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ORIGINAL ARTICLE

Effect of fabrication parameters on the pore concentration of the aluminum metal foam, manufactured by powder metallurgy process

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Abstract In this paper, the effect of fabrication parameters on the pore concentration of aluminum metal foam manufactured by powder metallurgy process is studied. Aluminum metal foam specimens were fabricated from the mixture of aluminum powders (mean particle size 60 µm) and NaCl at 10,20,30,40(wt) % content under 200, 250, 300, MPa Pressures. All specimens were then sintered at 630°C for 2.5 hours in an argon atmosphere. For pore formation (foaming), sintered specimens were immersed into 70°C hot running water. Finally the pore concentration of specimens was recorded to analyze the effect of fabrication parameters (namely NaCl ratio, NaCl particle size and compacting pressure) on the foaming behavior of compacted specimens. As a result of the study, it has been recorded that the above mentioned fabrication parameters are effective on pore concentration profile while pore diameters remained unchanged.

Keywords Aluminum metal foam · Fabrication parameters · Pore concentration

1 Introduction

Cellular metallic materials have attracted more and more attention in the last few decades with increased availability of practical manufacturing technologies and improved understanding of their physical, chemical, and mechanical properties [1–5]. Aluminum foams have found increasing applications in a wide range of structural and functional products, due to their exceptional mechanical, thermal, acoustic, electrical, and chemical properties [6, 7]. Aluminum foam structures have densities only fractions of that of a solid structure and therefore have high specific strength and stiffness. They also have excellent properties for impact energy, vibration, and sound absorption. Examples of their applications include lightweight panels for building and transport against buckling and impact, non-flammable ceiling and wall panels for thermal and sound insulation. There is a great diversity of cellular metallic materials that show various structures and properties. According to the connectivity of cells, cellular metals can be categorized as either closed-or open-celled. Open cell foams can also be used as heat exchangers, filters, and catalyst carriers. The applications of Al foams on a large scale are likely to be in the automotive industry with an aim to improve the vehicle crashworthiness and thus passenger safety. Aluminum closed-cell foams are also materials increasing importance because of their energy absorption capabilities combined with good thermal and acoustic properties.

There currently exists a wide range of manufacturing methods [8, 9], which can generally be grouped into five categories according to the forms of the precursory Al and the types of the pore-forming agents, namely melt-gas injection, melt-foaming agent, powder-foaming agent, investment casting, and melt infiltration. However, the Al foams produced by these methods are either too expensive due to the high production costs or too poor in quality due to poor controllability in pore structure and porosity. As a consequence, the commercial applications of Al foam

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Table 1 Chemical composition of aluminum powder

Element	Al	Fe	Si	Mn	Zn	Cu	Mg	Ni	Cr	Ti	Others
Content (wt)%	99,5	0,027	0,101	0,015	0,023	0,003	0,011	0,015	0,012	0,018	0,275

components are still limited. With a rapidly increasing demand for high quality Al foams, there has been a growing need for developing cost effective manufacture technologies.

The manufacturing method employed in this project is not a novel process and has been studied by researchers under various parameters. In this project foaming ability and effect of fabrication parameters on pore concentration of sintered Al-NaCl powders were experimentally studied under given conditions.

2 Materials and experimental procedure

The raw materials are aluminum and NaCl powder. Chemical composition of aluminum powder with a mean diameter of 60 μm is given in Table 1. The particle sizes of the Al powder are not critical but generally required to be smaller than 1 mm and should be protected against corrosion. The particle sizes of the NaCl powder depend on the intended pore sizes of the final foam. 500 μm (between 415–546 μm) and 1100 μm (between 941–1217 μm) mean particle size NaCl used for fabrication of specimens. Necessary actions are taken at segregation stage, to prevent the size of NaCl particles since they can easily crash. For precise evaluation and comparison of foaming behavior, NaCl-free (specimens) aluminum powders were compacted at the same molds, under same pressures and sintered at same conditions.

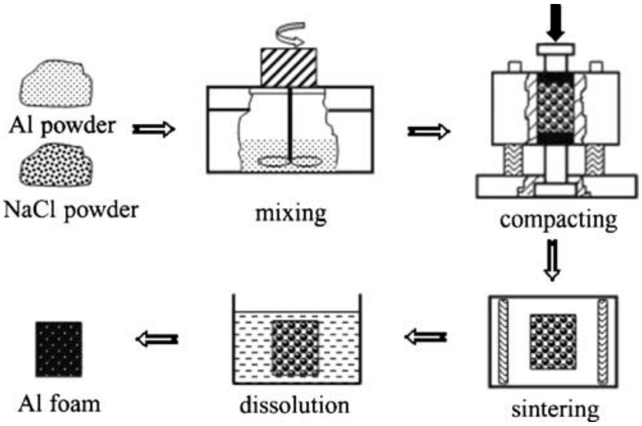


Fig. 1 Sintering-dissolution process (SDP) consists of the mixing, compacting, sintering, and dissolution stages

The aluminum powder is gently mixed with the NaCl particle in turning drums at a pre-specified weight ratio. The resultant Al/NaCl powder mixture and NaCl-free Al powders were compacted into a net-shape preform under 200, 250, 300 MPa pressures. The perform are then sintered at a 630°C for 2.5 hours in argon atmosphere, below the melting point of Al (660°C) but far below that of NaCl (801°C). Sintering-dissolution process (SDP) consists of the mixing, compacting, sintering, and dissolution stages as shown schematically in Fig. 1. After sufficient diffusion process, the Al powder in the preform forms a well-bonded networked structure, then the preform is cooled to room temperature. The imbedded NaCl particles are finally dissolved in hot water, leaving behind an open cell aluminum metal foam with the same chemical composition as that of the original aluminum powder. The specimens were washed in vibrated baskets to reduce the amount of NaCl particles retained in the structure. Finally the specimens were dried with pressurized air.

The foaming evaluations (pore concentrations) are based on the weight lost (pore volume)/ volume (perform) fractions of specimens. All specimens were fabricated at the same dimension (same volume). For each parameter combination 3 samples were fabricated. The weights of samples before and after foaming process recorded. The Al powder perform (NaCl free) mean weights were taken to evaluate pore concentration. Optical micrograph of samples is given in Figs. 2 and 3.

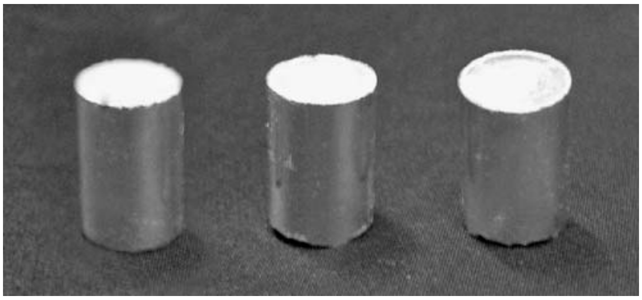


Fig. 2 Optical micrograph of samples

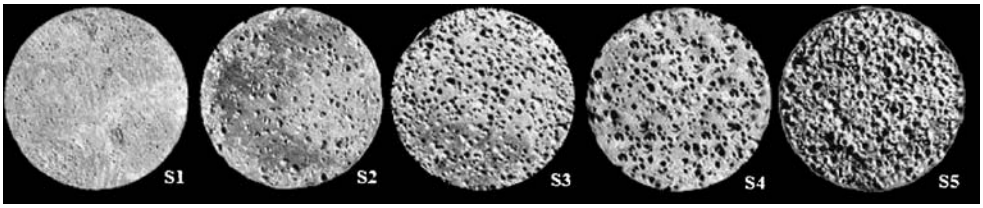


Fig. 3 Optical micrographs of aluminum metal foam cross sections

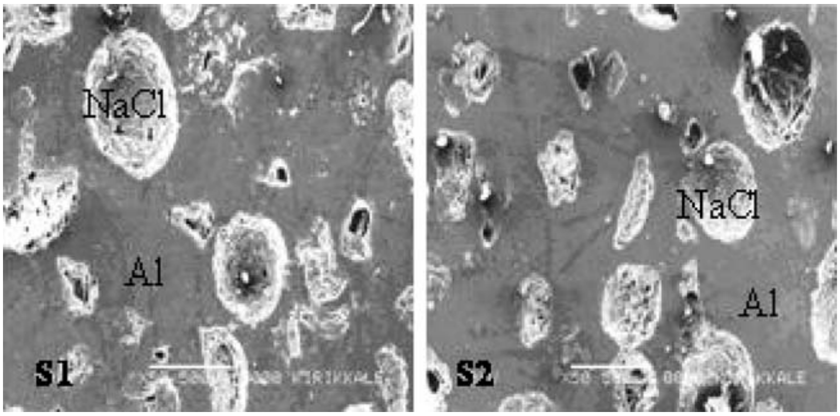
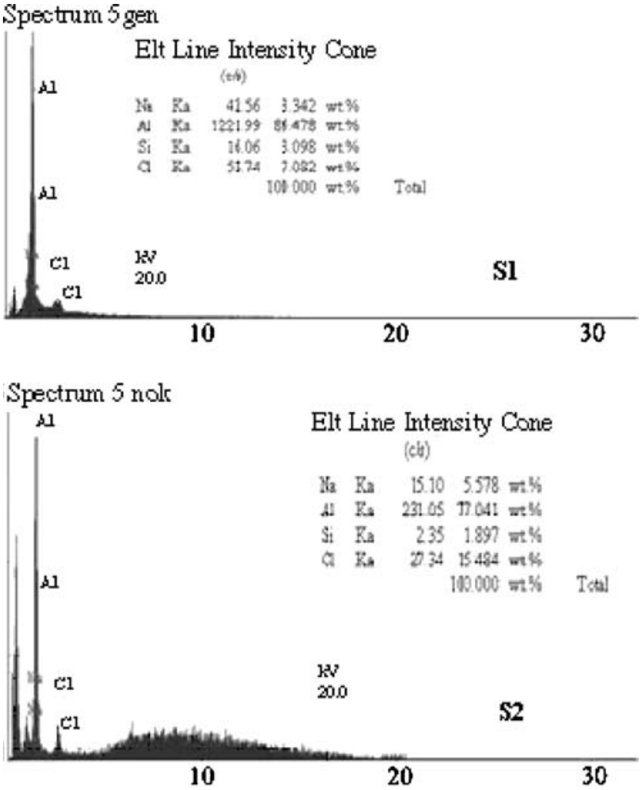


Fig. 4 SEM micrographs of compacts (S1–S2) samples



Elt	Line	Intensity (c/s)	Conc		
Na	Ka	41.56	3.342	wt.%	
Al	Ka	1221.99	86.478	wt.%	
Si	Ka	16.06	3.098	wt.%	
Cl	Ka	51.74	7.082	wt.%	
			100.000	wt.%	Total

Elt	Line	Intensity (c/s)	Conc		
Na	Ka	15.10	5.578	wt.%	
Al	Ka	231.05	77.041	wt.%	
Si	Ka	2.35	1.897	wt.%	
Cl	Ka	27.34	15.484	wt.%	
			100.000	wt.%	Total

Fig. 5 EDS results of compacts (S1–S2) samples

3 Results and discussion

The foaming process employed in this study is a simple and cheap process if small amounts are involved. For commercial applications NaCl additions to Al powders may create problems since NaCl particles can easily be crushed. The particle size effects the foaming ability of the metal foam, since very small particles tend to result closed cells. To overcome this problem slow motion drums or layered mixture method can be used to mix the NaCl -Al powders. SEM micrographs of compacts (S1–S2) are presented in Fig. 4 and EDS results are presented in Fig. 5 for structural observations.

Measurements and experimental results presented in Table 2 indicate that pore concentration (pore volume per total structure volume) is a function of fabrication parameters namely, NaCl ratio, NaCl size, and compacting pressure of the powder metallurgy process, while sintering temperature and time were kept unchanged. NaCl ratio(wt) has a naturally significant effect on foaming behavior especially at high NaCl contents. At low rate additions (10%) of NaCl, pore percent is nearly 6%. The pore concentration per NaCl content is 0.6 (%6/%10). This can be explained by the existence of closed cells resulting in retained NaCl in the structure. The amount of retained NaCl is decreasing at higher NaCl contents and at high rate additions (wt-40%) of NaCl, pore percent is nearly 35%. The pore concentration per NaCl content is 0.88 (%35/%40). Optical micrographs of

Table 2 Pore concentration (volume) % of compacts related with fabrication parameters

Sample No:	NaCl content	NaCl particle size (μm)	Compacting pressure (MPA)	Pore concentration %(volume)
S1-	10	500	200	7,00
S1a	10	1100	200	7,20
S1b	10	500	250	6,00
S1c	10	1100	250	6,60
S1d	10	500	300	5,40
S1e	10	1100	300	6,10
S2-	20	500	200	14,60
S2a	20	1100	200	15,30
S2b	20	500	250	13,40
S2c	20	1100	250	14,20
S2d	20	500	300	13,00
S2e	20	1100	300	14,80
S3-	30	500	200	27,00
S3a	30	1100	200	28,60
S3b	30	500	250	24,70
S3c	30	1100	250	26,30
S3d	30	500	300	24,80
S3e	30	1100	300	26,10
S4-	40	500	200	37,00
S4a	40	1100	200	38,60
S4b	40	500	250	34,70
S4c	40	1100	250	36,30
S4d	40	500	300	34,90
S4e	40	1100	300	36,10

aluminum metal foam cross sections were given in Fig. 3. NaCl particle size is effective on the foaming behavior between confined dimensions. In our study, NaCl mean particle size 1100 μm resulted slightly (2–3%) better pore concentrations of the specimens. Finally from test results it has been recorded that the compacting pressure is effective on foaming behavior and high pressures decrease the pore concentration of specimens.

4 Conclusions

Fabrication parameters namely NaCl particle size, NaCl content (wt), compacting pressure are effective on foaming behavior of aluminum metal foam manufactured by powder metallurgy process. Higher particle size and ratio of NaCl increases the foaming behavior resulting in higher pore concentration profile while compacting pressure decreases the pore concentration, within given conditions namely at 630°C sintering temperature for 2.5 hours in an argon atmosphere.

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