FABRICATION OF LIGHT BIMETALLIC AZ31/6060 MATERIAL BY COMPOUND CASTING

Tomasz BUCKI, Renata MOLA

Kielce University of Technology, Kielce, Poland, EU, tbucki@tu.kielce.pl

Abstract

The AZ31/6060 bimetallic material was fabricated through compound casting, which involved pouring AZ31 magnesium alloy heated up to 660 °C onto a 6060 aluminum alloy insert placed in a steel mould, both preheated to 300 °C. The microstructural analysis was performed with an optical microscope (OM) and a scanning electron microscope equipped with an energy-dispersive X-ray spectrometer (SEM-EDS). Three characteristic areas could be distinguished in the 400-500 μm thick continuous bonding zone, which formed between the alloys. The EDS quantitative analysis revealed that the area close to the AZ31 was a eutectic (an $Mg_{17}Al_{12}$ phase and a solid solution of Al in Mg); then, there were dendrites of an $Mg_{17}Al_{12}$ phase; and finally, in the area adjacent to the 6060 alloy, an Al_3Mg_2 phase was detected. Fine particles of an Mg_2Si phase and phases rich in Al, Mn and Fe were distributed over the entire bonding zone. Small porosity was observed only locally.

Keywords: Magnesium alloy, aluminum alloy, compound casting, intermetallic phases, microstructure

1. INTRODUCTION

Compound casting is a technique of joining two dissimilar alloys. It involves pouring a liquid alloy directly onto a solid one placed in the cavity of a mould. This method enables efficient and cheap fabrication of bimetallic parts, especially elements complex in shape.

The literature data shows that compound casting has been used for years to join various dissimilar alloys, e.g. steel-cast iron [1-3], steel-Al [4], Al-Cu [5], dissimilar Al alloys [6,7] or dissimilar Mg alloys [8]. In recent years, extensive research has been conducted to join Mg alloys to Al alloys using various methods [9]. This trend is particularly evident in the automotive and aerospace industries, where the application of Mg/Al bimetallic parts is desirable, due to their low density and favorable properties. A review of the literature shows that there have been very few studies on the application of compound casting to produce bimetallic parts based on Mg and Al. Most researchers, however, focus on joining pure Mg to pure Al [10-14]. In such a case, the structure of the bonding zone is composed of a solid solution of Al in Mg, a solid solution of Mg in Al, and $Mg_{17}Al_{12}$ and Al_3Mg_2 phases. Some studies reveal that when pure Mg or an Mg alloy is joined to an Al alloy (Mg-AlMg1 [15], AZ91-A356 [16] and AZ91-AlSi17 [17-19]), the microstructure and properties of the bonding zone undergo significant modification.

The aim of this study was to fabricate a light bimetallic material, composed of AZ31 magnesium alloy and 6060 aluminum alloy, using the compound casting method. The microstructure and composition of the bonding zone formed between the alloys were analyzed.

2. EXPERIMENTAL DETAILS

AZ31 magnesium alloy, containing 3.07 wt.% Al, 1.05 wt.% Zn and 0.31 wt.% Mn, was used as the cast material. The solid insert, 10 mm in thickness and 30 mm in diameter, was cut from 6060 wrought aluminum alloy (0.50 wt.% Si, 0.47 wt.% Mg and 0.19 wt.% Fe). The surface of the insert was ground using SiC papers up to 800 grit and cleaned in ethanol. The insert was then placed in a steel mould, both heated to 300 °C. The AZ31 (100 g) was melted in a furnace under argon atmosphere at a temperature of 660 °C and poured into the mould with the aluminum alloy insert under normal atmospheric conditions.

The samples for structural observations were cut from the AZ31/6060 joints. The samples were polished using aluminum oxide slurry and colloidal silica. The microstructural analysis was performed with a Nikon ECLIPSE MA200 optical microscope and a JEOL JSM-5400 scanning electron microscope equipped with an energy-dispersive X-ray spectrometer (EDS).

3. RESULTS AND DISCUSSION

Figure 1 shows the microstructure of the bonding zone of the AZ31/6060 specimen observed with the optical microscope. The low magnification image in **Figure 1(a)** indicates that the compound casting process resulted in a continuous, 400-500 µm thick bonding zone. Three characteristic areas, marked A, B and C, can be distinguished in the bonding zone. The high magnification image in **Figure 1(b)** reveals that the area on the AZ31 side (area A) has a two-phase structure with fine, dark particles. In the transition area (area B) light dendrites are visible (upper part of **Figure 1(c)**). Below the dendrites, there is a single-phase white matrix with fine needle-like particles and coarser dark particles regular in shape. **Figure 1(d)** illustrates area C, adjacent to the 6060 alloy, where dark particles are distributed over the light matrix.

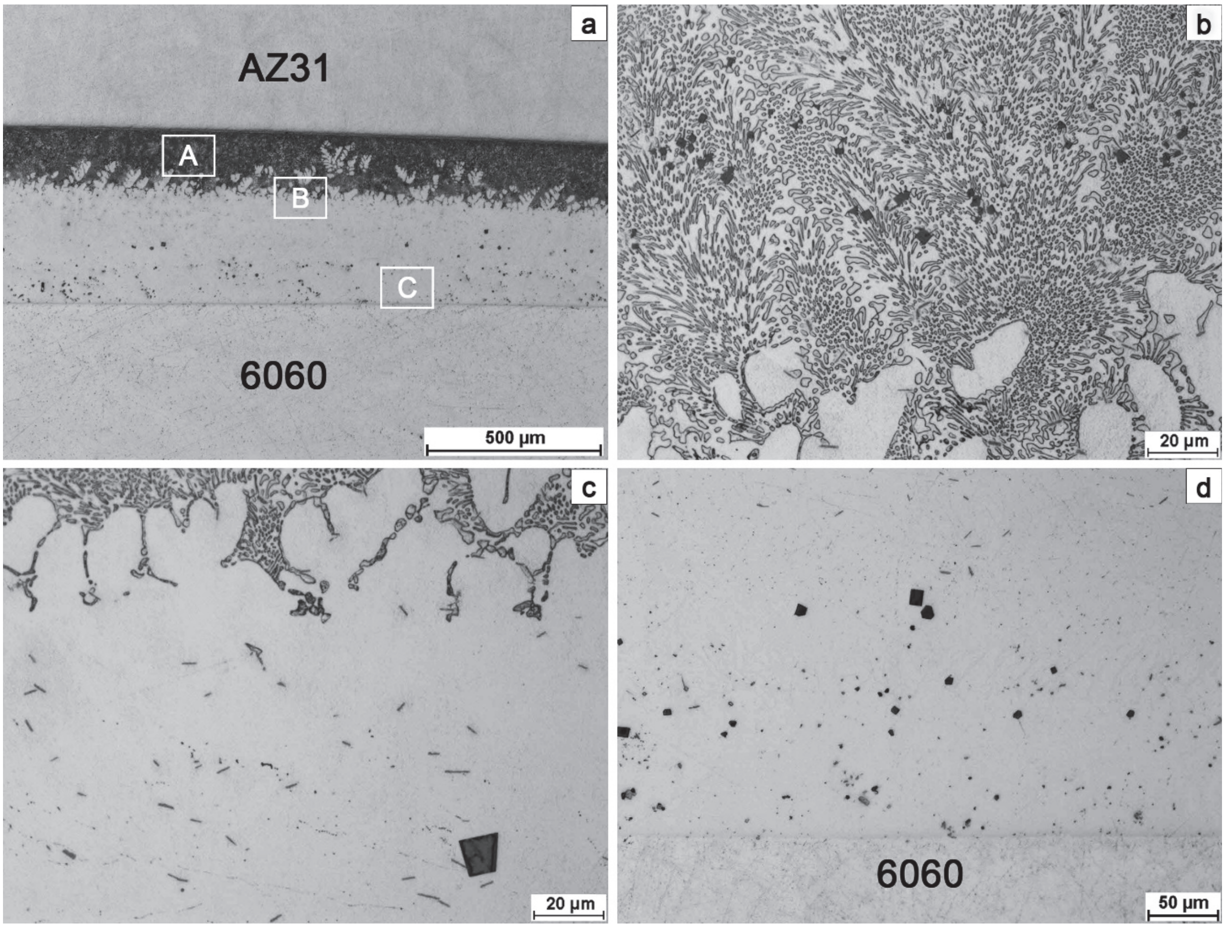

Figure 1 OM images of the microstructure of the bonding zone in the AZ31/6060 joint fabricated by compound casting: (a) low magnification image, (b) high magnification image of area A, (c) high magnification image of area B, (d) high magnification image of area C

Figure 2 shows the microstructure of the bonding zone close to the AZ31 alloy observed through scanning electron microscopy, The EDS linear analysis along the marked line reveals that the bonding zone is composed mainly of Mg and Al. Si and Mn occur locally.

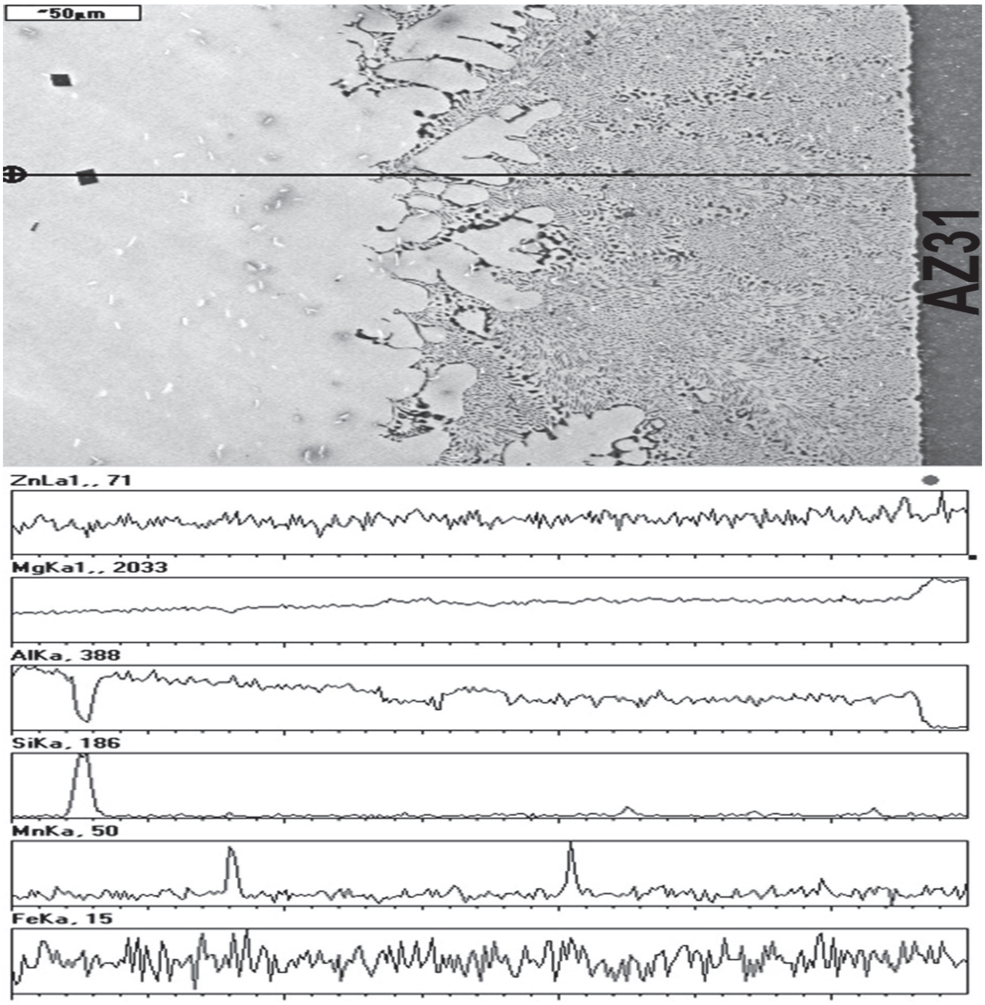

Figure 2 SEM image of the microstructure of the bonding zone close to the AZ31 alloy and the linear distributions of the elements (Zn, Mg, Al, Si, Mn and Fe)

Figure 3 presents details of the microstructure at the interface between areas A and B. The EDS quantitative analysis was carried out at different points (marked in this figure) and the results are given in **Table 1**. From the Al-Mg equilibrium diagram it is clear that the light dendrites (points 1a and 1b) are an $Mg_{17}Al_{12}$ intermetallic phase. The EDS results for the dark phase (points 2a and 2b) indicate a solid solution of Al in Mg. From the concentration of Si along the marked line (**Figure 3(a)**) it is evident that the particles regular in shape are rich in this element. The result of the quantitative analysis suggests that these particles are an Mg_2Si phase. The chemical composition of the two-phase matrix (points 3a and 3b) suggests a eutectic composed of an $Mg_{17}Al_{12}$ phase and a solid solution of Al in Mg. The linear distribution of the elements in these regions (**Figures 3(a)** and **3(b)**) reveals that the fine, needle-like particles are rich in Al, Mn and Fe.

Figure 4 presents details of the microstructure of the bonding zone on the 6060 alloy side. The results of the EDS quantitative analysis for the points marked in this figure are provided in **Table 2**. The chemical composition of the area located about 60 µm from the 6060 alloy (analysis at point 1) is similar to that of the Al_3Mg_2 intermetallic phase. The result obtained for the area near the 6060 substrate (point 2) also indicates the Al_3Mg_2 phase. The composition of the dark particles (point 3) suggests the Mg_2Si phase. The linear analysis results along the line marked in **Figure 4** reveals the occurrence of light particles rich in Al, Mn and Fe. The quantitative analysis for the light particles (point 4) confirms the Al-Mn-Fe multicomponent phase.

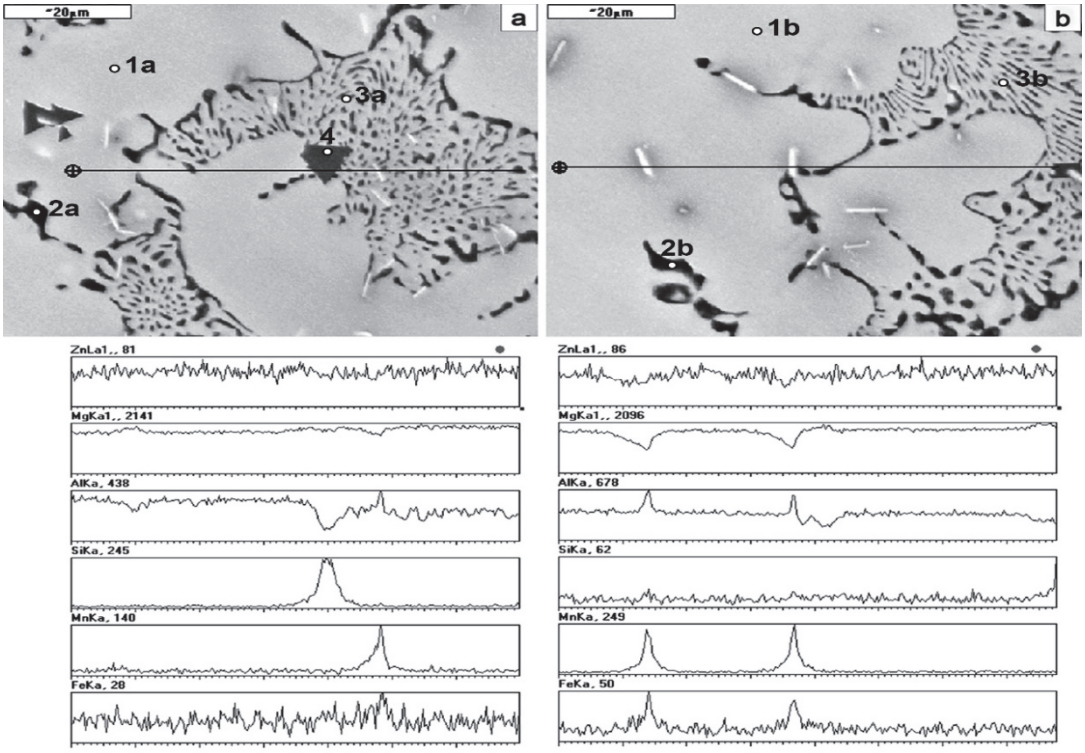

Figure 3 Details of the microstructure of the interface between areas A and B and the linear distributions of the elements (Zn, Mg, Al, Si, Mn and Fe)

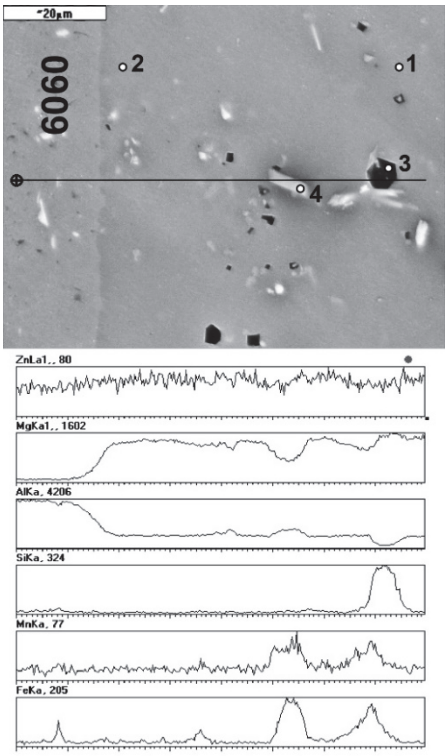

Figure 4 Details of the microstructure of the bonding zone on the 6060 alloy side and the linear distributions of the elements

Table 1 Chemical composition (at.%) of the areas marked in **Figures 3(a) and 3(b)**

Point	Mg	Al	Zn	Si
1a	66.83	32.96	0.21	-
1b	65.06	34.78	0.16	-
2a	80.03	19.97	-	-
2b	80.21	19.79	-	-
3a	73.44	26.56	-	-
3b	72.48	27.52	-	-
4	69.45	0.87	-	29.68

Table 2 Chemical composition (at.%) of the areas marked in **Figure 4**

Point	Mg	Al	Si	Fe	Mn
1	44.02	55.98	-	-	-
2	41.77	58.23	-	-	-
3	67.36	-	32.64	-	-
4	26.95	65.92	0.40	5.02	1.71

The microstructural analysis of the bonding zone along the entire length of the sample shows that the bonding zone is continuous and uniform in thickness. As can be seen from **Figure 5**, porosity occurs locally, mainly in the eutectic area.

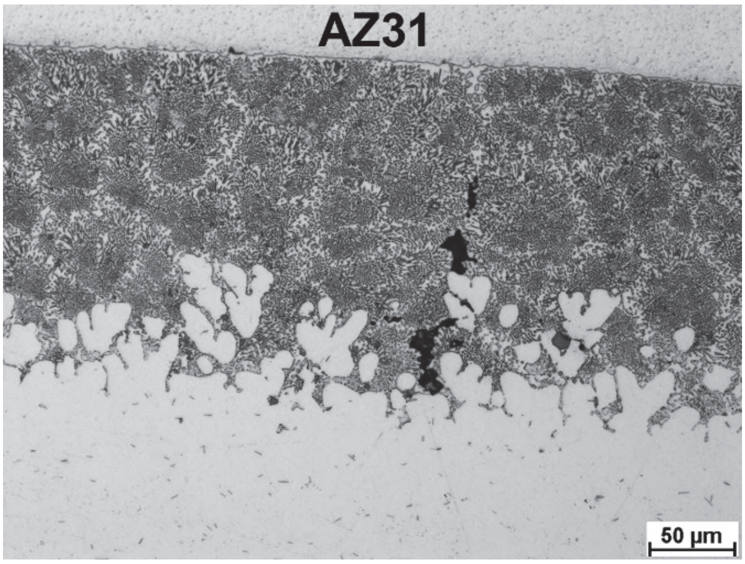

Figure 5 OM image of the microstructure of the AZ31/6060 joint with some porosity locally distributed over the bonding zone

4. CONCLUSION

The analyzed AZ31/6060 bimetallic material was fabricated through compound casting, which involved pouring AZ31 magnesium alloy heated to 660 ºC onto a 6060 aluminum alloy insert placed in a steel mould, both preheated to 300 ºC. The process resulted in the formation of a continuous, 400-500 μm thick bonding zone. Three characteristic areas were distinguished. The area close to the AZ31 was composed of a eutectic (an $Mg_{17}Al_{12}$ phase and a solid solution of Al in Mg), below, there were dendrites of an $Mg_{17}Al_{12}$ phase and finally, in the area adjacent to the 6060 alloy, an Al_3Mg_2 phase was detected. In whole bonding zone, fine particles of an Mg_2Si phase and phases rich in Al, Mn and Fe were detected. Small porosity occurred locally, mainly in the eutectic area.

REFERENCES

[1] TENEROWICZ, Sławomir, SUCHOŃ, Jacek and CHOLEWA, Mirosław. Studies of the transition zone in steel - chromium cast iron bimetallic casting. *Archives of Foundry Engineering.* 2010. vol. 10, no. 1, pp. 199-204.

[2] WRÓBEL, Tomasz and SZAJNAR, Jan. Bimetallic casting: ferritic stainless steel - grey cast iron. *Archives of Metallurgy and Materials.* 2015. vol. 60, no. 3, pp. 2361-2365.

[3] AVCI, Ahmet, ILKAYA, Nevzat, SIMSIR, Mehmet M. and AKDEMIR Ahmet. Mechanical and microstructural properties of low-carbon steel-plate-reinforced gray cast iron. *Journal of Materials Processing Technology*. 2009. vol. 209, no. 3, pp. 1410-1416.

[4] CHOE, K. H., PARK, K. S., KANG, B. H., CHO, G. S., KIM, K. Y., LEE, K. W., KIM, M. H., IKENAGA, A. and KOROYASU, Sadatoshi. Study of the Interface between steel insert and aluminum casting in EPC. *Journal of Materials Science & Technology*. 2008. vol. 24, no. 1, pp. 60-64.

[5] ZARE, G. R., DIVANDARI, Mehdi and ARABI, Hossein. Investigation on interface of Al/Cu couples in compound casting. *Materials Science and Technology*. 2013. vol. 29, no. 2, pp. 190-196.

[6] PAPIS, Konrad J. M., HALLSTEDT, Bengt, LÖFFLER, Joerg F. and UGGOWITZER, Peter J. Interface formation in aluminum - aluminum compound casting. *Acta Materialia*. 2008. vol. 56, no. 13, pp. 3036-3043.

[7] SUN, Jianbo, SONG, Xiaoyang, WANG, Tongmin, YU, Yingshui, SUN, Min, CAO, Zhiqiang and LI, Tingju. The microstructure and property of Al-Si alloy and Al-Mn alloy bimetal prepared by continuous casting. *Materials Letters*. 2012. vol. 67, pp. 21-23.

[8] PAPIS, Konrad J. M., LÖFFLER, Joerg F. and UGGOWITZER, Peter J. Interface formation between liquid and solid Mg alloys - an approach to continuously metallurgic joining of magnesium parts. *Materials Science and Engineering*. 2010. vol. 527, no. 9, pp. 2274-2279.

[9] LIU, Liming, REN, Daxin, and LIU Fei. A Review of dissimilar welding techniques for magnesium alloys to aluminum alloys. *Materials (Basel)*. vol. 7, no. 5, pp. 3735-3757.

[10] HAJJARI, Esmaeil, DIVANDARI, Mehdi, RAZAVI, Seyed H., EMAMI, S. M., HOMMA, Tomoyuki and KAMADO, Shigeharu. Dissimilar joining of Al/Mg light metals by compound casting process. *Journal of Materials Science*. 2011. vol. 46, no. 20, pp. 6491-6499.

[11] PARAMSOTHY, Muralidharan, SRIKANTH, Narasimalu and GUPTA, Manoj. Solidification processed Mg/Al bimetal macrocomposite: Microstructure and mechanical properties. *Journal of Alloys and Compounds.* 2008. vol. 461, pp. 200-208.

[12] HAJJARI, Esmaeil, DIVANDARI, Mehdi, RAZAVI, Sayed. H., HOMMA, Tomoyuki and KAMADO, Shigeharu. Intermetallic compounds and antiphase domains in Al/Mg compound casting. *Intermetallics.* 2012. vol. 23, pp. 182-186.

[13] EMAMI, S.M., DIVANDARI, Mehdi, ARABI, Hossein and HAJJARI, Esmaeil. Effect of melt-to-solid insert volume ratio on Mg/Al dissimilar metals bonding. *Journal of Materials Engineering and Performance.* 2013. vol. 22, no. 1, pp. 123-130.

[14] MOLA, Renata, BUCKI, Tomasz and DZIADOŃ, Andrzej. Formation of Al-alloyed layer on magnesium with use of casting techniques. *Archives of Foundry Engineering*. 2016. vol. 16, no. 1, pp. 112-116.

[15] PAPIS, Konrad J.M., LOEFFLER, Joerg F. and UGGOWITZER, Peter J. Light metal compound casting. *Science China Technological Sciences.* 2009. vol. 52, no. 1, pp. 46-51.

[16] HAJJARI, Esmaeil, DIVANDARI, Mehdi, RAZAVI, Sayed. H., HOMMA, Tomoyuki and KAMADO, Shigeharu. Microstructure Characteristics and Mechanical Properties of Al 413/Mg Joint in Compound Casting Process. *Metallurgical and Materials Transactions A.* 2012. vol. 43, no. 12, pp. 4667-4677.

[17] LI, Guangyu, JIANG, Wenming, FAN, Zitian, JIANG, Zailiang, LIU, Xinwang and LIU, Fuchu. Effects of pouring temperature on microstructure, mechanical properties, and fracture behavior of Al/Mg bimetallic composites produced by lost foam casting process. *The International Journal of Advanced Manufacturing Technology*. 2016. vol. 91, no. 1-4, pp. 1355-1368.

[18] MOLA, Renata, BUCKI, Tomasz and DZIADOŃ, Andrzej. Effects of the pouring temperature on the formation of the bonding zone between AZ91 and AlSi17 in the compound casting process. *IOP Conference Series: Materials Science and Engineering*. 2017. vol. 179, pp. 1-6.

[19] MOLA, Renata, BUCKI, Tomasz and DZIADOŃ, Andrzej. Microstructure of the bonding zone between AZ91 and AlSi17 formed by compound casting. *Archives of Foundry Engineering*. 2017. vol. 17, no. 1, pp. 202-206.

[20] MOLA, Renata and BUCKI, Tomasz. The microstructure and properties of the bimetallic AZ91/AlSi17 joint produced by compound casting. *Archives of Foundry Engineering*. 2018. vol. 18, no. 1, pp. 71-76.