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ANALYSIS OF PRODUCTION METHOD AND STABILIZING AGENT ON STRUCTURE OF ALUMINUM METAL FOAMS

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ABSTRACT

Aluminium alloy foams are a form of porous metal whose structure resembles the shape of natural materials such as coral, bone, sponge, etc. Due to their structure, these materials retain good mechanical properties of the base material while being significantly lighter than non-porous metal. Metal foams can be used as energy and vibration absorbers, heat exchangers, insulators, and filters. The main disadvantage of this type of material is its high production cost. To reduce production costs, aluminium alloy chips are used as base material. Foams are made of A360 and AA 7075 aluminium alloys. To produce a porous structure, $CaCO_3$ is used as a foaming agent while Zn and CaO were added as stabilizing agents. The main goal of the paper was to investigate the difference in the shape of pores and relative density after foaming with different stabilizing agents.

Keywords: metal foam, chip waste, recycling, relative density, stabilizer

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1. INTRODUCTION

Metal foams imitate the structure of coral, sponge, and bone [1] and can be made from materials such as aluminium, titanium, nickel, and polymers [2]. They are characterized as low-density materials with high energy and sound absorption. Foams are divided into two groups, with open and closed cells. Open cell foams are made by compacting base material and space holder. After that material is heated and the space holder leaks [3]. These types of foams are used as filters, heat exchangers, and electrodes [4]. Closed-cell foams are made by compacting alloy powder and foaming agents such as TiH_2, $CaCO_3$, and others [5]. They can be made with hot compaction or extrusion. After that process, samples are heated depending on the foaming agent. Titanium hydride's decomposition temperature is close to the melting point of aluminium alloy thus making it an optimal foaming agent. Calcium carbonate, however, is much cheaper and, due to higher decomposition temperature, requires no pre-treatment which leads to lower production costs [6,7,8].

Movahedi et. al proved that foaming with calcium carbonate gives smaller pores, even though temperature, foaming time, and $CaCO_3$ concentration were higher. Foams produced with $CaCO_3$ have greater compression strength and energy absorption, but lower density [9]. Sudharsan et. al proved that adding Mg and Cu, increased the wettability and stability of the foams. It is important to avoid premature gas release [10]. Wang et al. used the pre-oxidation process by heating TiH_2 to postpone gas release at lower temperatures [11]. Carbon dioxide gas stabilizes the foam and prevents coagulation. The difference between TiH_2 and $CaCO_3$ foaming agents is that $CaCO_3$ has a greater decomposition temperature which is needed for the foaming process [12,13].

The most common starting material for aluminium foam production is aluminium powder. The costs associated with this base material lead to a drastic increase in the overall production cost [14]. Using chips that are a by-product of the different machining processes could significantly decrease the production cost of these types of materials. The main challenge in producing foams from aluminium chips is the mixing of larger alloy chip waste and small powder grains of foaming agents. Tsuda et al. analyzed the influence of different base materials on pore sizes. Their research concluded that foams produced with powder alloy have a more homogeneous structure than foams produced using alloy chip waste [15].

The goal of this paper is to analyze the expansion and shape of aluminium foam pores produced using different weight percentages of $CaCO_3$ foaming agent. This paper is an extension of the previous article in which differences between foaming with TiH_2 and $CaCO_3$ were given [16].

2. EXPERIMENTAL WORK

Materials used for foam production were aluminium alloy chips A360 and AA 7075. Chips were produced on vertical machining center Spinner VC 560. The cutting tool and cutting parameters used for chip production of both alloys were the same to keep the chip dimensions comparable. The samples were split into groups: first to be compacted and second to be extruded. A certain percentage of foaming agent ($CaCO_3$) and stabilizing agents (CaO or Zn) was mixed with the aluminium alloy chips. The correct weight percentages of the foaming and stabilizing agents are shown in Table 1. Firstly, the mixture of both groups was cold compacted with a force of 400 kN. Compression force was measured with the HBM load cell C6A 1MN sensor.

Table 1. Production parameters

Sample number	Process	Alloy	Foaming and stabilizing agent	Foaming temperature (°C)	Foaming time (min)
1	Extrusion	A360	5% $CaCO_3$ + 2% Zn	800	15
2	Extrusion	AA 7075	5% $CaCO_3$ + 2% Zn	800	15
3	Extrusion	A360	5% $CaCO_3$ + 2% CaO	800	15
4	Extrusion	AA 7075	5% $CaCO_3$ + 2% CaO	820	15
5	Extrusion	A360	5% $CaCO_3$ + 2% Zn	820	15
6	Extrusion	AA 7075	5% $CaCO_3$ + 2% Zn	820	15
7	Compaction	A360	3% $CaCO_3$ + 2% Zn	800	20
8	Compaction	AA 7075	3% $CaCO_3$ + 2% Zn	800	20

After cold compacting, the samples from the first group were hot compacted. The process started with heating in the furnace for 20 minutes at a temperature of 420 °C. The furnace used to heat the sample was Demiterm Easy 9. After the heating process, the sample was put in the hydraulic press. The mould used for the compression was heated to 400 °C. After that, the sample was hot pressed with a force of 400 kN. Omron temperature regulator E5CC and a relay G3PE-225B DC12-24 were used for measuring the temperature. Finally, the samples were placed in a mould with a diameter of 40 mm and heated to foaming temperatures.

The second group of samples was hot extruded with previous heating in the furnace at the same temperature as the first group. They were also foamed at similar temperatures which are visible in Table 1. The mould used for the foaming of the second group was 22 mm in diameter.

Relative density can be calculated as a ratio of foams density (ρ_f) and the density of aluminium alloy (ρ_s) [17].

$$\rho = \frac{\rho_f}{\rho_s} \tag{1}$$

3. RESULTS

Table 2 shows the results of the calculated relative density. It can be seen that the density of compacted samples is higher in comparison with extruded samples. The main reason is the higher percentage of $CaCO_3$ in the extruded samples. In comparison with the previous research [16], relative densities are as low as 0,26. The important difference between these two analyses is the addition of Zn as a stabilizing agent.

It can be concluded that Zn promotes higher expansion, even though the amount of foaming agent is very low at just 3%. There is a small difference in relative density comparing two alloys A360 and AA 7075 with the same temperature and time of foaming. Because of the higher decomposition temperature of $CaCO_3$, different liquidus temperatures of aluminium alloys are not an influencing factor in the process.

From Table 2 it can be concluded that foams with the addition of CaO have the highest density of extruded samples. Because of that, this stabilizing agent was not used in the process of compaction. High relative densities with CaO can be attributed to the high oxide level in the material during foaming that prevents foam expansion. Oxides help to stabilize the foams, but in this process, they are already present after the decomposition of calcium carbonate into CO_2.

Table 2. Relative density

Sample number	Process	Alloy	Foaming and stabilizing agent	Foaming temperature (°C)	Foaming time (min)	Relative density
1	Extrusion	A360	5% $CaCO_3$ + 2% Zn	800	15	0,26
2	Extrusion	AA 7075	5% $CaCO_3$ + 2% Zn	800	15	0,286
3	Extrusion	A360	5% $CaCO_3$ + 2% CaO	800	15	0,41
4	Extrusion	AA 7075	5% $CaCO_3$ + 2% CaO	820	15	0,39
5	Extrusion	A360	5% $CaCO_3$ + 2% Zn	820	15	0,337
6	Extrusion	AA 7075	5% $CaCO_3$ + 2% Zn	820	15	0,289
7	Compaction	A360	3% $CaCO_3$ + 2% Zn	800	20	0,442
8	Compaction	AA 7075	3% $CaCO_3$ + 2% Zn	800	20	0,53

Comparing samples 1 and 5 which are made of A360, it can be concluded that higher density is achieved when using a higher temperature of 820 °C. The reason for this can be the coagulation of foams at higher temperatures and the same foaming times, Figure 1.

Similar results are found in samples 2 and 6 even though this difference is far lower. At lower temperatures, sample 2 with AA 7075 has a higher relative density than sample 1. When comparing samples foamed at a higher temperature, the opposite was observed. This can be due to the end of the expansion of A360 at a lower temperature. After that, foam coagulates and leaks, and the density rises.

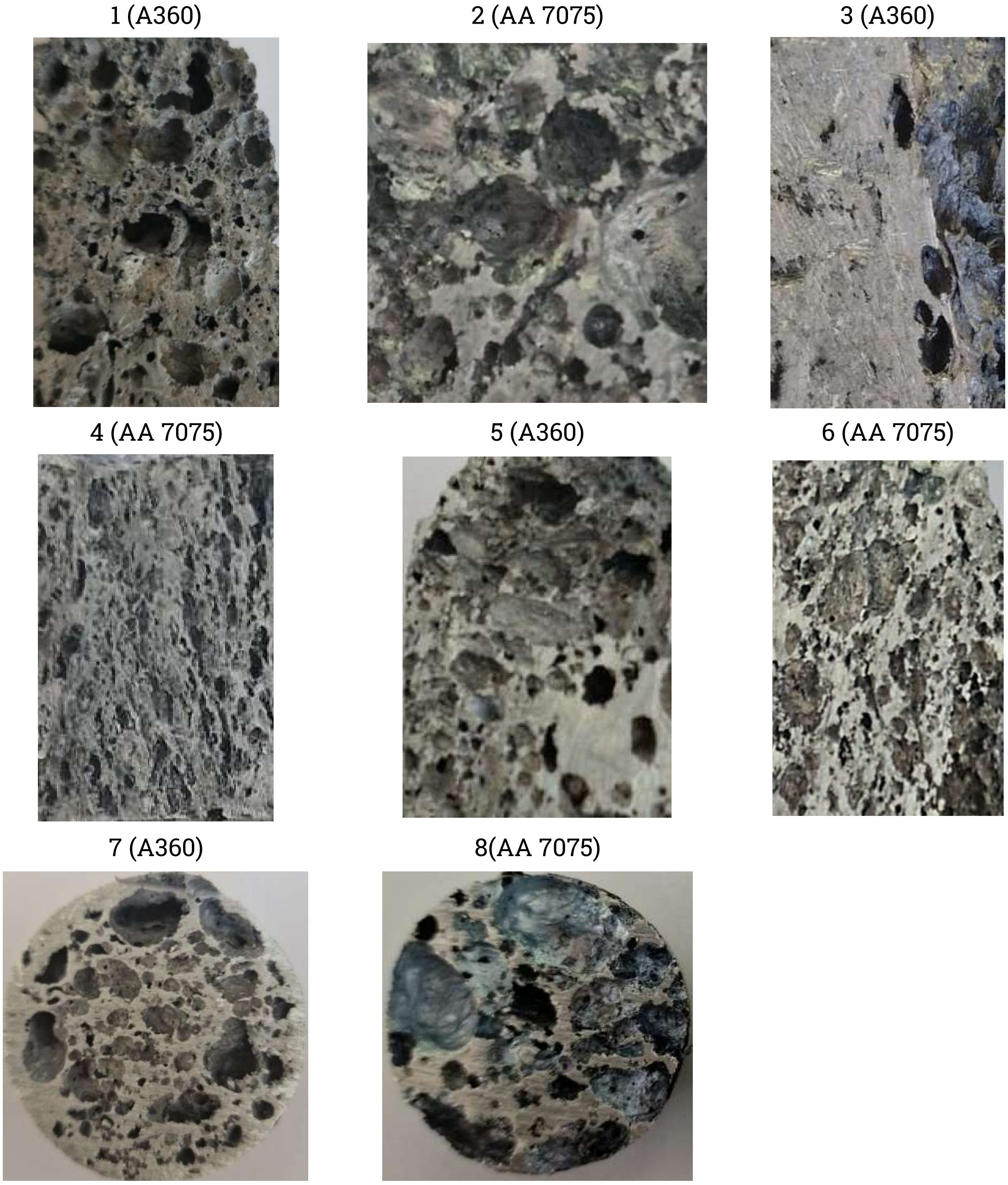
1 (A360)
2 (AA 7075)
3 (A360)
4 (AA 7075)
5 (A360)
6 (AA 7075)
7 (A360)
8(AA 7075)

Figure 1. Structure of samples

Sample 4, made with CaO, has a structure that is horizontal with the foaming direction. This foam has no rounded and homogenous pores 1. It is also similar to sample 3 which has only a few larger pores directed in the same way as sample 4. Because of this inhomogeneous structure of foams, CaO was not used as a stabilizer for the compacted samples. As it was mentioned previously, calcium carbonate decomposes to CO_2 and the addition of CaO raises the viscosity of samples. Generally, oxides to one limit act as stabilizing agents, however, the viscosity in this sample is too high and prevents grow of foams.

Samples with zinc as a stabilizing agent have more rounded pores and structure that is not directed in one way. The first sample has the most homogenous structure out of the extruded samples. It can be concluded that A360 is more convenient for foaming with this stabilizing and foaming agent than AA 7075. That is confirmed by Figure 1, where samples 1, 5, and 7 have a more rounded structure. Samples 7 and 8 have rounded pores that are not directed.

A more uniform structure was obtained due to a lower concentration of $CaCO_3$. Several larger pores can be related to powder accumulation at the beginning of the process.

4. CONCLUSION

In this paper production of aluminium foams using various production processes and stabilizing agents were analyzed. Aluminium A360 and AA 7075 chip waste were used in the foaming process together with $CaCO_3$ as a foaming agent. Additionally, Zn and CaO were used as stabilizing agents. Analyzing the pores and relative densities of the produced foams, the following was concluded:

- Samples with CaO had an inhomogeneous structure that is related to higher oxide levels in the foam. Oxides act as stabilizers, but with a higher percentage, they raise the viscosity and prevent expansion.
- Zinc helps to stabilize the foams, and using this agent pores are more rounded than in samples 3 and 4 with CaO.
- Foams 7 and 8 had the highest density because of the lower $CaCO_3$ percentage. Rounded pores were also observed.
- The higher temperature of foaming leads to higher relative density. That can relate to an increase in pore diameter which can cause coagulation and leakage.
- At lower temperatures, sample 1 with A360 has a lower density than sample 2 with AA 7075, and at higher temperatures, there is a higher density with A360 foam.

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Conflicts of Interest

The authors declare no conflict of interest

5. References

[1] M. F. Ashby, A. Evans, N. A. Fleck, L. J. Gibson, J. W. Hutchinson, H. N. Wadley, Metal foams: a design guide, Vol. 23, No. 1. 2002

[2] E. Prados Martín, Microstructural parameters affecting the compressive response of closed-cell aluminum foams, *Mech. Adv. Mater. Struct.*, 0(2021) 0, p. 1–20, doi: 10.1080/15376494.2021.1872747

[3] H. Ali, A. Gábora, M. A. Naeem, G. Kalácska, T. Mankovits, Effect of the manufacturing parameters on the pore size and porosity of closed-cell hybrid aluminum foams, *Int. Rev. Appl. Sci. Eng.*, 12(2021) 3, p. 230, doi: 10.1556/1848.2021.00262

[4] A. Bisht, B. Gangil, Structural and physico-mechanical characterization of closed-cell aluminum foams with different zinc additions, *Sci. Eng. Compos. Mater.*, 25(20178) 4, p. 789–795, doi: 10.1515/secm-2016-0307

[5] R. Karuppasamy, D. Barikm, Production methods of aluminium foam: A brief review, *Mater. Today Proc.*, 37,/(2020) Part 2, p. 1584–1587, 2020, doi: 10.1016/j.matpr.2020.07.161

[6] D. P. Papadopoulos, H. Omar, F. Stergioudi, S. A. Tsipas, N. Michailidism, The use of dolomite as foaming agent and its effect on the microstructure of aluminium metal foams-Comparison to titanium hydride, Colloids Surfaces, *A Physicochem. Eng. Asp.*, 382(2011) 1–3, p. 118–123, doi: 10.1016/j.colsurfa.2010.12.005

[7] J. An, C. Chen, M;. Zhang,m Effect of CaCO3 content change on the production of closed-cell aluminum foam by selective laser melting, *Opt. Laser Technol.*, 141(2021), p. 107097, doi: 10.1016/j.optlastec.2021.107097

[8] V. Kevorkijan, S. D. Skapin, I. Paulin, B. Sustarsic, M. Jenkom, Synthesis and Characterisation of Closed Cells Aluminium Foams Containing Dolomite Powder As

Foaming Agent, *Mater. Tehnol.*, 44/(2010) 6, p. 363–371

[9] N. Movahedi, S. M. H. Mirbagherim, Comparison of the Energy Absorption of Closed-Cell Aluminum Foam Produced by Various Foaming Agents, *Strength Mater.*, 48(2016) 3, p. 444–449, doi: 10.1007/s11223-016-9783-y

[10] N. Sudharsan, T. Rajasekaran, and G. S. Vinod-Kumar, Optimizing the hot compaction parameters of Al-Mg-Cu foams processed through elemental powder route, *IOP Conf. Ser. Mater. Sci. Eng.*, 402(2018) 1, doi: 10.1088/1757-899X/402/1/012202

[11] H. Wang, D. F. Zhu, S. Hou, D. H. Yang, T. G. Nieh, Z. P. Lu, Cellular structure and energy absorption of Al–Cu alloy foams fabricated via a two-step foaming method, *Mater. Des.*, 196(2020), doi: 10.1016/j.matdes.2020.109090

[12] A. H. Jaafar, H. Al-Ethari, K. Farhan, Modelling and optimization of manufacturing calcium carbonate-based aluminum foam, *Mater. Res. Express*, 6(2019) 8, doi: 10.1088/2053-1591/ab2602.

[13] T. N. Praveen Kumar, S. Venkateswaran, S. Seetharamu: Effect of Grain Size of Calcium Carbonate Foaming Agent on Physical Properties of Eutectic Al–Si Alloy Closed Cell Foam, *Trans. Indian Inst. Met.*, 68(2015) 1, p. 109–112, doi: 10.1007/s12666-015-0631-8

[14] G. S. V. Kumar, F. García-Moreno, J.Banhart, A. Kennedym, The stabilising effect of oxides in foamed aluminium alloy scrap*, Int. J. Mater. Res.*, 106(2015) 9, p. 978–987, doi: 10.3139/146.111255

[15] S. Tsuda, M. Kobashi, N. Kanetake, Producing technology of aluminum foam from machined chip waste, *Mater. Trans.*,. 47(2006) 9, p. 2125–2130, doi: 10.2320/matertrans.47.2125

[16] K. Grgić, B. Lela, S. Jozić, J. Krolom, Aluminium foams made of various aluminium alloys scrap and various foaming agents, 2022, Proc. of 11th Int. Conf. Mechanical Technology and Structural Materials, ed. S. Jozić, B. Lela and N. Gjeldum, [Croatia: Croatian society for mechanical technologies]

[17] M. R. Farahani, H. R. Rezaei Ashtiani, S. H. Elahim, Effect of Zinc Content on the Mechanical Properties of Closed-Cell Aluminum Foams*, Int. J. Met.*, 16(2021) 6, p. 713-722, doi: 10.1007/s40962-021-00635-2.