METALURGI
Majalah Ilmu dan Teknologi
p-ISSN 0126-3188 | e-ISSN 2443-3926
ejurnalmaterialmetalurgi.lipi.go.id

THE EFFECT OF Al_2O_3 AND STIRRING TIME ON DENSITY AND POROSITY OF ALUMINUM ADC12 FOAM

Yeni Muriani Zulaida*, Muhammad Nurul Izzudin, Suryana
Department of Metallurgy, Sultan Ageng Tirtayasa University
Jl. Jenderal Sudirman Km 3, Cilegon, Banten, Indonesia 42435
*E-mail: yeni_m_zulaida@untirta.ac.id

Received: 11-03-2023, Revised: 07-08-2023, Accepted: 15-08-2023

Abstract

The instability of the foam forming during metallic foam manufacture commonly occurs, which will cause undesirable pores. The stability of the foam structure is one of the important factors. A stabilizer can maintain the foam cell during the melting process. In this study, the metal used is ADC12 with a 12 wt.% of Si element content, and the foaming agent is $CaCO_3$. $CaCO_3$ will produce gas to form bubbles in the melt during the solidification process and use a stabilizer to strengthen cell walls so that foam does not easily fall off or collapse. The stabilizer uses Al_2O_3 with the variation of Al_2O_3 are 1 to 3 wt.%. The stirring time is as variable as well. A stirring process is conducted to distribute foaming agents so that the foam distribution is more homogeny throughout the aluminum foam. The variation of the stirring time is carried out for 60, 120, and 180 seconds. The results show that as the time of stirring and the addition of stabilizer increases, the porosity will rise, but the density decrease. Compressive strength results show it has no significant relation with increasing the stabilizer and stirring time. The highest compressive strength is obtained in the sample with a stirring time of 120 seconds with an Al_2O_3 content of 1 wt.%.

Keywords: *ADC 12 metal foam, foaming agent, stirring, Al_2O_3*

1. INTRODUCTION

The popularity of aluminum foam nowadays has increased. It can be investigated easily by the number of scientific articles that discuss it [1]. Metal foams are known for their unique combinations of physical and mechanical properties, such as lightweight, higher specific strength & stiffness, improved elevated temperature strength, and excellent energy absorption capacity at very low plateau stress. The implementation of aluminum foam in the automotive and aerospace fields is unquestionable. Aluminum foam can be used as crash energy or vibration-absorbing material [2]. Because of its lightweight material, aluminum foam can reduce the weight of vehicles. Mass-reduction vehicles achieve significant weight loss, reduce greenhouse gas emissions, and save intake fuel [3]. All of these are the advantages of using metal foam.

Different methods have been developed to produce foams, which can be divided into two categories: direct foaming by introducing gas bubbles into a conditioned melt [4] and foaming with the help of blowing agents [5]. Metal foam making using the molten metal can be called the direct method because liquid metal can form foam by directly injecting gas or gas from blowing agents [6]. Gas that appears in molten metal will form gas bubbles and be dispersed in the liquid. Generally, gas bubbles formed in molten metal tend to immediately rise to the surface due to the high buoyancy forces in the high-density melt. However, this upward movement will be hampered by increasing the viscosity of the liquid metal. This condition can be conducted by adding fine ceramic powders or alloying elements to form stable melt particles [7].

Using foaming agent $CaCO_3$ can produce foam under optimum conditions, resulting in a

DOI : 10.55981/metalurgi.2023.707

Metalurgi is Sinta 2 Journal (https://sinta.kemdikbud.go.id/journals/profile/3708) accredited by Ministry of Education, Culture, Research, and Technology, Republic Indonesia

density of 0.9 g/cm^3 with a rounded pore shape. [8]. Too high a stirring speed, up to 2000 rpm, causes the porosity to increase, but the pore size decreases. The use of $CaCO_3$ is considered very efficient and effective and thus can replace the role of conventional TiH_2 foaming agents [9]. The effect of porosity percentage is very significant on the compressive strength of the aluminum foam. The value of the porosity is higher; the foam strength will be low [10].

In a previous study, aluminum in the liquid will react to form aluminum oxide (Al_2O_3) and then continue with calcium carbide to become calcium-alumina [11]. It will increase the viscosity of the melt so that the bubbles that form do not quickly come out to the surface. In this study, the formed aluminum oxide slag was cleaned, so how effective the addition of Al_2O_3 in forming porosity in the foam metal.

So, this study aims to understand the effect of additional alumina and stirring time on the density and porosity of foam aluminum, pore shape and size, and the strength of the aluminum foam as a foaming agent using calcium carbonate ($CaCO_3$).

2. MATERIALS AND METHODS

This experiment uses base metal aluminum ADC12 and foaming agent calcium carbonate, as much as 300-gram dan 2 wt.%. The liquid metal stabilizer compound uses alumina (Al_2O_3) with a composition variation of 1, 2 and 3 wt%. All materials melt in an electric furnace. Each specimen was coded based on the stirring time and stabilizer composition, as described in Table 1. S denotes the sample, the first two or three numbers indicate the stirring time, and the last digit indicates the alumina composition. For example, if the specification is S1203, the stirring is carried out for 120 minutes with a 3 wt.% alumina composition.

First, the aluminum ingot was cut into smaller sizes and then put into an electric furnace until around 800 °C. After the metal has melted, the slag on the surface of the liquid is cleaned and then mixed with alumina and stirred with stirring variations of 60, 120, and 180 seconds with a constant rotational speed of 1200 rpm. The stirring process at a set time aims to obtain an evenly distributed alumina in the melt, then the foaming agent $CaCO_3$ is added, stirred for 60 seconds, and held for 3 minutes.

At a temperature of 800 °C, $CaCO_3$ has decomposed into CaO and CO_2. CO_2 gas will be trapped in melted molten aluminum and form bubbles in large quantities and will eventually be referred to as foam. The alumina slag that comes from the reaction of melted aluminum with the surrounding air is removed from the melt surface. It aims to observe the effect of the added alumina more clearly. It is different from what was done by previous researchers who used alumina that came from the reaction between the melt and air [11]. Then, the same process was carried out for other research variations of the alumina composition.

Density and porosity can be calculated using Archimedes' principle [12]. Density (ρ_{sample}) and porosity tests were carried out to determine the percent pore level formed. In the density test, the sample is weighed to determine the dry sample weight (M_k). Then, the sample is immersed in a container filled with water for 1 hour and weighed to determine the wet sample weight (M_b). Then, do the calculations using equation (1) after knowing the value of the hanging mass (W_t), the sample mass in water (W_b), and the specific gravity of water (ρ_{water}) :

$$\rho_{sample} = \frac{M_k}{M_b-(W_b-W_t)} \times \rho_{air} \quad \text{.....(1)}$$

Porosity percentage can calculate using this equation follow,

$$Porosity = 1 - \left(\frac{\rho_{Aluminum}}{\rho_{foam}} \times 100\%\right) \text{....(2)}$$

Compressive strength is observed to obtain the ability of metal foam to accept loads. Compressive testing of aluminum foam uses a universal testing machine Shimadzu AG-X Plus. The 10 KN of load and 2.5 mm/minute of loading speed. The dimension of the compressive test sample is 20x20x30 mm according to the standard. Mechanical properties of commercial aluminum metal foam according to reference in the 0.04-14 MPa [13]. Compressive strength was measured by going through a compressive test with a test speed of 2.5 mm/min at a temperature of 21.2 °C with a humidity of 52.9% RH.

Figure 1. Aluminum without adition foaming agent

The next step is to observe the pore morphology of foam aluminum. This observation includes the pore size and pore area fraction. This step is supported by the ImageJ application to obtain the values. The pore size is determined by measuring the pores' length and width and then averaged.

3. RESULT AND DISCUSSION

After adding the foaming agent and stabilizer, the dimension of the casting is higher than before, which shows that the pore is formed in the melt during solidification. It is possible to see the differences between the sample before and after foaming after cutting it in the transversal direction. The sample has no apparent porous structure without adding the foaming agent and stabilizer (Fig. 1).

The effect of the foaming process is that the casting colour is darker than the casting without the process. After the tranverse cut, the surface have porous (Fig. 2). The composition of Al_2O_3 influences the morphology, density, porosity and, compressive strength of the aluminum foam.

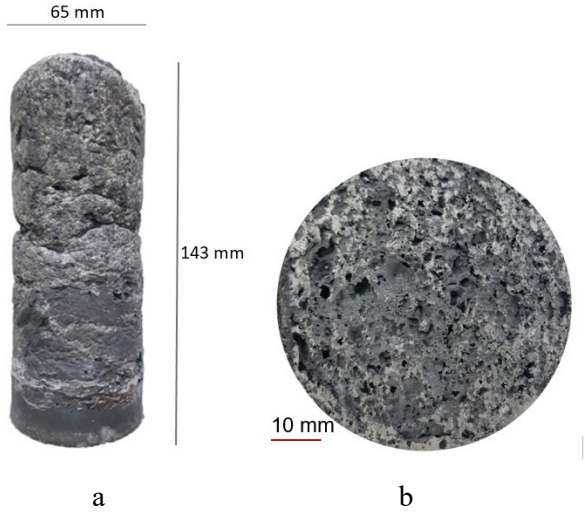

Figure 2. (a) Specimen as cast before cutting, (b) aluminum with adition foaming agent

3.1 Morphology

Figure 3 shows that all samples form pores. The change in the morphology of this precursor material into foam was due to the addition of partition materials that have their respective purposes, namely $CaCO_3$ as a foaming agent and Al_2O_3 as a foam stabilizer.

From the data shown in Table 1, it can be observed that there are differences in the size and fraction of the pore area in the sample cut layers. The S1201 specimen has the highest average pore size and the lowest pore area fraction. The sample with a longer stirring time of 180 seconds will produce a smaller pore size than others, with a larger pore area fraction. These differences will affect the percentages of porosity, density values, compressive strength, and energy present in each sample.

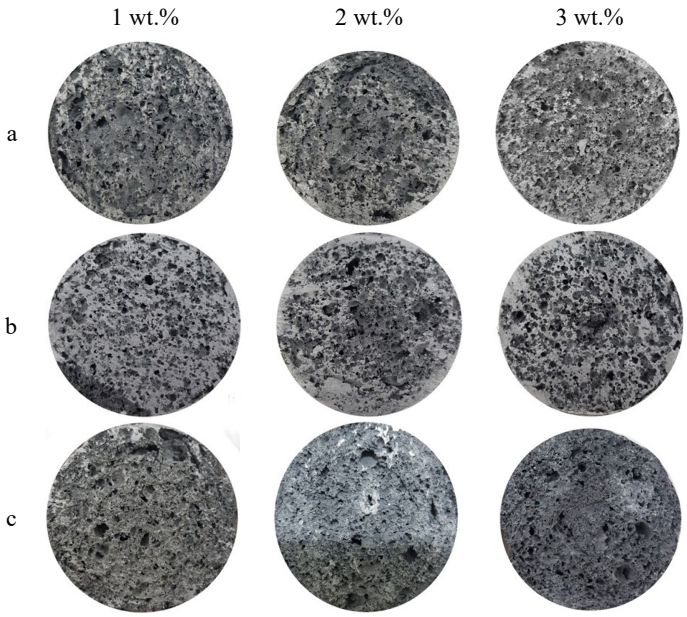

Figure 3. Pore at each stirring time (second) (a) 60, (b) 120, (c) 180

The pore shape can be seen in Fig. 4. The alumina composition affects the pore wall thickness. The specimens with the same stirring time, namely 120 seconds for 2 wt% by weight (S1202) alumina, had thinner walls and more irregular foam shapes than samples with 1 wt.% of alumina composition.

Table 1. Pores size and fraction in every specimen

No	Specimens	Pore Size average (mm)	Pore Fraction Area (%)
1	S601*	1.85	54.52
2	S602	1.72	50.62
3	S603	1.39	50.96
4	S1201	2.46	38.66
5	S1202	1.68	56.06
6	S1203	2.2	54.20
7	S1801	0.94	71.64
8	S1802	0.95	75.84
9	S1803	1.02	76.29

Note : *S is specimen, 60 is stirring time, 1 is stabilizer content

3.2 Density and Porosity

Figure 5 shows the effect of alumina content on the density and porosity of aluminum foam. The blue curve shows 60 seconds of stirring, red for 120 seconds, and green for 180 seconds of stirring.

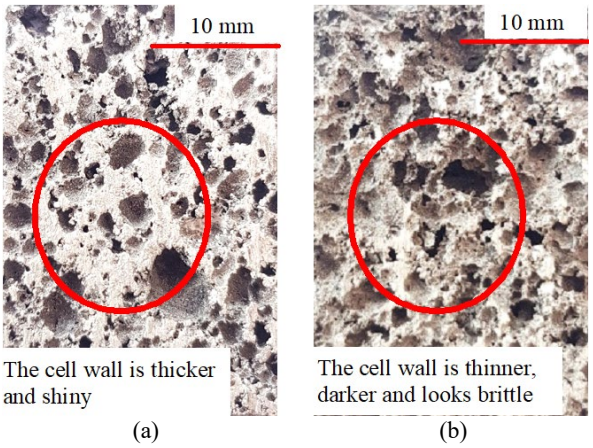

Figure 4. The differences in the pore wall thickness at stirring time 120 seconds with different compositions of alumina (wt.%) (a) 1, and (b) 2

The highest porosity was obtained in 2 wt.% of the alumina composition with a stirring time 120 seconds while adding 3 wt.% of alumina at stirring time 120 seconds which results in lower porosity than the addition of 2 wt.% of alumina. This exhibits that the additives added to the aluminum melt have yet to shown that increasing the levels of additives that increase porosity and reduce density.

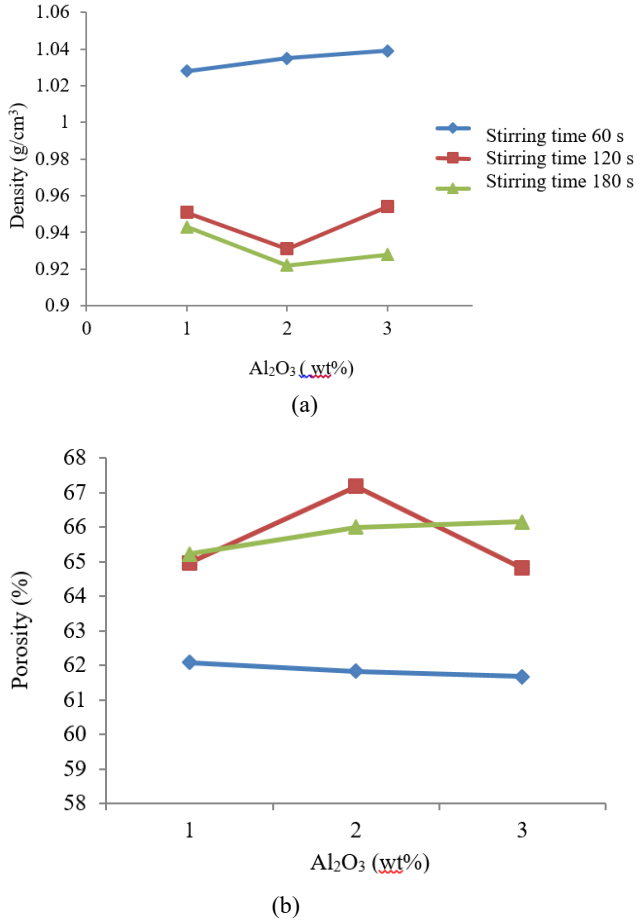

Figure 5. The effect of alumina composition on (a) the density, and (b) the porosity value

Different things are shown in the effect of increasing the stirring time. In Figure 6, the blue, red, and green lines indicate the alumina composition of 1, 2, and 3 wt.% consecutively. The curves show that increasing the stirring time can increase the porosity and decrease the density. It is due to the effect of the stirring process that can help distribute the foaming agents and additives more evenly in the aluminum liquid.

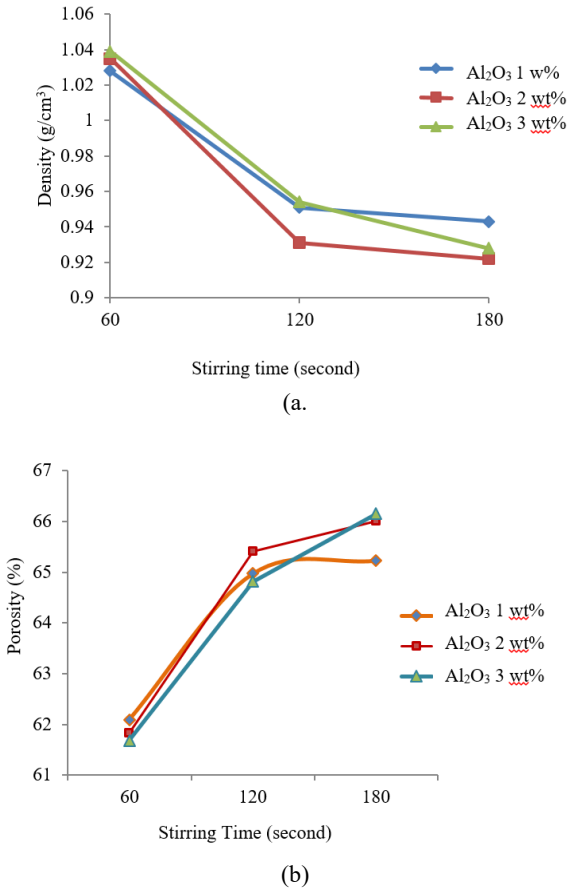

Figure 6. The effect of stirring time on (a) the density and (b) the porosity value

In the 3 wt.% alumina composition, from the results of successive stirring for 60, 120, and 180 seconds, the density values obtained were 1.039, 0.954, and 0.928 gr/cm^3 consecutively, while for porosity were 61.68%, 64.82%, and 66.15%. According to the graphic trend, the same direction can be seen in other alumina compositions.

3.3 Compresive Strength of Aluminum Foam

The effect of adding Al_2O_3 on the compressive strength produced from all aluminum foam specimens can be seen in the figure presented in Fig. 7. The change of the compressive strength values for each sample as the effect of the Al_2O_3 content increases.

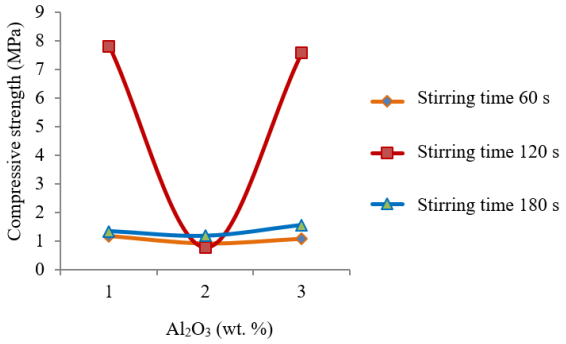

Figure 7. The effect of addition Al_2O_3 on compressive strength of aluminum foam

The compressive strength values obtained from all samples increased with each difference in stirring time. During the 60-second mixing time marked with the orange line, there was an increase and decrease in the compressive strength from 1.17 MPa to 0.90 Mpa, and then it increased again to 1.07 MPa. A significant difference in compressive strength values was obtained for a specimen with a stirring time of 120 seconds marked with a red line. The difference in the compressive strength value in sample 4 was 7.82 MPa, and it decreased very significantly to 0.76 MPa then experienced a significant increase again to 7.58 Mpa.

Figures 8 and 9 show the difference in the pressure test curve lines. Those lines tend to be smooth and go up and down. This indicates that there are differences in the mechanical properties of the samples themselves and that they can be classified into ductile or brittle samples. In the pressure test results, the specimen with a stirring time of 120 seconds had the highest pressure test value compared to other conditions, around 70.73 joules. Meanwhile, the non-smooth curve, as shown in the S1202 sample, includes samples with brittle properties, and you can also see that the energy value is the lowest compared to the other samples, namely 9.58 joules. The shape of the curve that goes up and down is because when pressing is done, the pore walls are immediately destroyed, and consequently, the pressure value at a certain point on the curve decreases. This is also described in previous research [14].

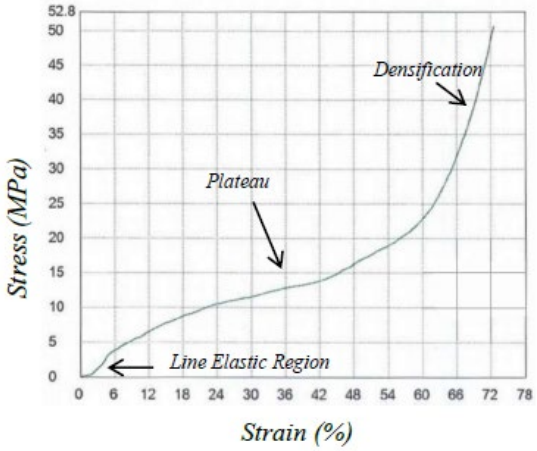

Figure 8. Compressive test result at 120 seconds of stirring time with addition Al_2O_3 1 wt% (S1201)

Representative stress-strain curve from sample S1202 during compression testing (Fig. 8). The first zone is the linear elastic at strain values up to 3% or 4%. In this first zone, the pore shape has not changed permanently. The second zone is the plateau zone, which continues with strain values up to around 6-70%. Plateau is a state of little or no change following a period of activity or progress, but in this case, the stress continues to move up even though it is slower than the first zone. As the pressure increases in this zone, the pores begin to collapse and continue to collapse until the pores are flatter and have the properties of solid materials.

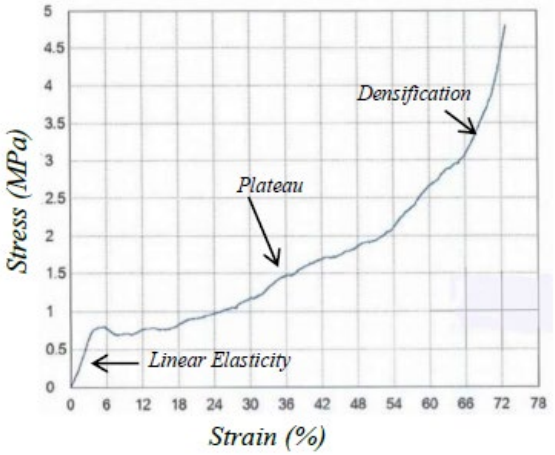

Figure 9. Compressive test result at 120 second of stirring time with addition Al_2O_3 2 wt.% (S1202)

The third zone is the densification zone, with a strain value of around 70% and above. In this zone, the pore wall and the opposite wall close together until they touch each other, and the pore completely collapses, indicated by a significantly increased stress value.

4. CONCLUSION

In this research, adding alumina aims to increase the viscosity of the aluminum melt so that the bubbles that form do not easily come out of the melted surface. Stirring ensures that the alumina and calcium carbonate are distributed evenly throughout the liquid. The conclusions of this study are as follows: The addition of alumina to aluminum melt has not shown a significant effect on density and porosity in the formation of foam. This is obtained value being still lower than the metal foam criteria.

Stirring time shows a significant effect on foam formation. This can be seen by decreasing the density value and increasing the porosity value. This could be due to the foaming agent $CaCO_3$ and additive Al_20_3, which are more evenly distributed in the aluminum alloy.

The distribution of pores formed in the samples improved with increasing stirring time, even though the larger the pores became, the longer the stirring. The higher the compressive strength value of aluminum foam, the longer the stirring time with the addition of Al_2O_3.

ACKNOWLEDGMENT

The authors would like to thank and appreciate to all parties involved, Metallurgy Laboratory of Metallurgical Department, Engineering Faculty, University of Sultan Ageng Tirtayasa for all their scientific discussion and technical support during aluminum foam experiment.

REFERENCES

[1] F. Garai, "Modern applications of aluminium foams," *Int. J. Eng. Manag. Sci.*, vol. 5, no. 2, pp. 14-21, 2020. Doi: https://doi.org/10.21791/ijems.2020.2.3.

[2] S. S. Sharma, S. Yadav, A. Joshi, A. Goyal, and R. Khatri, "Application of metallic foam in vehicle structure: A review," *Mater. Today Proc.*, vol. 63, pp. 347-353, 2022. Doi: 10.1016/j.matpr.2022.03.201.

[3] A. Kumar, R. Maithani, A. Kumar, D. Kumar, and S. Sharma, "An all-aluminium vehicle's design and feasibility analysis," *Mater. Today Proc.*, vol. 64, pp. 1244-1249, 2022. Doi: 10.1016/j.matpr.2022.03.714.

[4] J. Banhart and J. Baumeister, "Production methods for metallic foams," *Mater. Res. Soc. Symp. - Proc.*, vol. 521, pp. 121-132, 1998. Doi: 10.1557/proc-521-121.

[5] T. Miyoshi, M. Itoh, S. Akiyama, and A. Kitahara, "ALPORAS aluminum foam: Production process, properties, and applications," *Adv. Eng. Mater.*, vol. 2, no. 4, pp. 179-183, 2000. Doi: 10.1002/(SICI)15272648(200004)2:4<179::AID-ADEM179>3.0.CO;2-G.

[6] J. Banhart, "Manufacture, characterisation and application of cellular metals and metal foams," *Prog. Mater. Sci.*, vol. 46, no. 6, pp. 559-632, 2001. Doi: 10.1016/S0079-6425(00)00002-5.

[7] J. Banhart, "Metal foams: Production and stability," *Adv. Eng. Mater.*, vol. 8, no. 9, pp. 781-794, 2006. Doi: 10.1002/adem.200600071.

[8] A. M. Solhi, J. K. Allafi, M. Yusefi, M. Yazdani, and A. Mohammadzadeh, "Fabrication of aluminum foam by using $CaCO_3$ foaming agent," *Material Research Express*, pp. 11-14, 2018. DOI: 10.1088/2053-1591/aad88a.

[9] T. Nakamura, S. V. Gnyloskurenko, K. Sakamoto, A. V. Byakova, and R. Ishikawa, "Development of new foaming agent for metal foam," *Mater. Trans.*, vol. 43, no. 5, pp. 1191-1196, 2002. Doi: 10.2320/matertrans.43.1191.

[10] D. S. P. Nugroho, A. W. Nugroho, and B. N. Rahman, "Pengaruh penambahan blowing agent $CaCO_3$ terhadap porositas dan kekuatan tekan aluminium foam dengan cara melt route process," *Tek. Mesin UMY*, pp. 1-6, 2012.

[11] A. A. K. Sutarno, and S. Soepriyanto, "Pengaruh kalsia alumina (CaO. Al_2O_3) pada busa aluminium AL-7000 dengan agen pembusa kalsium karbonat ($CaCO_3$)," *Pros. Simp. Nas. Inov. dan Pembelajaran Sains 2015*, vol. 2015, pp. 149-152, 2015.

[12] ASTM, "ASTM C373-88 standard test method for water absorption, bulk density, apparent porosity, and apparent specific gravity of fired whiteware products," *Astm C373-88*, vol. 88, pp. 1-2, 1999.

[13] M. F. Ashby, A. Evans, N. A. Fleck, L. J. Gibson, J. W. Hutchinson, H. N. G. Wadley, and F. Delale, "Metal foams : A design guide, *Appl. Mech. Rev.*, vol. 54, no. 6, pp. B105-B106, 2000. Doi:10.1115/1.1421119.

[14] D. C. Curran, "Aluminium foam production using calcium carbonate as a foaming agent," University of

Cambridge, 2003. [Online]. Available: https://www.repository.cam.ac.uk/handle/1810/252945. (accessed July 03, 2023)