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Fabrication of aluminum foam from aluminum scrap

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Abstract
In this study the optimum parameters affecting the preparation of aluminum foam from recycled aluminum were studied, these parameters are: temperature, $CaCO_3$ to aluminum scrap wt. ratio as foaming agent, Al2O_3 to aluminum scrap wt. ratio as thickening agent, and stirring time.
The results show that, the optimum parameters are the temperature ranged from 800 to 850^oC, $CaCO_3$ to aluminum scrap wt. ratio was 5%, Al_2O_3 to aluminum scrap wt. ratio was 3% and stirring time was 45 second with stirring speed 1200 rpm. The produced foam apparent densities ranged from 0.40-0.60 g/cm3.
The microstructure of aluminum foam was examined by using SEM, EDX and XRD, the results show that, the aluminum pores were uniformly distributed along the all matrices and the cell walls covered by thin oxide film.

I. Introduction

Aluminum scrap is considered as a permanent resource for recycling because it has resistant to corrosion and the recycling of aluminum requires only 5% of the energy for primary aluminum production [1, 2]. Metal foams are a new class of materials for various engineering applications. The metals foam can be defined as a metallic material with a cellular structure, which has an interesting combination of physical and mechanical properties, such as light weight in conjunction with high stiffness or ultra low weight combining with high thermal insulation withstand elevated temperatures because of their extremely low densities and an outstanding combination of mechanical, acoustic, and thermal properties [1, 3]. First attempt to produce metal foam began in 1943 by Benjamin Sosnick of San Francisco California by melting a mixture of aluminum and mercury as foaming agent in a high pressure chamber [4, 5]. Also, many attempts have been done to produce metallic foam structures; these attempts were not successful, because of their relatively high costs. Furthermore, it was not possible to produce metallic foam with reproducible properties. Problems occurred with a low foamability of the molten metal, the varying size of cellular structures or solidification shrinkage. Recently these issues have been solved by extensive research that has lead to the development of new production technologies. Now, metal foams have become one of the most challenging materials for scientific and industrial investigations [6]. There are two main strategies for making metal foams: The direct foaming methods start from a molten metal containing uniformly dispersed non-metallic particles into which gas is injected to create foam. Alternatively, titanium hydride or zirconium hydride can be added to the melt which then decomposes leading to the same effect but the new trend is using a calcium carbonate or dolomite as a foaming agent. Indirect foaming methods start from a solid precursor which consists of an aluminum matrix containing uniformly dispersed blowing agent particles, mostly titanium hydride. Upon melting this precursor expands and forms foam [7, 8].

The present study aims to investigate the possibility of recycling aluminum and producing aluminum foam in one step from aluminum recycled using calcium carbonate as foaming agent. And alumina as thickening agent for increasing viscosity to help the formation of the produced foam. An attempt to characterize the product foam; macrostructure, mechanical properties.

II. Experimental work

1. Materials

The materials used in this study are:

1.1. Metal: aluminum scrap, such as aluminum cans and the ancient pieces of aluminum that have been used for domestic purposes. The analysis of these scrap are performed using XRF, the results are shown in Table 1:

Table 1 Analysis of aluminum scrap using XRF.

Element,	Fe	Si	Mn	Mg	Ni	Ca	Na	V	Ti	Al
%	0.66	0.12	0.0924	0.0970	0.0075	0.0006	0.0015	0.0066	0.0071	Rem.

1.2. Foaming agent: Calcium carbonate powder ($CaCO_3$) is used as foaming agent, the purity of $CaCO_3$ powder is 99% purity with a size up to 38 µm.
1.3. Thickening agent: Alumina powder (Al_2O_3) with a purity of 99% and size up to 80 µm is used to adjusting the viscosity of the melt.

2. Procedure

Amount of aluminum scrap was weighed and charged in a silicon carbide crucible and inserted into vertical muffle furnace. The temperature of molten metal was adjusted between 750-900^oC. After melting, the layer of oxides on the surface of the molten metal was removed using graphite rod. a sample was taken from molten aluminum for analysis and estimating the efficiency of recycling process, the chemical analysis was done using XRF to determine chemical composition of the recycled aluminum. The molten metal was hold at temperature ranged from 760 to 850^oC and the thickening agent (Al_2O_3 powder) was investigated from 1 to 5% from recycled aluminum and added to molten recycled aluminum. The recycled molten aluminum containing alumina was mixed by stainless steel mixer with stirring speed 1200 rpm to about 30 second then a weighed amount of foaming agent ($CaCO_3$ powder) was added and mixed by stainless steel mixer with the same stirring speed 1200 rpm to about 45 second. After mixing process, the mixing process was stopped and leaved in the furnace to about 3-6 minutes to complete the foaming process, and then the aluminum foam cooled in the air.

The density of sample can be determined by a volumetric method (from the weight and the geometry) [8-11].

Relative density (ρ^*) could be calculated from the ratio of aluminum foam density to dense metal density ($\rho^* = \rho f / \rho s$) [3, 8-13]

The porosity of metal foam can be calculated using the following equation:
Porosity (%) = $(1- \rho^*) \times 100$ [3, 10, 14].

The aluminum foam samples were prepared to the macrostructure and microstructure examination using a wire cutting machine. Thereafter, the prepared specimens were examined by using X-ray diffraction (XRD); scanning electron microscopy (SEM) provided with (EDX).

III. Results and discussion

The results of the efficiency of aluminum recycling from the aluminum scrap are indicated in Fig.1. From Fig.1, the recycling efficiency of aluminum increases with increasing temperature up to 825^oC, then the efficiency decreases with increasing temperature due to the increasing of oxidation with increasing temperature. Table 2: shows the chemical composition of the recycled sample carried out by XRF.

Table 2 Chemical composition of the recycled aluminum

Run	Fe	Si	Mn	Mg	Ni	Ca	Na	V	Ti	Al
Avg.	0.66	0.12	0.0924	0.0970	0.0075	0.0006	0.0015	0.0066	0.0071	Rem.

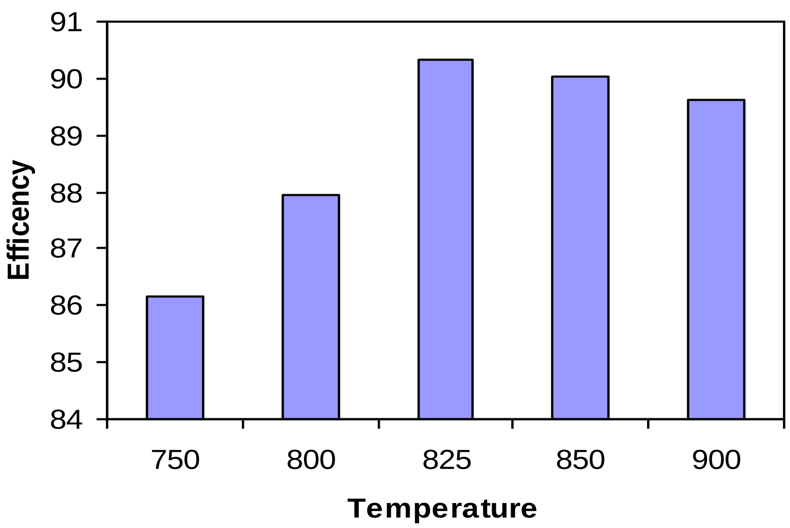

Fig. 1 Relation between temperature and recycling efficiency

Effect of foaming parameters on relative density
Relative density is the main parameter to evaluate the aluminum foam; it can control by adjusting the process parameters, because the main applications of

aluminum foam are in light weight constructions and energy absorption cases [8, 15].

1. Effect of foaming agent ($CaCO_3$)

In this work calcium carbonate ($CaCO_3$) is used as foaming agent in foaming process.

The thermal decomposition of pure calcium carbonate at temperature about 900oC, but, when the calcium carbonate contacting the molten metal, it decompose at temperatures above 700°C, because the molten metal act to reduce temperature of decomposition of calcium carbonate and creation complex chemical reaction which lead to the formation of gaseous phases (CO_2, CO) which act as a foaming catalyst and various solid phases (CaO, Al_2O_3, Al_4C_3) which stabilize the liquid metal suspension by modify the viscosity and surface energy of the molten metal [8, 12].

The effect of calcium carbonate on relative density is shown in Fig. 2, relative density decreases with increasing foaming agent addition ($CaCO_3$) to 5% as clarified in the first part of the curve, because the viscosity of the melt increases with increasing in the foaming agent ($CaCO_3$) that causes increasing in porosity [3]. From the second part of the curve, the relative density increases with increasing foaming agent because at too high viscosity the release of gas from the foaming agent is suppressed and the growth of the bubbles is stopped which lead to decrease the porosity [8].

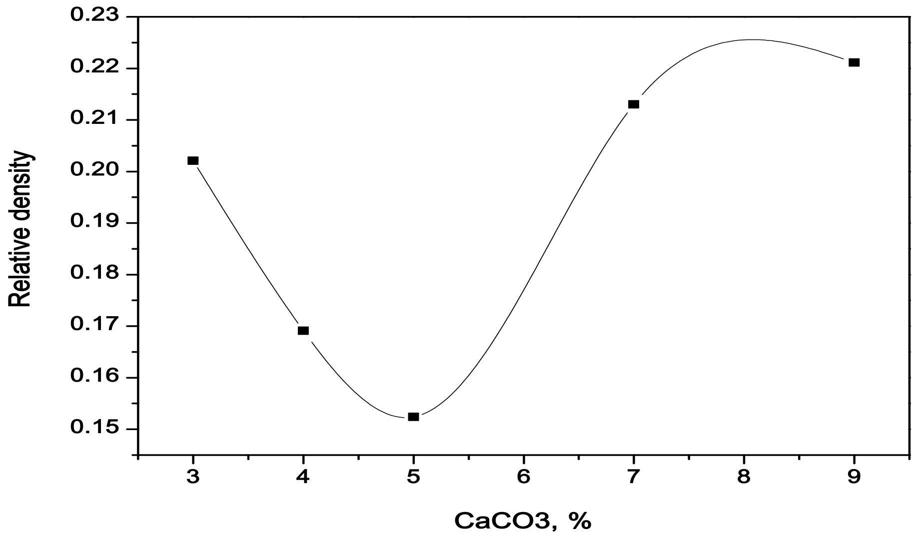

Fig.2 Effect of $CaCO_3$ on aluminum foam density

2. Effect of thickening agent (Al_2O_3)

Alumina (Al_2O_3) can be use as thickening agent in foaming process.

The molten aluminum can be made foam by injecting gases into it, but that not easily because the gas bubbles when will tend to rise to the surface of the molten aluminum due to the high buoyancy forces, this rise is inhibited by the drainage of liquid [1, 8]. So it can use the alumina (Al_2O_3) to prevent this drainage by adjusting the viscosity of the molten metal.

The effect of alumina is showed in Fig.3, when alumina is added with percent from 1-3 % and stirred within the metal, the alumina particles are distributed uniformly within the metal particles, which works to increases the viscosity and decreases the surface energy of the metal and formed oxides metals during foaming process which works to stabilize the gas bubbles and thus the cell wall prevent it from the falling which leads to prevent the bubbles breakage and formation of spherical aluminum foam that leads to decrease the relative density of aluminum foam and that indicated from the first part of the curve in Fig.3. From the second part of the curve the increasing in Al_2O_3 percent lead to increasing the relative density because at too high viscosity reduce the release of gas from foaming agent and the growth of bubbles.

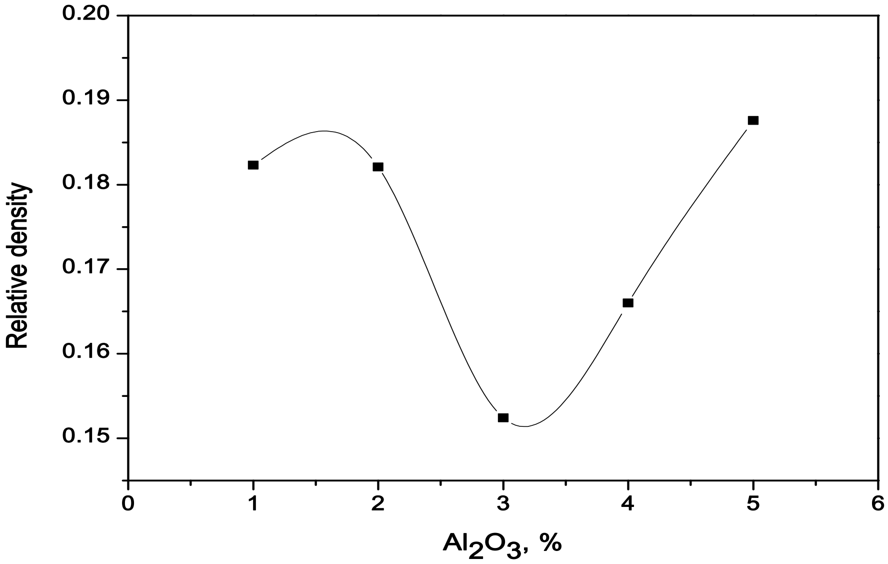

Fig. 3 effect of alumina on relative density

3. Effect of stirring time

Stirring time is the time of stirring of molten metal after adding thickening agent and foaming agent [8].

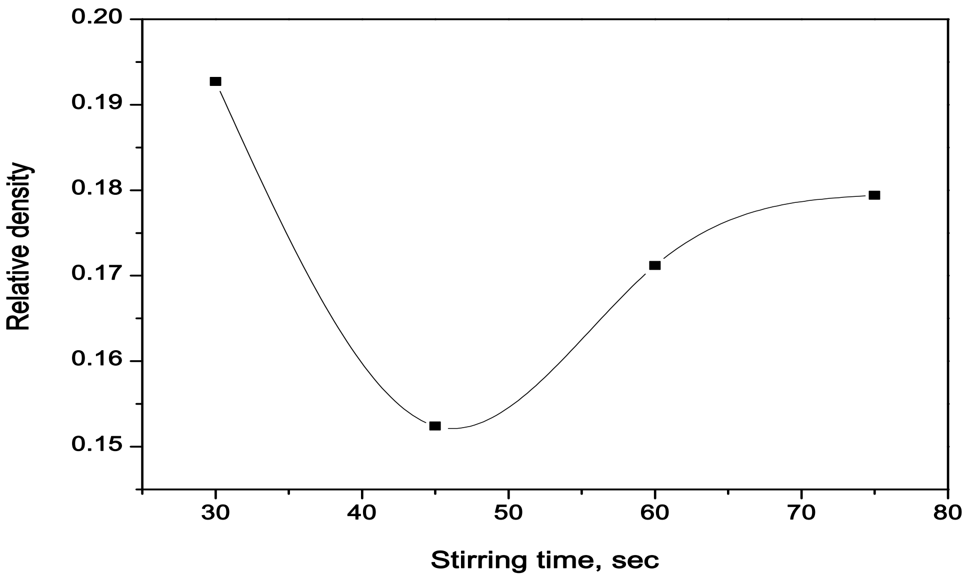

Fig.4 Effect of stirring time on relative density

The effect of stirring time on relative density is shown in Fig.4. From the first part of the curve, the relative density decreases with increasing stirring time to 45 sec, because the stirring works on formation of oxides, which leads to adjust the viscosity of the molten metal and release CO_2 gas and the formation of foam with low relative density. The relative density increases with the continuity of stirring time, this is clarified from the second part of the curve, because the increasing in stirring time leads to too high increasing in viscosity of the melt, that suppresses the release gases from foaming agent and the growth of bubbles.

4. Effect of process temperature

Process temperature is the temperature of foaming process, in this paper is ranging from 750 to 850^{o}C. The effect of temperature on relative density is shown in Fig.5.

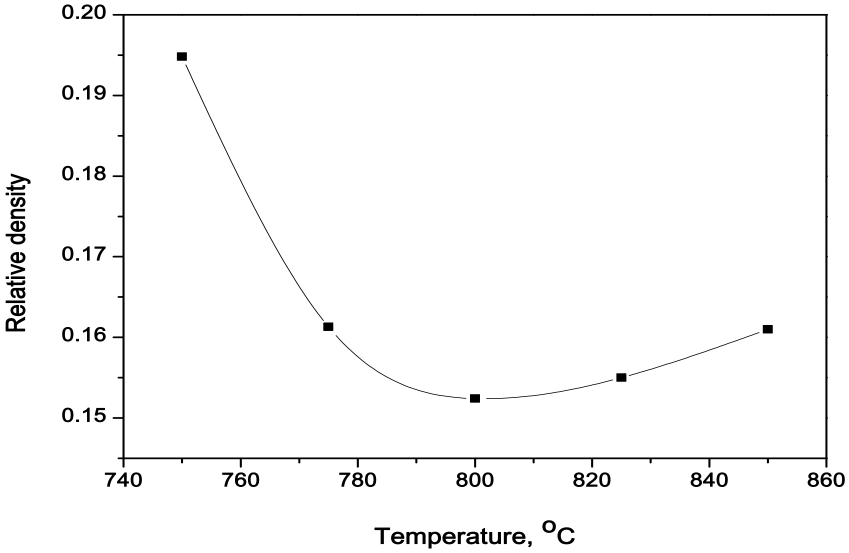

Fig.5 Effect of temperature on relative density

From Fig.5, the first part of the curve showed that, the relative density decreases with increasing temperature to 800^{o}C, because at this temperature the dissociation of $CaCO_3$ leads to the formation of CaO and CO_2 gas which acts as a foaming catalyst and the foam with large porosity are formed, that causes an incremental increase in gas bubbles.

From the second part of the curve, relative density increases with increasing temperature the continuous heating for long time leads to decrease in melt viscosity which causes instability and drainage in cell walls of the metallic foam which results in complete decay of foam feature[3,8,16-18].

Fig.6 shows the cross section of the specimens foamed from the aluminum scrap at optimum conditions, with 5% $CaCO_3$, 3% Al_2O_3, 45 sec as stirring time and 800oC after wire cutting.

Fig.6 Macrostructure of aluminum foam with 5% $CaCO_3$, 3% Al_2O_3, 45 sec stirring time and 800^{o}C after wire cutting.

Fig.6 showed that, the foams have cells of nearly spherical shape, closed and uniformly distributed.
The density was calculated from its dimensions, the density ranging from 0.40-0.60 g/cm3, its relative density was ranging from 0.148-0.222 and the porosity was very high and was between 78% - 85%.
Microstructures of cell walls of the aluminum foam with 5% $CaCO_3$, 3% Al_2O_3, 45 sec as stirring time and 800^oC were examined by SEM. As in Fig.7, The walls of these cells are surrounded by various mixed thin oxides film such as oxides of aluminum, calcium, such as Al-Ca-Mg-Si oxides indicate from EDX analysis in the table 3 and Fig.8 or inter metallic compounds which were formed during the foaming process by the thermal decomposition of $CaCO_3$ during the foaming stage, these oxides are working to stabilize the walls of the cells of the foam at this stage.

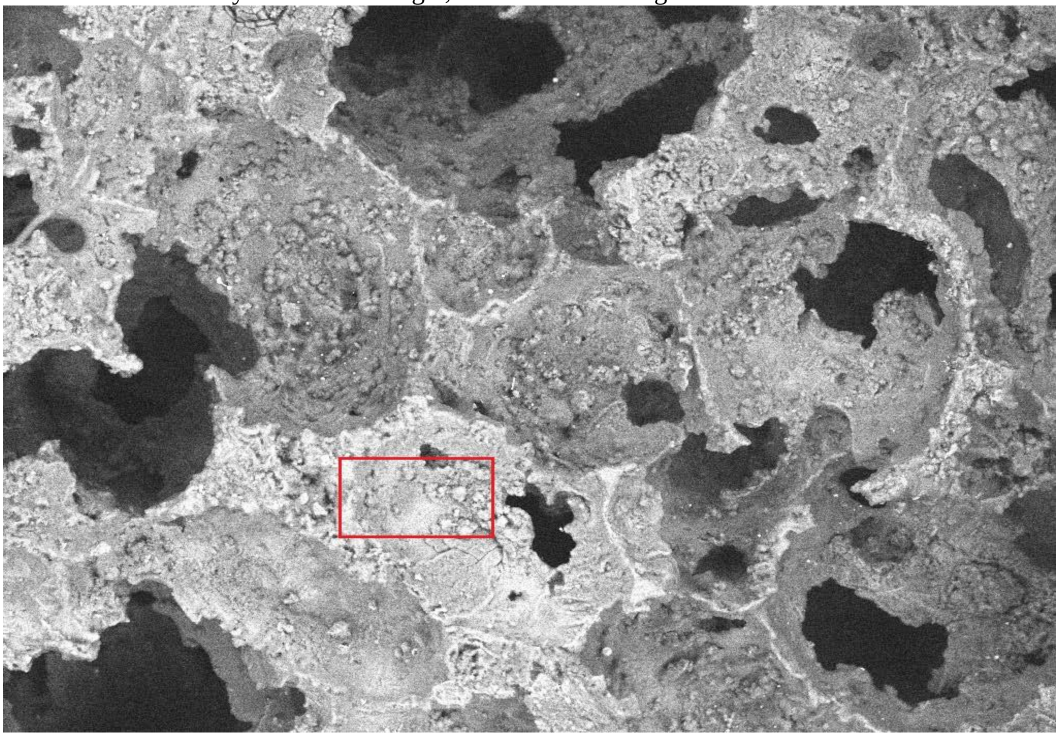

Fig.7 SEM images of cell walls of the aluminum foam with 5 % $CaCO_3$ and 3% Al_2O_3, 45 sec stirring time and 800^oC after wire cutting.

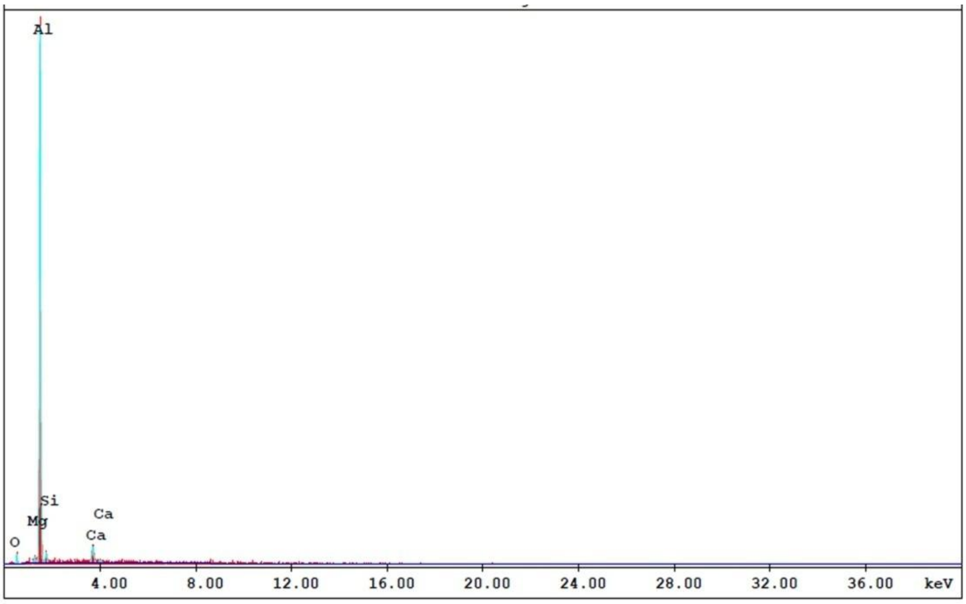

Fig.8 EDX analysis of aluminum foam with 5 % $CaCO_3$ and 3% Al_2O_3, 45 sec stirring time and 800^oC after wire cutting.

Table3 EDX analysis of aluminum foam with 5 % $CaCO_3$ and 3% Al_2O_3

Element	Wt%	At%
O	8.33	13.51
Mg	1.05	1.12
Al	78.78	75.76
Si	7.06	6.53
Ca	4.77	3.09

IV. Conclusion

- Aluminum scrap can be recycled with recycling efficiency up to 90.33% at a temperature of 800^{o}C.
- Aluminum scrap can be foamed at temperature ranged from 800^{o}C to 850^{o}C with 5% of $CaCO_3$ as foaming agent, 3% of Al_2O_3 as thickening agent and stirring time 45 second with stirring speed 1200 rpm.
- Oxides formed are working to stabilize the foam during foaming process.
- The density of foamed aluminum ranging from 0.40-0.60 g/cm3, with very high porosity and was between 78% - 85%.

References

[1] Won Ha, Shae K. Kim and Young-Jig Kim, A New Aluminum Recycling Process for High Performance Foam Materials, Light Metals, Sungkyunkwan University, Korea, 2002.

[2] G.O. Verran , and U. Kurzawa, An experimental study of aluminum can recycling using fusion in induction furnace, Resources, Conservation and Recycling, Brazil, 52, 2008, 731-736.

[3] Nawal E. Abdullatef, Adel Mohammad Jaber, Preparation of Al-12Si Foam Using Liquid Technique, Eng. And Tech. Journal, Baghdad, 27 (12), 2009, 2479- 2493.

[4] A. K. Shaik dawood and S. S. Mohamed Nazirudeen, A Development of Technology for Making Porous Metal Foams Castings, Jordan Journal of Mechanical and Industrial Engineering, 4(2), 2010, 292-299.

[5] John Banhart and Denis Weaire, On the road again: metal foams find favor, American Institute of Physics, PHYSICS TODAY, 2002, 37-42.

[6] Biljana Matijašević-Lux, Characterization and Optimization of Blowing Agent for making Improved Metal Foams, PhD Thesis, Faculty III, Process Sciences, Technical University of Berlin, 2006.

[7] J. Banhart, Industrialisation of Aluminium Foam Technology, Proceedings of the 9th International Conference on Aluminium Alloys, Institute of Materials Engineering, Australasia, 2004.

[8] Refaie A. Sharkawi, Studies on the aluminum foam production and characterization, Msc thesis, Assiut University, Egypt, 2011.

[9] John Banhart, Manufacturing Routes for Metallic Foams, journal of metals, 52(12), 2000, 22-27.

[10] Varužan Kevorkijan, low cost aluminum foams made by CaCO3 particulates, MJoM, Association of Metallurgical Engineers, Serbia, 16 (3), 2010, 205-219.

[11] YU Hai-jun, YAO Guang-chun, and LIU Yi-han, Tensile property of A1-Si closed-cell aluminum foam, Trans. Nonferrous Met. SOC., China, 16, 2006, 1335-1340.

[12] CAO Xiao-qing, W ANG Zhi-hua, MA Hong-wei, ZHAO Long-mao, and YANG Gui-tong, Effects of cell size on compressive properties of aluminum foam, Trans. Nonferrous Met. Soc. China, 16, 2006, 351-356.

[13] Wang Zhihua, Ma Hongwei, Zhao Longmao, and Yang Guitong, Studies on the dynamic compressive properties of open-cell aluminum alloy foams, Scripta Materialia, China, 54, 2006, 83-87.

[14] M. Malekjafarian, S.K. Sadrnezhaad, M.S. Abravi, M. Golestanipour and H. Amini Mashhadi, Manufacturing Aluminum Foams by Melt Gas Injection Process, 7th International Conference on Porous Metals and Metallic Foams, Iran, 2011, 195-202.

[15] John Banhart, Aluminium foams for lighter vehicles, int. J. Vehicle Design, 37(2/3), 2005, 114-125.

[16] John Banhart: "Manufacture, characterisation and application of cellular metals and metal foams, Progress in Materials Science, 46, 2001, 559-632.

[17] John Banhart, Metal Foams: Production and Stability, Advanced Engineering Materials, 8(9), 2006,781–794.

[18] C.C. Yang, and H. Nakae, Foaming characteristics control during production of aluminum alloy foam, Journal of Alloys and Compounds, 313, 2000, 188-191.