CHAPTER 3

Investigation of Structural Properties and Gravity Die Casting Technology in Aluminium Alloys

Hakan GOKMESE

Necmettin Erbakan University, Türkiye

Saban BULBUL

Necmettin Erbakan University, Türkiye

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Introduction

This section presents the "permanent mold casting technology", which is one of the special casting methods. This process is a special casting method that is widely used in the casting of aluminum alloys, especially light alloys. It is preferred for complex-shaped parts with narrow dimensional tolerances and a large number of parts. Special quality cast iron or steel is generally used as the mold material, which must have the refractoriness required by the metal to be cast. Up to 3,000-10,000 pieces of parts can be obtained by pouring iron-based materials into permanent molds, and up to 100,000 pieces of parts can be obtained by pouring low-melting materials such as aluminum into permanent molds. Since the cooling during solidification in the metal permanent casting method is faster than in sand molds, the internal structure is finer-grained. To increase the life of the mold, the mold cavity is coated with heat-resistant materials, and in this way, removing the part from the mold also becomes easier.

Al-Si alloys are widely used casting components due to their excellent casting properties, thermal properties, expansion coefficient, and corrosion resistance. It is known that Si element is added to Al alloys to increase the viscosity (improve the fluidity) of the liquid metal during casting, prevent hot cracking after casting, and reduce the density of the alloys (Timpel et. al., 2021; Nogita et. al., 2004). However, although silicon Al alloys have excellent corrosion resistance, the fact that their microstructure is in the form of plate/needle-like morphology negatively affects the mechanical properties (Rao et. al., 2009). To eliminate these disadvantages in the alloys, preserve corrosion resistance, and provide grain refinement/modification, elements such as strontium, sodium, antimony, calcium, scandium, and titanium are used for the modification of Al-Si alloys (Yan et. al., 2011; Jiahong et. al., 2018; Zhang et. al., 2022; Kim et. al., 2004; Li et. al., 2021). The modification of Al-Si alloys has become a common foundry practice used in recent years for both the improvement of mechanical properties and the preservation of corrosion resistance (Lian et. al., 2023). There are many scientific studies in which alkali metals,

alkaline earth metals, and some earth metals are used for Si modification (Kobayashi et. al., 1985; Lu & Hellawell 1985; Jie et. al., 2003; Makhlouf & Guthy 2001; Bian & Wang 2000). The most commonly used elements commercially are Na, Sb, and Sr. Na increases microporosity, while Sb makes the modification effect permanent. However, the performance of Sr modification exhibits a relatively higher effect than the others, and this effect lasts for a long time; therefore, it needs to be investigated in detail (Hegde & Prabhu 2008; McDonald et. al., 2008; Lian et. al., 2002; Luo et. al., 2023; Lee et. al., 2023).

In a study conducted by Zhao et al., Al-Si-Mg alloy was modified by adding TiB_2 and the alloy's strength-ductility property was investigated. They emphasized that the TiB_2 additive has positive effects on the development of strength-ductility properties (Zhao et. al., 2022). In a study that investigated the effect of Sr modification on the microstructure and thermal conductivity of hypoeutectic Al-Si alloys, it was reported that the plate/needle-like microstructure decreased after Sr modification, thermal properties improved, and the increase in thermal conductivity reached a maximum level (Gan et. al., 2020). In another study, the authors stated that the eutectic modification process plays an important role in improving all mechanical properties of Al-Si alloys by changing the morphology of eutectic silicon. In addition, they reported that Sr addition is sufficient for a good eutectic modification and activation of the twinning mechanism in hypoeutectic Al-Si alloys (Gursoy & Timelli 2020).

6082 aluminum alloy (deformed Al-Mg-Si series alloy), which is one of the alloys used in permanent mold casting applications (along with 6005, 6061, and 6063), has advantages such as medium strength, good weldability, and corrosion resistance. It is mostly used in aerospace, transportation, and structural engineering applications. This alloy cannot be hardened by machining; however, it can be strengthened by heat treatment to obtain a higher strength, while ductility decreases in this material (Zhao et. al., 2020; Zhang et. al., 2020). This alloy provides the most favorable mechanical properties after the aging heat treatment process. 6082 aluminum alloy has recently become more widely used in automotive and aerospace applications because lightness is emphasized in these applications (Fadida et. al., 2015; Puga et. al., 2015; Asgari et. al., 2014). In addition to this alloy, the use of the 7xxx series (Al-Zn-Mg-Cu system), known as AA 7075 wrought aluminum alloys, is quite limited in casting due to the high hot tearing sensitivity of this series. Unlike some casting aluminum alloys, since the 7xxx series creates a wider solidification range, it maintains its ductile structure, especially over a wide temperature range. In addition, unstable solidification of 7xxx series alloys often leads to the occurrence of different microstructure and mechanical properties. Therefore, it can be said that the defects, microstructures, and mechanical properties of 7xxx series alloy parts prepared by casting are more difficult to control compared to wrought aluminum alloys (Yue 1997; Fang et. al., 2020; Jahangiri et. al., 2017; Guan et. al., 2016).

In this study, a new permanent mold was produced for casting experiments based on the ASTM B108 aluminum standard tensile bar mold. This mold was used in melting and casting studies. AA 7075, 6082, and 6013 aluminum alloys, whose usage have been rapidly increasing in application areas such as aerospace, automotive, military, and defense industry in recent years, were used in permanent mold casting applications. Following the melting processes of the mentioned aluminum alloys, the casting process was carried out at 800°C into the permanent mold. After the casting applications, the produced permanent mold was found to be suitable in terms of solidification and standard tensile bar in terms of runner and riser (feeder) design. The tensile bar obtained after solidification as a result of the casting process was processed by the standards. Tensile tests, hardness measurements, and microstructural examinations were performed using the prepared tensile bar.

Material and Methods

In this study, the metal mold casting technology, which is mostly used in the casting of aluminum alloys, especially light alloys, was investigated. The purpose of the study was to manufacture a metal mold to produce a tensile test bar mold (for manufacturing a single metal tensile bar) by ASTM B108 (Twilley 2012) standard in metal mold casting applications. In addition, it was aimed to provide error-free casting part production suitable for casting three different aluminum alloys (AA 7075, 6013, 6082) used in the study. Before the applications of casting to the metal mold, casting applications were carried out after the necessary runner and riser design to prevent any casting errors that may occur due to the mold both in industrial and experimental works.

The melting processes were carried out in a Reverber-type oven with a natural gas burner. Three different aluminum alloys supplied by Eti Inc. were used in the melting processes. The casting temperature of aluminum alloys was determined as 800 °C. Samples were taken from the oven to determine the chemical compositions of melted aluminum alloys. Three repeated measurements were made on different points of the samples, and spectral analysis results were obtained based on these measurements. Spectral analysis applications were performed using the Spectralab brand M5 model analyzer. After the melting process, before the casting operations, the cleaning and lubrication process of the permanent mold was carried out using a certain amount of graphite powder. Then, the permanent mold was subjected to heating with a vacuum cleaner (approximately 100°C), and preheating was applied to it. Finally, the melted liquid aluminum alloy was taken from the oven and permanent mold casting processes were performed. Melting and casting processes are shown in Figure 1.

Figure 1.
Melting and casting process



The permanent mold to be used for the production of a single tensile test bar was manufactured using H13 hot work tool steel. The image of the permanent mold used in the casting applications of aluminum alloys is presented in Figure 2. In addition, the metallic tensile bars obtained after the separation from the mold after the solidification process following the casting applications of 6013, 6082, and 7075 aluminum alloys are also shown in Figure 2.

Figure 2.
Metallic mould and tensile test specimens



The dimensions of the metallic tensile bars obtained as a result of the casting processes into the permanent mold are given in Table 1. The tensile tests of the tensile bars obtained after the casting process were performed on the DARTEC brand M9000 model 600 kN Universal Tester by TS EN ISO 6892-1 standards. Hardness measurements of aluminum alloys after casting application were carried out on REICHERTER brand BL 3 model experimental device by TS 139-1 EN ISO 6506-1 0 standards. Hardness measurements of the experimental samples were performed by applying a 0.5 mm^2 ball tip and a 500 kg load.

Table 1.
Tensile test bar dimensions

Test piece diameter do (mm)	Diameter of head d1 (mm)	Length of head h (mm)	first measure length Lo (mm)	Length of tapered part Lc (mm)	total length Lt (mm)	Curve radius R min
10	M18x2.5	25	50	60	110	10

The general metallographic studies of the cast aluminum alloys were carried out in terms of microstructural characterization. The cast aluminum alloys were subjected to sanding, polishing, and etching processes with Keller's solution (0.5 HF-1.5HCl-2.5HNO_3-95.5 H_2O), respectively. To understand the microstructural transformations of cast aluminum alloys and to determine the broken surface morphologies exhibited by the experimental samples after tensile test experiments, the Leica optical microscope was used in experimental studies.

Experimental Results

6013, 6082, and 7075 aluminum alloys were used in permanent mold casting technology applications. After the liquid metal was melted, casting applications were made with the permanent mold, and the production of tensile bars for each alloy was completed without errors. Immediately before the casting applications, a sample was taken from

the melted liquid metal for each alloy, and spectral analyses were performed. For the three different alloys, the material chemical compositions obtained as a result of the analyses are given in Tables 2, 3, and 4, respectively. In the tables, the average material compositions obtained as a result of three repeated analyses performed for three different alloys were shown. It was determined that the chemical compositions of the obtained materials are compatible with the alloy compositions in the literature.

Table 2.
The chemical composition of casting 7075 alloy

Analysis	Al	Si	Fe	Cu	Mn	Mg	Zn	Ni	Cr	Ti	Zr
First	89,0	0,368	0,382	1,71	0,172	2.54	5,46	0,0133	0,163	0,0227	0,0466
Second	89,1	0,368	0,381	1,70	0,171	2,57	5,39	0,0119	0,163	0,0229	0,0468
Third analysis	89,1	0,373	0,382	1,69	0,171	2,57	5,35	0,0112	0,162	0,0223	0,0463
Average	89,1	0,370	0,381	1,70	0,171	2,56	5,40	0,0121	0,163	0,0226	0,0466

Table 3.
The chemical composition of casting 6082 alloy

Analysis	Al	Si	Fe	Cu	Mn	Mg	Zn	Ni	Cr	Ti	Zr
First	96,6	1,12	0,247	0,0851	0,612	1,03	0,0176	0,0104	0,163	0,0277	0,0059
Second	96,6	1,10	0,237	0,0842	0,612	1,05	0,0183	0,0070	0,163	0,0284	0,0061
Third analysis	96,6	1,10	0,230	0,0811	0,588	1,05	0,0190	0,0046	0,158	0,0288	0,0051
Average	96,6	1,11	0,238	0,0834	0,604	1,04	0,0183	0,0073	0,161	0,0283	0,0057

Table 4.
The chemical composition of casting 6013 alloy

Analysis	Al	Si	Fe	Cu	Mn	Mg	Zn	Ni	Cr	Ti	Zr
First	96,0	0,844	0,513	0,769	0,489	0,949	0,300	0,0133	0,0247	0,0184	0,0065
Second	95,8	0,878	0,561	0,782	0,494	0,994	0,308	0,0117	0,0240	0,0177	0,0071
Third analysis	95,9	0,854	0,521	0,797	0,491	1,00	0,305	0,0133	0,0244	0,0190	0,0069
Average	95,9	0,859	0,532	0,783	0,491	0,981	0,304	0,0127	0,0243	0,0183	0,0068

By using the permanent mold, which is manufactured with H13 hot work tool steel, melting and casting processes were performed for three different aluminum alloys. Microstructure images of aluminum alloys obtained as a result of metallographic studies performed after the casting processes are given in Figures 3, 4, and 5. When the optical microstructure images given for three different alloys are examined, it can be seen that there are coarsening and intermetallic phases at the grain boundaries.

Based on this, it can be said that microsegregation and coarse grain structures at grain boundaries may emerge, especially for high-strength 7xxx alloys during casting. In addition, the mechanical properties of 7xxx series alloys are seriously affected by the presence of different types of intermetallic phases during casting. It is well known that several main intermetallic phases such as ($MgZn_2$), ($Al_2Mg_3Zn_{3)}$, (Al_2CuMg), (Al_2Cu), and (Al_7Cu_2Fe) are formed during solidification of the Al–Zn–Mg–Cu below the solidification temperature (Ghosh & Ghosh 2018). In the 6xxx series alloy, the formation of Mg_2Si particles, which increases the corrosion resistance of this alloy microstructurally, occurs during solidification. In addition, magnesium-rich intermetallic particles mainly contain Al_3Mg_2 for the 5xxx series and Mg_2Si for the 6xxx series (Zeid 2019). In a study, it has been stated that semi-stable and stable strengthening phases (Mg2Si) are formed microstructurally in GP regions after heat treatment. In addition, it has been mentioned that during the hot processing of ingot casting, the inter-metal phase particles are located in a position parallel to the plastic deformation direction and allow the formation of a deformation band structure (Mrówka-Nowotnik 2010).

Figure 3.
AA 6013 aluminium alloy microstructure images

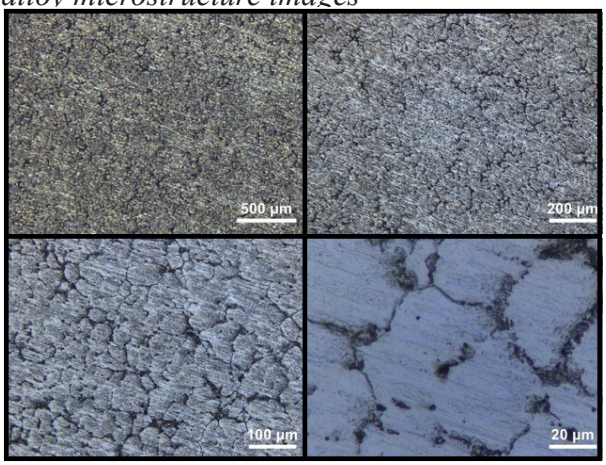


Figure 4.
AA 6082 aluminium alloy microstructure images

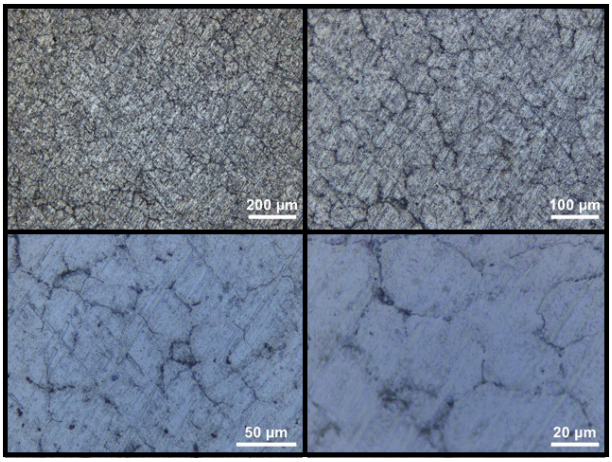
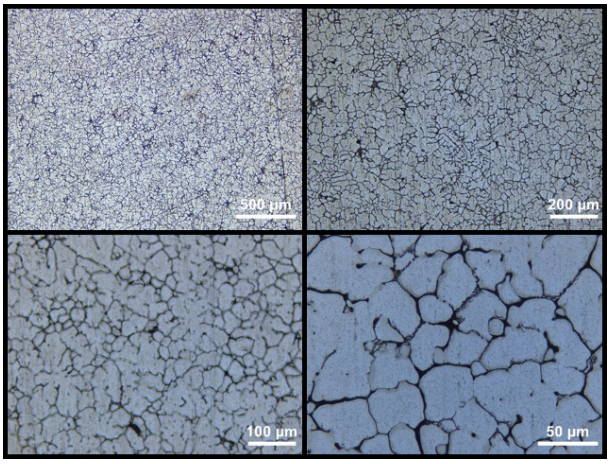
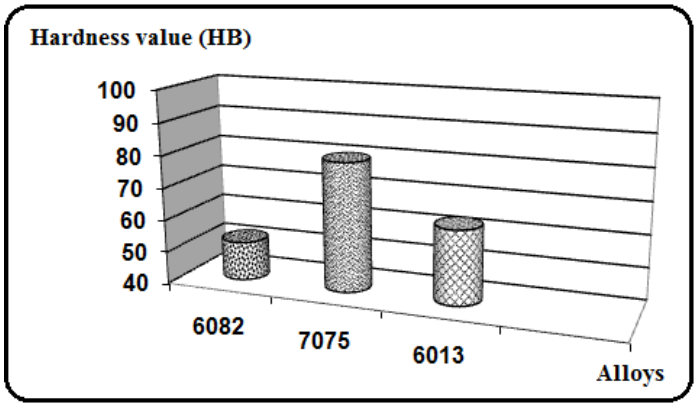


Figure 5.
AA 7075 aluminium alloy microstructure images



At the end of the casting experiments performed on the metallic mold at 800°C, three different aluminum alloys were examined microstructurally. The hardness results obtained are shown in Figure 6. When the hardness results of the cast aluminum alloys were examined, it was determined that the highest hardness (80HB) belonged to AA 7075 material. This aluminum alloy was followed by AA 6013 (63HB) and 6082 (50HB) aluminum alloys, respectively.

Figure 6.
Aluminium alloys hardness after casting



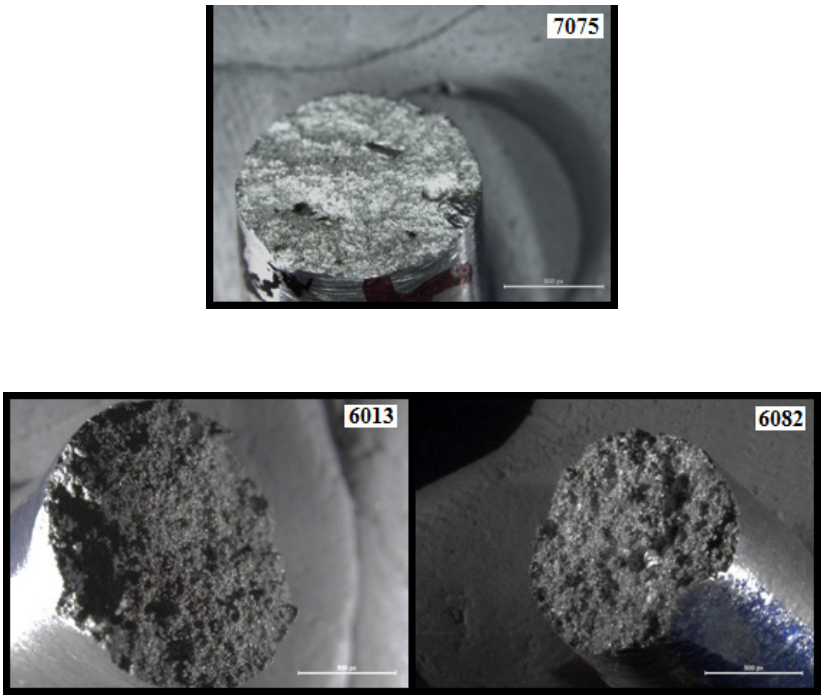
The tensile strength and percentage elongation test results of metal tensile bars obtained after casting experiments of three different aluminum alloys are shown in Table 5. When the tensile test results in Table 5 were examined, it was seen that the alloy with the highest hardness value was AA 7075 aluminum alloy. In addition, it was determined that this alloy had the highest percentage elongation (7%) and tensile strength (125.9N/mm^2). Al−Mg−Si(−Cu) alloys, also known as the 6xxx series, are listed among the most used aluminum alloys. Mg and Si chemicals are the main soluble elements and play a significant role in increasing the hardness and strength of the material.

Table 5.
Tensile test results of aluminium alloys after casting

Alloy	Percentage Elongation (%)	Tensile Strength (N/mm^2)
6013	5.1	144.1
6082	4.7	171.5
7075	7	125.9

To improve precipitation and increase mechanical properties, chemicals such as Cu can be added (Zhong et. al., 2014). In these alloy series, in particular, the increased Mg and/or Si content accelerates the natural aging response of the alloy. Therefore, they provide the desired increase in hardness and strength (Zhong et. al., 2013). 6xxx series alloys including aluminum alloyed with magnesium and silicon are a group of precipitation-hardening alloys that have sufficient specific strength and toughness and are relatively cheaper compared to the 2xxx and 7xxx Al alloy series (Dubey et. al., 2023). In this alloy, which was used in permanent mold casting, the hardness and strength of the material can be increased, especially by heat treatment. In such alloys, heat treatment can be performed in two ways. It can be applied as solutionizing and then as artificial aging. In the process of solutionizing, the alloy is heated to a certain temperature (400 ºC-530ºC). When the specified temperature values are reached, the quenching process is performed. At the end of this process, the material is subjected to a hardening process at about 200°C (in the case of Al alloys of the 6xxx group) (Rajaa et. al., 2018).

Figure 7.
Fractured surface results of aluminium alloys after tensile



When the broken surface morphologies exhibited by the alloys were examined in tensile tests applied after casting experiments (Figure 7), the presence of split (cleavage) type breaks was not observed on the breaking surfaces of AA 6013 and 6082 aluminum alloys, which have high ductility properties compared to AA 7075 aluminum alloy. In AA 7075 alloy, on the other hand, cleavage-type breaks were observed on the fracture surfaces. Moreover, in AA 6013 and 6082 aluminum alloys, it can be seen that ductile (dimple) breaks, which usually occur as a result of stress crack progression in ductile fracture mode, are located in the microstructure. In a study conducted on AA6061 aluminum alloy, it was stated that ductile fractures are observed when broken surfaces are examined. It was mentioned that fewer ductile pits appeared in samples whose hardness increases with aging heat treatment (Sevim et. al., 2014). It was determined that ductile pits and network structures were predominant in the images. Broken surface images of aged samples exhibit a smaller number of ductile pits. SEM images of broken surfaces are related to tensile graphs. In AA7075 aluminum alloy, breakage or fracture manifests itself in the form of cleavage morphology inside grains. In this case, mechanical properties such as ductility (total plastic deformation rate) and toughness occur low in these materials. Therefore, cleavage-type breaks are observed exactly instead of pits on the fracture surfaces of this alloy, which exhibits ductility value.

Conclusion

The results obtained within the scope of permanent mold casting technology, which is mostly used in casting applications as a special casting method, and casting of aluminum alloys are summarized below.

Permanent mold casting technology, which is usually used in the casting of non-ferrous metals, is preferred in the mass production of parts whose dimensional tolerances are narrow and the number of productions is high. In addition, when sand casting technology or other casting methods are considered, the mechanical properties of the material are very important depending on the chemical composition of the melted liquid metal before casting. In this case, especially tensile testing comes to the fore to able to determine

the mechanical properties of the material or quality control. The rapid transfer of melted liquid metal to the mold and the use of permanent molds in the production of the tensile bars stand out in terms of mass production and time-saving in aluminum and light alloy foundries. Therefore, in the melting and casting applications for the 6xxx and 7xxx aluminum alloy series, it can be seen that the gravity mold runner and feeder produce a faultless tensile bar after the liquid metal solidifies. In this study, as a result of casting applications, a tensile bar was produced in the desired dimensions, and the produced material was assessed in terms of hardness, tensile properties, and fracture morphologies. In addition, for the 6xxx and 7xxx aluminum alloy series, the microstructural characterization of the material was studied. The highest hardness value was measured in AA 7075 material as 80HB, and in AA 6013 and 6082 aluminum alloys as 63HB and 50HB, respectively. The highest percentage elongation and tensile strength were determined as 7% and 125.9 N/mm2, respectively, in AA7075 alloy. When the material fracture surface morphologies were examined, it was determined that AA 7075 material exhibited brittle fracture compared to the other two aluminum alloys.

References

Asgari, H., Szpunar, J. A. & Odeshi, A. G. (2014). Texture evolution and dynamic mechanical behavior of cast AZ magnesium alloys under high strain rate compressive loading. Materials & Design, 61, 26-34. https://doi.org/10.1016/j.matdes.2014.04.049

Bian, X. & Wang, W. (2000). Thermal-rate treatment and structure transformation of Al–13 wt.% Si alloy melt. Materials letters, 44(1), https://doi.org/54-58. 10.1016/S1471-5317(02)00003-2

Dubey, R., Jayaganthan, R., Ruan, D., Gupta, N. K., Jones, N., & Velmurugan, R. (2023). Energy absorption and dynamic behaviour of 6xxx series aluminium alloys: A review. International Journal of Impact Engineering, 172, 104397. https://doi.org/10.1016/j.ijimpeng.2022.104397

Fadida, R., Rittel, D. & Shirizly, A. (2015). Dynamic mechanical behavior of additively manufactured Ti6Al4V with controlled voids. Journal of Applied Mechanics, 82(4), 041004. https://doi.org/10.1115/1.4029745

Fang, H. Z., Li, R. X., Chen, R. R., Yu, B. Y., Qu, Y. D., Xun, S. W. & Rong-De, L. I. (2015). Microstructure and mechanical properties of Al–6Zn–2.5 Mg–1.8 Cu alloy prepared by squeeze casting and solid hot extrusion. Transactions of Nonferrous Metals Society of China, 25(7), 2130-2136. https://doi.org/10.1016/S1003-6326(15)63824-9

Gan, J. Q., Huang, Y. J., Cheng, W. E. N. & Jun, D. U. (2020). Effect of Sr modification on microstructure and thermal conductivity of hypoeutectic Al− Si alloys. Transactions of Nonferrous Metals Society of China, 30(11), 2879-2890. https://doi.org/10.1016/S1003-6326(20)65428-0

Ghosh, A., & Ghosh, M. (2018). Microstructure and texture development of 7075 alloy during homogenisation. Philosophical Magazine, 98(16), 1470-1490. https://doi.org/10.1080/14786435.2018.1439596

Guan, R. G., Zhao, Z. Y., Li, Y. D., Chen, T. J., Xu, S. X., & Qi, P. X. (2016). Microstructure and properties of squeeze cast A356 alloy processed with a vibrating slope. Journal of Materials Processing Technology, 229, 514-519. https://doi.org/10.1016/j.jmatprotec.2015.09.038

Gursoy, O. & Timelli, G. (2020). Lanthanides: A focused review of eutectic modification in hypoeutectic Al–Si alloys. Journal of Materials Research and Technology,

9(4), 8652-8666. https://doi.org/10.1016/j.jmrt.2020.05.105

Hegde, S. & Prabhu, K. N. (2008). Modification of eutectic silicon in Al–Si alloys. Journal of materials science, 43, 3009-3027. https://doi.org/10.1007/s10853-008-2505-5

Jahangiri, A., Marashi, S. P. H., Mohammadaliha, M., & Ashofte, V. (2017). 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, 245, 1-6. https://doi.org/10.1016/j.jmatprotec.2017.02.005

Jiahong, Z., Shuming, X., Qingyou, H., Qiang, G., & Rufen, W. (2018). Synergistic effect of Sr and Ca combined additions on the microstructure of A390 aluminum alloy. Rare Metal Materials and Engineering, 47(11), 3301-3308. https://doi.org/10.1016/S1875-5372(18)30236-4

Jie, W., Chen, Z., Reif, W., & Müller, K. (2003). Superheat treatment of Al-7Si-0.55 Mg melt and its influences on the solidification structures and the mechanical properties. Metallurgical and Materials Transactions A, 34, 799-806. https://doi.org/10.1007/s11661-003-1008-x

Kim, M., Hong, Y., & Cho, H. (2004). The effects of Sc on the microstructure and mechanical properties of hypo-eutectic Al− Si alloys. Metals and Materials International, 10, 513-520. https://doi.org/10.1007/BF03027412

Kobayashi, K. F., & Hogan, L. M. (1985). The crystal growth of silicon in Al-Si alloys. Journal of Materials Science, 20, 1961-1975. https://doi.org/10.1007/BF01112278

Lee, J. Y., Lee, J. M., Son, K. S., Jang, J. I., & Cho, Y. H. (2023). A study on the interaction between a Sr modifier and an Al-5Ti-1B grain refiner in an Al-7Si-0.35 Mg casting alloy. Journal of Alloys and Compounds, 938, 168598. https://doi.org/10.1016/j.jallcom.2022.168598

Li, C., Wang, C., Yang, Z. Z., Ma, P. K., Ren, M. W., & Wang, H. Y. (2021). Effect of complex modification of Ca and Sb on the microstructure and mechanical properties of hypoeutectic Al-11Mg2Si alloy. Journal of Alloys and Compounds, 869, 159304. https://doi.org/10.1016/j.jallcom.2021.159304

Lian, P., Mao, H., Wei, Q., Ma, R., Li, C., & Xu, H. (2023). Tailoring the strength and corrosion resistance of Al-7Si: Eutectic Si modification by Sr and Sc. Materials Letters, 348, 134505. https://doi.org/10.1016/j.matlet.2023.134505

Liao, H., Sun, Y., & Sun, G. (2002). Correlation between mechanical properties and amount of dendritic α-Al phase in as-cast near-eutectic Al–11.6% Si alloys modified with strontium. Materials Science and Engineering: A, 335(1-2), 62-66. https://doi.org/10.1016/S0921-5093(01)01949-9

Lu, S. Z., & Hellawell, A. (1985). Growth mechanisms of silicon in Al-Si alloys. Journal of Crystal Growth, 73(2), 316-328. https://doi.org/10.1016/0022-0248(85)90308-2

Luo, Q., Li, X., Li, Q., Yuan, L., Peng, L., Pan, F., & Ding, W. (2023). Achieving grain refinement of α-Al and Si modification simultaneously by La–B–Sr addition in Al–10Si alloys. Journal of Materials Science & Technology, 135, 97-110. https://doi.org/10.1016/j.jmst.2022.07.009

Makhlouf, M. M., & Guthy, H. V. (2001). The aluminum–silicon eutectic reaction: mechanisms and crystallography. Journal of light metals, 1(4), 199-218. https://doi.org/10.1016/S1471-5317(02)00003-2

McDonald, S. D., Nogita, K., & Dahle, A. K. (2004). Eutectic nucleation in Al–Si alloys. Acta materialia, 52(14), 4273-4280. https://doi.org/10.1016/j.actamat.2004.05.043

Mrówka-Nowotnik, G. (2010). Influence of chemical composition variation and heat treatment on microstructure and mechanical properties of 6xxx alloys. Archives of materials science and engineering, 46(2), 98-107.

Nogita, K., McDonald, S. D., & Dahle, A. K.. Solidification mechanisms of unmodified and strontium-modified hypereutectic aluminium–silicon alloys, Philosophical Magazine. 84(17), (2004), 1683-1696. https://doi.org/10.1080/14786430310001659803

Puga, H., Carneiro, V., Barbosa, J., & Vieira, V. (2015). Effect of ultrasonic treatment in the static and dynamic mechanical behavior of AZ91D Mg alloy. Metals, 5(4), 2210-2221.https://doi.org/10.3390/met5042210

Rajaa, S. M., Abdulhadi, H. A., Jabur, K. S., & Mohammed, G. R. (2018). Aging time effects on the mechanical properties of Al 6061-T6 alloy. Engineering, Technology & Applied Science Research, 8(4), 3113-3115. https://doi.org/10.48084/etasr

Rao, A. P., Das, K., Murty, B. S., & Chakraborty, M. (2009). Al–Ti–C–Sr master alloy—A melt inoculant for simultaneous grain refinement and modification of hypoeutectic Al–Si alloys. Journal of Alloys and Compounds, 480(2), L49-L51. https://doi.org/10.1016/j.jallcom.2009.02.147

Sevim, I., Sahin, S., Cug, H., Cevik, E., Hayat, F., & Karali, M. (2014). Effect of aging treatment on surface roughness, mechanical properties, and fracture behavior of 6xxx and 7xxx aluminum alloys. Strength of materials, 46, 190-197. https://doi.org/10.1007/s11223-014-9535-9

Timpel, M., Wanderka, N., Schlesiger, R., Yamamoto, T., Lazarev, N., Isheim, D., Banhart, J. (2012). The role of strontium in modifying aluminium–silicon alloys. Acta Materialia, 60(9), 3920-3928. https://doi.org/10.1016/j.actamat.2012.03.031

Twilley, M. (2012). ASTM B-108 Aluminum Tensile Bar Mold Redesign. International Journal of Metalcasting, 6(1), 57-61.

Yan, L. O. U., Xing, B. A. I., & Li, L. X. (2011). Effect of Sr addition on microstructure of as-cast Mg-Al-Ca alloy. Transactions of Nonferrous Metals Society of China, 21(6), 1247-1252. https://doi.org/10.1016/S1003-6326(11)60849-2

Yue, T. M. (1997). Squeeze casting of high-strength aluminium wrought alloy AA7010. Journal of materials processing technology, 66(1-3), 179-185. https://doi.org/10.1016/S0924-0136(96)02516-2

Zeid, E. A. (2019). Mechanical and electrochemical characteristics of solutionized AA 6061, AA6013 and AA 5086 aluminum alloys. Journal of Materials Research and Technology, 8(2), 1870-1877. https://doi.org/10.1016/j.jmrt.2018.12.014

Zhang, L., Ji, Z. W., Zhao, J., He, J., & Jiang, H. (2022). Factors affecting eutectic Si modification in Al-Si hypoeutectic alloy with the addition of Na, Sr, Eu and Yb. Materials Letters, 308, 131206. https://doi.org/10.1016/j.matlet.2021.131206

Zhang, P., Song, A., Fang, Y., Yue, X., Wang, Y., & Yu, X. (2020). A study on the dynamic mechanical behavior and microtexture of 6082 aluminum alloy under different direction. Vacuum, 173, 109119. https://doi.org/10.1016/j.vacuum.2019.109119

Zhong, H., Rometsch, P., & Estrin, Y. (2014). Effect of alloy composition and heat treatment on mechanical performance of 6xxx aluminum alloys. Transactions of

Nonferrous Metals Society of China, 24(7), 2174-2178.

Zhong, H., Rometsch, P. A., & Estrin, Y. (2013). The influence of Si and Mg content on the microstructure, tensile ductility, and stretch formability of 6xxx alloys. Metallurgical and Materials Transactions A, 44, 3970-3983. https://doi.org/10.1007/s11661-013-1740-9

Zhao, Z., Li, D., Zhang, D., Liu, G., Liu, S., & Liu, X. (2022). Enhancement of the strength-ductility synergy of Al-Si-Mg alloys via C-doped TiB2 particles. Materials Letters, 328, 133094. https://doi.org/10.1016/j.matlet.2022.133094

Zhao, G., Yuan, Y., Zhang, P., Zhou, T., & Zhou, H. (2020). Influence of orientations biomimetic units processed by laser on wear resistance of 6082 aluminium alloy. Optics & Laser Technology, 127, 106196.https://doi.org/10.1016/j.optlastec.2020.106196

About The Authors

Hakan GOKMESE, PhD is an Associate Professor of Mechanical Engineering at Necmettin Erbakan University in Konya, Turkey. I have a master's degree in Mettalurgical Education from Gazi University. His main areas of interest are casting technology, powder metallurgy, heat treatments and composites-nanocomposites applications.
E-mail: hakan1440@gmail.com , **ORCID:** 0000-0003-0053-8444

Saban BULBUL, PhD is an Associate Professor of Mechanical Engineering at Necmettin Erbakan University in Konya, Turkey. I have a master's degree in Mettalurgical Education from Karabuk University. His main areas of interest are casting technology, powder metallurgy, polymer materials and polymer applications.
E-mail: sabanbulbul42@hotmail.com , **ORCID:** 0000-0002-9268-1469

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