Light Metals 2014
Edited by: John Grandfield
TMS (The Minerals, Metals & Materials Society), 2014

Interface Evolution in the Process of Fabricating Aluminum Foam Sandwiches

Hao Lin[1], Hongjie Luo[2], Wei Sun[3], Guangchun Yao[4]
[1,2,3] School of Materials & Metallurgy, Northeastern University, [4] Shenyang NEU Advanced Materials Company
[1234]Address; Shenyang, Liaoning, 110819, China

Keywords: AFS, hot-press, interface evolution, metallic bonding

Abstract

Aluminum foam sandwiches (AFS) which have the properties of high impact strength, efficient capacity of energy dissipation, high damping and thermal insulation, were obtained by combining steel face sheets with a lightweight closed-cell aluminum foam core. The steel sheet was hot-dipped in pure aluminum and the precursor was prepared by powder metallurgy method. The pre-combination of the precursor and the hot-dipped steel sheet was carried out by using hot-pressing technology. The three-layer composite was baked rapidly in a furnace to fabricate AFS. It was found that the steel sheet coated by pure aluminum combined very well with the precursor by hot-press. Then the further diffusion was promoted in the foaming process. The boundary of the AFS which was between the foam core and the face sheet had a high strength by diffusion bonding. Simplified theoretical diffusion model was introduced to explain the evolution of the boundary in the hot-pressing process.

Introduction

Aluminum foam has received many attentions in recent years because of its unique properties such as high specific strength, sound absorption and heat resistance. Due to the low strength, it can't be used as structural material. Aluminum foam sandwich (AFS) is a product comprising a aluminum foam core and two face sheet. Such sandwich panels have the main advantage that the face sheet allows the sandwich to bear tensile loads when the panel is bent [1-3]. Several methods for fabricating AFS have been proposed by now, including rolling, thermal spraying, gluing, laser welding, brazing and so on [4]. The interfacial bonding stiffness between face sheet and aluminum foam varies with different technologies [5,6]. For example, the interface of AFS with a low strength could become invalid after a long period of time by cluing. By laser welding, the boundary with high stiffness shows good resistance to corrosion while the cost is too high.

In this paper, the AFS was fabricated by hot-press as the pre-combined method which was easily implemented and was relatively economical. The interface evolution in the process of preparing AFS was mainly studied. The effect of hot-pressing process on the diffusion bonding of the interface was investigated. A simplified diffusion model is also proposed to explain the metallic bonding mechanism on the interface.

Experimental procedures

Materials

The commercial aluminum powder and magnesium powder were used as the main raw materials of the precursor whose average size was less than 47μm. The particle size of SiC as additive ranged from 5μm to 10μm. The metal powder was characterized in the state "as received" without any further modification. Titanium hydride was employed as foaming agent which was treated at 480°C for 3h. A commercial Q235 steel sheet which was hot-dipped in pure aluminum was used as the face sheet of the AFS.

Pre-treatment of steel sheet

Even though the steel sheet was cleaned by physical or chemical method, it was still easily oxidized during the hot-press and foaming process owing to the high ambient temperature. The oxide on the surface of the steel would have an adverse effect on the pre-combination of the steel and precursor. It was necessary to modify the steel sheet in order to protect it from oxidizing. For this reason, the steel sheets in our experiment were coated with pure aluminum which would have a beneficial effect on the diffusion between the steel sheets and the precursor. The steel sheets for hot-dip were immersed into a pure aluminum (purity 99.0%) molten bath at 720°C for 120s, and then cooled down in the air.

Preparation of precursor

For making the precursor which would be foamed to be the foam core of the AFS, aluminum powder (purity 99.8%) with magnesium powder of 1wt.% (purity 99.0%) and pre-heated TiH_2 of 0.8wt.% content was mixed sufficiently for 3h in a high energy planetary ball mill. Then the mixture was axially compacted to an almost dense tablet (named foamable precursor, porosity<2%) under the pressure of 400MPa for 600 seconds. Small pieces (Φ24×5mm) were cut out of the tablet to be used as the core to make AFS.

Hot-press process and foaming

The steel sheet and the precursor should be pre-combined by means of hot-press in order to promote the formation of the boundary. The hot-press process was carried out at a pressure of 8MPa with high heating rate of 100°C/min using a device made in house. The foaming process was carried out by baking the pre-combined three-layer composite at a constant temperature of 720°C in a resistance furnace with the power of 5kW.

Characterization

The morphology of the pore structure of aluminum foam and the AFS was observed. Furthermore, the characteristics of the cross-sectional interface of the pre-combined precursor and the AFS was investigated by means of scanning electron microscopy (SEM) using both secondary electron imaging (SEI) and backscatter electron imaging (BEI) with energy dispersive spectroscopy (EDS). We examined the evolution of the microstructure and the phase constitution on the bonding interface in the hot-dip, hot-press and foaming process.

Results and discussion

The appearance of three-layer composite obtained by hot-pressing and the cross-section of the AFS which was obtained by baking the composite are shown in Figure 1. To expose the combination of the interface between the core matrix and the hot-dipped steel sheets, the composites were ground and polished. As we can see, the steel sheets and the precursor were bonded very well on a macro level (Figure 1a). The pre-combined interface would facilitate the further combination between the aluminum foam core and the steel sheets during the foaming process (Figure 1b), which will be explained in the below.

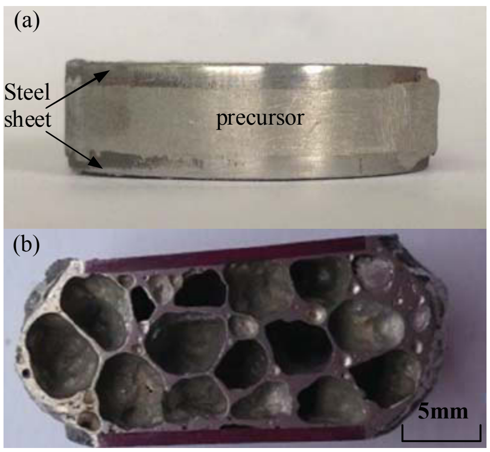

Figure 1. Images of (a) the foamable three-layer composite and (b) AFS

The BEI cross-section micrograph of steel after hot-dipping for 180 seconds is shown in Figure 2. The coating layer was composed of aluminum layer and inner Fe-Al intermetallic layer. The overall thickness of the coating layer was about 160μm, while the Fe-Al intermetallic layer was about 100μm. The tongue-like Fe-Al intermetallic was composed of an outer minor amounts of $FeAl_3$ and inner major Fe_2Al_5 layer by EDS analysis, which showed the same result with Wei-jen Cheng[7].

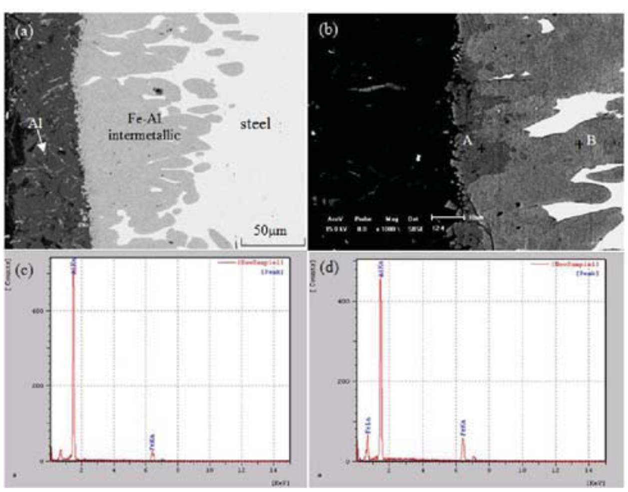

Figure 2. (a) BEI image of interface of hot-dipped steel; (b) Magnification of a local area in (a); (c), (d) EDS analysis of location A and B in (b), respectively

The tongue-like Fe-Al intermetallic and the serration-like morphology of the steel substrate were formed by the non-uniform distribution of the iron from the steel substrate. The aluminum coating would protect the steel sheet from oxidizing at a high temperature in the later hot-pressing process. On the other hand, the aluminum coating could also promote the combination of steel sheet and the precursor. This is mostly due to the proceeding of element diffusion between Al and Al atoms will be easier than that between Fe and Al atoms.

The SEI cross-section micrograph of the three-layer composite is shown in Figure 3. A solid diffusion between the precursor and the hot-dipped steel sheet (mainly the aluminum coating layer) was carried out during the hot-press. The thickness of the Fe-Al intermetallic was about 110μm. The thickness didn't change obviously comparing with the intermetallic which was in the hot-dipped steel sheet. As we can see, a narrow gap between the precursor and steel sheet could be observed. All the SiC particles were in the region of precursor. The diffusion occurred only in a small region and it was a mainly mechanical bonding.

Before the hot-press process, the oxide membrane on the surface of aluminum coating of hot-dipped steel was ground slightly. The hot-press temperature had a great influence of the formation of interface in the composite. At a low temperature the energy was not enough for a rapidly diffusion bonding. The phenomenon that the premature decomposition of TiH_2 would be detrimental at a relatively high temperature should also be considered. As the blowing agent was pre-heated at 480°C for 3h, the decomposition range of TiH_2 was modulated (more precisely from the onset to the maximum of gas) [8-10]. So the precursor and the steel sheet were hot-pressed at 470°C, 510°C and 550°C. The steel sheet and precursor were separated at 470°C and the precursor deformed seriously at a higher temperature of 550°C. As seen in Figure 1a, a three-layer composite was pre-combined at 510°C. The solid diffusion would not be proceeding entirely at this temperature. As a result, the precursor and the steel sheet were partially combined and some narrow gap was still existed.

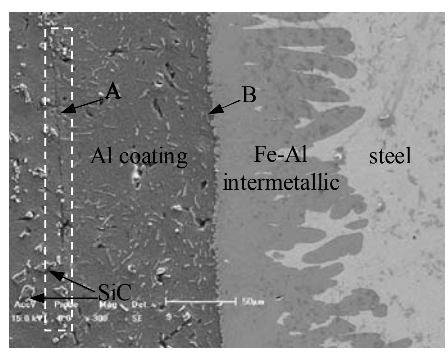

Figure 3. SEI cross-section micrograph of the three-layer composite; A-the interface of precursor and the Al coating layer; B-the interface between the Al coating layer and the intermetallic

The SEI cross-section micrograph of AFS is shown in Figure 4. In a foaming process for making AFS, a uniform diffusion interface could be observed and the gap between the aluminum foam and the steel sheet was disappeared. The thickness of the intermetallic layer was still about 110μm, which was not increased notably in this process. But the aluminum coating layer could not be observed clearly as before. The indistinct gap is displayed in the dashed area (As seen in figure 5, A), referring to the same area which was at the same distance from the boundary between the Al coating and the intermetallic (As seen in figure 5, B). It couldn't be observed after the foaming process. Another notable phenomenon was that the dispersive SiC particles could be also detected in the area of aluminum coating layer. These implicate that a further diffusion on the interface of the steel sheet and precursor occurred in the foaming process. As a result, the metallic bounding with high strength could be formed mainly in this process.

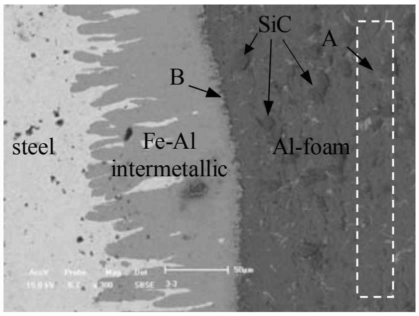

Figure 4. SEI cross-section micrograph of the AFS; A-the interface of Al-foam and the Al coating layer; B-the interface between the Al coating layer and the intermetallic

A simplified diffusion model was proposed to depict the interface evolution as is shown in Figure 5. The microstructure and the phase constitution on the hot-dipped steel sheet are diagrammed in Figure 5a. The direction of arrow depicts the non-uniform diffusion of the iron from the steel substrate. Due to the low temperature and a short time, some narrow gap existed in the three-layer composite which would have an adverse effect on the property of the composite or AFS (Figure 5b). The microstructure and the phase constitution didn't have obvious changes in this process. But in the further research, the gap became thinner gradually during foaming process. The reason is that the temperature at which the foaming process was carried out is high enough for the fast diffusion of aluminum atoms on the interface (Figure 5c, d). At last, the gap was indistinct and a mainly metallic bonding on the interface of AFS could be obtained (Figure 5e).

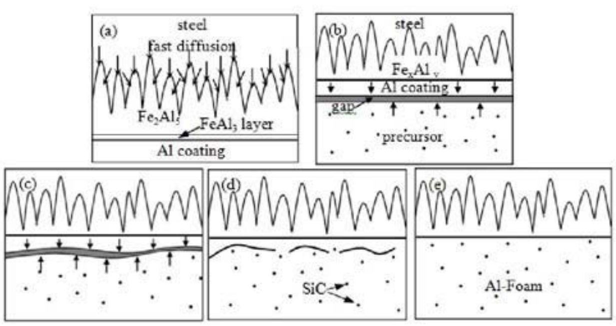

Figure 5. Schematic configuration for the interface in (a) the hot-dip process; (b) the hot-press process; (c), (d), (e) the foaming process

Conclusion

The AFS could be fabricated by the hot-press method. The steel sheet should be pre-treated by hot-dip to prevent it from oxidizing, and the foamable precursor was fabricated by powder metallurgy. The coating layer of the hot-dipped steel sheet consists of the aluminum coating and Fe-Al intermetallic layer. The coating layer protects steel sheet from oxidizing efficiently. The pre-combination of the hot-dipped steel sheet and the precursor before foaming process played an important role in facilitating the diffusion bonding. In the hot-press process, the diffusion was proceeding insufficiently due to the low temperature in a short period of time. The boundary of the AFS was transformed from a mainly mechanical bonding to be a mainly metallic bonding, and the AFS with substantial diffusion bonding can be fabricated.

Acknowledgements

This work was financially supported by National Natural Science Foundation of China (51174060) and by National High Technology Research and Development Program of China (2008AA03Z512). The authors would like to acknowledge these organizations for financial support.

References

1. J. Banhart, "Manufacture, Characterization and Application of Cellular Metals and Metal Foams," *Progress in Materials Science*, 46 (2) (2001), 559 - 632.
2. B. Jiang et al., "A Novel Method for Making Open Cell Aluminum Foams by Powder Sintering Process," *Materials Letters,* 59 (26) (2005), 3333-3336.
3. J. Banhart and H.W. Seeliger, "Recent Trends in Aluminum Foam Sandwich Technology," *Advanced Engineering Materials*, 14 (12) (2012), 1082-1087.
4. H.W. Seeliger, "Manufacture of Aluminum Foam Sandwich (AFS) Components," *Advanced engineering materials*, 4 (10) (2002), 53-758.
5. A. Nabavi and J.V. Khaki., "A Novel Method for Manufacturing of Aluminum Foam Sandwich Panelst," *Surface and Interface Analysis*, 42 (4) (2010), 275-280.
6. M. Maurer, L. Zhao, and E. Lugscheider, "Surface Refinement of Metal Foams," *Advanced engineering materials*, 4 (10) (2002), 791-797.
7. Wei-jen Cheng, "Growth of Intermetallic Layer in The Aluminide Mild Steel During Hot-dipping," *Surface & Coating Technology*, 204 (6) (2009), 824-828.
8. M. Biljana and J. Banhart, "Improvement of Aluminum Foam Technology by Tailoring of Blowing Agent," *Scripta Materialia*, 54 (2006), 530-508.
9. A.R. Kennedy and V.H. Lopez, "The Decomposition Behavior of As-received and Oxidized TiH_2 Foaming-agent Powder," *Materials Science & Engineering A*, 357 (1-2) (2003), 258-263.
10. B. Matijasevic-Lux et al., "Modification of Titanium Hydride for Improved Aluminum Foam Manufacture," *Acta Materialia*, 54 (7) (2006), 1887-1900.