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Research Article

Characterization of the Role of Squeeze Casting on the Microstructure and Mechanical Properties of the T6 Heat Treated 2017A Aluminum Alloy

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In this study, the effects of squeeze casting process and T6 heat treatment on the microstructure and mechanical properties of 2017A aluminum alloy were investigated with scanning electron microscopy (SEM), energy dispersive X-ray spectrometry (EDS), differential scanning calorimetry (DSC), and microhardness and tensile tests. The results showed that this alloy contained α matrix, θ-Al_2Cu, and other phases. Furthermore, the applied pressure and heat treatment refines the microstructure and improve the ultimate tensile strength (UTS) to 296 MPa and the microhardness to 106 HV with the pressure 90 MPa after ageing at 180°C for 6 h. With ageing temperature increasing to 320°C for 6 h, the strength of the alloy declines slightly to 27 MPa. Then, the yield strength drops quickly when temperature reaches over 320°C. The high strength of the alloy in peak-aged condition is caused by a considerable amount of θ' precipitates. The growth of θ' precipitates and the generation of θ phase lead to a rapid drop of the strength when temperature is over 180°C.

1. Introduction

Due to their excellent mechanical and physical properties, Al-Cu cast alloys are used in automobile and military industries, aerospace, and in applications such as floor beams, engine pistons, wing box, covers, brake components, fuel tanks, slot tracks wheel, fittings, fuel systems, body skin connectors [1–3].

However, the major problems in casting these alloys consist in their high tendency to form casting defects such as hot tearing, solidification shrinkage, porosity [2], and their bad fluidity in conventional casting processes. These problems have negative effects on the mechanical properties and have greatly limited the application of Al-Cu cast alloys. Nowadays, for improved alloy properties, the microstructure refinement of Al-Cu cast alloys has become an important research field because mechanical properties can be significantly enhanced by microstructure refinement.

Squeeze casting is one of the modern casting processes which have been invented to address these imperfections and has a high potential to produce sound castings. It is a metal-forming process which combines permanent mould casting with die forging into a single operation where molten metal is solidified under applied hydrostatic pressure [4–6].

The process, which is suitable for shaping both cast and wrought alloys, improves product quality by pressurized solidification, which prevents the formation of shrinkage defects, retains dissolved gases in solution until freezing has completed, and has the priority to form the equiaxed grain structure [7, 8]. Many research works on the advantages of squeeze casting process have been discussed. Souissi et al. [9] have shown that squeeze casting caused the refinement of the microstructure and reduction in the dendrite arm spacing (DAS) of the cast structure possibly due to increasing the cooling rate of 2017A aluminum alloy. They found that the gravity cast specimens have the lowest UTS compared with the squeeze cast specimens. However, the increase of UTS and YS is obvious at the 50 MPa and 100 MPa pressure. In the same way, Souissi et al. [10] have studied Al-13% Si alloy and found that the dendrite size of the alloy decreases with the increase of the squeezing pressure in the center and the edge of specimens. Maleki et al. [11] have investigated considerably the effects of squeeze casting parameters on the microstructure and mechanical properties of aluminum alloys.

Moreover, another method for improving the mechanical properties of the cast Al-Cu alloys is the heat treatment; the most used method for these alloys is the T6 heat treatment. A typical precipitation hardening treatment involves three steps: (1) the solution treatment that brings all the elements into solid solution state; (2) rapid quenching in order to avoid diffusion and to retain supersaturated solid solution at room temperature; and (3) ageing treatment to form fine precipitates by controlled decomposition of metastable supersaturated solid solution.

In this regard, Panuskova et al. [12] have investigated the effects of the heat treatment solution of Al-Si-Cu cast alloys on the microstructure of the alloy in three aspects, namely, the dissolution of coarse Al_2Cu, homogenization of the microstructure, and improvement of eutectic silicon morphology (fragmentation, spheroidization, and coarsening). In addition, Barhoumi et al. [13] have studied the effect of the T6 heat treatment on Al_9Si_3Cu alloy that caused changes in the morphology of eutectic silicon, the Cu-rich, and Fe-rich phases. The eutectic is converted into fine spherodised Si-phases uniformly distributed in the aluminum matrix. The dissolution of Cu-rich phases during heat treatment increases the concentration of Cu and other alloying elements (Mg and Si) in the aluminum matrix. In this regard, Muzaffer et al. [14] found that the ageing heat treatment mechanisms responsible for the strengthening effect are based on the formation of intermetallic phases during the decomposition of a metastable supersaturated solid solution obtained by solution treatment and quenching. Thus, the mechanical properties (UTS, YS, El%, and microhardness HV) of these alloys are influenced by the presence of precipitates.

In this work, the influence of pressure and T6 treatments with different ageing temperatures was carried out on cast aluminum alloy 2017A. The microstructure and precipitation behavior obtained under different squeeze pressures and heat treatment conditions were also investigated to provide theoretical support for the evolution of strength. This is to find the relationship between the microstructure of alloy and the mechanical properties under the peak ageing of various heat treatment conditions.

2. Experimental

The material investigated in this study is 2017A wrought aluminum alloy. The material provides average tensile strength and good machinability. It is widely used in mechanical applications. The alloy is received as an extruded bar of 80 mm diameter. The chemical composition is presented in Table 1, and it was analyzed by using an optical emission spectrometer (ICP-MS). The material was melted in an electric resistance furnace using a graphite crucible. Squeeze casting was performed using experimental setup as shown in Figure 1. The melt was poured into the die preheated to 250°C. The pressure was applied to the melt after pouring by using a 50-ton vertical hydraulic press using a ram until solidification was completed. The applied pressures were 0, 30, 60, and 90 MPa. The cast billets were cylindrical in shape with 23 mm in diameter and about 100 mm in height.

Table 1: Chemical composition of 2017A aluminum alloy (wt.%).

Cu	Mg	Si	Mn	Ni	Fe	Cr	Zn	Pb	Al
4.47	0.45	0.86	0.36	0.36	0.49	0.1	0.25	0.03	Rest

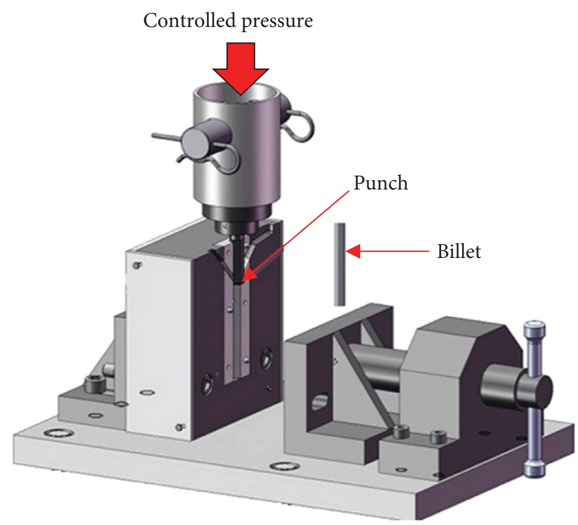


Figure 1: Schematic presentation of squeeze casting setup.

The casting was subjected to heat treatment T6 consisting of solution treatment and ageing treatment. Firstly, the temperature of homogenization treatment of the alloy was performed at 500°C for 8 h and then quenched into water at room temperature and ageing at 180°C for 6 h and 320°C at 6 h in order to further prove that the second phases were dissolved into the matrix after solution heat treatment. After heat treatment, samples were subjected to the microstructural and mechanical test; all samples for metallographic analysis were cut in the middle of the specimens. Metallographic samples were polished and then etched with the Keller solution for 10 seconds before rinsing with distilled water. For the specimens morphology, observations were performed by using an optical microscope LEICA DMLP with a digital camera JVC. A PHILIPS-XL30 ESEM scanning electron microscope (SEM) equipped with energy dispersive X-ray spectrometry (EDS) was used to quantitatively analyze the sizes of the intermetallic compounds and the α (Al) dendrite in the as-cast and heat-treated samples. The intermetallic particles were identified by using X-ray diffraction analysis and differential scanning calorimetry (DSC) at a heating rate of 10°C/min.

To evaluate tensile tests on the specimens of the gravity die cast (0 MPa) and squeeze cast for each experimental condition, an INSTRON universal testing machine was used. The tests were performed under displacement control with a strain rate starting at 1 mm/min. An extensometer (gage length of 14.3 mm) is attached with two rubber bands to the central part of the specimen. Three specimen samples were prepared.

A Micro-Vickers hardness analysis HV was performed employing a MEKTON Vickers Hardness Tester with a diamond pyramidal indenter. Three measurements were taken at randomly selected points with a load of 300 g applied for 30 s.

3. Results and Discussion

3.1. Microstructural Characterization of As-Cast Alloy. Figure 2 shows the DSC analysis of the samples in different pressures, which exhibits three exothermic peaks (A, C, and D) and two endothermic peaks (B and E): peak A corresponds to the formation of Guinier–Preston (GP) zones, followed by an endothermic (peak B) in the interval [145–195°C] which corresponds to the formation of the θ'' phase (coherent precipitate). The larger exothermic (peak C) signifies the precipitation of the θ' phase (semicoherent precipitate). However, the dissolution peak of the precipitates of peak C was not detected; this can be explained by the overlap of the peaks due to the rapidity of the transformations. A third exothermic (peak D), located in the temperature range 447–510°C, is related to the formation of the θ-Al_2Cu phase. This is followed by a last and more intense endothermic (peak E) at the temperature range 510–560°C; it signifies the dissolution of the θ-Al_2Cu phase [15], and there is a slight displacement of the peak E, for die-cast alloy under 90 MPa, at low temperatures. This discrepancy can be explained by the increase in the temperature of the eutectic transformation under the effect of the pressure [16].

Figure 3(a) shows the as-cast microstructure of 2017A alloy under 90 MPa squeeze pressure. It is clear that the sample mainly consisted of dendritic α-Al grains and intermetallic phases. Analyzing the microstructures along the different transverse sections of the samples, an α–rich aluminum dendritic matrix and interdendritic structures can be observed from the results of the micrograph. The EDX qualitative analysis allowed us to identify the intermetallic phases. From the chemical composition of the alloy, and based on the results of Birol [17, 18], the two phases are associated, respectively, with the two intermetallic compounds θ-Al_2Cu and $Al_{12}(FeMnCu)_3Si$. However, it seems that the distribution of the θ-Al_2Cu phase after the T6 heat treatment is strongly modified compared to the initial casting state. Indeed, its distribution becomes thinner and uniform at grain boundary levels as shown in Figure 3(b).

The results of SEM are confirmed with X-ray diffraction. Furthermore, XRD technique was utilized to help establish the results of the phase classification based on the metallographic study. The X-ray diffraction spectra of 2017A alloy of the 90 MPa under squeeze pressure in the as-cast and heat treatment conditions are shown in Figure 4. During heat treatment, no new phase was precipitated. Indeed, the precipitates (θ-Al_2Cu and $Al_{12}(FeMnCu)_3Si$) as indicated by the XRD patterns already revealed by SEM are identified.

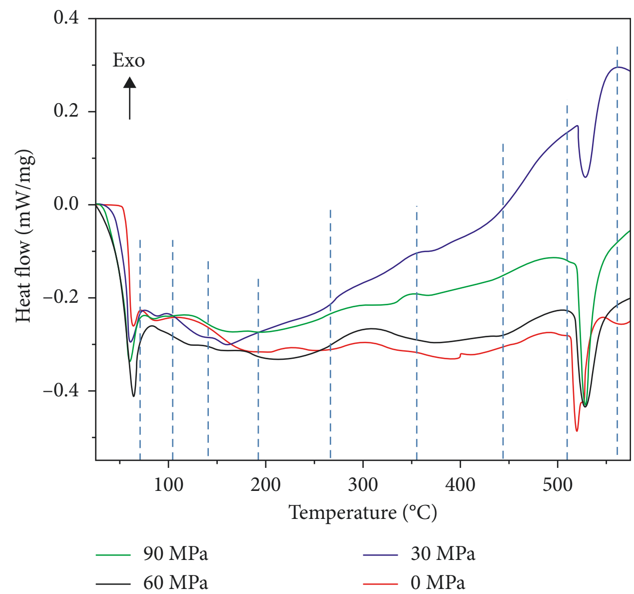
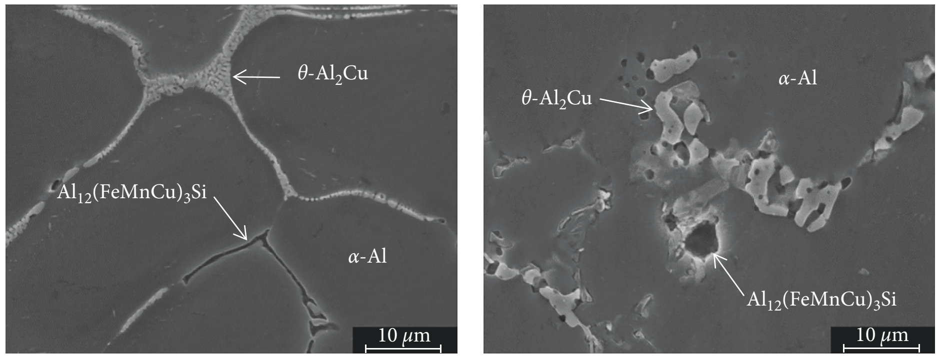


Figure 2: DSC analysis of squeeze cast specimens at different specific pressures.

3.2. As-Cast and Heat Treatment Microstructure. Figure 5 displays the microstructure of the as-cast alloy prepared at different squeezing pressures. It is clear that the squeezing pressure has significant influence on the microstructure of the alloy. The results show that the secondary dendrite arm spacing (SDAS) will be reduced to some extent when the squeeze pressure of 90 MPa is applied. In this study, it was found that microporosity was eliminated completely when the pressure was up to 60 MPa. Furthermore, the intermetallic phases in the alloy with no applied pressure are coarser than those under high squeezing pressure. Increasing the freezing point causes undercooling in the alloy that is already superheated. However, such change in freezing temperature with the increasing pressure is expected due to the reduction in interatomic distance and thus the restriction of atomic movement. The higher freezing point brings about the larger undercooling in the initially superheated alloy and thus elevates the nucleation frequency, resulting in a more fine-grained structure. Apart from the changes in undercooling of the molten alloy caused by applied pressure, greater cooling rates for the solidifying alloy can be realized due to reduction in the air gap between the alloy and the die wall and thus larger effective contact area [9, 19, 20].

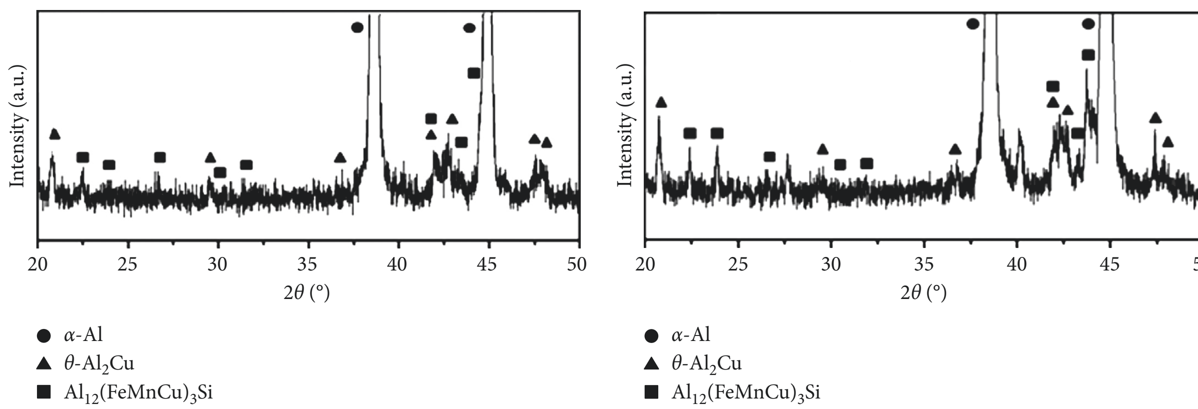
This is because squeeze pressure plays an active role in the diffusion of heat and thus enlarges the solidification rate. Obviously, the increase of undercooling degree and heat-transfer coefficient will result in the refinement of the grain size of squeeze casting alloy. In addition, the increase in density of the alloy will be obtained due to reduction of microporosity [11].

The microstructure for the heat-treated alloy (as-quenched, aged at 6 h at 180°C and aged at 320°C) conditions is presented in Figure 6.



(a) (b)

Figure 3: SEM micrographs of 2017A alloy under 90 MPa squeeze pressure: (a) as-cast state; (b) after T6 heat treatment.



(a) (b)

Figure 4: XRD patterns of the 90 MPa squeeze pressure in the (a) as-cast state and (b) after T6 heat treatment.

The microstructure reveals a significant difference between gravity casting and 90 MPa pressure casting in the heat treatment conditions of the alloy. From these optical micrographs, we can notice that all the microstructures consist of equiaxial grains but are of homogeneous size compared with Figure 5. We also distinguish the microstructure of the as-quenched sample (Figure 6(a)). It shows that only α-Al matrix was observed because the intermetallic phases dissolved in the matrix after the homogenization treatment. Therefore, the alloy components were evenly distributed despite some residual participants at the grain boundaries [21]. Compared to the microstructure of different ageing conditions, it can be found that when the ageing temperature of microstructure is 180°C (Figures 6(c) and 6(d)), there are a large number of precipitation phase in the matrix. Indeed, the presence of the precipitates and alloying elements causes braking of the grain boundaries in migration. The growth of precipitates is governed by the diffusion of the solute atoms towards the germs, which are thermally activated. At the same time, these precipitates are evenly distributed. All this is beneficial to improve the mechanical properties of the alloy. In addition, when the ageing temperature is 180°C, the precipitates observed showed a higher volume fraction than that of the hardened and quenched alloy that has returned to 320°C. Compared to the microstructure of different ageing conditions, along with the ageing temperature increase, the quantity of the coarse equilibrium precipitates also increased. It is not conducive to improvement in the mechanical properties, which is consistent with other reported studies [22–24].

3.3. Effect of Ageing Temperature on the Mechanical Properties. The variation curves of the ageing microhardness of the alloy in various pressure levels are shown in Figure 7. As can be seen from the curves, the peak microhardness increases at first and then decreases as ageing temperature increases under the different pressures. The hardness peak is attained when ageing at 180°C for 6 h. The hardening achieved is attributed to the formation of GP zones and the precipitation of phase θ' [17]. The 2017A aluminum alloy has now begun to nucleate heterogeneously on dislocations, as the homogenously nucleated GP zones have developed within the dislocation-free volumes of the alloy. Thus, the microstructure was found to consist of a high density $CuAl_2$ (θ') in the α-Al matrix [25, 26]. In this case, the dislocations will

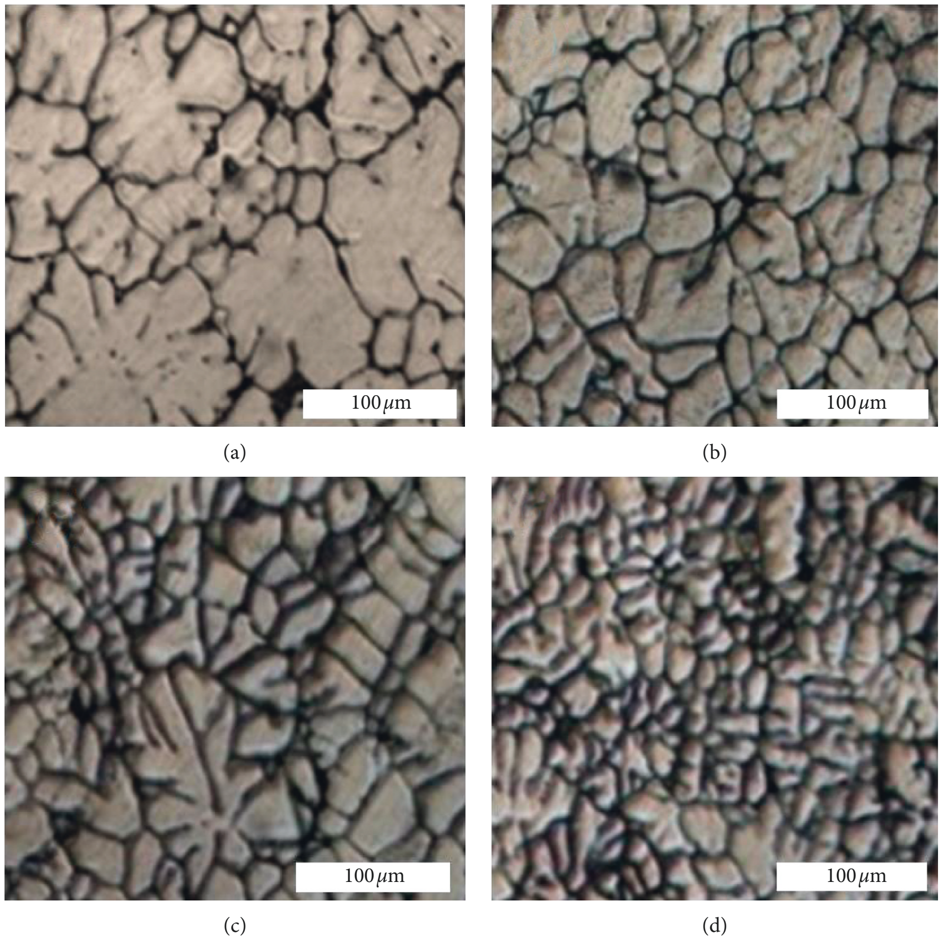


FIGURE 5: Microstructure of 2017A alloy in as-cast conditions: (a) $P = 0$ MPa, (b) $P = 30$ MPa, (c) $P = 60$ MPa, and (d) $P = 90$ MPa.

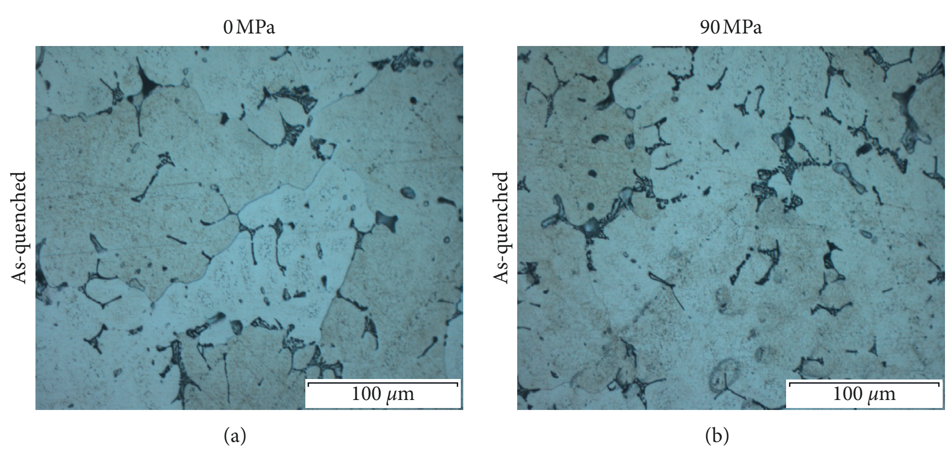


FIGURE 6: Continued.

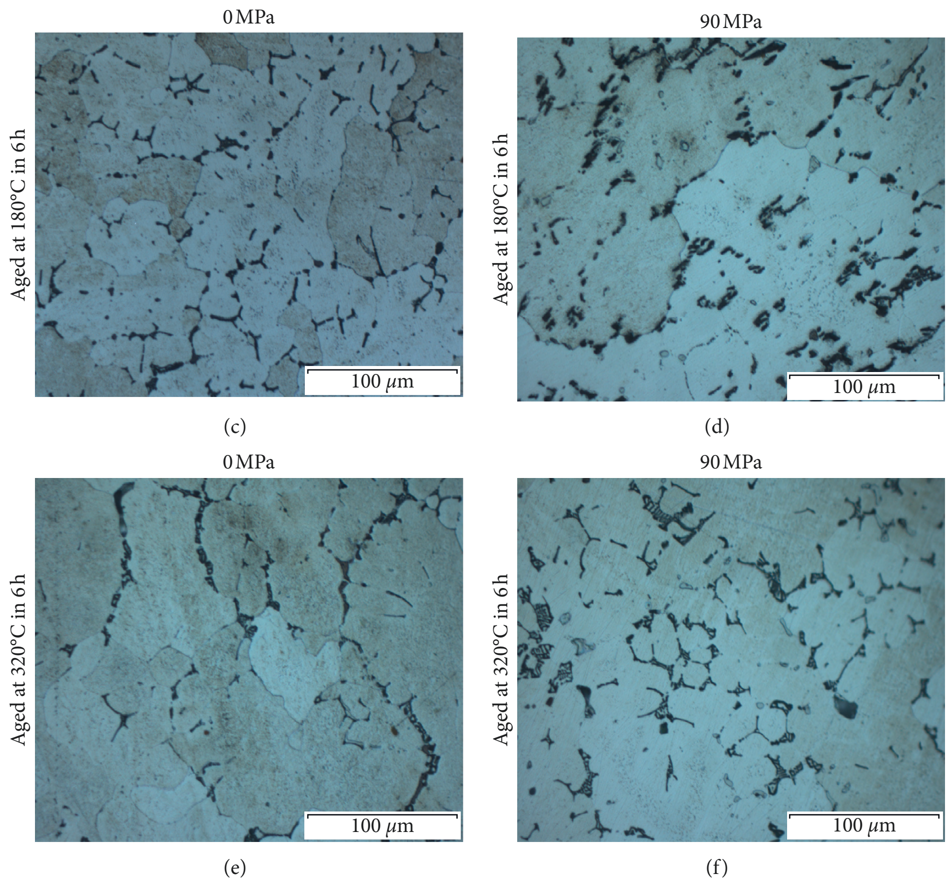


FIGURE 6: Optical micrographs of the 2017A alloy in heat treatment conditions.

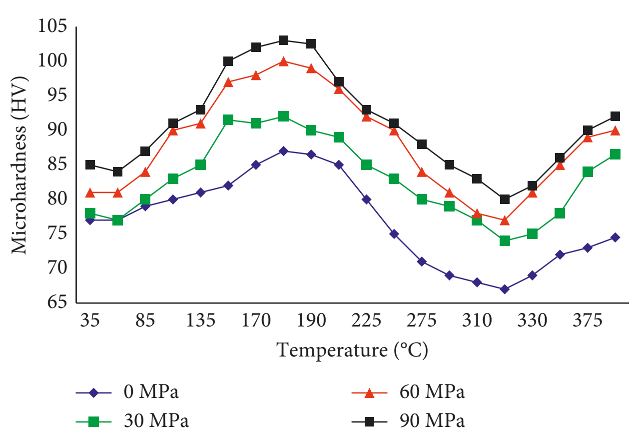


FIGURE 7: Graphical representation of microhardness values of alloy in heat treatment conditions with various pressures.

shear these precipitates by destroying their order. Indeed, generally the precipitates oppose the phenomena of sliding, which explain the increase of microhardness. In ageing treatment at 210°C, the microhardness of the alloy increases rapidly to a peak in a shorter time. Therefore, the second peak occurs, and with the extension of ageing time, the microhardness of the alloy declines due to overageing. Ageing of the test samples has been carried out at temperatures of 180°C. Every ageing temperature reached two peaks. This is called the "double peaks" phenomenon. Between these two peaks, there is a remarkable decrease of microhardness. For temperatures above 320°C, the microhardness increases again. This increase is apparently related to high concentration of the solute atoms in the aluminum matrix. This can precipitate during cooling, which leads to high microhardness values.

Results of tensile tests for the samples in the as-cast state, as-quenched state, and different ageing time at 180°C and 320°C after the solution treatment at 500°C for 8 h are summarized in Figures 8 and 9. As can be noticed from

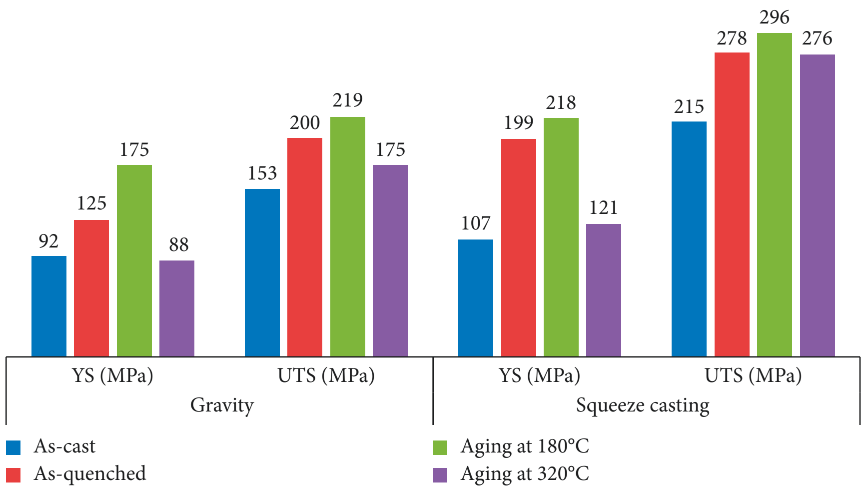


Figure 8: YS and UTS of the gravity die cast and the squeeze cast alloy under 90 MPa pressure in the different treatment conditions.

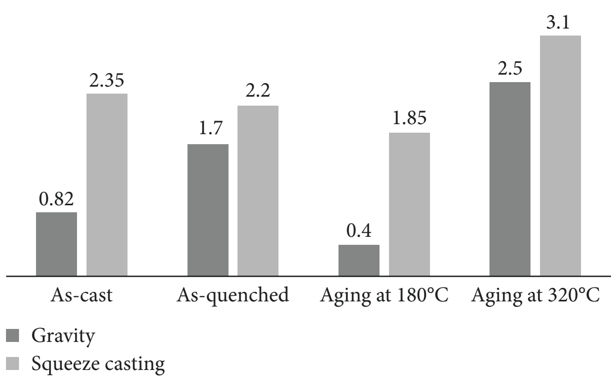


Figure 9: Elongation (%) of the gravity cast and the squeeze cast alloy under 90 MPa pressure in the different treatment conditions.

Figure 8, the gravity cast specimens have the lowest ultimate tensile stress (UTS) and yield stress (YS) compared with samples when squeeze pressure from 90 MPa is applied. Evidently, the tensile properties of the alloy are obviously improved because of the application of pressure. Actually, the strength of the alloy can be influenced by the grain size, the distribution, morphology as well as the intermetallic phases.

The improvement of mechanical properties results essentially from the microstructure refinement produced by the squeeze pressure during solidification. Furthermore, an increase of applied pressure contributes to the increase in solidification temperature of the alloy, which brings undercooling in a superheated alloy and increases nucleation ratio in the melt, resulting in a finer grain size [27–31].

The results of the heat treatment conditions showed higher values for tensile properties than the as-cast condition. For instance, in the case of this alloy, the ageing temperature at 180°C for 6 h leads to an increase in the YS and UTS of the squeeze cast samples from 107 to 218 MPa and 215 to 296 MPa, respectively. Also, an obvious improvement in elongation compared with the values in the as-quenched state and ageing temperature was observed at 320°C at 6 h. This variation is associated with the homogenization of solute atoms and the variation of the dissolution of intermetallics. After ageing treatment, due to the precipitation of nanosize phases, the strength especially (YS) is significantly improved and the elongation decreases. Furthermore, the effect of microstructural coarseness on the mechanical properties is reflected by comparing the tensile properties of each step. In fact, the tensile properties vary as a function of the morphology and the size of the microstructural constituents as well as porosity. The present results are confirmed by Barhoumi et al. [32], Tao et al. [21], and Jahangiri et al. [33]. As a result, the research confirmed that squeeze casting technique and the T6 heat treatment with ageing at 180°C at 6h has the potential to enhance the quality of casted parts.

4. Conclusion

The following conclusions are established for effect of applied pressure and ageing treatments on microstructure and the mechanical properties of squeeze casting 2017A alloy:

(1) The differential calorimetric study shows us the transformations of the different phases dissolved in the α-Al matrix. The results have shown that the application of pressure (90 MPa) has a significant effect on the morphology of the phases. On the other hand, the morphology of T6 heat treatment varies remarkably according to the ageing temperature.

(2) The microstructure was altered with the ageing treatment. Also, it was observed that the precipitate phases dispersed denser in structure with the increasing of the ageing temperature. In fact, the precipitates observed show a higher volume fraction in ageing at 180°C than as-quenched conditions and ageing at 320°C. These results are validated by tensile tests that are in good agreement with the results of microhardness and optical microstructure.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] G. S. Cole and A. M. Sherman, "Light weight materials for automotive applications," *Materials Characterization*, vol. 35, no. 1, pp. 3–9, 1995.

[2] H. M. Guo and X. J. Yang, "Preparation of semi-solid slurry containing fine and globular particles for wrought aluminum alloy 2024," *Transactions of Nonferrous Metals Society of China*, vol. 17, no. 4, pp. 799–804, 2007.

[3] C. G. Kang, P. K. Seo, and Y. P. Jeon, "Thixo diecasting process for fabrication of thin-type component with wrought aluminum alloys and its formability limitation," *Journal of Materials Processing Technology*, vol. 160, no. 1, pp. 59–69, 2005.

[4] C. C. De Brito, F. D. Magalhães, A. L. De Morais Costa, and C. A. Siqueira, "Microstructural analysis and tensile properties of squeeze cast Al-7% Mg alloy," *Materials Science Forum*, vol. 643, pp. 119–123, 2010.

[5] R. Li, L. Liu, L. Zhang, J. Sun, Y. Shi, and B. Yu, "Effect of squeeze casting on microstructure and mechanical properties of hypereutectic Al-x Si alloys," *Journal of Materials Science and Technology*, vol. 33, no. 4, pp. 404–410, 2017.

[6] Y. J. Shi, L. J. Liu, L. Zhang et al., "Effect of squeeze casting process on microstructures and flow stress behavior of Al-17. 5Si-4Cu-0.5 Mg alloy," *Journal of Iron and Steel Research International*, vol. 24, no. 9, pp. 957–965, 2017.

[7] A. Maleki, A. Shafyei, and B. Niroumand, "Effects of squeeze casting parameters on the microstructure of LM13 alloy," *Journal of Materials Processing Technology*, vol. 209, no. 8, pp. 3790–3797, 2009.

[8] A. K. Dahel, K. Nogita, S. D. Mcdonald, J. W. Zindel, and L. M. Hogan, "Eutectic nucleation and growth in hypoeutectic Al-Si alloys at different strontium levels," *Metallurgical and Materials Transactions A*, vol. 32, no. 4, pp. 949–960, 2001.

[9] S. Souissi, M. Ben Amar, and C. Bradai, "Microstructure characterization and tensile properties of direct squeeze cast and gravity die cast 2017A wrought Al alloy," *International Journal of Material Forming*, vol. 6, no. 2, pp. 249–254, 2011.

[10] S. Souissi, M. Ben Amar, and C. Bradai, "Experimental investigation on microstructure and mechanical properties of direct squeeze cast Al-13% Si alloy," *Strength of Materials*, vol. 44, no. 3, pp. 337–345, 2012.

[11] A. Maleki, B. Niroumand, and A. Shafyei, "Effects of squeeze casting parameters on density, macrostructure and hardness of LM13 alloy," *Materials Science and Engineering: A*, vol. 428, no. 1-2, pp. 135–140, 2006.

[12] M. Panuskova, E. Tillova, and M. Chalupova, "Relation between mechanical properties and microstructure of cast aluminum alloy AlSi9Cu3," *Strength of Materials*, vol. 40, no. 1, pp. 98–101, 2008.

[13] H. Barhoumi, S. Souissi, M. B. Amar, and F. Elhalouani, "Influence of heat treatment on the microstructures and mechanical properties of squeeze cast AlSi," *International Journal of Microstructure and Materials Properties*, vol. 10, no. 5-6, pp. 472–487, 2015.

[14] M. Zeren, E. Karakulak, and S. Gümüş, "Influence of Cu addition on microstructure and hardness of near-eutectic Al-Si-xCu-alloys," *Transactions of Nonferrous Metals Society of China*, vol. 21, no. 8, pp. 1698–1702, 2011.

[15] B. Zlaticanin, B. Radonjic, and M. Filipović, "DSC investigation of high-copper AlCuMg alloys," *Materials Science Forum*, vol. 453-454, pp. 193–198, 2004.

[16] S. W. Kim, D. Y. Kim, W. G. Kim, and K. D. Woo, "The study on characteristics of heat treatment of the direct squeeze cast 7075 wrought Al alloy," *Materials Science and Engineering: A*, vol. 304–306, pp. 721–726, 2001.

[17] Y. Birol, "Thixoforming of EN AW-2014 alloy at high solid fraction," *Journal of Materials Processing Technology*, vol. 211, no. 11, pp. 1749–1756, 2011.

[18] Y. Birol, "Age hardening of EN AW 2014 alloy extruded in the semi-solid state," *Materials Chemistry and Physics*, vol. 131, no. 3, pp. 694–697, 2012.

[19] N. Souissi, S. Souissi, C. Le Niniven, M. Ben Amar, C. Bradai, and F. Elhalouani, "Optimization of squeeze casting parameters for 2017 a wrought Al alloy using taguchi method," *Metals*, vol. 4, no. 2, pp. 141–154, 2014.

[20] N. Souissi, S. Souissi, J. P. Lecompte, M. Ben Amar, C. Bradai, and F. Elhalouani, "Improvement of ductility for squeeze cast 2017A wrought aluminum alloy using the Taguchi method," *International Journal of Advanced Manufacturing Technology*, vol. 78, no. 9–12, pp. 2069–2077, 2015.

[21] J. Tao, L. Zhang, G. Wu, A. Chen, X. Zhang, and C. Shi, "Effect of heat treatment on the microstructure and mechanical properties of extruded Al-4Cu-1Li-0.4Mg-0.4Ag-0.18Zr Alloy," *Materials Science and Engineering: A*, vol. 717, pp. 11–19, 2018.

[22] H. Wang, Y. Yi, and S. Huang, "Microstructure evolution and mechanical properties of 2219 Al alloy during aging treatment," *Journal of Materials Engineering and Performance*, vol. 26, no. 4, pp. 1475–1482, 2017.

[23] H. Z. Li, Z. X. Zhu, X. P. Liang et al., "Effect of T6-treatments on microstructure and mechanical properties of forged Al-4.4Cu-0.7 Mg-0.6 Si alloy," *Transactions of Nonferrous Metals Society of China*, vol. 27, no. 12, pp. 2539–2547, 2017.

[24] H. He, Y. Yi, S. Huang, and Y. Zhang, "Effects of deformation temperature on second phase particles and mechanical properties of 2219 Al-Cu alloy," *Materials Science and Engineering: A*, vol. 712, pp. 414–423, 2018.

[25] T. Ram Prabhu, "Effects of ageing time on the mechanical and conductivity properties for various round bar diameters of AA 2219 Al alloy," *Engineering Science and Technology, an International Journal*, vol. 20, no. 1, pp. 133–142, 2017.

[26] J. H. Jang, D. G. Nam, Y. H. Park, and I. M. Park, "Effect of solution treatment and artificial aging on microstructure and mechanical properties of Al-Cu alloy," *Transactions of Nonferrous Metals Society of China*, vol. 23, no. 3, pp. 631–635, 2013.

[27] S. Lü, S. Wu, W. Dai, C. Lin, and P. An, "The indirect ultrasonic vibration process for rheo-squeeze casting of A356 aluminum alloy," *Journal of Materials Processing Technology*, vol. 212, no. 6, pp. 1281–1287, 2012.

[28] B. Lin, W. Zhang, Z. Lou, D. Zhang, and Y. Li, "Comparative study on microstructures and mechanical properties of the heat-treated Al-5.0Cu-0.6Mn-xFe alloys prepared by gravity die casting and squeeze casting," *Materials and Design*, vol. 59, pp. 10–18, 2014.

[29] L. Hao, X. Yang, S. Lü, X. Fang, and S. Wu, "Influence of squeeze casting pressure and heat treatment on microstructure and mechanical properties of $Mg_{94}Ni_2Y_4$ alloy with LPSO structure," *Materials Science and Engineering: A*, vol. 707, pp. 280–286, 2017.

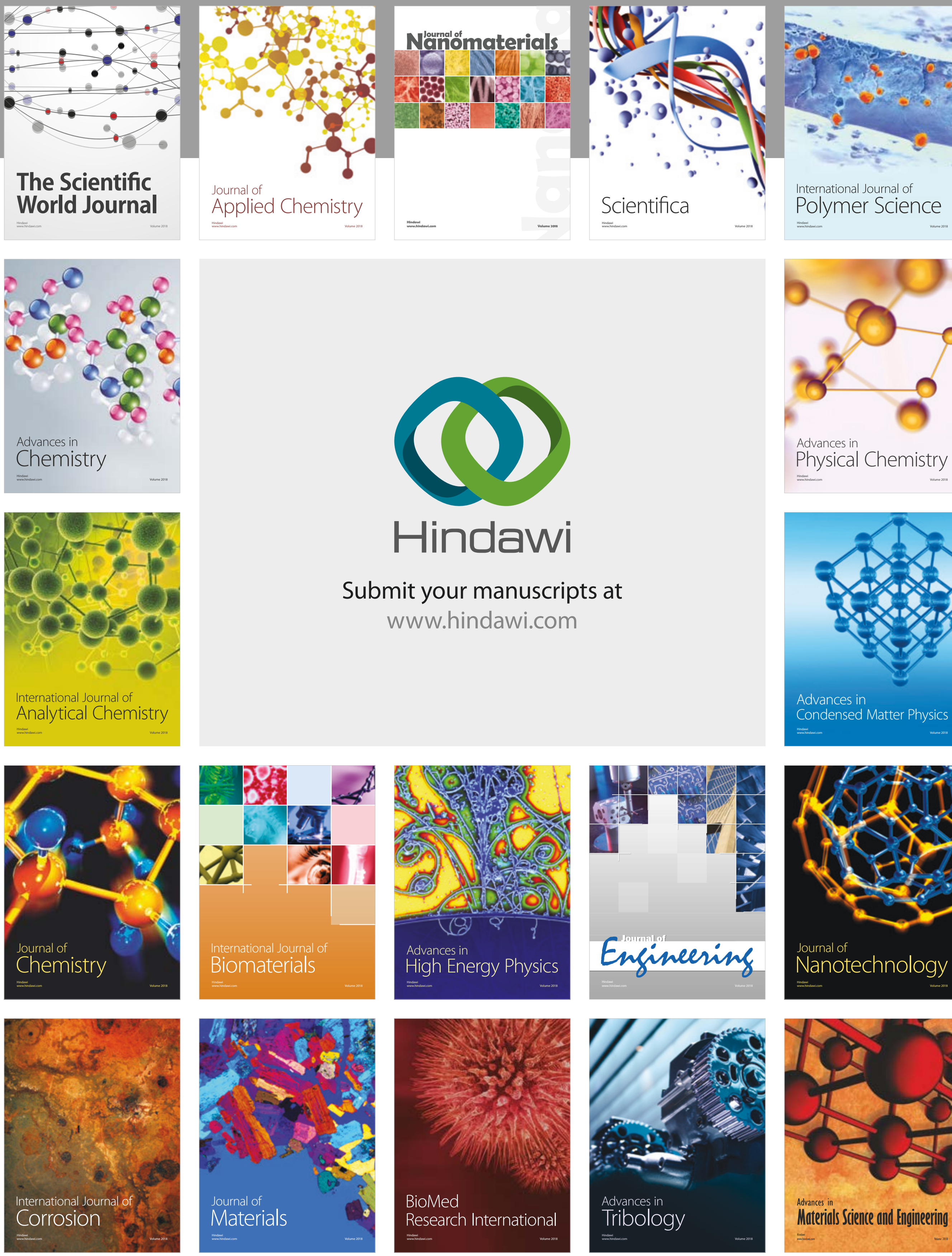
[30] C. Lin, S. Wu, S. Lü, P. An, and H. Wu, "Effects of high pressure rheo-squeeze casting on Fe-containing intermetallic

compounds and mechanical properties of Al-17Si-2Fe-(0, 0.8) V Alloys," *Materials Science and Engineering: A*, vol. 713, pp. 105–111, 2018.

[31] S. Lü, S. Wu, X. Yang, L. Hao, W. Guo, and X. Fang, "Microstructure and mechanical properties of $Mg_{97}Zn_1Y_2$ alloy reinforced with LPSO structure produced by semisolid squeeze casting," *Materials Science and Engineering: A*, vol. 732, pp. 359–367, 2018.

[32] H. Barhoumi, S. Souissi, M. Ben Amar, and F. Elhalouani, "Investigation of the microstructure and mechanical properties of squeeze cast Al-11% Si alloy heat treated," *Metallic Materials*, vol. 54, no. 4, pp. 249–256, 2016.

[33] A. Jahangiri, S. P. H. Marashi, M. Mohammadaliha, and V. Ashofte, "The effect of pressure and pouring temperature on the porosity, microstructure, hardness and yield stress of AA2024 aluminum alloy during the squeeze casting process," *Journal of Materials Processing Technology*, vol. 245, pp. 1–6, 2017.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