World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:9, No:7, 2015

Deformation of Metallic Foams with Closed Cell at High Temperatures

Emrah Ersoy, Yusuf Özçatalbaş

***Abstract*—**The aim of this study is to investigate formability of Al based closed cell metallic foams at high temperature. The foam specimens with rectangular section were produced from AlMg1Si0.6TiH$_2$0.8 alloy preform material. Bending and free bending tests based on gravity effect were applied to foam specimens at high temperatures. During the tests, the time-angular deformation relationships with various temperatures were determined. Deformation types formed in cell walls were investigated by means of Scanning Electron Microscopy (SEM) and optical microscopy. Bending deformation about 90° was achieved without any defect at high temperatures. The importance of a critical temperature and deformation rate was emphasized in maintaining the deformation. Significant slip lines on surface of cell walls at tensile zones of bending specimen were observed. At high strain rates, the microcrack formation in boundaries of elongated grains was determined.

***Keywords*—**Al alloy, Closed cell, hot deformation, metallic foam.

I. Introduction

ALTHOUGH fabrication techniques of porous metals or metallic foams were widely reported, studies on plastic working and metal forming of the materials have been limited [1]-[3]. Forming the foam material was not a preferable situation until nowadays due to the defects encountered frequently in its structure [4]. The solution of this problem is formalizing the foam material under high temperature. Thus, formability and deformation limits increase while shear stress decreases under high temperature [5]. Utsunomiya H. and Matsumoto R. indicated that deformation process of porous metals and metallic foams is advantageous for future industrial applications. Studies on deformation processes are demanded to widen applications. The forming process seems to be an obligation to have forming with undamaged foam structure; therefore a process window must be detected that considers such parameters such as the forming force, temperature as well as the forming velocity [1].

The purpose of this study is to determine formability of foam materials produced from preform material at high temperatures by applying bending test and free bending test with the effect of gravity.

E. Ersoy was a student in University of Gazi, Graduate School of Natural and Applied Science, Ankara, Turkey (e-mail: emrahersoy06@gmail.com). He is now with a manufacturing company in Ankara, Turkey.

Y. Ozcatalbas is with Gazi University, Technology Faculty, Metallurgical and Materials Engineering Department, 06500 Ankara, Turkey (e-mail: yusufoz@gazi.edu.tr).

II. Materials and Method

In the experimental study, AlMg1Si0.6TiH$_2$0.8 alloy preform material with dimensions of 5x20x200mm was used.

Fig. 1 Longitidunal section of Al alloy foam specimen

Preform material was foamed in dimensions of 17x22x200mm at furnace temperature. Foam specimens were produced with cell aspect ratio of 1.09 in the density of 0,7g/cm^3 (Fig. 1). Firstly, metallic foam specimens were subjected to bending tests by applying force from outside of furnace by means of bending test apparatus mounted to foaming furnace shown in Fig. 2. Bending tests were performed at 600, 625 and 640 °C and bending force was applied to the edge of the specimen placed on bending cylinder by the load arm with 0.01, 0.1 and 1< mm/sec rates. By using thermocouple, which was in contact with specimen, specimen temperatures were kept under control.

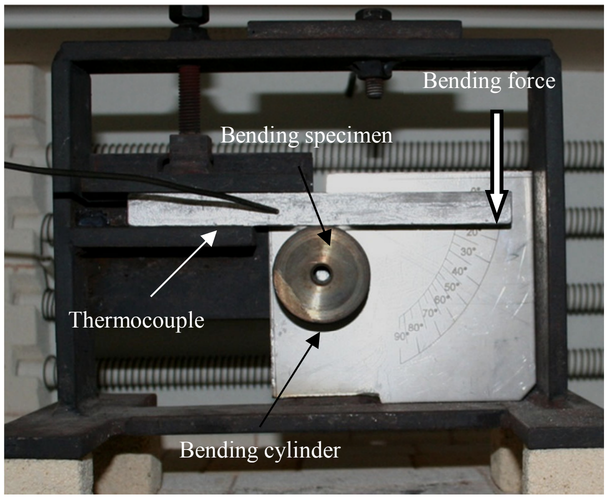


Fig. 2 Bending test apparatus

Procedures of free bending test with the effect of gravity were performed in the same apparatus illustrated in Fig. 2. Center of specimen was placed as overlapping with center of the bending cylinder ø50mm. Thus, bending inner diameters of the specimens, which were bent, remained the same. An angular scale which determines the angular deformation (bending) was placed in the back of specimen. In this way, angular deformation of specimens according to time was determined. Free bending tests were performed at 635, 640, 645, 650 and 656°C maximum temperatures for maximum 75 minutes.

III. Experimental Results and Discussion

Microstructure of cell wall with equiaxed grain of produced foam specimen was shown in Fig. 3.

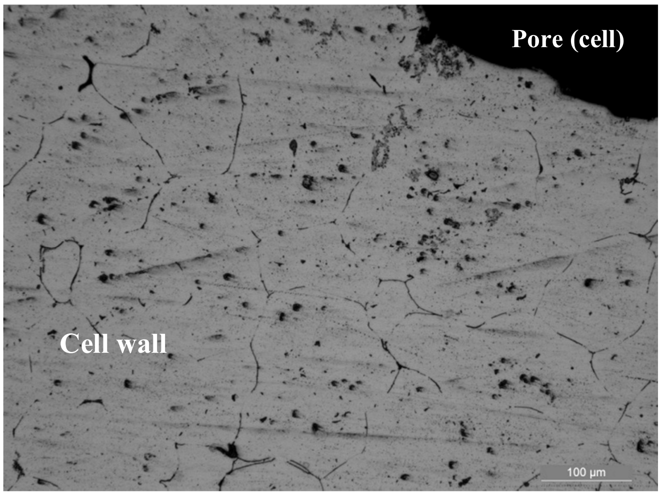


Fig. 3 Microstructure of cell wall of foam material (Etched with Tucker's)

In free bending test, specimens were placed in the apparatus in room temperature and angular deformation was measured based on time when they reached to bending temperatures. Moment effect occurring in bending point of specimen decreased with the increase in angular deformation. Generally angular deformation increases within 60 min as the deformation temperature increases. The increase of deformation temperature increased angular deformation in short times. During emergence of form change; tension has occurred in the upper side of material while a compression behavior was observed in its lower part. It is clearly seen that as long as the deformation temperatures increased, the cells got deformed with the effect of elongation and contraction as a result of being exposed to deformation in the direction of tension and compression without having any crack and as being compatible with each other.

Table I illustrates the effect of temperature and time on angular deformation of the specimen on which free bending was performed in different temperatures. It shows the increase in deformation based on time and temperature. In addition, it was determined that deformation rate in unit of time also increased with the increase in temperature. The increase in temperature and time provided maximum angular deformation with 82° angle.

TABLE I
Deformation Properties of Free Bending Specimens

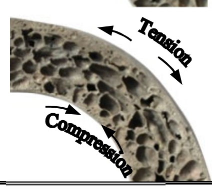
Deformation temperatures (°C)	Deformation time (min)	Angular deformation (°)	Cell aspect ratio in		Deformation zone macrograph
			Tensile zone	Comp. zone	
635	60	15	1.01	0.98	
640	64	26	1.04	1.00	
645	65	47	1.47	0.97	
650	64	67	1.49	0.90	
656	75	82	1.82	0.90	

Fig. 4 The specimen, on which free bending was performed in 656°C

Fig. 4 illustrates maximum angular deformation of 82° in the specimen on which free bending process was applied in 75 min waiting time and in 656°C temperature. An increase in the length of the specimen was also observed at the end of deformation applied at high temperature. In addition, as well as cell orientation along the direction of tensile deformation was observed. The cell deformation effects seen in the specimen in 650°C and 656°C were also observed in these specimens and cells changed their shapes as elongation in areas of tensile stress and contraction in cell dimensions in areas of compressive stress. Form change which occurred without crack in these free bending tests performed at high temperature could be explained with grain boundary sliding mechanism. As indicated erlier, typical grain boundary sliding behavior is observed both in metallic foams and bulk materials [6], [7].

Fig. 5 shows SEM micrograph from compressive zone of the bended specimen in 656°C. It can be seen that closing of the biggest cell and plication in the cell walls (arrowed in the interrupted circles) due to compressive effect of bending.

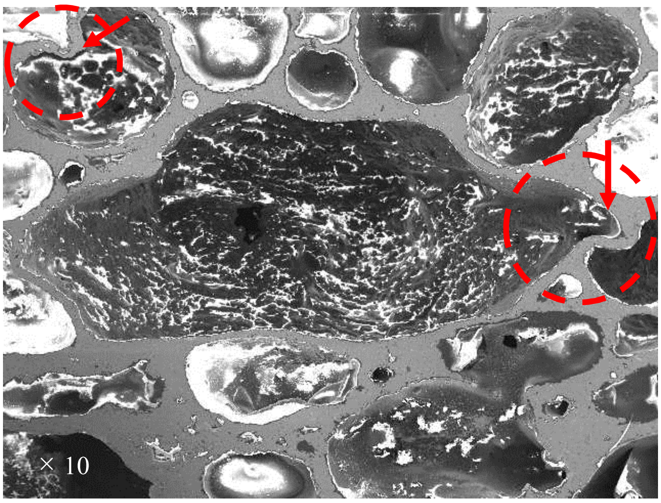


Fig. 5 Compressive strain of the cells in compression region at higher temperature

In tensile region of the specimen bended in 656°C, it can be seen that elongated cells in direction of tensile and slip line paths, parallel to the tensile direction, on the inner surface of cells. Also, especially cell wall thickening in the upper side of the bending specimen is remarkable. In this zone, it is possible that cells close to upper side shrink by elongating and increase the wall thickness by closing (showed between two interrupted lines in Fig. 6).

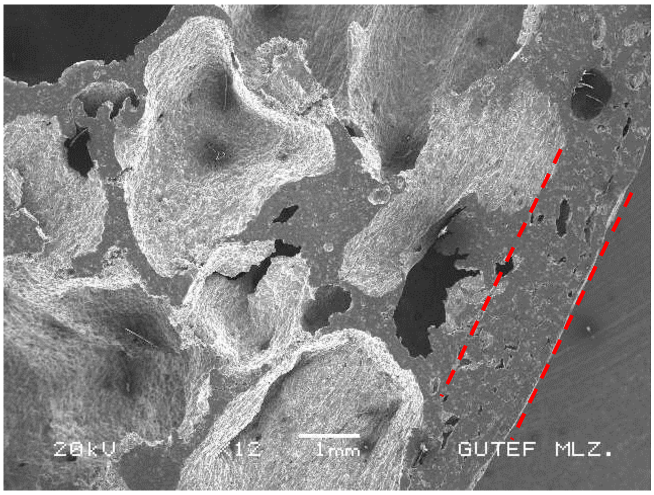


Fig. 6 Tensile region of bended specimen in 656°C

High or low deformation rates were performed in 600, 625 and 640°C. Angular deformation quantity decreased due to early crack formation with the increase of deformation rate in all temperatures in Table II. Approximately same angular deformation values were obtained in rates greater than 0.01 mm/sec load speed. After this deformation amount, cracks and then a rupture occurred in the locations where maximum moment took place on the top surfaces of specimens.

TABLE II
CHANGE OF ANGULAR DEFORMATION BASED ON LOAD SPEED

Temperature (°C)	Load arm speed, V (mm/s)		
	0.01	0.1	1<
	Angular deformation (°)		
600	13	11	
625	16	11	rupture
640	17	12	

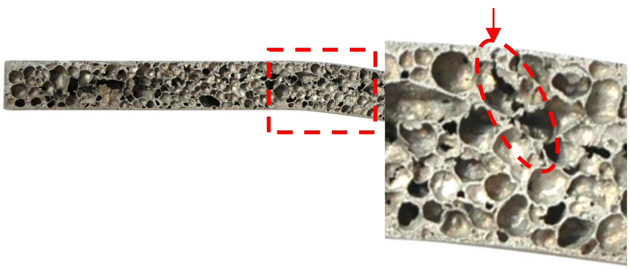
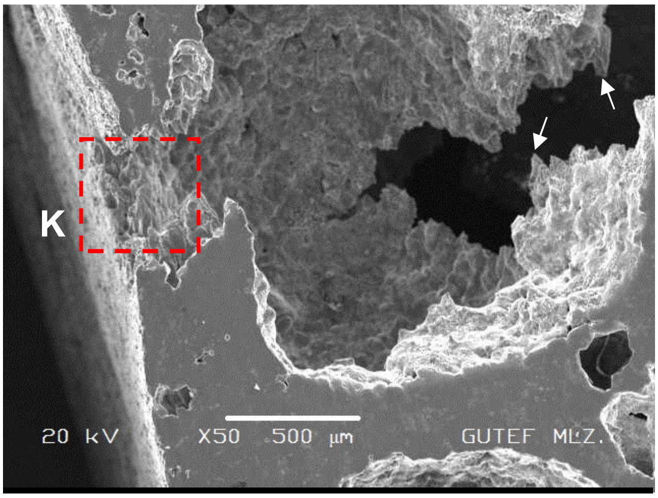
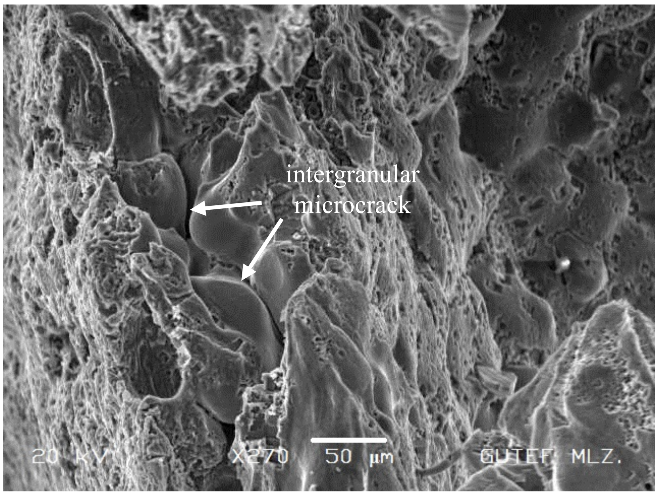


Fig. 7 Section macro views of bended specimen in 640 °C and crack formation on the top surface

Fig. 7 shows crack formation on the top surface and crack propagation through the cross section with certain angle of the specimen forced to bending in 640°C. It propagates along adjacent cell walls and ends in the center of the sample. Detailed Scanning Electron Microscopy (SEM) views of the crack formation in the tensile region of this specimen are given Fig. 8. Interrelated walls of the cell located on the top surface which is strained by tensile are broken by tensile strain. Crack surfaces are not smooth and deformation effects are seen from elongated grains (marked with white arrows in Fig. 8 (a)). Crack widths are about 0.5 mm and it decreases towards to bottom of the cell. When crack initiation at the bottom of the cell wall is examined in detail, it can be seen that microcracks formation parallel to the tensile direction between elongated grains (arrowed in Fig. 8 (b)). This generation of intergranular microcracks due to the high strain rate causes the macrocracks formation and then ruptures the foam material.



(a)



(b)

Fig. 8 SEM views from crack region on the top surface of bended specimen in 640 °C, General view (a), High magnification view of crack initiation zone marked with "K" (b)

IV. Conclusion

As a result of this experimental study conducted, following conclusions are obtained:

- In bending deformation of Al foams; increasing strain rates resulted in early microcrack formation in cell wall and the rupture of specimen. Microcracks that is parallel to the tensile direction occur in boundaries of elongated grains in the wall. This effect is seen in tensile region of the bended material.
- In free bending experiments; as deformation temperature and deformation time increased (decreased strain rate), angular bending deformation also increased.
- In tensile region of the specimen bended at high temperatures, it was observed that elongated cells without any microcracks in direction of tensile and slip line paths, parallel to the tensile direction, on the inner surface of cells.
- With low strain rates, an angular deformation of 82° was achieved at 656 °C temperature and in the areas, where deformation was intense, the thickening effect was observed in exterior walls of foam.

Acknowledgment

Authors thank to Gazi University providing support as being the 07/2012-16 coded project.

References

[1] H. Utsunomiya and R. Matsumoto, "Deformation processes of porous metals and metallic foams" Procedia Materials Science, 2014, 4, 234 – 238
[2] J. Banhart, ''Manufacture, characterization and application of cellular metals and metal foams'', Progress in Materials Science, 2001, 46: 559–632.
[3] H. Fusheng and Z. Zhengang, "The mechanical behavior of foamed aluminum" Journal of Materials Science, 1999, 34, 291-299.
[4] M. Yongliang, Y. Guangchun, L. Liang, L. Hongjie and Z. Guoyin, "Deformation mechanisms of closed-cell aluminum foam in compression", Scripta Materialia, 2010, 63, 629–632.
[5] M. Merklein and M. Geiger, "New materials and production technologies for innovative lightweight constructions", Journal of Materials Processing Technology, 2002, (125-126), 532-536.
[6] E. W. Andrews, S. Huang, and L., J. Gibson, "Creep Behavior of a Closed-Cell Aluminum Foam", Acta mater., 1999, 47, 2927-2935.
[7] F. Diologent, R. Goodall, and A. Mortensen, "Creep of aluminium–magnesium open cell foam", Acta Materialia, 2009, 57, 830–837.

Emrah Ersoy was a student in University of Gazi, Graduate School of Natural and Applied Science, Ankara, Turkey. He is now with a manufacturing company in Ankara, Turkey.

Yusuf Özçatalbaş was born in 1965 in Çorum, Turkey. He is a graduate of Gazi University, Technical Education Faculty-Metallurgical Education Department. Mr. Özçatalbaş got his master degree in 1989 and completed his PhD in 1996 from Gazi University, Turkey. His technical interests are powder metallurgy, metal matrix composites and machinability of metals. Recently, he has been studying metallic foam production by powder metallurgy method and deformation of the metallic foam materials. Mr. Özçatalbaş has been still working at Gazi University as a research professor and lecturer.