IEC TR 60068-3-12

Edition 2.0 2014-10

TECHNICAL REPORT

RAPPORT TECHNIQUE

Environmental testing –
Part 3-12: Supporting documentation and guidance – Method to evaluate a possible lead-free solder reflow temperature profile

Essais d'environnement –
Partie 3-12: Documentation d'accompagnement et guide – Méthode d'évaluation d'un profil de température possible de brasage sans plomb par refusion

IEC TR 60068-3-12:2014-10(en-fr)

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ENVIRONMENTAL TESTING –

Part 3-12: Supporting documentation and guidance – Method to evaluate a possible lead-free solder reflow temperature profile

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IEC TR 60068-3-12, which is a technical report, has been prepared by IEC technical committee 91: Electronics assembly technology.

This second edition cancels and replaces the first edition published in 2007 and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- the content has been adapted to the state-of-the-art of reflow-oven technology and termination finishes;
- minor language adjustments were performed.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
91/1158/DTR	91/1177/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all the parts in the IEC 60068 series, under the general title *Environmental testing*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,
- replaced by a revised edition, or
- amended.

ENVIRONMENTAL TESTING –

Part 3-12: Supporting documentation and guidance – Method to evaluate a possible lead-free solder reflow temperature profile

1 Scope

This part of IEC 60068, which is a technical report, presents two approaches for establishing a possible temperature profile for a lead-free reflow soldering process using SnAgCu solder paste.

This process covers a great variety of electronic products, including a large range of package sizes (e.g. molded active electronic components, passive components and electromechanical components).

Study A addresses requirements needed in the production of high-reliability electronic control units (ECU), as for example in automotive electronics. These requirements include measurement and production tolerances.

Study B represents consumer electronics products and includes reflow oven capability, board design and package sizes.

2 Basics

The process temperature for SnPb solder paste has a wide margin due to the liquid temperature of the solder alloy. During reflow soldering, temperature differences between components exist but are not critical. The process temperature of SnAgCu solder paste is about 20 K to 30 K higher than SnPb solder paste. Furthermore, the temperature difference between components (ΔT) becomes wider and sometimes the heat resistance temperature of components can become critical.

To avoid soldering failures which could be very harmful in safety-related applications and also generate higher failure costs, the capability of the soldering process is very important. A compromise between the temperature requirements of highly reliable solder joints and the limited solder-heat resistance of the electronic components has to be sought. In addition, the different aspects of mass production have to be considered. To achieve a reliable solder joint, the conventional reflow soldering process with eutectic SnPb solder paste is usually performed at a minimum peak temperature of about 203 °C at the coldest solder joint (i.e. at least 20 K above the liquid temperature of SnPb T_{liquid} = 183 °C).

The selected lead-free solder is SnAgCu with a melting point at around T_{liquid} = 217 °C [1] [1]. It is a generally preferred material for lead-free reflow and wave soldering in mass production [2]. Using SnAgCu solder paste, it is not possible to solder the coldest solder joints at least 20 K above the liquid temperature (T_{liquid} = 217 °C), which would result in minimum temperatures of 237 °C. When the coldest solder joint is 237 °C, the temperature spread between small and large components, small semiconductor, and passive components, as well as the printed circuit board (PCB), will be too large for the components to survive the heat impact. Despite the aim to achieve a relatively low temperature at the coldest solder joint, the reliability of the solder joint has to be assured.

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[1] Numbers in square brackets refer to the Bibliography.

To reach this target in Study A, the temperature at the coldest solder joint is taken to be T_{min} = 230 °C, for a minimum time of 20 s, which is just 13 K above the melting temperature. Considering the peak shape (see Figure 1) this condition corresponds to 1 s at 233 °C. From a physical point of view, the risk of insufficient solder wetting during mass production is significantly higher if the solder joint temperature is lower than the above mentioned temperature of 230 °C. In addition, lead-free termination finishes (like tin layers with a post-bake process or very thin NiPdAu finishes) are known to exhibit a poorer wetting behavior than conventional SnPb pin finishes.

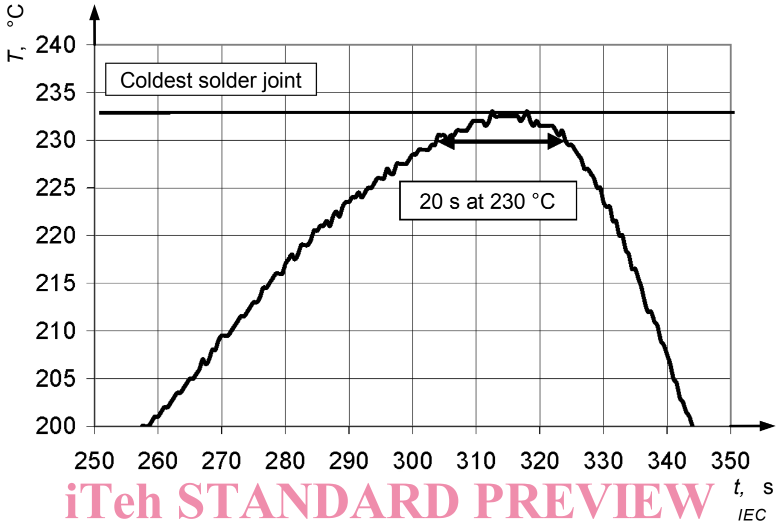


Figure 1 – Curve shape for a peak temperature of at least 20 s at 230 °C and 1 s at 233 °C

The experiments had been performed under mass production conditions (850 mm/min) using state-of-the-art reflow equipment, i.e ovens featuring multiple heating zones, full convection and N_2 atmosphere.

3 Boards under investigation

3.1 Test board approach

For the experiment in Study A, a special test PCB was designed. Polyimide resin with a glass transition temperature of T_g = 260 °C was used as base material for the PCB. Such a test board can represent the entire automotive ECU spectrum. The largest temperature difference (ΔT) between the coldest solder joint and the hottest point existing on this printed circuit assembly (PCA) spectrum is reflected on this test board (ΔT can be even larger for even more complex PCAs). The coldest solder joint was represented by a defined thermal mass, to represent large integrated circuits (ICs), coils or aluminium electrolytic capacitors. Its temperature behavior was correlated with the temperatures of the coldest solder joints on serial boards.

3.2 Production board approach

For Study B, PCB and reflow oven were taken from actual series production.

4 Temperature tolerances

4.1 Temperature tolerances in Study A

For tolerances during temperature profiling, different systematic failures shall be considered. First of all, there is an error associated with the temperature measurement itself. The measurement was performed in the centre on top of the packages with a well defined and repeatable preparation technique. Nevertheless, the failure due to preparation had to be fixed within ±1,0 K. In addition, the thermocouple (NiCrNi), together with the evaluation unit has an accuracy of ±1,5 K for pre-selected thermocouples. According to IEC 60584-2 [6] the NiCrNi thermocouples, class K, tolerance class 1 are specified with a tolerance of ±1,5 K for just the thermocouple itself without the measurement unit. Based on suppliers indication and own measurements, the furnace tolerance based on furnace load is ±0,5 K and the furnace tolerance for long term stability is ±2,5 K.

- Thermocouple with measurement unit: ±1,5 K
- Preparation of thermocouple: ±1,0 K
- Furnace load variation: ±0,5 K
- Long term stability of furnace: ±2,5 K

Because these variations are independent, the Gaussian error propagation can be applied, which results in a total tolerance of ±3,0 K, due to measurement errors and variations in mass production. The tolerance of –3,0 K results in the requirement to profile the coldest solder joint at 236 °C, instead of 233 °C (i.e. 233 °C + 3,0 K). This tolerance is known as the "lower tolerance". In addition to the measurement errors and variations due to mass production, the influences of the test board have to be considered. The measured temperatures of the electronic components depend also on the position on the test board because of the longitudinal and transversal temperature spread in the furnace and along the test board (see Figure 2). These temperature differences are the result of the heat flow conditions in the furnace and around the test board. The actual temperature of a device can be up to 3,5 K higher than the measured values at the position where the device is mounted on the test board. The temperature dependence on the device position was measured independently before measuring the device temperatures on the assembled test board.

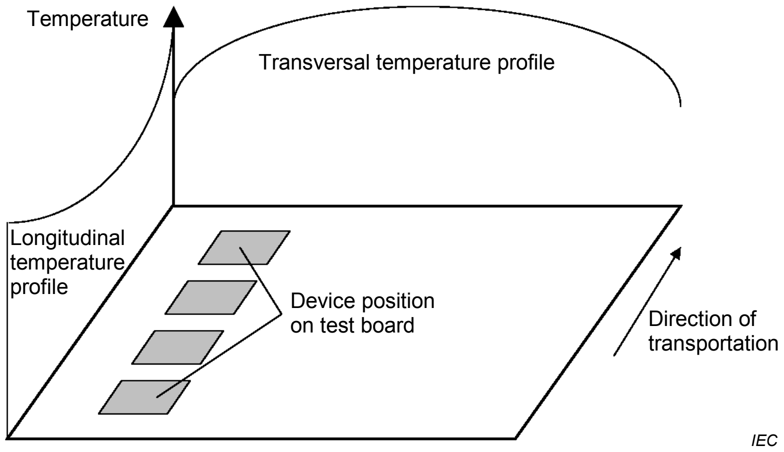
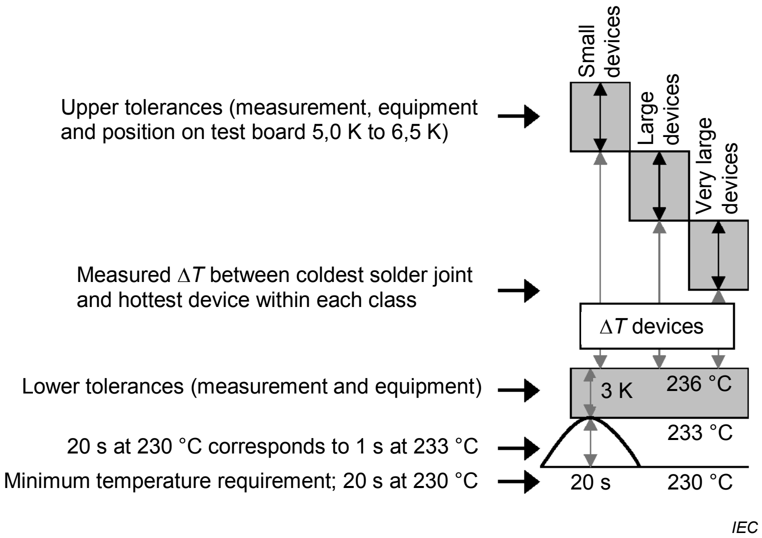


Figure 2 – Position of the assembled devices and temperature dependence on the device position

The thermal mass on the test board, which represents the coldest solder joint on the serial boards, was designed to include the relevant position-dependent tolerances. The upper temperature tolerances consist of the position-dependent temperature tolerances of 2 K to 3,5 K and the above mentioned +3 K. This leads to a total upper tolerance of 5 K to 6,5 K.

Regarding the whole temperature window of the lead-free soldering process, a total position-dependent temperature tolerance of 8 K to 9,5 K has to be added to the measured ΔT spread of the devices (see Figure 3).



NOTE Electronic devices are divided into three temperature classes.

Figure 3 – Lower and upper temperature tolerances of the reflow solder profile

4.2 Temperature tolerance and board size influence in Study B

In the consumer board study, the measured temperature includes lower temperature tolerance and upper temperature tolerance. Therefore at the coldest solder joint temperature of 230 °C, the "worst-case" temperature becomes 227 °C (i.e. 230 °C – 3 K) which is still 10 K higher than the melting point of the SnAgCu solder alloy (see Figure 4).

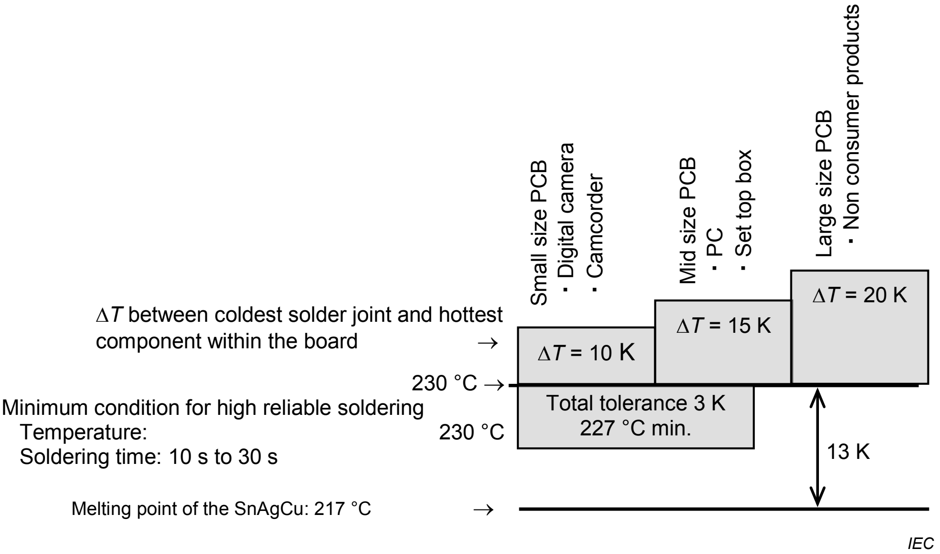
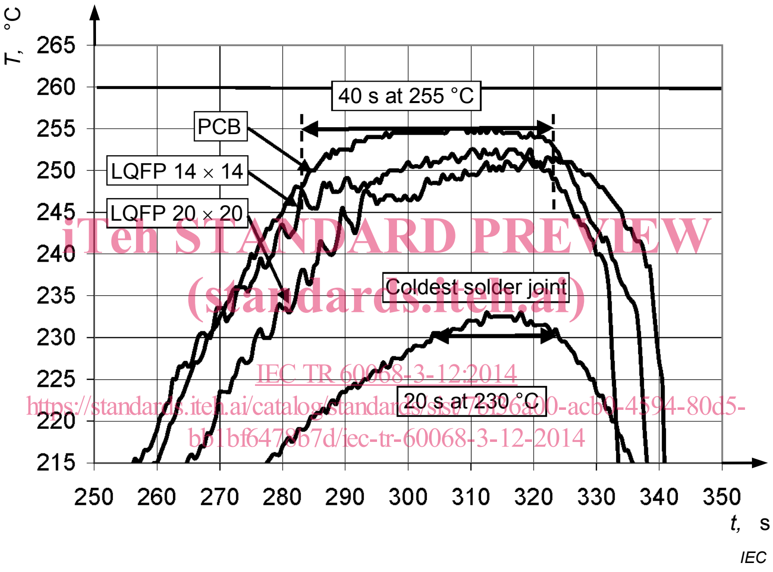


Figure 4 – Temperature tolerance and board size influence

5 Peak form and width

5.1 Peak form and width in Study A

The requirements were to maintain a temperature of at least 230 °C for 20 s at the coldest solder joint, and to limit the peak package temperature of the smallest devices (e.g. SOT23, small LQFP, TopLEDs and passive components) to $T_{peak} \leq 260$ °C. In order to meet these requirements, a soak-type preheating, as well as a hat type soldering peak were necessary in the investigation. The soak-type preheating allowed the temperatures of the individual packages to be close to each other upon entering the peak zone (see Figure 7). The hat type form of the soldering peak was used to minimize the temperature differences between the individual packages during reflow soldering. After conducting the experiment, it was discovered that the hat type form of the soldering peak required a soak time of 40 s at $T_{max} - 5$ K = 255 °C for the hottest devices on the PCB (see Figure 5).



NOTE Temperature tolerances are included.

Figure 5 – Hat type peak profile with 40 s at $T_{max} - 5$ K = 255 °C for the small devices and the PCB

5.2 Reflow oven investigation in Study B

Figure 6 shows temperature profiles on quad flat package (QFP) leads and a 1608 size surface mounting device (SMD) resistor using the same board but different reflow ovens. The reflow oven of Maker B, having more heating zones than the oven of Maker A, shows a wider temperature spread ΔT in the temperature profile than the oven of Maker A. Thus, the temperature spread ΔT does not depend primarily on the number of heating zones of the reflow oven but on the design of the reflow oven.

The peak reflow temperature for smallest components may vary according to the reflow oven being used. Also board size and board design are other factors affecting the peak reflow temperature.

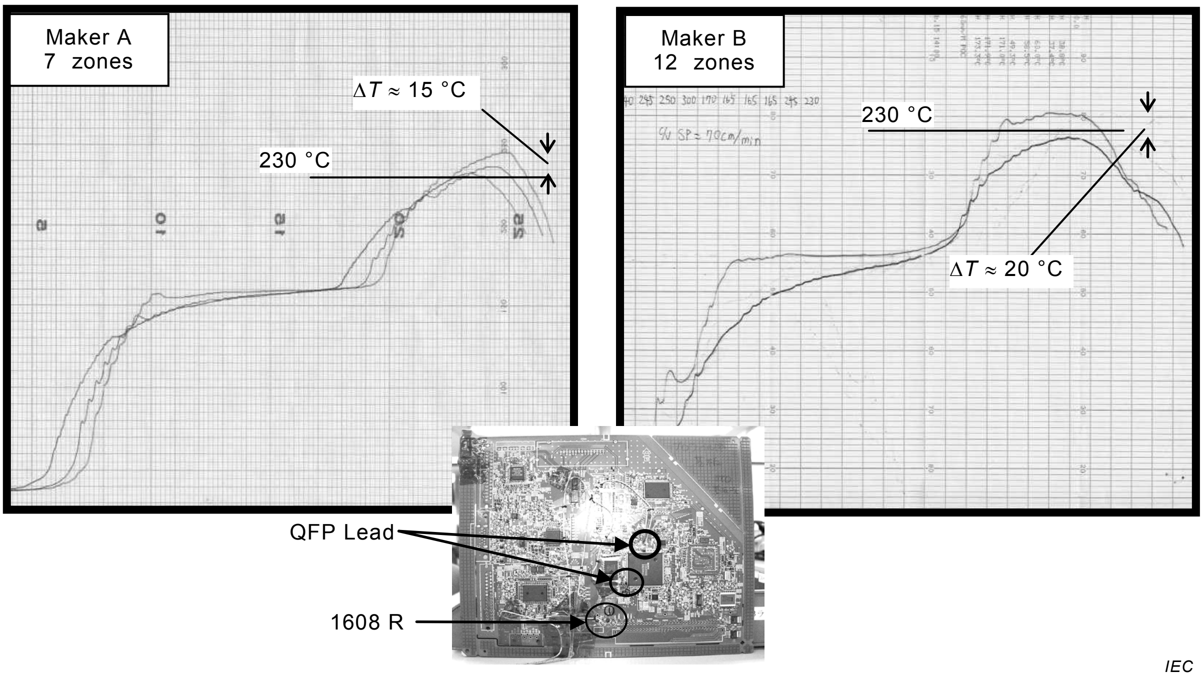
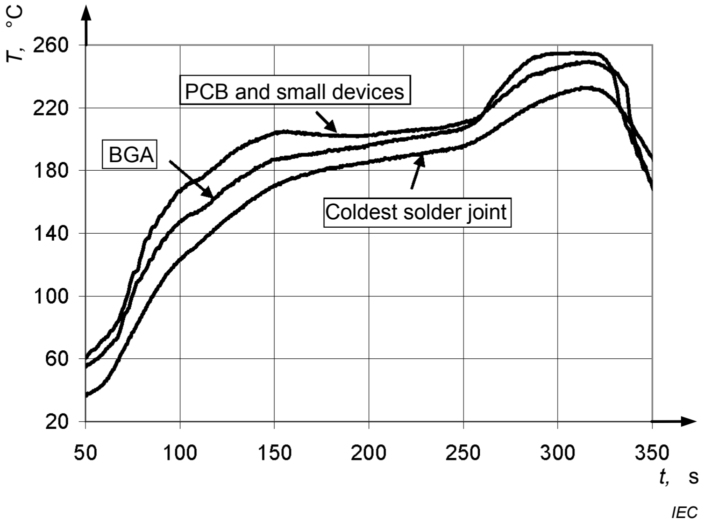


Figure 6 – Δ*T* by different reflow oven capabilities

6 Classification

6.1 Device classification in Study A

To classify the non-hermetic solid-state surface-mount devices into temperature groups with respect to the reflow peak, the heat capacity and heat conductivity should be taken into consideration. To simplify the study, the component similarity with respect to the composition (molded silicon) is taken into account and only the package volume and thickness are considered. In Figure 7, some typical temperature measurements of molded components using the described test board with a soak preheating and a hat-type reflow soldering peak are shown. The transportation speed was 850 mm/min and the temperature measurements were performed centrally on the top of the packages. In total, the temperature profiles for 19 characteristic molded package types and several passive and electromechanical devices were measured on a multiple heating zone reflow oven with full convection. Between the coldest solder joint and the PCB itself, a temperature difference of 13 K was measured. Small plastic components like small connectors, switches or TopLEDs showed even higher peak package temperatures with a temperature difference of 17 K from the coldest solder joint [3], [4].



NOTE Temperature tolerances are included.

Figure 7 – Representative test board measurements

Table 1 shows the measured temperatures and the temperatures achieved when the lower and upper tolerances are being added. Temperatures shown are for several characteristic molded devices with different peak temperatures.

Table 1 – Measured temperatures of devices and values including lower and upper tolerances

Device	Temperature				
	Measured value °C	Lower tolerance °C	Including lower tolerance °C	Upper tolerance °C	Including upper tolerance °C
Coldest solder joint	233,0	3,0	236,0	–	–
Plastic leaded chip carrier PLCC52	234,0	3,0	237,0	6,0	243,0
TO263	239,5	3,0	242,5	5,0	247,5
Ball grid array (BGA) (24 mm x 24 mm)	240,5	3,0	243,5	6,0	249,5
Low-profile quad flat package (LQFP) (14 mm x 14 mm)	243,5	3,0	246,5	6,0	252,5
Small outline transistor (SOT) devices	247,0	3,0	250,0	5,0	255,0
The upper tolerance is dependent on the position of the device on the PCB. The lower tolerance of 3,0 K represents the value that the minimum solder joint temperature has to be raised to, due to the mentioned measurement and process tolerances.					

In these examples, the maximum temperature difference between actual measured and tolerance corrected values was 9 K. These corrected temperatures represent the theoretically possible maximum package temperatures for the devices during reflow soldering. Referring to molded components (most active components) their internal structure is very similar. The specific heat capacity and the thermal conductivity do not deviate significantly (metal-based lead frame or interposer/silicon/mold compound). Therefore, it is possible to create temperature classes for the solder-heat resistance referring to volume and thickness of such molded devices. However, a similar approach is not feasible for the wide range of passive and