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Additive manufactured closed-cell aluminum alloy foams via laser melting deposition process

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ABSTRACT

Compared with traditional preparation methods to fabricate aluminum foams, additive manufacturing technology have some advantages such as the ability to prepare complex shapes and relatively high processing efficiency. In this paper, laser melting deposition (LMD) process has been used to additive manufacture aluminum alloy foams (AAFs). During LMD process, Ni-coated TiH_2 was used as the foaming agent. AAFs with different porosity and pore-size have been manufactured by LMD process. The pore size and porosity of AAFs are increasing with increasing addition of Ni-TiH_2. The sound insulation measurement results indicate that porosity and pore-size have influence on sound-insulated capability. With pore size and porosity increasing, sound-insulated capability of AAFs show a trend of decreasing at first and increasing later.

1. Introduction

Closed-cell aluminum alloy foams (AAFs) have recently aroused much concern due to its special performance [1]. Up to this day, various methods to fabricate aluminum foams have been developed, for instance, casting method [2–4], and the powder metallurgical method [5,6]. These traditional preparation methods have their own merits, however there are some deficiencies, such as poor ability to prepare complex shapes and relatively low processing efficiency. Even to this day, additive manufacturing (AM) techniques to fabricate metal parts had been evolved, and two of the most popular AM techniques are selective laser melting (SLM) [7,8] and laser melting deposition (LMD) [9]. There have been some attempts to manufacture porous metal materials by using SLM [8,10], but they are all about open-cell porous metal materials. Laser melting deposition (LMD) can produce the bulk materials through layer-by-layer [11]. During LMD process, multiple metal powders can be mixed together, and the composition of the sample can be designed as desired [12]. Therefore, LMD maybe an effective technique to manufacture AAFs. However, there are few researches on closed-cell AAFs manufactured by LMD process.

During LMD process, the temperature of melting pool is relatively high. Traditional foaming agent like TiH_2 can be instantaneously decomposed at so high temperature of LMD process. The foaming agent will be out of action. In the last few years, some scholars attempted to pretreat TiH_2, such as oxidation [13] and electroless nickel plating [14]. Thankfully, previous researches have provided us with inspiration that electroless nickel plating may be a good choice for manufacturing aluminum foams by LMD process. Nickel deposited on the surface of TiH_2 is able to withstand high temperatures, so that, TiH_2 particles will be protected and bring a good foaming effect. In this paper, we will manufacture AAFs via LMD process with the help of Ni-coated TiH_2. The closed-cell aluminum foams manufactured by LMD process can have different microstructures. Xia et al. have recently reported that closed-cell aluminum foams with different macrostructures have different acoustic properties [15]. Closed-cell aluminum foams are generally used for sound insulation due to the independence of the pores [16]. Noise pollution has become more and more serious in the world and caused wide public concern. Therefore, in this paper we will focus on the sound insulation property of the AAFs manufactured by LMD process.

2. Experimental procedures

As shown in Fig. 1(a), the process of manufacturing AAFs in this study is a combined process. It contains powder electroless plating, mechanical ball-mixing and laser melting deposition. Ni-coated TiH_2 (Ni-TiH_2) produced via a two-stepped electroless plating process was used as the foaming agent. During plating process, the

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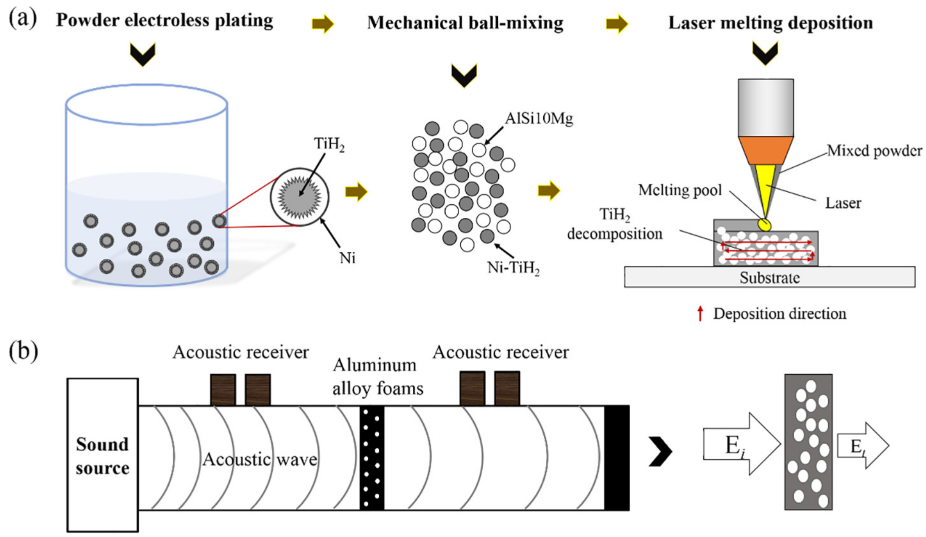

Fig. 1. Schematic diagram of the (a) process of manufacturing AAFs and (b) SETL.

steps of sensitization and activation were operated successively. $SnCl_2$ solution with molarity of 2.45 mol/L was used as sensitizer while $PdCl_2$ solution with molarity of 0.017 mol/L was used as activator. Aluminum alloy powders with average particle diameter of 100 µm and supplied from Tianjiu Corp (Changsha. China) were used as the matrix foam material. The composition of the aluminum alloy powder is listed in Table 1. For investigating the influence of Ni-TiH_2 on the foaming behavior of aluminum alloy manufactured by LMD, the designed contents of Ni-TiH_2 are 4 wt%, 5.5 wt%, 7 wt%, 8.5 wt%, 10 wt% and 11.5 wt% respectively. During LMD process, the optimized parameters are as follows: laser power of 2400 W, scanning speed of laser beam of 6 mm/s, powder feed rate of 14 g/min, overlap rate of 42%, and story height (the thickness of each individual layer) of 0.6 mm. In addition, LMD process was operated in an argon protection environment. Scanning electron microscopy (SEM), energy disperse spectroscopy (EDS), x-ray diffraction (XRD), and sound energy transfer loss test (SETL) were used to understand and evaluate the performance of the AAFs. SETL test was performed in a standing wave tube, and the test samples are all cylinders with a diameter of 30 mm and height of 10 mm. As shown in Fig. 1(b), two acoustic receiver were put in the two ends of the standing wave tube in order to test the incident sound energy (E_i) and transmitting sound energy (E_t). The following formula was used to calculate the sound insulation (R), and the unit is 'dB':

$$R = 10\log\left(\frac{E_i}{E_t}\right) \quad (1)$$

3. Results and discussion

As shown in Fig. 2(a), the surface of as-received TiH_2 powders are smooth. However, as shown in Fig. 2(b), some white particles can be seen easily on the surface of as-treated TiH_2. The white particles are mainly composed of Pd. Fig. 2(c) shows the feature of Ni-TiH_2. The size of Ni-TiH_2 is larger than that of as-received TiH_2, which indicates that many ions have been plated over the surface of TiH_2. The results of EDS show that the surface of Ni-TiH_2 is mainly composed of Ni. XRD patterns of AAFs which contain 4 wt %, 7 wt% and 11.5 wt% Ni-TiH_2 are shown in Fig. 2(d). The three XRD patterns all contain the peaks of Al (PDF-01-1180), Al3.21Si0.47 (PDF-41-1222) and Si (PDF-03-0534). No obvious peaks of Ni or Ti and their compounds are in the patterns, which indicates that the number of Ni or Ti and their compounds are tiny. Fig. 2(e) shows the cylindrical surface of as-deposited AAF which contains 8.5 wt% Ni-TiH_2. The other foams with different contents of Ni-TiH_2 have the same feature. The AAFs can be divided into three parts: fusion zone, complete foaming part and incomplete foaming part. Incomplete foaming part is near the surface where the heat accumulation is insufficient. Fig. 2(f1)-(f6) show the cross-section parallel to the depositing direction of the AAFs with different amounts of Ni-TiH_2 (4 wt%, 5.5 wt%, 7 wt%, 8.5 wt%, 10 wt% and 11.5 wt%). Porosity and pore-size are changed by adding different amount of Ni-TiH_2. Fig. 2(g1)-(g3) show the microstructures of the AAFs with 4 wt%, 7 wt%, and 11.5 wt% Ni-TiH_2. Maybe the increased porosity has reduced the cooling rate of AAFs, so that the grain size increases with increasing the adding amount of Ni-TiH_2. The morphology of the pores (this picture takes from the foam with 11.5 wt% Ni-TiH_2) shown in Fig. 2(g4) indicates that the microstructure near the pores is similar to the matrix.

Fig. 3(a)-(f) provide the macrostructures (circular cross-section) of the closed-cell AAFs with different additive amounts of Ni-TiH_2. The porosity and pore size are calculated by *ImageJ* software. The porosity of AAFs with the additive amount of 4 wt%, 5.5 wt%, 7 wt%, 8.5 wt%, 10 wt% and 11.5 wt% are 36% ± 2%, 43% ± 2%, 45% ± 2%, 53% ± 2%, 66% ± 2% and 70% ± 2% respectively. Fig. 3(g) presents the pore-size distribution of the AAFs. The pores are almost micron-sized until the additive amount of Ni-TiH_2 is over 8.5 wt%. When the additive amount of Ni-TiH_2 is small, the Ni-TiH_2 particles in the melting pool are scattered, therefore, the pores are scattered and small. When the addition of Ni-TiH_2 is over a certain amount, the distance between two Ni-TiH_2 particles will be small enough, and they can work together, resulting large pore-

Table 1
Elements content of the aluminum alloy powders.

Element	Fe	Ti	Cu	Cr	Zn	Mg	Mn	Si	Al
Wt%	0.7	0.15	~0.2	~0.08	~0.25	0.8	0.15	9.2	Balance