OBTAINING OF ALUMINIUM FOAM BY INTRODUCING MECHANOCOMPOSITES INTO THE MELT

ПОЛУЧЕНИЕ ПЕНОАЛЮМИНИЯ ВВЕДЕНИЕМ В РАСПЛАВ МЕХАНОКОМПОЗИТОВ

Prof., Dr. Eng., Cor. Member of NAS of Belarus Ilyushchenko A.[1], Cand. Eng., Assoc. Prof. Kusin R.[2],
Cand. Eng., Assoc. Prof. Letsko A.I.[2], Charniak I.[3], Ilyukevich A.I.[2], Zhehzdryn D.[3], Haliakov M. [2]
State research and production powder metallurgy association, State Scientific Institution "Powder metallurgy institute" [1],
Belarusian state agriculture technical university [2], State Scientific Institution "Powder metallurgy institute"[3] - Minsk, Republic of Belarus
E-mail: nil23niipm@tut.by, irinacharniak@tut.by

Abstract *The report focuses on the process of obtaining closed cell aluminum foam by introducing a composite material obtained by high energy mechanical treatment in a planetary mill into the melt. In contrast to known methods, the paper describes the foaming performed by introducing compressed precursors based on aluminum into the melt. Air-atomized aluminum powder and titanium hydride were used as raw materials for the production of precursors, AK5M2 silumin melt was used for the basis. Implementation of these works does not require the creation of a protective atmosphere and equipment for hot pressing. Photographs of the samples' appearance and study results have been presented. It has been shown that the method of introducing mechanocomposites into the melt may be used for the manufacture of closed cell aluminum foam.*

KEYWORDS: ALUMINIUM FOAM, ALUMINIUM-BASED MELT, MECHANOCOMPOSITES, HIGH-ENERGY MECHANICAL TREATMENT, PROPERTIES

1. Introduction

Recently there has been a considerable interest in the development of new compounds and technologies for production of aluminum foam because the products from this material possess an unusual set of properties due to chemical and physical properties of aluminum and the anisotropic structure of the material.

Aluminum foam is a cellular aluminum-based material. There are two types of aluminum foam:

(a) close-cellular; and

(b) open-cellular.

Aluminum foam is widely used in various branches of engineering and construction. It is also applicable for manufacturing filters and heat exchangers, sound insulation material, etc.

The method for production of open-cellular foam aluminum is as follows: Liquid metal is cast into a mould with filler (water-soluble salt with the melting temperature which is higher than the liquidus of the implemented alloy) [1, 2]. After removal of the filler we have a solid with interconnected pores.

Basic methods for production of close-cellular foam aluminum [3, 4, 5]:

Gas purging through the molten Al-SiC or Al-Al_2O_3. It is the least expensive method which is used for production of foam aluminum with a relative density of 0.03-0.1 and pore diameter of 5-20 mm [3, 4].

Addition of titanium hydride (zirconium) into the melt followed by dynamic stirring, heating and pressure control during cooling of the resulting material [3, 4]. *Mixing of metal powder (mainly aluminum) with titanium hydride (TiH_2), followed by melting to a pasty consistency* [3, 4, 5].

Mixing of the charge components may occur as a result of either a direct mixing or simultaneous milling [3, 4], or mechanical alloying of the matrix material by a foaming agent [5]. This technique [3 - 6] involves four steps: preparing powder mixtures of a matrix alloy and foaming agent; compacting; heating to the foaming temperature and aging; cooling. This method is suitable for Al-, Zn-, Fe-, Pb-, and Au- alloys. Foaming occurs by introduction of solid mixed powders of different chemical substances into the metal.

The method of mechanical alloying is a promising method for producing foam aluminum. It involves handling of powder components and their mixtures of various compositions in high-energy mills and the subsequent consolidation of the newly-formed activated mixture for producing semi-finished or finished components [7]. The advantage of mechanical alloying is the use of production waste and scrap of aluminum alloys, which greatly reduces the cost of the process.

In this paper we suggest entering mechanocomposites into the silumin melt in order to obtain close-cellular foam aluminum. Foaming is achieved by introducing pressed mechanocomposites into the silumin melt (Grade AK5M2). The mechanocomposites are obtained from mechanically alloyed aluminum powder and titanium hydride, a foaming agent. The implementation of the process does not require additional machining (obtaining cuttings, grinding etc.) of the matrix alloy, supply of gas medium for foaming the melt, hot [8] or a two stage compacting of mechanocomposites [5].

The purpose of this work is to study the process of obtaining aluminum foam with closed porosity by means of introducing mechanocomposites (based on dispersed aluminum powder) into the melt.

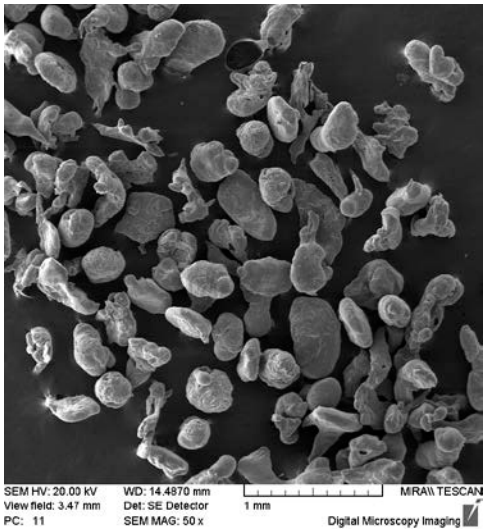
2. Results and discussion

In order to investigate the process of producing aluminum foam with closed porosity we used aluminum powder obtained by spraying molten metal by the gas flow, titanium hydride TiH_2 and silumin alloy of Grade AK5M2. The content of the foaming agent TiH_2 in the charge of the mechanocomposite Al + TiH_2 was Al 99,25 - Ti 0,75 % wt, Al 99,0 - Ti 1,0 % wt, Al 98,5 - Ti 1,5 % wt, Al 98,25 - Ti 1,75 % wt, Al 98,0 - Ti 2,0 % wt; Al 97,75 - Ti 2,25 % wt. The process of preparation comprises the following steps: drying of initial powders, mixing, mechanical alloying, extrusion, foaming.

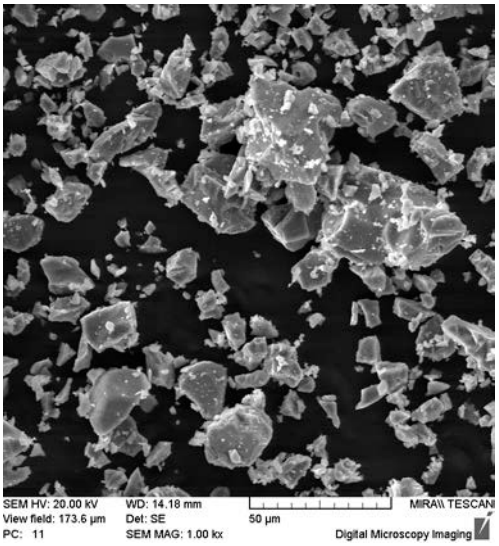
Drying of initial powders. The powders were dried on stainless steel trays. The depth of filling was not more than 30 mm. Drying was carried out in the oven SNVS 4,5.4,5.4/3I1 at 80 - 90 °C for two hours.

Mixing. In the creation of the mechanocomposite for producing aluminum foam we used the method of mechanical alloying which consists in intensive plastic deformation of the acquired charge in a high-energy mill. Initially suspended samples of dispersed aluminum powder fractions (-0.315 + 0.2) mm and 50 grams of the foaming agent (titanium hydride powder containing 1.5 % by weight of the powder) was placed in the mixer SMB-4 and stirred for four hours at the rotational speed of 60 min^{-1}. The photos describing the morphology of the powder particles of aluminum and titanium hydride are shown in Figure 1.

Mechanical alloying. Mechanical alloying of the powder mixture was carried out in a planetary ball mill RM400MA (Retsch, Germany) at the ratio of 10:1 (the weight of the balls to weight of the processed material). The rotational speed of the planetary disc was 400 rev/min (corresponding to an overload of 26 g) for 30 minutes.

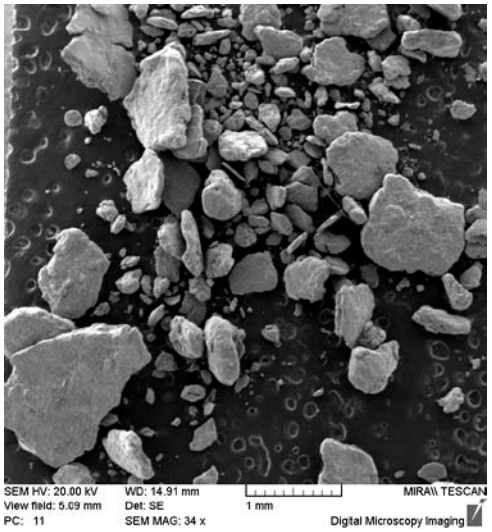


a)

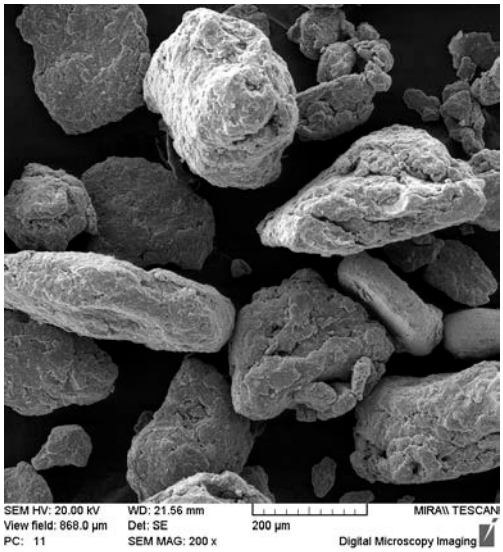


b)

Fig. 1 *Surface morphology of particles in the initial powders*
a) aluminum, atomization of molten metals by a gas flow (argon) × 50;
b) titanium hydride (TiH_2), × 1000



a)



b)

Fig. 2 *Surface morphology of mechanocomposites Al – 1.5% TiH_2, for producing aluminum foam, 30 minutes after mechanical alloying in the planetary mill at different magnifications a) × 34; b) × 200*

We used steel balls (structural bearing steel) of 10 mm in diameter as grinding media. The surface morphology of the acquired mechanocomposites was performed using a scanning electron microscope MIRA from Tescan (Czech Republic) in the backscatter electron mode at accelerating voltage of 20 kW (Figure 2).
The phase composition study of the mechanocomposite Al + TiH_2 after mechanical alloying was performed in $Cu_{k\alpha}$ radiation using an x-ray diffractometer DRON-3. The analysis results show that the phase composition of the samples as follows: aluminum (Al), titanium hydride (TiH_2), aluminum hydride (AlH_3), titanium aluminide (Al_3Ti). The X-ray diffraction image of the sample mechanocomposite is shown in Figure 3.

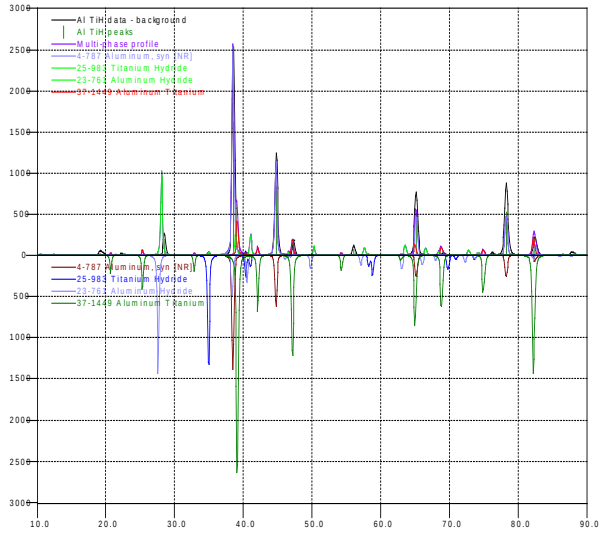


Fig. 3 *X-ray diffraction image of the sample mechanocomposite Al + TiH_2*

During the high-energy treatment a partial interaction of Al and TiH_2 takes place with formation of intermetallics Al_3Ti and AlH_3. Semi-quantitative analysis using the programs DRWIN (point-to-point X-ray processing) and Qual (comparison of the cards with processed X-ray images) is difficult due to the superposition of the main peaks of the identifiable phases.

Extrusion. The sample of mechanocomposite Al + TiH_2 was weighed on the scales VK-600 within the accuracy of 0.01 g. It was filled into the forming block with the diameter of 30 mm and then molded in a press type ZD40 at 425 MPa. After molding the preform is extruded from the die. Appearance of compacts is shown in Figure 4.

Fig. 4 *Appearance of a compact made of the mechanocomposite Al + TiH_2*

Foaming. Foaming was achieved by introducing compacts of the mechanocomposite Al + TiH2 into the silumin melt AK5M2. The silumin AK5M2 was melted at 700 °C in a muffle furnace SNOL 1.6 equipped with a pot for manufacturing test specimens of foam aluminum by mechanical alloying. The pot with the melt was removed from the furnace chamber and mechanocomposite compacts were added into the melt. While warming up the mechanocomposite to 350-400 °C, decomposition of the foaming agent intensified, together with evolution of hydrogen. During decomposition of the foaming agent the mechanocomposite was destroyed. Its particles were distributed in the melt, releasing hydrogen and foaming the silumin melt. Then the fixture was placed in the refrigerator for the final crystallization of the melt. After cooling, the experimental sample of aluminum foam was taken out. The structure of the aluminum foam is shown in Figure 5.

Fig. 5 *Structure of aluminum foam. The mechanocomposite Al + TiH_2 contains 1.5 % of the foaming agent (titanium hydride)*

The study of dependence of porosity on the content of the foaming agent showed the following results. When the charge contains less than 1.25 % of TiH_2 the porosity of the samples is uneven, some solid portions are not foamed and the close cell rate is low: (48 % or lower). The samples prepared using the charge with 1.25 – 1.5 % TiH_2 have a uniform structure, high close cell rate (56 and 63 %) and no cavities. The samples prepared using the charge with 1.75 % TiH_2 have uneven structure and contain unmelted inclusions of compacts. When the amount of TiH_2 exceeds 2 % the samples have open pore structure, cavities in the surface and a low close cell rate (lower than 55 %).

Based on the acquired data, the optimal composition of a workpiece for processing in a charge shall contain 1.5% of the foaming agent.

The results show that when the mechanocomposite Al + TiH_2 contains 1.5 % of TiH_2 there is a complete dissolution and uniform distribution of AK5M2 silumin in the melt. We observed a uniform distribution of closed pores without cavities. The porosity of the samples containing 1.5 % of the foaming agent TiH_2 was 63 %.

3. Conclusion

The study results show that when the mechanocomposite Al + TiH_2 contains 1.5% of TiH_2 there is a complete dissolution and uniform distribution of AK5M2 silumin in the melt. The porosity of the samples containing 1.5% of the foaming agent TiH_2 was 63%.

It is proved that the proposed method of manufacturing closed cell aluminum foam allows obtaining a uniform structure of closed pores. The method implies introduction of mechanically alloyed atomized aluminum-based powder into the melt.

The described works do not require additional mechanical treatment (shaving, grinding, etc.) of the matrix alloy, admission of gas environment for foaming the melt, hot [8], or a two stage compacting of mechanocomposites [5].

4. Literature

1. Kovtunov A., Khokhlov Y., Chernyshova Y. Technology of manufacturing products from foam aluminum. The proceedings of V All-Russian scientific conference "Problems and prospects of development of aviation, ground transportation and energy "ANTE-2009". 2009, vol. 2, pp. 320-322, (in Russian).

2. Pat. 2400552 Russian Federation, IPC C22C 1/08, C22B 21/00, B22D 21/04. Method for producing foam aluminum. Kovtunov A., Chermashentseva T., Semistenov D., Sidorov V. Applicant and patentee OOO Srednevolzhskij sertifikacionno-diagnosticheskij centr "Del'ta". No. 2008146788/0 dd 26.11.2008; publ. 27.09.2010, Bulletin No.27, 4 p. (in Russian).

3. Butarovich D. Aluminum foam as an energy absorbing material and its mechanical properties (eds. D. Butarovich, A. Smirnov, D. Ryabov) Izvestija vysshih uchebnyh zavedenij. Mashinostroenie, No. 7, pp. 53-58, 2011 (in Russian).

4. Ashby, M.F. Metal Foams: A Design Guide [Text] / MF Ashby, A.G. Evans, N.A. Fleck, L.J. Gibson, J.W. Hutchinson and H.N.G. Wadley, Butterworth-Heinemann, 2000.

5. Ivanov D. Research and modeling of aluminum foam produced by alloying from recycled aluminum raw materials (eds. O. Ivanov, A. Aksenov, I. Ivanov) Izvestija vuzov. Cvetnaja metallurgija. No. 6, pp. 56-61, 2007 (in Russian).

6. Ivanov D. Research and development of aluminum foam produced by mechanical alloying from secondary raw materials. Dissertator: Cand. Sc. Eng: Dmitry O. Ivanov. 05.16.01, Moscow, 2008 (in Russian).

7. Kuzmich Y. Mechanical alloying (eds. Y. Kuzmich, I. Kolesnikova V. Serba, B. Freidin; Executive Editor: E. Poliakov), Moscow: Nauka, 213 p., ISBN 5-02-033726-9, 2005 (in Russian).

8. Ersoy, Emrah. An experimental study on hot formability of closed cell metallic foams (eds. Emrah Ersoy, Yusuf Özçatalbaş, Ersin Bahçecı) The Proceedings of 1st International Symposium: Porous and Powder Materials (PPM 2013), 3-6 September 2013, Izmir Turkey, pp. 68-72; ISBN 978-975-6590-05-8.