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Research paper

Fabrication of unidirectional porous-structured aluminum through explosive compaction using cylindrical geometry

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ABSTRACT

A method for fabricating an unidirectional porous (UniPore) aluminum structure employing a cylindrical explosive compaction assembly is proposed and the condition for successful recovery is discussed. The microstructure of the compacted samples is demonstrated to show tight bonding between the walls with uniform pores oriented in one direction. The compacting process is numerically simulated by the Autodyn code and the results are in a good agreement with the experimental results. The results of compression tests showing a plateau region are also demonstrated.

1. Introduction

Porous materials are expected to be applied due to their excellent energy absorption capabilities at impact or heat conductivity properties, rather than the conventional solid materials. Among such porous materials, elongated pored materials called “lotus type porous materials” or “gasar” have been developed and are well known (Nakajima, 2007). They are produced through solidification of liquid metal with gas forming elongated pored structure.

Besides, the present investigation focuses on fabrication of a bulk body having uniformly elongated pore structure through explosive compaction by inserting many small pipes filled with paraffin into a large pipe. As the related technique, explosive welding has been industrialized already, and it is well known that quite high bonding strength is possible to be achieved when the colliding two plates are impacted at high velocity with a certain inclination angle (Crossland, 1982). By suing process, explosive welding of multilayered plates is also possible (Hokamoto et al., 1995). In contrast with the lotus type porous materials, it is expected that the pores made by the present method are uniform and straight at any cross-section vertical to the longitudinal direction of the pipe. The fabrication of similar structure using conventional plastic metalworking process has been proposed (Utsunomiya and Tsuruoka, 2012). However, such conventional method of stretching a composite structure through longitudinal direction easily induces plastic instability (necking) on the wall of thin pipes (Hokamoto et al., 1988), so, the fabrication of long-sized rods seems to be difficult. The present method, accelerates plates at high velocity toward the center of the longitudinal axis, causing only minor change in the thickness of each wall, which is an known effect of the explosive welding technique. Explosive welding already allows producing several meters sized clads (Crossland, 1982). It is also possible to fabricate long-sized rods, while their industrialization is considered not too difficult.

So far, some of the authors have developed fabrication of such unidirectional porous material (UniPore) made by industrial pure copper and evaluated some mechanical and thermal properties (Fiedler et al., 2015; Hokamoto et al., 2014; Vesenjak et al., 2015; Vesenjak et al., 2016a; Vesenjak et al., 2016b). The present investigation is trying to fabricate UniPore material made by industrial pure aluminum. By modifying the thickness of the pipes the experimental conditions to fabricate Al UniPore structures have been sought. The authors also numerically analyzed the high-rate deformation process with computer simulations and performed compression tests that are reported as well.

2. Experimental procedure

Fig. 1 shows the schematic illustration of the explosive compaction

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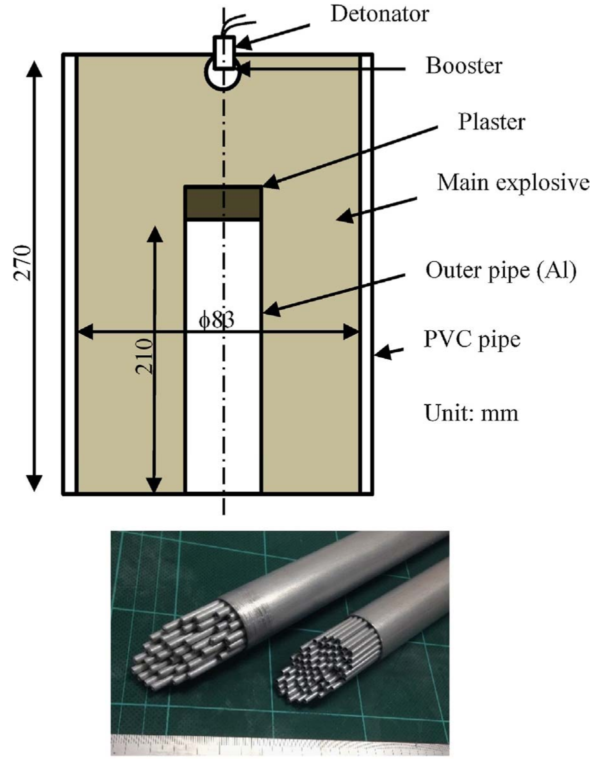

Fig. 1. Experimental assembly.

Table 1
Experimental conditions.

Symbol	Inner pipe (JIS A1070)			Outer pipe (A1050)	
	Outer diameter /mm	Inner diameter /mm	Number of pipes	Outer diameter /mm	Inner diameter /mm
LL	3.0	2.6	68	30	28
LS	3.0	2.6	61	32	26
SL	4.0	2.0	37	30	28
SS	4.0	2.0	32	32	26

(cylindrical) assembly, while the experimental conditions are listed in Table. 1. Solid paraffin was inserted in small aluminum pipes by heating to fill all the voids inside the pipes. Then the small pipes (32–68) were inserted in the outer large pipe (approx. 30 mm in outer diameter). The upper and lower ends of the outer pipe were sealed by epoxy resin. As listed in Table 1, two types of outer (large) and inner (small) pipes were prepared, respectively, and total 4 samples were fabricated.

The main explosive used for the present investigation was PAVEX, provided by Kayaku, Japan Co. Ltd., (detonation velocity; approx. 2.3km s^{-1}, density; approx. 530kg m^{-3}), and the mass of the explosive was 750 g in all the experiments. The main explosive was ignited by an electric detonator through a booster, 10 g SEP explosive, provided by Kayaku, Japan Co. Ltd. The PAVEX explosive is ammonium-nitrate based having low detonation velocity, used often for explosive welding. The thickness of the PAVEX explosive was 25.5–26.5 mm and not significantly changed between each experiment. After igniting the main explosive, detonation wave propagated in it. The detonation gas accelerates the outer pipe toward the center axis with a velocity high enough to achieve the welding between the pipes. The remained paraffin in the recovered samples was removed after cutting one end and heating.

The recovered samples were characterized through microstructural observations followed by the compression tests. The experimental tests were performed by compressing the samples parallel and transversal to the longitudinal axes using the INSTRON 8801 machine at a fixed crosshead speed of 0.1 mm s^{-1}. The compression tests were also performed for as received outer pipes as well (outer diameter x wall thickness; 30 × 1.0, 32 × 3.0 mm).

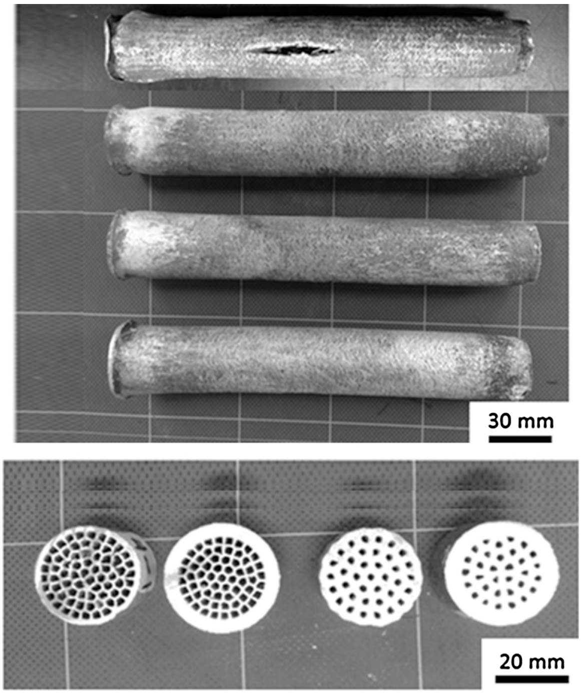

Fig. 2. Appearance of samples recovered.

3. Experimental results and discussion

3.1. Microstructure of recovered samples

Fig. 2 shows the recovered samples (LL, LS, SL, SS from top) and their cross-sections (LL, LS, SL, SS from left). The sample LL, using thin outer and inner pipes, clearly shows fracture of the outer pipe, while other specimens were successfully recovered without fracture. Therefore, it is necessary to choose moderate thickness of the pipes, because plastic instability during high-velocity deformation is expected to be induced. The cross-sectional views suggest that many pores have similar areas which are stretched along the longitudinal axis.

Fig. 3(a) shows enlarged view of the cross-section for the sample LL. Fractures are confirmed in the inner pipes. Fig. 3(b) shows the longitudinal cross-section after etching for the sample LL, and wavy interface which is typically found in explosively welded clads (Crossland, 1982). Accordingly, it is considered that the welding was achieved at a high velocity. Other area is welded showing planar interface. Fig. 4 shows the micrographs of the cross-section for the sample LS after etching. The inner pipes are welded successfully without any gaps. It is also confirmed that the melting areas, indicated by arrows in the figure, are induced by the collision of metal jet where three pipes collided (Crossland, 1982). The metal jet may induce a clean surface through an intense plastic deformation which contributes to the bonding of the welded materials (Crossland, 1982). Similar melting area has been reported for the explosive compaction of spherical powders (Mamalis and Gioftsidis, 1990).

Table 2 lists the theoretical and measured porosity and the diameter of the recovered samples. The theoretical porosity ($p_{\text{theoretical}}$) is calculated based on the original cross-sectional area covered by copper and paraffin (A_{Cu}, A_{paraffin}) where the gaps between the pipes are fully densified ($p_{\text{theoretical}} = A_{\text{paraffin}}/(A_{\text{Cu}} + A_{\text{paraffin}})$). The measured