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SOLDERABILTY OF HIGH-PURITY ALUMINIUM WITH THE LEAD-FREE SOLDERS

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Abstract: *The work deals with solderabilty of high-purity aluminium with the lead-free tin solders. Soldering was performed in the air with and without application of flux and with mechanical removal of surface oxides. Wettability measurements have shown that all lead-free solders wetted aluminium surface with wetting angle below 42°. The shear strength of experimental joints attained the values from 25 to 48 MPa. The study of boundary zones of fabricated joints was performed by use of EDX analysis.*
Key words: *solderability, aluminium, lead-free solders, cadmium-free solders*

1. INTRODUCTION

The basis of classical solders destined for joining alumimium consists of heavy metal alloys containing Cd, Sn, Pb, less frequently with Ag and Sb (Ruža, 1988; Koleňák 2008). For soldering aluminium, for example the solders type Sn20Cd1Ag, Sn63Pb3Zn, Zn16Cd etc, were used.

In agreement with valid legislation in EU, the solders containing lead and/or cadmium must not be used in electric equipment. Owing this reason, experiments were performed, with the aim to determine the material solderability of high-purity aluminium with use of alternative solders, which are considered for a perspective substitution of classical solders containing Pb and Cd (Chen, 1996; Liang, 2006). Only a part of experimental resuts is given in this contribution.

2. EXPERIMENTAL

It is supposed that a solder applicable for aluminium must contain the alloying elements which form the solid solution or intermetallic phases with aluminium, whereas their mutual solubility may be low. For example zinc creates relatively wide range of solid solution with with aluminium. Aluminium creates relatively smaller range of solid solution with Ag, Cu, Mg, Mn and Li. Al creates minimum zone of solid solution with tin (Ruža, 1988; Koleňák 2008; Li, 2010).

Based on the mentioned assumptions, following from the equilibrium diagrams, five alternative solders were designed with the effort to attain them as a pure metal, of eutectic and/or close-to-eutectic composition.

2.1 Experimental material

Solder composition	Melting point [°C]	Thermal conductivity [$W.m^{-1}K^{-1}$]	Electric conductivity IACS [%]
Sn	232	63,2	-
Sn3.5Ag	221 E	33	16.00
Sn9Zn	199 E	61	15.00
Sn3.8Ag0.7Cu	217 E	-	13.50
Sn6Ag4TiCe	221-232	48	-

Tab. 1. Composition and properties of experimental solders

Chemical name	Wt.%	Symbol	Risk Phrases
Monoethanolamine	30-60	Xn, C	R20/21/22-34
Ammonium hydrogendifluoride	5-10	T, C	R25 - 34
Tin Chloride dihydrate	10-15	None	None
Zinc Chloride	5-10	Xn, C, N	R22-34-50/53

Tab. 2. Composition of experimental flux

Soldering experiments were performed with aluminium with 5N (99.999%) purity. Chemical composition of the suggested alternative solders and their properties are given in Table 1. Soldering was executed with a flux from LA-CO® #60 company, with composition given in Table 2.

2.2 Soldering methods and parameters

Soldering was realised in the air, whereas two methods for removing oxides were used:

- by use of flux,
- by mechanical removing of oxides - by scraping under the layer of molten solder.

For flux-free soldering, with a mechanical removing of oxides, only the Sn6Ag4TiCe solder is destined (Koleňák, 2005; Koleňák 2011). In case of other solders, soldering was perfomed with flux application.

Heating on soldering temperature was applied by the hot plate method. Soldering temperature was selected to 20°C above the melting point temperature of the used solders.

3. RESULTS

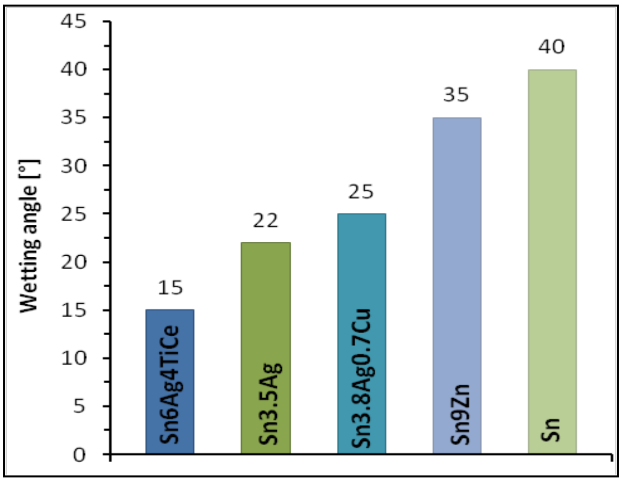

Fig. 1. Results of wetting angle measuremenst

Experiment assessment consisted of measuring the wetting angles of alternative solders on pure aluminium substrate. The metallographical cross sections from the boundary of solder - aluminium were investigated. The boundary zones were assessed by use of optical microscopy, SEM and chemical microanalysis. The results of wetting angle measurements are given in Fig 1.

The best results of wetting were achieved in soldering with the solder type Sn6Ag4TiCe without use of flux and with mechanical removing of oxides. In case of flux application, the best results were achieved with an eutectic solder type Sn3.5Ag, containing silver, with wetting angle of 22°. On the contrary, the worst results were shown with the solder of pure Sn, whereby also the theoretical assumptions were confirmed.

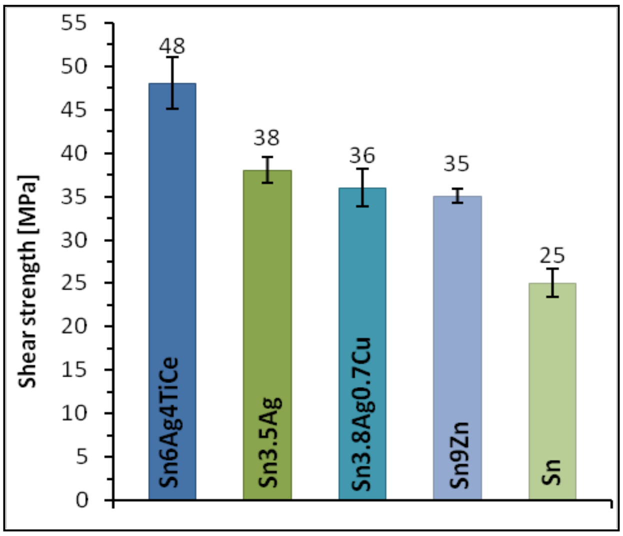

Fig. 2. Shear strength of soldered joints

Based on the results of wetting angle measurements, the test pieces for testing shear strength of soldered joints were prepared. The highest shear strength was achieved with the solder type Sn6Ag4TiCe (Martinkovič, 2010). On contrary, the lowest strength was achieved with pure tin - Fig 2. This result is related with the value of wetting angle and interaction taking place on aluminium - solder boundary.

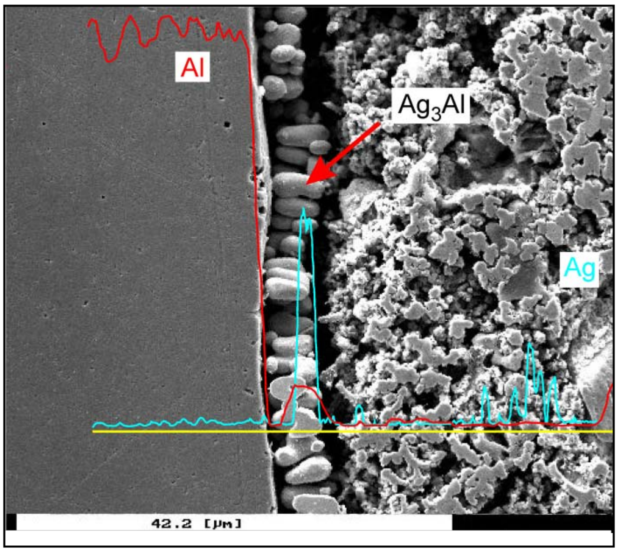

Fig. 3. Microstructure of joints Al - Sn6Ag4TiCe solder and concentration profiles of Ag, Al elements

Transition zone was highlighted by a deep etching down of tin matrix (Fig. 3) and it is formed of a new intermetallic phase, which enhances the joint formation between the solder and Al.

In case of Sn3.5Ag solder, soldered with the flux, a finer morphology of the new-formed phase was revealed, whereas in case of joint fabricated with Sn6Ag4TiCe solder without flux, a coarse morphology was observed, see Fig. 3.

Analysis of chemical composition has shown that the interaction of pure aluminium with the solder containing Ag resulted in formation of transition zone rich in Ag from the solder and aluminium from the soldered material.

Formation of a new AgAl phase, rich on Al is proved also by the concentration profiles of Ag and Al elements, on the boundary of parent metal of aluminium and Sn6Ag4TiCe solder - Fig. 3. (Zhong, 2002).

From the results of chemical analysis and according to the equilibrium binary diagram it may be concluded, that by aluminium - silver interaction, the Ag_3Al phase is formed.

4. CONCLUSION

The research was aimed to study of material solderability of high-purity Al by use of alternative solders, free from lead and cadmium, whereas the following results were achieved:

- wetting angles on pure aluminium attained with the suggested alternative solders were determined,
- the best wetting angle α = 14° was achieved with the Sn6Ag4TiCe solder without use of flux,
- the best wetting angle in case of flux application α = 21°, was achieved with the eutectic solder type Sn3.5Ag,
- the shear strength of experimental joints ranged from 25 to 48 MPa.
- it was found out that the highest effect on wettability of the studied solders was exerted by the silver content in solder,
- the metallographic analysis and X-ray microanalysis have shown that on the aluminium - solder (containing silver) boundary a new phase, rich in silver, was formed,
- the results of chemical analysis have revealed that owing to interaction of aluminium with silver, the Ag_3Al phase was formed, which is responsible for wetting and formation of a diffusion bond between the pure aluminium and solder.

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