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The influences of calcia silica contents to the compressive strength of the Al-7000 aluminium foam

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Abstract. This experiment evaluated the effect of calcia alumina and alumina silica that formed as side products involved in metal mixture of aluminium foam. These compounds are formed from additional calcium carbonate and silica in the mixture. Calcium carbonate (CaCO₃) acts as a blowing agent source of carbon dioxide (CO₂). The formation of calcia alumina (CaO.Al₂O₃) is desired to improve the viscosity and to strengthen of cell wall of aluminium foam. However, Al-7000 aluminium foam showed a decrease tendency of compressive strength probably due to existence of alumina silica (3Al₂O₃.SiO₂) in the metal mixture. In this case, the silica that thermally combines with alumina compound may degrade the metal mixture of aluminium foam structure.

1. Introduction

Aluminum foams have been studied in recent years because of its low density and unique functional properties regarding to energy absorption, sound absorption, flame resistance and heat resistance. Variety of methods for their manufacture were developed. Some methods for the production of aluminum foams are basing on the use of a foaming agent. Open and closed pore morphologies and relative densities can be achieved. There are a variety of ways to produce open-celled aluminum foams, in which investment casting, pre-form infiltration and sintering-dissolution process (SDP) are the most widely used routes. Other methods such as Alcan, Alporas and Gasar are the most widely used to produce closed-celled aluminum foams.[1]

With a rapidly increasing demand for high quality Al foams, there has been a growing need for developing other cost effective manufacture technologies. The formation an aluminium foam using carbon dioxide as a blowing agent was reported. During melting process, the carbon dioxide gas was released by calcium carbonate. In parallel, other possible chemical reactions involving pure aluminium may occur as the following main reactions.[2]

\[
\begin{align*}
2 \text{Al} (l) + 3/2 \text{O}_2 (g) & \rightarrow \text{Al}_2\text{O}_3 (s) \\
2 \text{Al} (l) + 3 \text{CO}_2 (g) & \rightarrow \text{Al}_2\text{O}_3 (s) + 3 \text{CO} (g) \\
8 \text{Al} (l) + 3 \text{CO}_2 (g) & \rightarrow 2 \text{Al}_2\text{O}_3 (g) + \text{Al}_4\text{C}_3 (s)
\end{align*}
\]

Exothermically the calcium carbonate will decompose to release calcium oxide and carbon dioxide. The calcium carbonate can decompose in equal mole quantity to release the products, as the following equation:

\[
\text{CaCO}_3 (s) \rightarrow \text{CaO} (s) + \text{CO}_2 (g)
\]

The main products of the above reaction are alumina and calcia, which thermally combine further in an equal molar quantity to produce calcia alumina. The calcia alumina can be synthesized from the calcia and alumina that complies with the following equation:

\[
\text{CaO} (s) + \text{Al}_2\text{O}_3 (s) \rightarrow \text{CaO.Al}_2\text{O}_3 (s)
\]
In the previous work, the author examines that the calcia alumina correlated to strengthen the cell wall of the aluminium foam.[3] In this study, the silica compound was added to understand its correlation with possible reaction with alumina, calcia thermally to form alumina silica, calcia silica and calcia alumina silica.

\[
3\text{Al}_2\text{O}_3(s) + \text{SiO}_2(s) \rightarrow 3\text{Al}_2\text{O}_3.\text{SiO}_2(s) \quad (6)
\]

\[
\text{CaO}(s) + \text{SiO}_2(s) \rightarrow \text{CaO.\text{SiO}_2}(s) \quad (7)
\]

\[
\text{Al}_2\text{O}_3(s) + \text{CaO}(s) + \text{SiO}_2(s) \rightarrow \text{Al}_2\text{O}_3.\text{CaO.\text{SiO}_2}(s) \quad (8)
\]

B.L. Hakim et.al (2014) observed the existence of alumina silica in metal ceramics of Yttria Zirconia. Although this alumina silica is desired to stabilize Yttria Zirconia during phase transition, but this compound tend to decrease the mechanical strength of Yttria Zirconia. [4] In previous research, Olurin, et al (2001) investigated an effect of silicon content of aluminium foam on the fatigue crack propagation response, in which the foam with higher silica content has a lower fatigue resistance than the other with the lower silica content, and consistent with its lower fracture toughness. [5] The compression loading rate was also examined to find the proper testing condition to be applied for all tested specimens. The parameter of loading rate was selected whether 2.5, 5 or 10 mm/minute. Further, the selected testing parameter will be applied to conduct the testing of the specimens.

2. Experimental Procedure

The aluminium chip of Al-7000 aluminium blocks was used in this experiment. The Al-7000 aluminium foam was prepared for understanding the physical mechanical characteristic of this material. This material property was further compared with the similar technology product of Alporas and metallic honeycomb core. The metallic honeycomb core is currently known as airframe material for aircraft structure. The compressive strength of the Al-7000 aluminium foam was tested with refer to ISO13314 standard. Test specimens which are rectangular in cross-section shall be used in the compressive test. All spatial dimensions of the specimen (W₀ and D₀) shall be at least 10 times the average pore size, dₐ, and no less than 10 mm, with a sample length to diameter ratio (H₀: D₀) or sample length to edge length ratio (H₀:W₀) of between 1 and 2. The sample geometry was recorded. The average pore size (i.e. diameter, in the case of spherical porosity, and the axial and transverse dimensions in the case of non-spherical porosity) was measured in the cut section and recorded. The type of porosity (i.e. open or closed) was also recorded. The composition of the raw material as stabilizer will be also examined. This study will identify the influence of the additional calcium and silica compound in different composition to the Al-7000 aluminium foam. The combined parameters of different additive in different operating condition were also examined.

3. Result and Discussion

3.1. Calcia Silica Content

The processing temperature influences significantly to the composition of additional silica in different proportion. The additional SiO₂ content in different proportions were evaluated in relation to relative density, porosity, the average pore diameter and compressive strength. In the case of aluminum foam, the criteria of quality are emphasis on minimum relative density, maximum porosity, an average pore diameter and compressive strength.

On the SiO₂ content of between 0.3-1% weight, the minimum relative density is 0.381 gr/cm³, retrieved maximum porosity is 86%, an average pore diameter is 0.93 mm and maximum compressive strength is 4 MPa at 725°C as shown in Figure 1. The higher content of silica in calcia silica, alumina silica and calcia alumina silica tend to decrease the compressive strength of the foam product. However, the compressive strength was found more stable at about 3 MPa at processing temperature of 725°C while compared with other processing temperature.
In this case, all specimens for the compressive strength measurement were conducted at similar constantly strain rate of 2.5 mm/minutes. The existence of calcia in alumina bulk may form the side product of calcia alumina (CaO.Al\textsubscript{2}O\textsubscript{3}). This calcia alumina at proper concentration (2.7%) may reinforce the mechanical strength of aluminium foam. Meanwhile the additional of silica in the metal mixture may form alumina silica (3Al\textsubscript{2}O\textsubscript{3}.SiO\textsubscript{2}) called mullite that decrease to the mechanical strength of the metal mixture. The mullite compound can be formed stoichiometrically at about 2.55:1 proportion by weight. The mullite or likely mullite compound tends to decrease the hardness and mechanical strength of aluminium foam. In this case, silica in this metal mixture may role as an impurities to the formation of strong aluminium foam, instead of reinforce the strength of the cell wall (pores).

3.2. Flatwise Compression

The compressive strength of the seri-7000 aluminium foam valued in the range of 1 to 4.5 MPa. These values are competitive while compared with the compressive strength of A1050 aluminium foam at about 3.57 MPa [6], or Alporas aluminium foam at about 3MPa at similar condition of loading rate at 2.5 mm/minute [7]. The Alporas aluminium foam showed typical curve of compression characteristic, and also showed inconsistence of compressive strength with different loading rate from 2.5 to 10 mm/minute (Figure 2.a). However, the metallic honeycomb provided more regular curve during compressive testing at the value of 4 MPa (Figure 2.b). The side compression test for honeycomb showed lower both of in parallel (0.05 MPa) and perpendicular to ribbon direction (0.1 MPa).
The metallic honeycomb core of CRIII-1/8-5052-15 #13 has the cell size of 3/16 inch with hexagonal cell unit and available thickness of 13 mm. The compressive modulus of this honeycomb is 1034 MPa.[8] The compressive strength of this metallic honeycomb theoretically is 4.2 MPa and comparable with experiment result of Al 7000 foam specimen with the compressive value of 4 MPa.

4. Conclusion
The effect of calcia silica that formed as side products involved due to using calcia carbonat as blowing agent and silica as stabilizer in metal mixture of aluminium foam. Al-7000 aluminium foam showed a decrease tendency of compressive strength probably due to existence of alumina silica (3Al₂O₃·SiO₂), calcia silica (CaO·SiO₂) and calcia alumina silica (CaO·Al₂O₃·SiO₂) in the metal mixture. In this case, the silica that thermally combines with alumina and calcia compound may degrade the metal mixture of aluminium foam structure.

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