Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 100 (2015) 1319 – 1323

Procedia Engineering

www.elsevier.com/locate/procedia

25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014

Research of Interactions between Al Substrate and Zn-Al Solders

Igor Kostolný*, Roman Koleňák

Slovak University of Technology in Bratilsava, Faculty of Materials Science and Technology in Trnava, Institute of Production Technologies Paulínska 16, 91724 Trnava, Slovak Republic

Abstract

The aim of work consists in the study of interactions on solder/substrate boundary in fluxless soldering of self-hardening Al alloy Al7075. The ZnAl5Mg3 and ZnAl5Cu3 solders were used in experiments. The soldering parameters were as follows: soldering temperature from 350 ºC to 390 ºC., acting time of ultrasonic energy 3 to 5 s, ultrasound frequency 20 kHz. Soldered joints were assessed by optical light microscopy, EDX microanalysis and XRD analysis. It was found out that the ZnAl5Mg3 solder is composed of β-Zn phase and of eutecticum composed of Mg_2Zn_{11} intermetallic phase. ZnAl5Cu3 solder is composed of β-Zn phase and $CuZn_5$ intermetallic phase in base β-Zn matrix. Due to eutectic reaction between the solder and substrate, strong interaction on boundary was observed. The reaction layer was formed mostly of α(Al)-β(Zn) mixture.

© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Peer-review under responsibility of DAAAM International Vienna

Keywords: interface; boundary; ultrasonic energy; fluxless soldering; interaction

1. Introduction

Fluxless soldering is a technology which, owing to application of certain techniques, allows to eliminate the need of flux in the process of removing surface oxides during soldering. Interest in such a method is ever growing at present mainly from the side of industrial plants, since there is growing number of products, that cannot be fabricated by use of flux [1]. This concerns for example the sensor devices, bio-medicine of photonic equipments.

With growing use of Al and its alloys also suitable way of metallurgical joining of these materials was searched for [2]. Soldering technology is one of such possibilities. Due to environmental requirements, interest in fluxless soldering is topical nowadays. Soldering of Al and its alloys at low temperatures is usually done with Sn based solders, but in case of higher temperatures the Zn based solders are mostly used [2].

* Corresponding author. Tel.: +421 918 746 159

E-mail address: igor.kostolny@stuba.sk

1877-7058 © 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Peer-review under responsibility of DAAAM International Vienna

doi:10.1016/j.proeng.2015.01.499

Authors [3, 4, 5, 6] have studied the microstructure and mechanical properties of joints by application of ZnAl5, ZnAl3 and Zn-Sn solders. Removing of surface oxides was realised with the aid of ultrasonic energy. The Al 2024/ZnAl5/Al 2024 joints were fabricated at soldering temperature 400 ºC. By prolonging the time of ultrasonic vibrations from 3s to 30s a drop in the volume of fine eutectic phases from 12.9 % to 0.9 % was observed and also tensile strength increased up to 149 to 153 MPa. The Al 1060/ZnAl3/Cu joints were fabricated at soldering temperature 400 to 480 ºC. Formation of $Al_{4,2}Cu_{3,2}Zn_{0,7}$ intermetallic phase with the lowest thickness 1.9 µm was observed at soldering temperature 440 ºC. The highest tensile strength measured at this temperature was 78.93 MPa.

Authors [7, 8, 9, 10, 11] studied the properties of Zn-Al based solders for higher application temperatures. Considered were ZnAl5Cu3, Zn-Al-Ge, ZnAl4Mg3Ga3 and ZnAl4 solders. Addition of higher amount of Al and Cu affected the growth of eutectic-eutectoid phase what caused increase in hardness and tensile strength. Wettability of Zn-Al-Ge solder was better at higher temperatures approaching the maximum working temperature of silicon chips. The measured shear strength varied from 15.5 MPa to 22.3 MPa. Soldering of chips by use of ZnAl4Mg3Ga3 solder may be realised at temperature 320 ºC or higher. The fabricated joint has shown good properties after exposure to thermal cycles. No cracks or other defects were observed. Addition of 1% Cu to ZnAl4 solder in case of soldering on Cu substrate resulted in reduction of activation energy for growth of intermetallic compounds. Soldering of pure Al and Cu with ZnAg6Al6 solder was studied in the work [12,13].

The work deals with fluxless method of soldering Al alloy type 7075 with application of solders for higher application temperatures. The research was oriented to study of interactions on solder/substrate boundary. ZnAl5Cu3 and ZnAl5Mg3 solders were used in experiments. Disruption of surface oxides will be realised via ultrasonic vibrations.

2. Experimental

Self hardening aluminium alloy type Al 7075 in form of rolled sheet 2 mm in thickness was used for soldering. The speciments were made in a round shape with diameter ø 15 mm and 12x5 mm. ZnAl5Cu3 and ZnAl5Mg3 solders were selected for soldering Al 7075 alloy. Chemical composition of solders is given in Table 1.

Table 1. Chemical composition of used solders.

Chemical composition	Zn [wt. %]	Al [wt. %]	Cu [wt. %]	Mg [wt. %]
ZnAl5Cu3	92	5	3	-
ZnAl5Mg3	92	5	-	3

The hot plate with thermostatic regulation was used as the heat source for achieving the soldering temperature. Removal of surface oxides was ensured by application of ultrasonic equipment type UZP 2 with 40 kHz frequency (Fig. 1). Soldering temperature varied within the range from 350 ºC to 390 ºC. Time of acting of ultrasonic vibrations was 3 to 5 seconds.

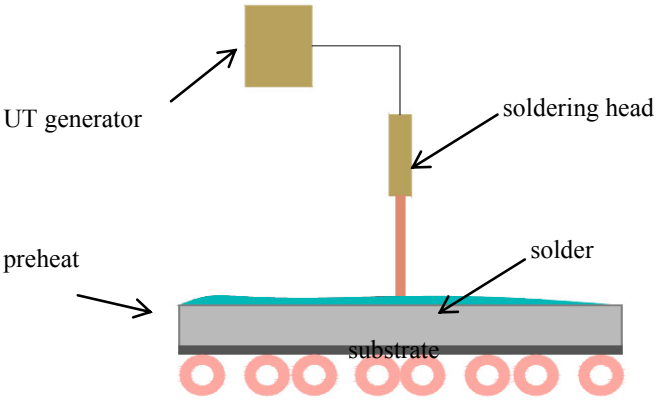

Fig. 1. Scheme of equipment for ultrasonic soldering.

3. Experimental Results

Microstructure of ZnAl5Cu3 and ZnAl5Mg3 solders is shown in Fig. 2. Structural components of solders were determined by use of equilibrium binary diagrams, microanalysis EDX and by calculation using Thermo-Calc software. Solders consist of βZn solid solution and βZn+$CuZn_5$ (ZnAl5Cu3) and βZn+Mg_2Zn_{11} (ZnAl5Mg3) respectively.

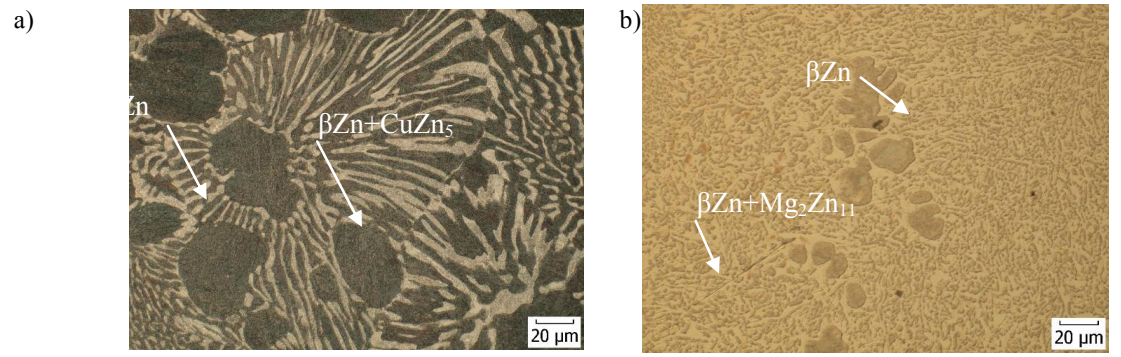

Fig. 2 Microstructure of solders a) ZnAl5Cu3; b) ZnAl5Mg3.

The soldered joint of Al 7075/ZnAl5Cu3/Al 7075 is shown in Fig. 3. Structural constituents were determined by linear microanalysis EDX (Fig. 3a). Solder/substrate boundary is shown in Fig. 3 b. Strong interaction between substrate and solder was observed. The transition zone is formed by α(Al)-β(Zn) mixture. It can be seen that Zn diffused from solder to substrate and formed a thick layer. Spatial distribution of elements is shown in Fig. 3 c.

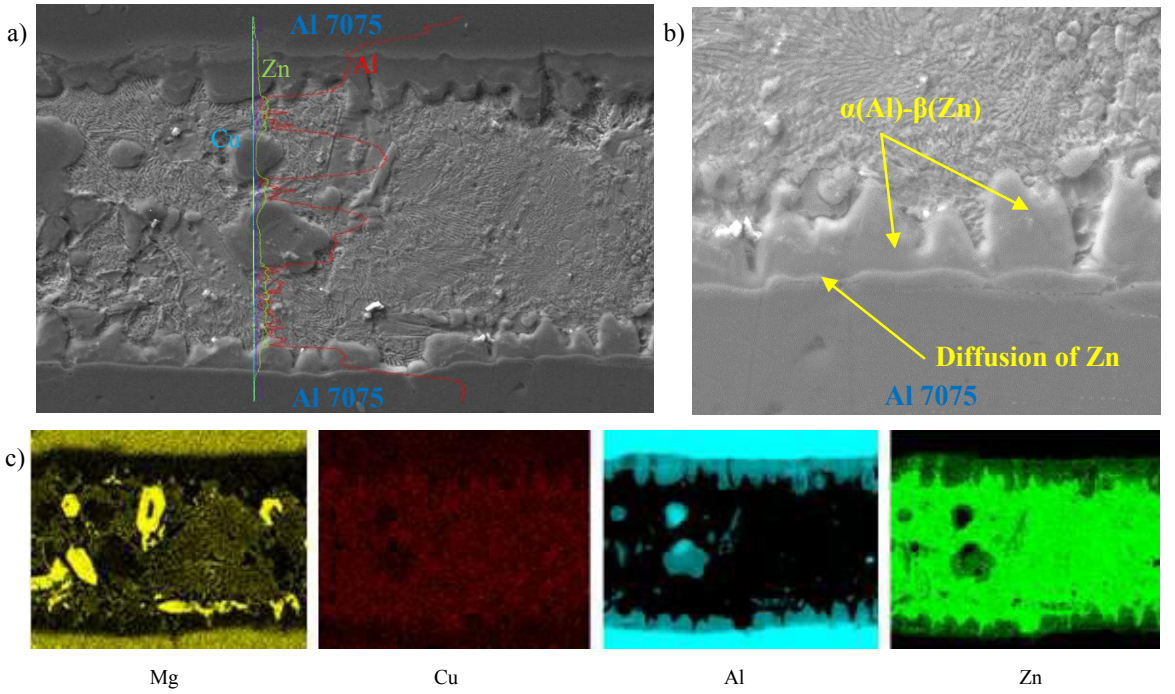

Fig. 3. Al 7075/ZnAl5Cu3/Al 7075 jointa) line microanalysis EDX of the joint; b) solder/substrate boundary c) spatial distribution of elements.

The soldered joint of Al 7075/ZnAl5Mg3/Al 7075 is shown in Fig. 4. Structural constituents were determined by linear microanalysis EDX (Fig. 4a). Strong interaction between substrate and solder created a different structure of the solder after soldering. Solder/substrate boundary is shown in Fig. 4 b. As in the case of previous joint, the transition zone is formed by α(Al)-β(Zn) mixture. Between that phase, Mg_2Zn_{11} intermetalic compounds were identified. Spatial distribution of elements is shown in Fig. 4 c.

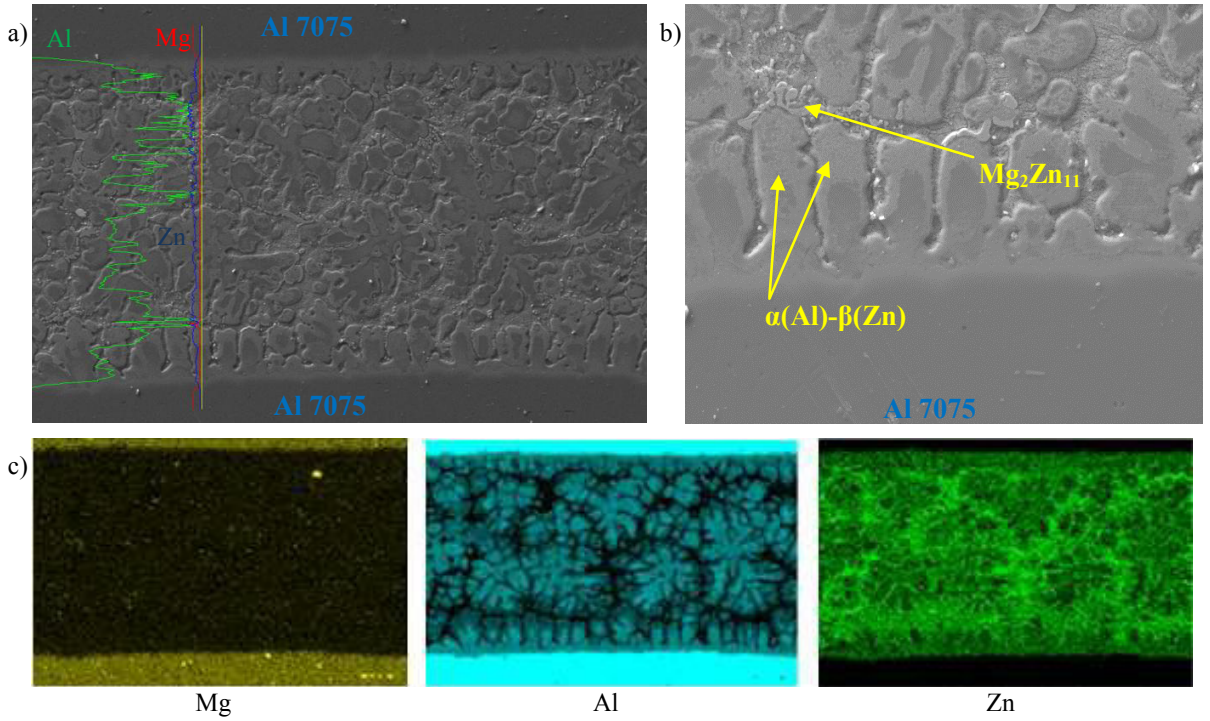

Fig. 4. Al 7075/ZnAl5Mg3/Al 7075 jointa) line microanalysis EDX of the joint; b) solder/substrate boundary c) spatial distribution of elements.

4. Conslusions

The present work dealt with soldering Al alloy substrates with use of Zn-Al based solders. Subject of this work consisted in the study of interactions on solder/substrate boundary. Soldering was realized by use of ultrasonic energy with 20 kHz frequency. ZnAl5Cu3 and ZnAl5Mg3 solders were used in experiments. Soldering temperature varied within the range from 350 ºC to 390 ºC. Acting time of ultrasonic vibrations varied in range from 3 to 5s. The fabricated joints were analyzed by use of light microscopy and EDX microanalysis.

Based on achieved results, the following was observed:

- ZnAl5Cu3 solder consists of βZn solid solution and βZn+$CuZn_5$ mixture
- ZnAl5Mg3 solder is composed of βZn solid solution and βZn+Mg_2Zn_{11} mixture
- strong interaction between the liquid solder and solid substrate was observed
- mechanical mixture of α(Al)-β(Zn) on the solder/substrate boundary was identified
- diffusion of Zn from ZnAl5Cu3 solder to substrate was observed at the interface

It was proved, that application of ultrasound in soldering resulted in high quality of metallurgical bonds. Strong interaction between the solder and substrate was achieved. In further research, determination of the strength properties of solders and joints is necessary.

Acknowledgement

The contribution was prepared with the support of APVV-0023-12: Research of new soldering alloys for fluxless soldering with application of beam technologies and ultrasound and VEGA 1/0455/14: Research of modified solders for fluxless soldering of metallic and ceramic materials.

The authors of contribution thank Ing. et Ing. Pavel Bílek for the EDX analysis of Al 7075/ZnAl5Cu3 and Al 7075/ZnAl5Mg3 joints.

References

[1] Ch. C. Lee and J. Kim: Advanced Packaging Materials: Processes, Properties and Interfaces, 2005, pp. 33-38
[2] A. E. Gickler, F. H. LePrevost Jr., T. Pan, A. M. Jaoquin, C. A. Blue and M. L. Santella: Aluminium Soldering - A New Look , 2003
[3] Y. Li, W. Zhao, X. Leng, Q. Fu, L. Wang and J. Yan, Trans, Nonferrous Met. Soc. China21, 2011, pp. 1937-1943.
[4] Y. Xiao, H. Ji, M. Li and J. Kim, Materials and Design 52, 2013,pp. 740–747.
[5] J. Pstrus, P. Fima and T. Gancarz, Journal of Materials Engineering and Performance, Volume 21, Issue 5, 2012, pp. 606-613.
[6] J. Lee, K. Kim, K. Suganuma, J. Takenaka and K. Hagio, Materials Transactions, Volume 46, Special Issue on Lead-Free Soldering in Electronics III, 2005, pp. 2413-2418.
[7] N. Kang, H. S. Na, S. J. Kim and Ch. Y. Kang, Journal of Alloys and Compounds 467,2009, pp. 246–250.
[8] A. Haque, Y. S. Won, A. S. M. A. Haseeb, H. H. Masjuki: Investigations on Zn-Al-Ge Alloys as High Temperature Die Attach Material, University of Malaysia, Kuala Lumpur, Malaysia.
[9] T. Shimizu, H. Ishakawa, I. Ohnuma and K. Ishida, Journal of Electronic Materials, Volume 28, Issue 11, 1999, pp. 1172-1175.
[10] Y. Takaku, L. Felicia, I. Ohnuma, R. Kainuma and K. Ishida, Journal of Electronic Materials, Volume 37, Issue 3, 2008, pp. 314-323.
[11] A. Haque, Y. S. Won, A. S. M. A. Haseeb and H. H. Masjuki, Investigations on Zn-Al-Ge alloy as High Temperature Die Attach Material, in: 3rd Electronics System Integration Technology Conference, ESTC 2010, Berlin, Germany.
[12] R. Koleňák, I. Kostolný, R. Čička, Research of Fluxless Soldering of High-Purity Aluminium with Solders Type Zn-Al, Advanced Materials Research, Volume 905, 2014, pp. 132-136.
[13] M. Prach, R. Koleňák, M. Sahul, Ultrasonic soldering of copper substrate by zinc solders, IDS 2014. International Doctoral Seminar 2014, Zielona Góra, Poland, May 19 -21, 2014, ISBN 978-80-8096-195-4, pp. 193-199.