Quantification of NaCl in Al foams manufactured by sintering and dissolution process

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This paper investigates the variations of the rate of NaCl dissolution with dissolution time for different volume fractions of NaCl in Al/NaCl compacts and the variations of the amount of residual NaCl with volume fraction for different NaCl/Al size ratios in Al foams manufactured by the sintering and dissolution process. The rate of NaCl dissolution is approximately proportional to the NaCl volume fraction in the initial Al/NaCl compact and inversely proportional to the square root of dissolution time. The fraction of the residual NaCl relative to the initial NaCl in the Al/NaCl compact decreases with increasing NaCl volume fraction and with decreasing the NaCl/Al particle size ratio. When the initial NaCl volume fraction is greater than 0.70, there is no discernible NaCl trapped in the foams after dissolution.

1. Introduction

Al 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 [1-3]. For example, Al foams can be used for lightweight panels in building and transport against buckling and impact, non-flammable ceiling and wall panels for thermal and sound insulation. Al foams can be manufactured by a variety of methods [1-3]. However, the foams manufactured by the current commercial methods are either expensive due to the high production costs or poor in quality due to course and non-uniform pores. Therefore, there have been constant efforts in developing new technologies for manufacturing high quality foams at lower costs.

The sintering and dissolution process (SDP) is a novel process for manufacturing Al foams developed at Liverpool [4]. SDP consists of mixing, compacting and sintering of Al and NaCl powder mixtures and final dissolution of the NaCl. SDP is a low cost process for manufacturing Al foams because of the relatively cheap raw materials and simple process equipment. The morphology and sizes of the pores in the foam can be controlled by selecting appropriate NaCl particles. The porosity of the foam can also be controlled accurately by specifying the NaCl/Al ratio in the mixture. However, the duration of an SDP cycle is largely dependent on the time needed for completing dissolution of the NaCl particles in the sintered compact. Furthermore, there are often some residual NaCl particles trapped inside the Al foams after the dissolution process. The residual NaCl could result in corrosion of the Al matrix and could therefore reduce the strength of the Al foam. Other properties of the foam can also be adversely affected. Therefore, there is a need to measure the rate of NaCl dissolution and to characterise the amount of residual NaCl in the foams as a function of processing conditions.

In this paper, the variations of the rate of NaCl dissolution with dissolution time will be investigated experimentally for different NaCl volume fractions in the initial Al/NaCl mixtures. The amounts of residual NaCl in the specimens after thorough dissolution as a function of initial NaCl volume fraction for different NaCl/Al size ratios will also be determined.

2. Experimental

Commercially pure Al and NaCl powders with particle sizes ranging from 100 to 400 μm and from 100 to 1000 μm, respectively, were used. In the preparation of the specimens for the measurements of the rates of NaCl dissolution, the Al and NaCl powders were mixed directly without classification. In the preparation of the specimens for the measurements of the amounts of residual NaCl in the foams, the Al and NaCl powders were divided into different size groups using an analytical sieve and were then mixed into different size combinations, as shown in table 1, where D and d represent the diameters of the NaCl and Al particles, respectively. The powder mixtures were first put into φ21×50mm steel tubes and cold compacted under a pressure of 200 MPa. The specimens were then pressureless sintered in an electrical radiation furnace at a temperature of 650°C for 2.5-30 hours and cooled down to the room temperature.

For the measurements of the rates of NaCl dissolution, all the surfaces of the specimens were sealed with a waterproof glue except only one flat surface, which remained uncovered. The specimens were placed in a hot water bath at 95°C for a fixed time. After being removed from the water bath, they were immediately dried at 500°C for at least 20 minutes in an electric furnace. The dried specimens were weighed. The above procedure was repeated until the weights of the specimens did not vary significantly. For the measurements of the residual NaCl the dissolution was carried out in flowing hot water with all the surfaces of the specimens uncovered. The specimens were dried and weighed after all the free NaCl particles were dissolved. The weights of the specimens at each processing stage were measured using a digital balance to an accuracy of 0.01g.

The rate of NaCl dissolution can be defined as the weight of NaCl dissolved through a unit surface area in unit time. The mean rate of dissolution in each time interval between two consecutive measurements, R, can be determined by: $R = \Delta W / (A \Delta t)$, where A is the area of the uncovered surface of the specimen subject to the hot water, Δt is the time interval and ΔW is the weight loss of the specimen after Δt.

3. Results and discussion

Figure 1 shows the variations of the rate of NaCl dissolution with dissolution time for different NaCl volume fractions in the initial Al/NaCl compacts. The NaCl inside the specimens was dissolved at very high rates at the beginning of the dissolution process. The dissolution was gradually slowing down with increasing dissolution time. The rate of dissolution became very small after 9 hours. The rate of NaCl dissolution at a certain dissolution time increased with increasing NaCl volume fraction in the initial Al/NaCl compact.

Figure 2 shows the variations of the fraction of the dissolved NaCl in the specimen in relation to

Table 1. Combinations of NaCl and Al powders

combination	powder	size (μm)	D/d range	mean D/d
1	NaCl	250-1000	2.4-18.9	7.5
	Al	53-106		
2	NaCl	106-250	1.0-4.7	2.4
	Al	53-106		
3	NaCl	250-1000	0.6-4.0	1.7
	Al	250-400		
4	NaCl	106-250	0.3-1.0	0.5
	Al	250-400		
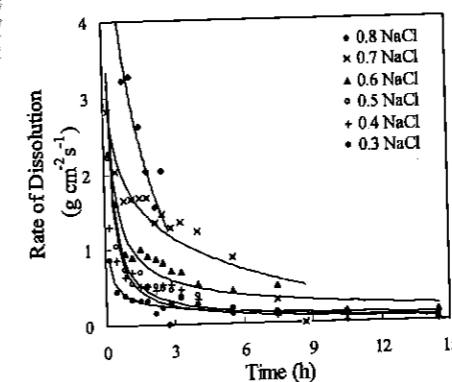
Figure 1. Variations of rate of NaCl dissolution time

Figure 2. Variation of fraction of dissolved NaCl with dissolution time

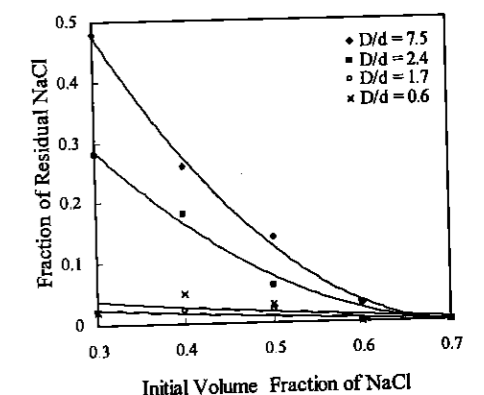**Figure 3.** Measured values of rate of dissolution against $f / \sqrt{t}$.

Figure 4. Variations of residual NaCl with initial NaCl volume fraction for different NaCl/Al size ratios.

its original NaCl with dissolution time for different NaCl volume fractions in the initial Al/NaCl compacts. The fraction of the dissolved NaCl increased with dissolution time, initially rapidly and then slowly. The higher the NaCl volume fraction in the compact, the higher the rate of NaCl dissolution, as shown in figure 1. As a result, the fraction of dissolved NaCl increased more rapidly with dissolution time for a higher NaCl volume fraction. At a NaCl volume fraction of 0.8 in the initial Al/NaCl compact, the NaCl was dissolved completely in 2.5 hours. However, there were still some NaCl particles trapped inside the Al foams with NaCl volume fractions below 0.7 even after long dissolution times.

The variation of the rate of NaCl dissolution with time can be explained by the following model. Given a sintered Al/NaCl compact with a NaCl volume fraction of f and an uncovered surface area of A, it can be treated as a semi-infinite bar with a cross-sectional area of A. Assuming that at any time t the local volume fraction of NaCl in the compact varies linearly from 0 at the uncovered end to f at a certain distance x from the end and beyond. In other words, there is a constant gradient of NaCl volume fraction, f/x, in the compact along the longitudinal direction up

to x. The total volume of the NaCl dissolved by time t, V, is therefore: $V = 0.5 fAx$. The rate of NaCl dissolution can also be assumed to be proportional to the gradient of NaCl volume fraction: $R = kf/x$, where k is a constant. By definition, the rate of dissolution is the weight of NaCl dissolved through a unit surface area in unit time and can be expressed by: $R = (\rho/A)\dfrac{dV}{dt}$, where ρ is the density of NaCl. Substituting the previous equations for V and R into the above equation and integrating it gives the rate of dissolution as: $R = Kf/\sqrt{t}$, where $K = 0.5\sqrt{k\rho}$ is a constant. Integrating the final equation for the rate of dissolution with respect to time gives the weight of the dissolved NaCl, W, as a function of time as: $W = Kf\sqrt{t}$.

The model predicts that the rate of NaCl dissolution is proportional to the NaCl volume fraction in the initial compact and inversely proportional to the square root of dissolution time and that the weight of the dissolved NaCl is proportional to the product of the NaCl volume fraction and the square root of dissolution time. These model predictions are qualitatively consistent with the experimental results as shown in figures 1 and 2. Figure 3 shows the measured values of the rate of dissolution against $f/\sqrt{t}$. The relationship is reasonably linear with the proportionality K around 115.4 g cm^{-2}s$^{-0.5}$.

Figure 4 shows the variations of the fraction of residual NaCl relative to the initial NaCl as a function of NaCl volume fraction in the original Al/NaCl compacts for different NaCl/Al size ratios. For a fixed size ratio D/d, the amount of residual NaCl decreased with increasing initial NaCl volume fraction. There was no discernible NaCl trapped in the foams when the initial NaCl volume fraction was over 0.7. This is due to the fact that more NaCl in the Al/NaCl compact means more chances for the NaCl particles to be in contact with other NaCl particles. There are therefore fewer NaCl particles that are completely surrounded by Al particles and thus trapped in the Al matrix. The NaCl/Al size ratio, D/d, also had a great effect on the fraction of residual NaCl. For a fixed NaCl volume fraction, increasing D/d leads to a decreased ratio of the number of NaCl particles to that of Al particles. A NaCl particle is more likely to be surrounded completely by Al particles and trapped in the Al matrix. Therefore, the fraction of residual NaCl increased with increasing NaCl/Al size ratio.

4. Conclusions

The rate of NaCl dissolution in SDP is approximately proportional to the NaCl volume fraction in the initial Al/NaCl compact and inversely proportional to the square root of dissolution time. The fraction of the residual NaCl relative to the initial NaCl in the Al/NaCl compact decreases with increasing NaCl volume fraction and with decreasing NaCl/Al particle size ratio. When the initial NaCl volume fraction is greater than 0.70, there is no discernible NaCl trapped in the foams after the dissolution process.

References

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CHARACTERISATION

AND

PROPERTIES