RISK FOR CERAMIC COMPONENT CRACKING DEPENDENT ON SOLDER ALLOY AND THERMO-MECHANICAL STRESS

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ABSTRACT
New solder alloy development for high temperature applications have increased the last few years; for example, automotive applications now use both Innolot and/or HT1 alloys, especially when the devices have to work at temperatures up to 170°C. For the solder alloy and the interconnection itself, there are some fatigue life advantages when using Innolot, especially for thermal cycles -40/+150°C. On the other hand, by using Innolot there is a relatively high thermo-mechanical stress induced which can create ceramics defects at the passive components. The paper will compare and discuss the differences of the alloy, based stress in ceramic components due to passive cycle tests, real customer tests, and stress analyses based on the finite element method.

Key words: Reliability, FEM, Field Defects, TCT, Solder Alloy, Ceramic Components

INTRODUCTION

Over the last years a lot of soft solder alloys and/or new assembly technologies have been developed for higher temperature application. Especially in the range from 125°C to 150°C or even higher (175°C) Innolot (IL) was developed for pcb applications or HT1 solder for TF and DCBs [1].

Although both alloys are based on Sn, the mechanical properties are different due to the additional elements inside the alloy. Especially the plastic and creep properties have an influence for the whole interconnect and therefore an influence on the components (mostly passive) as well. The target of the investigations reported here was to qualify and quantify the stress on the components due to thermo-mechanical stress for automotive requirements -40/+150 for IL, HT1 as well as SAC387 as a reference. The basis for the FEA are the residual stresses after the soldering and they will be compared for field and test conditions.

QUALIFICATION FOR AUOMOTIVE

Devices for -40/+130 N=515

For an automotive product the whole devices were tested including conformal coating according the OEM requirement TCT -40/+130 with N=515. In that case, four different alloys were running in the qualification, that means SAC305, low silver SAC0307, IL as well as HT1. Figure 1a and b show the results for the SAC alloy and Figures 2a and b the results for IL and HT1 after the TCT at cross sections.

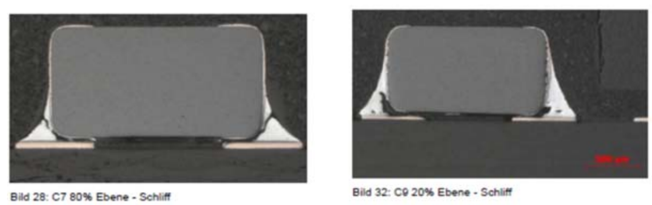

Figure 1. a) Cross section of SAC305 and b) Cross section of SAC0307 after TCT -40/+130

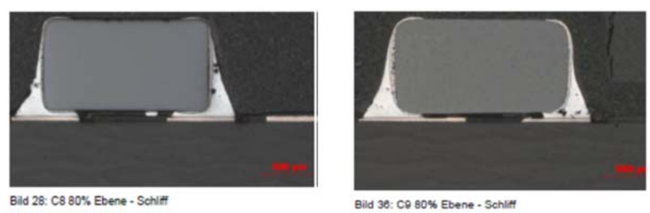

Figure 2. a) Cross section of IL and b) Cross section of HT1 after TCT -40/+130

The pictures show that both SAC alloys failed after the thermo-mechanical stress due to the TCT. The electrical function was not O.K. and by the cross section, there can be detected a fatigue failure inside the solder joint, beginning inside the gap and crowing from the gap to the outside (meniscus). The two high temperature alloys show no irregularities and the electrical function was O.K., too. However, a little deeper view on the cross sections shows a crack at the IL, Figure 3, while the HT1 does not have that effect, Figure 4.

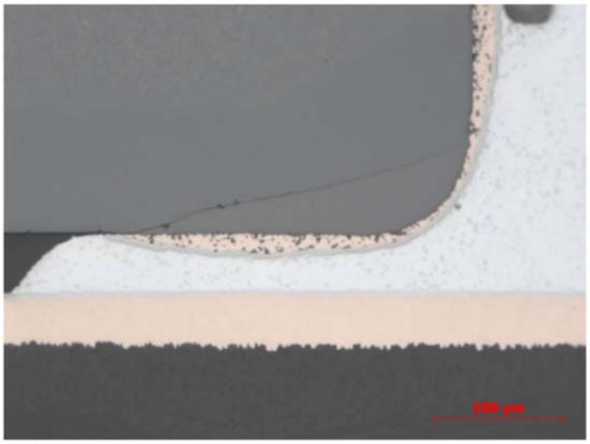

Bild 54 C8 – Ebene 80% – Detailbild Schliff

Figure 3. IL after TCT -40/+130 with a crack in the capacitor

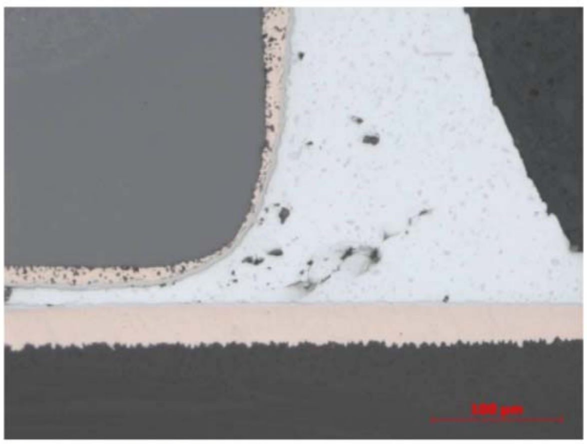

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Figure 4. HT1 after TCT -40/+130 with a crack in the capacitor

Due to the risks of capacitor cracks, HT1 alloy had been selected for that automotive device. The major question is if there is really a risk of such types of cracks by using IL or a similar alloy (equal mechanical properties).

Field returns

To understand that critical point for component cracks there are many investigations from the automotive industry to analyze field failures after return [2]. Figure 5 a and b show one result of such analyzes, where they have detected component cracks after mechanical stress.

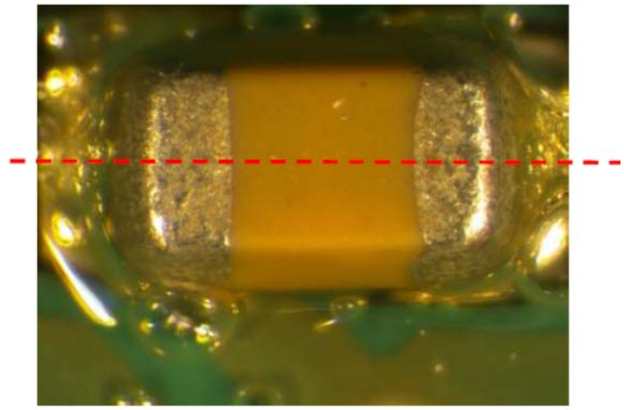


Figure 5a. Capacitor Line for Cross Section [2]

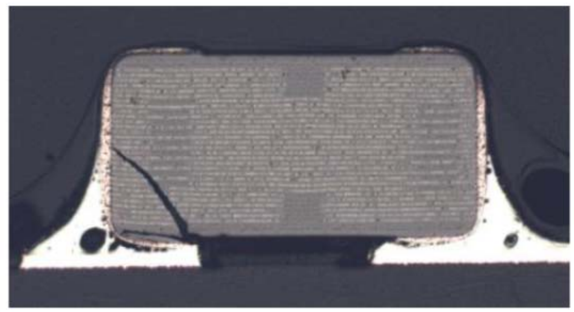


Figure 5b. Cross Section: Capacitor with a Crack after field return [2]

The limit for critical ceramic capacitors or other components are a max. bending stress of 800µm/m. In addition, there is a major concern, if there is a correlation between pure mechanical stress and thermo-mechanical stress.

TEST REQUIRMENTS AND RESULTS

Thermal Load

Figure 6 shows the requirements for the TCT. The T-gradients measured are higher than the recommended ones of max. 15K/min according the JESD22-A104D.

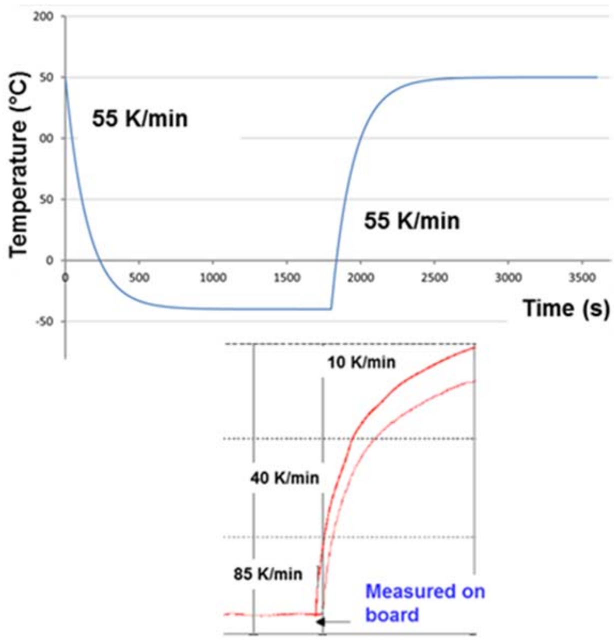


Figure 6. Air/Air TCT -40/+150 in simulation and test

For comparison a linear profile was selected within the range of the recommended ramp, Figure 7.

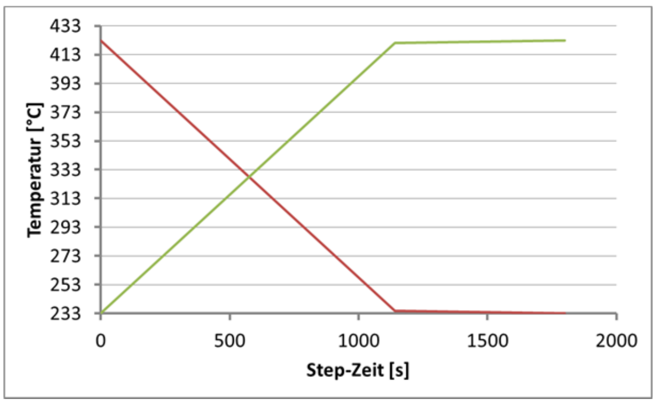


Figure 7. Gradient for Air/Air TCT -40/+150 in simulation

Compared to typical field cycles, where there are characteristic T-gradients between 1 and 3 K/min, even the standards recommend much higher gradients. By using soft solder alloys, which are able to reduce the stress by creep, different failure mechanisms can be created by different loads/stresses and there rates, too. The field stress in [3] described with 22/93°C 6 hour was selected for comparison to a service cycle.

Ceramic Capacitor Cracks with IL

For most of the standard soft solder alloys, solder joint defects developed during TCT. IL has more resistance against TCT but could create different failures like discussed in [2]. One example is capacitor cracks as shown in Figure 8.

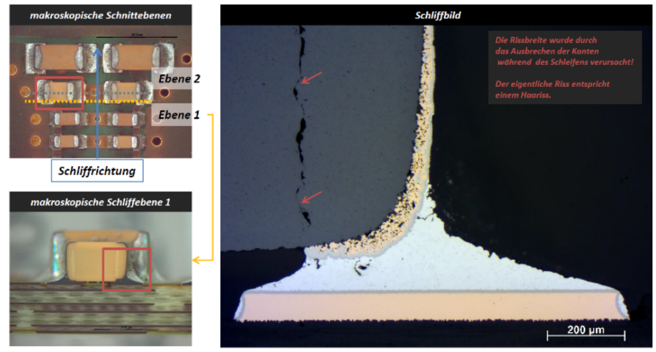


Figure 8. C0805 Ceramic crack after TCT -40/+150 N=1000

Another defect which can occur, is lifting of the metallization from the ceramic resistors, Figure 9.

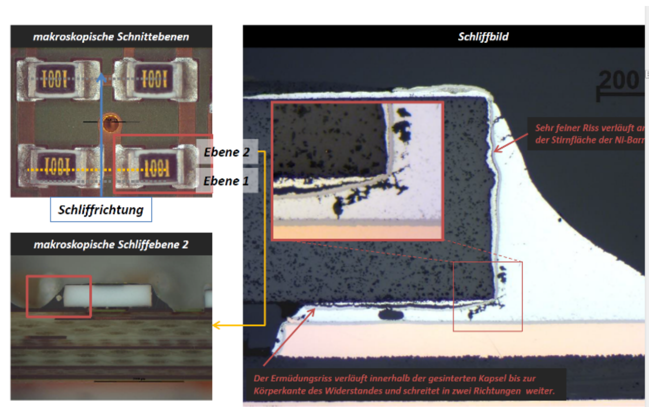


Figure 9. R0805 Metallization Lifting after TCT -40/+150 N=1000

Figure 10 shows a rack beginning in the meniscus with IL.

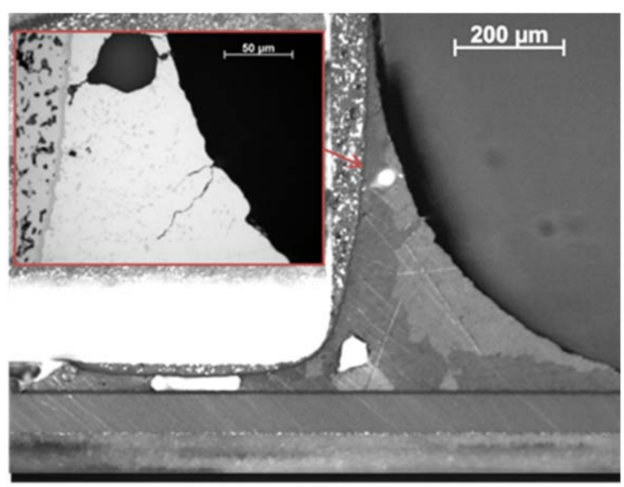


Figure 10. Characteristic cracks after field-test with 22/93 N=6500 for IL

Based on these results, there is consensus that such a failure mechanism does not occur at standard field loads. However, there is always a chance based on the results for the automotive devices, it can have a correlation and therefore it makes sense to analyze the stress and the differences between the alloys in more details.

FENITE ELEMENT SIMULATION

Geometry Model

Incoming information quality is a major requirement for producing reliable and repeatable results. Size, Area; etc. are generally described very well; however, total material information lacks depth, especially when taking it directly from a technical datasheet.

Figure 11 and 12 shows the FE Models typically used for solder joint/ device investigation.

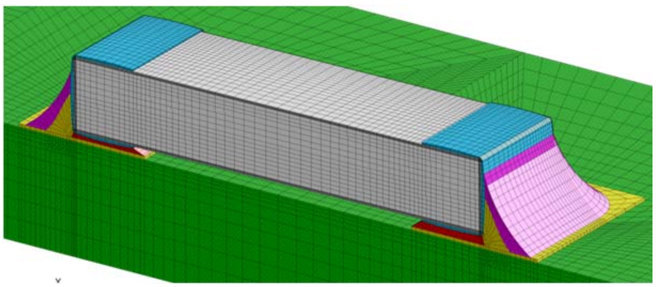


Figure 11. FE-Model for R1206 with asymmetric standoff/gap (26µm/50µm) and variation meniscus variation

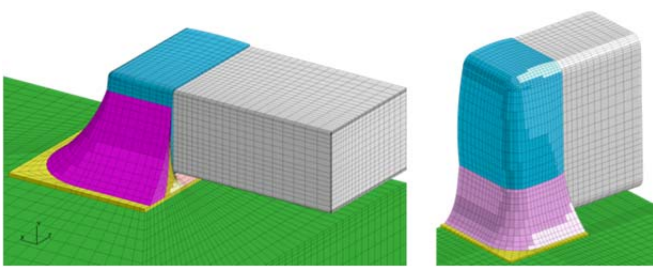


Figure 12. FE-Model for R1206 and C1206 considers the entire geometry, including edges and solder joint quantity.

Due to process variation; especially related to solder joint quality/ quantity, this model contains only ideal information based on one quality. All parameter are a result of real devices with a pcb thickness of 0.8mm.

Material Model

One important factor for soft solder is its creep property. This is how the alloy reacts to thermo/ mechanical stress, which then influence the stresses within the entire component. Other important factors include additional elements within the soft solder alloy, IMC formation (ageing) and the microstructure itself.

In previous investigations of SAC (SAC105….SAC378) alloys, analysis showed that just the inherent differences in the alloys have relatively big effects on the creep property; Innolot was also included in these investigations [4]. Additionally, the question whether other elements has such influence, was already described [5, 6]. The investigations; which utilized different solder conditions, among of material (solder joint) and differences in the IL quality (three supplier). Furthermore, the property of the alloy was measured utilizing probes, and was determined to have a realistic geometry similar to passive components on PCB. These investigations provided basic data for the creep property of different alloys and alloy combinations.

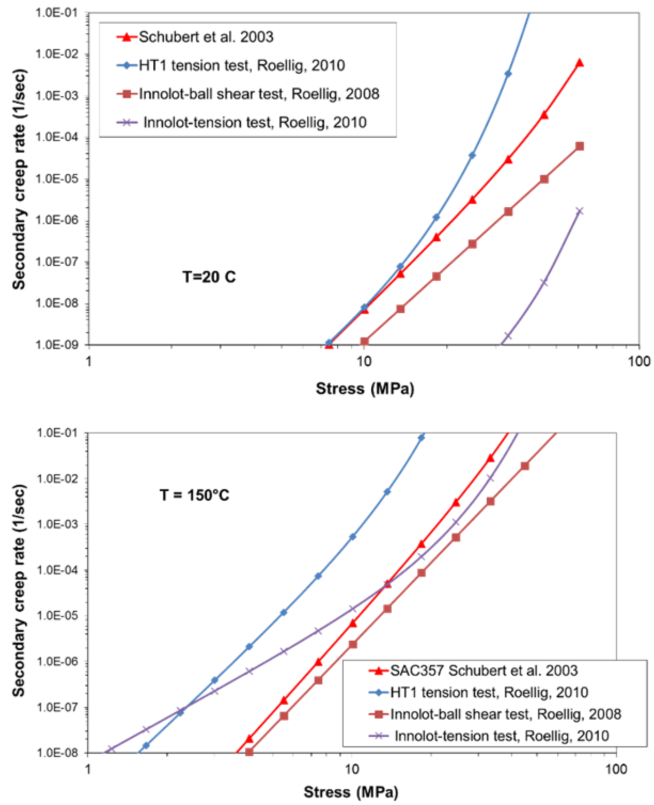


Figure 13. Secondary creep rate at T=20°C and T=150°C

Figure 13 shows the creep rate SAC, IL and HT1 at 20°C, and 150°C. Based on the result of [7] it shows that the highest creep rate is the HT1 alloy, while IL has the lowest creep rate. In additional to this, there is a comparison to standard SAC [8]. The SAC result has include the primary creep in additional, like [8] describes.

Because all alloys tested possess inherently similar solidus temperatures, 190°C was adopted as a stress free temperature.

SIMULATION RESUTS

Thermal Shock and Cycle

The focus of this investigation was to determine the stress influence alternate alloys create on passive ceramic components. In general, stresses increase during cooling, with maximum stress realized at the lowest temperature. Analyzed examples shown in Figure 14.

Because of the tendency for brittle fractures the maximum stress can be used for interpretaion. Figure 14 shows the max. shear stress at the lower temperature -40°C, indicating that the max stress occurs and is detected at the end of the metalization.

For resitors, this could prodce a risk factor for delamination of the entire metalization, Figure 15, while for capacitors there is a greater risk of crack formation in the ceramic.

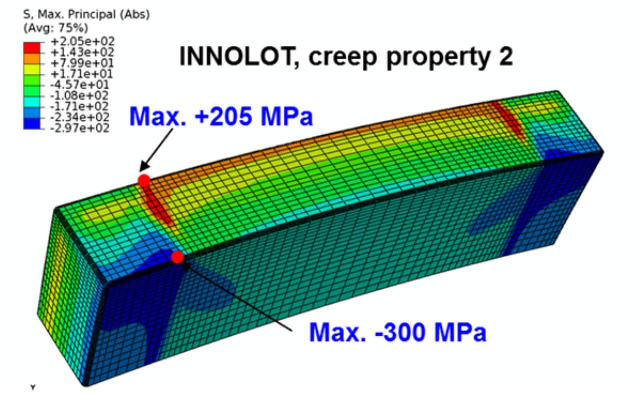
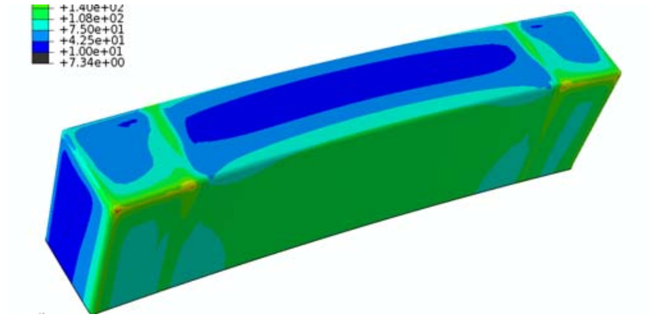
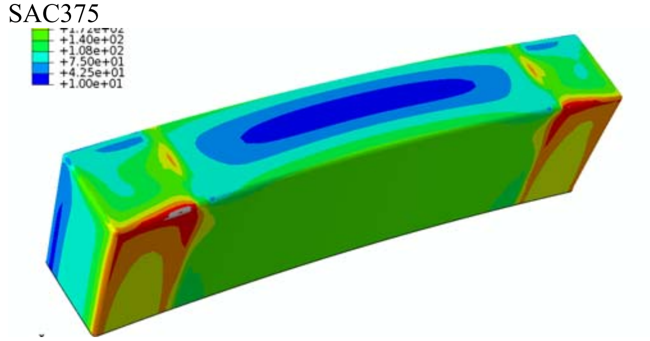


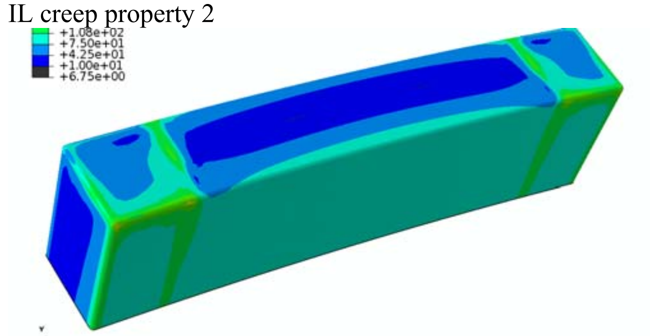
Figure 14. R1206: distribution of the principal stress at -40°C (deformation 30 times) with SAC375



SAC375



IL creep property 2



HT1

Figure 15. Comparison of R1206 v. Mises stress distribution for different alloys at -40°C

Because of the initial internal stress the interpretation is more complex [9]. Comparisions of the different alloys in Figure 16, show that the max stress was created with IL, the lowest with HT1, and the main stress was detected at the end of the ceramic metallization.

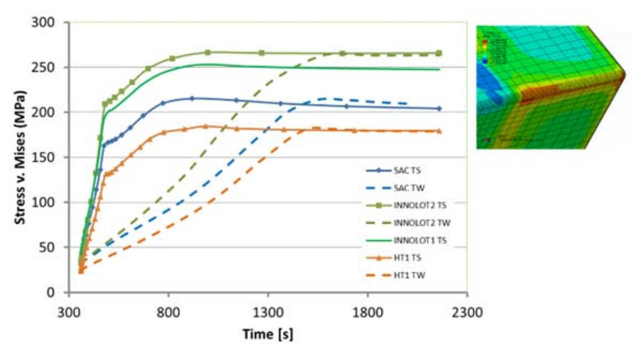


Figure 16. Comparison of v. Mises stress for different alloy and R1206 with thermal shock and cycle due to cooling

Figure 16 shows the time to reach the Mises stress for different alloys when cooling from +150°C t0 -40°C. Because of shock and cycle, there are differences in the time to reach the Mises stress, but there is no difference in the final stress.

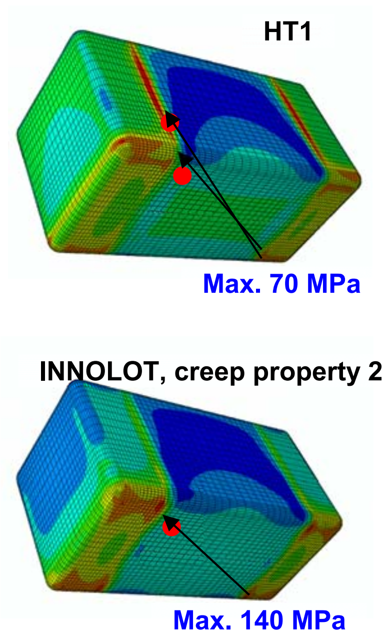


Figure 17. Comparison of v. Mises stress for HT1 and IL at C1206

TCT results on capacitors, are similar to those on resistors, with the stress produced by HT1 being sinificantly lower than that produced by IL. The lower stress typical to resistors are a result of the lower CTE and lower E-Modul. Critical is the lower strength of the ceramic body of C, which is approximately 150MPa.

Field Test

Due to the lower cycle temperature, and much longer cycle times, the field test should be non-critical compared the thermal shock test. To prove that, the same FE model has been used for analyzing down to RT (room temperature). Due to the more critical results with IL, this was the only alloy selected for analysis, Figure 18.

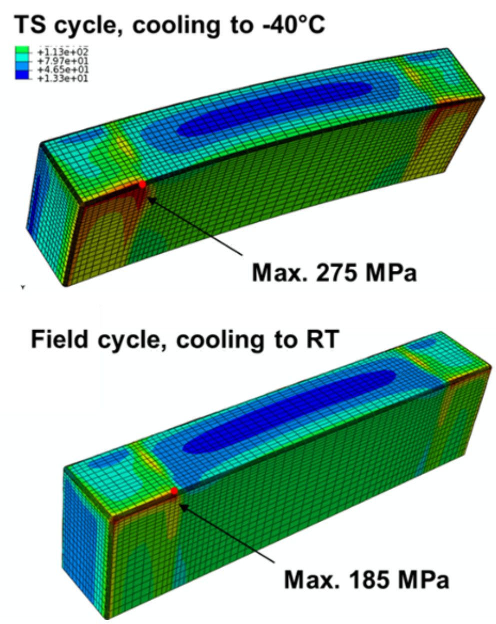


Figure 18. Comparison of R1206 v. Mises stress between TCT and field test, IL

SUMMARY

During physical testing, standard SAC alloys show fatigue, while both high temperature alloys produced acceptable results for the solder joint, and the IL alloy produced a ceramic crack after TCT. Due to additional active TCT tests, utilizing other alloys, there were also similar results detected. Field test conditions that seems to be non-critical. By an FEM it has been analyzed the stress on the passive components with different alloys. With regard to component stress, IL was determined to be the most critical alloy, with HT1 producing the lowest stress. Therefore, when there is a risk of ceramic cracks, using an alloy with a higher shear rate may provide a possible solution. Further activities will analyze other combinations such as devices with conformal coating etc. In addition, the knowledge can influence the quality of the ceramic passive components.

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