Development of Aluminium-Yttrium Oxide Metal Matrix Composite Foam Through FSP

Sachin Rathore, Ratnesh Kumar Raj Singh and K. L. A. Khan

Abstract Nowadays safety is the most important concern in the automobile industries. The safety can enhance by applying high-strength materials, but in general high-strength material is heavy and reduces the fuel economy of the automobiles. Thus, there is a requirement of such a material which have high strength to weight ratio. One such type of material is aluminium foam having high strength to weight ratio and also has very good impact-absorbing capability. The friction stir processing (FSP) opens a new route for developing aluminium foam. Also, if it is possible to develop the foams by light metal matrix composite (MMC) materials, then it added more features into it. Thus in present work, aluminium-yttrium oxide (Al–Y_2O_3) MMC foam is developed by using FSP technique by adding TiH_2 and pure aluminium powder. The result shows proper foam is developed by using FSP route. The pores are uniform and equally distributed into the aluminium matrix. The compressive strength of the foam decreases with increasing the amount of TiH_2 (Titanium hydride) into the metal matrix. This is because of the increase in size of the pores which increases the distance between load-bearing matrix.

Keywords Friction stir processing · Aluminium composite · Foam · Compressive strength

1 Introduction

The human lives are dependent on the safety guard attached in the automobiles. The main factor for the loss of human lives is road accidents. These accidents cause high impact force occurring on the vehicle. To minimize the adverse effect of these impact forces, many safety factors are employed into the vehicle. One such safety factor is to applying the foaming material at different places in the vehicle which absorb the

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impact forces during road accident. The aluminium is widely used to develop the foam material because of its lightweight and good strength. There are lots of methods available for development of aluminium foam [1]. Powder metallurgy is common method used for developing aluminium foam [2]. In this process, a “precursor” is fabricated [3], which contains a foaming agent and a stabilizer with the aluminium powder. Then, this precursor is heated to a desired temperature so that foaming agent decomposes and release gases. These gases entrapped in the metal matrix and produce pores into it and the structure is known as foam. There are various methods used for making of precursors [4]. But these conventional routes for developing aluminium foam are costly and time-consuming. The other routes for development of precursor are electro-deposition technique [5], accumulative roll bonding (ARB) route [6] and the compressive torsion processing (CTP) route [7]. However, various factors associated with these processes affect their application and enhance the cost of fabrication of foam [8]. So, it is required to develop a method which will support the sustainable development.

Recently, friction stir processing (FSP) is widely used for development of aluminium surface composite and also used for development of precursor [9]. In the friction stir processing technique, the mixing blowing agent powder used for fabrication of precursor [10] and powder (stabilization agent) into aluminium plates utilizing the huge mixing activity of FSP [11]. It reduces the processing cost [12] and enhances productivity of the process [13]. In this research, initially the FSP route is used to develop aluminium–Y_2O_3 MMC and then this fabricated composite is used to fabricate foam. In the FSP route, for development of foam, first the precursor is fabricated by mixing a foaming agent along with aluminium powder which acts as a stabilizer in the aluminium plates during the stirring action in FSP. In this study, AA7075–Y_2O_3 metal matrix campsite porous foam has been fabricated. Then the fabricated porous structure has been nondestructively observed by scanning electron microscopy. The mechanical properties of fabricated foam have been evaluated by compression testing.

2 Experimental Procedure

2.1 Composite Making

The Al–Y_2O_3 MMC was fabricated by friction stir processing. For development of composite, aluminium plates were chosen of 100 mm × 200 mm × 6 mm dimensions. A special tool is fabricated for grooves making on shaper machine. Then using this tool, grooves were developed on the aluminium plates along its length with 1.5 mm thickness and up to 3 mm depth. The spacing between two consecutive grooves was keeping 2.5 mm. These grooves then filled with Y_2O_3 powders with average powder size is 67 μm measured by SEM. The FSP is employed to mix the Y_2O_3 powder into the aluminium matrix. This mixing produces aluminium–Y_2O_3 metal matrix composite. Then, this composite plate is machined on milling machine up to 0.5 mm depth to remove the irregularities present on the top of the plate. Further, these plates were used for development of aluminium foam.

2.2 Precursor Making

The Al–Y_2O_3 MMC plates were drilled with 3 mm diameter drill bit up to 3 mm depth (Fig. 1). Then these holes are filled by foaming material containing foaming agent as a TiH_2 and stabilizer as a pure aluminium powder. The size of TiH_2 particles is approximately 36 µm with ~10 µm aluminium powder have been used in this experiment. The percentage amount (weight %) of the TiH_2 was kept 10, 30 and 50% during the experimentation. After filling the holes, the plates are stacked and FSP was carried out on a vertical milling machine. Figure 2 shows a schematic diagram of the stacked plates and the position of tool used to do processing in this study. The FSP tool used in this study has a cylindrical pin with flat shoulder. The diameter of the tool shoulder is 20 mm, the diameter of the tool probe is 9 mm and its length is 8 mm. The H-13 hot-die steel is used as the tool material. The FSP parameters were selected based on the trial run experiments and best-suited parameters are chosen for processing. The tool rotation and traverse speed were kept 900 rpm and 100 mm/min, respectively. In this experiments, tool was kept 2° tilt from vertical axis of the machine. Figure 3 shows the plate on which FSP was carried out. The PSW was done in such a way that the tool is sifted little away (approximately about the diameter) when finished processing on a line and then moves back and so on.

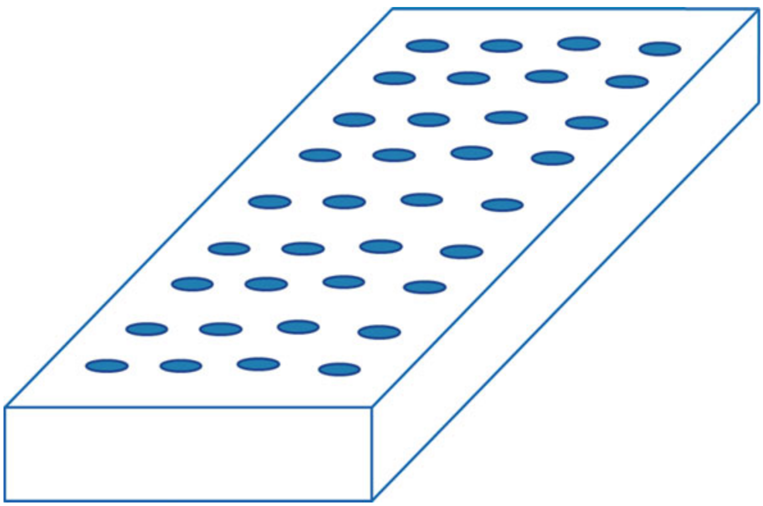

Fig. 1 Schematic diagram of drilled plate for developing precursor

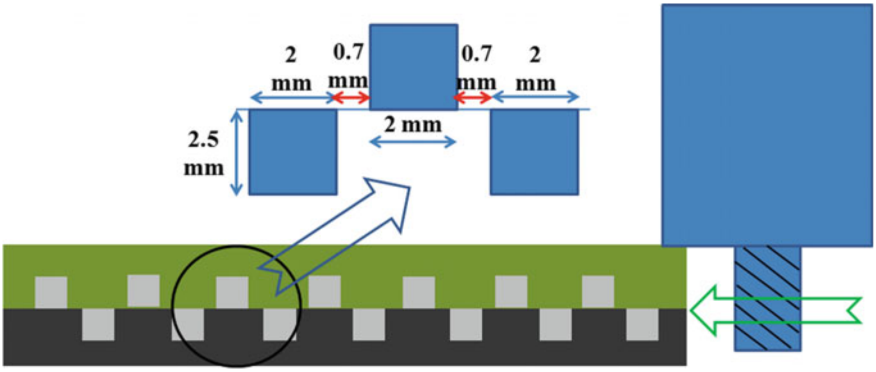

Fig. 2 Schematic diagram of precursor development by FSP

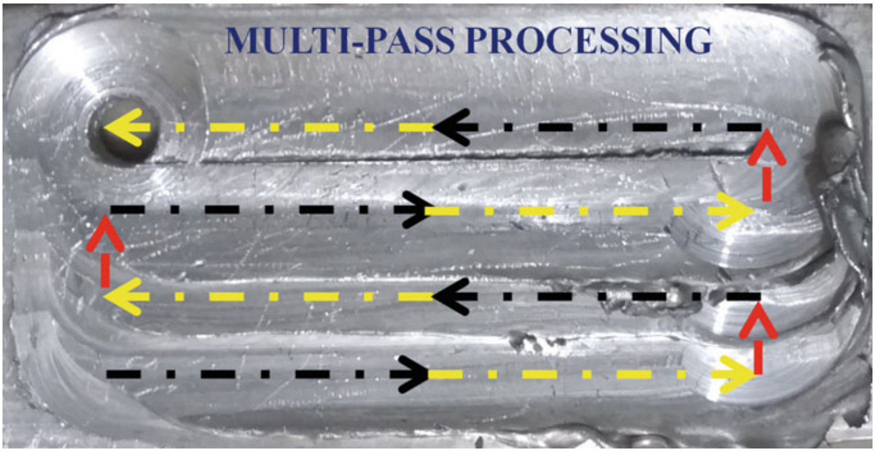

Fig. 3 Multi-pass FSP for development of precursor

2.3 Foam Making

The processed precursor is heat-treated in a preheated electric furnace to induce foaming. The holding temperature and the holding time have been kept 550 °C and 20 min, respectively. The sample was then cooled to room temperature under water. Then, the compression test specimen of 10 × 10 × 6 mm has been cut out from the foamed sample by wire electro-discharge machining.

3 Results and Discussion

3.1 SEM Inspection

The pores in the foam have been observed nondestructively by SEM using a tabletop SEM TM-3000 (made of Hitachi) at room temperature. The SEM analysis has been done to study the size of pores developed in different composition of TiH_2 powder. The samples were prepared with 10 mm × 10 mm × 6 mm in dimensions. Figure 4a shows images of a precursor obtained just after FSP. Grey regions represent the aluminium matrix while black one indicates pores. The pores occur in the matrix due to the heat generated during FSP. But the generated pores in the precursor are not uniformly distributed and a tunnel defect is also observed in precursor as shown in Fig. 4a. But roughly good circularity of pores was obtained but the size of these pores is very small. However, it is essential to reheat the precursor further to fabricate porous aluminium matrix with proper pores size and higher circularity. Figure 4b shows, foam produced after heating in furnace, indicating proper pores developed with greater in size. Then this fabricated foam is mechanically tested for their strength. The compression test is the most essential test to check the deformation behaviour of the foam. Figure 5 shows the stress–strain curve obtained from compression test for the precursor. From Fig. 5, it is clear that compression strength decreases with increasing the foaming agent. This is because, as the amount of foaming agent increases, the size of pores increases. Thus, the distance between the load-resisting metal matrix increases. It causes more deformation takes place on a given load and reduces the compressive strength of the foam. Generally, the characteristic of foam material is defined by the plateau stresses and its region [14]. The plateau region is a horizontal line occurred in the compressive stress–strain curve [15]. This plateau region shows

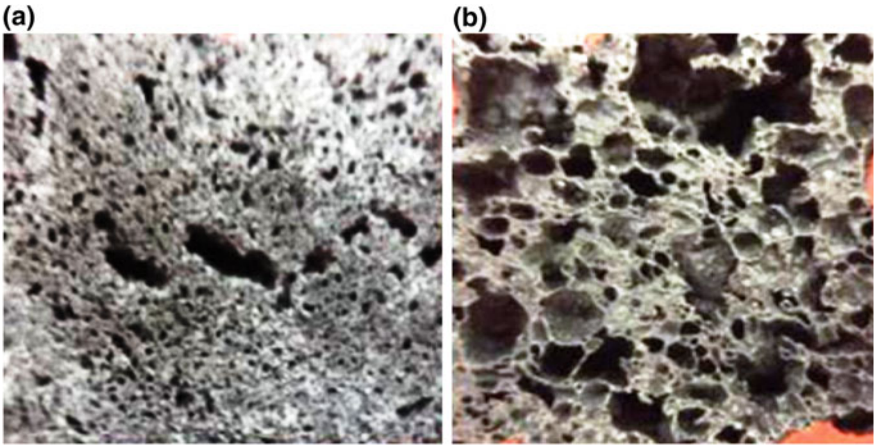

Fig. 4 **a** Precursor developed after FSP and **b** Foam developed after heat treatment

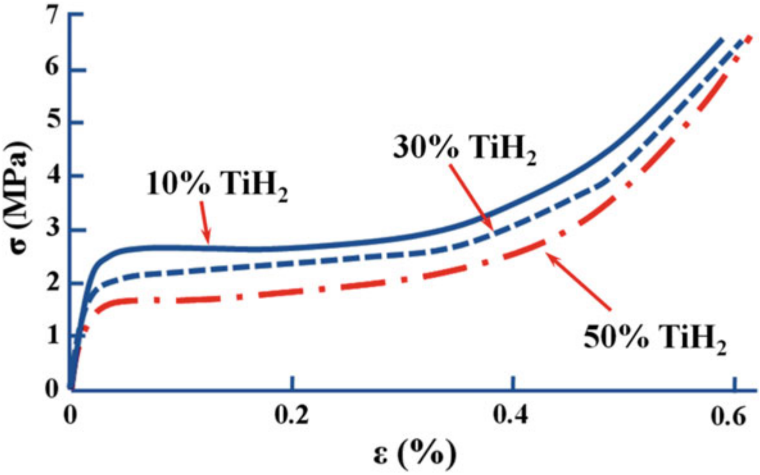

Fig. 5 Compression stress–strain curve obtained from porous foam fabricated by friction stir processing

the force absorbing capacity of the foam. Increasing the amount of plateau region increases the force absorbing capacity of the foam [16]. In this experiment, it is found that increasing the amount of TiH_2, increases the plateau region in the foam.

4 Conclusion

The successful Al-MMC foam has been developed by using FSP route. The preliminary study shows that as the weight % of foaming agent increases the tendency to resist the compressive load decreases. The composite has tendency to absorb impact energy by propagating crack at faster rate in all direction. This is also represented in the compression test as the compression strength decreases the collapse rate of pores in foam increases. This tendency increases the absorption of energy without transferring it. From the result, it is also clear that as the plateau region increases, it increasing the load-bearing capacity of the foam.

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