doi:10.4028/www.scientific.net/KEM.594-595.780

EFFECT OF ORGANIC SPACE HOLDER IN FABRICATION OF CLOCED-CELL ALUMINIUM FOAM

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Keywords: Aluminium Foam; Carbamide; Sintering; Mechanical properties

Abstract :. In this work, the closed-cell aluminium foams were fabricated via powder metallurgy route with organic space holder which also known as carbamide (urea). Carbamide was added with aluminium powder at different compositions from 50wt% to 70wt%. Then the influences of sintering temperatures were also investigated at 500°C, 550°C and 600°C. Physical and mechanical tests were conducted on the fabricated closed cell aluminium foam samples. The result showed that the porosity inversely proportional with density, that means the porosity decreases as the density of the foam increased. Also, it was revealed that the highest compressive strength was obtained at sintering temperature of 550°C. However, the compressive strength of the closed-cell aluminium foam decreased at the sintering temperature of 600°C. This is due to the occurrence of oxidation problem. It can be concluded that carbamide can be proposed as one of the organic space holder material in the fabrication of closed–cell aluminium foam. Then, the experimental parameters such as sintering temperature, type of space holder and composition gave great influence to the mechanical and physical properties of the fabricated closed-cell aluminium foam.

Introduction

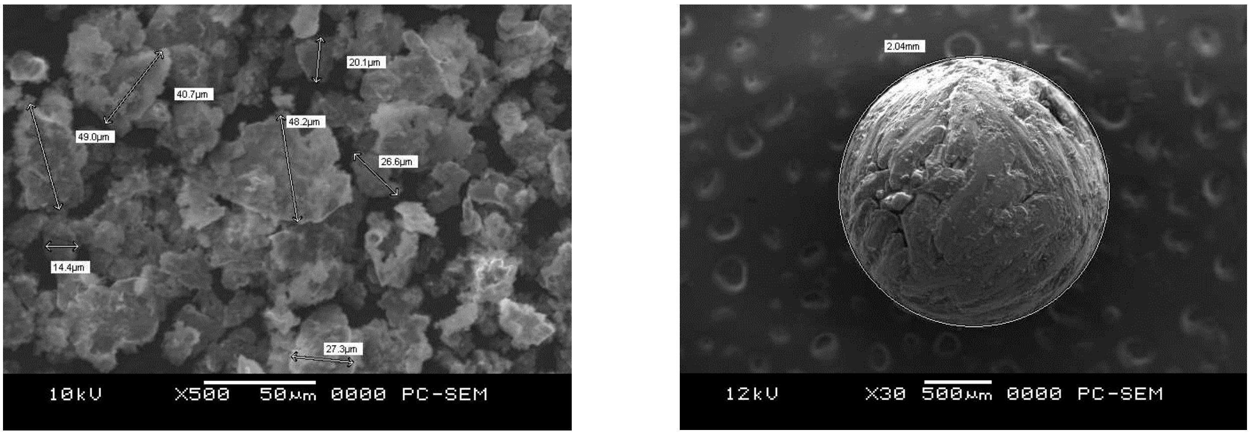
Metal foam is identified as a new group of materials of great interest due to their unique combinations of properties derived from their cellular structure and metallic behaviour[1,4].. The cells of aluminium foam can be categorised as either closed or open cell. Closed cell aluminium foam has a higher modulus, strengths and impact energy absorption as compared to open cell aluminium foam [1]. Moreover, closed-cell aluminium foams have a broad range of applications due to their fire resistance, vibration damping and noise reduction properties; and cost efficiency [2].

There are several methods in fabrication of closed cell aluminium foam such as investment casting and powder metallurgy method. Normally, powder metallurgy method was chosen since it was widely used to produce sample of aluminium foam. The powder metallurgy method involves three main stages: (i) powder preparation and mixing, (ii) compacting and (iii) sintering [3].
The aluminium can be foamed by using space holder materials. However, it is crucial for the fabrication of aluminium foam to account the type of space holder used in order to obtain higher strength and low density foam properties. Also, the space holder materials must be having low melting point than aluminium [4]. In this work, carbamide ($(NH_2)_2CO$) as an organic space holder material was introduced in fabrication of aluminium foam.

Experimental Procedure

Materials and sample preparation : Aluminium powder with purity of 97% was used in fabrication of aluminium foam. For organic space holder, carbamide particle size was 2.04mm. *Differential Thermal Analysis* was carried out on carbamide and revealed its melting temperature was at 132°C, which about similar result found with previous researcher [5].

Fig. 1 and Fig.2 show the aluminium powder and carbamide morphologies observed by a *Scanning Electron Microscope* (JEOL-JSM6380LA).



(a) (b)

Fig. 1: Morphology Observation via SEM (a) aluminium powder and (b) carbamide

For sample preparation, aluminium powder was firstly mixed with carbamide in a planetary ball mill (*Fritsch Planetary Mono Mill Pulverisette*) for two hours (100 RPM). After mixing process the powder was placed into cylindrical mould (d = 13mm, h = 100mm) and pressed using *Carver Hand Press* machine. Later, the compacted powders were sintered at 500 ºC, 550 ºC, and 600 ºC in the higher temperature furnace. The sintering time was set for 120 min with heating and cooling rate of 5°C/min. The weight ratio of aluminium powder to carbamide and sintering temperature selected in this study is shown in Table 1.

Table 1: Weight ratio of aluminium to carbamide and sintering temperature

Aluminium (wt%)	Carbamide (wt%)	Sintering Temperature (ºC)
30	70	500
40	60	550
50	50	600

Density and porosity test: One of most important criteria in fabricating of foam material is their density and porosity values. The foam density usually varies from 0.07 to 1 g/cm^3, which provides a relative density (i.e., the density of the foam relative to the density of its solid material) ranging from 0.02 to 0.35 [6].

The *Mettler Toledo* machine was used to measure the density, ρ and porosity, η of sintered foam sample. Eq. 1 and Eq. 2 were applied to obtain the results for density, ρ and porosity, η respectively [7].

$$\rho = \frac{w_d}{w_w - w_s} \tag{1}$$

$$\eta = \frac{w_w - w_d}{w_w - w_s} \tag{2}$$

where

w_d is dry weight of the sample
w_w is weight of the sample after immersed in the water
w_s is weight of the sample when suspended in the water

Uniaxial compression test : The mechanical properties of aluminium foam have been mostly investigated using uniaxial compression testing [8-12]. Therefore, the similar method of testing was used to obtain the compressive strength, σ from *Universal Testing Machine* (Shimadzu – AG1). This machine recorded the load and displacement of each sample. Crosshead speed was fixed at 0.5mm/min in order to allow cell collapsed and ruptured gradually.

Result and Discussion

Density and Porosity: It can be seen clearly in Fig. 2 that the density, ρ of aluminium foam decreases as the sintering temperature and percentage of carbamide increased. This signifies that carbamide evaporated and created empty space or pores in the aluminium sample. Also, it was recognized that the reaction of carbamide more significantly at higher temperature and this condition led to a lower density, ρ properties. Basically, the density, ρ is inversely proportional with the porosity, η that means denser material consists of small amount of pores. Fig. 3 represents the result of porosity, η at different sintering temperature and percentage of carbamide. It shows that the higher porosity was obtained at higher sintering temperature with higher content of carbamide particles. This confirmed that sintering temperature and contribution of carbamide give great influenced in fabricating closed cell aluminium foam.

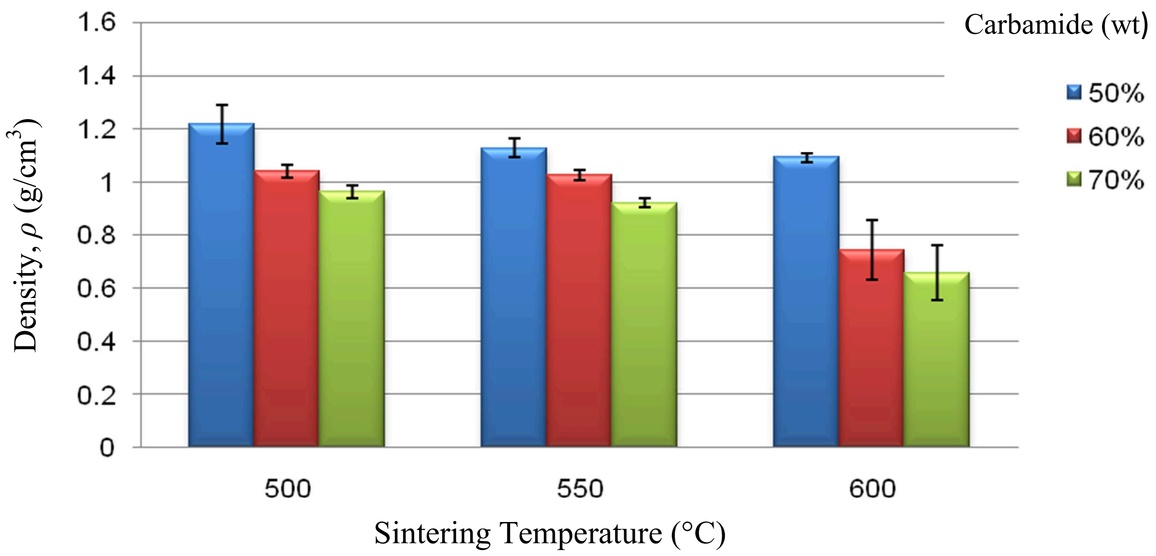


Fig. 2 Density of aluminium foams at different sintering temperature

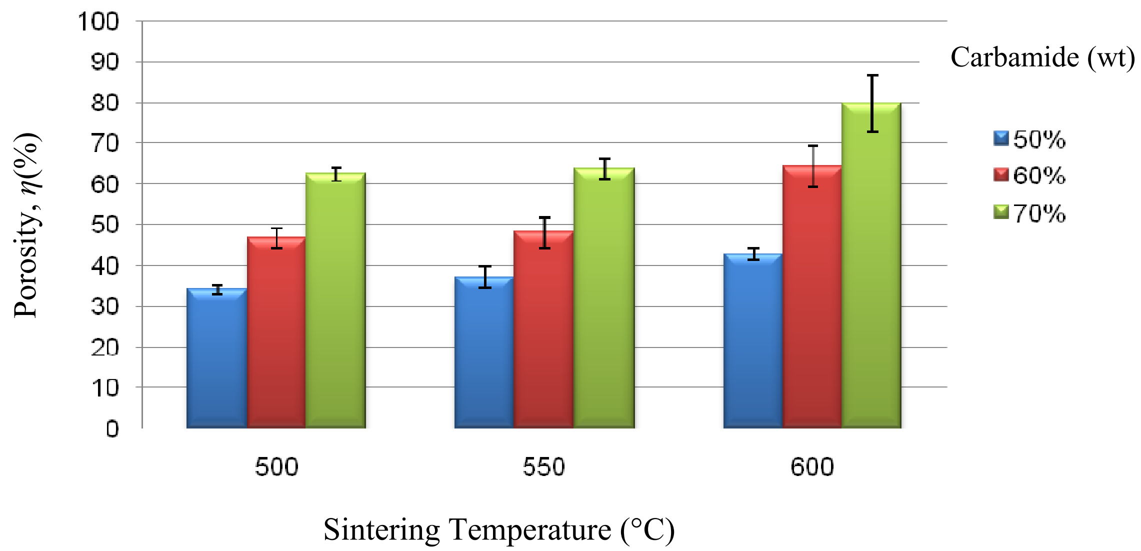


Fig. 3 Porosity of aluminium foams at different sintering temperature

Compressive strength : The result from unixial compression test on fabricated closed cell aluminium foam ranges from 1.8 MPa to 5.5 MPa (Fig.4). It was obviously shown that the compressive strength of fabricated aluminium foam was lowest at sintering temperature of 500°C as compared to the other sintering temperature. This particular behaviour was revealed by Jiang *et al.* (2005) when they found that the bonding between aluminium particles was not satisfied and gave lower mechanical properties if the sintering temperature was below 550°C. The quality of aluminium foam was mostly preferable at the sintering temperature above than 550°C [11]. Therefore, the highest compressive strength, σ was found at sintering temperature of 550°C with weight percentage of carbamide is 50%. It seems showed that the higher weight percentage of carbamide decreases the strength of aluminium foam. This may be due to the existence of many pores weaker the total strength of the sample. Moreover, it was also realized that the compressive strength, σ decreases as the sintering temperature increased. This trend can be seen at the sintering temperature of 600°C. It was believed that the occurrence of oxidation process at higher temperature produced aluminium oxide. This oxide weakens the cell wall and as a result reduced the strength of the aluminium foam

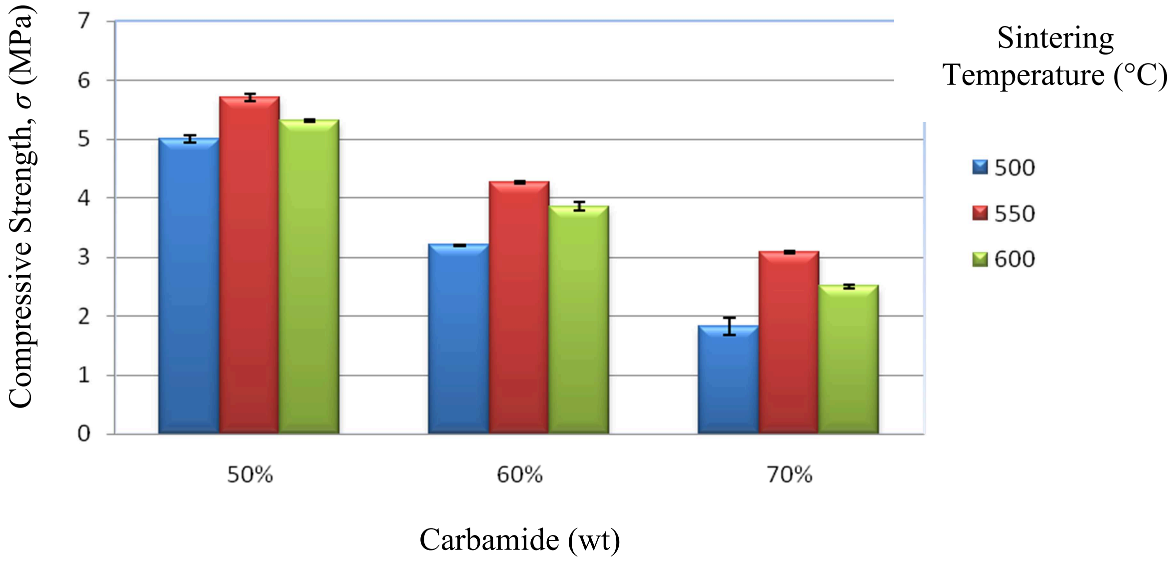
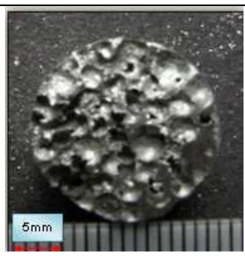
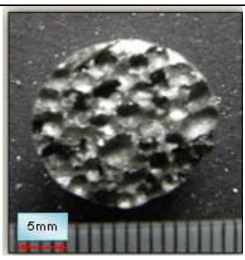


Fig. 4 Compressive strength, σ of aluminium foams at different percentage of carbamide

Micro and Macrostructures : The microstructure of aluminium foam was examined and it was clearly shown the formation of pores from the evaporation of carbamide. Then, the cross-section of aluminium foam at different percentage of carbamide and sintering temperature is exhibited in Table 2. It can be concluded that the mixing process between aluminium powder and carbamide at earlier stage resulted in uniform formation of pores in the aluminium foam.

Table 2: Cross section macrostructures of aluminium foam at different percentage of carbamide and sintering temperature

Sintering Temperature (°C)	**Percentage of Carbamide (wt%)**		
	50	**60**	**70**
500			
550			
600			

Conclusion

In this study, it was found that the carbamide as an organic space holder was capable to fabricate aluminium foam. Furthermore, following were concluded:

(i) Higher weight percentage of carbamide formed lower density of aluminium foam
(ii) Higher possibility of oxidation process occurred at higher sintering temperature
(iii)Compressive strength reduces as the sintering temperature and carbamide content increased

Acknowledgements

The authors would like to thank Universiti Tun Hussein Onn Malaysia and Ministry of Education for financial support.

References

[1]I.Ch. Konstantinidis, G.Paradisiadis, and D.N. Tsipas : Theor Appl Fract Mec (2009) Vol.51: 48-56

[2]M. I. Idris, T. Vodenitcharova and M. Hoffman : Mater. Sci. Eng. A., Vol. 517 (2009), p 37-45

[3] C.J Yu, H.H. Eifert, J. Banhart, and J. Baumeister : Mater Res Innov (1998)181-188

[4] R. Surace, L.A.C. De Filippis, A.D. Ludovico, and G.Boghetich: Mater Design, Vol.30 (2009) p 1878-1885

[5] Hasan Bafti and Ali Habibolahzadeh: Mater Design, Vol.31 (2010) p4122-4129

[6]M. F. Ashby, A.G. Evans, N. A. Fleck, L. J. Gibson, J. W. Hutchinson and H. N. G. Wadley : Metal Foams: A Design Guide (Butterworth-Heinemann, 2000).

[7] P. L. Mangonon: The Principle of Materials Selection for Engineering Design (Prentice Hall, Inc., 1999)

[8] Y.Sugimura, J. Meyer, M. Y He, H. Bart-Smith, J. Grenstedt and A.G. Evans: Acta Mater,Vol.45(1997) p 5245-5259

[9]E. W. Andrews, W. Sanders and L. J. Gibson: Mater. Sci. Eng. A., Vol. 270 (1999), p 113-124.

[10] U. Ramamurty and A. Paul : Acta Mater, Vol.52, (2004) p 869-876..

[11] B. Jiang, N.Q. Zhao, C.S. Shi, X.W. Du, J.J. Li, H.C. Man : Mater Lett Vol 59 (2005) p 3333-3336

[12] T. Vodenitcharova, M. I. Idris and M. Hoffman : Mater. Sci. Eng. A., Vol. 527 (2010), p 6033-6045