INVESTIGATION OF THE INFLUENCE OF ALLOYING ELEMENTS IN ZN-AL ALLOY ON THERMAL AND MECHANICAL PROPERTIES

Igor Kostolný, Roman Kolečák

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

Abstract

The aim of work consist in the investigation of the influence of alloying elements in Zn-Al alloy on thermal and mechanical properties. The Zn-Al(1-5), Zn-Al5-Cu(1-3) and Zn-Al5-Mg(1-3) solder alloys were used experiments. Solders were assessed by DSC analysis and by measuring tensile strength and hardness. It was found out that by adding of alloying elements, the melting temperature is decreasing. The opposite was observed in the case of Zn-Al5-Mg(1-3) alloys. By increasing of wt. % of Al in Zn-Al(1-5) solder, the hardness and tensile strength was increased. In case of Zn-Al5-Cu(1-3) and Zn-Al5-Mg(1-3) solder, decreasing of tensile strength and increasing of hardness was observed.

Keywords: solder alloy; melting temperature; tensile strength; hardness, soldering

This Publication has to be referred as: Kostolny, I[gor] & Kolenak, R[oman] (2016). Investigation of the Influence of Alloying Elements in Zn-Al Alloy on Thermal and Mechanical Properties, Proceedings of the 26th DAAAM International Symposium, pp.0699-0703, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-07-5, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/26th.daaam.proceedings.096

1. Introduction

As a result of EU directives of avoiding the use of lead [1] in solder joints, the attention of soldering at higher application temperatures is especially focused to trying to find most appropriate alloy as a substitute for Pb-Sn solder. The research is focused mainly on Zn based solders with the addition of other elements to lower the melting temperature and improve their properties [2, 3, 4, 5]. Because of the low price of zinc alloys, they are very attractive nowadays. The use of these solders is oriented not only to die-attaching but also for attaching optical components, circuit modules, in the automotive, aerospace industry and many others. Effect of the addition of rare earth (Er, Nd) on the structure and properties of Sn-Zn solder dealt the authors of [6, 7]. The results showed improvement in wettability, physical and strength properties. The investigation of properties of Zn-Al based solders has been studied by the authors [8, 9, 10]. The addition of Cu resulted in the creation of intermetallic phase CuZn₄. In the structure of eutectic solder, Zn-Al phase and basic Zn matrix were observed. Increasing the amount of Cu growing volume fraction of intermetallic phases CuZn₄. Increasing the amount of Al resulted in increasing the formation of eutectic phase of the Zn-Al and increasing micro hardness and tensile strength. The addition of Mg and Ga to Zn-Al solder and investigation of its properties is dedicated by authors [11]. Solder was tested for die-attaching applications. The melting temperature of solder was lowered to 347 ° C. Decreasing of micro-hardness with increasing temperature was observed. Authors [12] studied the fluxless soldering. The addition of Ag to the structure of Zn-6Al solder resulted with creating of intermetallic phase AgZn₃. The melting temperature of solder was 380 ° C. The addition of In to the basic Zn solder and analyze its properties are dealt by authors [13, 14]. A small amount of In to Zn-Al solder decreases the melting temperature. It also resulted in an increase of electrical resistance compared to Zn-Al eutectic solder. The contact angle of the Al and Cu substrate is reduced with increasing of In content. The overall analysis of influence of adding alloying elements Al, Cu and Mg to Zn-Al solder is still not completely implemented. This paper therefore focuses on the study of changes in melting temperature, hardness and tensile strength depending of alloying elements.

2. Experimental

As the input component for the production of the solder alloy, materials of high purity of 3N to 5N are used. Manufacture of solder alloy was carried out in a vacuum oven. Alloys were cast into ingots. As a basis for the creation of ternary solders Zn-Al5 alloy was used due to higher concentrations of Al. The chemical composition of each alloy is shown in Tab. 1

Chemical composition	Zn [wt. %]	Al [wt. %]	Cu [wt. %]	Mg [wt. %]
ZnAl1	99	1	-	-
ZnAl2	98	2	-	-
ZnAl3	97	3	-	-
ZnAl4	96	4	-	-
ZnAl5	95	5	-	-
ZnAl5Cu1	94	5	1	-
ZnAl5Cu2	93	5	2	-
ZnAl5Cu3	92	5	3	-
ZnAl5Mg1	94	5	-	1
ZnAl5Mg2		93	5	2
ZnAl5Mg3		92	5	3

Table 1. Chemical composition of used solders

The alloys were prepared by normalized sizes and thoroughly cleaned of impurities to perform the static test of the tensile strength. Illustration of the test specimen in mm is shown in Fig. 1.

Fig. 1. Schematic of the specimen

To measure the tensile strength, the LABORATECH LabTest 5250 SP1 equipment was used. Measurement of microhardness indentation of diamond consisted of regular tetrahedral pyramid (Vickers hardness). The actual measurements were carried out on the device BEUHLER indentata Met 1100. To carry out the DSC analysis, test samples weighing 3-8 grams were prepared.

3. Experimental results

DSC analysis was performed for understanding the thermal reactions of investigated solders during heating. The melting temperatures of Zn-Al (1-5) solders are significantly changing depending on the quantity of Al. After reaching the composition of Zn-Al4, the melting point had decreasing character. This composition is characterized as a eutectic melting temperature and reached 378.6 °C. After adding of next 1% Al, the temperature decrease to 380.5 °C. In the case of solders Zn-Cu-Al5 (1-3) was also observed decreasing character. The Lowest point reached Zn-Al5-Cu3 solder with value 376.2 °C. The opposite was observed in the case of Zn-Al5-Mg (1-3) alloy. In this case was characterized increasing character and the highest melting temperature reached the Zn-Al5-Mg3 solder with value of 342.9 °C.

Fig. 2. DSC Analysis of examined solders

The melting temperatures of examined solders are shown in tab. 2.

Solder	Melting temperature [°C]	Solder	Melting temperature [°C]
ZnAl1	400,8	ZnAl5Cu1	380.9
ZnAl2	379,3	ZnAl5Cu2	376.4
ZnAl3	378,3	ZnAl5Cu3	376.2
ZnAl4	378,6	ZnAl5Mg1	339,1
ZnAl5	380,5	ZnAl5Mg2	340,3
		ZnAl5Mg3	342,9

Tab. 2. Melting temperature of examined solders

From Fig. 3 it can be seen that the tensile strength ranged from 160 to 200 MPa. The highest value of the ultimate strength of 196 MPa reached Zn-Al4 solder and the lowest Rm reached ZnAl1 solder. The results show that the gradual addition of Al to Zn increases its strength. When reaching 4 wt. % of Al, which is an alloy of nearly eutectic composition, its strength is highest.

Fig. 3. Tensile strength and Vickers hardness of Zn-Al(1-5) solders

Adding of next 1 wt. % of Al, the strength of alloy decreases again. From the measured values, the lowest hardness reached Zn-Al1 solder with an average hardness 47.5 HV and vice versa highest hardness was observed in Zn-Al5 solder with an average hardness 60.27 HV. This means an increasing the hardness with adding of next wt. % of Al into the Zn-Al1 alloy. The Increasing of the hardness of solder was caused because of greater hardness of Al compared to Zn.

Fig. 4. Tensile strength and Vickers hardness of Zn-Al-Cu(1-3) solders

Three test samples from each solder was prepared to analysing tensile strength (fig. 4) and then subsequently calculated the total average strength. From fig. 4 can be deduced that with a higher percentage of Cu, alloys decreasing their average tensile strength. Cu and Zn creates a brittle intermetallic phase CuZn_5 . By increasing of the content of Cu in solder, the content of the intermetallic phase is increasing as well. Therefore, the greatest tensile strength reached solder with the lowest content of Cu. The lowest average tensile strength was observed at Zn-Al-Cu3 solder. The results of measuring hardness showing that the HV hardness increased with increasing percentage composition of Cu in the Zn-Al5 alloy. The highest average hardness reached a ternary alloy Zn-Al5-Cu3 due to the formation of intermetallic phases.

Fig. 5. Tensile strength and Vickers hardness of Zn-Al-Mg(1-3) solders

Fig. 5 is showing ultimate tensile strength of ZnAl5Mg (1-3) solder. Three test pieces was used and then from the measured values was calculated average value. From the fig. 5 it can be seen that how tensile strength decreasing with increasing of content of Mg in Zn-Al5 solder. It means that the highest average tensile strength reached Zn-Al5-Mg1 alloy. This is due to the presence of intermetallic compound Mg₂Zn₁₁, which is at the higher content of Mg (3%) dispersed in about 48% of the volume of the solder.

4. Conclusions

The present work dealt with the investigation of the influence of alloying elements in Zn-Al alloy on thermal and mechanical properties. Subject of study consisted in the study of effect of Al, Cu and Mg addition on hardness, thermal and mechanical properties. Zn-Al (1-5), Zn-5Al-Cu(1-3) and Zn-Al5Mg(1-3) solders were used in experiments.

Based on achieved results, the following was observed:

- addition of alloying elements to Zn decreased melting temperatures,
- the tensile strength of Zn-Al(1-5) had increasing character, in case of Zn-Al5-Cu(1-3) and Zn-Al5Mg(1-3) was observed opposite character due to presentence of intermetallic phases,
- the hardness of examined solders had increasing character. The highest values reached Zn-Al5 (60.27 HV), Zn-Al5Cu3 (108.1 HV) and Zn-Al5-Mg3 (94.5HV)

It was found that the addition of alloying elements to the Zn-Al solder significantly changing the thermal and mechanical properties. In further research, determination of the strength of solder joints is necessary.

5. 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.

6. References

- [1] KROUPA, A., ANDERSSON, D., HOO, N. Current Problems and Possible Solutions in High-Temperature Lead-Free Soldering. In *Journal of Materials Engineering and Performance*, Vol. 21(5), 2012, pp. 629-637
- [2] HAQUE, A., LIM, B.H., HASEEB, A.S.M.A., MASJUKI, H.H. Die attach properties of Zn-Al-Mg-Ga based high-temperature lead-free solder on Cu lead-frame. In *Journal of Material Science: Materials in Electronics*, Vol. 23, 2012, pp. 115-123
- [3] TAKAKU, Y., FELICIA, L., OHNUMA, I. Interfacial Reaction Between Cu Substrates and Zn-Al Base High-Temperature Pb-Free Solders. In *Journal of Electronic Materials*, Vol. 37, Is. 3, 2008, pp. 314-323
- [4] ALIBABAIE S., MAHMUDI, R. Microstructure and creep characteristics of Zn-3Cu-xAl ultra high-temperature lead-free solders. In *Materials and Design*, Vol. 39, 2012, pp. 397-403
- [5] ZENG, G., MCDONALD, S., NOGITA, K. Development of high-temeprature solders: Review. In *Microelectronics Reliability*, Vol. 52, 2012, pp. 1306-1322
- [6] ZHANG, L., XUE, S., GAO, L., ZENG, G., SHENG, Z., CHEN, Y., YU, S. Effects of rare earths on properties and microstructures of lead-free solder alloys. In *Journal of Material Science: Materials in Electronics*, Vol. 20, 2009, pp. 685-694
- [7] WANG, S., ZHOU, H., KANG, Y. The influence of rare earth elements on microstructure and properties of 6061 aluminum alloy vacuum-brazed joints. In *Journal of Alloys and Compounds*, Vol. 352, 2003, pp. 79-83
- [8] MAHMUDI, R., ALIBABAIE S. Elevated-temperature shear strength and hardness of Zn-3Cu-xAl ultra-high-temperature lead free solders. In *Materials Science and Engineering A*, Vol 559, 2013, pp. 421-426
- [9] XIAO, Y., JI, H., LI, M., KIM, J. Ultrasound-assisted brazing of Cu/Al dissimilar metals using Zn-3Al filler metal. In *Materials and Design*, Vol. 52, 2013, pp. 740-747
- [10] KIM, S., KIM, K., KIM, S., KANG, CH., SUGANUMA, K. Characteristics of Zn-Al-Cu Alloys for High Temperature Solder Application. In *Materials Transactions*, Vol. 49, 2008, pp. 1531-1536
- [11] SHIMIZU T., ISHIKAWA, H., OHNUMA, I., ISHIDA, K. Zn-Al-Mg-Ga Alloys as Pb-Free Solder for Die-Attaching Use. In *Journal of Electronic Materials*, Vol. 28, No. 11, 1999
- [12] KOLENAK, R., KOSTOLNY, I., CICKA, R. Research of Fluxless Soldering of High-Purity Aluminium with Solders Type Zn-Al. In *Advanced Materials Research*, Vol. 905, 2014, pp. 132-136
- [13] LEE, J., KIM, K., SUGANUMA, K., INOUE, M., IZUTA, G. Thermal Properties and Phase Stability of Zn-Sn and Zn-In Alloys as High Temperature Lead-Free Solder. In *Materials Transactions*, Vol. 48, 2007, 584-593
- [14] GANCARZ, T., PSTRUS, J., FIMA, P., MOSINSKA, S. Thermal Properties and Wetting Behavior of High Temperature Zn-Al-In Solders. In *JMEPEG*, Vol. 21, pp. 599-605