

Examination of Fe-Sn Intermetallic Layer Formation on C45 Steel in Calm SAC305 Solder Melt

Zsolt Sályi¹, Márton Benke²,

¹MSc student, ²associate professor

^{1,2}*University of Miskolc, Institute of Physical Metallurgy, Metalforming and
Nanotechnology, Hungary, Miskolc - Egyetemváros*

ABSTRACT

Selective soldering tools, such as nozzles and soldering irons are made of iron, or high purity ARMCO iron. The lifetime of these components is limited to around one month of continuous operation due to a degradation process during which the reactive solder melt dissolves iron atoms from the tool. A physical simulator was designed and produced to study the reaction between C45 steel samples and calm SAC305 solder melt. Experiments were performed up to 20 days of reaction which was followed by scanning electron microscope based microstructure analysis. It was shown that after a few days of reaction, the SAC305 alloy dissolved a notable amount of Fe. Increasing the reaction time a clearly distinguishable Fe-Sn intermetallic layer formed at the C45 steel/solder melt interface. The thickness of the intermetallic layer increased with further increasing the reaction time.

INTRODUCTION

Unlike wave soldering techniques, selective soldering technologies are applied when only a single or a few joints are desired to be produced at a time. Selective soldering can be divided into two main groups, being selective wave soldering and selective hand soldering. Although the realization and target use of the two methods differ, their common character is to produce a single joint through the precise deposition of the desired amount of solder melt. For both technologies, the soldering tool is most often made of iron or high purity ARMCO iron to ensure the required proper wetting between the solder melt and soldering tool. The proper wetting ensures a constant wave height during selective wave soldering, and the required solder amount at the iron tip during selective hand soldering. For both soldering types, the soldering tool is in contact with the solder melt, which tends to dissolve the Fe atoms from the tool. The continuous dissolution of Fe atoms macroscopically degrades the soldering tools: the smooth tool surface becomes rugged, and, as a result, improper wetting conditions form which demands the replacement of the soldering tools (Fig. 1).

As the European Union issued the RoHS (Restriction of use of Hazardous Substances) directive, lead-free solder alloys replaced the previously used Sn-Pb alloys in most applications [1]. However, lead-free solder alloys have higher Sn content compared to previously used Sn-Pb alloys, and are proved to be more reactive in dissolution process of most metals, including iron [2-12].

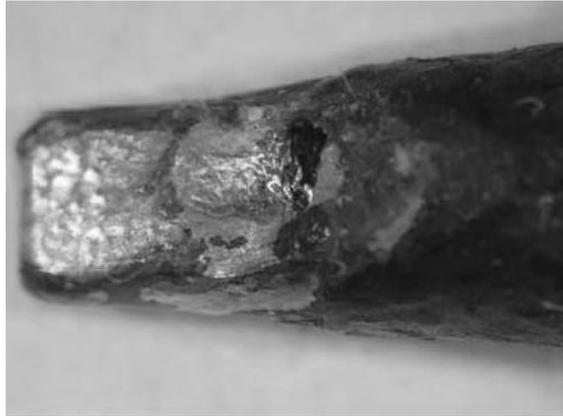


Figure 1. Eroded soldering iron tip [2]

The average lifetime of a selective wave soldering tool (nozzle) made of iron is about one month with continuous production using lead-free solder alloy. The frequent tool replacement and associated production interruption cause a notable economic drawback for the soldering industry. Therefore, many researches were addressed to investigate the underlying mechanism of the soldering tool degradation. It was revealed that an FeSn_2 intermetallic is formed at the Fe/solder melt interface which thickens as the degradation proceeds (Fig. 2.) [2, 13].

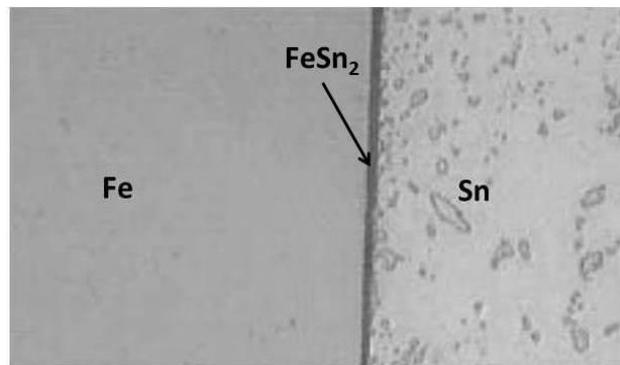


Figure 2. FeSn_2 intermetallic layer at the Fe/solder melt interface [2]

The aim of the present research is to investigate the Fe-Sn intermetallic layer formation on C45 steel samples placed in calm SAC305 solder alloy melt. To induce the intermetallic formation, a physical simulator furnace was designed and produced.

EXPERIMENTAL

The produced physical simulator is a cylindrical, resistance heated furnace with double (inner and outer) crucibles. The crucibles are made of thermal shock resistant borosilicate glass to avoid any reactions between the solder alloy melt and the crucible. The 17 x 12 x 5 mm rectangular samples are fixed with borosilicate glass sample holders (lower and upper) within the inner crucible. The outer crucible

was designed to be a safety barrier to avoid the furnace's heating system from the solder alloy melt in case the inner crucible fractures. The simulator is powered through an emergency magnetic relay which exhibited the furnace from automatic reheating if an experiment was temporarily interrupted due to main power supply failure. The experiments were kept under daily control. In case of main power supply interruption, the furnace was reheated only after switching the magnetic relay manually on. In such case, the stop date of the actual experiment was corrected to reach the designed time duration. Because of that, the simulator is capable to perform experiments over periods of days. The furnace temperature was measured with a thermocouple placed between the inner and outer crucibles and was set to 305°C with a temperature controller. From above, the crucibles were covered with a steel closing cup. The closing cup was designed to push the upper sample holder and thus, avoid the samples from floating. The scheme of the physical simulator is shown in Fig. 3.

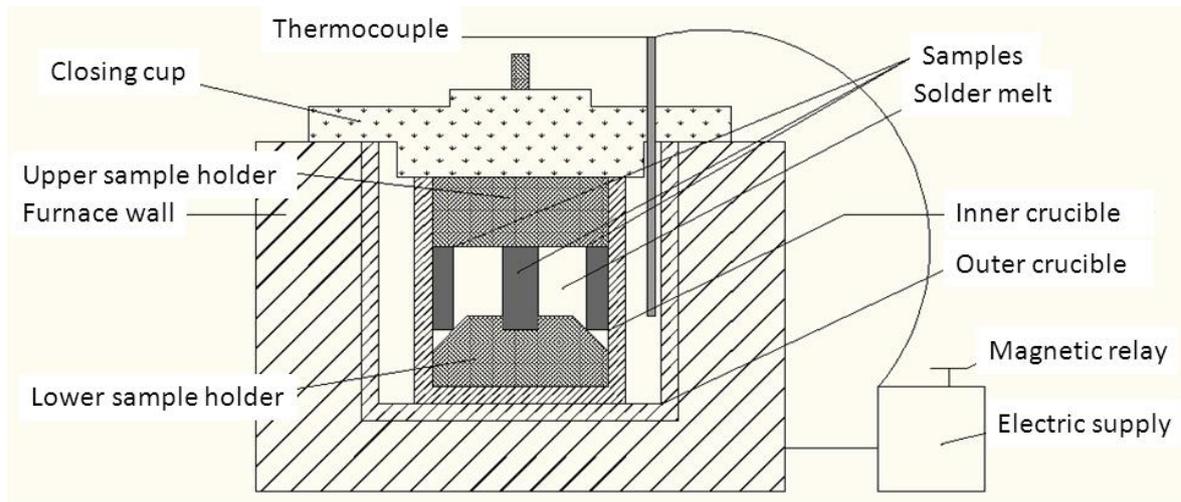


Figure 3. Schematic illustration of the physical simulator

The examined samples were made of C45 steel. The samples were austenitized at 860 °C for 30 minutes, water quenched and subsequently annealed at 600°C for 20 minutes and let to cool down in room temperature air. The 0.5 mm thick surface of the samples was machined to remove the oxides and decarbonised layer. Before the dissolution experiments, the samples were placed in the sample holder within the inner crucible. The solder alloy was melted in air furnace and poured on the samples. Thus, the samples were protected from oxidation. Dissolution experiments were performed for 5 and 10 days. The tested samples were hot mounted in resin and cross sections were prepared with standard metallographic preparations. Microstructure analysis was carried out with a Zeiss Evo MA 10 scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS).

RESULTS

The SEM image taken from the cross section of the sample tested for 5 days is shown in Fig. 4. The composition of the solder alloy melt frozen on the sample is inserted.

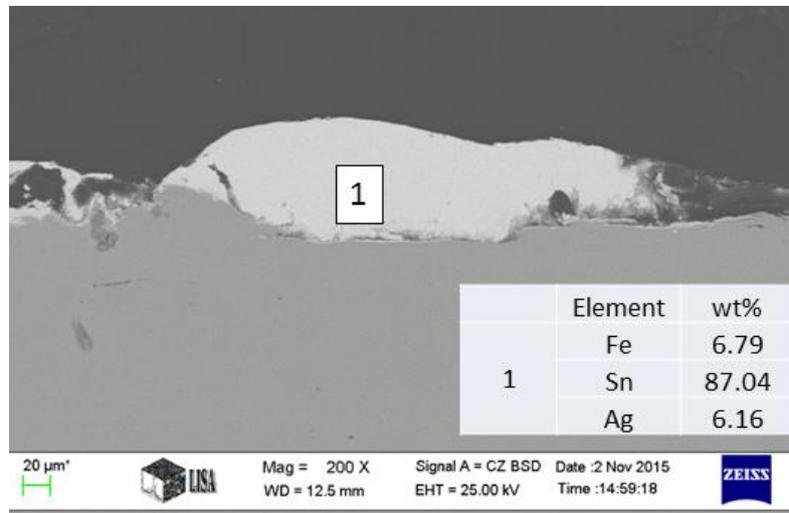


Figure 4. SEM image of the C45 sample tested for 5 days

According to Fig. 4, no intermetallic layer is visible on the surface of the sample tested for 5 days. The Fe content of the solder alloy frozen on the sample is around 7 wt%. Since Fe is not an alloying element of SAC305 solder alloy, the Fe atoms were dissolved from the C45 sample, without a doubt. No Fe-Sn intermetallic layer is visible at the sample/solder melt interface.

The SEM image taken from the cross section of the sample tested for 10 days is shown in Fig. 5. Compositions taken from the marked locations are inserted.

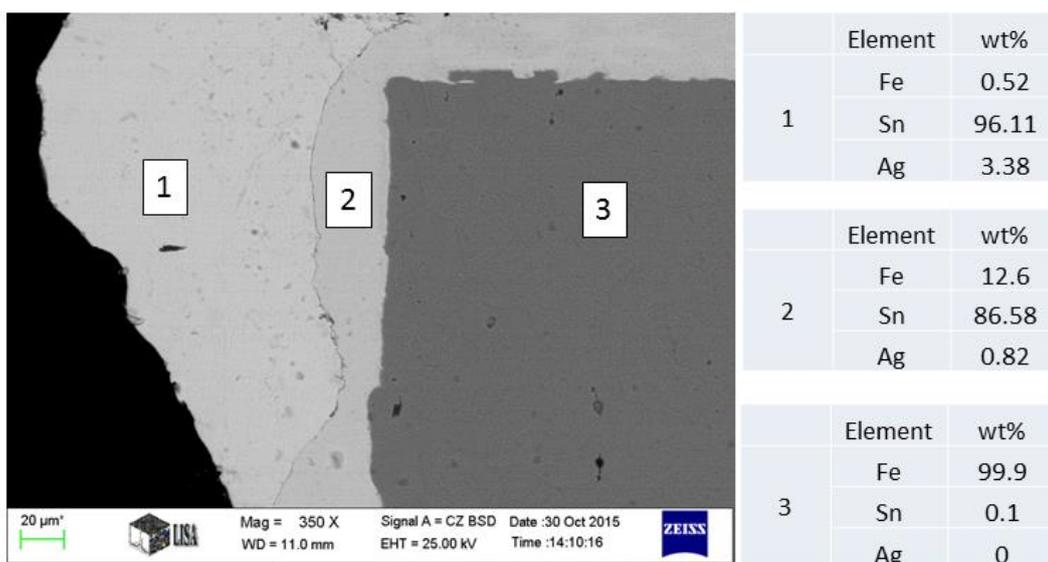


Figure 5. SEM image of the C45 sample tested for 10 days

As seen in Fig. 5, a clearly visible intermetallic Fe-Sn layer is formed on the surface of the sample tested for 10 days. The Fe/Sn atom ratio is about 1/3 of the intermetallic layer, which is not the stoichiometric ratio of the FeSn₂. The thickness of the intermetallic layer varies within the magnitude of a few 10µm. The Fe content of the solder alloy is around 0.5 wt%. Accordingly, a notable Fe dissolution was observed after 10 days of testing.

SUMMARY

In the present study, the dissolution of Fe atoms into calm SAC305 solder alloy melt was investigated. To carry out the dissolution experiments, a physical simulator was designed and produced. The crucible of the simulator is resistant against the reactive lead-free solder alloy melt. Using the simulator, C45 samples were submerged into calm SAC305 solder alloy melt for 5 and 10 days to induce the dissolution. Scanning electron microscope microstructure analysis was performed on the tested samples. After 5 days, notable Fe dissolution was observed, but no Fe-Sn intermetallic layer formed on the surface of the samples. After 10 days, visible Fe-Sn intermetallic layer formed with Fe/Sn atom ratio of about 1/3. The thickness of the intermetallic layer is in the magnitude of a few 10 µm. The physical simulator was proved to be suitable to perform dissolution reactions between different test materials and solder alloy melts, which is fundamental for selective soldering tool development.

ACKNOWLEDGEMENTS

The research work presented in this paper based on the results achieved within the TÁMOP-4.2.1.B-10/2/KONV-2010-0001 project and carried out as part of the TÁMOP 4.2.1C-14/1/Konv-2015-0012 project in the framework of the New Széchenyi Plan.

REFERENCES

- [1] http://ec.europa.eu/enterprise/policies/european-standards/harmonised-standards/restriction-of-hazardous-substances/index_en.htm
- [2] http://www.elexp.com/Images/Weller_Coping_with_Lead_Free.pdf
- [3] D. Shangguan, Lead-free solder interconnect reliability, ASM International, 2005.
- [4] G. Henshall, J. Bath, C. A. Handwerker, Lead-free solder process development, Wiley, 2011.

- [5] H. Ipser, JMM 43 B (2) (2007) 109-112
- [6] A. Kroupa, A.T. Dinsdale , A. Watson, J. Vrestal and A. Zemanova, JMM 43 B (2) (2007) 113-123
- [7] A. Kroupa,, A. Dinsdale, A. Watson, J. J. Vřešťál, A. Zemanova, P. Broz, JMM 48 (3) B (2012) 339-346
- [8] T. Takemoto, T. Uetani, M. Yamazaki, Solder Surf MT Tech 16 Iss. 3 (2004) 9-15
- [9] H. Nishikawa, S. Kang, T. Takemoto, T JWRI 38 (2009) No.2 53-56.
- [10] <http://www.circuitspecialists.com/blog/soldering-tip-care-tips>
- [11] H. Nishikawa, A. Komatsu, T. Takemoto, Mat Trans 46 (2005) 2394-2399
- [12] J. Watanabe, N. Sekimori, K. Hatsuzawa, T. Uetani, I. Shohji, J Phys, Conf. series 379 (2012) 012025 1-10
- [13] H. Nishikawa, T. Takemoto, K. Kifune, T. Uetani, N. Sekimori, Mat Trans 45 No 3 (2004) 741-746