ISSN 0543-5846
METABK 63(2) 197-200 (2024)
UDC – UDK 621.747-669.71.3:539.43:539.42:536.58:620.18=111

FATIGUE STRENGTH OF Al-Cu CAST ALLOY WITH DIFFERENT POURING TEMPERATURE

Received – Primljeno: 2023-09-11
Accepted – Prihvaćeno: 2023-11-11
Original Scientific Paper – Izvorni znanstveni rad

This experiment aimed to evaluate how pouring temperature affects fatigue strength of Al-Cu cast alloy. Subsequently, commercial aluminum ingots, such as Al-2024 were remelted and then machined into samples for both tensile and fatigue testing. These samples were cast at three different temperature of 688, 738, and 788 °C while maintaining a constant mold temperature of 220 °C. The results showed that the highest tensile strength was 201,06 MPa at 738 °C. Additionally, the greatest fatigue strength was observed at 80,4 MPa at pouring temperature of 738 °C. It was observed that variations in pouring temperature can significantly impact fatigue strength of cast alloy. At the highest pouring temperature of 788°C, the presence of pores in the metal casting samples resulted in a decrease in both tensile and fatigue strength. Furthermore, when examining the surface fractography of casting sample, the presence of brittle cracks in alloy was observed.

Keywords: Al-Cu cast alloy, fatigue strength, tensile strength, pouring temperature, microstructure

INTRODUCTION

Fatigue resistance of a metal alloy is influenced by various casting factors, including pouring temperature (PT), grain refinement [1], and casting defects such as porosity, and macro and micro shrinkage [2,3]. In the case of cast aluminum alloy A319, fatigue testing revealed cracks initiating from pores and propagating through alloy until failure occurred [4]. Another defect of cast alloy is the formation of internal cavities which affect fatigue strength of die-cast magnesium alloy [5]. Fatigue strength experiments on Al-Cu alloy have been intensively investigated [6].

The application of ultrasonic fatigue testing has been investigated, using two frequencies, 100 and 20 Hz respectively.

Both frequencies have been affected by similar lifespans and high fatigue cyclical behavior [7]. Subsequently, fatigue testing applied to automotive elements such as motorcycle wheels produced by centrifugal cast has been investigated [8]. Based on the background above, this experiment aimed to evaluate the difference in pouring temperature on fatigue resistance of Al-Cu cast alloy. Additionally, observations were carried out on the fracture surface and microstructure of cast samples caused by differences in pouring temperature.

Akhyar (akhyar@unsyiah.ac.id), Department of Mechanical Engineering, Universitas Syiah Kuala, Jln. Syech Abdurrauf No.7, Darussalam – Banda Aceh, 23111, Indonesia
P.T. Iswanto, V. Malau, F.P. Putra, Department of Mechanical and Industrial Engineering, Gadjah Mada University (UGM), Jln. Grafika No.2, Yogyakarta, 55281, Indonesia
A. Farhan, Department of Physic Education, FKIP Universitas Syiah Kuala, Banda Aceh, Indonesia

EXPERIMENTAL PROCEDURES

Al-2024 alloy was re-melted and cast into metal molds to form square plates using the gravity casting process. Tensile and fatigue strength test samples were machined from Al-Cu alloy cast products. The chemical compositions shown in Table 1 were tested using spectroscopic metal standards. Figure 1 shows fatigue-tested sample that was cut by a machining process in cast product.

Casting products were obtained using three different pouring temperature: 688, 738, and 788 °C. Meanwhile, the mold temperature was kept constant at 220 °C for the three pouring temperature. All tensile test samples were cut following the ASTM E8-09 standard and fatigue test was carried out following the JIS Z2274 standard.

RESULTS AND DISCUSSION

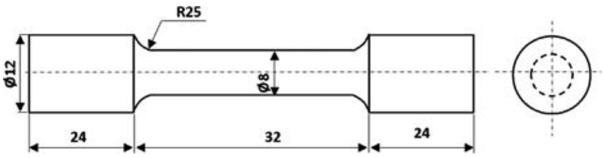
Figure 2 shows the average results of tensile tests, with each test repeated three times. The highest tensile

Table 1 **Chemical composition /wt.%**

Si	0,1597
Fe	0,2531
Cu	5,9311
Mn	0,7332
Mg	1,9359
Cr	0,0118
Ni	0,0122
Zn	0,1835
Ti	0,0143
Fe	Bal.

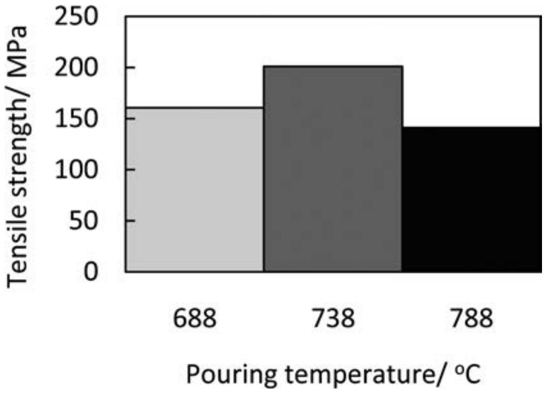
(a)

(b)

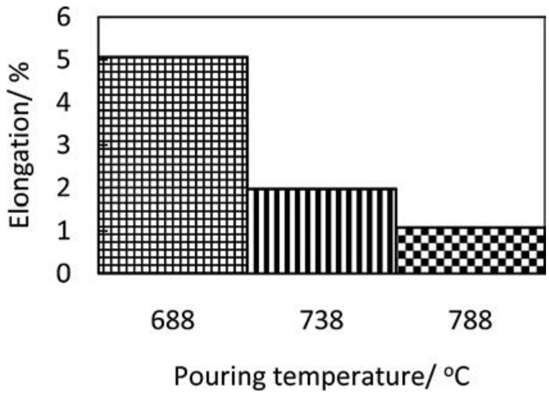


(c)

Figure 1 (a) the site of fatigue sample was machined from cast plate [9], (b) fatigue samples, (c) the sample configuration for fatigue test.



(a)



(b)

Figure 2 (a) tensile characteristics at room temperature, (b) elongation.

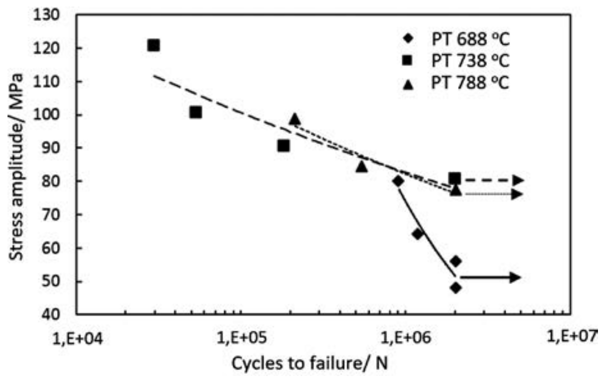


Figure 3 Al-Cu alloy fatigue data at various pouring temperature.

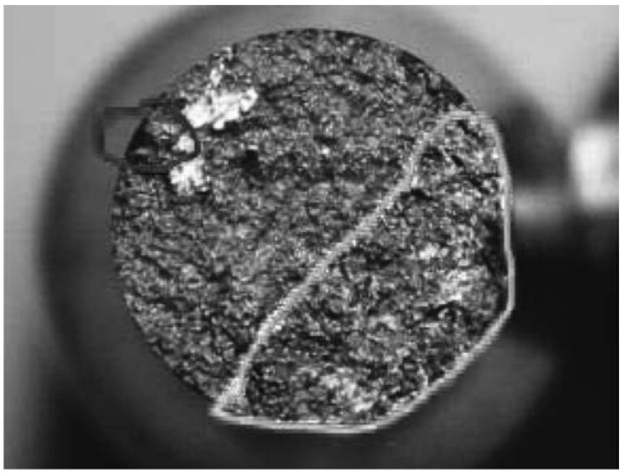


Figure 4 Macrostructure of the fracture surface in fatigue samples cast at 788 °C.

strength obtained was 201,06 MPa at pouring temperature of 738 °C, while the lowest tensile strength of 141,13 MPa was achieved at pouring temperature of 788 °C. The highest elongation from this experiment was 5,06 at 738 °C and the lowest elongation was 1,08 at 788 °C. Tensile strength initially increases and then decreases with increasing pouring temperature, as well as the elongation index. The effect of pouring temperature includes an increase in tensile strength, then tensile strength decreases when pouring temperature is increased but has no significant effect [9].

Fatigue data for cast alloy fatigue is plotted on a logarithmic S-N curve, which will be used to analyze and compare the effect of pouring temperature on fatigue strength. A straight line (trend) is used to approximate the measured experimental data, as shown in Figure 3. The load used for fatigue testing is based on the ultimate tensile strength, and data is recorded for up to two million cycles. The best fatigue resistance is fatigue limit of 80,4 MPa from the S-N plot shown from samples with pouring temperature variation of 738 °C. Then the second level of fatigue strength is 77,8 MPa at 788 °C. The third level of fatigue strength is 56,62 MPa at 688 °C.

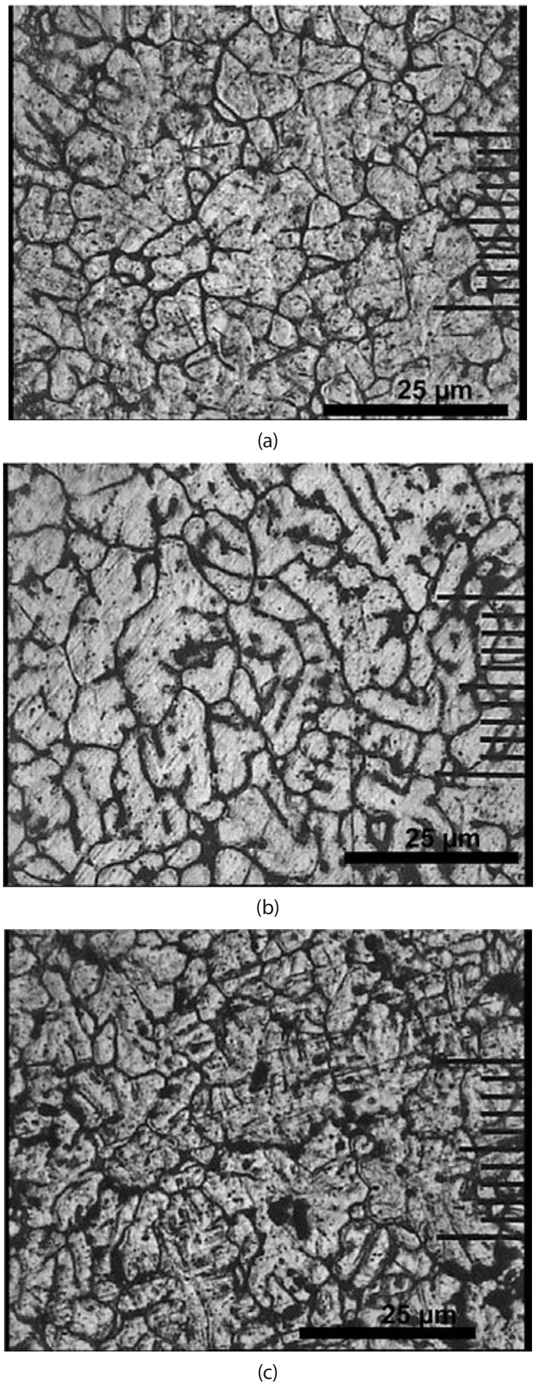


Figure 5 Microstructure of cast samples with varying pouring temperature: (a) 688 °C, (b) 738 °C, and (c) 788 °C.

The macrostructure of the fracture surfaces of the three fatigue samples is shown in Figure 4. The areas marked with red lines are identified as catastrophic failure and the areas colored green are identified as crack initiation. Subsequently, crack propagation in the image is marked with a benchmark on the macro-fractogram. Brittle fractures were found in all fatigue samples produced by the metal casting process due to three different pours temperature. The brittle fracture is characterized by a rough surface that appears structured on the fracture surface of fatigue sample [10].

The microstructure of the sample cast with different pouring temperature is shown in Figure 4. The three pouring temperature used when manufacturing the sample cast were 688, 738, and 788 °C, respectively. It can be seen that the grain size increases as pouring temperature increases. Subsequently, increasing pouring temperature will increase the grain size caused by thermal release from the melt during solidification. The highest pouring temperature can change the grain morphology [9].

The experimental results show that pouring temperature plays a significant role in determining fatigue strength. Subsequently, this fatigue strength value is synergistic with tensile strength index. The greatest fatigue strength index was obtained at pouring temperature of 738 °C. The decrease in tensile strength index at 788 °C was caused by the presence of porosity (casting defects). It can be seen from the microstructure in Figure 5. Fatigue limit can be estimated from tensile strength index. When cast metal sample exhibits a favorable tensile performance, it will enhance fatigue indicator. Therefore, it can be concluded that fatigue strength is directly proportional to tensile strength index [6]. The arrow on the S-N curve (Figure 3) indicates that fatigue sample will not fracture again after $2x10^6$ cycles in this experiment.

CONCLUSIONS

In conclusion, the effect of different pouring temperature on fatigue resistance of Al-Cu alloy during casting was investigated in this experiment, and the following are drawn: Differences in pouring temperature, which was one of the parameters of metal casting, could affect fatigue resistance of Al-Cu alloy. The highest tensile strength was 201.06 MPa at pouring temperature of 738 °C. The best fatigue strength was 80.4 MPa at pouring temperature of 738 °C. Increasing pouring temperature could change the morphology and grain size, which accordingly increased tensile strength and fatigue resistance in Al-Cu cast alloy.

ACKNOWLEDGMENTS

This study was funded by a grant from the Research Fund of the Ministry of Education, Culture, Research and Technology, the Republic of Indonesia, (Direktorat, Teknologi, dan Pengabdian kepada Masyarakat. Direktorat Jenderal Pendidikan Tinggi, Riset, dan Teknologi. Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi). LPPM Universitas Syiah Kuala (Number: 168/E5/PG.02.00.PL/2023). The authors are grateful to all participants of the InAES international conference for their suggestions when presenting both parts of the data and the entirety of this paper. This paper has been revised according to input from participants at the conference.

REFERENCES

[1] B. Gieseke, V. K. Sikka, The effect of casting temperature on the fatigue properties of cast nickel aluminide alloys,

Editor(s): S.H. Whang, D.P. Pope, C.T. Liu, High Temperature Aluminides and Intermetallics, Elsevier, 1992, pp. 520-524, https://doi.org/10.1016/B978-1-85166-822-9.50083-2.

[2] Alagarsamy, A., Kumar, S. Demystifying Shrinkage Porosity in Ductile Iron Castings. Inter Metalcast 14, 1136–1151 (2020). https://doi.org/10.1007/s40962-020-00440-3

[3] Dehua Li, Zhiqian Zhang, Shengci Li, Jiamin Yang, Siyu Zhang, Xinli Bian, Yuqin Zhang, Liang Qi, Olanrewaju A. Ojo, Microstructure, mechanical properties and fatigue crack growth behavior of an Al-Zn-Mg-Cu-Si-Zr-Er alloy fabricated by laser powder bed fusion, International Journal of Fatigue, Volume 172, 2023, 107636,https://doi.org/10.1016/j.ijfatigue.2023.107636.

[4] D.D. Tian, X.S. Liu, G.Q. He, Y. Shen, S.Q. Lv, Q.G. Wang, Low cycle fatigue behavior of casting A319 alloy under two different aging conditions, Materials Science and Engineering: A, Volume 654, 2016, Pp. 60-68, https://doi.org/10.1016/j.msea.2015.12.023.

[5] Kim, J.E., Kim, Y.J., Bae, J.H. et al. Tensile and High-Cycle Fatigue Properties of Die-Cast SEN6 Magnesium Alloy. Met. Mater. Int. (2023). https://doi.org/10.1007/s12540-023-01473-z

[6] Iswanto P.T., Akhyar, Pambekti A. Heat treatment T4 and T6 effects on mechanical properties in Al-Cu alloy after remelt with different pouring temperatures. Metalurgija 59 (2020) 2, 171-174. Preuzeto s https://hrcak.srce.hr/232455

[7] K. Tahmasbi, F. Alharthi, G. Webster, Meysam Haghshenas, Dynamic frequency-dependent fatigue damage in metals: A state-of-the-art review, Forces in Mechanics, 10 (2023), 100167, https://doi.org/10.1016/j.finmec.2023.100167.

[8] P.T. Iswanto, Akhyar, E.U.K. Maliwemu, Fatigue crack growth rate of motorcycle wheel fabricated by centrifugal casting, Metalurgija 58 (2019) 1-2, 51-54.

[9] Akhyar, H., Iswanto, P. T., & Malau, V. (2018). Non Treatment, T4 and T6 on Tensile Strength of Al-5.9Cu-1.9Mg Alloy Investigated by Variation of Casting Temperature. Materials Science Forum, 929, 56–62. https://doi.org/10.4028/www.scientific.net/msf.929.56

[10] Minghe Ju, Jianchun Li, Xiaofeng Li, Jian Zhao, Fracture surface morphology of brittle geomaterials influenced by loading rate and grain size, International Journal of Impact Engineering, 133 (2019), https://doi.org/10.1016/j.ijimpeng.2019.103363.

Note: The responsible English translator is Native Proofreading Service Institute.