EFFECTS OF MISSING CELLS ON THE COMPRESSIVE DEFORMATION OF THE CLOSED-CELL AL FOAM

I. Jeon, Y. Yamada, T. Yamada, K. Katou, T. Sonoda and T. Asahina

Materials Research Institute for Sustainable Development, National Institute of Advanced Industrial Science and Technology(AIST), Japan

ABSTRACT

For this research, a simple experimental approach is attempted. Firstly, different size of specimens of the closed-cell Al foam, ALPORAS® of Shinko Wire Co. Ltd., such as 50x50x50mm^3, 15x15x15mm^3 and 10x10x10mm^3 are fabricated using EDM(Electrical Discharge Machine) for the uniaxial compression test. Secondly, the missing cells in the fabricated specimens are carefully investigated through the density measurement and the surface observation. Then two specimen groups that include or do not include the missing cells are arranged and tested separately and the measured results are compared with each other. From this research, the effect of the missing cells on the mechanical properties of the closed-cell Al foam, i.e., the elastic stiffness and peak stress is clarified.

1 INTRODUCTION

The cellular material has lately attracted considerable attention for the lightweight components of transportation applications[1]. The mechanical properties of the material that are the elastic stiffness and peak stress, i.e., the stress at the first peak of the stress-strain curve should be important parameters for designing those components. Because the processing defects in the cellular structures are known for affecting on the mechanical properties, many researchers have investigated for the effects of the defects.

The numerical study using 2-D honeycomb structures for the influence of geometrical imperfections, i.e., missing cells, fractured cell walls, rigid inclusions, cell-wall waviness, etc. on the mechanical properties of the honeycomb structure has been carried out to provide the guideline for improving the properties of the commercial metallic foams[2,3]. Among the imperfections, missing cells show a large influence on both the elastic modulus and the yield strength of 2-D cellular structures. Only a few experimental results, however, about the effect of imperfections, i.e., cell wall curvatures and cell wall microstructures of actual cellular solids have been reported up to present[4,5].

In this research, a simple experimental approach is attempted to analyze the effects of missing cells, which are generally found in the closed-cell Al foam and should be expected to reduce the mechanical performance seriously[2,3], on the compressive deformation. Considering the volume fraction of the missing cells, different size of specimens are fabricated using EDM(Electrical Discharge Machine) such as 50x50x50mm^3, 15x15x15mm^3 and 10x10x10mm^3. The missing cells in the fabricated specimens are carefully investigated through the density measurement and the surface observation. Then two specimen groups that include or do not include the missing cells are arranged and tested separately to compare the results with each other.

2 EXPERIMENTAL PROCESS

The closed-cell Al foam, ALPORAS® of Shinko Wire Co. Ltd is selected for the uniaxial compression test, which has a highly isotropic and homogeneous cellular structure with no significant spatial or orientational variation[6]. For the fabrication of the different size of specimens, EDM(Electrical Discharge Machine) is used to ensure the surface flatness for the uniaxial compression test and the surface clearness for the observation of the missing cells included in the specimens. A regular hexahedron is considered for the geometry of the specimens to prevent the unexpected buckling during the compressive process. The edge length $L=50mm$ is considered for the compressive deformation of the bulk cellular structure and $L=15, 10mm$ are considered for increasing the volume fraction of the missing cells. The average cell size is determined as $\bar{d} = 4.36mm$ following the definition of the equivalent diameter[6], which is measured from the digital microscopic system, VHX-100 of KEYENCE Corp. using over 200 cells in the fabricated specimens.

For investigating the missing cells in specimens, first of all, the density of the specimens is measured and the range of the density $\rho = 0.222 \sim 0.235Cm^3$ is carefully chosen. Then the surface of the specimens is observed using the naked eyes and the digital microscope system. The one helps to sort the specimens that include the non-uniformly distributed cell structure and the other helps to distinguish the missing cells near the surface of the specimens. From these two processes, it is possible to arrange two groups that include the missing cells and also do not include the missing cells, that is, potentially small amount of the missing cells. Figure 1a shows the fabricated specimens for the compression test, which do not include the missing cells. For the statistical reliability, over 7 specimens for each size without the missing cells are selected. These two groups give the basis compressive deformation to compare with the deformation behavior of the specimens including the missing cells.

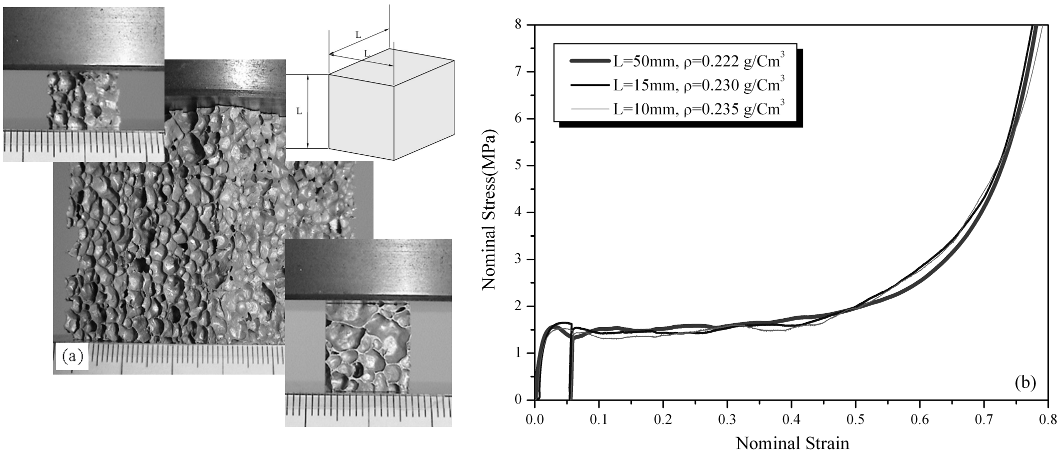
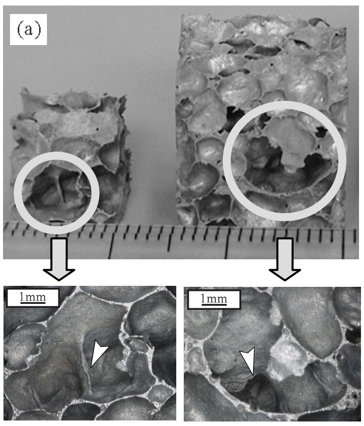


Figure 1: (a) Fabricated specimens without the missing cells and (b) measured compressive curves

The test machine, AUTOGRAPH of SHMADZU Corp. is used for the uniaxial compression test. The displacement rate 1mm/min is applied on the top surface of each specimen as an outer loading. All specimens are loaded to 80% of strain to observe the full compressive deformation. The unloading process is begun to measure the elastic stiffness at 6% of strain for each specimen soon after the first peak stress. Particularly, the compliance of the test machine is considered for the exact measurement of the elastic stiffness[7]. The missing cells included in specimens are shown in Fig. 2a and these should be regarded as the actual defects for the modeled missing cells in 2-D honeycomb structure[2,3].

3 RESULTS AND DISCUSSIONS

The representative measured compressive stress-strain curves for each size of specimens are shown in Fig. 1b. Though the small specimens such as *L=15, 10mm* are used for the test, consistent results with small variations in the stress-strain curves can be obtained because of the selected specimens without the missing cells. However, small variations in the curves are observed along with the decrease of the specimen size. Because of the difficulty to fabricate the small specimens that perfectly do not include the missing cells, some parts of the defects still remain in the fabricated specimens and these parts affect the compressive deformation of the small specimens. The different stress-strain behavior soon after the peak stress can be found between the large specimen *L=50mm* and the small specimens *L=15, 10mm*. This result is induced by the small amount of cell structures in small specimens that produces the small resistance for the compressive loading after the peak stress.



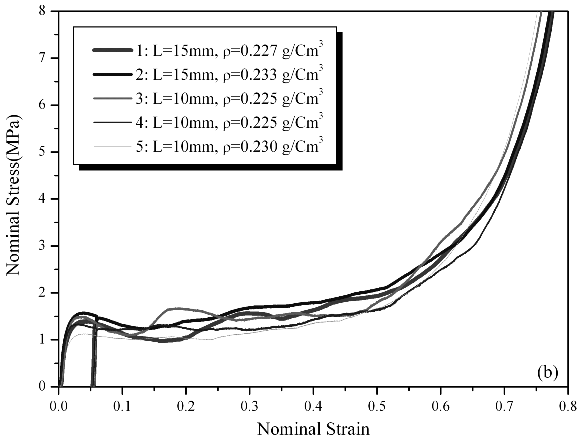


Figure 2: (a) Specimens including the missing cells and (b) measured compressive curves

Table 1 shows the average density, the elastic stiffness and the peak stress together with their standard deviations. Small magnitudes of standard deviations with no severe variations comparing with the ones of the average value mean that all of the measured values exist close to their average values. From these results, it is found that the measured values of the elastic stiffness show the ‘size effect’ [8] but the measured values of the peak stress do not show a serious dependency on specimen size.

Figure 2b shows the effect of the missing cells on the stress-strain response. The severely scattered responses are observed for each specimen. The measured elastic stiffness and peak stress of the specimens with the missing cells are listed in Table 2. From the results in Table 2, it is clear that the missing cells have serious decreasing effect on the elastic stiffness and peak stress comparing with average values of those measured from the specimens without missing cells. Particularly, the case for *L=10mm*, which means the large volume fraction of the missing cells, has more serious effect than the case for *L=15mm*. These results show a good agreement with the results of Chen et al.[2,3]. However, some measured peak stresses of specimens with the missing cells show a small difference to the average value of the peak stress measured from the specimens without the defects. Because the peak stress is considerably affected by the band collapse[9], the effect of a missing cell that is not connected with the deformation of other cells should be small.

Table 1: The measured elastic stiffness and peak stress for specimens without the missing cells

L(mm)	Density(g/Cm^3)		E_{UL}(MPa)		σ_{Peak}(MPa)	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
50	0.224	0.00287	777.631	57.615	1.550	0.0651
15	0.227	0.00271	726.774	91.907	1.650	0.0825
10	0.228	0.00470	663.435	69.107	1.588	0.0600

Table 2: The measured elastic stiffness and peak stress for specimens with the missing cells

L(mm)		Graph No.	E_{UL}(MPa)	σ_{Peak}(MPa)
Ave. E_{UL}(MPa)	Ave. σ_{Peak}(MPa)			
15		1	659.484	1.397
726.774	1.650	2	663.142	1.572
10		3	590.506	1.494
		4	587.595	1.334
663.435	1.588	5	509.954	1.131

4 CONCLUSION

The effect of missing cells on the compressive deformation and mechanical properties of the closed-cell Al foam named ALPORAS®, are analyzed through the experimental investigation. Considering the volume faction of the structural defects, three different sizes of specimens are fabricated and the specimens with or without the missing cells are separately grouped and tested. Through this research, it is found that the missing cells have significant effects on decreasing the elastic stiffness and peak stress of the closed-cell Al foam. Therefore, the optimization of the fabrication process to reduce the missing cells is essential to improve the mechanical performance of closed-cell Al Foam.

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