International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

December 2023	Issue 57	Volume 15	Number 4	Pages 89-93

IMPACT ASPECT RATIO ON MECHANICAL PROPERTIES OF ALUMINUM ALLOY PRODUCED BY SQUEEZE CASTING PROCESS

S.S. Mutar N.S. Abtan

Mechanical Engineering Department, University of Tikrit, Tikrit, Iraq, eng.saadhbm@gmail.com, najeebsalman@tu.edu.iq

Abstract- Squeeze casting, a technique used to avoid the development of shrinkage porosity, involves applying external pressure to an alloy melt while it solidifies. The squeeze casting method was created with sectors like the auto and aerospace in mind since the squeeze cast components have better mechanical qualities. Series (6xxx) alloys are among the most important aluminum alloy chains containing silicon and magnesium as basic elements and are widely used in various engineering applications. These alloys have characteristics like high strength to weight, formability and moderate corrosion resistance. The effect of *H*/*D* ratios of 2/3, 3/3, 4/3 at applied pressure of 90 MPa on the mechanical properties (hardness - density - porosity - wear rate) of AA6061 aluminum ingot was studied after the examination process, the hardness, density decreased with the increasing of the *H*/*D* ratio, while the values of the porosity ratio and the wear rate increased at the applied Pressure values.

Keywords: Aspect Ratio, 6061 Aluminum Alloy, Direct Squeeze Casting, Mechanical Properties.

1. INTRODUCTION

Direct Squeeze casting is a technique where pressured molten metal forms inside closed molds positioned in between the press cylinder. The pressure applied and metal's quick contact with the die surface produce a fine grain casting with mechanical properties resembling those of a wrought product [1].

The squeeze casting method may readily be mechanized to create components with near-net to net shapes of excellent quality. With this method, components made of copper, magnesium, and aluminum alloys are easily produced [2]. The rate of heat transmission is increased due to the inner mold and molten metal continue to be in direct touch surface because of the high pressure during solidification [3]. The tight contact between the castings and the inner mold surface during the solidification process causes the castings to solidify fast, which results in fine secondary arm spacing this close contact is necessary for the castings to attain an adequate level of strength and ductility [4]. The introduction of squeeze casting as a production process has provided materials and process engineers with a new alternative to the conventional methods of casting and forging, especially in light of the current emphasis on reducing materials consumption through virtually net shape processing and the demand for higher-strength parts for weight savings. In high density castings, near net forms may be produced by applying pressure to liquid metals as they solidify. This manufacturing processes near net and net form capabilities are among its primary benefits. Squeeze cast pieces have improved mechanical characteristics as well [5]. Also, several studies have been conducted to improve the squeeze casting process' various process parameters for various materials and its alloys [6-11].

In this study, Aluminum alloy AA6060 was squeeze cast at a pressure of 90 MPa. The density, Porosity, hardness, wear rate of alloy AA6061 was studied, as well as their relationships with section thickness were given.

2. METHODOLOGY

In the form of a plate with a 4mm thickness, the 6061 Al alloy's chemical composition is presented in Table 1. Electrical discharge machine (EDM) was used to slice the plate into specimens that were 30×20 mm.

Table 1. Chemical makeup of 6061 Al-alloy

Element	Wt. (%)
AL %	Bal
Mg %	1.06
Si %	0.86
Cu %	0.2
Fe %	0.27
Cr %	0.11
Mn %	0.09
Zn %	0.03
Co %	0.01
Ni %	0.01

A series of cylindrical specimen's aspect ratio *H*/*D* of 2/3, 3/3, 4/3 was cast either by squeeze casting, using pressures(90MPa). The squeeze casting system consists of an electric hydraulic press and three die molds of steel (medium carbon AISI 1040) with fixed diameters and different heights, as shown in Figure 1.

The molds consist of the following parts:

- The lower part of the mold (Die), which is a hollow cylindrical part with a diameter of 30 mm and an outside diameter of 50 mm with heights of 25, 35, 45 mm, as shown in the Figure 1.

- The upper part of the mold contains the Punch, which has diameter of 29 mm and a height of 40 mm.

Figure 1. Used molds and presses

The pieces of alloy were melted in graphite crucibles at 800 °C. The melt was subsequently poured directly ingoing the steel mold cavity (medium carbon AISI 1040). A small electric furnace was utilized to heat the cylindrical mould assembly for casting to 300 °C. Before to casting, the whole mold was covered with graphite. Within 7 seconds after pouring, squeeze pressure was applied to the casting and maintained for 120 seconds.

The cooling curve was drawn using a Data logger thermometer, as shown in Figure 2. The thermocouple type (K) was connected to the Data logger thermometer, while the other end passed through a hole located in the center of the base at the bottom of the mold and fixed at the inner surface of the base of the mold and touched the casting. Recording the temperature during the squeeze casting process over time with one reading per two seconds.

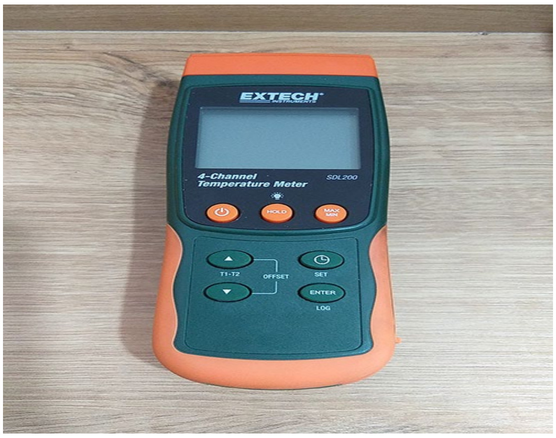

Figure 2. Data logger thermometer

Vickers hardness test is used to determine the samples' hardness (using hardness test machine) as shown in Figure 3. Density measurements were used to assess porosity. After weighing each specimen in distilled water and air, according to ASTM standard D3800, the Archimedes principle was used to determine each specimen's real density $(R.d)$ [12].

$$R.d = \frac{W_{air} \times d_{water}}{W_{air} - W_{water}} \tag{1}$$

where, W_{air} and W_{water} (the weight of the specimen in air, in water, respectively) and d_{water} is the density of water. The porosity of each specimen was calculated by the following equation (ASTM Standard C948) [13].

$$Porosity(\%) = \frac{T.d - R.d}{T.d} \times 100\% \tag{2}$$

where, $T.d$ is the theoretical density of the alloy AA6061, which is 2.727 g/cm^3.

To find the wear rate, use a wear tester of the type (Pin on disc) and the process conditions are (Speed: 480 rpm, the weight: 20 N, time taken: 20 Sec, disc diameter: 60 mm) Then the samples were weighed after conducting the wear test to find out the lost weight. The lost weight was calculated by the difference between the two weights and according to the Equation (3) [14].

$$\Delta W = W_1 - W_2 \tag{3}$$

where, W_1 and W_2 are the Weigh the sample before testing and weigh the sample after testing, respectively. Then calculate wear rate by Equation (4) [14].

$$Wear\ rate = \frac{\Delta W}{S} \tag{4}$$

where, S is the total sliding distance.

Figure 3. Hardness tester

3. DISCUSSION OF THE RESULTS

3.1. Cooling Rate

Figure 4 shows the typical cooling curves of squeeze cast AA6061 where the pressure was applied 90 MPa with H/D of 2/3, 3/3, 4/3 which were computed by Thermometer data logger. The ratios 2/3 and 3/3 portions required 3.5 and 4.5 seconds to cool from liquidus 652 °C to solidus 580 °C, however the 4/3 segment took just 5 seconds. Thus, the cooling rate for ratio H/D of 2/3, 3/3, 4/3 are 20, 15.5, 14 °C/Sec, respectively.

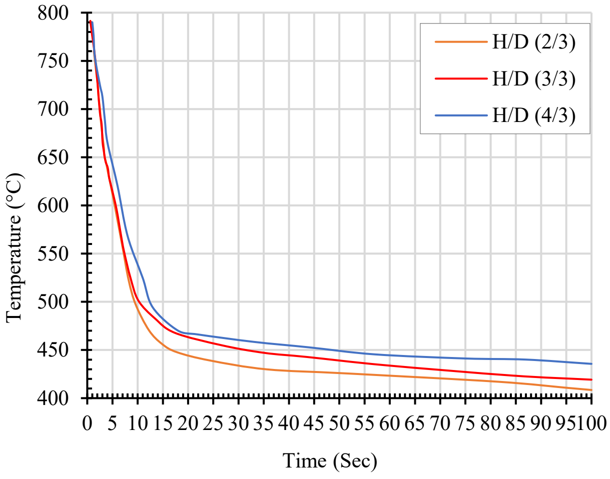

Figure 4. Cooling curves of samples with aspect ratio *H*/*D*

3.2. Density and Porosity Evaluation

Figure 5 shows the relationship between the *H*/*D* ratio with each of the true density and porosity of the castings, which were produced by the pressing casting process at a pressure of 90 MPa and the casting temperature of approximately 800 °C with a preheating of the mold 300 °C.

Density is affected by several factors such as the casting temperature, the preheating temperature of the mold, applied pressure and porosity. It is already known that the *H*/*D* ratio (the volume of the casting) is associated with an inverse relationship with the applied pressure, which is considered one of the main factors affecting density and porosity in casting operations. Therefore, the amount of applied pressure must be sufficient to get rid of porosity or reduce it and increase the density values. As a result, the density values increased as the *H*/*D* ratio dropped, where the density values were recorded as 2.71, 2.718, 2.724 g/cm^3 for the 2/3, 3/3, 4/3 ratios, respectively and the sample with ratio 2/3 approaches the theoretical density value of 2.726 g/cm^3 compared to other models with ratios 3/3, 4/3. The reason is due to the increased in volume resulting from the increase in height against the applied pressure, which reduce the effect of applied pressure.

The density characteristic is associated with a major factor, which is porosity, and we note that the relationship between density and porosity is an inverse relationship, that is, the higher the porosity, the lower the density. so, the porosity values were 0.66, 0.32, 0.08 % for 2/3, 3/3, 4/3 ratios, respectively.

applied pressure plays a major role in reducing porosity, especially in casting operations in the squeeze casting technique. Where sufficient applied pressure works to increase the feeding mechanism between dendritic, which in turn leads to filling the gaps between the Dendritic Arms Spacing with liquid metal, which results in reducing or eliminating the shrinkage porosity and thus increasing the density. The feeding mechanism between the dendritic may be affected under the conditions of the casting process, which causes the liquid metal to not reach sufficiently in the areas of gaps or voids between the dendritic arms, which leads to an uneven decrease in the amount of density [15, 16].

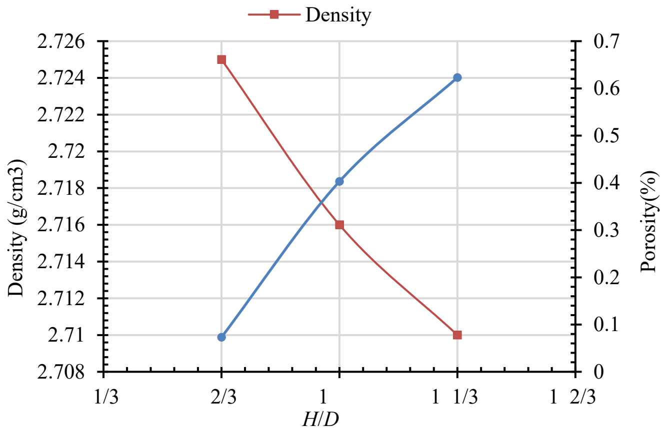

Figure 5. Porosity level and density at pressure (90Mpa)

3.3. Hardness Evaluation

It is known that the hardness property is directly affected by the increase or decrease in the cooling rate during the casting process. Therefore, the relationship between the cooling rate and hardness is a direct relationship, that is, when the cooling rate of the casting is increased, the hardness increases, but the cooling rate in squeeze casting process is affected by the value of the fraction of the area of the eutectic phase and the applied pressure, which is inversely proportional to the size of the casting. The increase in *H*/*D* ratio decreases effect of the applied pressure, which in turn leads to a decrease in the cooling rate.

Therefore, it was observed that the hardness values decrease with the increase in the *H*/*D*, and the values 69, 65, 59.5 HV were recorded for the ratios of 2/3, 3/3, 4/3, respectively. Increasing the cooling rate resulting from decreasing the ratio of *H*/*D* and increasing the pressure effect reduces or eliminates the air gap formed between the casting surface and the inside surface of the mold wall. As a result, we will obtain a smooth microstructure and reduce both the grain size and the distance between the dendritic arm spacing as a result of feeding between the arms.

Figure 6 Illustrating the relationship between hardness values and the *H*/*D* ratio.

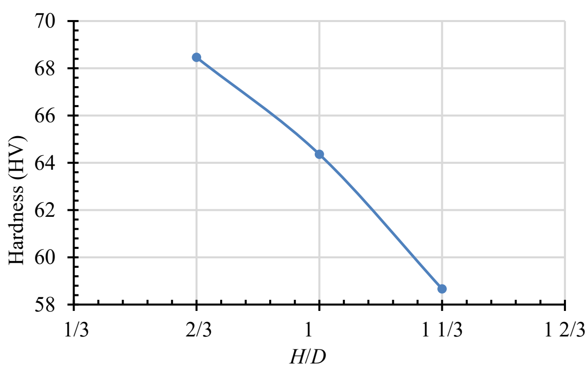

Figure 6. Hardness and aspect ratio *H*/*D* at pressure (90Mpa)

3.4. Wear Rate Evaluation

Figure 7 shows the relationship between the wear rate and the ratio of *H*/*D* for the samples prepared by the squeeze casting method at a pressure of 90 MPa for the aluminum ingot AA6061. It is noted from the figure that an increase of *H*/*D* ratio produced an increase in the wear rate, as it was found that the value of the wear rate was recorded 27×10^{-8} g/cm at the ratio 2/3 and the value increased to become 33×10^{-8} g/cm at the ratio 3/3, then it also increased to reach the value 38×10^{-8} at the ratio 4/3 the reason is attributed to the increase in the wear rate with an increase in *H*/*D* to the decrease in the amount of hardness resulting from the decrease in the cooling rate due to the decrease in the effect of pressure.

The improvement of wear resistance is related to the smoothness of the grain size and the uniform distribution of the eutectic phase. Therefore, we note that the grain structure improves with the decrease in the value of the *H*/*D* ratio, due to the increase in applied pressure's impact, which causes the squeeze casting process's cooling rate to increase.

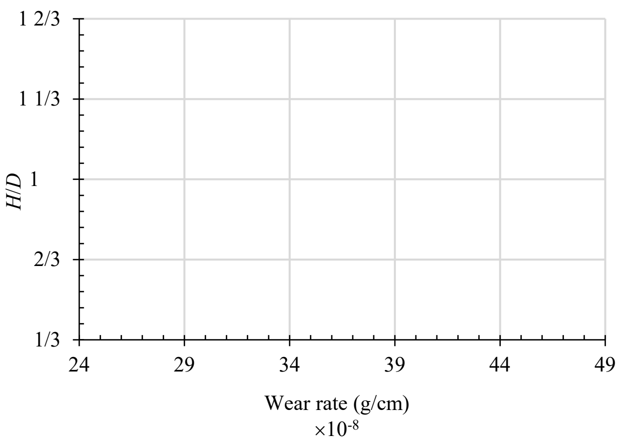

Figure 7. Wear rate and aspect ratio *H*/*D* at pressure 90 MPa

4. CONCLUSIONS

1) The increase in *H*/*D* ratio produced a decrease of the cooling rate in the squeeze casting technique.
2) Increasing *H*/*D* ratio produced a decrease in density, and the density value of the *H*/*D* ratio of 2/3 is closer to the theoretical density value compared to other ratios of 3/3, 4/3. The reason is attributed to the effect of the compressibility factor of the molten metal greater than the rate of Cooling while applying pressure.
3) A decrease in the porosity was observed with a decrease in the *H*/*D* ratio, due to the increase in pressure that increases the density and the increase in the feeding mechanism between the dendritic arms.
4) The best obtained mechanical properties were at the ratio *H*/*D* of 2/3, as it gave the highest density value, the lowest porosity value, the highest hardness value, and the lowest wear rate.

REFERENCES

[1] P. Vijian, V. Arunachalam, "Optimization of Squeeze Casting Process Parameters Using Taguchi Analysis", The International Journal of Advanced Manufacturing Technology, Issue 83, Vol. 33, pp. 1122-1127, August 2007.
[2] P. Vijian, V. Arunachalam, "Modelling and Multi Objective Optimization of LM24 Aluminum Alloy squeeze Cast Process Parameters Using Genetic Algorithm", Journal of Materials Processing Technology, Issue 1-3, Vol. 186, pp. 82-86, May 2007.
[3] K. Sukumaran, et al., "Studies on Squeeze Casting of Al 2124 Alloy and 2124-10% SiCp Metal Matrix Composite", Materials Science and Engineering, Issue 1, Vol. 490, pp. 235-241, 25 August 2008.
[4] L. Yang, "The Effect of Solidification Time in Squeeze Casting of Aluminum and Zinc Alloys", Journal of Materials Processing Technology, Issue 1, Vol. 192, pp. 114-120, October 2007.
[5] P. Vijian, V. Arunachalam, Optimization of Squeeze Cast Parameters of LM6 Aluminum Alloy for Surface Roughness Using Taguchi Method", Journal of Materials Processing Technology, Issue 1-3, Vol. 180, pp. 161-166, 1 December 2006.
[6] N.S. Abtan, K.H. Ghlaim, L.A. Proff, "Comparisons of Applied Pressure Effect on Improving Density, Hardness, and Microstructure by both Squeeze Casting Process and Pressure Die Casting Process for 380-Al Alloy", The Iraqi Journal for Mechanical and Material Engineering, Issue 2, Vol. 12, pp. 334-343, 2012.
[7] M.T. Azhagan, et al., "Influence of Squeeze Pressure on the Mechanical Properties of Squeeze Cast Aluminum Alloy AA6061", Advanced Materials Research, Issue 13, Vol. 984-985, pp. 350-354, July 2014.
[8] J. Hao, et al., "The Effect of Squeeze Casting Process on the Microstructure, Mechanical Properties and Wear Properties of Hypereutectic Al-Si-Cu-Mg Alloy", International Journal of Metalcasting, Issue 4, Vol. 16, pp. 153-165, February 2021.
[9] A. Raji, R. Khan, "Effects of Section Thickness on the Optimum Properties OF Al-8% Si Alloy Squeeze Cast Components", Global Journal of Engineering Research, Vol. 4, No. 1, pp. 13-16, January 2005.
[10] R. Tamuly, A. Behl, H. Borkar, "Effect of Squeeze Casting on Microstructure and Wear Properties of Aluminum Al-Si Alloy", Advances in Lightweight Materials and Structures, Springer, Vol. 8, pp. 705-714, 14 October 2020.
[11] M.M. Saeed, M. Najeeb Abdullah, A.D. Younis, "Effect of Change in Dies Shape and Metals on Extrusion Force-Numerical Analysis and Experimental Study", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 53, Vol. 14, No. 4, pp. 86-91, December 2022.
[12] A. Bouayad, M. Alami, "The Effect of Mold and Pouring Temperature on Hardness and Microstructure of a HPDC Hyper- Eutectic Aluminum Alloy", International Journal of Engineering Research and Technology, Issue 8, Vol. 4, pp. 1162-1165, February 2015.
[13] B. Amar, et al., "Pressure and Die Temperature Effects on Microstructure and Mechanical Properties of Squeeze Casting 2017A Wrought Al Alloy", International Journal of Microstructure and Materials Properties, Issue 4, Vol. 7, No. 6, pp. 491-501, 2 January 2013.

[14] M.K. Abbass, "Study of Dry Sliding Wear Behavior of Al-12% Si Alloy Produced by Squeeze Casting", The Iraqi Journal for Mechanical and Material Engineering, Issue 3, Vol. 9, pp. 369-382, 3 December 2009.
[15] A. Jahangiri, et al., "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, Issue 76, Vol. 245, pp. 1-6, July 2017.
[16] T. Reguła, et al., "Effect of Applied Pressure on the Quality of Squeeze Cast Parts Made from AlSi9Mg Alloy", Archives of Foundry Engineering, Issue 3, Vol. 11, pp. 55-60, 18 April 2011.

BIOGRAPHIES

Name: **Saad**
Middle Name: **Saud**
Surname: **Mutar**
Birthday: 24.03.1980
Birthplace: Anbar, Iraq
Bachelor: Mechanical Engineering, College of Mechanical Engineering, Anbar, Iraq, 2002
Master: Student, Metallurgy and Production Engineering, Mechanical Engineering, College of Mechanical Engineering, Tikrit University, Tikrit, Iraq, Since 2021
Research Interests: Casting Processes, Materials

Name: **Najeeb**
Middle Name: **Salman**
Surname: **Abtan**
Birthday: 01.01.1962
Birthplace: Baghdad, Iraq
Bachelor: Metallurgy and Production Engineering, Technology University, Baghdad, Iraq, 1984
Master: Metallurgy Engineering, Metallurgy and Production Engineering Department, Baghdad, Iraq, 1997
Doctorate: Metallurgy Engineering, Technology University, Baghdad, Iraq, 2006
The Last Scientific Position: Assist. Prof., Metallurgy, Mechanical Engineering Department, Tikrit University, Tikrit, Iraq, 2014
Research Interests: Casting, Welding
Scientific Publications: 20 Papers, 10 Projects, 15 Theses
Scientific Memberships: Scientific Committee Member and Postgraduate Committee Member, Tikrit University, Tikrit, Iraq