International Conference "ADVANCED METALLIC MATERIALS"
5 – 7 November, 2003, Smolenice, Slovakia

FOAMING CHARACTERIZATION REOLOGICAL, THERMAL MECHANICAL PROPERTIES OF Al ALLOY FOAM

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Abstract – Al foam is produced by directly melt foaming method. In this process, the viscosity and surface tension of Al as two most important factors have been investigated at the temperature range 933 – 1223K by the ring method and Rotation method respectively. The experimental results show that both the surface tension and viscosity of the melt decrease linearly with the increase of temperature. Addition of Ca decreases surface tension but increases viscosity significantly.

Metallic foam is a class of new materials and it can be fabricated by the different matrix such as Al, Fe, Zn, and Mg etc. with the different matrix the properties of metal foam are different; apparently the process parameters are different.

Mechanical properties of metal foams depend on cell type, shape, size, homogeneity, surface area and relative density, and particularly are proportional to their density. Deformation of metal foams includes the plastic deformation and collapse and shows a plateau area followed by yielding point.

Metallic foam is made by the casting method and the matrixes pure Al, Al-Si alloy and some kinds of recycling Al alloy are used to make metal foam. For the affection of discriminating element the foaming characteristics and the properties are distinct. The compressive stress-strain curve, at the strain rate 0.5 the energy absorption capacity is $3.5MJ/m^3$. The same porosity production of ALPORUS is $1.0MJ/m^3$, which is very lower than the production by pot furnace method. The foam cell will collapse when the compressive rate is over 0.5. The relationship between the impact energy absorption capacity and cell size were studied. The results show that the highest value 27.5 Kg-cm are gotten when the average size of cell is 2.7mm and with the decrease of cell size the absorption capacity is decreasing.

Keywords: metallic foam, viscosity and surface tension, mechanical properties

1. INTRODUCTION

Recently, the demand of lightweight materials is increasing for saving energy. Metal foam is just a kind of ultra light and high strength material containing many cells inside. The metallic foam has many combinations properties for its special cellular structure, so it is used as structural and functional material in many fields. Such as: energy absorption, heat insulated, electromagnetic shielding and the sound absorption, etc. The bumper made by the metallic foam in the car will be produced commercially in a few years. Up to now, there are many kinds of method to manufacture the metallic foam, all those methods can be classified as: powder metallurgy and casting method. The latter method is used commercially to produce the metal foam for its low cost. [1] In this paper Al foam is made with the casting method, i.e. by pouring the foaming agents into the Al melt and with the decomposition of foaming agent, the bubble deformed and finally we can get the cellular structure. [2] In generally, the cell's deformation contains 3 steps: generation; growing; collapsing. The final morphology of metallic foam is decided mainly by the bubble's growth, which is affected by the foaming parameters: viscosity and surface tension and mixing temperature. [3] In this paper, the influences of those parameters on the foaming behaviours of Al-Si alloy foam are investigated.

2. EXPERIMENTAL APPARATUS

Here the main equipment is mixing furnace, holding furnace and cylinder model. The matrix metals are Al-Si alloys pro-alloyed with pure Al and mother alloy. The chemical compositions of matrix metals are shown in Table 1.
The foaming agent used is TiH_2 powder (the mean diameter was 45μm). Cylinder samples of Al foam containing 1.5wt% TiH_2 are made by the casting method.
The indexes that describe the structure of closed cell are porosity and the foam morphology. The porosity is calculated in the formula:

$$P= [1-(\rho_f / \rho_s)] \times 100\% \qquad (1)$$

Where, ρ_f is the density of Al foam; ρ_s is the density of Al alloys.
The whole procedure contains the following steps:
Melting: 700g of Al–Si alloy were melted in a carbon crucible under atmospheric pressure.

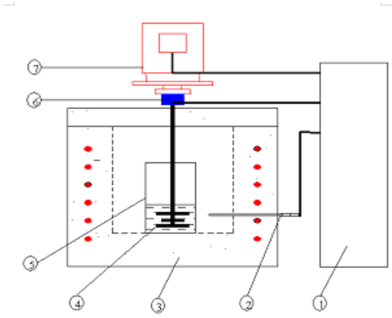
Thickening: For modifying the viscosity of the melt, 0.5 ~ 2.5wt% Ca (~1 mm in diameter) was added to the melt and stirred at 400 rpm for 20 min to make the melt viscous.
Foaming: 1.5wt% titanium hydride powder (TiH_2) as a foaming agent was introduced into the melt at a stirring speed of 550 rpm. After stirring, the melt remained in the furnace to allow the titanium hydride to decompose to form hydrogen gas.
Solidifying: The melt was taken out of the furnace with the crucible and directionally solidified in atmosphere to obtain foamed Al. [4]

TABLE I. Chemical composition of pure Al and mother alloy

(*wt%*)

Comp.	Al	Si	Mg	Cu	Ti	Mn
Al	99.70	0.10	0.14	0.06	-	-
Mother alloy	92.33	7.17	0.43	0.01	0.06	-

And the mixing furnace is shown in Fig. 1.



1. Controller, 2. Thermocouple, 3. Electric furnace, 4. Impeller, 5. Mold, 6. Torquemeter, 7. Motor

Fig. 1. Schematic drawing of the mixing apparatus.

3. RESULTS AND DISCUSSION

3.1. The affection of viscosity

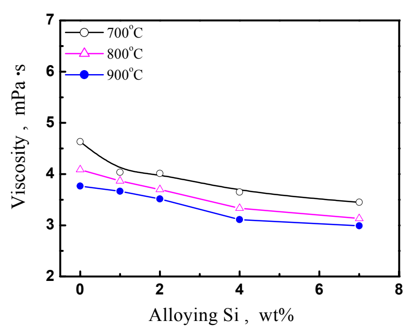


Fig. 2. Content of Si dependences of the viscosity of Al – Si alloys.

There exit two main problems in the foaming process: the drainage phenomenon and the foaming temperature of sample. Drainage: Under the normal gravity, the bubbles generation, growth and collapse is a short-lived course. The reason is for the existence of drainage, which is caused by the gravity. The creation of solid metal foam is a race against time. Once foam formed in the liquid state, it must be frozen quickly enough to avoid drainage, which could lead to inhomogeneous and collapse. [3] One of effective artifices is to pour the additives into the molten Al to increase the viscosity, which could decrease the affection of the drainage and prolong the life of the foam.

The affection of Ca on the surface tension of Al-Si molten metal is very small. But the viscosity of the molten Al-Si alloy measured prior to making the metallic foam. (Shown in Fig. 2,) is decreased inversely with the addition of Si. To find the proper viscosity value for the manufacturing of Al foam the amount range of Ca content is investigated. In the following steps the macrostructure of each elements with different content of Ca is studied. [5].
For the Pure Al the Ca is added from 0.5 to 2.0 wt% at 690 ℃,the macrostructures are shown in Fig. 3.

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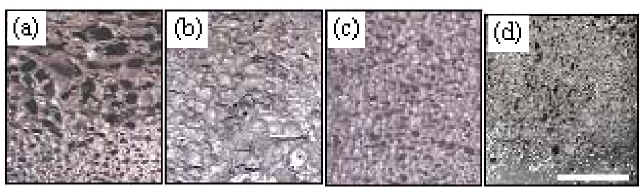

Fig. 3. Macrostructures foamed by pure Al with variation of Ca content: (a) 0.5, (b) 1.0, (c) 1.5 and (d) 2.0wt%

From Fig.3 we can know that the viscosity is increased with addition of Ca and the average cells size become smaller. If the viscosity is too high the growth of cells will be suppressed. For the Al-2Si case the added Ca is from 1.0 to 2.5wt% at 670℃.

The macrostructures are shown in Fig. 4.

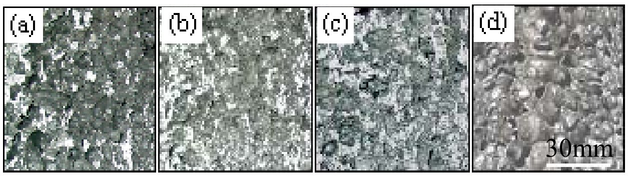

Fig. 4. Macrostructures of Al-2Si alloy foam with various content of Ca: (a) 1.0, (b) 1.5, (c) 2.0, (d) 2.5wt%

For the Al-4Si case the added Ca is from 1.0 to 2.5wt% at 670℃. The macrostructures are shown in Fig. 5. With decreasing of the viscosity of matrix metal (Al-4Si) drainage phenomenon become serious and the average cell size become bigger.

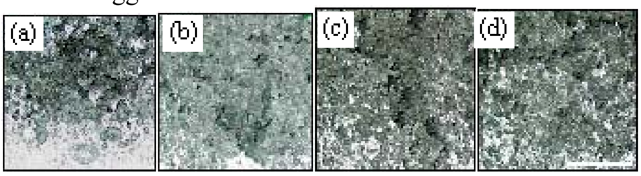

Fig. 5. Macrostructures of Al-4Si foam with various content of Ca : (a) 1.0, (b) 1.5, (c) 2.0, (d) 2.5wt%

To compare the formability of different elements the porosity of each sample is calculated. (Shown in

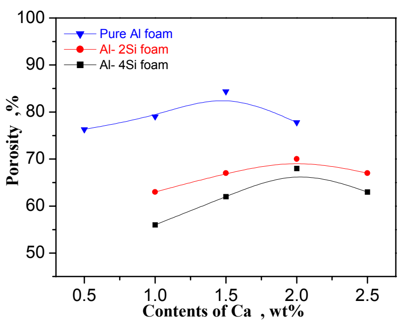

Fig.6)

Fig. 6. The porosity of Al alloy foam with different Ca contents

3.2 The affection of foaming temperature

The molten Al is poured into the model in the mixing furnace superior to mixing. Then pouring the foaming agent (TiH_2), the mixture is mixed at 550 rpm.[6,7,8] With the decomposition of TiH_2, the bubbles form and disperse. In the experiments, we just cold the Al foam in the atmosphere. After taking the model containing Al foam out of the mixing furnace the Al foam is still growing, and 2~3minutes later the surface exposed to the atmosphere and contacted with the surface of model solidified firstly, subsequently the whole foam is solidified from the exterior to the interior. [9,10] The true morphologies of section of samples are shown in Fig. 7 ~9.The mixing temperature acts as the driving force in the foaming process. And it is important for the growth of the bubbles and solidification rate of foams. [10] We just adjust the mixing temperature in the range above 50℃ of melting point.

For the pure Al case the mixing temperature is from 670℃ to700℃ at 1.5wt%Ca. The macrostructures are shown in Fig. 7. With the increase of temperature the average cell size increased ,but high temperature make the foam collapse easily.

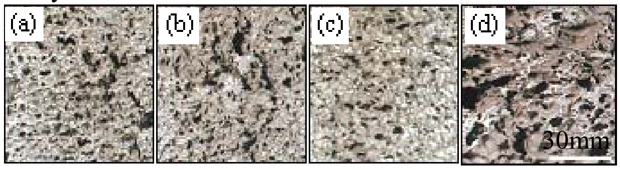

Fig. 7. Macrostructures foamed by pure Al at various foaming temperature: (a) 670, (b) 680, (c) 690 and(d)700℃

For the Al-2Si case the mixing temperature is from 670 ℃ to 700℃ at 2.0wt%Ca. The macrostructures are shown in Fig. 8. we can know that with the increasing of foaming temperature the cells coalesce and the cracks occur .

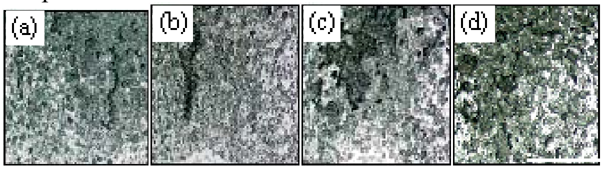

Fig. 8. Macrostructure of Al-2Si alloy foam at different foaming temperature :(a) 660, (b) 670, (c) 680 and (d) 690 ˚C.

For the Al-4Si case the mixing temperature is from 670℃ to700℃ at 2.0wt%Ca. The macrostructures are shown in Fig. 9 With the increasing of the foaming temperature the foam morphology turn bad that shows the foaming temperature has big affection to the formation of Al foam.

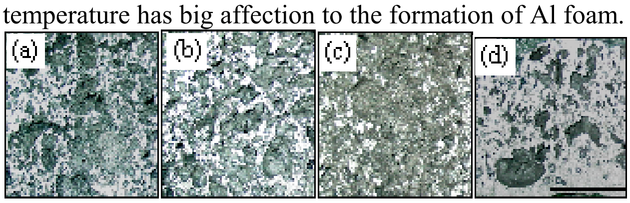

Fig. 9. Macrostructure of Al-4Si alloy foam at different foaming temperature: (a) 640, (b) 650, (c) 660 and (d) 670˚C

As before, the porosity of each sample is shown in Fig.10.

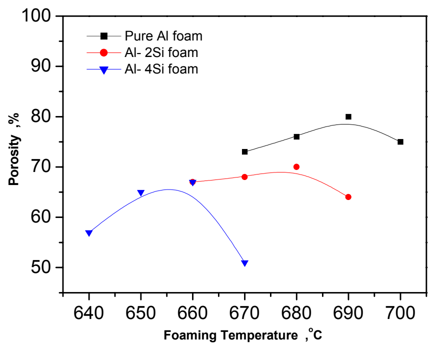

Fig. 10. The porosity of Al alloy foam at different foaming temperature.

3.3 The compression behaviors of Al alloy foam

Compression property is one of the main properties of Al Foam. The Al foam samples (pure Al, Al-2Si foam. Al-4Si foam) size are 35x35x40mm and all the samples are tested on the UTS machine(Instron A1740-3003) in the compression rate 2.4mm/min at the room temperature. Fig.12 shows the testing results. With the increasing of content of Si the plateau strength increased, but the strain of plateau stage decreased. Al-4Si foam has the strain of 40%, Al-2Si foam has strain of 50% and pure Al foam has strain of 80% .And the curve of Al-Si foam is fluctuant, which appears in the brittleness materials.

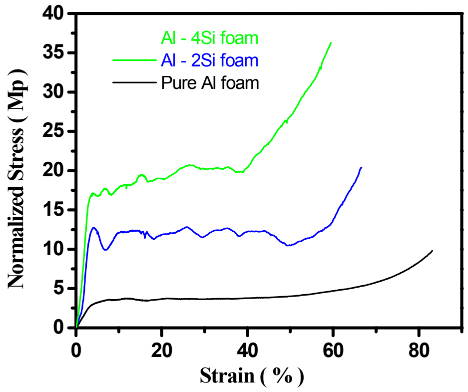

Fig. 11. The normalized stress – strain curve of Al-Si alloy foams.

4. CONCLUSION

In present study Al foam was manufactured by mixing foaming agent with the molten metal. Each of key parameters, the viscosity, and foaming temperature were investigated respectively when others were fixed.

With the increasing of viscosity, which was controlled by the content of Ca addition, the degree of drainage is decreased significantly while the growth velocity of the bubbles is suppressed greatly. When the Ca content of 1.5wt%(pure Al) and 2.0wt% (Al-2Si, Al-4Si) were added, the value of viscosity is most suitable for foaming process considering the influence of both the degree of drainage and the velocity of growth.

Foaming temperature effect the solidification rate of the Al foam and Al foam’s final the morphology, in this study the proper values are above 30℃ of melting temperature.

The compression strength of Al-Si alloys are increased with the increasing of content of Si, and the energy absorption is also increased .The curve of plateau stage is like the brittleness’ materials.

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Authors: Foaming Characterization Reological, Thermal, Mechanical Properties of Al Alloy Foam

Hur, B. Y. - Park, S. J. - Song, K. H. - Lee, W. H. - Park, S. H. - Kim, S. Y.

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