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CORRELATION BETWEEN PIN MISALIGNMENT AND CRACK LENGTH IN THT SOLDER JOINTS

In this manuscript, correlations were searched for between pin misalignments relative to PCB bores and crack propagation after cyclic thermal shock tests in THT solder joints produced from lead-free solder alloys. In total, 7 compositions were examined including SAC solders with varying Ag, Cu and Ni contents. The crack propagation was initiated by cyclic thermal shock tests with 40°C / +125°C temperature profiles. Pin misalignments relative to the bores were characterized with three attributes obtained from one section of the examined solder joints. Cracks typically originated at the solder/pin or solder/bore interfaces and propagated within the solder. It was shown that pin misalignments did not have an effect on crack propagation, thus, the solder joints' lifetime.

Keywords: THT solder joint, pin misalignment, crack propagation, thermal shock tests

1. Introduction

Both use of lead-free solder alloys and the related researches widespread since the issue of RoHS (Restriction of Hazardous Substances) and WEEE (Waste Electrical and Electronic Equipment) directives [1,2]. Sn-Ag-Cu (SAC) solder alloys are promising candidates for alternatives of the previously used Sn-Pb alloys. Many researches have been carried out that aiming the improvement of mechanical properties and resistance against failure through modifying the composition of SAC alloys [3-5]. Special attention is given to the effect of Ni, one of the main alloying elements on microstructure, mechanical properties and fracture modes [4-6]. In regard to reliability, most researches focused on the examination of failure modes and thermal cycle performance of Ball Grid Array (BGA) solder joints [1,7-8]. It is generally accepted that besides chemical composition and microstructure, the geometry of the solder joints strongly affects the resistance against thermal fatigue. On the other hand, available literature on solder joints produced by Through Hole Technology (THT) is deficient. During THT soldering, the pins of the electronic components are placed into the bore of the Printed Circuit Board (PCB) and the solder melt fills the void all around in between the pin and bore. However, pins have a small degree of displacement before producing the solder joint, which result slightly misaligned pins relative to the center of the bore in the solidified solder joint. In such a case, the thickness of the solder varies around the pin and from top to bottom of the PCB. It is well known that the difference in thermal expansion coefficients of the solder, pin and PCB is one of the main reasons of solder joint failures [1,7-8]. Different solder thickness can result uneven thermal stresses around the pins which can influence crack initiation. The aim of the present work is to investigate the influence of pin misalignments relative to PCB bore on crack initiation and propagation in THT solder joints made of SAC solder alloys with different alloying element/impurity contents.

2. Experimental

In total, 7 types of SAC solder alloys with different Ag, Cu and Ni concentrations were used to prepare THT solder joints. The compositions of the solder alloys were determined with ICP (Inductively Coupled Plasma spectrometry). The measured compositions are listed in Table 1.

TABLE 1

Chemical composition of the solder alloys determined by ICP [wt.%]

Sample	Ag	Cu	Ni	Fe	Bi	Pb	Sb	Sn
SAC 307	3.03	0.76	0.0018	0.154	0.0051	0.0136	0.0079	bal.
SAC 302	2.79	0.32	0.0039	0.160	0.0235	0.0344	0.0111	bal.
SAC 309	2.85	0.96	0.0072	0.108	0.0048	0.0245	0.0106	bal.
SAC 205	1.95	0.57	0.0064	0.038	0.004	0.0162	0.0086	bal.
SAC 405	3.81	0.52	0.002	0.044	0.0029	0.0134	0.0106	bal.
SAC 305 Ni0.025	2.81	0.51	0.0195	0.029	0.0033	0.0096	0.0093	bal.
SAC 305 Ni0.050	2.79	0.63	0.0359	0.051	0.0038	0.0131	0.0091	bal.

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For the THT assembly, electronic capacitors with one pin made of Fe and the other made of Cu coated with Ni and Au were used. Only the Cu pins were examined. The pins were soldered to test PCBs using an ERSA ECOSELECT 2 type selective wave soldering equipment. To initiate crack propagation, the test PCBs were subjected to cyclic thermal shock tests in a VÖTSCH VT 7012 S2 equipment. During thermal cycling, the test PCBs were held at –40°C for 30 minutes, then rapidly heated to +125°C and held isothermally for 30 minutes. Test PCBs were taken out for examinations after 1500, 3000 and 4500 thermal cycles (TC). After each cycle, 6 THT solder joints per solder alloy were cut from the test PCBs and sections of the solder joints were prepared through standard metallographic preparations (grinding, polishing) for optical microscope examinations. Optical microscope images were obtained with a ZEISS AXIO IMAGER M1m type microscope. Pin misalignments relative to bore were characterized with three properties: eccentricity, off-plane (*OP*) tilt and tilt, measured on one section of each solder joint. Eccentricity describes the position of the pin relative to the center of the bore on the examined section. Eccentricity was calculated by dividing the larger area occupied by the solder with the smaller area occupied by the solder on the left and right sides of the joint on the examined cross section (Fig. 1a), (Eq. 1).

$$Eccentricity = \frac{MAX\left(L/R\right)}{MIN\left(L/R\right)} \tag{1}$$

Off-plane tilt describes the tilting of the pin relative to the centerline of the bore in the plane perpendicular to the examined section. Off-plane tilting is calculated by dividing the larger width of the pin with the smaller width of the pin measured at the top and bottom PCB surfaces on the examined section (Fig. 1b), (Eq. 2).

$$OP-tilt = \frac{MAX\left(T/B\right)}{MIN\left(T/B\right)} \tag{2}$$

Tilt describes the tilting of the pin relative to the centerline of the bore in the plane of the examined cross section. Tilting is measured as the angle between the centerline of the pin and the centerline of the bore on the examined section (Fig. 1c). Crack lengths were measured in the vertical direction (parallel with the PCB bore) on the obtained optical microscope images and are given in % values relative to PCB thickness.

3. Results and discussion

Typically, two crack initiation locations were observed after cyclic thermal shock tests in THT solder joints: one at the solder/pin interface, the other at the solder/PCB interface. The cracks propagated either along the solder/pin interface or within the solder (Fig. 2). The crack initiation locations and crack propagation

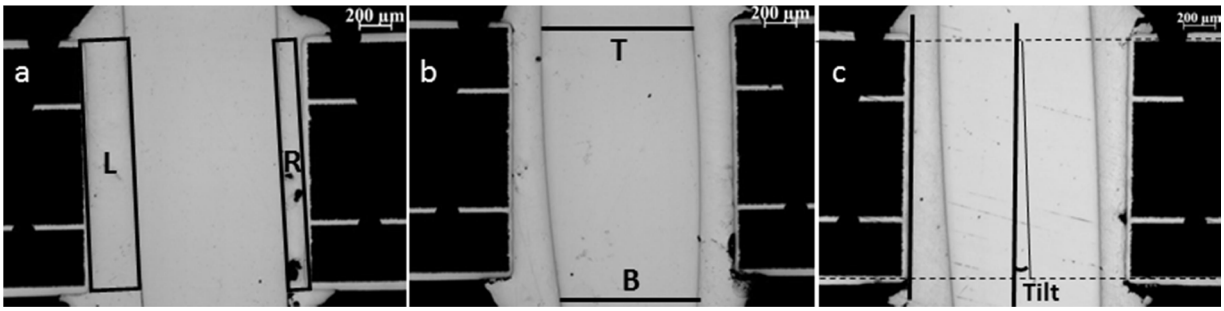

Fig. 1. Misalignment properties of the pins. a) eccentricity, b) off-plane tilt and c) tilt

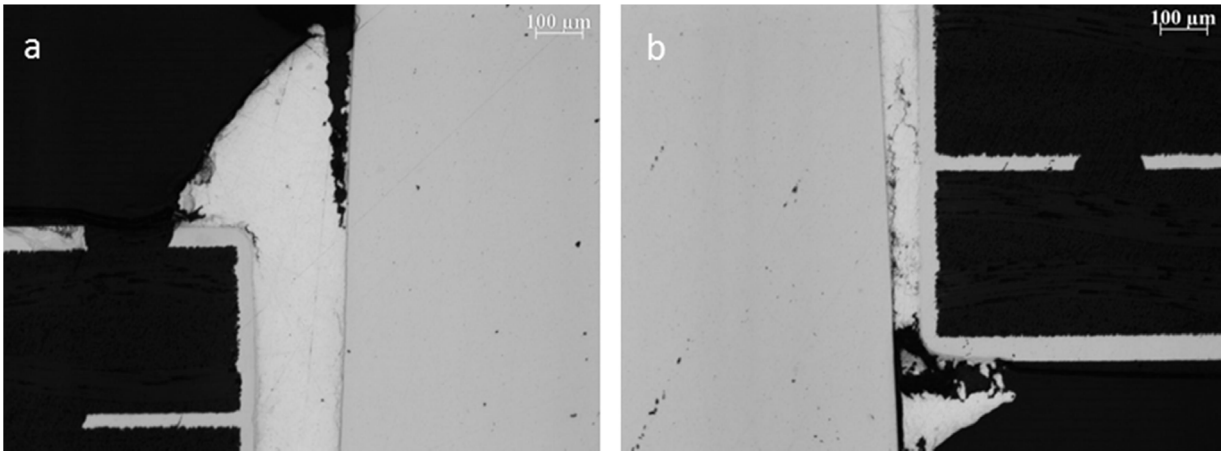

Fig. 2. Typical crack initiation locations and crack propagations in THT solder joints during thermal shock cycling. a), crack initiation at the solder/pin interface, crack propagation along the solder/pin interface, b) crack initiation at the solder/PCB interface, crack propagation along the solder/pin interface and inside the solder

modes were independent on alloying element concentrations and misalignments of the pins in the examined SAC alloys.

Figs. 3-5 show the measured crack length vs eccentricity, crack length vs off-plane tilt and crack length vs tilt plots of all the examined THT solder joints after 1500, 3000 and 4500 thermal cycles, respectively.

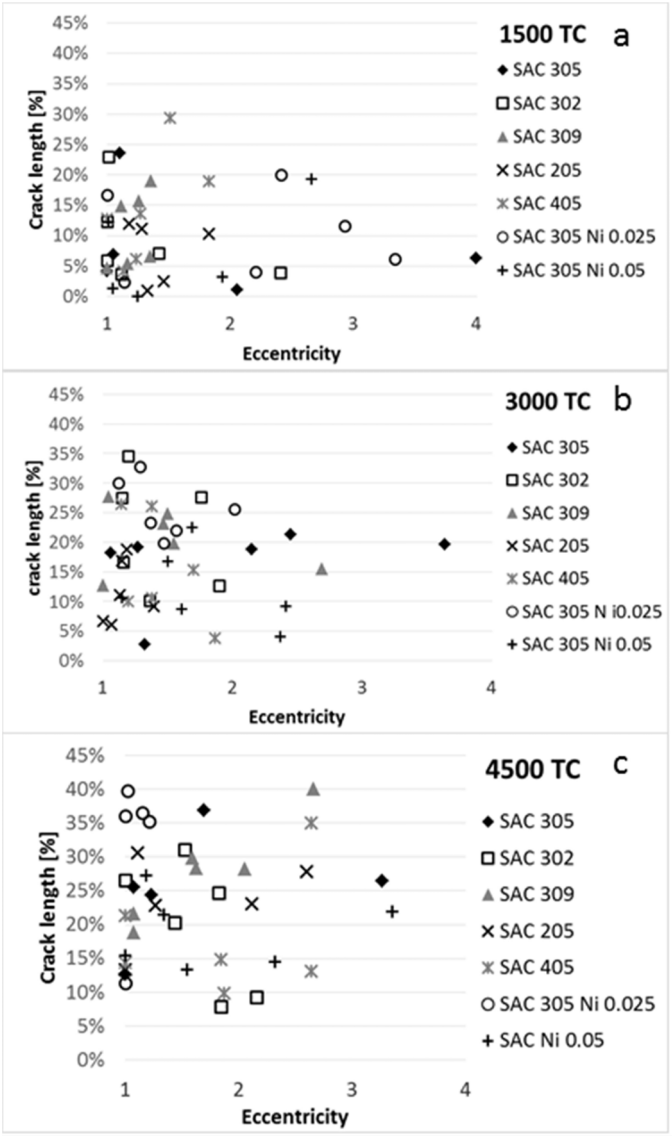

Fig. 3. Measured crack length vs eccentricity of THT solder joints a) after 1500 TC, b) 3000 TC, c) 4500 TC

It can be seen in Fig. 3 that for all examined solder alloys and thermal cycles, the variation of measured crack length does not follow any trend with increasing eccentricity. Thus, it can be deduced that pin eccentricity does not have an influence on crack propagation during cyclic thermal shock tests.

According to Fig. 4 the measured crack length versus off-plane tilt plots are chaotic independently on solder alloy composition and thermal cycle. This suggests that off-plane tilt does not affect crack propagation during cyclic thermal shock tests.

As seen in Fig. 5, the measured length of cracks does not depend on with tilt for all examined solder alloy compositions

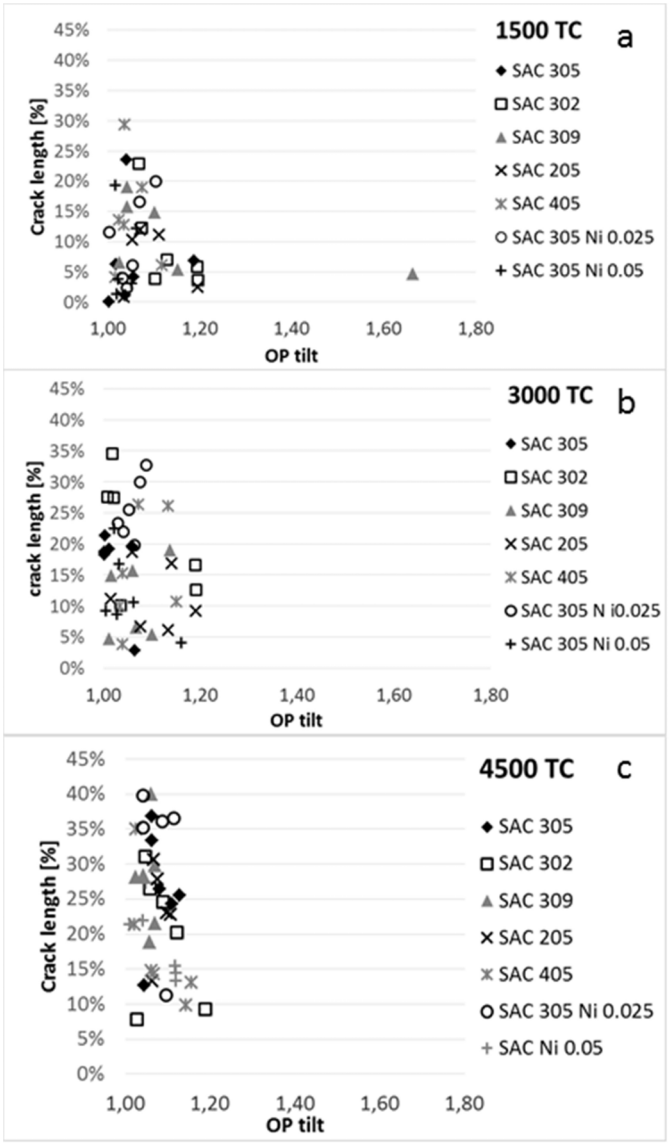

Fig. 4. Measured crack length vs off-plane tilt of THT solder joints a) after 1500 TC, b) 3000 TC, c) 4500 TC

and thermal cycles. Again, tilt does not affect crack propagation during cyclic thermal shock tests.

It was seen in Figs. 3-5 that the measured length of cracks within the examined THT solder joints increased as thermal cycle number increased. On the other hand, no correlations were found between pin misalignments and crack initiation and propagation. Pin misalignments cause varying solder thickness between pin and PCB along the PCB bore. Since the pin, the solder and the PCB have different thermal coefficients, different thermal stresses perpendicular to the bore centreline are expected at different solder thicknesses. However, the observed crack propagation was independent on pin misalignments, which suggests that the effect of stresses perpendicular to bore do not play noticeable role in crack propagation. More likely, thermal stresses parallel with the bore are the major stress components affecting crack propagation in THT solder joints.

It was also seen that crack initiation was not affected by composition change in the examined SAC solder alloys. It is

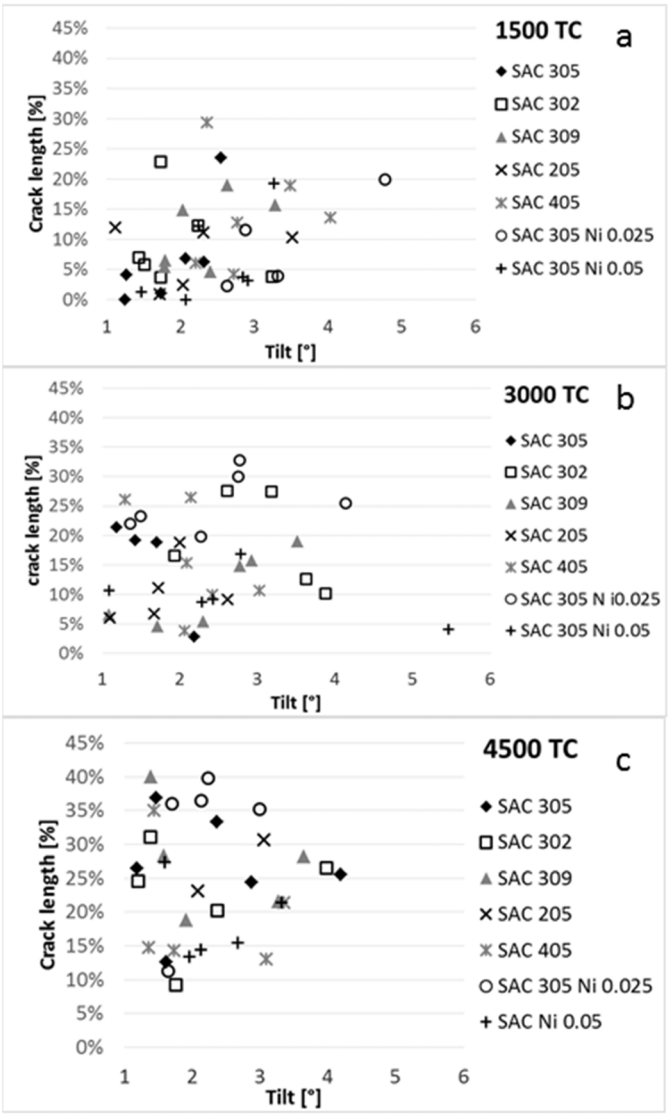

Fig. 5. Measured crack length vs tilt of THT solder joints a) after 1500 TC, b) 3000 TC, c) 4500 TC

known that similarly to all other alloys, mechanical properties of SAC solder alloys depend on their composition. However, it was seen that crack initiation occurred at well-defined locations within the THT solder joints independently on their mechanical properties.

4. Conclusions

In this study, correlations were searched for between pin misalignments of SAC THT solder joints, composition, crack initiation locations, crack propagation modes and crack lengths after 1500,3000 and 4500 cycles of thermal shock tests. It was found that misalignments of the pins and varying solder compositions do not influence crack initiation and propagation, nor on crack length of THT solder joints made of SAC solder alloys with varying Cu, Ag and Ni concentrations. It can be concluded that the unavoidable small displacements of pins relative to PCB bores during industrial soldering do not affect crack propagation and solder joint lifetime.

Acknowledgments

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