techniques.

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References

- [1] J. M. Silcock, T. J. Heal, H. K. Hardy, "Structural ageing characteristics of binary aluminium-copper alloys", *Japan Institute of Metals*, 82, pp. 239-248, (1954).
- [2] L. Backerud, G. Chai, J. Tamminen, "Solidification characteristics of Aluminium Alloys" Volume 2, AFS/SKANALUMINIUM, Oslo [1986].
- [3] N. Tenekedjiev, H. Mulazimoglu, B. Closset, J. Gruzleski, "Microstructures and Thermal Analysis of Strontium-Treated Aluminum-Si Alloys", *American Foundrymen's Society Inc., Des Plaines, Illinois, USA* [1995].
- [4] H. W. Doty, A. M. Samuel, F. H. Samuel, "Factors Controlling the Type and Morphology of Cu-Containing Phases in the 319 Aluminum Alloy", 100th AFS Casting Congress, Philadelphia, Pennsylvania, USA, April 20-23, pp. 1-30, [1996].
- [5] M. Djurdjevic, T. Stockwell, J. Sokolowski, "The Effect of Strontium on the Microstructure of the Aluminum-Si and Aluminum-Cu Eutectics in the 319 Aluminum Alloy", *Inter. Journal of Cast Metals Research*, 12, pp. 67-73, 1999.
- [6] Hansel Manuel Medrano-Prieto, Carlos Gamaliel Garay-Reyes, Cynthia Deisy Gómez-Esparza, Joaquín Aguilar-Santillán, María Cristina Maldonado-Orozco, Roberto Martínez-Sánchez, "Evolution of Microstructure in Al-Si-Cu System Modified with a Transition Element Addition and its Effect on Hardness", *Materials Research*, 19 (Suppl. 1): 59-66, (2016).
- [7] E. Matsubara, J. B. Cohen, "The G. P. zones in Al-Cu alloys II", *Acta Metallurgica*, Vol. 33 (11), pp. 1957-1969, 1985.
- [8] A. M. Abd El-Khalek, "The variation of work-hardening characteristics of Al-1wt%Si and Al-1wt%, Si-0.1 wt.%, Zr-0.1 wt.%, Ti alloys", *Physica B*, 315, pp. 7-12, (2002).
- [9] F. Abd El-Salam, M. R. Nagy, "Thermally induced structural and mechanical variations in ternary AL-Si based alloys", *Proc. Math. Phys. Soc. Egypt*, 47, (1979) 179-185.
- [10] J. A. Spittle, S. G. R. Brown, "Computer simulations of the effects of alloy variables on the grain structures of castings", *Acta Metallurgica*, Vol. 37 (7), pp. 1803-1810, (1989).
- [11] A. M. Abd El-Khalek, F. Abd El-Salam, "Effect of irradiation and pre-ageing temperature on the mechanical properties of Al-Si alloys", *Radiation Effects & Defects in Solids* 163, 10, (2008) 835-842.
- [12] G. H. Deaf, M. H. N. Beshai, A. M. Abd El-Khalek, G. Graiss, M. A. Kenawy, "Effect of structural transformation on the stress-strain characteristics of Al-Si alloys", *Cryst. Res. Technol.* 32 (1997) 3.
- [13] J D James, J A Spittle, S G R Brown and R W Evans, "A review of measurement techniques for the thermal expansion coefficient of metals and alloys at elevated temperatures", *Measurement Science Technology*. 12 (2001) R1-R15.
- [14] R. V. Nandedkar, A. K. Tyagi; In *Metallic Glasses*; T. R. Anantharaman, Ed. Trans. Tech. Pub. (1984) 165-174.
- [15] Alveera Khan, Shirish Joshi, M. Ayaz Ahmad, Vyacheslav Lyashenko, "Some effect of Chemical treatment by Ferric Nitrate salts on the structure and morphology of Coir Fibre Composites", *Advances in Materials Physics and Chemistry (AMPC)*, Vol. 5 (1), pp. 39-45, (2015) doi: 10.4236/ampc.2015.51006
- [16] Alveera Khan, M. Ayaz Ahmad, Shirish Joshi, Vyacheslav Lyashenko, "Synthesis of Alumina Fibre by Annealing Method using Coir Fibre", *American Chemical Science Journal*, Vol. 15 (2), (2016), pp. 1-7.
- [17] Alveera Khan, M. Ayaz Ahmad, Shirish Joshi, Said A. F. Al Said, "Abrasive Wear Behaviour of Chemically Treated Coir Fibre Filled Epoxy Polymer Composites", *American Journal of Mechanical Engineering and Automation*, Vol. 1 (1) (2014), pp. 1-5.
- [18] Alveera Khan, M. Ayaz Ahmad and Shirish Joshi, "A systematic study of electrical properties of chemically treated coir fibre reinforced epoxy composites with ANN model", *International Journal of Science and Research (IJSR)*, Vol. 4 (1), (2015), pp. 410-414.
- [19] Alveera Khan, Ayaz Ahmad M, Shrish J, Abd. El-Khalek AM. "Study of mechanical and electrical behavior of chemically treated coir fibre reinforced epoxy composites", *Int. J. of Multidisciplinary Research & Advcs. in Engg. (IJMRAE)*. Vol. 2, (2013): 171-180.
- [20] Vyacheslav V. Lyashenko, Mohammad Ayaz Ahmad, Valentin A. Lyubchenko, Alveera Khan, Oleg A. Kobylin. "The methodology of image processing in the study of the properties of fiber as a reinforcing agent in polymer compositions", *International Journal of Advanced Research in Computer Science*. Vol. 7(1), (2016): 15-18.
- [21] Alveera KS. Joshi, Vyacheslav L, Nicolina P, Ayaz Ahmad M. Artificial neural networking (ann) treatment on electrical properties of coir fiber reinforced epoxy composites. *Saudi International Meeting on Frontiers of Physics (SIMFP)*. at February 17-19, 2015, Jazan University, Saudi Arabia; 2015.
- [22] Alveera Khan, Quraishi AM, Joshi S, Ayaz Ahmad M. Synthesis and characterization of chemically treated fibre and its reinforced epoxy polymer composites. *Mathematical Sciences International Research Journal*. Vol. 2(2), (2013): 673-676.