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Preparation of aluminum foam sandwich reinforced by steel sheets

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Abstract

Aluminum foam sandwich (AFS) possesses excellent performance of light weight, high specific strength and stiffness, impact resistance, etc., which can be widely used in rail transit vehicles, aviation and aerospace industry and military field. In this paper, the bonding tests between steel sheets and aluminum foam have been done. In the tests, steel sheets pretreated by hot dipping were chosen as the reinforcement and a foamable precursor compacted by powder metallurgy as the core. The three-layer composite was connected by hot pressing and the aluminum foam sandwich was prepared by the later heating quickly. The results showed that the steel sheets coated by Zn-55wt.%Al alloy can be combined with the foamable precursor by liquid phase diffusion welding. The AFS with diffusion bonding interface can be also obtained by baking in furnace.
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Keywords: AFS; hot dipping; hot pressing; liquid phase diffusion welding; interfacial bonding

1. Introduction

Aluminum foam plate can be fabricated by liquid foaming routes, such as introducing blowing agent or injection by air. Duo to its weak strength, the aluminum foam plate needs to be glued with metal sheet and becomes sandwich structure when it is used to be engineering materials. However, the problems, e.g. the aging of adhesive or interfacial debonding, limit the application of these sandwiches. Therefore, the AFS with diffusion bonding interface has been widely focused on since the end of last century. The methods used to prepare AFS mainly include accumulative roll-bonding (Kitazono et al. (2004)), powder compaction (Liang et al. (2005)), powder rolling (Zhang et al. (2006), Banhart et al. (2008)), direct liquid bonding between aluminum foam and aluminum sheet (Wang et al. (2010)) and thermal spraying (Maurer et al. (2002)). Among them, big scale AFS panels (1m×2m) have been already prepared by some European countries through powder rolling (Banhart et al. (2008)), such as Germany and Austria. A new

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method will be introduced in this paper, which employs the way of hot pressing to obtain three-layer foamable precursor and then bakes it in furnace quickly to get the AFS with diffusion bonding interface.

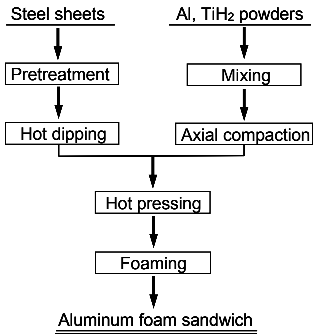

Fig. 1. Diagrammatic sketch for preparation of AFS

Fig. 2. Morphologies of the three-layer foamable composites obtained at different temperature under hot-dipping alloy: Zn-5wt.%Al, axial pressure: 6MPa, holding time: 90min

2. Experimental approach

The carbon steel sheet (Q235) was used as the face panel. The sheets were dipped into Zn-5wt.%Al or Zn-55wt.%Al alloy melt after pretreatment and a protective layer was coated on their surface by Sendzimir process.

The matrix aluminum powders (analysis purity, particle size 74μm) were mixed with 1wt.% titanium hydride (industry purity, particle size 48μm) by a tumbling mixer at a velocity of 80 rpm for 120min. The mixture was axially compacted to a cylindrical billet (Φ50mm×19mm) under the pressure of 400MPa for 10 min by a compression-testing machine and this cold pressure step was to give a foamable precursor.

The steel sheet coated with Zn-5wt.%Al or Zn-55wt.%Al alloy layer and the above compacted billet were put into a graphite mould in turn and the mould was placed in a hot-pressing sintering furnace. A certain pressure was exerted on the steel sheets and the billet which was trapped between the two steel sheets and then they were heated for some minutes at a given temperature. The hot pressure step was to obtain the three-layer foamable composite with a primary bonding interface between the steel sheets and the foamable core. Finally, the composite was baked quickly in an electrical resistant furnace to prepare AFS. The above process is sketched in Fig.1. The morphologies and internal structure of AFS were photographed by a camera (Nikon D90) after it was cut along longitudinal direction and its microstructure was observed and analyzed by SEM (Shimadzu SSX-550) coupled with EDS.

3. Results and Discussion

It was difficult to join the steel sheets coated with Zn matrix alloy and the compacted billet together even in vacuum state because the oxidation is very serious during the heating process. The compositions of two kinds of Zn matrix alloys used in hot-dipping are listed in Tab.1. Therefore, the hot-pressing sintering is an essential intermediate step. In order to reveal the effect of parameters on the process, different values were devised, such as temperature 340℃, 390℃ and 440℃, axial pressure 4MPa, 6MPa and 8MPa, as well as holding time 60min, 90min and 120min. Fig.2 is the morphologies of the three-layer foamable composites obtained at different temperature. Some metal balls appear between the steel sheet and the billet when temperature reaches 390℃ and become more obvious at 440℃.

Table 1. Alloy compositions used in hot-dipping

element	Al	Mg	Si	RE	Zn
Zn-5wt.%Al	4~5	0.2~0.5	0.05~0.09	0.03~0.18	balance
Zn-55wt.%Al	55~58	0.6~1.5	1.6	0.15~0.2	balance

The temperature scale of liquid phase diffusion welding is usually between $0.6T_m$ and $0.8T_m$. Here, T_m refers to the melt point of the aluminum matrix and the unit is Kelvin. In addition, the decomposition temperature of TiH_2 is also taken into account. So, three special temperature points in Fig.2 were selected. However, it is obvious that the diffusion at 340℃ isn't enough to make the interface between the steel sheet and the billet stronger. The interface can be broken easily when the three-layer foamable composite is subjected to a big external force. Meanwhile, it shouldn't be neglected that the extrusion problem of metal melt exists at 440℃. The temperature around 390℃ is relatively suitable. Its interfacial morphology and element distribution are shown in Fig.3. As seen in Fig.3, a diffusion layer of about 30 μm thickness has been formed between the steel sheet and the billet and an irregular pattern appears close to the Al matrix. Along the line scanning direction, the counts of element Fe presents ladder decline and the counts of Al always keep high. The count variation of Zn illustrates that element Zn has completely shifted from near the Fe to near the Al. All the phenomena prove that the diffusion layer consists of Fe and Al or their compounds. As for the influence of axial pressure and holding time on hot-pressing, an effective diffusion layer wasn't formed when the axial pressure exceeded 8MPa and a remarkable crack occurred near the side of Al matrix when the holding time kept for 120min. The reasons about these phenomena aren't analyzed in this paper because of the limited space.

It was thought that the AFS could be fabricated by using the above composites. Unfortunately, the AFS couldn't be obtained repeatedly by using the composites as precursors. However, when the Zn-5wt.%Al alloy was replaced by the Zn-55wt.%Al alloy in hot-dipping process, the AFS was prepared successfully. Fig.4 is the morphology and internal structure of the AFS.

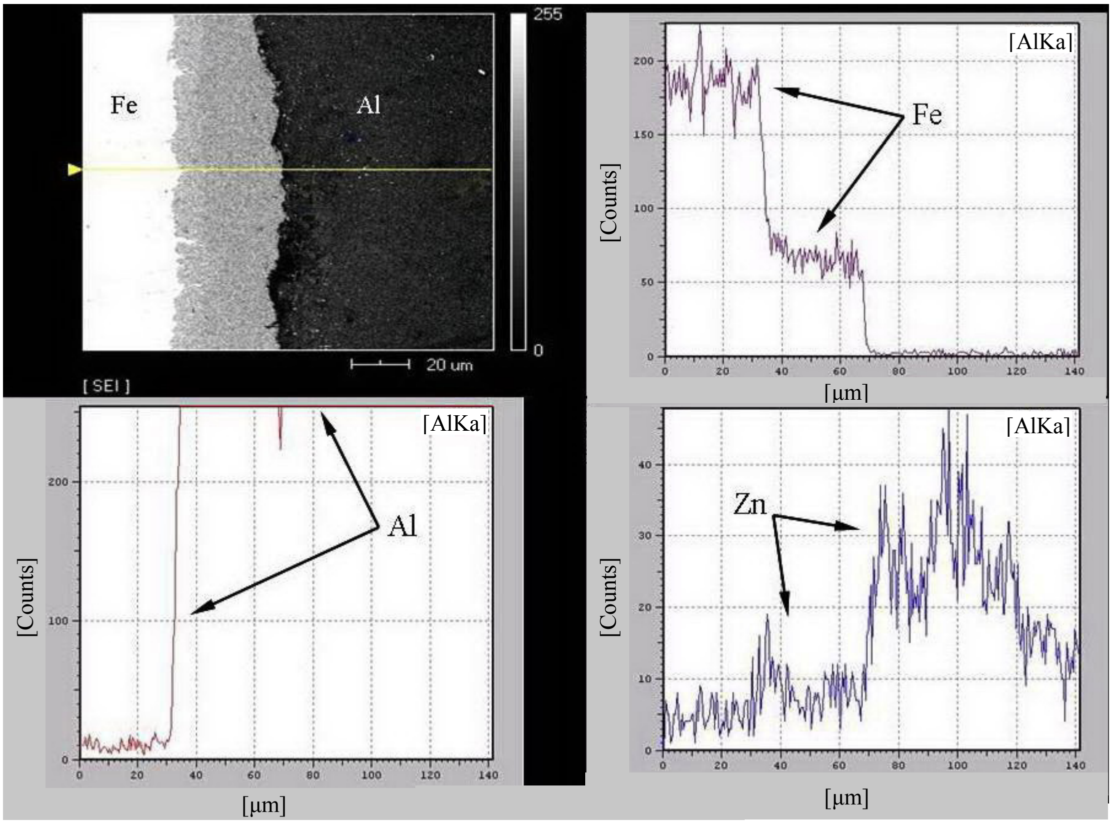

Fig. 3. Interfacial morphology and line scanning microphotographs of element distribution of the composite under hot-dipping alloy: Zn-5wt.%Al, hot-pressing temperature:390℃, axial pressure:6MPa, holding time:90min.

It can be seen in Fig.4 (b) that a uniform diffusion bonding interface has been formed between steel sheets and aluminum foam core and they are connected by the interface tightly. The internal structure of AFS is legible and the shape of cells is round or ellipse. The good porous structure of AFS plate proves the feasibility of this new method.

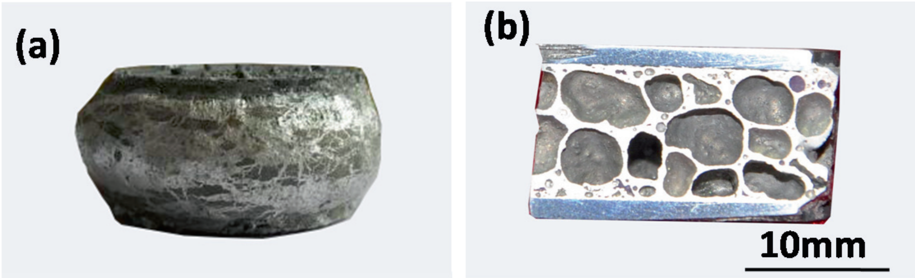

Fig. 4. Photographs of the obtained AFS under baking temperature at 700℃, where (a) is the surface morphology, (b) its internal structure.

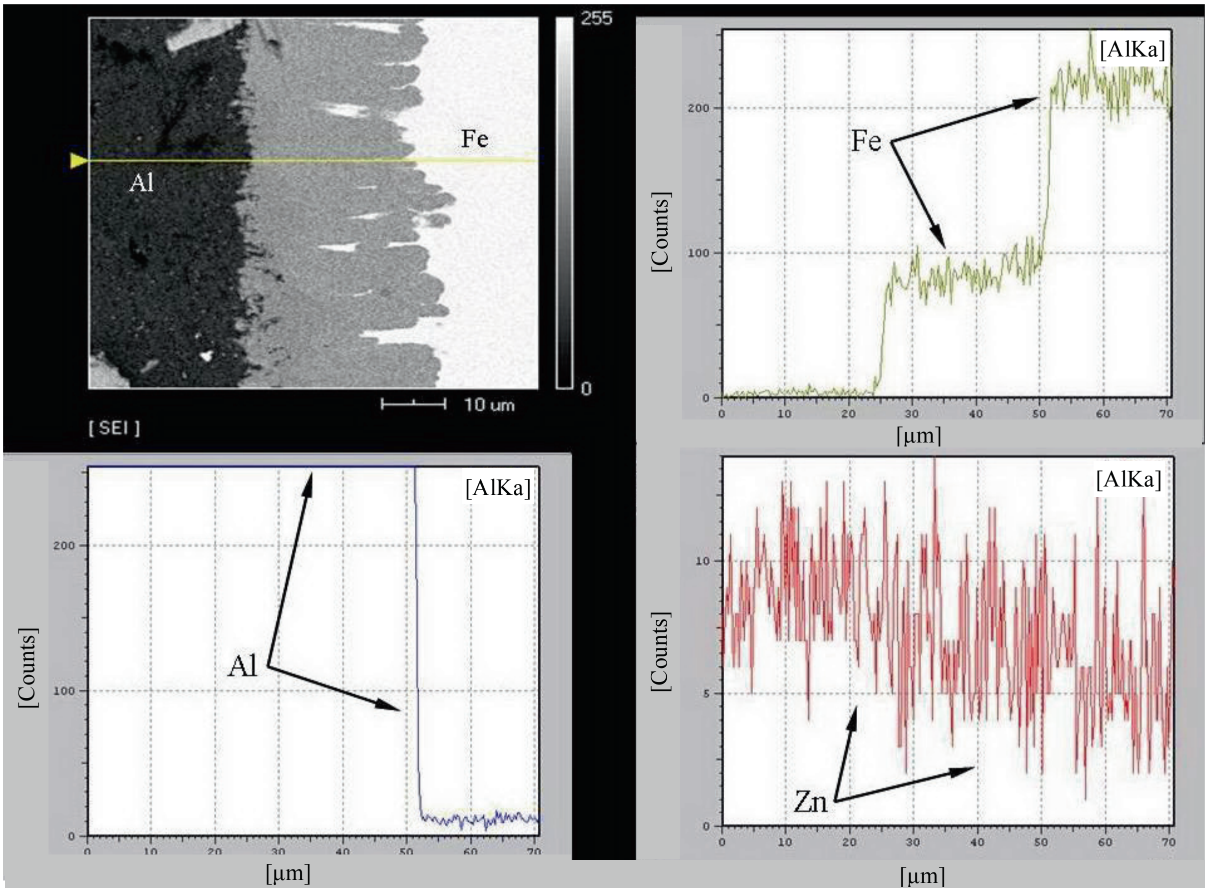

Fig. 5. Interfacial morphology and line scanning microphotographs of element distribution of the composite under hot-dipping alloy: Zn-55wt.%Al, hot-pressing temperature:450℃, axial pressure:6MPa, holding time:30min.

An interesting phenomenon has arisen in the above results why the alloy composition used in hot-dipping plays a key role on the preparation of AFS. The interface microstructure between steel sheet and the billet after hot-pressing has to be observed, but here, the alloy composition in hot-dipping is Zn-55wt.%Al (see Fig.5). As shown in Fig.5, there are no significant changes in the thickness, counts and variation trend of Fe and Al, but, the front edge of diffusion layer inserts both sides of the matrixes in the patterns of dendritic structure. Especially, the counts of element Zn are weak and its distribution almost has no change along the scanning direction. The EDS analysis indicated that the diffusion layer consisted of different Fe-Al intermetallic compounds. Therefore, the formation mechanism of AFS can be explained as follows. Although the diffusion layer is formed between the steel sheets and the billet when Zn-5wt.%Al alloy is used as matrix in hot-dipping, element Zn is accumulated on the surface of the billet, i.e. near the Al matrix, and may exist in form of Zn-Al eutectic compound (Zn based solid solution and secondary phase), which melt point is relatively low. The premature melting of Zn-Al eutectic compounds may weaken the interfacial strength as the foamable composite is heated at higher temperature and the internal force coming from the escape of hydrogen may result in the separation between the steel sheet and the billet. On the contrary, the distribution of Zn in the primary interface is relatively uniform and the amount of Zn-Al eutectic compounds with low melting point is less when using Zn-55wt.%Al alloy as matrix in hot-dipping, they almost have no effect on the later foaming process and the tight bonding interface can be formed in AFS plate.

4. Conclusion

The steel sheet can be connected with the compacted billet by liquid phase diffusion welding. The composition of matrix alloy in hot-dipping process gives great influence on formation of the AFS. AFS plate with diffusion bonding interface can be prepared by using steel sheet coated by Zn-55wt.%Al alloy as reinforcement and a compacted Al precursor as core.

Acknowledgements

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