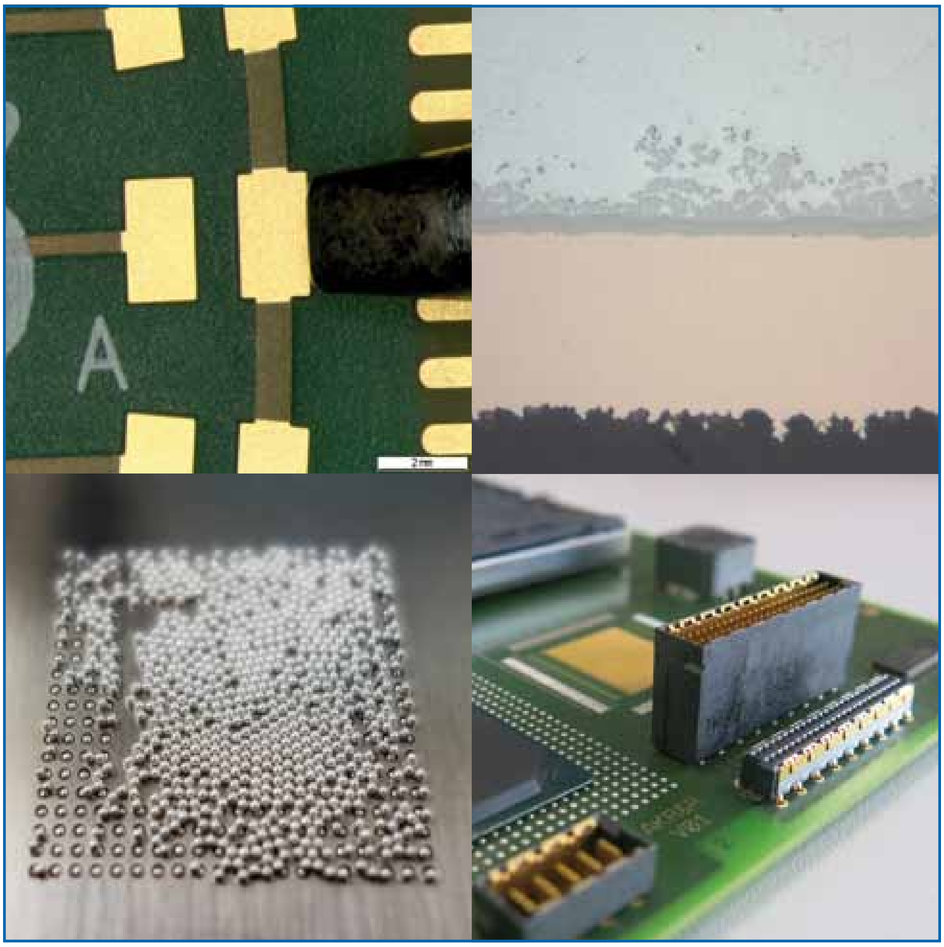
ZVEI: Die Elektroindustrie

Guidelines

Rework of Electronic Assemblies

Qualifiable Processes for Rework



German Electrical and Electronic Manufacturers' Association

Rework of Electronic Assemblies

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1 Introduction

Keywords such as process or machine capability, six-sigma approaches, flat-rate zero-defect strategies or lean are initially oriented primarily to the high-throughput line and mass soldering processes, leaving little acceptance for (seemingly) useless, non-value-adding processes such as rework or repairing electronic flat assemblies.

Particularly within specific sectors, any additional rework or even repair step is regarded as a neglected additional discipline not worthy of discussion.

If these reasons for a strictly negative attitude are exclusively due to the fact that these exceptional corrective steps are a supposedly expensive measure, this might seem an acceptable justification. Unfortunately, the fundamental quality of these supplementary measures is often questioned without having considered the procedures used in detail.

These uncertainties about the assessment and design of any necessary rework or repair steps are nurtured by the supposedly poor initial situation with regard to established process principles for safe process design.

The aim and purpose of the ZVEI Rework and Repair (R+R) Working Group (WG) is to present the understanding gained in the form of an industry recommendation with regard to the chances and risks of rework and repair processes and, if necessary, to sensitise them to specific needs.

The guide is intended to enable both customers and manufacturers to identify possible process limitations and process specifics and to help them develop a more consistent perception, need-oriented acceptance and improved understanding of the topic of rework and repair.

This guide first presents the basic considerations for rework and repairing assemblies.

Only rework will be covered in the guide, as its aim and purpose is to ensure the conformity of the finished product with drawings and specifications.

In the event of doubt, the user must, together with his client, weigh up for his project whether or not his process is a repair as defined in chapter 2.1.

At the same time, relevant norms, standards and guidelines for the implementation of high-quality, reproducible rework or repair will be presented.

The content of this guide is based on the prior knowledge and individual experience of all members of the WG, and on the other hand the findings of the test assemblies of ZVEI-WG R+R (especially created for this purpose).

Specific risks and neuralgic points within the entire process design are presented and recommendations for implementation are given on the basis of the respective parameters of the procedures and processes.

Irrespective of the solder alloys to be used, the effects of lead-free rework and repair with SnAg3.0Cu0.5 solders (SAC305 solders) are primarily discussed in the present case, but the findings on soldering processes with other alloys can be carried over at suitable process temperatures in the light of the thermal load capacity of the assemblies/components.

The user of the guide will be given a summary of all important factors for the safe implementation of R+R processes in the form of a decision or processability matrix.

2 General Aspects

2.1 Definition of rework and repair

Only too easily are non-original value-adding processes such as rework and repair classified as repairs and not separately considered.

However, a closer look is needed to properly assess the underlying procedures and concepts of rework, repair or modification (as a special case) if required.

A compact definition of the respective methods is provided by the IPC-T-50J [1], in which the terms are described as below.

Rework:
Rework of a non-conforming article with original or equivalent processing in a way which ensures the complete consistency of the article with the corresponding drawings or specifications (could also definitely include a component replacement).

Modification:
Revision of the functionality of a product to meet new acceptance criteria. Changes are generally necessary to take account of design changes, which are made in drawings, by alteration orders, etc. Changes are to be made only with the express permission and accompanied by the detailed documentation in the applicable documents.

Repair:
Restoring the operability of a defective article in a way which does not ensure the complete consistency of the article with the corresponding drawings or specifications.

Irrespective of which type of corrective action is chosen, some basic questions must first be clarified:

- Is the corrective measure only an unscheduled transitional measure or is there a risk of it becoming routine?
- How effective is the measure?
- Are there any qualitative restrictions on the change?
- Are there restrictions on reliability?
- Is it possible to apply an additional measure at all?
- Are suitable ESD protection measures implemented to protect the components and assemblies?
- Are there any restrictions with respect to moisture-sensitive components (MSL)?
- Are cleanliness, proper handling and sufficient employee qualification ensured?

2.2 The line process as a model

In order to meet the individual thermal requirements and general conditions for the reworking of electronic assemblies, the soldering processes to be applied must first be defined and assessed.

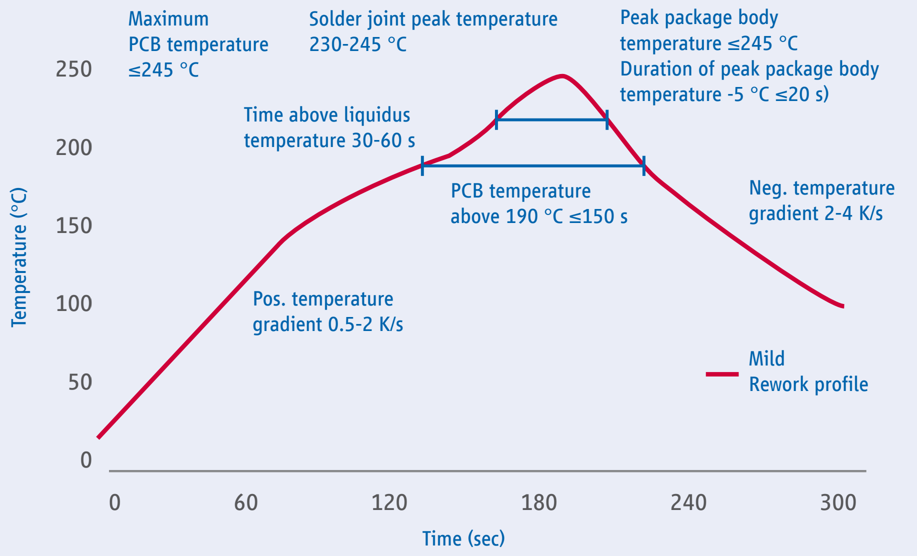
While separate consideration is particularly necessary for manually guided soldering devices (such as manual soldering irons or hot gas grinders) (see chapter 2.14.1), thermal conditions can be clearly defined for so-called rework systems or quasi-stationary systems (see chapter 2.14.2).

In terms of thermal conditions, the reflow line process, including the corresponding documents, is in a certain sense the reference process.

The objectives of an optimised reworking step using the rework system are:

- Thermal profile stability and characteristic in line with the (reflow) line process
- Transfer of the assembly requirements of all components to the individual requirements of the structures which are the focus of the rework
- Rework profiles may deviate from the "classic" reflow profile (DIN EN 61760-1) [2] - see chapter 2.5 - of the assembly, but in no case breach the individual component specifications.

Fig. 1: Recommendation for a mild reflow profile for the rework



Source: ZVEI

In accordance with these basic considerations, the local thermal profiles to be applied to individual components should be adapted as follows

- Compliance with the manufacturer's specifications (component, Printed Circuit Board (PCB) and soldering material)
- Compliance with the limits of J-STD-020 [3]
- Compliance with component handling under J-STD-033 [4]
- Compliance with the limits of J-STD-075 [5]
- Achieving the recommendations of IPC 7095 [6]
- Achieving the recommendations of IPC 7093 [7]

The following parameters (for SAC305) are recommended in addition to strict adherence to the minimum and maximum limits of the components for process-safe processing and to ensure temperature compensation on the assembly (based on reflow soldering):

- Positive temperature gradient of 0.5-2 K/s at the solder joint (heating)[1, 4]
- Negative temperature gradient of 2-4 K/s at the solder joint (cooling)[1, 4]
- The Printed Circuit Board (PCB) temperature should not be above 190°C for more than 150 s[4]
- The Printed Circuit Board (PCB) temperature should not be above 245 °C[4]
- The time above liquidus temperature (about 220 °C) at the solder joint should be between 30 s and 60 s[1, 2]
- The peak temperature at the solder joint should be between 230 °C and 245 °C[1, 2]
- The maximum temperature at the solder joint should not apply for more than 20 s
- The maximum peak package body temperature should not be more than 245 °C[1]
- The maximum temperature at the top of the component should not be applied for more than 20 s[1, 3]

The often discussed consideration of keeping the rework process as cool as possible seems to be plausible at first, in order to expose the components to the lowest possible thermal stress. The following aspects must be considered:

- Achieving stable solder joint training IMC (Inter Metallic Compound) layer
- Compliance with the minimum process limits in order to ensure the classification of the flux residues
- Process fluctuations must be considered

For assemblies with a large thermal mass, solder profiles can be significantly longer. These should be regarded as permitted as long as the above criteria are met.

[1] Limiting values of components take priority.
[2] Recommendation from the project (if the permitted process limits are exceeded an additional crosssection analyse should be taken to account).
[3] Measured maximum temperature -5 °C.
[4] Follow the instructions of the material manufacturer.

Tab. 1: Parameter-conserving and permitted processing

Profile parameters	Mild processing	Permitted processing
Positive temperature gradient at the solder joint [1, 4]	0.5-2 K/s	<3 K/s
Negative temperature gradient at the solder joint [1, 4]	2-4 K/s	<6 K/s
Time of the Printed Circuit Board (PCB) temperature above 190 °C [4]	≤150 s	≤240 s
Maximum Printed Circuit Board (PCB) temperature[4]	≤245 °C	≤260 °C
Time above liquidus temperature at the solder joint (about 220 °C) [1, 2]	30-60 s [2]	45-90 s
Peak temperature [3] Solder joint [1, 2]	230-245 °C [2]	235-250 °C
Duration of peak temperature [3] Soldering point	≤20 s	≤20 s
Peak package body temperature [1]	≤245 °C	≤260 °C
Duration of peak package body temperature [1, 3]	≤20 s	≤30 s

[1] Limiting values of components take priority.
[2] Recommendation from the project (if the permitted process limits are exceeded an aaditional cross-section analyse should be taken to account
[3] Measured maximum temperature -5 °C.
[4] Follow the instructions of the material manufacturer.

2.3 Norms, standards and guidelines

A large number of norms, standards and guidelines deal more or less extensively with the topic of rework, modification and repair of assemblies. Individual documents consider only partial aspects in some cases with contradictions. The reader will now be given an overview of the most important works and contents and thus a basis for taking decisions.

The guide refers to the latest revision of the documents at the time of preparation. Future revisions of the listed documents might lead to a significant change, which cannot be considered here.

Tab. 2: Overview of the rules

Document	Document name	Main contents
IPC-T50 [1]	Terms and Definitions for Interconnecting and Pack-aging Electronics Circuits	• Glossary for a clear set of definitions to avoid misunderstandings
J-STD-001 [8]	Requirements for Soldered Electrical and Electronic Assemblies	• The specification for production quality results in the requirement for rework, modification and repair • Requirement for docu-mentation and deter-mination of the repair procedure • Requirements for verifica-tion, cleaning and training

Tab. 2: Overview of the rules

Document	Document name	Main contents
DIN EN 61191-1 to 4 [9]	Electronic assemblies on Printed Circuit Board (PCB) - Part 1 to 4	• Analogous to J-STD-001 [8]
DIN EN 61192-5 [10]	Product performance requirements Part 5: Rework, modification and repair of soldered electronic assemblies	• Definition • Lists preconditions for successful rework • Describes rework operations before and after soldering • Provides recommendations for drying before component replacement, preheating Printed Circuit Board (PCB) and sensitive replacement components and tool selection (not complete) • Provides guidelines for personnel training
J-STD-033 [4]	Handling, packaging, shipping and use of moisture-/reflow-sensitive components for surface mounting	• Labelling, shipping and packaging of moisture-sensitive components • Recommendation for PCB rework and drying of components (assembled and unassembled)
DIN EN 61760-2 [11]	Surface assembly technology - Part 2: Transport and storage conditions of surface assembled components (SMD) - Application guide	• Climatic and mechanical conditions during transport and storage of surface assembled components (SMD)
IPC-7711/7721 [12]	Rework, modification and repair of electronic assemblies	• Detects and describes procedures for the rework, modification and repair of electronic assemblies, e.g. handling (cleanliness, ESD protection), removing/replacing paintworks, substrate repair, typical procedures with various devices, training
DIN EN 61760-1 [2]	Surface assembly technology - Part 1: Standardised method for specifying surface assembled devices (SMDs)	• Expansion and/or replacement of soldered and glued SMDs • Solder profile specification
J-STD-020 [3]	Classification of moisture/reflow sensitive non-ferromagnetic semiconductor components for surface mounting	• Classification of moisture sensitivity • Prescribes a handling rule to avoid moisture-induced damage during the reflow soldering process (in assembly manufacturing and in the repair process) and to increase yield and reliability

J-STD-075 [5]	Classification of non-IC electronic components for assembly processes	• Specification of process limits for the soldering process for specific components (families) that are accepted in the sector (but are not recommended as process parameters for assembly manufacturers) • Described is a process for determining a process sensitivity level (PSL)
IPC-7095 [6]	Design and Assembly Process Implementation for BGAs	• Recommendation for the performance of a BGA rework process
IPC-7093 [7]	Design and Assembly Process Implementation for Bottom Termination Components	• Recommendation for the performance of a BTC rework process
Data sheet for the solder paste manufacturer	Data sheet	• Solder profile specification • Processing of solder pastes
Data sheet for the component manufacturer	Data sheet	• Processing instructions • Rework recommendation
ECSS-Q-ST-70-28 [13]	Repair and modification of printed circuit boards assemblies for space use	• Number of maximum repair processes per assembly, range, solder joint* • Requirements for procedures/sequence of repair processes*
ECSS-Q-ST-70-08 [14]	Manual soldering of high-reliability electrical connections	• Specifications for procedures, materials and temperatures of manual soldering processes as well as ambient conditions, ESD protection and tools • Inspection and training • Drying of printed circuit boards

Tab. 2: Overview of the rules

Document	Document name	Main contents
ECSS-Q-ST-70-38 [15]	High-reliability soldering for surface-mount and mixed technology	• Specifications for procedures, materials and temperatures of SMD soldering and repair processes* • Drying of printed circuit boards
IGF 15.535N [16]	Resistance to soldering and reliability of new designs in the manual repair process of leadless electronic assemblies	• Recommendations of procedures and temperatures for manual SMD and THT soldering and rework and repair processes • Workmanship • Stencils for work instructions • Reliability studies

* The definition of rework and repair according to ECSS is different from the IPC definition. In this guide the IPC definition is used (see Glossary).

2.4 Flux interaction "No-clean - but..."

In the production of electronic assemblies, flux systems are used which have to be cleaned (cleanable) or not cleaned (no-clean) after soldering.

For the classification of fluxes, the IPC J-STD-004 [20] and the DIN EN 61190-1-1 [18] are standardly used.

In IPC J-STD-004B [17] (Table 3-2 "Test Requirements for Flux Classification"), the no-clean state means that the classified flux must pass the SIR (Surface Insulation Resistance) and ECM (Electrochemical Migration) test in the unclean state after soldering. This means that the test samples loaded with the flux to be tested are not cleaned (no-clean) prior to the SIR and ECM tests. After the SIR test has been completed, the surface insulation resistance of the test samples is at least 100 MΩ and the test criteria must be met to pass the ECM test.

The SIR test, including the pre-treatment and preparation of the test samples with the flux according to IPC J-STD-004B [17] (item 3.4.1.4), is carried out in the IPC-TM650 [19] (Test Methods Manual, point 2.6.3.7) and the ECM test in the IPC-TM650 [19] (Test Methods Manual, point 2.6.14.1).

DIN EN 61190-1-1:2003 describes the test requirements for the classification of the flux activity. In the case of no-clean fluxes, their residues may only be tested in the unclean state. It should be noted here that the sample with the flux is subjected to a thermal load before the SIR test with the prescribed soldering process.

If an assembly for which a no-clean flux is used is to be cleaned before applying protective coatings, the user should check the SIR values after cleaning.

The requirements for the surface insulation of fluxes for the satisfaction of the 100-MΩ-SIR requirements of DIN EN 61190-1-1:2003 must be determined in accordance with test method 5E01 of the standard DIN EN 61189-5:2006.

The SIR test is used to characterise fluxes in accordance with DIN EN 61189-5:2007 by determining the drop in the electrical insulation resistance of test samples from rigid Printed Circuit Board (PCB) through the action of a specific flux. This test is carried out under high humidity and under heat stress in climatic chambers.

No-clean is a product-specific and isolated property of flux residues. Secure compatibility with other no-clean products as well as with not explicitly specified cleaning media is not guaranteed.

Please note the following in the rework process:

The no-clean properties apply only to flux residues which have experienced the soldering process (thermal load) which is intended for them. Separate evidence (SIR/ECM) must be provided for areas which have not been sufficiently heated.

Tab. 3: Table EN 61190-1-1

Substances contained in the composition of the flux [1]	Efficacy levels of the flux (wt. % halide) [2]		Description of the flux according to IEC[3]	Description of the flux according to ISO[4]
Rosin (RO)	Low	(<0.01) L0	ROL0	1.1.1
	Low	(<0.15) L1	ROL1	1.1.2.W, 1.1.2.Z
	Moderate	(<0.01) M0	ROM0	1.1.3
	Moderate	(0.15-2.0) M1	ROM1	1.1.2.Y, 1.1.2.Z
	High	(<0.01) H0	ROH0	1.1.3.X
	High	(> 2.0) H1	ROH1	1.1.2.Z
Resin (RE)	Low	(<0.01) L0	REL0	1.2.1
	Low	(<0.15) L1	REL1	1.2.2.W, 1.2.2.X
	Moderate	(<0.01) M0	REM0	1.2.3.W
	Moderate	(0.15-2.0) M1	REM1	1.2.2.Y, 1.2.2.Z
	High	(<0.01) H0	REH0	1.2.3.X
	High	(> 2.0) H1	REH1	1.2.2.Z
Organic (OR)	Low	(<0.01) L0	ORL0	2.1, 2.2.3.E
	Low	(<0.15) L1	ORL1	-
	Moderate	(<0.01) M0	ORM0	-
	Moderate	(0.15-2.0) M1	ORM1	2.1.2, 2.2.2
	High	(<0.01) H0	ORH0	2.2.3.0
	High	(> 2.0) H1	ORH1	2.2.2
Inorganic (IN)	Low	(<0.01) L0	INL0	Not applicable (inorganic ISO flux is procured elsewhere)
	Low	(<0.15) L1	INL1	
	Moderate	(<0.01) M0	INM0	
	Moderate	(0.15-2.0) M1	INM1	
	High	(<0.01) H0	INH0	
	High	(> 2.0) H1	INH1	

[1] Fluxes are available in solid (S), pasty/creamy (P) or liquid (L) form.
[2] 0 and 1 indicate the absence or presence of halides. See 4.2.3 for an explanation of the classification of L, M and H.
[3] See 7.2 and 7.3 for the comparison of the composition classes RO, RE, OR and IN as well as the efficacy levels L, M and H with the conventional classes such as R, RMA, RA, water-soluble and low-solid species which do not require subsequent purification (no-clean).
[4] ISO designations, with the exception of small feature deviations, are similar to the IEC designations.

Tab. 4 Comparison J-STD-004B [17]/DIN EN 61190-1-1 [18]

Flux composition	Efficacy level of the flux	Permitted halide content according to IPC J-STD-004B [17] In [weight%]*	Permitted halide content according to DIN EN 61190-1-1 [18] [Weight%]**
RO (rosin) RE (modified resins) OR (organic acids) IN (inorganic acids)	L0	<0.05	<0.01
	L1	<0.5	<0.15
	M0	<0.05	<0.01
	M1	0.5-2.0	0.15-2.0
	H0	<0.05	<0.01
	H1	> 2.0	> 2.0

* refers to Cl, Br, F, I.
** refers to Cl, Br, F.

The fluxes used in the SnPb wave soldering and reflow soldering process can only be used, for example, due to the increased peak temperatures and the prolonged activation time in the lead-free soldering process, after corresponding modifications of the flux formulation.

In addition, fluxes developed for SnPb solders and SnPb solder powders as well as their derivatives show reduced or inadequate technological properties when used for lead-free soldering and lead-free solder powders.

2.5 Parameters

Lead-free soldering process

The introduction of lead-free soldering processes is due to the entry into force of the EC Directive 2002/95/EC (RoHS 1) [21] and its successor, EC Directive 2011/65/EU (RoHS 2) [22], as well as the WEEE Directive (Waste Electrical and Electronic Equipment) 2002/96/EC and the subsequent 2012/19/EU [23] on waste electrical and electronic equipment.

In this context, RoHS means "Restriction of (the use of certain) hazardous substances" or "restriction of the use of specific dangerous substances".

According to this EC Directive, the lead content has been limited to a maximum 0.1% by weight for the homogeneous materials contained in the product in electrical and electronic devices.

This restriction resulted in the development and use of lead-free solder alloys. Today, mainly eutectic SnCu solders, as well as eutectic and near-eutectic SnAgCu solders, in some cases with reduced silver content, are used in the lead-free soldering process. Microalloying elements are standardly added to these solders in order to optimise the technological properties.

The main difference between the physical properties of the lead-free solder alloys lies in the increased melting point or in the increased melting range and in contrast to the SnPb solders in the reduced wetting behaviour.

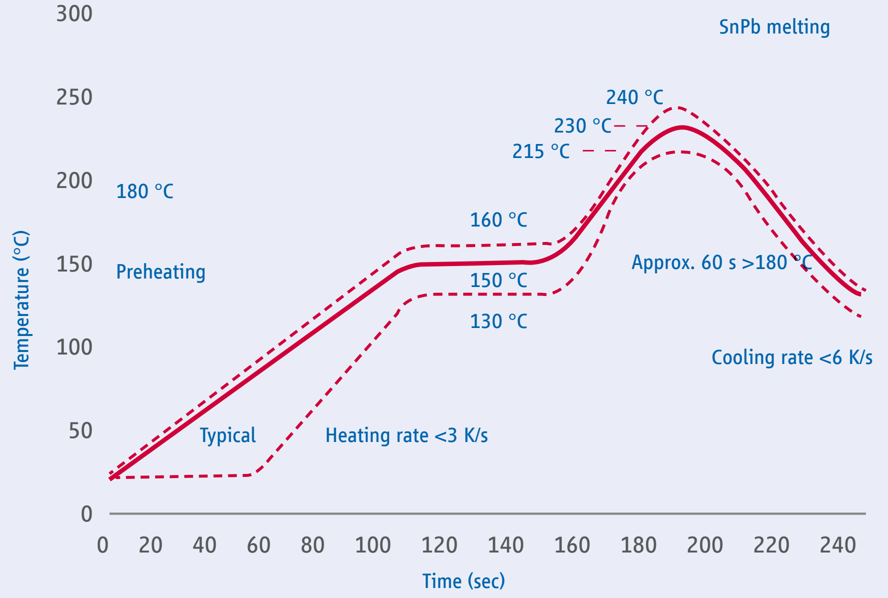
The eutectic Sn63Pb37 has a melting point of 183 °C. The eutectic SnCu solder with a melting point of 227 °C is higher than the SnAgCu solder with a melting range of 217 °C to 220 °C (SAC305) or with a melting point of 217 °C for the SAC387 solders. The SnAgCu solders with an Ag content of 1.0 percent by weight have a melting range of 217 °C. to 227 °C.

Tab. 5: Overview of typical solder alloys

Designation	Alloy/ Composition [%]	Melting temperature [°C]
AuSn	Au80 Sn20	280
SC	Sn99.3 Cu0.7	227
SnAg	Sn96.5 Ag3.5	221
SAC105	Sn98.5 Ag1.0 Cu0.5	217-227
SAC387	Sn95.5 Ag3.8 Cu0.7	217
SAC305	Sn96.5 Ag3.0 Cu0.5	214-220
Innolot	Sn90.95 Ag3.8 Cu0.7 Bi3.0 Sb1.4 Ni0.15	206-218
SnPb	Sn63 Pb37	183
SnPbAg	Sn62 Pb36 Ag2	179
BiSn	Bi58 Sn42	139

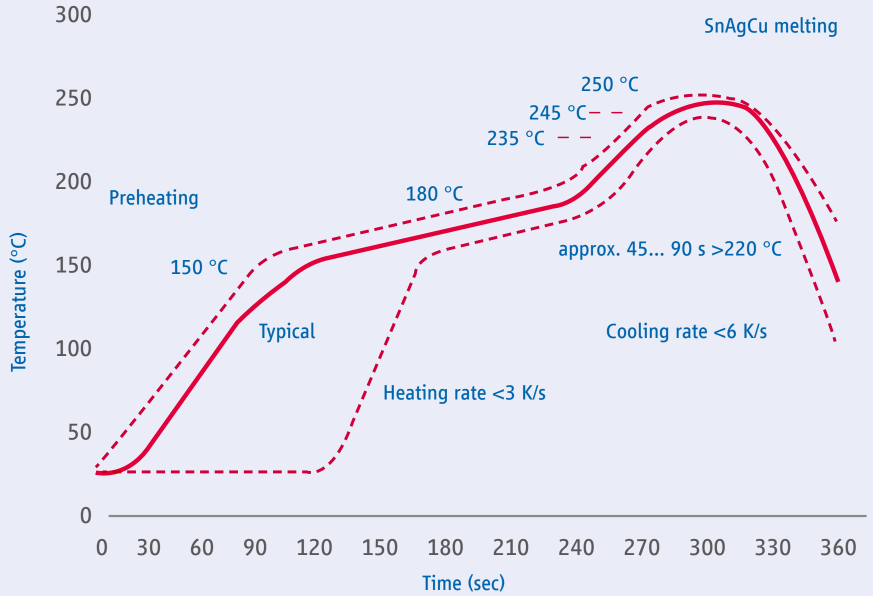
The increased melting temperatures (compared to SnPb solders, see Figure 2) of the lead-free solder alloys are reflected in the temperature/time profile using the example of the SnAgCu reflow profile according to DIN EN 61760-1:2006 (see Figure 3). In addition, the prolonged pre-heating times and thus activation times for the fluxes are evident.

Fig. 2: Solder profile for SnPb solder according to DIN EN 61760-1



Source: DIN EN 61760-1

Fig. 3: Solder profile for SAC solder according to DIN EN 61760-1



Source: DIN EN 61760-1

Modern no-clean flux formulations for the lead-free soldering process take into account the increased thermal requirements for the activation system, the required surface insulation resistance and the interaction with the lead-free solders and solder powders.

2.6 Acceptance requirements

With the focus on the best possible applicability and transparent transferability of all the knowledge and recommendations given in the guide, all test focuses and criteria for the evaluation of the assembly states are based on the acceptance requirements of the IPC-A-610 [24] for Class 3 products.

Wherever it was sensible and possible, visual assessment was used; for hard-to-reach or concealed solder joints, the diagnostics were supported by x-ray inspection.

Further results and findings on special designs or artefacts observed due to special procedures are also presented, and, if necessary, reference is made to parallel or alternatively applicable norms, standards and guidelines.

2.7 Printed circuit board

In addition to the basic need of temperature resistance of the printed circuit board during lead-free soldering process, the question of the thermal stress of the printed circuit board in the application must also be clarified before a base material for the printed circuit board is selected.

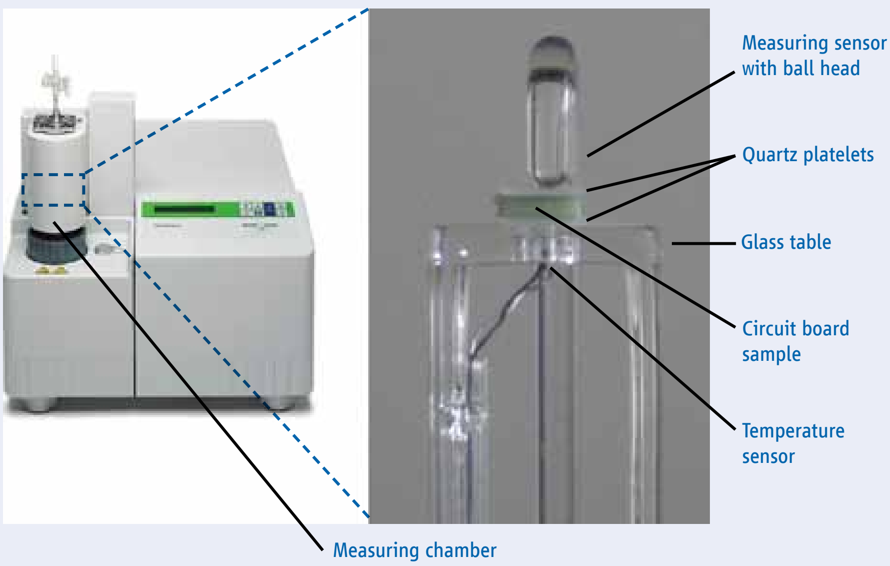
Various base material parameters which could be helpful for selection are briefly presented below. Finally, the question is raised whether there are any corresponding parameters for the base material and what they look like for different materials.

The first thing to mention here is the so-called T260/T288 value. In order to determine this value for a material, a corresponding TMA measurement is carried out. Thermomechanical analysis (TMA) is a method in which the expansion of a material as a function of temperature is measured under a defined load. The measurement setup is briefly shown in the following figure.

To accommodate the expansion of the entire circuit board samples with the ball head, it is placed between two quartz platelets in the measuring transducer (see above). The expansion of the quartz platelets (~ 1.5-1.7ppm/°C or ~ 0.5µm over the temperature range considered here) is negligible.

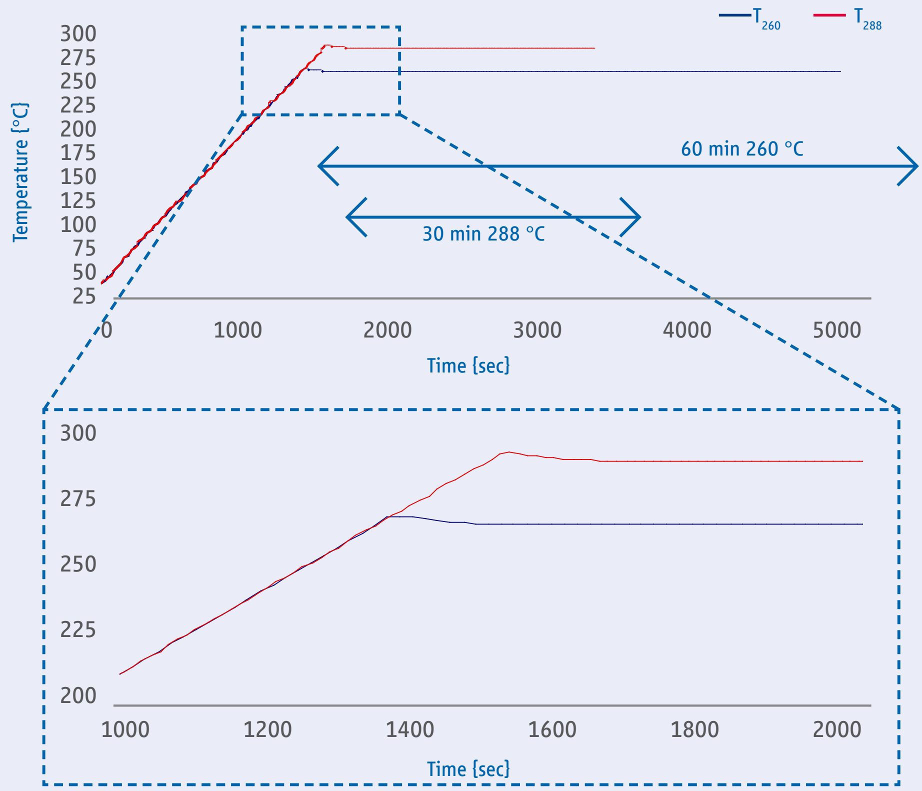
The sample is here heated to 10 °C/min to 260 °C/288 °C and then left at this temperature for 60 min/30 min. The time from reaching the 260 °C/288 °C mark, up to the first delamination (irreversible z-axis expansion/jump) must then be measured from the recorded z-axis expansion curve (see below). The measured time then corresponds to the T_{260}/T_{288} value.

Fig. 4: TMA measuring device (left). Sensor with ball head (right). The sample can be heated up or cooled by means of gas cooling in the measuring chamber. During the entire measurement, a predefined force is applied to the sensor (typically 5-20 g).



Source: Würth Elektronik

Fig. 5: Temperature control during T_{260} or T_{288} measurement. Due to the heating rate of 10 K/min, the temperature rises slightly at the beginning of the 260 °C or 288 °C phase.

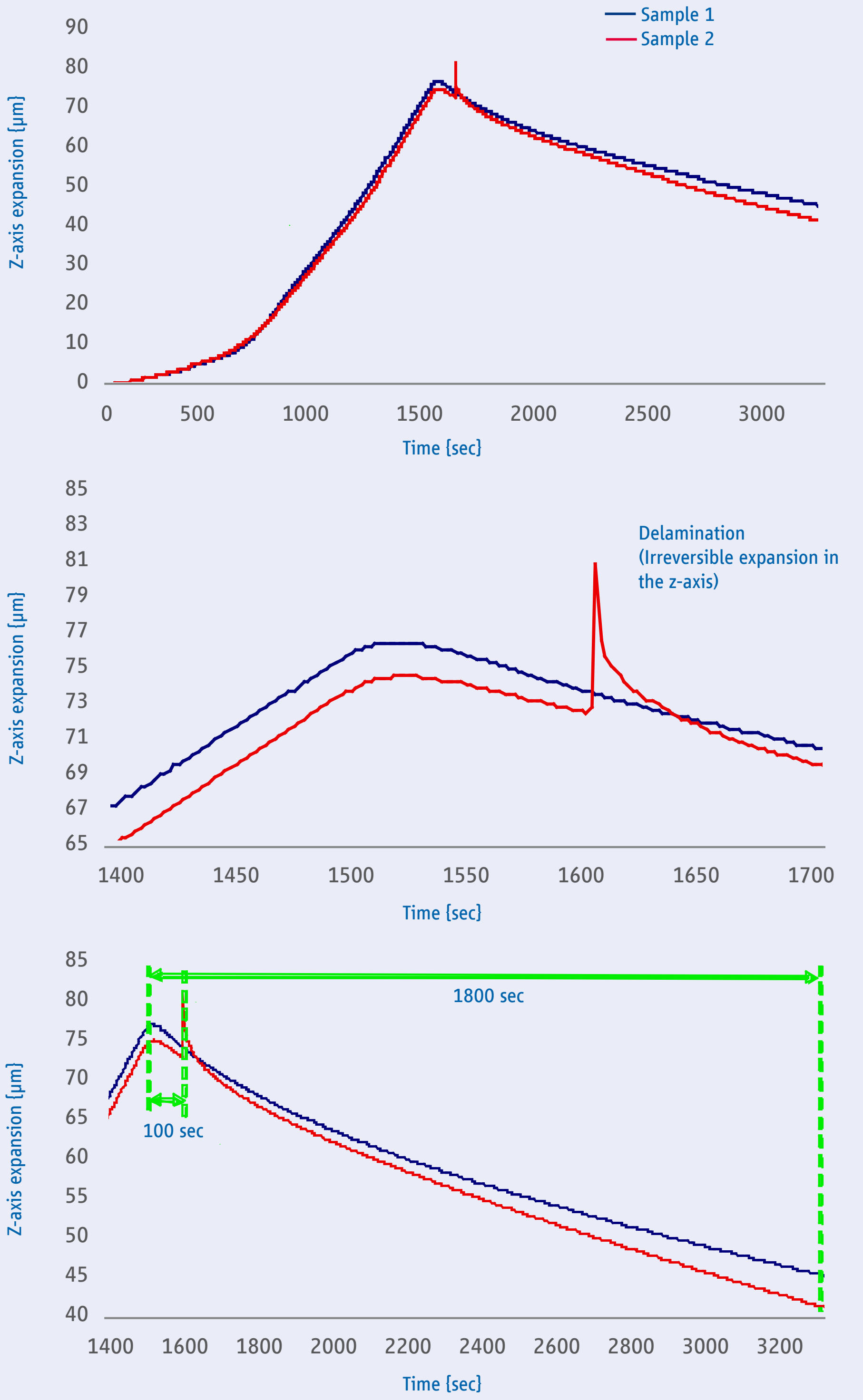


Source: Würth Elektronik

Standard FR4 reaches T_{260} values of ~ 10-20 min and T_{288} values ≤ 5 min. Base materials with phenolic curing or halogen-free systems have T_{260} and/or T_{288} values of ≥60 min and ≥30 min, respectively, and are therefore significantly more stable thermally than standard FR4.

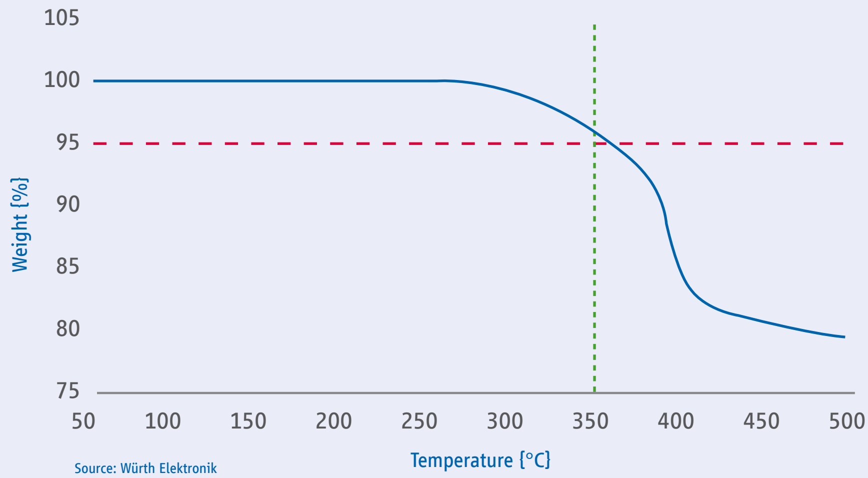
Another value for the base material is the so-called T_D value. "D" comes from the English word "decomposition". The T_D value is determined gravimetrically by TGA (thermogravimetric analysis). In this case, the sample is heated to very high temperatures (500 °C) at 10 K/min and its weight loss during heating is determined (see below). The temperature at which a weight loss of 5 percent is achieved is called T_D = decomposition temperature.

Fig. 6: Evaluation of the T_{288} values / times. In the examples shown, sample 1 reaches a T_{288} value of >/=30 min (total measurement time) and sample 2 reaches a value of T_{288} = 1 min. 40 sec.



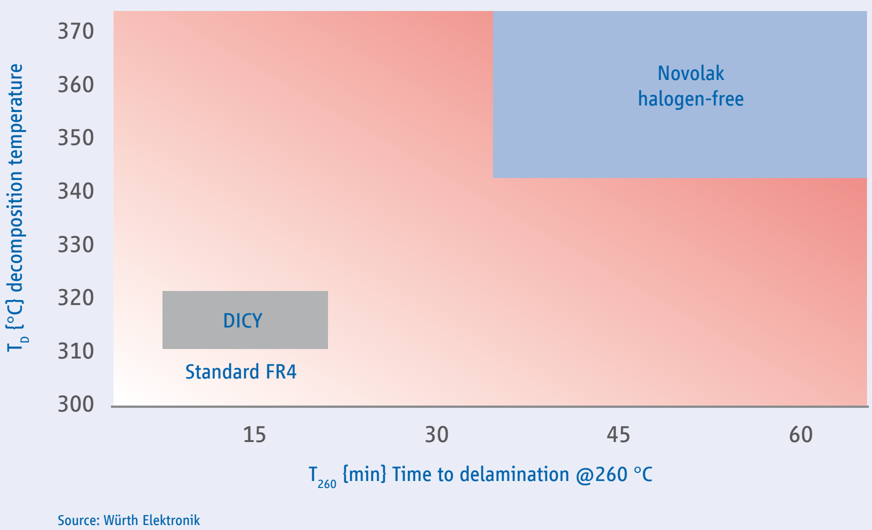
Source: Würth Elektronik

Fig. 7: Example of TGA measurement. The temperature at which a weight loss of 5 percent is achieved is called T_D = decomposition temperature.



If the decomposition temperature is reached or exceeded, the base material is destroyed irreversibly. The T_D value for standard FR4 is in the range of ~ 310 °C. At temperatures above 310 °C, FR4 is thus irrevocably destroyed. Standard high-T_G materials (DICY, hardened as standard FR4) show no advantages with respect to the two values T_D and $T_{260}/_{288}$. Base materials with phenolic curing or halogen-free systems have significantly higher T_D values (≥340 °C.). There are now base materials with T_D values of 400 °C.

Fig. 8: Overview of different materials using the T_{260} and T_D values. The halogen-free and phenolic (novolak) annealed systems have significantly higher thermal load bearing capacity.



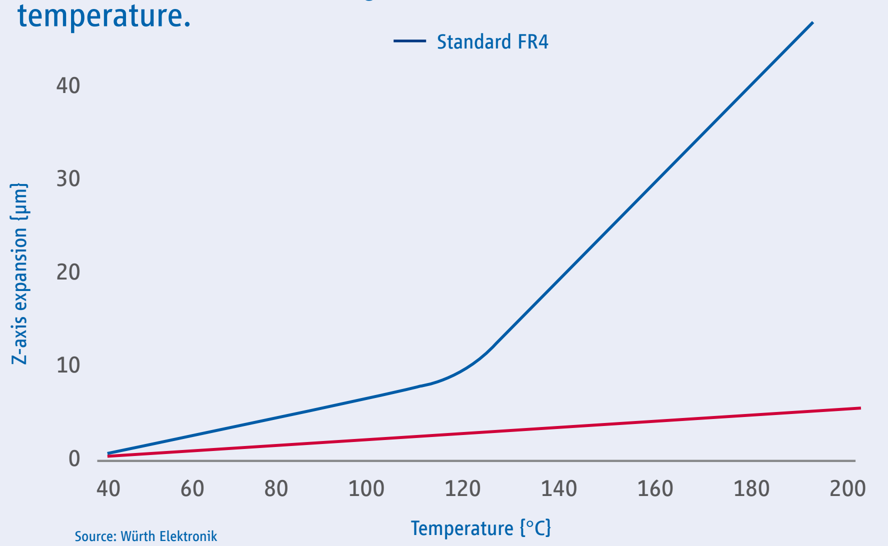
A corresponding overview of the base materials used here can be found in the following table. The coloured deposits correspond to the areas shown above.

Tab. 6: Material overview

	$T_{G/TMA}$ [°C]	T_{260} [min]	T_{288} [min]	T_D [°C]
Standard FR4 comparison	≥120	~ 10-15	≤5 min	~ 310
halogen-free T_G150-filled	≥140	≥60	≥20	≥345
Phenolic hardened bromine-containing T_G150-filled	≥140	≥60	≥10	≥330

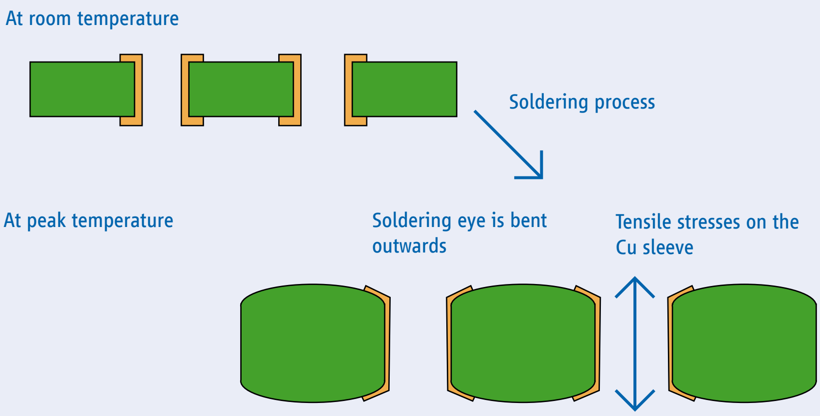
For each technical system which is composed of several components, differences in the expansion coefficients have to be considered for thermal loads. Different dimensions lead to mechanical stresses within a system which can lead to system defects. Transferred to the circuit board, the two materials FR4 and copper must be examined here. Copper shows a much smaller expansion than FR4 (see the next figure) over the temperature range from 25 °C to 260 °C.

Fig. 9: Expansion behaviour in z-axis, (thickness of the circuit board) of standard FR4 (T_G135) and copper as a function of the temperature.



This difference in the expansion coefficient causes the plated through holes to be pulled apart at high temperatures in the circuit board and the soldering pad to be pressed outwards, as shown schematically in the following figure.

Fig. 10: Because of the different expansion behaviour of the base material and the copper, the printed circuit board deforms in the way shown. Due to the greater expansion of the FR4 material, the copper sleeve is stretched and the solder eyes are bent outwards. Strictly speaking, the circuit board material will also push the sleeve inwards, which is not shown here for the sake of simplicity.



Source: Würth Elektronik

In the worst case, these stresses in the sleeve can lead to cracking and thus to electrical interruption, i.e. a failure.

The expansion of the base material is not constant as with copper over the temperature range considered here, rather has the behaviour shown above. In the temperature range from room temperature to a temperature of ~ 120 °C, the expansion behaviour is still similar to that of copper, but above -120 °C, the expansion behaviour again increases very strongly. The kink point in this curve is also referred to as the glass transition point (T_G). It is clear from the curve that, with increasing T_G values, the overall expansion over the temperature range considered here becomes smaller. However, a smaller overall expansion also causes a small mechanical stress on the copper sleeve and thus a higher reliability of the through-hole interconnection! At this point, it becomes clear why high-T_G material is desirable. However, we will describe in detail below why this is by no means a panacea. For example, a so-called filled T_G150 system has a smaller z-axis expansion than an unfilled T_G170 system and thus in both the soldering process and the thermal cycling test (-40 °C - 125 °C) causes less stress on the copper sleeve. In this way, very high service life can be achieved, as required, for example, in the automotive sector.

Fig. 11: z-axis expansion as a function of temperature of a circuit board type, built with different base materials (standard FR4 is always unfilled!). The filled T_G150 system has the smallest expansion values in all areas.

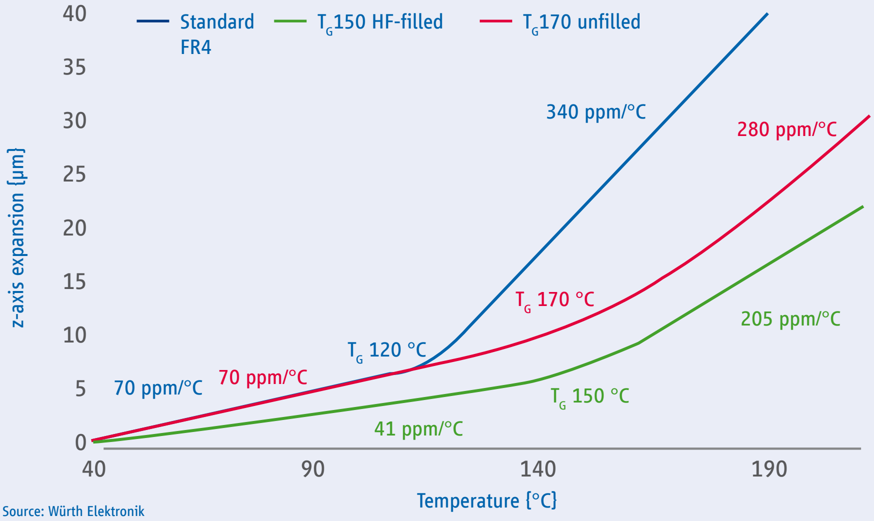


Fig. 12: Comparison of total z-axis expansions of the materials shown above in different temperature ranges. On the left the comparison of total expansion of the printed circuit board from room temperature (RT) to peak temperature with lead-free soldering of 260 °C, and right for temperature cycling tests in the range (-40 °C... 125 °C). In both cases, the lowest values are obtained with the filled T_G150 system, that is, in both cases, it is an improvement on the printed circuit board reliability.

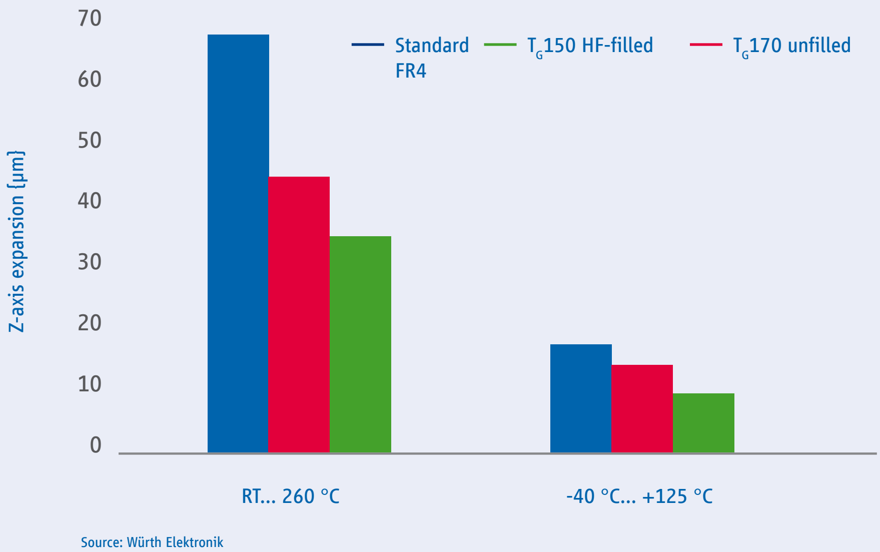
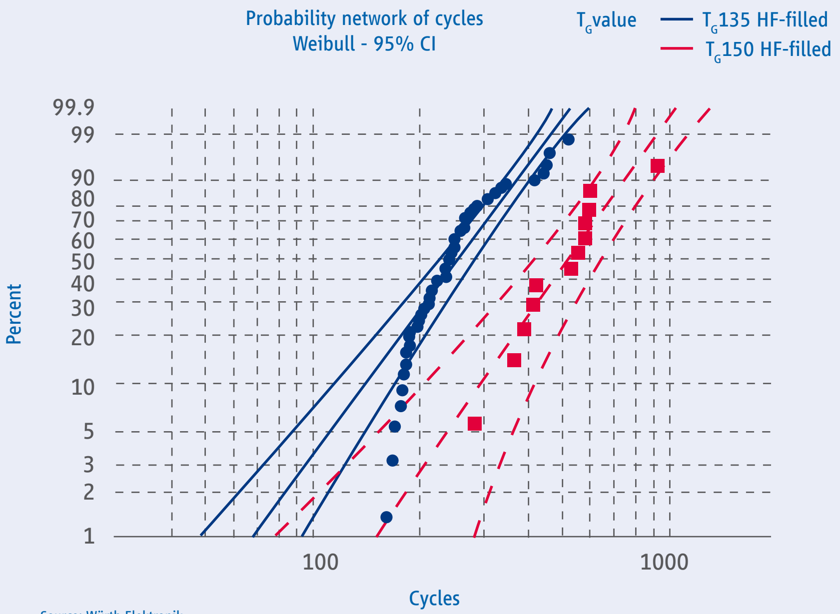


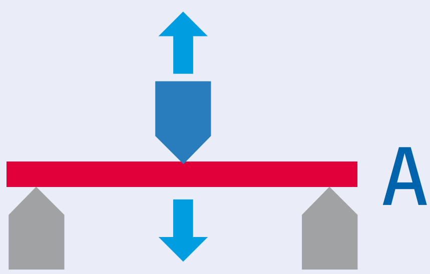
Fig. 13: Comparison of reliability behaviour of standard FR4 (T_G135) and a filled T_G150 HF material in the Interconnect Stress Test (IST). The cycle test was carried out in the temperature range 25 °C... 150 °C. The higher reliability of the filled T_G150 material can be clearly seen.



Source: Würth Elektronik

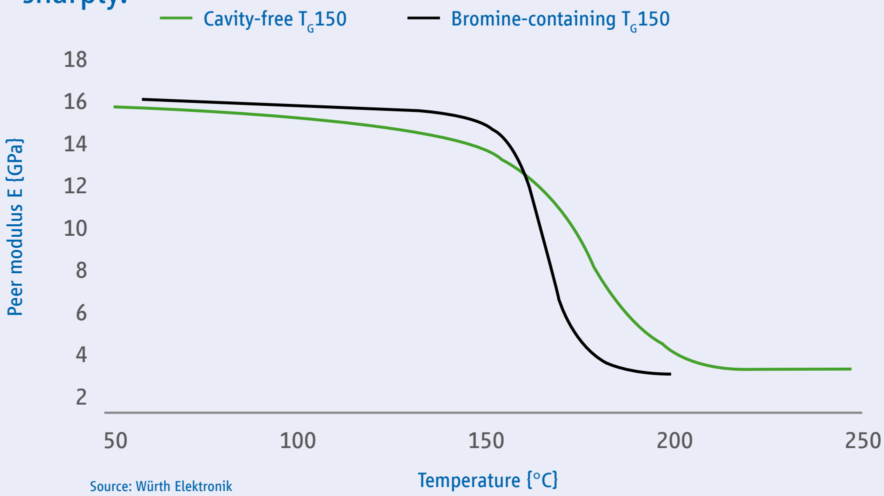
The above parameters are important for reliability requirements in the application of the assembly and the resulting requirements for the base material of the printed circuit board. On the other hand, it must also be considered that other mechanical parameters can play a decisive role. If, for example, press-fit connectors are used in an assembly in addition to soldered components, the mechanical

Fig. 14: Three-point bending assembly for the DMA. However, this is only one possibility out of several measuring setups. The complete measuring set-up is located in a furnace which can be heated up or maintained at a specific temperature according to the specifications.



Source: Mettler Toledo

Fig. 15: DMA measurements of two filled base materials, measured by the three-point bending test. In the range of the glass transition temperature, the modulus of elasticity drops sharply.

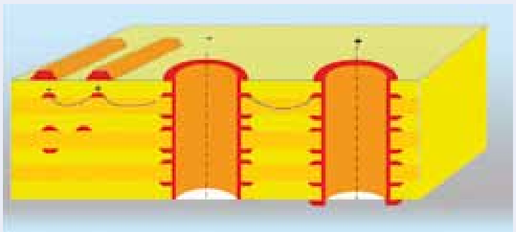


Source: Würth Elektronik

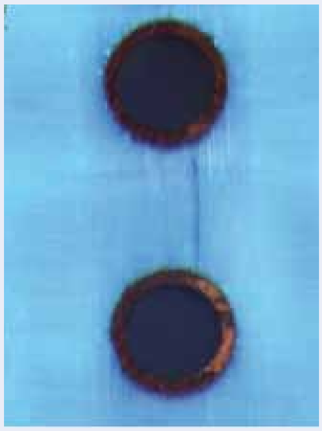
strength (modulus of elasticity) of a material in the temperature range must also be considered in the application. Base materials exhibit the effect of becoming "soft" at high temperatures (in the region of the glass transition point) which would lead to increased transitional resistances and possibly failure in press-fit contacts. The modulus of elasticity can be determined by means of DMA (dynamic mechanical analysis) (see Figure 15).

Another property that must be considered for the reliability of an assembly under extreme environmental conditions, in particular high temperature and high humidity, is the behaviour of the base material with respect to CAF. CAF (Conductive Anodic Filamentation) means the formation of copper filaments in the base material which grow from the anode to the cathode (see Figure 16). If the copper filament reaches the cathode, a short circuit is produced between the two poles (as shown in the measuring diagram shown below). A comparison of standard FR4 (DICY-annealed) with phenolically hardened or halogen-free systems shows that standard FR4 is significantly worse with regard to CAF!

Fig. 16: Under the influence of electric fields (voltages), copper filaments can form in the printed circuit board at high atmospheric humidity, the filaments starting from the anode and growing in the direction of the cathode.
This effect is called CAF.

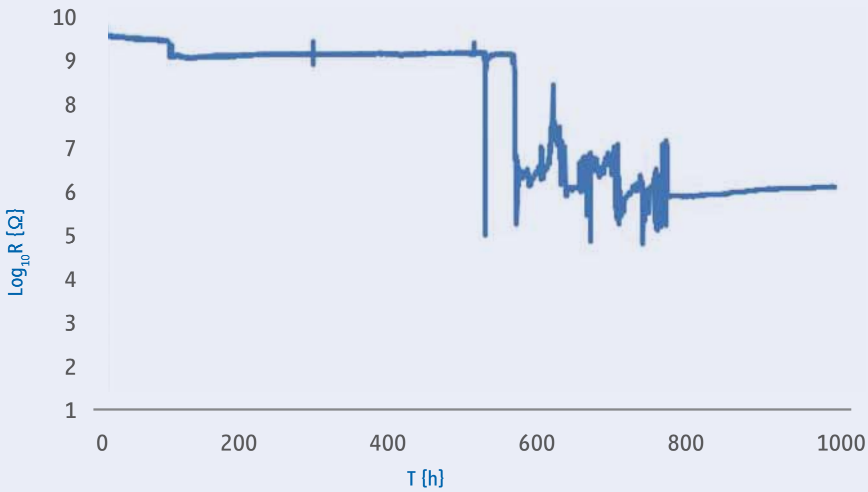


Source: Würth Elektronik



Source: ZVEI

Fig. 17: CAF measurement at 85 °C, 85 percent relative humidity and 100 V applied voltage. The borehole spacing considered here was 400 µm (pitch 700 µm, tool diameter 300 µm). The limit of the resistance to 1 MΩ is determined by the built-in series resistor which should also prevent the filament from burning off.

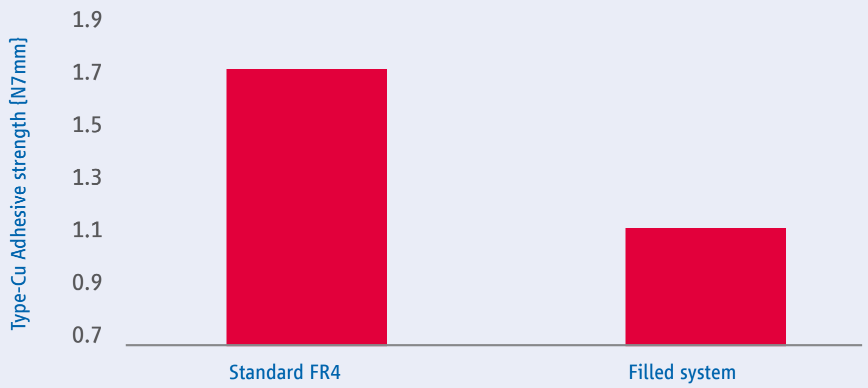


Source: Würth Elektronik

Although the filled, phenolic annealed and halogen free materials have some advantages in thermal as well as CAF resistance, they are more brittle than standard FR4 and have lower copper adhesion. This is especially the case with the filled systems. The typical copper adhesion in filled systems is about 30 percent lower than in standard FR4.

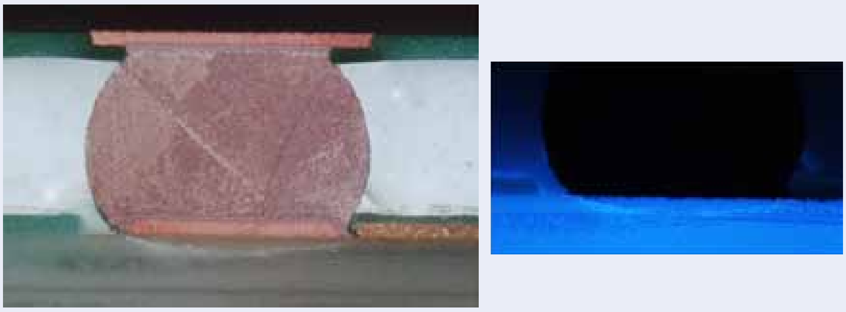
The higher brittleness is also evident in the case of effects such as so-called pad cratering. Due to the increased brittleness of the base material, the soldering process can lead to cracking in the base material due to deformation of the components or the circuit board (see Figure 19).

Fig. 18: Copper strength of a 35 µm copper foil on different base materials. Phenolically hardened or halogen-free filled systems have an approx. 30% lower copper adhesion than standard FR4.



Source: Würth Elektronik

Fig. 19: Pad cratering on a BGA ball after soldering process, left recorded with visible light and right recorded under UV illumination. The crack is clearly visible through the base material below the BGA pad.



Source: Würth Elektronik

2.8 Components

Small footprint - high currents - logic and performance - highly integrated. The requirements for a modern printed circuit assembly are multi-dimensional.

The testboard created in the working circle reflects this multi-dimensionality precisely in the selection of components, following the actual conditions:

There are highly thermally demanding components, such as a BGA socket for microprocessors, in addition to thermally sensitive components such as an MEG array connector on the assembly.

In addition to the fundamental question of a basic rework process, this wide range of possible constructions opens up the opportunity for an in-depth, individual knowledge about rework of the respective construction presentation.

Component specifics are discussed in the same way as the possibly not uniform motives and modes for successful reworking.

In what follows, reference is made to subspaces of the testboard and the rework variant, and in addition the underlying individual objective is discussed.

2.9 MSL - Moisture Sensitivity Level

With respect to optimised thermal profiling, the requirement is first to meet the soldering requirements and to avoid any unnecessary additional thermal stress from the assembly.

A special role in the sense of superimposed criticality is the tendency of many structural elements to store them in the housing in the presence of atmospheric moisture (for example during storage or transport).

The term "moisture sensitivity" is used to describe this topic in all its associated facets.

During the soldering process, the entrapped moisture does not always escape in a controlled way, which can lead to flaws in the form of delamination or "popcorning" (bursting of the housing). This is exacerbated by the lead-free thermal process management.

The underlying and most prevalent standards for this are IPC/JEDEC J-STD-020 [3] and IPC/JEDEC J-STD-033 [4], such that the transition to an increased soldering temperature (from SnPb to SAC- Processes) can result in a more critical class classification.

Against the background of the reworking, there may be a conflict with regard to the permitted time corridor (see Table 7: Overview of MSL classification according to J-STD-020 [3]).

Note:
- In any case of doubt, the assembly must be dried back immediately before the rework measure, since the moisture history of the affected assembly is often not known reliably or sufficiently for uncontrolled moisture absorption.
- In the broadest sense, the printed circuit board is also a moisture-sensitive component (but without MSL classification).

Table 7: Overview MSL classification according to J-STD-020 [3]

Table 5-1 Moisture Sensitivity Classes

Class	Component dwell time		Requirements for moisture absorption				
			Standard		Accelerated equivalent 1		
					eV 0.40-0.48	eV 0.30-0.39	Conditions
	Time	Conditions	Time (hours)	Conditions	Time (hours)	Time (hours)	
1	Unlimited	≤30 °C/85% relative moisture	168 +5/-0	85 °C/85% relative moisture	Not applicable	Not applicable	Not applicable
2	1 year	≤30 °C/60 % relative moisture	168 +5/-0	85 °C/60 % relative moisture	Not applicable	Not applicable	Not applicable
2a	4 weeks	≤30 °C/60 % relative moisture	6962 +5/-0	30 °C/60 % relative moisture	120 +1/-0	168 +1/-0	60 °C/60 % relative moisture
3	168 hours	≤30 °C/60 % relative moisture	1922 +5/-0	30 °C/60 % relative moisture	40 +1/-0	52 +1/-0	60 °C/60 % relative moisture
4	72 hours	≤30 °C/60 % relative moisture	962 +2/-0	30 °C/60 % relative moisture	20 +0.5/-0	24 +0.5/-0	60 °C/60 % relative moisture
5	48 hours	≤30 °C/60 % relative moisture	722 +2/-0	30 °C/60 % relative moisture	15 +0.5/-0	20 +0.5/-0	60 °C/60 % relative moisture
5a	24 hours	≤30 °C/60 % relative moisture	482 +2/-0	30 °C/60 % relative moisture	10 +0.5/-0	13 +0.5/-0	60 °C/60 % relative moisture
6	Time according to label (Time on label TOL)	≤30 °C/60% relative moisture	TOL	30 °C/60 % relative moisture	Not applicable	Not applicable	Not applicable

Note 1: ATTENTION - The requirements for moisture absorption under the accelerated equivalent must not be applied until the correlation of the damaging effect (including electrical damage) after the moisture absorption and reflow has been determined according to the standard moisture absorption requirements or the known diffusion activation energy of the housing material in the ranges 0.4-0.48 eV and 0.3-0.39 eV, respectively. The times of the accelerated moisture absorption can vary depending on the material properties (e.g. injection moulding compound, encapsulation, etc.). The JEDEC document JESD22-A120 contains a method for determining the diffusion coefficient.

Note 2: The standard moisture absorption time takes into account a default value of 24 hours for the manufacturer's exposure time (MET) between the annealing and the packaging in damp-proof bags. The maximum permitted time that the components spend outside the bag at the distributor is included. If the actual MET is less than 24 hours, the moisture absorption time can be reduced. For moisture absorption conditions of 30 °C/60% relative humidity, the moisture absorption time is reduced by 1 hour for each hour that the MET is less than 24 hours. For moisture absorption conditions of 60 °C/60% relative humidity, the moisture absorption time is reduced by 1 hour for each 5-hour block that the MET is under 24 hours. If the actual MET is over 24 hours, the moisture absorption time must be increased. For a humidity absorption of 30 °C/60% relative humidity, the moisture absorption time is increased by 1 hour for each hour in which the MET is over 24 hours. For a humidity absorption of 60 °C/60% relative humidity, the moisture absorption time is increased by 1 hour for each 5-hour block which is the MET over 24 hours.

Note 3: The supplier can increase the moisture absorption time at his own risk.

2.10 Thermal profiling

2.10.1 Tools and Sensor positioning

A multichannel measuring transducer (consisting of a separate transmitting and receiving unit including software) and calibrated NiCr-Ni thermocouples (type K) are typically used for the temperature measurement. In the best case, the temperature measuring system and thermocouples are calibrated as a unit, but at the minimum they should be calibrated separately. For the temperature measuring system, regular maintenance including recalibration and the classification as measuring equipment in the QM system are recommended.

Shell thermocouples of accuracy class 1 with an outer diameter of 0.25 mm have proven to be effective. Due to their measuring characteristics and their low heat capacity, they provide fast and precise measurement data. The precondition, however, is the proper assembly of the thermocouples. The lead is fixed, for example, with a small amount of SMD adhesive or polyimide adhesive tape on the printed circuit board. The sensor is contacted with aluminium tape or small amounts of thermal paste and polyimide adhesive tape. A solid and secure thermal contact between the sensor and the measuring object which is maintained over the entire measurement provides the basis for successful temperature measurement.

The application of the temperature sensors determines the quality of the measurement. Incorrect assembly can lead to considerable faults with impermissible deviations. The reason for this is, for example, shading of convection, excessive heat capacity of the measuring point or inadequate contact with the measuring object.

The soldering process is to be measured at soldering points (also at concealed soldering points, here, if necessary, by means of a CNC drilling machine, to drill the soldering point from below, see IPC-7095 [6]). In order to monitor compliance with limit temperatures, temperature-sensitive components or exposed positions on the assembly are measured. Areas of minimum and maximum thermal mass are taken into account.

2.10.2 Methodology of profile determination

The solder profile used in the series process serves as the basis for the rework solder profile. Since, during reworking, "only" the component to be reworked must reach the soldering temperature, a shorter solder profile which satisfies the component requirements can also be used, taking into account the limiting parameters.

The following basic work steps serve as the main thread for the profile determination. Depending on the rework system used (or manual soldering station used in the case of manual soldering), this results in device-specific sequences which are described in detail in sections 2.14 ff.

Basic steps for profile creation on a test assembly:

1. Setting a parameter set
   Do not set the target temperature too high in order to avoid damage (e.g. conductor plate delamination)
2. Working out a temperature profile in the process window
   The specifications are based on line process, norms/standards, data sheet for the soldering material, restrictions on LP and component manufacturers
3. Test of the measurement setup to exclude systematic measurement faults
4. Performance of a temperature measurement and process qualification
   Check the plausibility of the results
5. Retraction of the solder profile with a view to a stable process
   This should ideally be located in the middle of the process window
6. Verification of the solder quality on a test assembly
7. Monitoring of the rework system (the manual soldering system), through ongoing process and device control

The soldering and solder profile is almost identical to the solder profile in the inline reflow process. Since the rework temperature-time profile in the postprocessing process must be optimised only for one component, it may possibly be slightly colder and shorter than the inline profile. Recommendations can be found on this, for example, in IPC-7095 [6] (processing of BGAs).

With a large-area under-heating system which heats the entire assembly, the majority of the required heat energy should be introduced from below, so that only the required "residual heat" needs to be introduced to the component via the upper heating system up to the maximum temperature. This significantly reduces the risk of overheating the component. Attention must be paid to the thermal protection of temperature-sensitive adjacent components.

The circuit board temperature on the upper side should be suitable for soldering of SAC alloys at at least 140-160 °C, in order to achieve uniform heating and to avoid local overheating. Different stretching behaviour of cool, rigid circuit board areas in direct proximity to hot, soft (heated over T_G) LP areas can cause mechanical stresses.

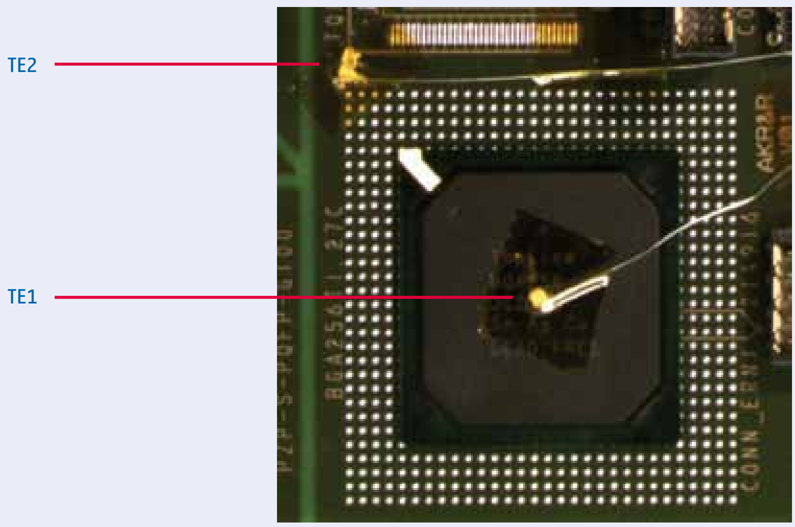
The consequences may be sleeve cracks, delaminations or other defects.

In general, the following applies:

- If component temperatures (component type J-STD-033 [4]) above 200 °C are reached during the reworking process, the entire assembly must be re-dried before starting the rework.
- Moisture-sensitive SMD housing must at no time exceed the characteristics of its moisture-sensitive class according to J-STD-020 [3].
- According to J-STD-033 [4], the components/assembly are preferably dried at 125 °C in the circulating furnace. In the presence of temperature-sensitive components, drying can also be carried out at lower temperatures and lower relative humidity.
- The solder heat resistance of all components on the assembly must be observed.
- Component temperatures are measured on the top side of the component in the centre of the housing.

In what follows, profile creation and process qualification will be shown by way of the example of a BGA256.

Fig. 20: Positioning of thermocouples, PCB top

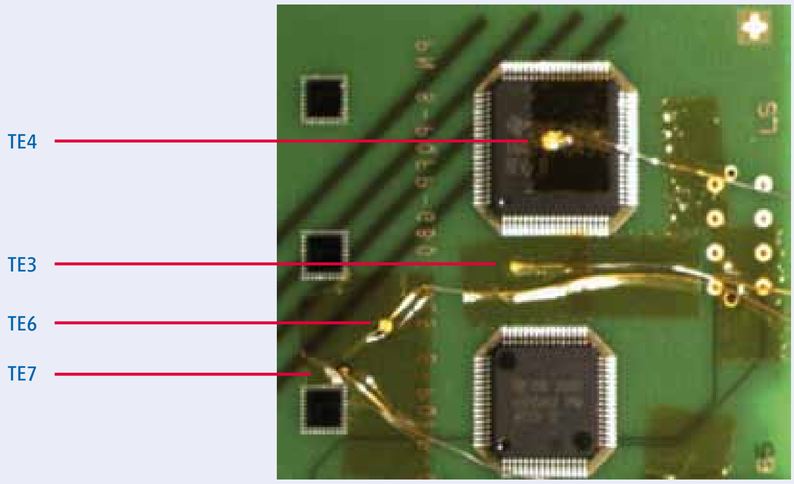


Source: Fraunhofer ISIT

Figure 20 and Figure 21 show the positioning of the thermocouples to measure the temperatures at the relevant measuring points.

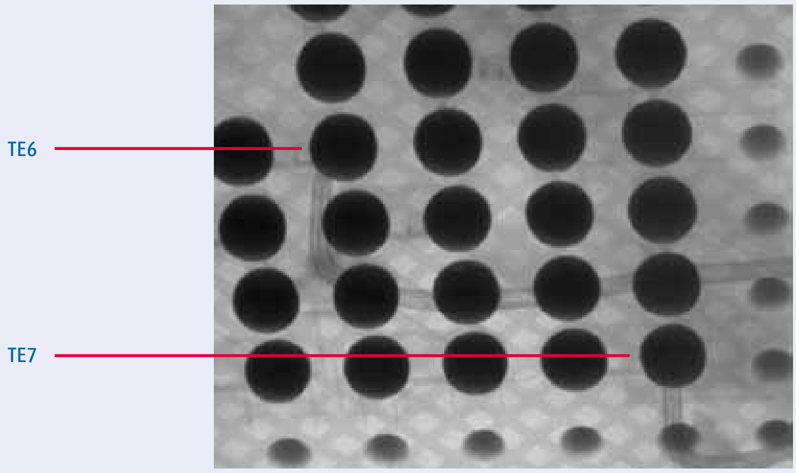
Figure 22 shows the measurement in the concealed BGA solder joints. Thermocouple 5 is located in the middle of the printed circuit board and is not visible in the image sections.

Fig. 21: Positioning of thermocouples, PCB bottom



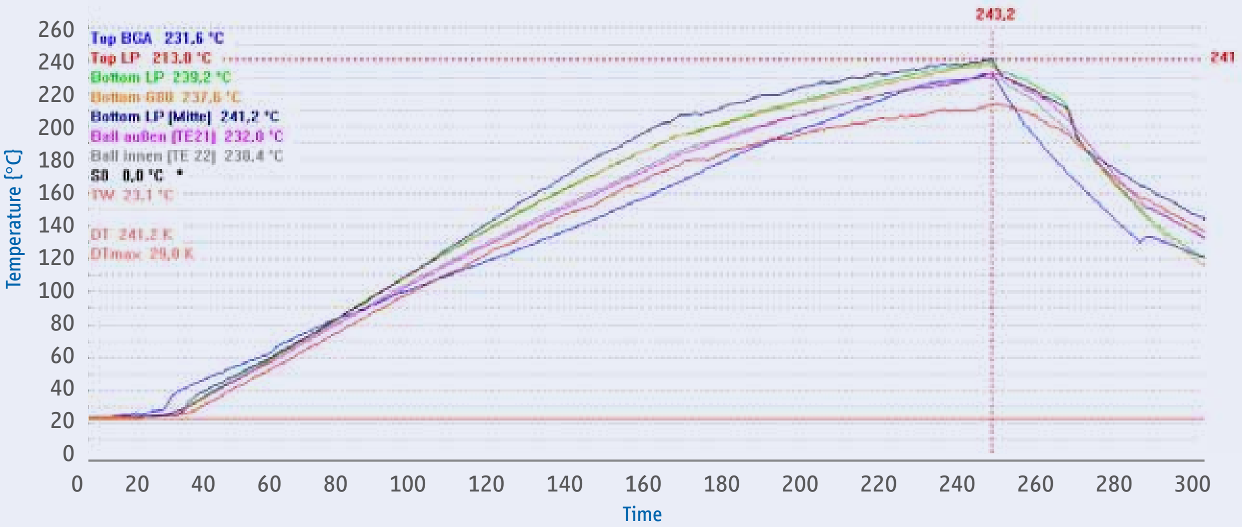
Source: Fraunhofer ISIT

Fig. 22: Positioning of the thermocouples in concealed solder joints



Source: Fraunhofer ISIT

Fig. 23: Rework solder profile BGA256TI1.27C



Source: Fraunhofer ISIT

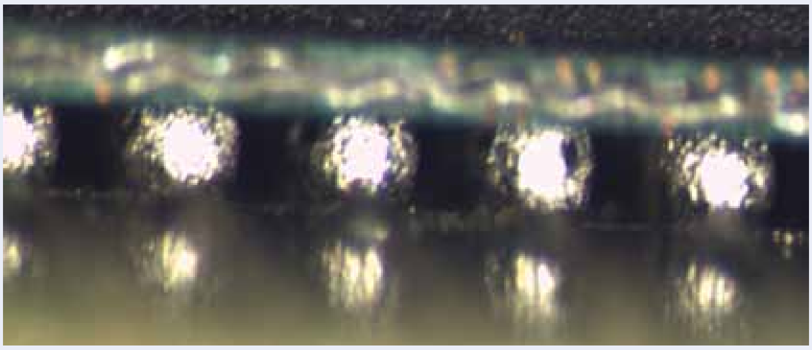
Figure 23 shows the temperature profile of the rework profile and Table 8 shows the determined soldering parameters.

Tab. 8: Soldering parameters for rework solder profile BGA256TI1.27C

Parameter	Target value for mild processing	Target value for permitted processing	Top BGA	Top LP	Bottom LP under BGA	Top BE G80	Bottom LP centre	Ball outside	Ball inside
Positive temperature gradientat solder joint [K/s]	0.5-2	<3	1.8	1.3	1.6	1.5	1.8	1.3	1.4
Negative temperature gradient at solder joint [K/s]	2-4	<6	3.5	2.2	4.1	3.9	3.4	2.7	2.5
Time PCB temperature >190 °C [s]	<150	≤240	-	85.5	112.7	-	122.4	-	-
Maximum PCB temperature [°C]	≤245	≤260	-	214.2	239.2	-	241.2	-	-
Time over 220 °C [s]	30-60	30-90	33.0	0.0	67.0	62.0	79.0	48.0	44.0
Peak temperature at solder joint [°C]	230-245	230-250	-	-	-	-	-	232.1	230.4
Time within peak temperture (-5°C) at solder joint [s]	20	20	-	-	-	-	-	1.0	3.2
Peak package body temperature [°C]	≤245	≤260	232.5	-	-	237.6	-	-	-
Duration of peak package body temperature [s]	≤20	≤30	1.4	-	-	2.0	-	-	-

The verification of the solder quality is carried out by optical inspection (Figure 24), X-ray inspection (Figure 25) and, in the case of boundary processes, by cross-hatch analysis (Figure 26).

Fig. 24: BGA256TI1.27C, optical inspection after soldering



Source: Fraunhofer ISIT

Fig. 25: BGA256TI1.27C x-ray inspection after soldering

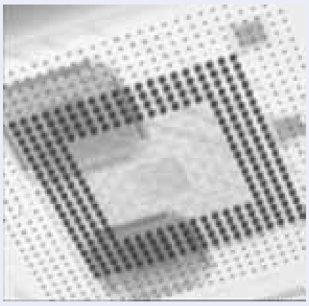


Fig. 26: BGA256TI1.27C, cross-hatch analysis after soldering

Source: Fraunhofer ISIT

2.11 The nth soldering

In the context of the present guideline, the nth soldering situation is an essential criterion for the basic assessment of the extent to which assemblies can be exposed without damage to multiple solder stress which is not planned in advance.

In principle, the suitability of both the components concerned and the circuit board must be considered as a basis for the assessment.

Assuming that the reflow-based rework case is based on the thermal parameters described in Chapter 2.2, multiple soldering can be based on the J-STD-020 [3] (triple reflow capability).

For the circuit carrier or the printed circuit board, this means higher multiple soldering tolerances. Six-layer (lead-free process control SAC soldering) solder stress tests are now regarded as customary.

The direct comparison between the reflow line process (full convection) and a comparative view using rework systems with the same cycle loading in chapter 4.5 provides further information on the degrading effect of multiple solder stress scenarios.

The maximum upper limit for the risk assessment is the three-times thermal reworking at a component position which is not based on the actual correction requirement, but should only represent the worst-case scenario.

2.12 Heat transfer

The primary types of the heat transfer forms are shown below. In the following context only the forms of heat input (convection and radiation) which are customary for the use of rework systems are further considered.

The heat demand of the assembly depends on the substrate, the components and the solder paste requirements. The amount of heat required ΔQ for heating to the soldering temperature results from

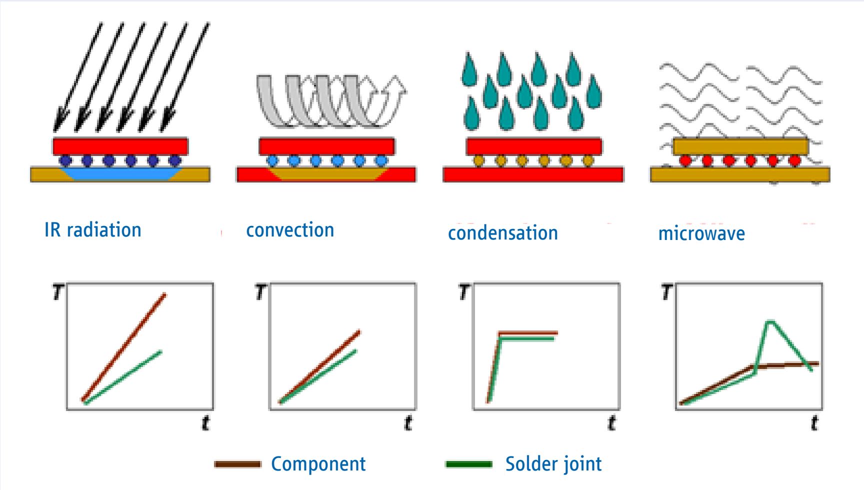
$$\Delta Q = V \times \rho \times cp \times \Delta T$$

with:	ΔQ	required heat quantity,
	V	volume,
	P	density,
	C_p	heat capacity of the entire assembly
	and	
	ΔT	difference between room temperature and soldering temperature.

As a rule, the assembly is not in thermal equilibrium in the soft soldering process. The heat input is differentiated between heat conduction, convection and heat radiation. In the case of heat transfer, the essential process variables to be considered are:

- Achievable heat transfer coefficient α (heat transfer efficiency)
- Controllable temperature difference between the heat source and the assembly
- Heat requirement of the assembly/soldering point (heat capacity and thermal resistance)

Fig. 27: Development of connection technology



Source: University of Rostock

Typical heat transfer figures in the rework process:

Tab. 9: Heat transfer forms

Heat transfer mechanism	Typical numerical values for heat transfer efficiency (α)
Radiation	20 to 60 (primarily dependent on radiator temperature)
Management	500 (with ideal contact)
Convection	5-80 (primarily dependent on the flow velocity)

Source:
Temperature Measurement in Reflow, Max H. Poech, Fraunhofer Institute for Silicon Technology, ISIT-Seminar Temperature Measurement Technology, October 2013 [23]

The most common soldering processes in the rework process are reflow soldering by means of convection and infrared radiation.

For reflow soldering with forced convection, a tempered gas (standardly nitrogen as a protective gas) is blown onto the assembly at a suitable flow rate. Here, the heat transfer coefficient α essentially depends on the flow velocity of the gas, whereas the surface colour is of no importance. It should be noted that too much airflow can blow away components. However, this danger is minimised by means of sensible parameter selection. With covers (hoods, solder masks) on the assembly, temperature-sensitive components can be protected against overheating.

Reflow soldering with infrared radiation transfers the heat from ceramic surface or quartz lasers. Here, the heat transfer is primarily dependent on the temperature difference of the (hot) radiators to the object to be heated. A precondition for an efficient transfer to components and substrates is a low-loss coupling (absorption) into the materials to be heated. Radiation heat can be localised with simple methods (shielding). In reworking, a protective gas is generally not used in IR soldering. Due to the high temperature of the radiator, thermal overloading of the surfaces can occur in inadequately controlled processes. However, this danger is minimised by means of sensible parameter selection.

Hot gas rework systems, IR rework systems and a combination of both are widely used in the reworking of assemblies, and if the mode of operation is right, there is hardly any danger of damage to components and printed circuit boards.

2.13 Process flows

2.13.1 When an element "must" - "can" - "must not" be reworked

Reworking the component is only useful if the cause of the error is identified. In the first place, all other possible faults should be checked and excluded as far as possible. Pull-up, blocking capacitors or subsequent IC components are often responsible for functional faults in assemblies, but in the electrical test a different component is indicated as the cause of the fault. In particular, complex components, e.g. BGAs, LGAs, BTCs with their concealed solder joints which cannot be visually inspected, are likely to be classified as being defective. Therefore, further measures should be taken only after a reliable diagnosis which has correctly identified the component to be repaired or at least highly likely to be faulty, in order to remedy component, assembly or soldering defects. According to J-STD-001 [8]/Class 3, faults and rework must be documented (these ought to be documented for classes 1 and 2).

Another mistake which is often committed is that supposedly bad or unsightly solder joints are reworked. For example, the visible end faces are not always solderable from outside BTC terminals and do not need any soldering in accordance with IPC-A-610 [24]. Further soldering should be avoided simply due to the lack of wetting on the side connection surface. These exclusively cosmetic operations mean an additional heat input into the assembly and create the risk of thermally overloading the component. Especially since the reworking is often carried out with insufficient tools for convenience. BTCs are typically approved by the component manufacturer for three reflow soldering processes at specified temperature time profiles. Reworking with the hand-held soldering iron is therefore not recommended by the component manufacturer, and can easily lead to damage due to bond wire breaks or melting of the mould materials.

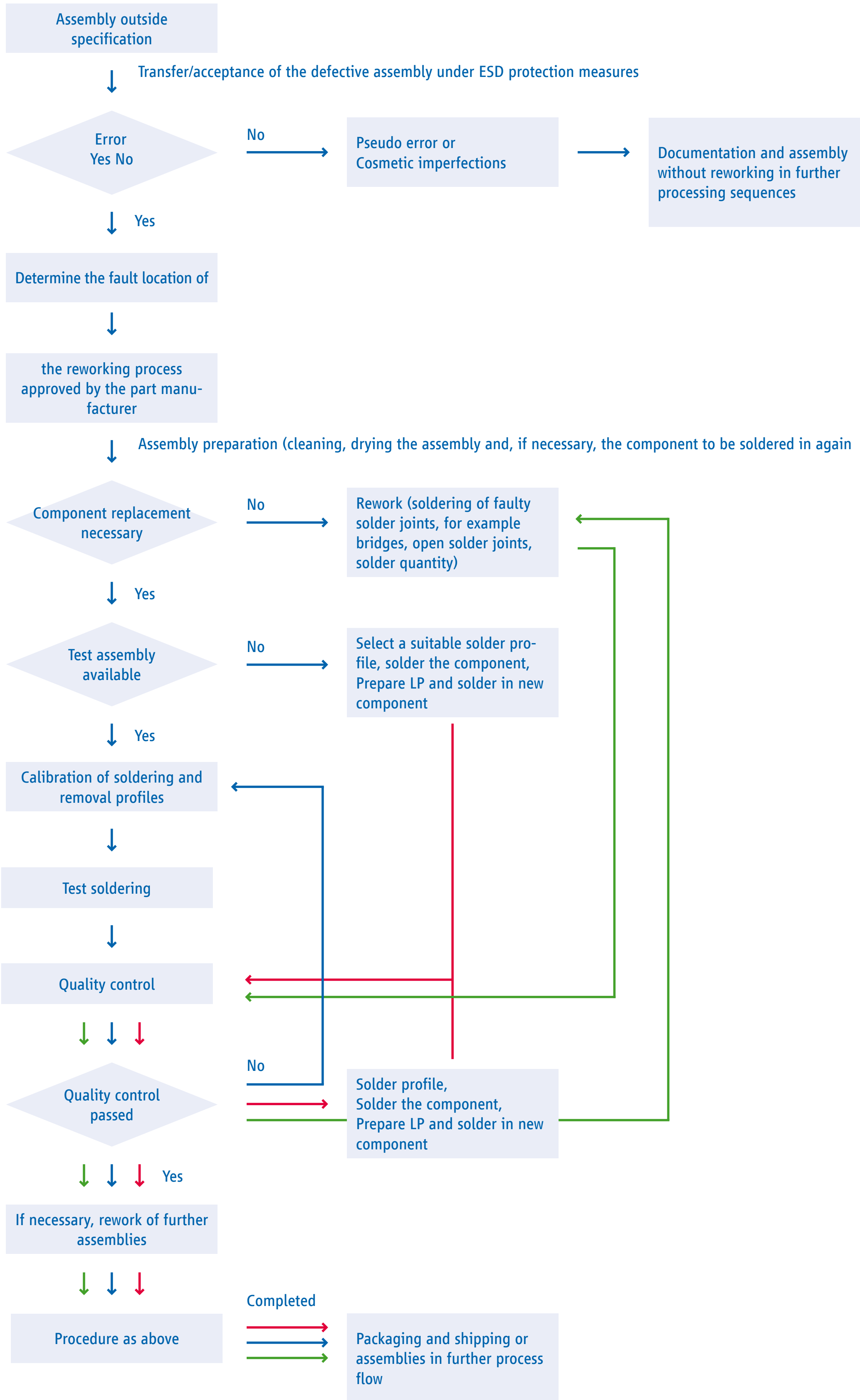
Faulty components are typically replaced by new ones. The re-use of removed components could mean an inadmissible (more than three times) soldering thermal load for the component. Soldering out and removal requires two reflow processes. This may also be accompanied by the thermal load on removal of the residual solder. If the complex component has already passed through two reflow soldering processes in the production process or by rework soldering processes carried out in the neighbourhood on the assembly, the permitted number of three reflow soldering processes is exceeded. In this context, the data sheet of the respective component manufacturer must be complied with.

2.13.2 Sequence of component replacement

Component replacement comprises the following work steps:

1. Transfer/acceptance of the defective assembly under ESD protection measures
2. Assembly preparation (cleaning, drying of the assembly and, if necessary, of the component to be soldered in again)
3. (Ideally) measurement of the soldering in and soldering out profiles on a sample assembly*
4. Test soldering*:
    a. Solder component assemblies carefully
    b. Prepare the circuit board surface for the soldering process
    c. Apply the solder paste, or alternatively apply the flux
    d. Align and place the component
    e. Solder the component
    f. Quality control, inspection and electrical or function test, if necessary, cross-hatch analysis for process release
5. Rework of defective assemblies (serial rework)
    a. Solder component assemblies carefully
    b. Prepare the circuit board surface for the soldering process
    c. Apply the solder paste, or alternatively apply the flux
    d. Align and place the component
    e. Solder the component
6. Quality control, inspection and electrical or functional test

* If there is no typical sample for the process optimisation, these steps are omitted.


Assembly outside specification
Transfer/acceptance of the defective assembly under ESD protection measures
Error
Yes No
No
Pseudo error or
Cosmetic imperfections
Documentation and assembly without reworking in further processing sequences
Yes
Determine the fault location of
the reworking process approved by the part manu-facturer
Assembly preparation (cleaning, drying the assembly and, if necessary, the component to be soldered in again
Component replacement necessary
No
Rework (soldering of faulty solder joints, for example bridges, open solder joints, solder quantity)
Yes
Test assembly available
No
Select a suitable solder pro-file, solder the component, Prepare LP and solder in new component
Yes
Calibration of soldering and removal profiles
Test soldering
Quality control
Quality control passed
No
Solder profile,
Solder the component,
Prepare LP and solder in new component
Yes
If necessary, rework of further assemblies
Procedure as above
Completed
Packaging and shipping or assemblies in further process flow

2.13.3 Detailed process flow

1. Transfer/acceptance of the defective assembly under ESD protection measures

The defective assemblies are accepted under suitable ESD protection measures from our own production, as a customer recourse or as a service order. They are then transferred to the clean ESD-protected rework environment. All further work must be carried out under ESD protection conditions.

2. Assembly preparation (cleaning, drying of the assembly and, if necessary, of the component to be soldered in again)

If necessary, the assemblies are cleaned with suitable cleaning processes. Subsequently, the components are dried, if necessary, according to the manufacturer's instructions. The assemblies are also dried with suitable parameter selection. In this case, the recommendation is to dry with a plastic housing at 125 °C for 24 hours in the circulating oven, analogous to most moisture-sensitive IC components. However, this can lead to damage in temperature-sensitive components. Therefore, the maximum temperature of the unit drying must be adapted to the most heat-sensitive component type. This requires a study of the data sheets, especially if the drying temperature is to be as high as possible for reasons of time. Common combinations when using temperature-sensitive components are drying in the circulating oven for 48 hours at 80 °C. or 60 hours at 70 °C. (DIN EN 61192-5 [10], literature reference). Drying should always be carried out when the assembly has been open for more than the open time of the moisture-sensitive component (MSL class 3 e.g. 168 hours = 7 days).

3. Calibration of the soldering in and soldering out profiles on a sample assembly

Since the proper solder profile setting is rarely achieved in the first run-up, the solder profile should be measured on a sample assembly as described above. The sample assembly is ideally an identical (defective) assembly to be processed. This passes through several soldering processes and should no longer be put into circulation as a result of the additional thermal load. If a sample assembly is not available, at least the bare PCB is to be used. Although not equipped, it has a lower thermal mass, but the profile finding can thus take place in a first approximation. If no sample assembly is available, proceed as described under Test Soldering.

4. Test soldering

a. Solder component assemblies carefully

For this purpose, the component is soldered with the previously measured solder profile. If no solder profile can be measured, a temperature-time profile is set on the rework system which is expected to be able to solder the component. This setting is based on experience gained with the same or similar assemblies. In any case, a profile with mild initial parameters should be selected in order to be able to extend or increase the time and/or temperature in the peak phase during the soldering process. Experience with the rework system is helpful. Understanding how the rework system responds to different settings helps to minimise the number of necessary iterations. The approach of using a relatively low parameter setting to the soldering task has the advantage that it can be repeated in the event of an unsuccessful (too cool) soldering test. Setting the temperature too high (temperature or time) can lead to irreversible assembly damage. There is the possibility, according to IPC-7711/7721 [12], of repairing damaged printed circuit boards. However, this procedure is not recommended here.

An online control of the soldering process with a pivoting side camera is particularly helpful during the soldering process. This results in improved process reliability on rework on unknown assemblies. It is thus possible to observe the melting of the solder. It is only when the solder is completely melted that the component can be lifted safely without the need for individual, still solid solder connections to pad trimmers on circuit boards or components. If the component is lifted off, the soldering out programme is terminated or the cooling phase is initiated to cool the component and circuit board.

b. Prepare the circuit board surface for the soldering process (residual solder removal, cleaning the pad surfaces)

The circuit board is now freed of excess residual solder and flux residues. This can be done manually or with machine support. In particular, BTCs are extremely sensitive to non-uniform soldering volumes of the individual solder joints with regard to short-circuit formation, non-soldering and reliability. In this case, unlike in the case of BGAs, it is particularly important to ensure a uniform solder application (paste pressure) and to ensure a good uniform residual solder removal in advance. The "soldering" in the residual solder, as is often the case with BGAs with a larger grid size, is not recommended, since a uniform levelling of the residual solder amounts is only possible within specific limits. Therefore, the residual solder should be reduced to a small residual quantity.

With the aid of a suitable flux, a safe, machine-supported residual solder removal which is mild on the printed circuit boards, is possible, for example by means of contactless vacuum extraction. However, care must also be taken to avoid the exposure of intermetallic phases by application of excessive temperatures or too long process times, since otherwise wetting problems may occur during the subsequent soldering process.

Improper use of manual soldering irons and/or de-soldering leads to the risk of damage or even tearing of printed circuit boards or adjacent components.

Pouring and varnish residues are removed according to IPC 7711/7721 [12].

If any impurities remain, they are removed with a suitable cleaning medium and a brush or lint-free cloth. Care must be taken to ensure that the cleaning medium is approved for this application and that no residues remain on the printed circuit board. In particular, no media should flow under adjacent components. If necessary, a subsequent automatic cleaning process will be necessary.

c. Application of solder paste (optionally on printed circuit board or component)

In order to solder the new or cleaned old component, new solder paste must be applied. This is done by means of manual solder paste printing with so-called mini-sheets either on the printed circuit board or predominantly on the component bottom. Rework device manufacturers offer optionally available tools (see chapter 4.7).

The same pressure parameters (stencil thickness, opening size, layout) should be applied as in inline processing. If in doubt, work must be carried out according to the recommendation of the component manufacturer or the stencil manufacturer.

Alternatively, manual (inaccurate dosing) or automatic dispensing or dipping transfer methods can also be used. It is important to use a uniform application of solder paste in order to achieve a good soldering result.

The solder application by manual soldering is unsuitable because of the difficult to control process. A uniform pre-soldering as a basis for evenly shaped solder joints is very hard to make reliably reproducible. There is also the risk of component damage caused by the uncontrolled heat input. This method is not recommended for components that are only reflow-specified (many BTCs).

d. Align and place the component

The component is recorded with the support of the rework station, and aligned and placed with respect to the pin-1 mark. In particular, BTCs have only a limited ability to float and thus compensate for a misalignment. Inaccurate positioning leads to bridging. In this case an offset of less than 25 percent of the connection width is recommended according to IPC-7093 [7]. Typically, alignment is by beam splitter and/or camera system. By comparing the images of pads or reference marks to the component, manual or automatic positioning (x, y, Θ) is possible. The component is then placed on the assembly.

e. Solder the component

The component is soldered with a suitable rework station using the soldered profile which was measured or formed during desoldering.

The soldering of, for example, a BTC with a soldering iron due to the inaccessible connection surfaces and the above mentioned dangers of damage caused by the uncontrolled heat input is not recommended and is generally not compliant with the manufacturer.

f. Process control

Success monitoring can be performed by optical inspection, X-ray inspection, and also by an electrical test or a functional test. In the case of boundary soldering (very low or very high heat input), a cross-hatch analysis is recommended for process release. The solder joint is assessed for the wetting and formation of the intermetallic phase. In addition, the circuit board and components are examined for structural integrity.

5. Rework of defective assemblies (serial rework)

After the test soldering and the process qualification has been completed, the series rework can be carried out. The specifications according to J-STD-020 [3] and J-STD-033 [4] must be complied with.

a. Solder component assemblies carefully (see 4.a.)
b. Prepare the circuit board surface for the soldering process (see 4.b.)
c. Apply the solder paste or alternatively the flux (see 4.c.)
d. Align and place the component (see 4.d.)
e. Solder the component (see 4.e.)

6. Quality control, inspection and electrical or functional test

The quality control is carried out through non-destructive testing by means of optical inspection (as far as possible) and x-ray inspection as well as the proof of electrical function.

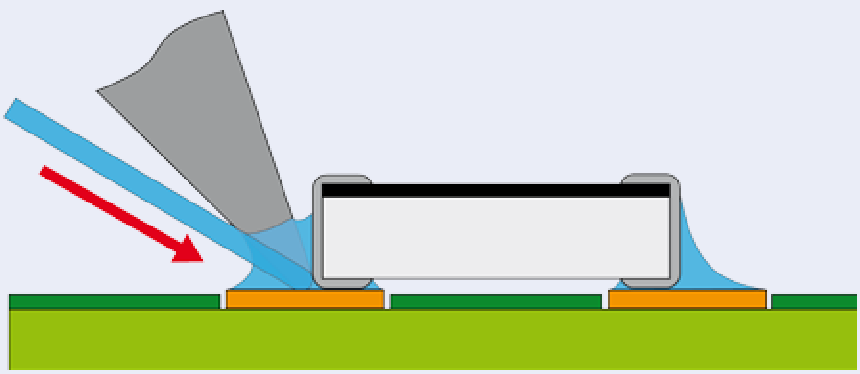
2.14 Device technology

2.14.1 Manual soldering devices

1. Contact soldering (soldering iron, pliers,...)

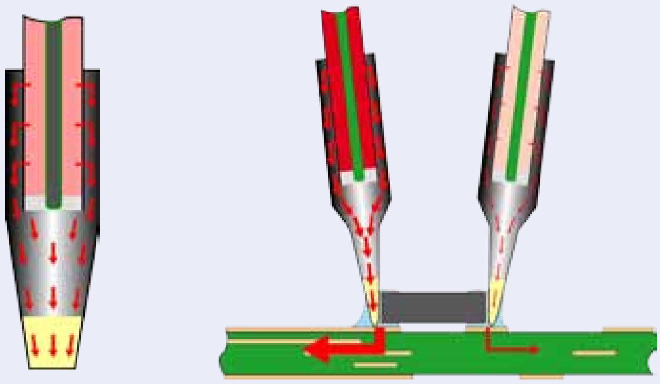
The classic soldering technique is the electric soldering iron; although the patent of Ernst Sachs from the year 1921 is now only an historical document, the basic technology has proven itself to this day. The leading manufacturers of hand tools focus on the refinement of heating and control technology to adapt modern tools to the needs of electronics manufacturing. The soldering tips are becoming ever finer and the demands on exact soldering tip temperatures ever higher. At the same time, today's highly integrated electronic assemblies often require a high amount of heat which requires intelligent post-heating behaviour, i.e. a rapid reaction of the heating system.

Fig. 28: SMD soldering with contact heat (soldering tip)



Source: Ersa

Fig. 29: Heat flow in a soldering tip from the heating element to the active soldering surface, in the inner (green) sensor for detecting the temperature, heat flow in the two soldering tips of a pair of desoldering tweezers or in two soldering irons used in parallel.



Source: Ersa

Soldering iron manufacturers have long been focusing on the measurement of the real soldering tip temperature and thus ensure that the control always responds to the immediate change in this temperature.

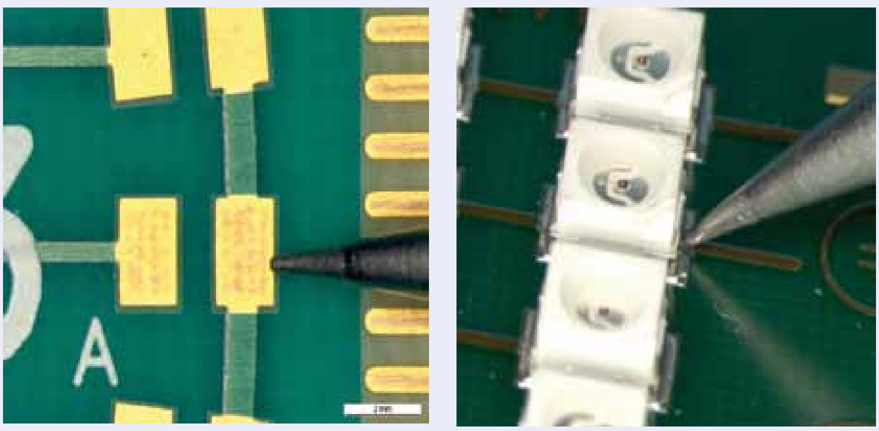
This system has proven itself with soldering irons from all manufacturers. The calibration of the soldering tip temperature can also be carried out very simply by the user in a simple way and ensures that an accurate measurement and thermal control behavior is ensured at all times.

In addition to the proper temperature, it is the geometry of the soldering tip which often determines the success or failure of the soldering process.

The soldering tip must match the soldering task (Figure 30 and Figure 31).

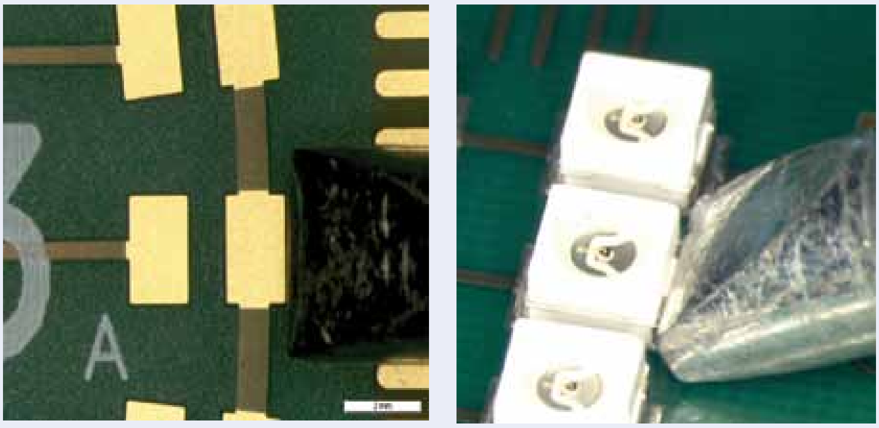
The manufacturers have a wide range of soldering and desoldering tips for their soldering tools which is geared to the needs of the market and is constantly being expanded. The following pictures are showing examples of mistakes that may occur when selecting soldering tips, or the proper selection.

Fig. 30: Images of small soldering tips



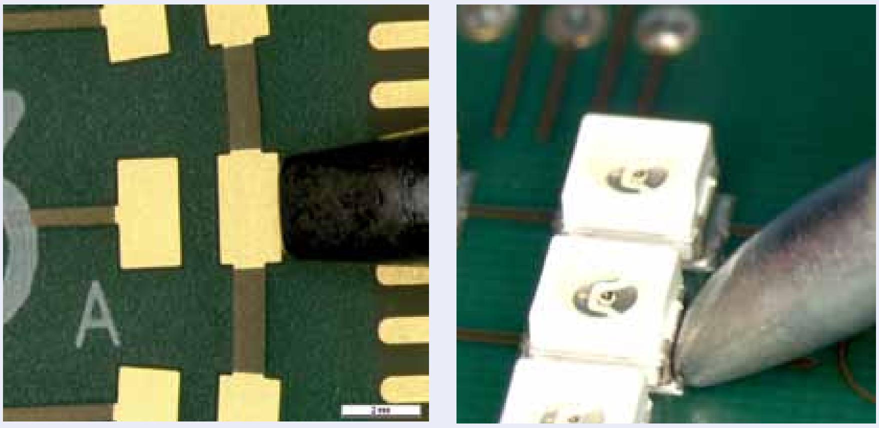
Source: Fraunhofer ISIT

Fig. 31: Images of too large soldering tips



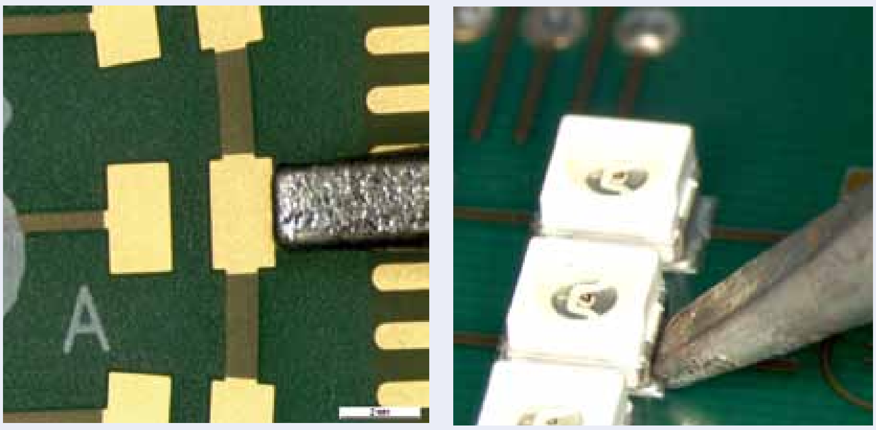
Source: Fraunhofer ISIT

Fig. 32: Images of suitably wide, but too thick soldering tips



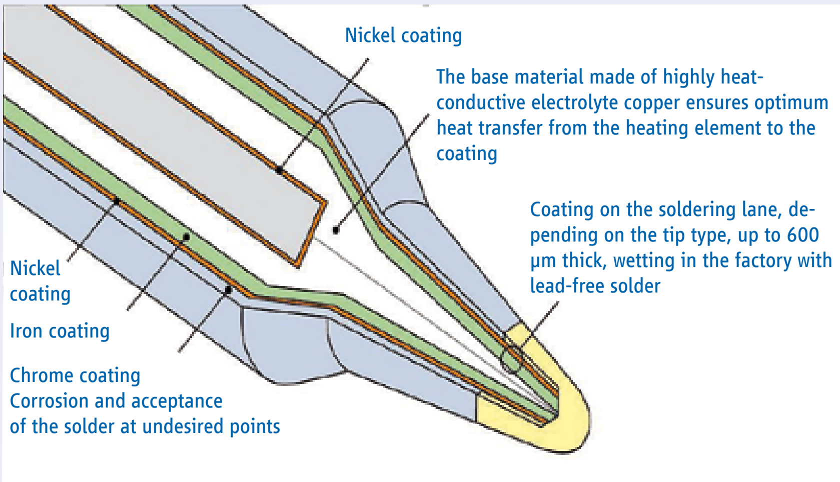
Source: Fraunhofer ISIT

Fig. 33: Images of correctly selected soldering tips



Source: Fraunhofer ISIT

Fig. 34: Exemplary coating of a soldering tip



Schematic representation, not to scale

Source: Ersa

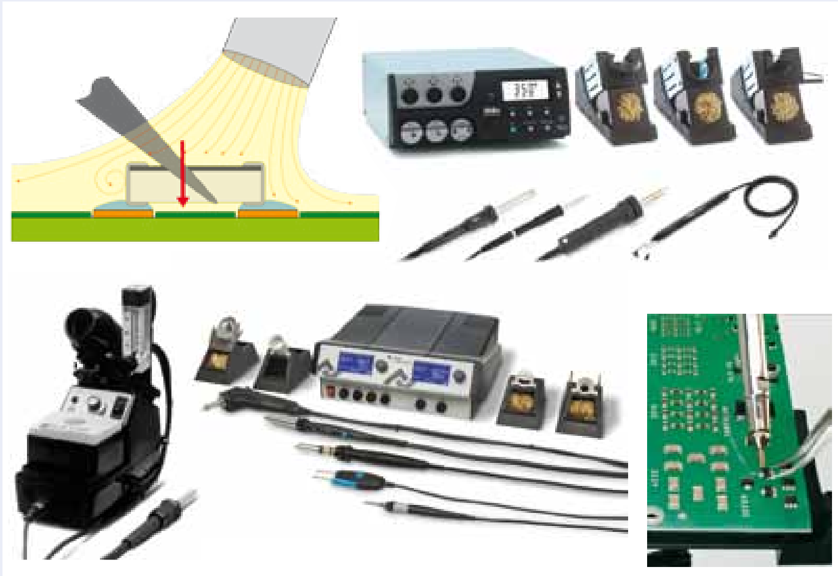
In addition, there are special soldering tips with which manufacturers can react to the needs of special applications.

There is an advantage in using soldering stations of which the soldering tips can also be changed during the heated state. This is particularly noticeable when the type and size of the soldering tips must be influenced flexibly. Also the speed of the heating up and the temperature stability at the soldering tip do not play a negligible role in the process. The display standardly provides information on the temperature situation at the soldering tip.

Fig. 35: Soldering stations with directly heated soldering tips possible as single or double station

Source: Weller, JBC, Ersa

Fig. 36: Hot-gas soldering stations, optionally with air or inert gas



Source: Edsyn, Weller, and Ersa

2. Hot gas soldering

At the use of hot gas soldering station, the fine adjustment of the gas quantities is very important in addition to temperature control. Devices with a display of the flow rate (e.g. flowmeter with float) have proved to be helpful. Depending on the device, both air and well known inert gases can be used as process gas. The best-known is nitrogen. Since the temperature of the gas is standardly not measured directly at the gas outlet, but in the gas stream before it, the temperature displayed is not necessarily the temperature that prevails at the solder joint. Depending on the gas set, the gas temperature is considerably higher than that of conventional heat. The heat input to the soldered joint is thereby decisively determined by the gas temperature, the flow rate and the nozzle distance to the solder joint. Typically this achieves considerably lower heat transfer rates than with contact heat.

2.14.2 Quasi-stationary rework systems

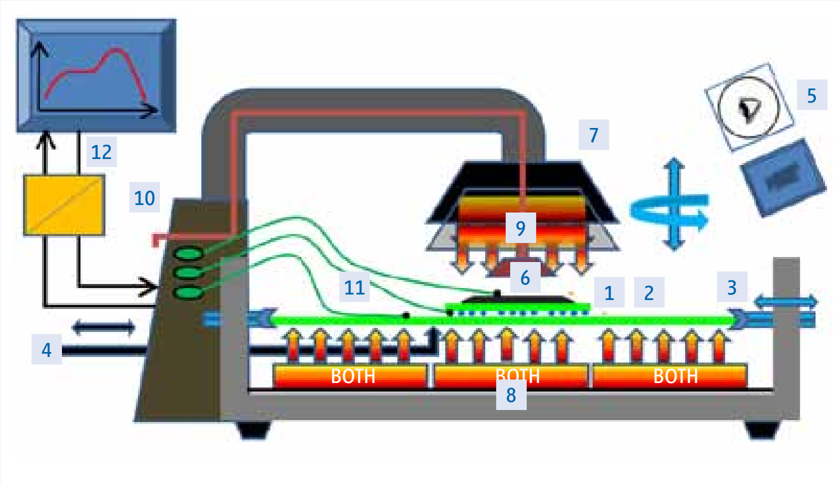
The rework of complex components is to be carried out with so-called rework stations specially developed for this processing. These are suitable both for the rework and for the precise selective placement of components. They support the operator in handling of the assemblies and are designed to at least partially automate workflows. Special optics and lighting facilitate positioning. A computer-controlled, reproducible temperature-time control and axis movement is possible by means of programmable top and bottom heating (hot gas, infrared or a combination of both) adapted to the assembly.

Modern rework systems are quasi-stationary systems with which reflow solder profiles can be realized similar as in in-line reflow soldering processes but using an isolated process concept. The main difference between this category of soldering systems compared to manually guided devices is the more user-independent process management.

In this group of rework systems, the device-specific options are differentiated primarily with regard to degree of automation, performance of top heater (TOPH) with the so-called heating head and bottom heater (BOTH) as well as conceptual variants for assembly fixing or support.

In what follows, three typical rework systems, concepts and options are presented and finally discussed in chapter 5 and 6 with regard to their result correlation.

Fig. 37: Schematic image of rework station



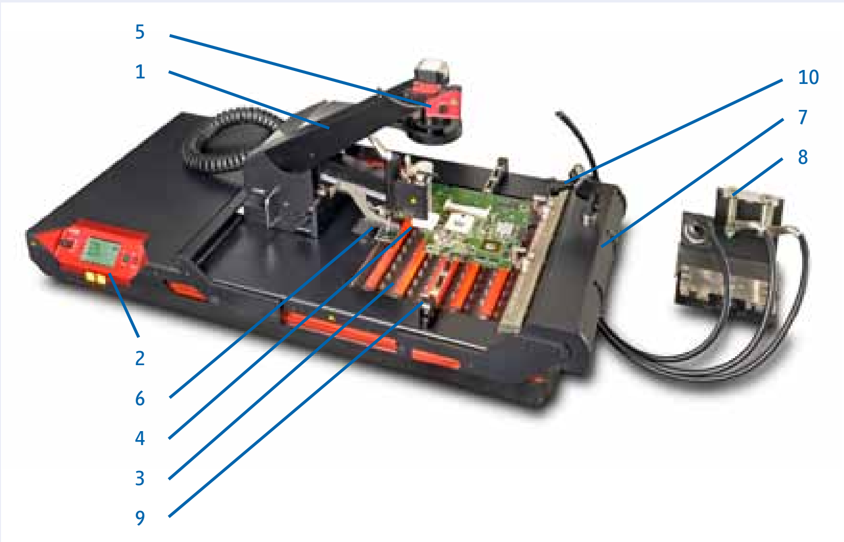
1. Component (e.g., BGA)
2. PCA
3. APCA Main Support
4. Centre support
5. Control optics
6. Component vacuum tool
7. Optical placement aid
8. Bottom heater (BOTH)
9. Top heater (TOPH)
10. Process gas supply
11. Temperature sensor
12. Control/Unit

Source: Airbus DS Electronics and Border Security

2.15 Devices - Systems - Concepts

2.15.1 Semi-automatic Hot gas rework system

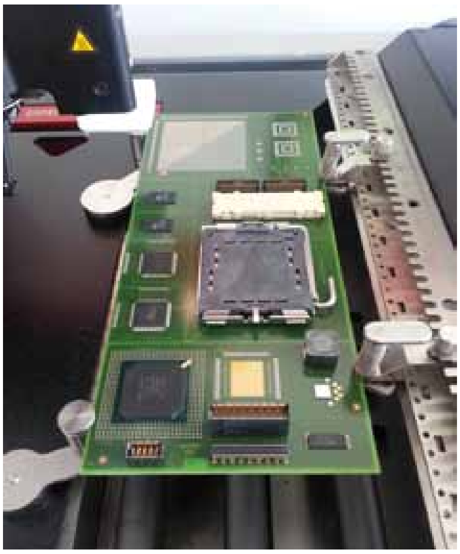
Fig. 38: Semi-automatic hot gas rework system



1. Placement arm (AVP) with LED ring light and HDD camera
2. Control unit
3. 3000-W hybrid under-heating
4. Hot air top heating
5. Infrared temperature sensor
6. Nozzle for Dip, Print and μSMD Tool (APP TOOL)
7. Hand rest with cooling fan
8. Stylus stand with: Dosing, soldering and vacuum grippers
9. Flexible circuit board support (Flex Support)
10. Side camera

Source: Martin

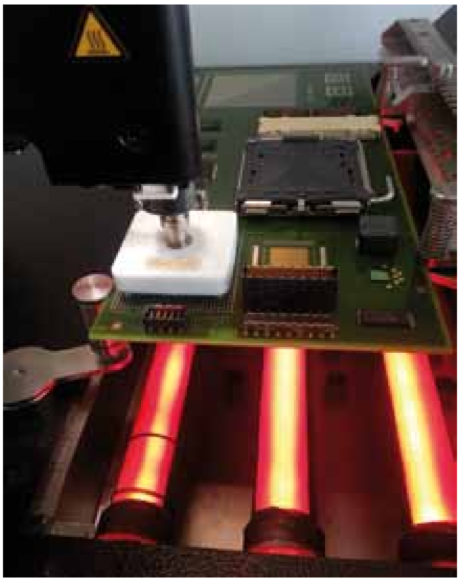
1 PCA main support
Fastening: force and form-locking magnetic force-assisted.
Form aspect: contour variable.
Size aspect: optional support (Flex Support).



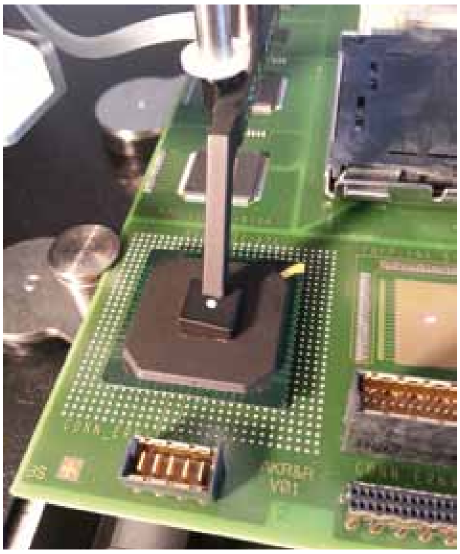
2 Align to component (desolder)
Positioning parameters: x-, y-, z-axis. Positioning concept: manually guided soldering head positioning.
Position control: camera-assisted, visual.

3 Desoldering
Programme sequence: automated z-axis positioning of the hot-gas nozzle.
Solder profile selection: alternatively from profile library or by individually created profile.
Measure/Capture/Control/Rules: Type K thermocouples / NiCr-Ni) and IR sensor.
Operating modes: Closed loop => LP temperature as control signal; Open Loop => Programme sequence according to defined programme.
Solar thermal management:
Bottom (BOTH): Hybrid heating (combination of radiation (IR) convection) with separately selectable, continuously adjustable zones.
Top (TOPH): Forced convection with solder nozzle with adjustable hot gas flow and temperature.

4 Lift the component



Programme sequence: Change of position of hot gas nozzle and vacuum pipette and subsequent lifting by means of vacuum-assisted pipette.
Concept: vacuum-assisted, fully automatic, coordinate-controlled.

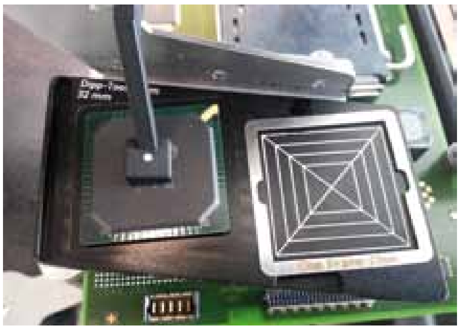


5 Remove of soldering residuals

Methodology: manually guided, UHZ-supported process with vacuum-controlled solder removal.
Equipment: Hot gas and vacuum pencil, hybrid UHZ.

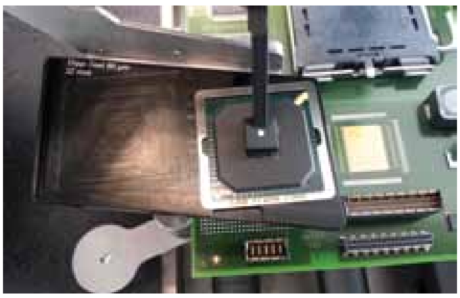
6 Adjuvant application

Principles for printed circuit boards: Dispensing (immediately before position 10), PIN transfer (immediately before position 9), stencil printing (immediately before position 7).
Principles for component: stencil print (immediately before position 7), dipping (immediately before position 9).
(Auxiliary) materials: Fluxes, solder pastes dispensable and/or cracked.



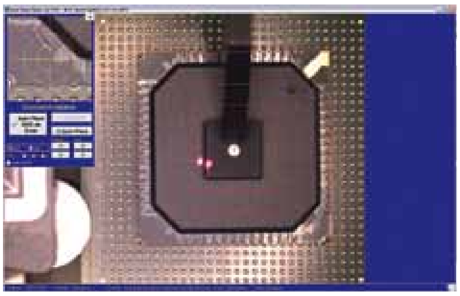
7 Lay the component

The component is removed from the component presentation by means of a vacuum. These are available for µSMD, BGAs and QFN.



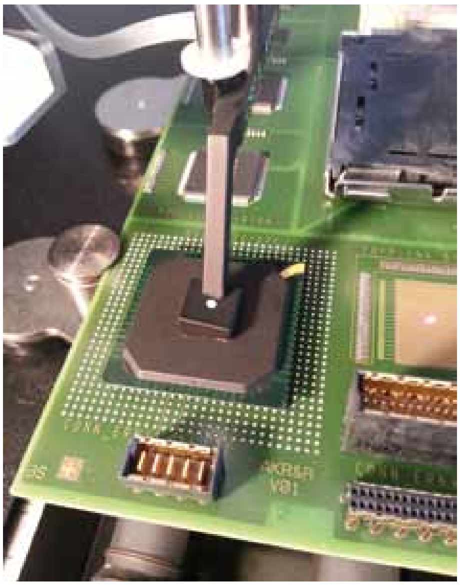
8 Components aligments

Position parameters: x, y (angle of rotation). Positioning concept: semi-automatic (CCD-camera-assisted) positioning. Position control: optical guidance.
Features: LED ring light, software-based componentcentre point detection with 3-point selection.



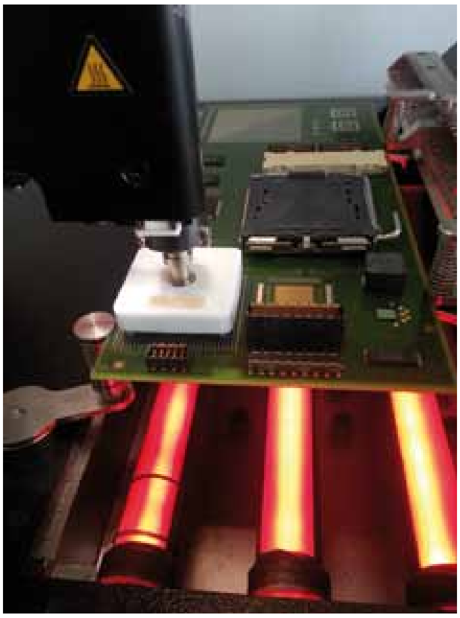
9 Place the component

Placement parameters: coordinate-controlled, z-axis optionally contactless or over-weight pipette component.
Placement: automatic.
Placement control: software-based.
Features: Component malfunction detection.



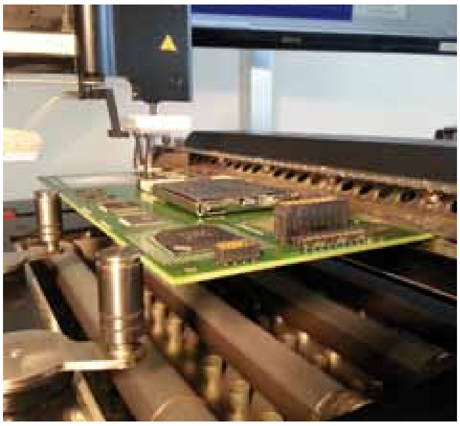
10 Soldering

Analogous to position 3, but possibly adapted solder profile (heat demand of soldering step is not necessarily identical to the desoldering step requirement).



11 Cooling

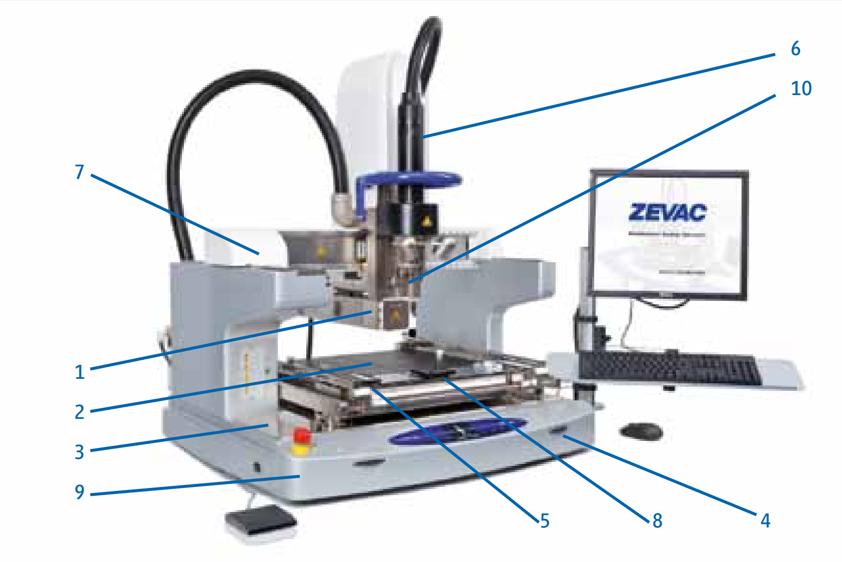
Programme sequence: Switch off the heat supply by BOTH and TOPH.
Solder profile selection: typically part of the solder profile (position 3 and 11), time and/or temperature controlled.
Heat management:
Top: Cooling by means of adjustable gas flow of the hot gas nozzle.
Bottom: Ventilation assembly side and bottom.



Source: Martin

2.15.2 Automatic operation
Hot gas rework system

Fig. 39: Automatic hot gas rework system



ONYX 29: SMT rework system and flexible platform

1. MFoV vision system
2. 4-zone preheater 6000 W
3. Base plate with force measurement
4. X/Y fine adjustment
5. Dip fluxer
6. Heating head above, 2000 W
7. X/Y portal
8. Pickup Tray
9. Sturdy cast iron base
10. Nozzle assembly

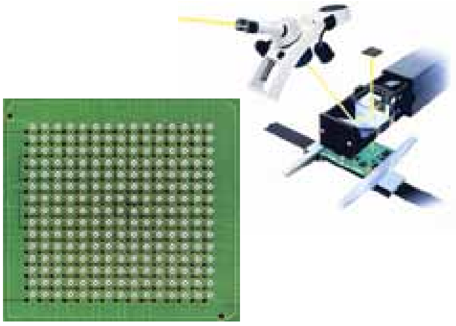
Source: Zevac

1 PCA main support

Fixing: force and form fit.
Form aspect: contour variable.
Size aspect: optional support.

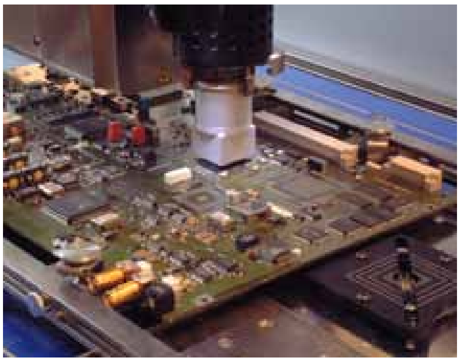
2 Align to component (desolder)

Positioning parameters: x-, y-, z-, Θ-axis.
Positioning concept: automatic.
Position control: automatic camera-based or manual.



3 Desoldering

Programme sequence: automated z-axis positioning of the hot gas nozzle.
Solder profile selection: alternatively from profile library or by individually created profile.
Measure/Capture/Control/Rules: Type K thermocouples/NiCr-Ni and IR sensors.
Optical process control: camera-based.
Operating modes: Closed loop => LP temperature as control signal Open loop => Programme sequence according to defined programme.
Solar soldering thermal management:
Bottom (BOTH): IR ceramic heating with separately selectable, continuously adjustable zones.
Top (TOPH): Forced convection by means of solder nozzle with adjustable hot-gas flow and temperature.



4 Lift the component

Soldering nozzle with integrated vacuum pump.
Concept: vacuum-assisted, fully automatic, coordinate-controlled.

5 Remove of soldering residuals

Method characteristics: automatically guided, non-contact, UHZ-assisted process with vacuums
Solder removal.
Equipment: Suction nozzle ceramic UHZ.

6 Adjuvant application

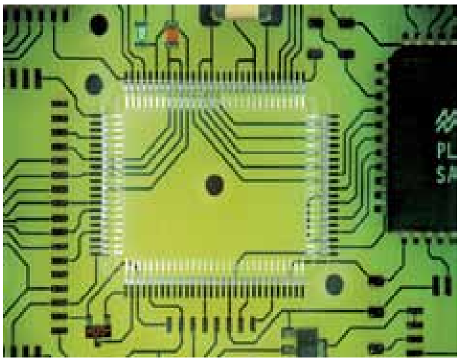
Principles for printed circuit boards: Dispensing flux or soldering paste.
Pin transfer of solder paste stencil printing (immediately before position 7).
Principles for component: stencil printing (immediately before position 7), dipping (immediately before position 8).
(Auxiliary) materials: Fluxes, solder pastes dispensable, dippable and/or raked.

7 Lift the component

The component is removed automatically from pinpoint 1 with freely oriented recording positions.

8 Lift the alignment of component

Position parameters: x, y (angle of rotation). Positioning concept: fully automatic, camera-assisted positioning.
Position control: Pin overlay.
Features: Creation of an overlay of printed circuit board and component by prism.



9 Lift the alignment of component

Placement parameters: coordinate-controlled, z-axis optionally with defined force or contactless.
Placement: automatic.
Placement control: with camera support.
Features: manual misalignment, correction.

10 Soldering

Analogous to position 3, but possibly adapted solder profile (heat demand of soldering step is not necessarily identical to the desoldering step requirement).

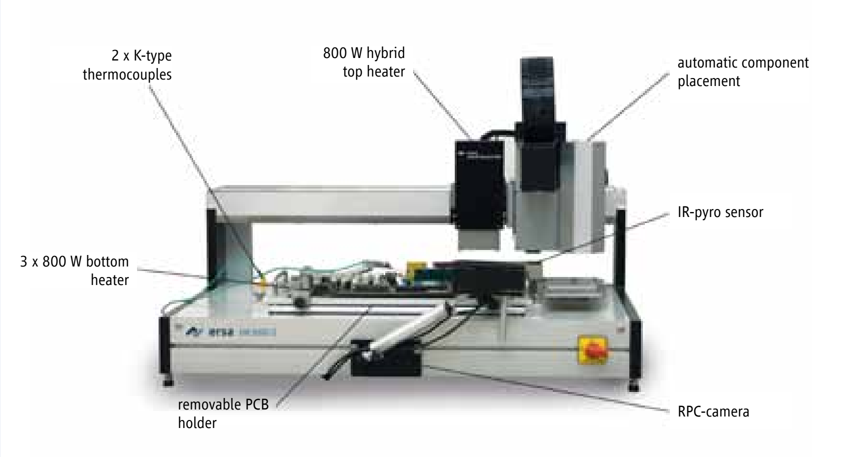
11 Cooling

Programme sequence: Switch off the heat supply by BOTH and TOPH.
Solder profile selection: typically part of the solder profile (position 3 and 10), time and/or temperature controlled. Heat management:
Top: Cooling by means of adjustable gas flow of the hot gas nozzle.
Bottom: air-cooled surface cooling via cold air knife.

Source: Zevac

2.15.3 Automatic operation IR rework system

Fig. 40: Automatic IR rework system

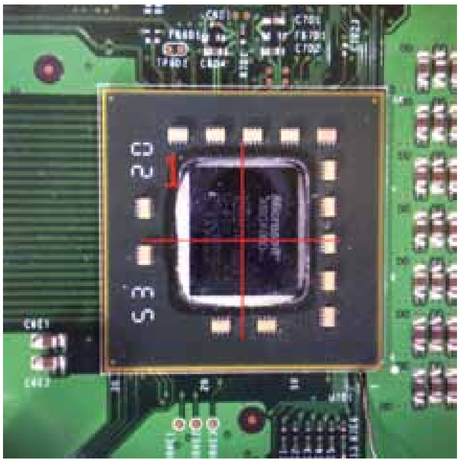


Technical details:

- Ersa IR (hybrid) superheating
- IR-ceramic under-heating (medium-wave)
- Placement technology with image processing
- Automatic or semiautomatic placement
- Dip&Print station for flux and solder paste
- Component size range
  1 × 1 mm² to 50 × 50 mm²(placement)
- Soldering area 60 x 60 mm²
- Closed loop temperature control with IR or TC sensor
- Process monitoring camera (RPC) optional
- Software-based process

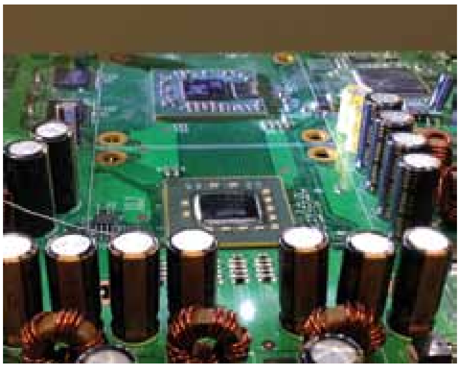
1 PCA main support

Fixing: force- and form-fitting to a defined surface level. Variable screw clamping.
Form aspect: contour variable.
Size: Support rails with pin receptacle (if necessary with opposing clamping).



2 Align to component (desolder)

Positioning parameters: x-, y-, z-, Θ-axis.
Positioning concept: automatic.
Position control: automatic camera-based or manual.



3 Desoldering

Programme sequence: automated z-axis positioning of the IR hybrid heating head. Selecting a solder profile: either from profile library or by using a custom profile, as desired.
Measure/Capture/Control/Rules:
Type K thermocouples / NiCr-Ni and IR sensors.
Optical process control: camera-based.
Operating modes: Closed loop => LP temperature as control signal Open loop => Programme sequence according to defined programme.
Soldering thermal management:
Under-heating (BOTH): medium-wave infrared. IR ceramic heating with separately selectable, continuously adjustable zones.
Top (TOPH): IR hybrid heating head. IR ceramic heating with separately selectable, continuously adjustable zones.

4 Lift the component

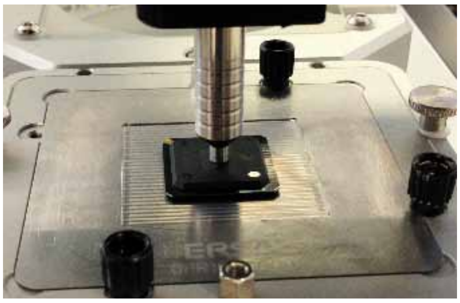
Programme sequence: vacuum pipette integrated in the hybrid heating head.
Concept: vacuum-assisted, fully automatic, coordinate-controlled.

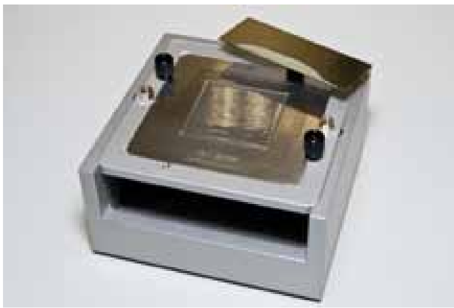
5 Remove of soldering residues

Process characteristics: manually guided, BOTH-supported process with external contact heat or vacuum suction.

6 Adjuvant application

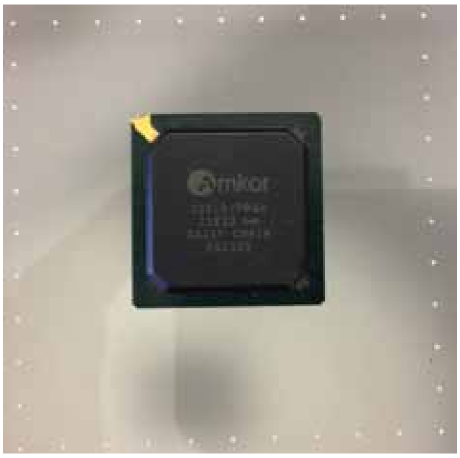
Principles for printed circuit boards: flat flux application (e.g. brush application) is not recommended
Principles for component: Stencil printing (immediately before position 7), dipping (immediately before position 9).
(Auxiliary) materials: Fluxes, solder pastes dispensable, dippable and/or raked.





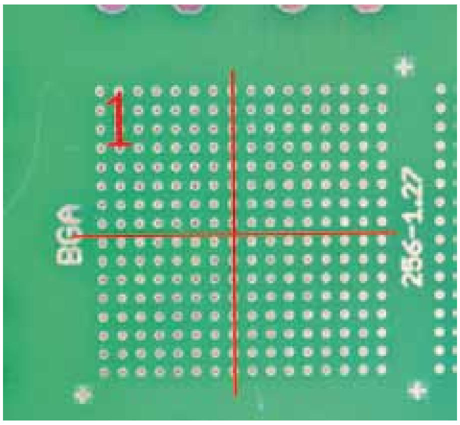
7 Lay the component

The component is provided with proper orientation of pin 1 on the glass plate of the camera system and automatically picked up.



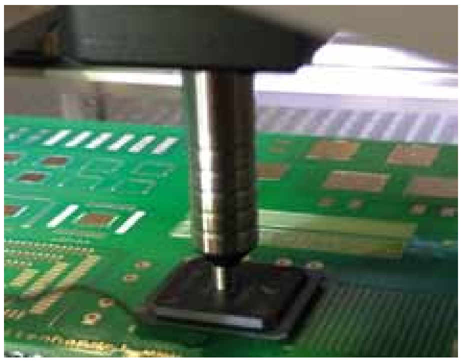
8 Align the component

Position parameters: x, y (angle of rotation). Positioning concept: fully automatic, camera-assisted positioning.
Position control: Pin overlay.
Features: automatic component recognition. Creation of an overlay of printed circuit board and component by prism.



9 Place the component

Placement parameters: coordinate-controlled, z-axis optionally with defined force or contactless.
Placement: automatic.
Placement control: camera-supported.
Features: manual misalignment.



10 Soldering

Analogous to position 3, but possibly adapted solder profile (heat demand of soldering step is not necessarily identical to the desoldering step requirement).
The process parameters include the soldering and desoldering profile.

11 Cooling

Programme sequence: Switch off the heat supply by BOTH and TOPH.
Cooling profile selection: time- or temperature-controlled.
Heat management:
Top: Airflow through hybrid heating head.
Bottom: air-cooled surface cooling.

Source: Ersa

3 Manual Soldering - Trials and Findings

3.1 Proven equipment within the trial series

- Direct heated micro solder irons for two-pole components
- Hot gas soldering station for multipole components (e.g. PQFP)
- Soldering tweezers for desoldering two-pole components
- Preheating plate for processing thermally critical switching parts with high thermal capacity
- Tweezers adapted to the component
- Vacuum pump for component handling
- Solder wick
- Flux (standard compliant)
- Leadless solder (SAC305)
- Microscope magnification (up to 40 times)
- Ethanol for cleaning the solder joints (compatible with the flux)
- Lint-free cleaning swabs
- Lint-free cleaning tissues

3.2 Two typical disciplines from the manual soldering area

3.2.1 Desoldering, replacement and manual soldering of two-pole components

The temperature setting on the manual soldering iron was 350 °C. To support the debouncing/soldering process and the shortening of the cycle time, it is recommended to use a preheating plate/an IR preheating/hot air furnace (contact heat/radiant heat/convection) in the range of 80-100 °C (target top assembly).

Care must be taken to ensure sufficient soaking during the entire process.

Before soldering the components, the solder joints have been wetted with flux. If mechanically possible, a pair of desoldering tweezers (two heated soldering tips) with the "chisel tips" adapted to the component should be used for the purpose of desoldering the components. For larger two-pole components, two identical manual soldering irons can also be used synchronously.

In each case, the residual solder was removed with a soldering tip adapted to the solder pad with the aid of a solder wick. Depending on the condition of the solder pads, additional flux was required.

The new components were fitted with the tweezers onto the pads prepared in this way, and fixed with the soldering iron on one side. After soldering both connections it is recommended to clean the areas with

Fig. 41: Preheating plate with infrared radiation

Source: Martin

Fig. 42: Combined stations with directly heated soldering iron and desoldering tweezers for two-pole components

Source: Weller, JBC

a suitable cleaning medium and lint-free cleaning cloths, if a machine cleaning process does not follow. If the requirements from the point of view of the climate load demand, a "flux test" is mandatory. This ensures that corrosive residues are removed.

3.2.2 Processing of PQFP components

When the components are removed, the solder joints are first wetted with flux.

The preheating of the component and the soldering points by means of the hot gas nozzle causes activation of the flux. Thereafter, the soldering points are heated to the melting point with the nozzle provided for the assembly. The time of remelting must be optically controlled by the operator. If all the soldering points are in the molten state, the component can be lifted off the assembly by means of a suitable tool (in this case with a vacuum pump). The residual solder is removed by means of desoldering. Ethanol is used as cleaning medium for flux residues.

The PQFP is first placed, optically manually aligned and tacked diagonally to the soldering iron at two terminals. The connections are wetted with flux and soldered with a depot soldering tip.

If solder bridges are formed, they are removed again with additional flux and a previously cleaned depot tip.

Following the soldering process, thorough manual cleaning is carried out.

3.3 Findings on manual soldering

Soldering temperature/Soldering tip temperature

For SAC solders a temperature range between 320 °C and 370 °C can be recommended. The temperature is, of course, decisively determined by the thermal capacity of the components and the mass ratios in the immediate vicinity of the soldering point to be processed.

Preheating

As a guideline, the temperature of >130 °C should not be exceeded on the underside of the assembly. This temperature is also dependent on the flow, since the efficacy of some fluxes, depending on time and temperature, is greatly reduced.

At the preheat temperature, the guidelines for occupational health and safety must be complied with. This can be done, for example, by marking or covering the hot surfaces. It is in any case sensible to inform the competent safety specialist (internally/externally) in advance.

Soldering in/out of high-poles SMD (e.g. PQFP, TSSOP,...)

Manual soldering was not recommended during the course of the studies. During the soldering process, pad damage or tearing can occur if, at the time of lifting, not all soldering points are molten. In the case of soldering in, terminal pins can be bent and due to the assembly density an ideal soldering iron guide cannot always be guaranteed. It is strongly recommended to use a rework station suitable for this purpose.

Remove component

Vacuum pipettes and gripping systems (tweezers, etc.) have proven themselves for the lifting of components.

Removal of residual solder

When using solder wicks, a suitable dimensioning of the soldering tip must be ensured according to the width of the solder wick. Preheating the assembly to 60-100 °C and using a relatively wide soldering tip reduces the risk of pad damage and tear. The amount of heat required to be supplied via the desoldering wire is reduced by the preheating and the probability of unwanted solidification of the solder with the desoldering wire is reduced.

The use of flux gel has the advantage of better heat transfer and supports the glide of the solder wick.

Cleaning

Both the cleaning medium and the cleaning process must be selected to match the flux residues and the compatibility with the assembly. An automatic assembly cleaning is recommended due to the reproducibility and safe removal of the dissolved residues.

Suitable designs for soldering

Regarding solderable structures, it is important to consider two aspects:

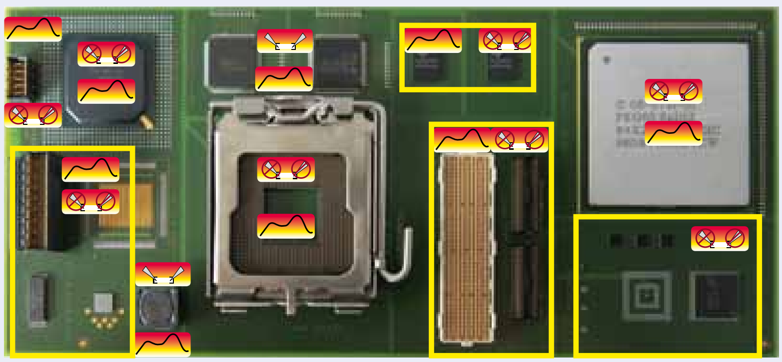
- Is the manual soldering process in principle capable of producing acceptable soldering joints within predetermined thermal, temporal limits (heat resistance, maximum temperature specifications of the component manufacturer, etc.)?
- Is the manual soldering process due to the heat transfer form by means of conduction (heat conduction) in principle approved for the design to be machined?

In Fig. 43, the component positions of the test board examined in detail are marked with soldering photograms. The reflow symbol is the indicator for a preferably reflowable construction and this circumstance is frequently associated with a non-solderable design. The hand solder symbol indicates a component that is hand solderable. While these application restrictions apply to the soldering, it is also possible that component patches are not released for reflow soldering. As a result, reworking is not permitted using rework system.

Soldering fume extraction

Industrial soldering stations with interface are available which can control a solder fume extraction for cleaning the process air. The interface ensures that the extraction is only

Fig. 43: Overview of the soldered or reflow soldered design of the testboard



Source: Zollner

carried out when soldering is performed. This saves energy and filter costs. A selection of suction arms and nozzles ensures the optimal extraction of the soldering dust in every application. It should also be borne in mind that these suction stations must be subject to regular functional checks in accordance with the applicable regulations.

In order to protect the employees, a fume extractor must be used in the workplace. This compulsory use is specified by the respective EU safety data sheet of the substance used.

Considered regulations on the topic of solder fumes extraction and regular testing:

- GefStoffV Hazardous Substances Ordinance [26] (Annex II, Chapter 2.3, Paragraph 7)
- TRGS 420 [27] "Process and material-specific criteria for hazard assessment" refers to BGI 790-014 [28] "Soldering with the soldering iron" in clause 5.1 paragraph 3
- TRGS 406 [29] "Sensitising substances for the respiratory tract", pt. 5. Fig. 2:
- TRGS 900 [30] "Workplace limit values"
- TRGS 528 [31]

4 Findings from the R+R Studies

4.1 Thermal profiles (target-actual)

The extent to which the determined solder profiles meet the targets of an assembly compatible soldering process is shown here. Table 10 (Target-to-actual adjustment of the profile parameters for rework processes) shows the comparison of the target specifications with the determined profile parameters.

The determined solder profiles correspond to the real application and were made under the requirement to ensure the complete melting of the solder connections. If there is only one assembly to be reworked no optimal solder profile adjustment is possible. The user will select a set of parameters which ensures the simultaneous melting of all soldering joints which can result in slightly higher temperatures and longer times above liquidus temperature than the values defined in chapter 2.2 as a pre-set for an assembly-compatible soldering process.

Some of the values for the positive temperature gradient are below 1.0 K/s. This is dependent on the thermal mass of the assembly as well as on the heating power used. However, under the specification of a carefully soldering process, very low temperature gradients of up to 0.5 K/s are possible, as long as all other specifications are adhered to (in particular maximum times over defined temperatures and the requirements of the flux producer).

If the component to be soldered has a large thermal mass, the values for the negative temperature gradient are partially exceeded. It is important here not to prolong the times above liquidus temperature so as to limit the growth of the intermetallic phase. If necessary, additional cooling must be used.

The requirements of the printed circuit board with respect to their thermal load were all respected.

The requirement to extend the time above liquidus temperature not over 60 seconds is only partially respected. If the achieved time is below 90 seconds, this is also considered uncritical.

The specified peak temperature in the solder joint is not exceeded and the maximum time in the peak is maintained.

The maximum permitted value for the component surface temperature was not exceeded, in addition the manufacturing specifications have been complied. The maximum time for the peak temperature was maintained.

In summary, it can be said that the determined and applied soldering profiles meet the requirements for a carefully rework process across different rework systems.

In chapter 4.5, the effect of the thermal load in the rework process with the profiles determined here is investigated.

For example, the soldering profiles of the rework systems used for the BGA256TI1.27C are shown below, see figures 44, 45 and 46.

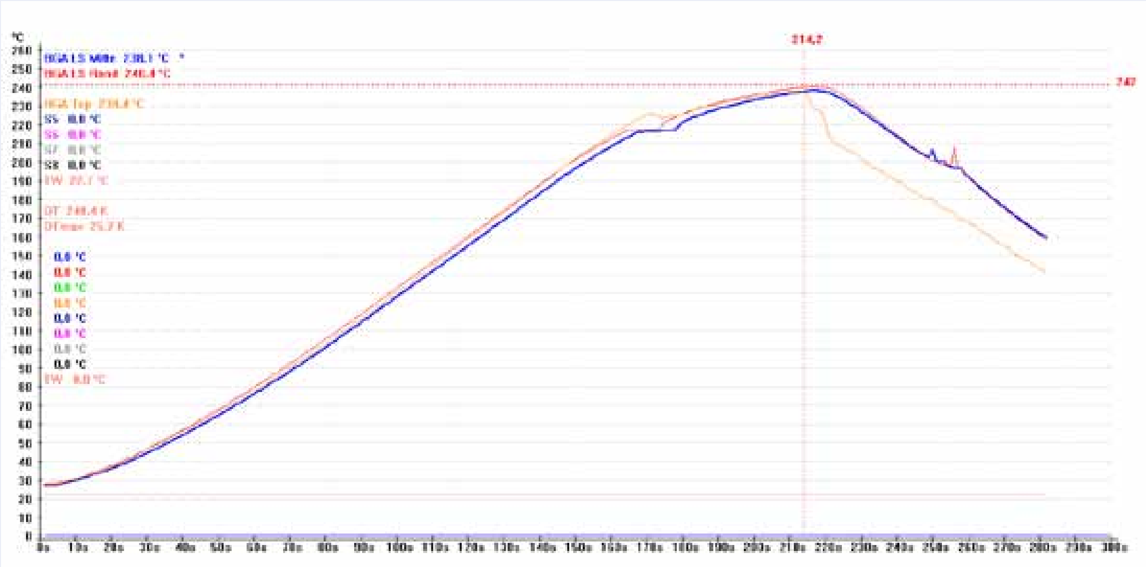
Tab. 10: Target-actual matching of profile parameters for rework processes

Profile parameters	Target	BGA 256:	Conn Erni	Conn FCI	PBGA176	PQFP	BGA socket
Positive temperature gradient at solder joint	0.5-2 K/s	√	√	√	√	√	√
Negative temperature gradient at solder joint	2-4 K/s	√	√	√	√	√	large thermal mass caused low cooling gradients
Time of the printed circuit board temperature maintained above 190 °C	150	√	√	√	√	√	√
Maximum printed circuit board temperature	≤245 °C	√	√	√	√	√	√
Time maintained above liquidus temperature (about 220 °C)	30-60 s	is sometimes above the target value, but below 90 s					
Solder joint Time within peak temperature (-5°C)	230-245 °C	√	√	√	√	√	√
Peak at solder joint	≤20 s	√	√	√	√	√	√
Peak package body temperature	≤245 °C	measured temperatures are sometimes higher than the target specification, but manufacturer specifications are complied with					
Duration of peak package body temperature	≤20 s	√	√	√	√	√	√

Semi-automatic hot gas rework system

T_{max} BGA Top:	238.7 °C	T_{max} solder joint edge:	240.5 °C
T_{max} solder joint centre:	238.4 °C	Time above liquidus:	58-72 s

Fig. 44: Rework solder profile BGA256TI1.27C, semi-automatic hot gas rework system



Source: Fraunhofer ISIT

Automatic hot gas rework system

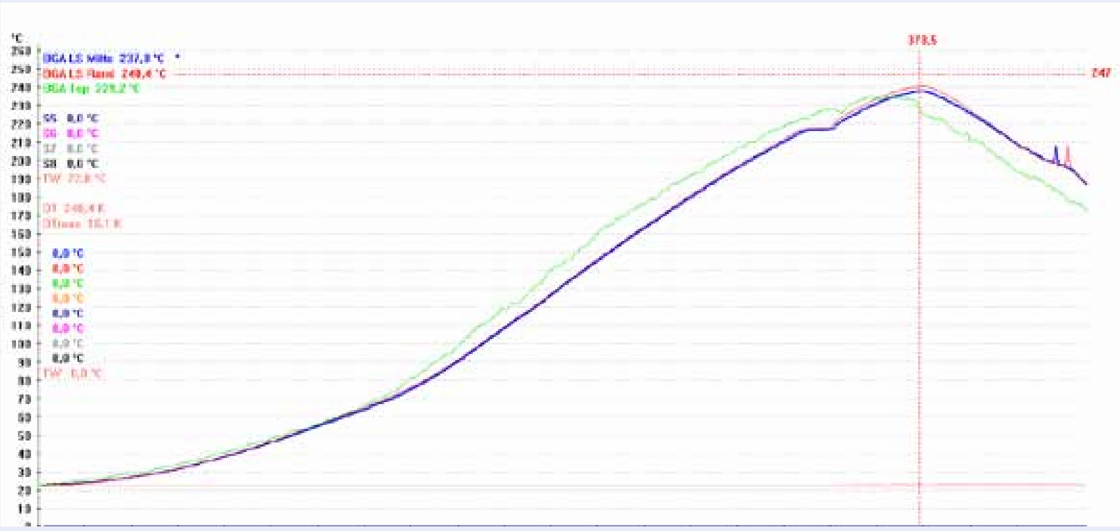
T_{max} BGA Top:	238.3 °C	T_{max} solder joint edge:	231.0 °C
T_{max} solder joint centre:	233.3 °C	Time above liquidus:	52-72 s

Fig. 45: Rework solder profile BGA256TI1.27C, automatic hot gas rework system

Source: Fraunhofer ISIT

T_{max} BGA Top: 235.1 °C
T_{max} solder joint centre: 238.0 °C
T_{max} solder joint edge: 240.7 °C
Time above liquidus: 70-84 s

Fig. 46: Rework solder profile BGA256TI1.27C, automatic IR rework system



Source: Fraunhofer ISIT

Tab. 11: Comparison of selected parameters for Rework solder profile BGA256TI1.27C

Parameter	Semi-Automatic hot gas rework system	Automatic hot gas rework system	Automatic IR rework system
T_{max} BGA Top [°C]:	238.7	238.3	235.1
T_{max} solder joint centre [°C]:	238.4	233.3	238.0
T_{max} solder joint edge [°C]:	240.5	231	240.7
Time above liquidus [sec]:	58-72	52-72	70-84

All investigated rework systems provide equivalent soldering profile characteristics which meet the requirements for soldering.

4.2 Printed circuit board as the dominant component

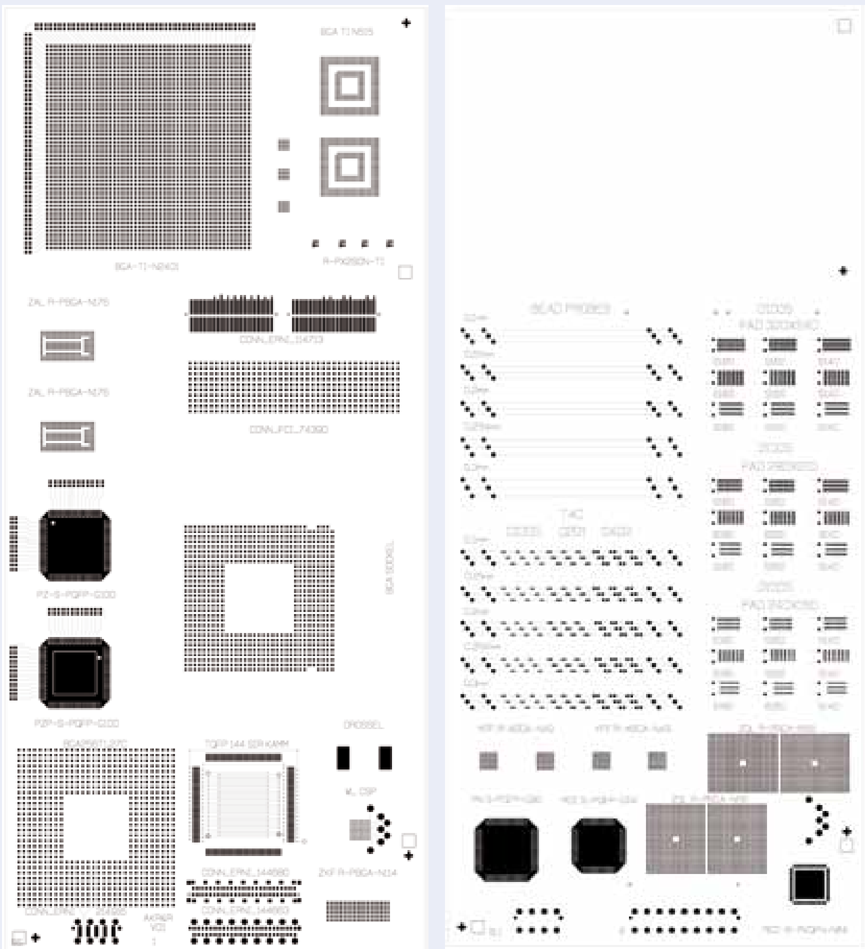
While, as a result of various rework or repair soldering processes, the functionality of the assembly can be decisively influenced or even impaired in its functionality, a clear assignment of effects, isolated for the printed circuit board texture, is often very difficult.

The printed circuit board occupies a special role as a dominant functional unit of a circuit carrier and at the same time as a physical foundation of the electronic assemblies.

For the thoroughly tested testboard, a printed circuit board with the following specifications was used:

Annealing mechanism	phenolic hardened	
Filler	ceramic filled	
Flame retardant	halogen-free	halogen-free
T_G [°C]	150	150
T_G [°C]	348	330
T260 [min]	60	60
T288 [min]	20	>10
Number of layers	6	
End surface	ENIG	
Hole plugging	metal filled/resin filled	

Fig. 47: Top and bottom layer of testboard



Source: Zollner

Fig. 48: Layer structure details

Top Mask		Artwork_21	
Top Layer	copper foil	Artwork_1	18 µm finished copper thickness > 35 µm
	Prepreg		
	Prepreg		
Multi Layer 1	copper foil	Artwork_2	35 µm
	core	CORE	350 µm
Multi Layer 2	copper foil	Artwork_3	35 µm
	Prepreg		
	Prepreg		
Multi Layer 3	copper foil	Artwork_4	35 µm
	core	CORE	350 µm
Multi Layer 4	copper foil	Artwork_5	35 µm
	Prepreg		
	Prepreg		
Bottom Layer	copper foil	Artwork_20	18 µm finished copper thickness > 35 µm
Bottom Mask		Artwork_22	
			end thickness (overall): 1.6 mm

Source: Zollner

The underlying individual local rework process cumulatively represents the stress collective for the entire assembly and thus, in particular, also for the printed circuit board.

With respect to the diagnostic options for the assessment of the damage effects occurring, there are in principle two variants.

One variant is based on a non-destructive, visual inspection (e.g. on the basis of the acceptance requirements from IPC-A-610 [24]), while the second variant is based on a destructive test which is primarily intended to reveal the internal damage to the printed circuit board.

In the context of a visual examination under specific consideration of the post-processed areas, the following damage/effects can typically be expected:

- Lifted
- Pads ripped of
- Discolouration of solder resist
- Discolouration of base material
- Burning, charring
- Changes to the circuit board surface
- Measling
- Delamination
- Bow/Twist

In the context of a destructive examination under specific consideration of the post-processed areas, the following damage/effects can typically be expected:

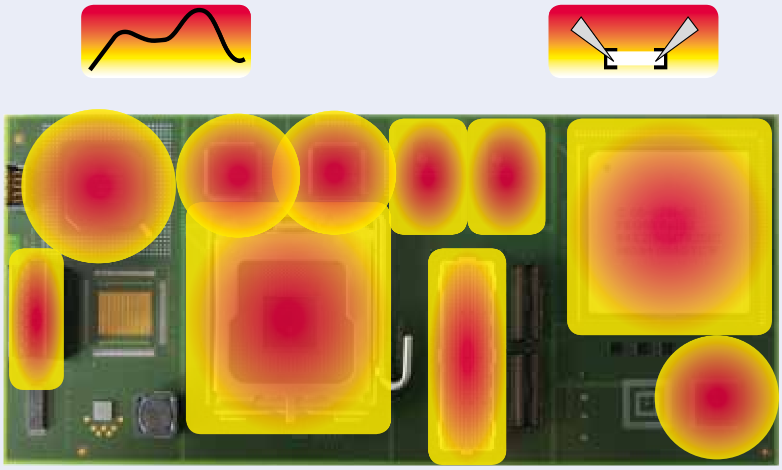
- Barrel plating crack as well as attachment defects
- Deformation of plated through holes
- Attachment defects in microvias
- Delaminations

Summarizing

Particularly at locations of the assembly, where took place a local (multiple) overlap of rework steps, it is necessary to subject the resulting thermal cutting quantities to a more detailed view since the potential of a PCB damage is the highest.

Depending on the frequency, intensity, concept and process management of the soldering processes used for the rework, there are more or less typical abnormalities or fault images on the printed circuit board which are shown in chapter 4, 5 in a configuration-specific manner.

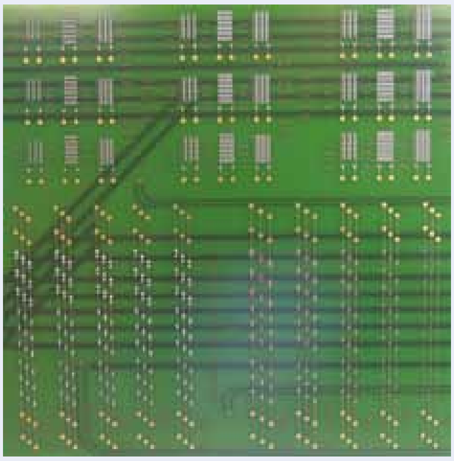
Fig. 49: Thermal stress on the testboard



Source: Airbus DS Electronics and Border Security

4.3 Component specifications, ordered according to their complexity

Fig. 50: Array of passive components



Source: Zollner

4.3.1 Two-pole, passive Components

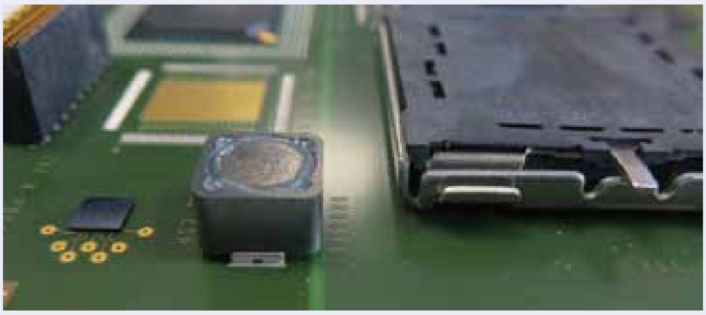
In order to simulate the requirements of industrial components, a wide range of passive components has been implemented in the layout.

The applied components range from 0402 (1.0 mm x 0.5 mm), via the 0201 design (0.6 mm x 0.3 mm), to 01005 with an edge length of 0.4 mm x 0.2 mm.

The challenge for the operator is to find a structured, prudent way of working with component rework in the array arrangement.

In particular, the replacement of components in this compact arrangement places the maximum demands on the tool as well as on the skill required.

Fig. 51: Ferrite inductor in a thermally heterogeneous environment between CSP and BGA socket



Source: Zollner

4.3.2 Two-pole, passive ferrite inductor with high heat demand

The high heat demand of the ferrite core inductor must be taken into account in order to achieve successful rework. The pad area, and thus the connection to the printed circuit board, is minimised in relation to the component size and places high demands on the operator in order to avoid typical rework faults such as padlifting or pad loss.

4.3.3 Components with flat Gullwing connectors

Characteristics of the classic Quad-Flat-Package-Forms (QFP):

- Pitch 0.5 mm
- Reduced mechanical strength of electrically non-connected pads alternating with functional pads
- Thermal bridges connected to the inner layers in the corner areas
- Connection to central thermal pad connected via several layers

The classic design QFP is in principle easy to handle, but modern layouts and massive thermal pads complicate a successful rework.

4.3.4 SMT connectors in mixed SMT-THT technology

The combination of SMT signal contacts and shielding using THT "pin-in-paste" technology confronts both production and reworking with new challenges.

4.3.5 Classic ball grid array designs

In order to qualify the industrial standard practiced rework process at a BGA, the Rework and Repair Working Group has developed strategies that make it possible to examine critical features of the rework:

- Control pads, implemented as circumferential, soldered pads:
  →Which area is melted during the rework as an "undesired" effect?
- Various differences in the anchoring/attachment of the pads:
  →Check the thermal limits of the rework
  →How do maximum stresses affect minimal anchorages?
- Daisy chain structures across all balls of the BGA
  →Simple recognition of the success in the nth rework case

Fig. 52: QFP components

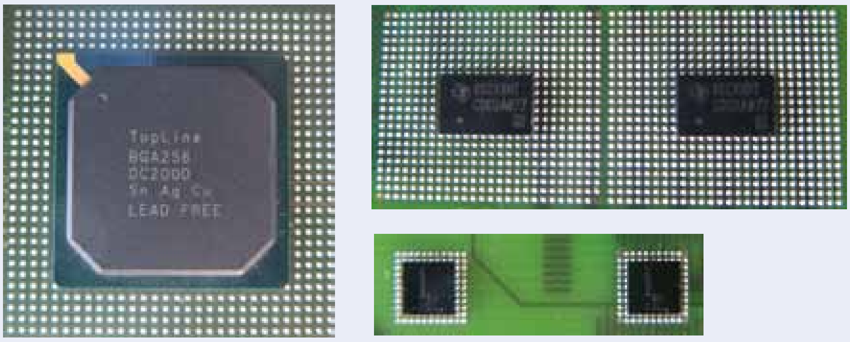
Source: Zollner

Fig. 53: Connectors with SMT and THT connections

Source: Zollner

To show the variety of requirements a modern rework process has to cover, there are components with fine pitch as well as an extremely high number of connections and different edge lengths on the testboard.

Fig. 54: Various BGA components with circumferential pads

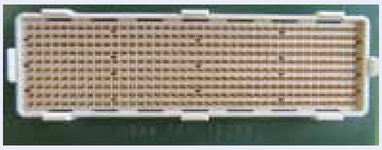


Source: Zollner

Fig. 55: Size comparison of BGAs

Source: Zollner

Fig. 56: Array connector without mounting aid (left) and with (right)

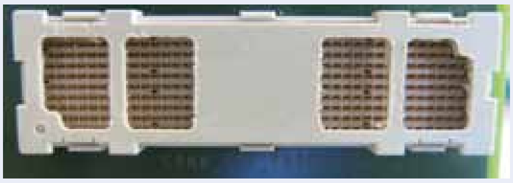
Source: Zollner

4.3.6 Array connectors (BGA pin-out)

The connector is thermally sensitive and has precision gold contacts with leadfree balls.

Especially for the rework process, the placement aid has been modified to improve the effect of convection.

Fig. 57: Array connector with modified mounting aid



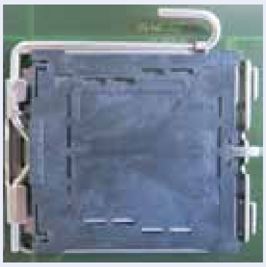
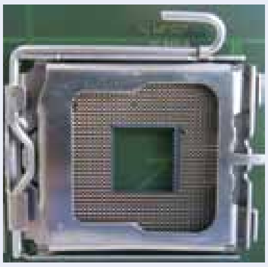
Source: Zollner

4.3.7 BGA socket

The BGA socket consists of a material mix with high metal content, temperature-sensitive (245 °C) plastic and gold-plated pins in the contact area to the processor. The placement aid hinders heat flow during rework process.

Without the placement aid, the base is thermally easier to profile, but is very vulnerable to contamination of the gold-plated pins with solder and flux during rework.

Fig. 58: BGA socket with mounting aid (left) and without (right)

Source: Zollner

4.4 Possible effects on assembly level

On assembly level one must also consider the increased thermal stress put on the area immediately surrounding the component in need of rework. In extreme cases, this can require that particularly temperature-sensitive components be removed prior to the actual rework and then be re-soldered.

Effects that can occur on the component in need of rework, as well as on neighbouring components:

- Burns on the component body (e.g. soldering tips, hot gas flows, infra-red radiation),
- physical damage to the component through incorrect handling - on the underside on the PCB as well (e.g. clamping, centre support) and
- (moisture-induced) damage to the component
  (e.g. tearing of the bond wire, delamination due to popcorn effect).

Effects on the circuit board:

- Damage to the conductor structure (e.g. pad avulsion, detachment of traces, lands damage),
- damage to the base material, for example blistering, measling, delamination and
- damage to coatings such as the solder resist and protective coatings like conformal coating (e.g. scratches, tears, spalling, burns, dissolving or detaching).

Side effects on the assembly level that can lead to a non acceptance-ready status (fault) pursuant to IPC-A-610 [24]:

- solder splatters, which even in remote regions can lead to reduced isolation distances, and at worst, short circuits;
- presence of inadmissible flux residues;
- additional reflow and danger of disruped nearby solder joints (as result of movement during solidification);
- "floating" components;
- physical contact causing components to shift;
- components being "blown off" under hot gas stream;
- voiding;
- cross-linking (for instance with BTC components);
- burns, carbonisation of (plastic) casings and
- physical damage or "freezing" of mechanical stresses due to component geometry changes such as twist or bow.

4.5 Multiple solder stress - Visual analysis/cross-sectional analysis

The following selection of components demonstrates how multiple soldering events affect the condition of both the circuit board and components.

Visual inspection and cross-sectional analysis yield a holistic understanding of how multiple rework can damage assemblies. Examples of selected components are shown below with assessments. The images show the initial condition (following dual inline reflow) and the visual appearance after simulating an additional two-pass or five-pass rework. Note that the component has only undergone thermal stress; it has not been replaced or moved (cumulatively up to twelve reflow soldering processes). This multiple heat stress test deliberately exceeds the reflow cycles under warranty by the component manufacturer and board manufacturer. The aim of the significant thermal overload (with respect to the number of cycles) is to simulate the multiple heat stresses of soldering and de-soldering more than one element in a crowded region of a circuit board.

The insights gained by multiple exposures to soldering heat are not aimed however at qualitatively acceptable solder joints, but rather at any deleterious side effects which may arise in the components or circuit board.

Effects such as disrupted wetting, de-wetting or major changes to the form of the solder joints are still to be expected.

4.5.1 Visual inspection of assembly groups after multiple solder stress

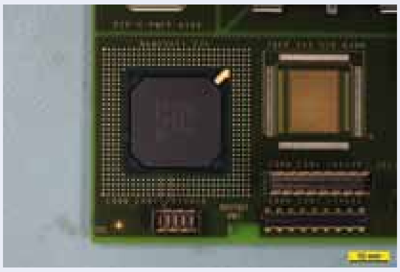
Table 12 provides information on the components described at the outset, which were visually inspected before and after additional thermal stress conditioning.

Tab. 12: Overview of components inspected visually after thermal stress

Components	Thermal stress	Assessment
BGA256TI1.27C	2 x inline reflow	No significant abnormalities
BGA256TI1.27C	2 x inline reflow + 5 x rework simulation	No significant abnormalities
BGA socket	2 x inline reflow	No significant abnormalities
BGA socket	2 x inline reflow + 5 x rework simulation	No significant abnormalities
CONN_FCI_74390	2 x inline reflow	No significant abnormalities
CONN_FCI_74390	2 x inline reflow + 5 x rework simulation	No significant abnormalities
CONN_ ERNI_114713	2 x inline reflow	No significant abnormalities
CONN_ ERNI_114713	2 x inline reflow + 5 x rework simulation	No significant abnormalities
ZAL R-PBGA-N176	2 x inline reflow	No significant abnormalities
ZAL R-PBGA-N176	2 x inline reflow + 5 x rework simulation	No significant abnormalities

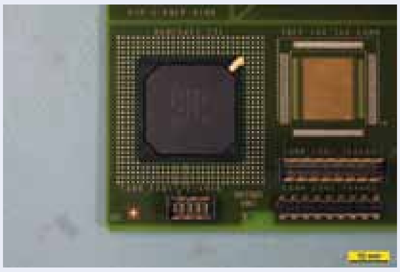
BGA256TI1.27C

Fig. 59:
after 2 x inline reflow



Source: Fraunhofer ISIT

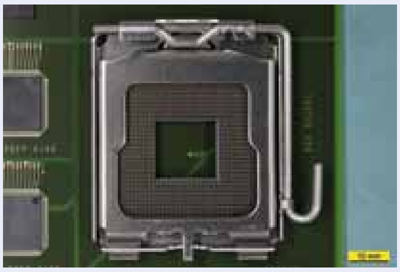
Fig. 60: after 2 x inline reflow
+ 5 x rework simulation



Source: Fraunhofer ISIT

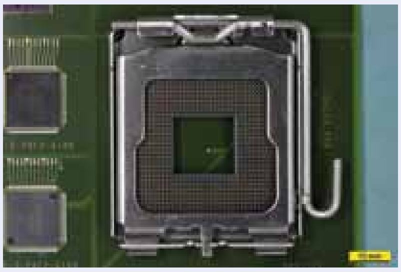
BGA socket

Fig. 61:
after 2 x inline reflow



Source: Fraunhofer ISIT

Fig. 62: after 2 x inline reflow
+ 5 x rework simulation



Source: Fraunhofer ISIT

CONN_FCI_74390

Fig. 63:
after 2 x inline reflow

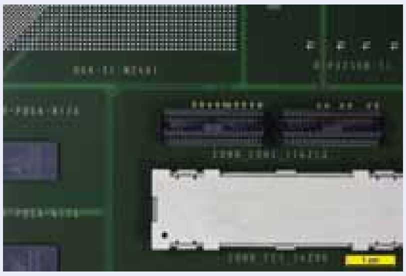
Source: Fraunhofer ISIT

Fig. 64: after 2 x inline reflow
+ 5 x rework simulation

Source: Fraunhofer ISIT

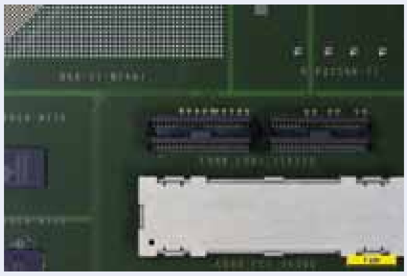
CONN_ERNI_114713

Fig. 65:
after 2 x inline reflow



Source: Fraunhofer ISIT

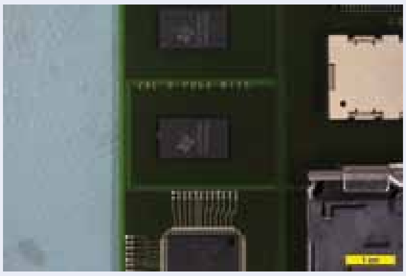
Fig. 66: after 2 x inline reflow + 5 x rework simulation



Source: Fraunhofer ISIT

ZAL R-PBGA-N176 – Area

Fig. 67:
after 2 x inline reflow

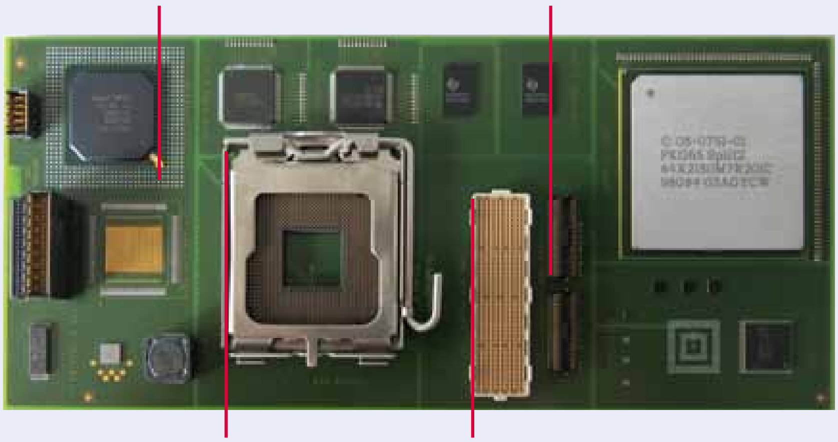


Source: Fraunhofer ISIT

Fig. 68: after 2 x inline reflow + 5 x rework simulation

Source: Fraunhofer ISIT

Fig. 69: Cross-sections marked on test assembly



Source: Fraunhofer ISIT

4.5.2 Cross-sectional analysis of printed circuit assemblies after multiple solder stresses

In addition to visual inspection, cross-sectional analysis yields more insight into the nature of the zones impacted by multiple solder stresses.

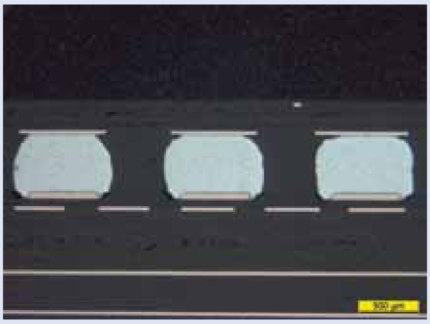
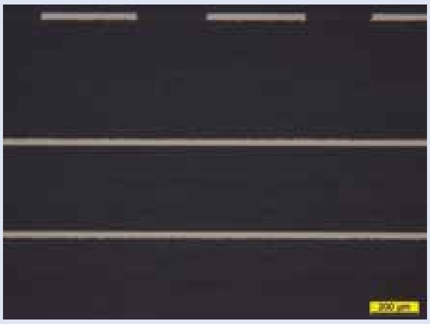
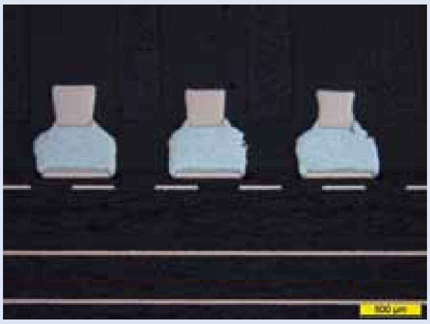
The following components and corresponding areas of the circuit board were investigated using cross-sectional analysis - see Figure 69 and Table 13.

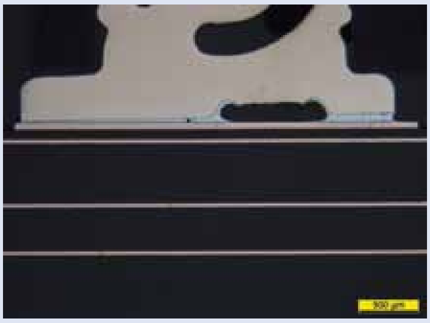
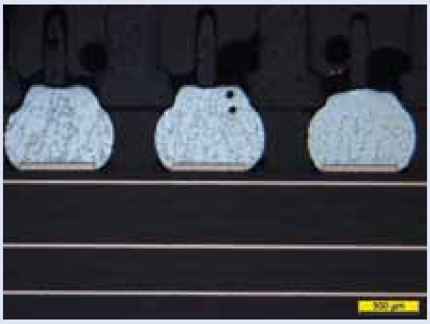
Tab. 13: Overview of the components and corresponding circuit board areas inspected with cross-sectional analysis following thermal stress

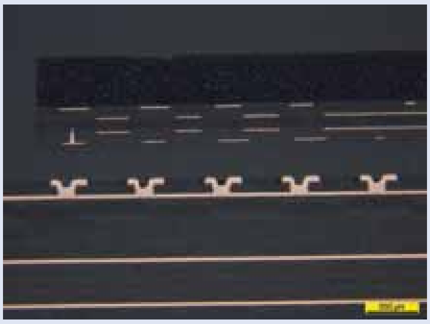
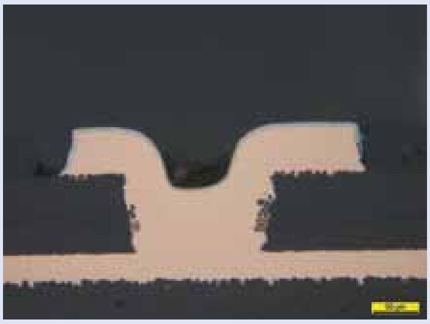
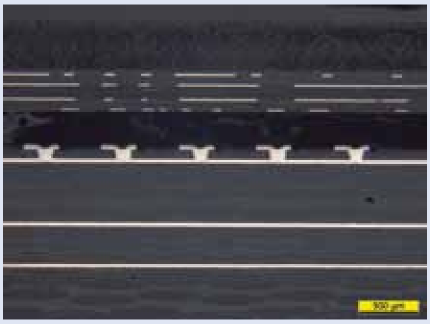
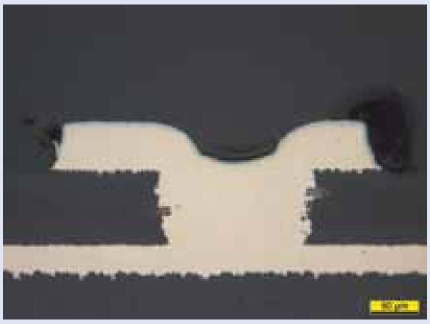
Components	Thermal stress	Assessment[1]
BGA256TI1.27C	2 x inline reflow + 2 x rework simulation	No significant abnormalities with respect to internal PCB or component damage such as delamination, damage to the laminate or sleeve, pad cratering, pad lifts etc. - assessing solder junctions was not the priority during this step of investigation.
BGA256TI1.27C	2 x inline reflow + 5 x rework simulation	
Circuit board under BGA256TI1.27C	2 x inline reflow + 5 x rework simulation	
BGA socket	2 x inline reflow + 5 x rework simulation	
Circuit board under BGA socket	2 x inline reflow + 5 x rework simulation	
CONN_FCI_74390	2 x inline reflow + 2 x rework simulation	
CONN_ ERNI_114713	2 x inline reflow + 5 x rework simulation	
ZAL R-PBGA-N176	2 x inline reflow + 2 x rework simulation	
Microvia under ZAL R-PBGA-N176	2 x inline reflow + 2 x rework simulation	
ZAL R-PBGA-N176	2 x inline reflow + 5 x rework simulation	
Microvia under ZAL R-PBGA-N176	2 x inline reflow + 5 x rework simulation	
Circuit board under ZAL R-PBGA-N176	2 x inline reflow + 5 x rework simulation	
Through-hole plating under Z-S-PQFP-G100	2 x inline reflow + 2 x rework simulation	

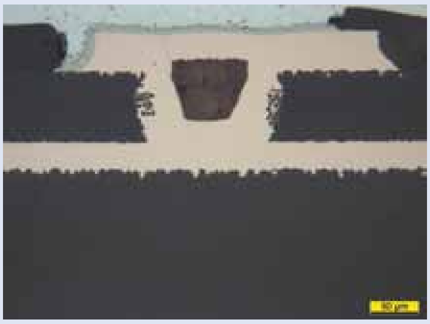
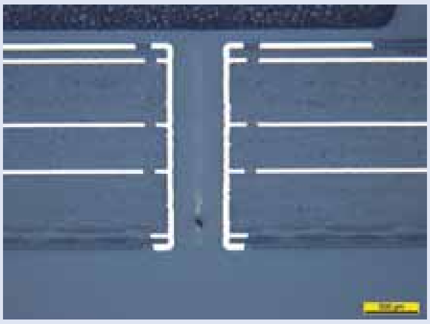
[1] In the process of extreme soldering heat stresses repeated on the same component, wetting faults and non-conforming solder joints may arise, which are not accounted for in the assessment.

Tab. 14: Cross-sectional analysis of components and corresponding circuit board areas after two-pass inline reflow and two- or five-pass rework simulation

Components	Remarks	Number of rework simulations
BGA256TI1.27C	Left corner shows control pad without BGA ball	 2 x
BGA256TI1.27C	Centre of component, dewetting beginning component side on the right ball	 5 x
Circuit board under BGA256TI1.27C	No abnormalities	 5 x
BGA socket	Ageing effects in micro-structure	 5 x
Circuit board under BGA socket	No abnormalities	 5 x

CONN_ ERNI_114713	No abnormalities		5 x
CONN_FCI_74390	Connector port not visible in cross-section		2 x
	Close-up of solder terminal		2 x
ZAL R-PBGA-N176	No abnormalities		2 x
Microvia under ZAL R-PBGA-N176	Resin-filled no abnormalities		2 x

Components	Remarks	Number of rework simulations
ZAL R-PBGA-N176	No abnormalities	 2 x
Microvia under ZAL R-PBGA-N176	No abnormalities following reflow cycles, except for noticeable fill level in microvia	 2 x
ZAL R-PBGA-N176	No abnormalities	 5 x
Microvia under ZAL R-PBGA-N176	No abnormalities following reflow cycles, except for noticeable fill level in microvia	 5 x
Circuit board under ZAL R-PBGA-N176	No abnormalities	 5 x

Microvia (resin-filled) under ZAL R-PBGA-N176	No abnormalities following reflow cycles, except for incomplete Ni/Au covering of the pad		5 x
Through-hole plating under Z-S-PQFP-G100	No abnormalities		2 x
Through-hole plating under Z-S-PQFP-G100	Close-up of through-hole plating, no abnormalities		2 x
Close-up of through-hole plating under Z-S-PQFP-G100	Close-up of upper through-hole plating, no abnormalities		2 x
Through-hole plating under Z-S-PQFP-G100	Close-up of lower through-hole plating, no abnormalities		2 x

Source: Fraunhofer ISIT

4.5.3 Assessment of the influence of multiple solder stresses

The components investigated for use on the working group's test vehicle serve as the basis for the assessment. Emphasis is placed on types that are most heavily exposed to repeated soldering heat stresses.

The aim of the extreme multiple solder heat stress (up to twelve reflow cycles) was not to develop qualitatively acceptable solder joints, but rather to systematically record the effects of heat stress on assemblies and components. Numerous solder processes on the same component can impact the shape of the solder joint, or in isolated cases cause wetting faults such as de-wetting. However, this is not important when describing how the circuit board or component bodies behave under multiple solder heat stresses. These effects will not receive further discussion.

There are limitations to generalising across other products what we have learned thus far. It is particularly difficult to extrapolate test effects when the circuit board specifications (respectively the pcb material used) differ from those of the material used here; in such cases further qualification testing is required.

Assessment - non-destructive - visual

Visually speaking, there are no marked changes to the assembly as a whole (circuit board or components). There is no sign of measling, no significant discolouration of the circuit board or components, no degradation or delamination. There are also no visible traces of the conductors or lands (land pattern) having lifted up.

Assessment - destructive - cross-sectional

In the cross-sections investigated, there were no significant changes in the circuit board material that would indicate excessive thermal stress on the circuit board material. We discovered no ruptures in the laminate, no ruptures in the Cu- or resin-filled microvias and through-hole plating, no resin retractions or any other abnormalities. No further materials analyses were carried out.

After realisation of all rework procedures implemented using optimised soldering profiles, no significant differences in quality (compared to the initial condition) were discovered following the dual reflow solder process.

Tab. 15: Circuit board fault(s) after reflow cycles

Effect/Defect	2 x reflow	2 x reflow + 2 x reworking simulation	2 x reflow + 5 x reworking simulation
Pad lift	no	no	no
Torn pad	no	no	no
Solder resist discolouration	no	no	no
Discolouration of base material	no	no	no
Burning, carbonisation	no	no	no
Measling	no	no	no
Delamination	no	no	no
Torsion; Bowing	no	no	no
Tear in sleeve	no	no	no
Deformation of sleeve	no	no	no
Tear in microvia	no	no	no
Delamination	no	no	no
Pad cratering	no	no	no

Phase growth exemplified by BGA256T1.27C after solder heat stress in simulated reworking process

Fig. 70: Intermetallic Phase (IMP) after 2 x inline reflow + 2 x reworking simulation (x6 with solder heat stresses)

Source: Fraunhofer ISIT

Fig. 71: Intermetallic Phase (IMP) after 2 x inline reflow + 5 x reworking simulation (x12 with solder heat stresses)

Source: Fraunhofer ISIT

Multiple solder heat stress: Assessment - summary

The extreme multiple solder heat stresses led in part to an increased phase formation in the solder points. With regard to the components investigated, this was considered non-critical, as the solder stress scenarios induced for these tests aren't as acute in practice anyway.

4.6 Reballing

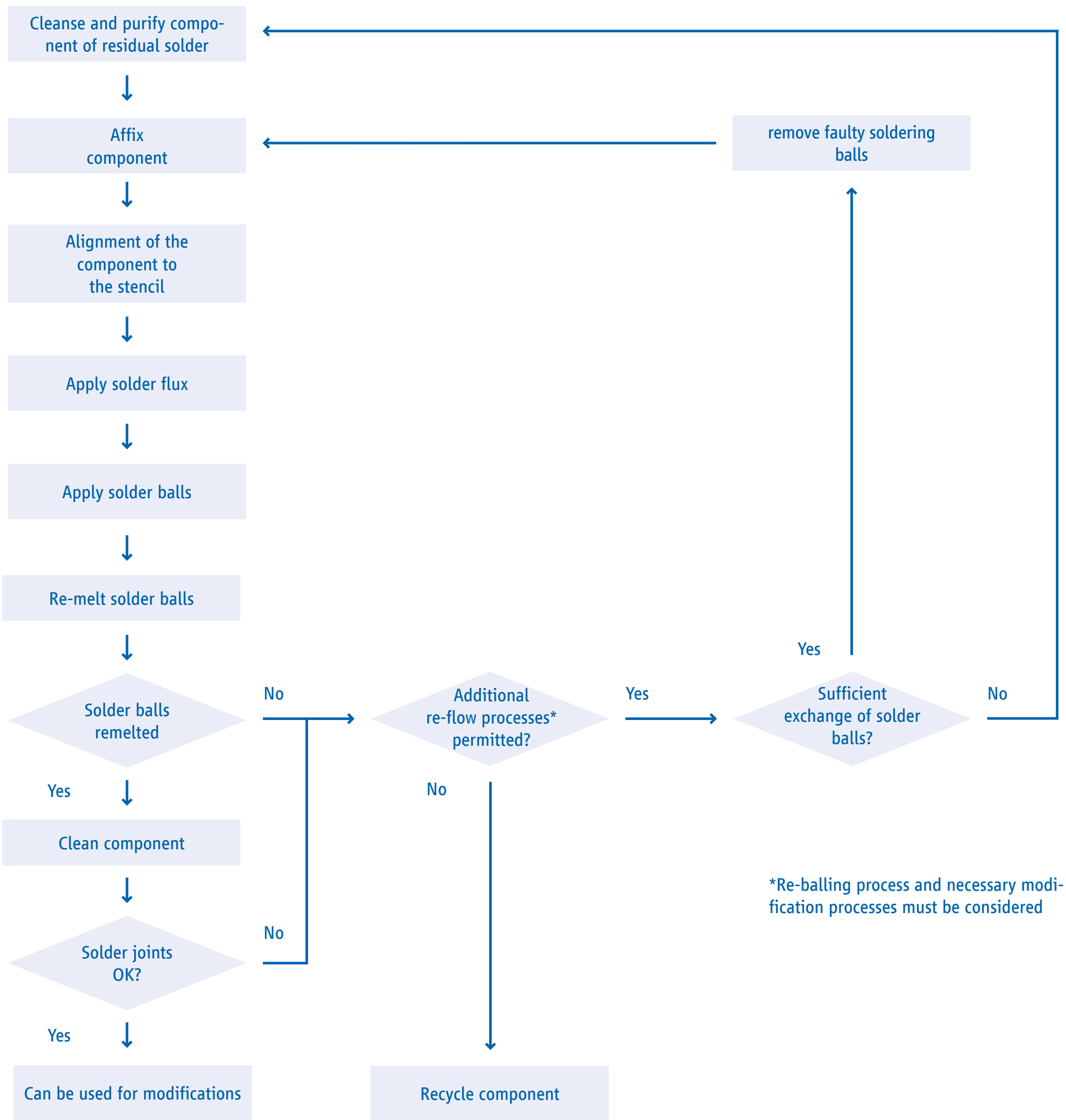
4.6.1 Motivation

Using so-called reballing it is possible to replace existing solder balls on SMDs, enabling de-soldered components to be reprocessed and recycled. This can be done with either the same or different alloy, as desired.

There are numerous reasons for reballing:

- Switching solder balls from lead-free to lead-based or vice versa,
- limited component availability,
- prohibitive component cost,
- prototyping,
- development pattern,
- faulty mountings,
- filling in missing balls,
- Increasing reliability through special component types (LGA -> BGA).

4.6.2 Reballing process - rough sequence



4.6.3 Devices - Systems - Schemes

Following are descriptions of devices and concepts which are employed variously according to throughput, task and batch size.

Tab. 16: Typical parameters of reballing schemes

	Reballing set	Reballing system	Laser balling
Ball positioning	stencil	stencil	X-Y axis system
Flexibility Balling process	entire surface	entire surface	selective
Typical component count per cycle	single piece	single piece or multi-use	single piece or multi-use
Footprint	300 × 150 mm²	300 × 400 mm²	>2 m²
Position correction (Balls to component)	fixed	adjustable	automatic
Typical processing surface area [mm²]	80 x 80	100 x 150	150 x 150/ 300 x 300
Applicability for high batch sizes	low	medium	low to medium
System cost	low	medium	very high
Cost to operate	low	low	high
Component finish level after processing	solder balls must still be re-melted in reflow	solder balls must still be re-melted in reflow	solder balls already re-melted by laser soldering
Microvia - tear	no	no	no
Delamination	no	no	no
Pad cratering	no	no	no

4.6.3.1 Reballing set

Fig. 72: Mini-oven and diagram

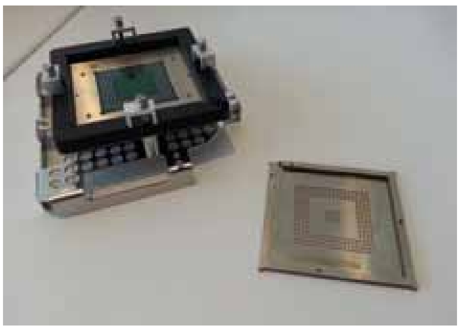
Source: Martin

1. Remove solder
manually/automatically

2. Clean component

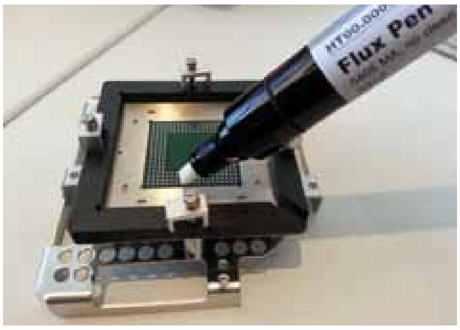
3. Visual inspection
Visual inspections should be done by microscope according to component and pad size. In this way, detached pads and defective structures can be detected.

4. Affix component
Component positioning: done with positioning collar. Observe pin-1 orientation.



5. Apply solder aid

Spread flux with a flux pen or other application device. Make sure to apply flux properly based on viscosity and component type.

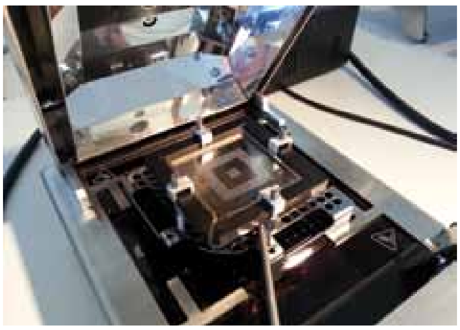


6. Apply the balls

Note: Do not forget to clean the stencil.
Breakdown of the process: Spread and apportion the solder balls manually. Spread and fill the reballing mask by means of hook or scraper. Remove excess solder balls.
Inspection: visual inspection by microscope or camera.

7. Re-melting the solder deposits or solder balls

Programme sequence:
Close the reflow chamber.
Selecting a solder profile: either from profile library or by using a custom profile, as desired.
Rules for measuring, data capture and control:
Type K thermocouple / NiCr-Ni
Heat supply from below by means of IR emitter.

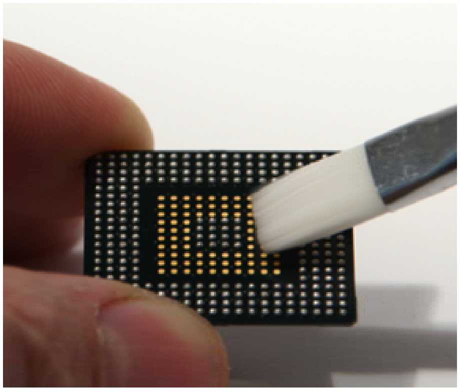


8. Cooling

Programme sequence: Shutting off heat supply is typically a component of the reflow profile.
Inspection: Display residual heat in the reflow chamber; chamber opens automatically once predefined temperature is reached.

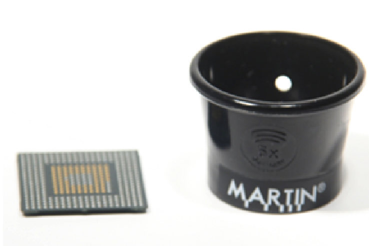
9. Clean component

Process sequence: Remove reballing mask. Extract component from frame. Clean according to appropriate procedure using a suitable cleaning agent.



10. Visual inspection

Visual inspection: by microscope or camera.
Test functioning according to guidelines.



Source: Martin

4.6.3.2 Reballing system

Fig. 73: Reballing system

Source: Wagenbrett

The reballing system uses gravity feeding to place solder balls on circuit boards and BGAs. This system was designed for rework prototyping and small serial production.

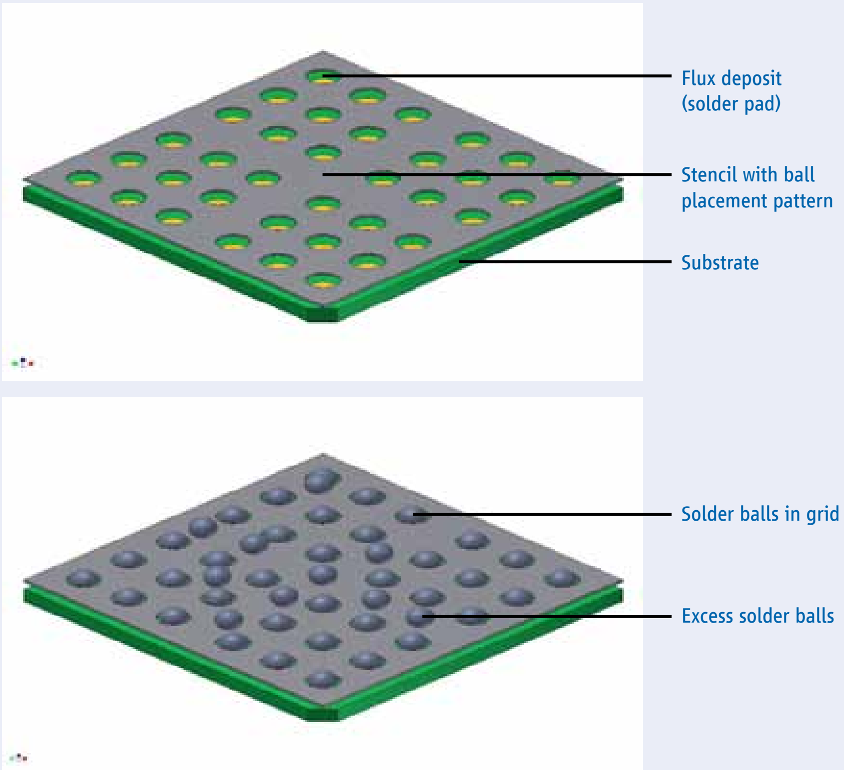
This mechanically operating system offers accurate and adjustable positioning and fixing capacities; orientation of the stencil openings towards the substrate; and defined location positioning. It features a high degree of precision and reproducibility.

In this ball placement procedure, solder balls are spread evenly over a stencil. For this purpose, the stencil with its balling grid is placed over the product, which already has been printed with flux by means of another stencil. The stencil has a precisely defined balling pattern reflecting the pads on either the circuit board or the component. The figure below schematically depicts the arrangement of substrate, flux deposits and stencil with balling pattern.

The component is fixed in place using an easily exchangeable vacuum plate. In this process the component is loaded [onto the vacuum plate], roughly oriented, and then fixed in place by vacuum. The stencils needed for positioning the solder balls are clamped in a clamping frame and are easy to replace. The arrangement also allows one to remove the entire clamping frame, allowing for easy swaps between the flux application stencil and the solder ball placement stencil. This construction enables a highly flexible manufacturing process and makes it possible to rework a wide variety of component models.

The pads of Loose components can be aligned to stencil openings (for the solder balls) using an X-Y positioning unit. A precise camera system, outputted to an LCD display, assists the user in aligning the component to the stencil, ensuring fast and simple operation. Differing component depths

Fig. 74: Gravity feed principle



Source: Wagenbrett

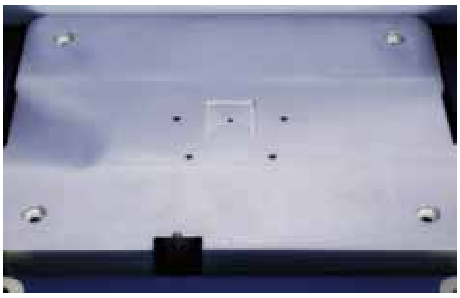
can be adjusted for by adjusting the height of the uptake vacuum plate. An integrated dial gauge allows the operator to define the exact heigt position / gap between product and stencil.

Its sophisticated design and simple handling make the PB46 the ideal tool to efficiently and cost-effectively apply flux and solder balls to BGAs and circuit boards up to 4" x 6" (100mm x 150mm) in size. The PB46 shines most in small batch production and repair of circuit boards and BGAs.

The entire process can be broken down into a few simple steps, which are detailed below:

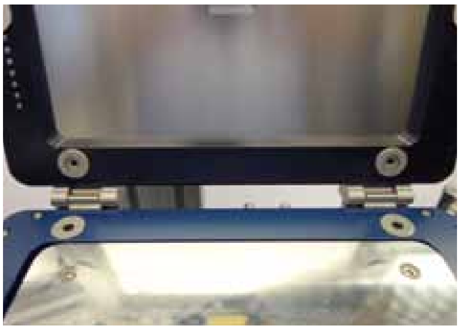
1. Set up the vacuum plate

Unique vacuum plates allow the component to be loaded and fixed in place, and can easily be swapped.
Here, a component up to 4" x 6" (100mm x 150mm) in size can be loaded.



2. Set up the stencil cover

By opening the hinge, the stencil together with its cover can easily be lifted out and exchanged.
By loosening the knurled screws the clamping frame can be lifted up and the stencil rapidly swapped.

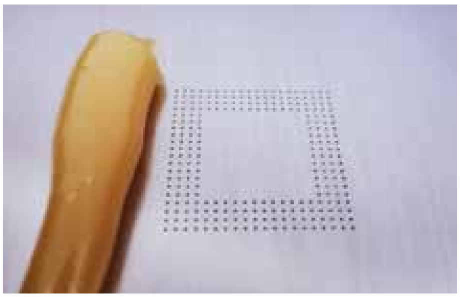


3. Fix the component onto the vacuum plate

The component is fixed in the defined position with the help of vacuum suction,
and its position in the x-y plane can be adjusted.

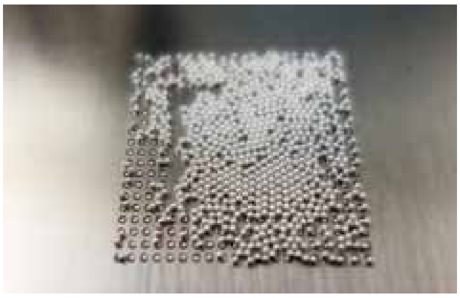
4. Apply flux

Flux is applied and reaches the component through the openings in the stencil.
Stencil thickness determines the amount of flux deposits.



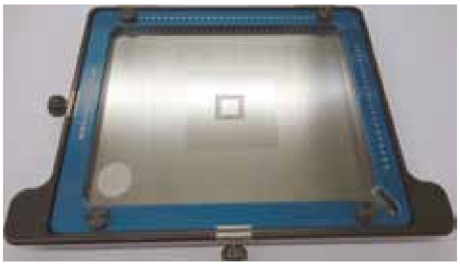
5. Deposit solder balls

After the stencil has been replaced, spread the solder balls over the stencil. As the work table of the device tilts, the solder balls roll over the stencil, fall through the openings and stick to the previously-applied flux.



6. Cleaning process

After the flux is applied the stencil is cleaned.
If a visual inspection shows that the balling process has contaminated the stencil, it must be cleaned again.



7. Re-melt solder

Solder balls are then re-melted in an external oven using a predefined solder profile.

Source: Wagenbrett

4.6.3.3 Laser balling

Another method of restoring a once-working connection configuration involves laser-assisted re-melting of the solder balls.

Implementations of laser balling fall into two principal categories with regard to ball placement.

- One variant is based on the principle demonstrated already in section 4.6.2, and in which laser balling replaces only the soldering part of the process; otherwise the process sequence remains the same.
- Another variant depends on addressing each individual BGA landing surface in turn with a sequential laser ball-soldering process, whereby the soldering process and ball placement are executed simultaneously.

The key technological difference between this energy-dense, radiation-based solder process and reflow-based heat application rests in the process design and its thermal effect at the BGA level.

The thermal conditions of laser soldering balls have little in common with those of the classical reflow solder process, yet the same technical requirements of the soldering process still apply, for instance the proper development of an intermetallic phase.

There are significant differences in comparison to the conventional reflow solder process (see section 2.2).

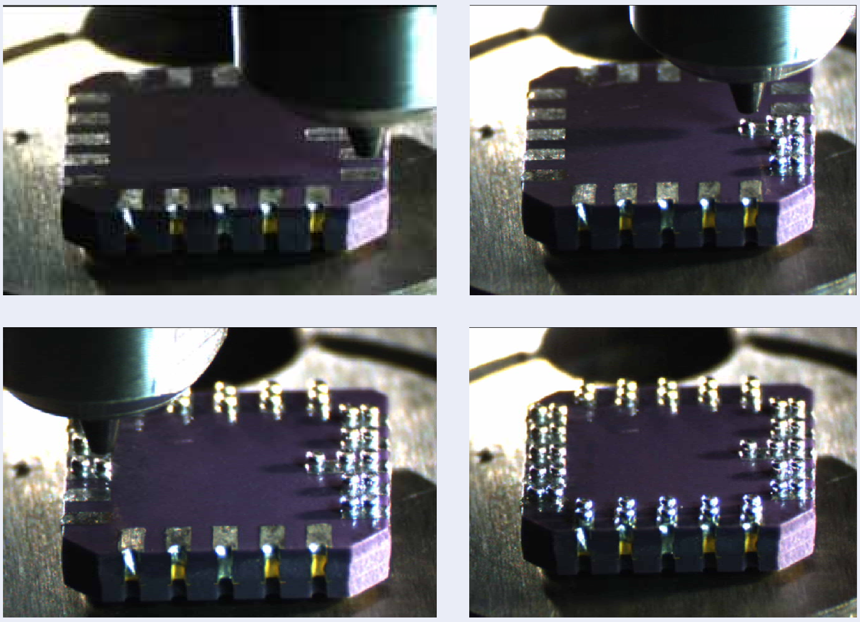
The principal differences between conventional reflow-based balling and its laser-assisted variant are outlined in Table 17:

Tab. 17: Comparison of reflow- and laser-based soldering

Solder procedure "Balling"	Conventional reflow	Laser-assisted
Basis for developing solder profile	Standard solder profile (e.g. based on DIN EN 61760-1 [2] or IPC-7095 [6]), optimised for the respective component housing where applicable	Custom profile development in order to match the unique heat transfer characteristics of laser soldering
Parameters and duration of heat input	Gradients, dwell times, peak temperature. Typically in the range of 3-5 minutes.	Component pre-heating where appropriate. Continuous pre-heating, laser impulse (timed), laser energy lasting albeit only fractions of a second.
Time above liquidus	Typically 30-90 seconds	Typically on the order of seconds
Principle of heat transmission	Heat supply by way of full convection, radiation or condensation	Direct radiative heat injection to the molten ball, with transmission by direct conductive contact with the component's pad
Typical soldering area	Solder heat paradigm applies to the entire component	Individual solder area selection
Temperature, upper surface of component	Approximately identical to temperature on component underside	In the range of the selected pre-heating
Process time per component	Identical to selected reflow profile 3-5 minutes	Depends on mode selected (full-surface balling or single ball). For example, approx. 2 minutes for PBGA 256
Process time per connection	Identical to selected reflow profile 3-5 minutes	Values are typically 0.5 seconds per ball + possible pre-heating
Primary risks	"Using up" a reflow life - manufacturers typically provide for 3 reflow cycles (J-STD-020 [3])	The component itself undergoes locally very limited solder heat input (lower than with gentle, point-by-point pad restoration by hand)
Secondary risks	As in conventional mounting processes, MSL must also be observed.	Typical laser profiles do not require that MSL be observed.

Advantages	Established sub-procedures constitute basis for implementation. No need to rethink materials selection, durability or process characteristics. Readily available. Cost-effective. Solder profiles often already exist. No need for a separate workstation.	After optimised parametrisation: High reproducibility and simultaneous minimisation of solder stress is attainable. Relatively short process times for BGAs with few balls. Time- and temperature-optimised treatment for individual balls possible.
Disadvantages	Negligible difference in process times between small and large component types (i.e. between few and many balls). Requires complete additional reflow cycle.	Costly. Few documents, standards and guidelines currently available for reference (GEIA-STD-0015) [53]. Requires separate workstation Expertise in conventional assembly process usually not especially pronounced.

Fig. 75: Laser placement head over component pad positions to be balled



Source: Airbus DS Electronics and Border Security

4.6.4 Balling stencils

Balling stencils are used to place solder spheres on a component. The first step is to print flux at the component. The purpose of the flux is twofold:

1. To provide a sufficient amount of activators for the soldering process.
2. To provide enough sticking power to keep the solder ball in position until the soldering process is complete.

This is followed by positioning the solder balls with a stencil. The stencil openings are designed so that only one ball fits inside, and other balls on the stencil's surface won't catch when they slide off.

4.6.5 Reballing - Recommendations for the process sequence

Tab. 18: Reducing risks during the reballing process

Step in process	Possible risks	Recommendation
Removing residual solder	Overheating destroys component Damage to or separation of pads due to overheating and/or physical impact	Observe the component's temperature limits, use contactless reflow-based solder residue removal, use flux.
Cleaning the component (where required)	No or insufficient cleaning, with inappropriate processes or substances	Use appropriate cleaning process.
Inserting the component	Use of the wrong positioning frame	Accurate documentation and work directives
Applying solder	Application of excessive solder can allow balls to change position during remelting. Insufficient solder application can lead to wetting errors.	Targeted application using suitable procedure
Setting stencil + balling	Using the wrong balls (size, alloy) or stencil	Accurate documentation and work directives
Re-melting	Use of solder process not suited to heating requirements Use of profile not adjusted for flow requirements	Use a suitable reflow profile (adapted to the specifications from solder material, flux and component manufacturer recommendations). Reduce flow velocity, increase flux adhesiveness, use a stencil during remelting.

Releasing the component	After the re-melting step, flux can cause the stencil to stick to the component. Use of tools (scalpels, etc.) or excessive force can result in damage when removing the component.	By using the right flux removal, it is possible to remove the component with a minimum of force.
	In addition, the solder may become stuck to the stencil during soldering. When lifting the component out, there is a danger of tearing off the pad(s).	Regular cleaning (suitable cleaning fluid, ultrasonic bath in cases of heavy soiling) and replacing the stencil at regular intervals will prevent sticking.
	With fine-pitch stencils or stencils with extensive grid arrays, heat exposure can lead to tensions between the balls and the stencil.	By using appropriate stencil technologies approved for use in soldering processes, waste due to heat-induced stresses can be avoided.

4.7 Stencil and process technology

4.7.1 Rework stencils for printing on circuit boards

4.7.1.1 Application

Rework stencils allow for a circuit board printing predominantly limited to one component; or the printing of one component with solder paste before it is put on the assembly. In this way the volume of solder necessary for the solder joint is provided, so that the component can be selectively soldered onto a complete assembly.

Rework stencils fall into three groups:

1. Stencils for selectively printing single and pattern on an already populated circuit board.
2. Stencils for the printing directly on components.
3. Stencils or apparatus for dipping components.

Stencils are used to provide solder paste to a vacated mounting position on an already finished assembly following removal of a component, to prepare for the rework soldering process.

Here the stencil has multiple functions:

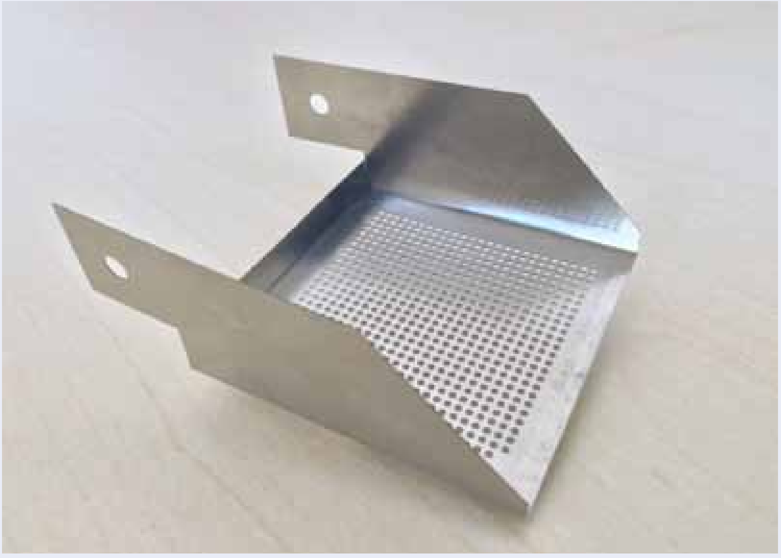
1. Preparing the right amount of solder paste together with a reproducible printable combination of opening sizes and stencil thicknesses.
2. Protecting the assembly against solder paste contamination during manual printing, for example by upwards-turned stencil edges.
3. Maintaining the position at the land pattern. By means of brackets for rework systems or by using circuit board guides, e.g. positioning holes.

4.7.1.2 Rework stencil design

The stencil's key feature are the openings for the component land pattern. If the causes of failure are known and lie in the initial layout, adjustments should be made in order to avoid future failures.

The distance between the paste shield and the opening is selected depending on the available space around the mounting place being worked on. The larger the gap can be made here, the easier manual printing will be later on.

Fig. 76: Stencil with bracket for use in a rework system



Source: Zevac

Such stencils are usually taken up by rework systems, to orient and position them on the circuit board. Depending on the rework system the stencil has to handle various mounting brackets.

Corresponding design documents on the form and execution of the brackets should be submitted when ordering such stencils.

If the stencil is to be positioned manually during printing, holes (if present), or the outer edge of the circuit board can be used to secure its position. These data should also be supplied when ordering such stencils.

Should the prescribed sizes of the circuit board pads or component pads not be observed, the solder paste transfer could be affected. In this regard, it is critical if the pad is too small, there may not be enough contact area for the solder paste during printing. In this way the solder paste may become (partially) stuck in the aperture of the stencil due to insufficient adhesion (pad-to-solder paste). Consequences include weak solder connections with low solder volume.

The flatness of the circuit board likewise plays a major role. If the solder resist protrudes too far above the pad surface, the lift (snap-off) created by the unevenness may well lead to an increased volume of solder paste being applied. With the heatsink area in particular, increased volume can result in the component drifting or tipping.

If the protrusions underneath the component are pronounced, it is important to ensure that the component receives enough solder paste to build up sufficiently high solder connections, which will fully fill the space between component and circuit board.

In both cases it is recommended to calculate the amount of paste needed so that there is sufficient solder volume to ensure complete wetting over the connection surfaces at the required solder joint height.

4.7.1.3 Benefit

This type of stencil allows paste application with components that can't be directly printed, e.g. components with delicate leads that may buckle during printing.

4.7.2 Rework stencils for printing on components

This type of rework stencil is used to carry out paste printing directly onto a component. It has the advantage that the stencil only has to hold the component itself. Here, the space available at the mounting position makes no difference. This technique is used preferentially with components that do not have legs, for example Bottom Terminated Components (BTCs).

Stencils are also employed when components, such as Land Grid Arrays (LGAs), should be deposited with solder. In some cases the solder paste is reflowed with the stencil still attached to the component. The advantage of this is that the solder paste does not have to be released from the stencil, thereby further reducing the area ratio. The disatvantages of this concept are the possablitys to jam the stencil openings with the reflowed solder depot and the effect of the aperture walls to get wettable for solder after a few reflow cycles. How fast the surface wets is dependent on the activity of the flux. If called for, the life time of the stencil can be extended through intensive, ultrasonically assisted cleanings in between the reflow cycles.

For the stencil outline, sensible dimensions have been established which fit the available handling systems from rework system manufacturers.

Component positioning is performed either manually by the user, or a cavity slightly larger than the component is provided in the stencil. The cavity receives the component by way of its outer contour, thereby securing the position to the openings in the stencil. With this kind of positioning it is important to pay attention to the tolerances of the outer dimensions relative to the component's pitch. However, if the dimensions' tolerances exceed one fourth of the opening width, the component will still have to be manually adjusted so as to avoid potentially misprinting. Pertinent guidelines come from PC-7527 [32] – Section 5.1 – Solder paste printing – Misalignment [30]. Here a maximum printing offset of 25 percent of the opening dimensions is specified.

Particularly with BTC component types it is important to ensure that the outer connection pads receive enough solder paste. Frequently the connection pads on the circuit board are significantly longer than those on the component. For this reason

Fig. 77: Dip and print station

Source: Ersa

it can become difficult to receive the same amount of solder in component printing as was used in the PCB printing. This is possible by overprinting the component pads and adjusting the thickness of the stencil, but the release of the solder paste must be checked by the area ratio.

If a rework is necessary due to a tipped component with open solder joints on some of the outer pads, the cause may lie in the solder paste layout of the thermal pad. If the thermal pad is given too much solder, the component may float, thus lifting the outer connection points on one or more sides. In such cases it is recommended to reduce the solder volume of the thermal pad. Thermal pads of QFN component types are typically pasted over 25 to 65 percent of their wettable surface area. 50 percent of the wettable area is an established figure. If this value does not produce acceptable results, it may help to refer to the stencil manufacturer for a calculation of the needed solder volume.

Other causes for tipping can include extreme voids, extreme variance in pad sizes or unevenness in the circuit board.

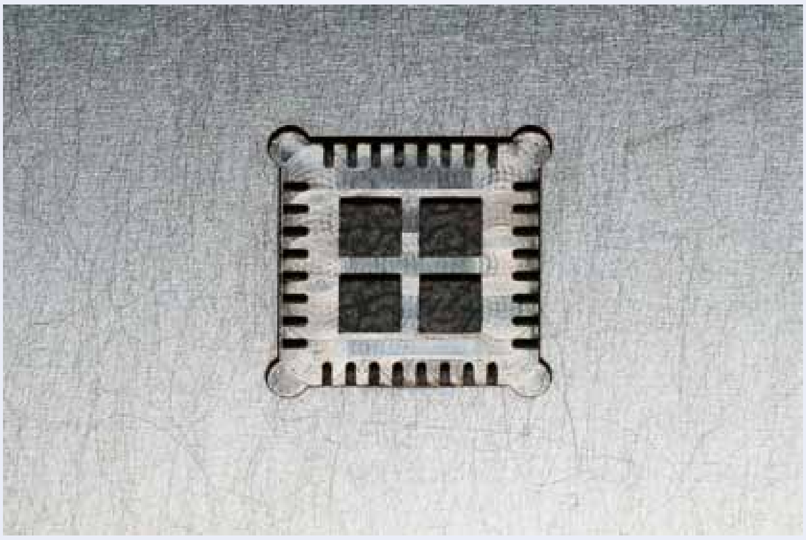
Larger voids, because of the volume they take in, create a change in the form of the solder joint, primarily through a change in the solder gap. X-ray analysis helps shed light on the actual state of the solder joint.

4.7.3 Rework stencils for component dipping

Components whose connections lie on their undersides and stick out of the component body (e.g. BGA types) can be dipped. This involves immersing them with their connections in a film of flux of solder paste. When the component is lifted out, the dipping medium sticks to the connections and is then available to assist the formation of the solder joint.

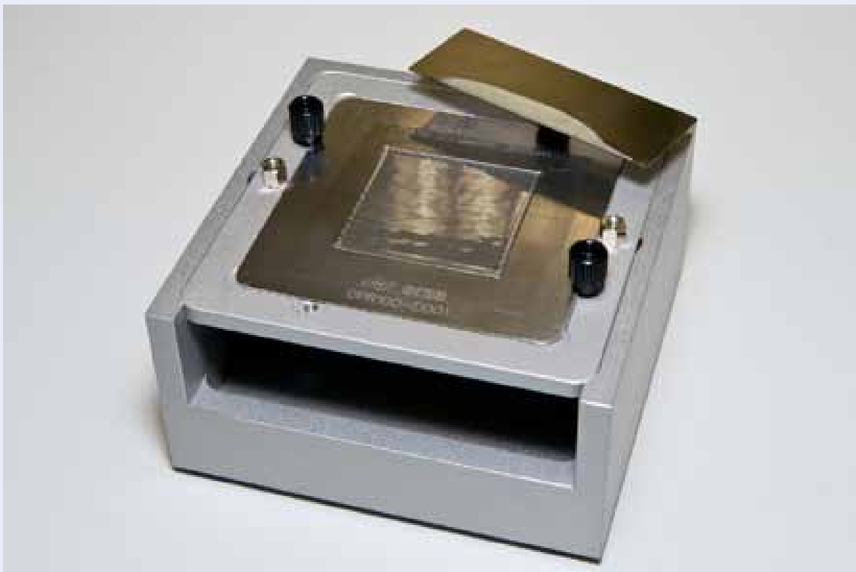
The amount of dipping medium that sticks to a component connection depends mainly on the form of the connection and the immersion depth. Dipping stencils are designed so that the depth of the cavity matches the immersion depth, so as to minimise process fluctuations.

Fig. 78: Rework stencil for QFN component (Quad Flat pack No leads)



Source: Ersa

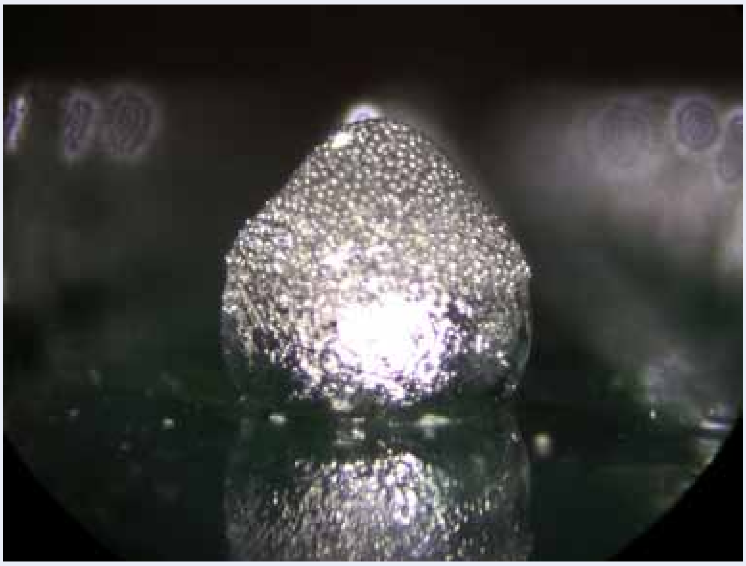
Fig. 79: Dip stencil, filled with flux



Source: Ersa

Dipping stencils allow for a reproducible volume application on the component without having to produce a component-specific stencil. Various types of SMD component can be dipped, but in gull-wing leads for example, volume application ends up being fairly low.

Fig. 80: BGA ball after being dipped in solder paste

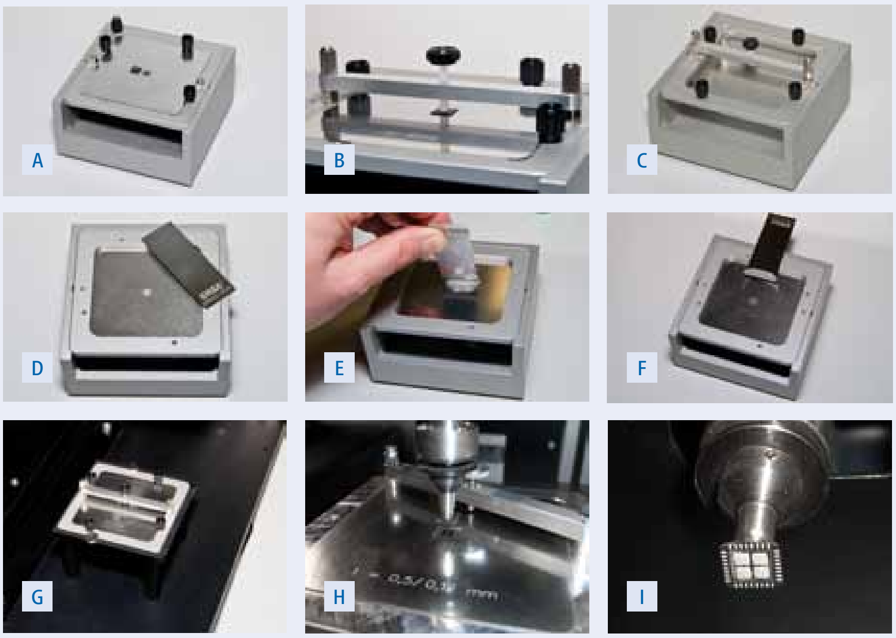


Source: Ersa

4.7.4 Process technique

The following sequence shows direct printing following the example of a BTC.

Fig. 81: QFN printing sequence, variant 1



A Handling tool with stencil inserted and component on top
B The component is inserted into the stencil and fixed in place
C Component inserted in tool
D The carrier frame is turned over for printing
E Printing the component
F Printing complete

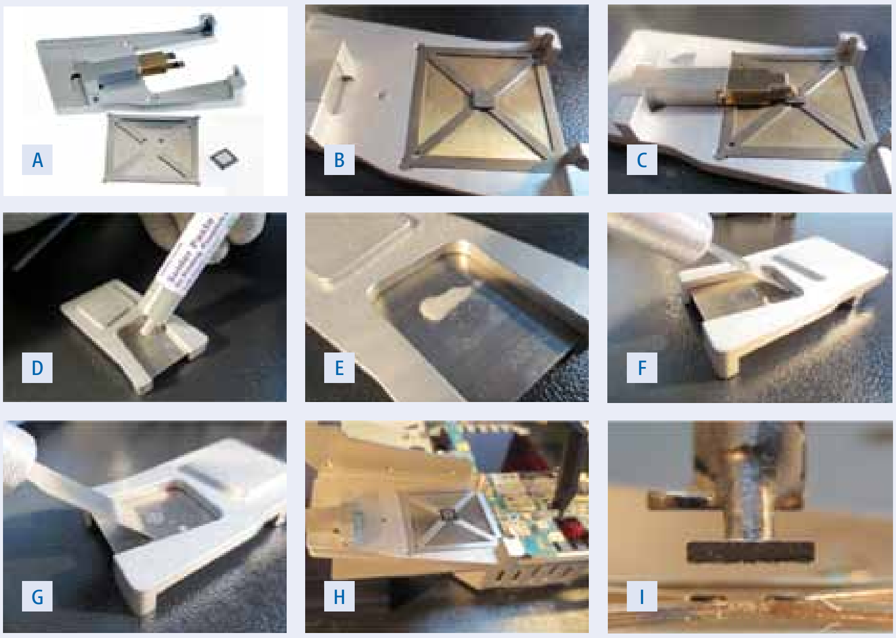
G The stencil is inserted with component into the rework system
H The fixing arm is pivoted away and the component is picked up with the pick and place head
I The printed component can now be positioned and placed

Source: Ersa

General notes

- Note the orientation of pin-1 when aligning the component.
- During manual printing, note the squeegee force and blade angle.
- After printing, visually inspect the level of filling.
- Pay attention to completly wipe the print area clean with your print stroke.
- A minimum of force is recommended when placing the component onto the circuit board.
- Clean the stencil with a suitable medium. In case of heavy contermination on the stencil, clean in an ultrasonic bath.

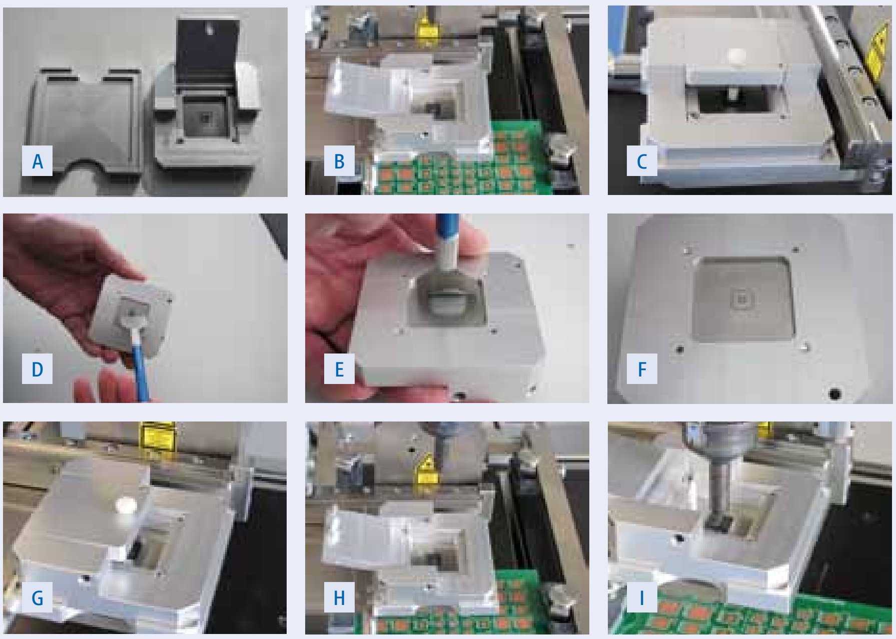
Fig. 82: QFN printing sequence, variant 2



- A BTC printing tool with stencil receptacle, hold-down device, printing stencil, component
- B Insert stencil and component
- C Fix component in place by closing the magnetic hold-down device
- D Apply the right amount of solder paste (cartridge, scoop)
- E Solder paste in position for printing
- F Printing the solder paste with a hand scraper
- G Result after printing
- H Insert BTC printing tool into rework system; remove hold-down device before removing component
- I Machine-assisted component removal

Source: Martin

Fig. 83: QFN printing sequence, variant 3



- A Handling tool with stencil inserted
- B The component is positioned in the stencil
- C Component inserted in tool and fixed in place
- D The carrier frame is turned over for printing
- E Printing the component
- F Printing complete
- G The carrier frame with printed component is inserted into the machine
- H The fixing arm is pivoted away and the component with mounting head is removed
- I The printed component can now be positioned and mounted

Source: Zevac

5 Neuralgic Points for Consideration

5.1 Fault-cause catalogue

The following section contains typical defect patterns that appear in machine-assisted rework. Defects that may emerge in manual soldering processes will not be addressed here in detail. Examples of these may be found in the AiF Project ("Reliability and soldering heat resilience of new constructions in the manual repair process of lead-free electronic assemblies") [33]. This list does not claim to be an exhaustive inventory of defect patterns or of their potential causes.

Potential defects and their causes when reworking with rework systems

1. Coplanarity
2. Twisting/bowing of circuit board
3. Uneven heat distribution (un-fused BGA solder joints)
4. Popcorning
5. Pad cleaning
6. Torn (away) pads
7. Thermal overload to component
8. Thermal overload to circuit board
9. Thermal overload to housing
10. Unacceptable residues (particulate matter, flux, improper cleaning process/ cleaning chemicals etc.)
11. Internal damage to circuit board

Defects observed at the test board

Heat exposure during the soldering process can lead to coplanarity problems. Uneven expansion of the element can cause deformation and thus the formation of unacceptably large gaps between the component and circuit board. This gap might not be closed with liquid solder during the solder process, resulting in an open solder joint.

This phenomenon can occur in rework as well as in the inline process itself. Large components (e.g. BGA sockets, long connector strips) are susceptible in particular. Uneven heat exposure (e.g.: due to improperly shaped jets) can exacerbate the problem. The effect can be mitigated by solder processes that are gentle on assemblies and by supporting the circuit board during the rework process.

The example of the BGA socket (edge length 60mm) is illustrative of this. Figure 84 shows solder points from the first row of connectors, Figure 85 the solder points from the opposing outer row of connectors (row 30). In the first row of connectors one can already see a variance in the heights of the corner connection solder points (far left, far right). However, these are still

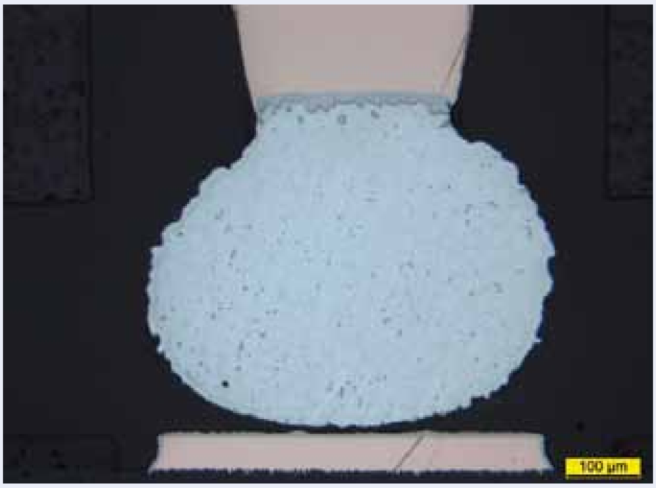
Fig. 84: BGA socket row 1, left, middle, right

Source: Fraunhofer ISIT

Fig. 85: BGA socket row 30 (section), left, middle, right

Source: Fraunhofer ISIT

Fig. 86: BGA socket, ball separation due to coplanarity defect, close-up

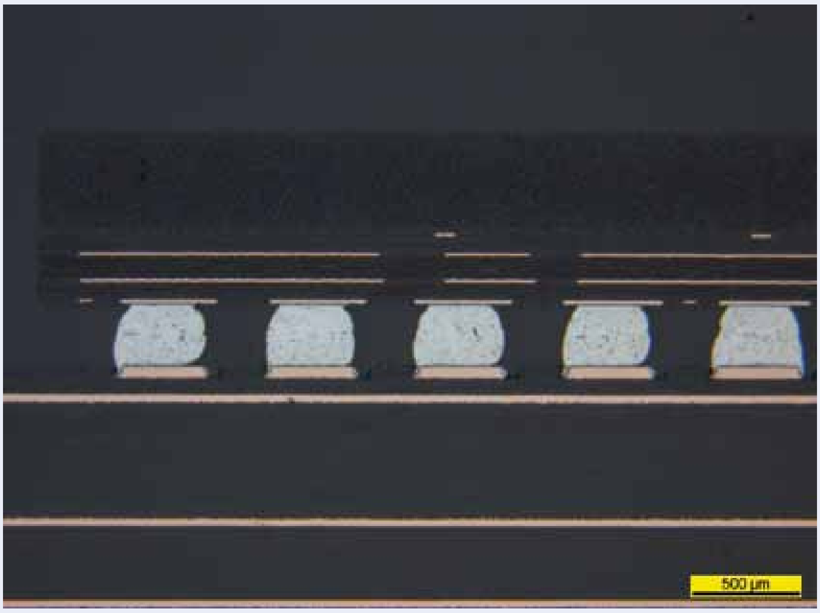


Source: Fraunhofer ISIT

within acceptable limits. On the opposite side (Figure 85) the differences are more pronounced. The open solder joint can be clearly seen (close-up in Figure 86), which can be traced back to a deformation of the component during the soldering process.

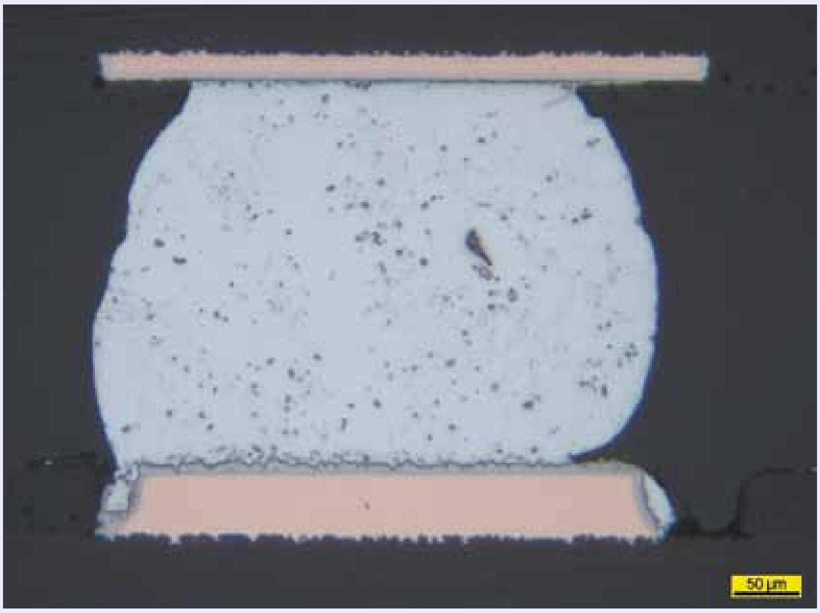
Excessive heat exposure during the removal of residual solder can result in exposure of the intermetallic phase on the circuit board pad. This is no longer wettable and inhibits a firmly bonded connection during the soldering process (Figures 87, 88). This wetting defect is difficult or impossible to verify non-invasively (e.g. by X-ray), making it easy to overlook. This defect mode can be avoided by using a gentle and, if possible, contact-free solder residue removal process.

Fig. 87: ZAL R-PBGA-N176, wetting defect, overview



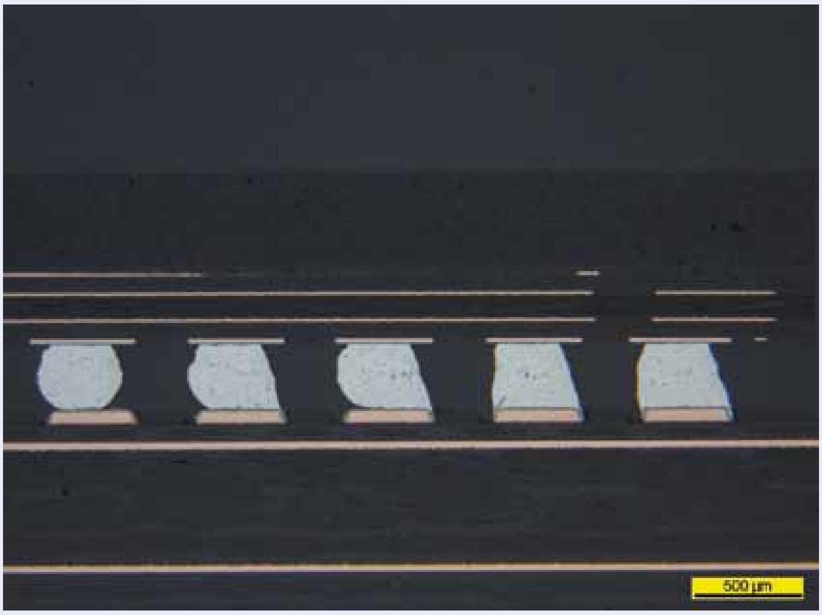
Source: Fraunhofer ISIT

Fig. 88: ZAL R-PBGA-N176, wetting defect, close-up



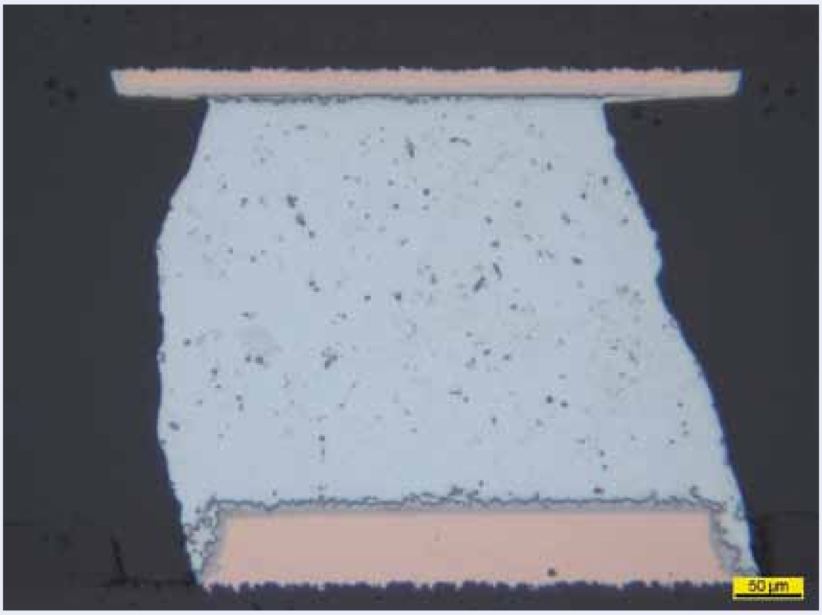
Source: Fraunhofer ISIT

Fig. 89: ZAL R-PBGA-N176, deformed solder joints



Source: Fraunhofer ISIT

Fig. 90: ZAL R-PBGA-N176, deformed solder joints, close-up



Source: Fraunhofer ISIT

In the case of insufficient soldering heat, not all solder points will be in a molten state for a sufficient length of time. This results in the component not being able to swim into position. Should the solder solidify in this position, the result is an improperly mounted component (Figures 89, 90). The proper temperature profile will help to prevent this defect.

Other typical defect patterns from manual-soldering

In light of the number of ways that manual-soldering can be executed, the resulting defect patterns can manifest in an equally diverse manner. Based on defect type and frequency, the defect in question may be systematic or random.

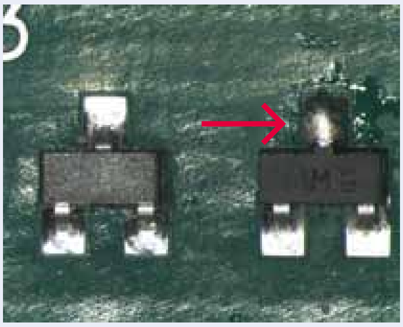
In the following, typical defect modes occurring during manual soldering will be used to demonstrate the correlation between defect patterns and their common causes and to suggest mitigation strategies. This list does not claim to be exhaustive, nor is it the last word with regard to correlations between faults, fault causes, and their prevention. Rather, the following overview is intended as a practical reference for the purpose of more readily identifying the cause(s) of defects.

In all manual soldering processes, particular attention should be paid to the functional interplay between operator and machine.

Thus, the dominant factor (besides power, thermal control characteristics and sensible device set-up) in the results of hand soldering processes is the trained, professional handling of the soldering device.

Defect / Causes / Prevention

Fig. 91: SOT23, acceptable manually soldered junction (top right)

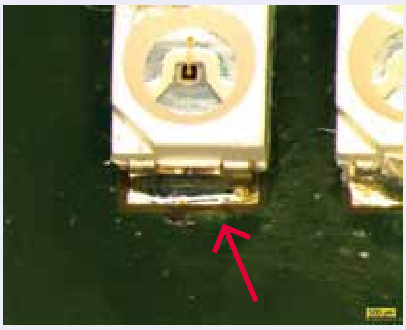


Causes:
Too much solder used during manual-soldering

Prevention:
While not necessarily required with the pictured component type (SOT23), the use of thinner solder wire and/or better soldering tip shape is recommended

Source: Fraunhofer ISIT

Fig. 92: Acceptable solder joint with undamaged component, but with first signs of damage to laminate (delamination)



Causes:
Too much heat exposure on critical areas

Prevention:
Training.
Adjust soldering tip geometry.
Monitor soldering tip temperature

Source: Fraunhofer ISIT

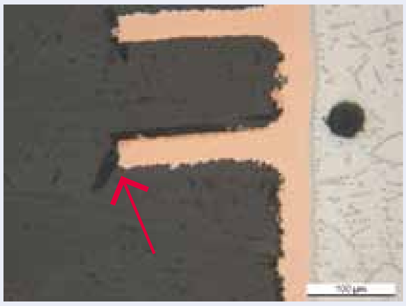
Fig. 93: Tear in laminate / not visible from surface

Cause:
Soldering tip temperature too high and/or contact period too long

Prevention:
Training. Controlled soldering tip temperature and suitable soldering tip shape. Simultaneous heating from underside to pre-heat assembly

Source: Fraunhofer ISIT

Fig. 94: Delamination of internal layer / not visible from surface



Cause:
Soldering tip temperature too high and/or contact period too long

Prevention:
Training. Controlled soldering tip temperature and suitable soldering tip shape.
Simultaneous heating from underside to pre-heat assembly

Source: Fraunhofer ISIT

Fig. 95: Pad lifting with tear in laminate due to excessive soldering time, barely visible

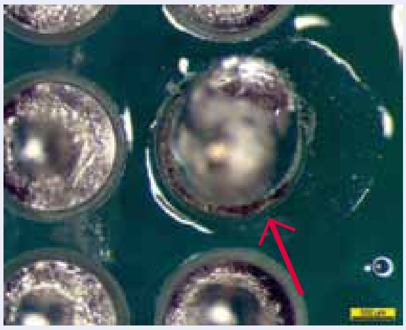
Cause:
Temperature of solder or soldering tip too high and/or contact period too long

Prevention:
Training. Controlled soldering tip temperature and suitable soldering tip shape. Simultaneous heating from underside to pre-heat assembly

Note:
This effect could be further reduced by use of z-axis CTE-optimised circuit board materials.

Source: Fraunhofer ISIT

Fig. 96: Resin content of the circuit board beginning to fuse, barely visible (danger of confusion with flux residues)



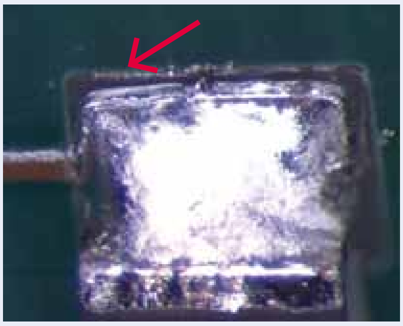
Cause:
Temperature of solder or soldering tip too high and/or contact period too long

Prevention:
Training. Controlled soldering tip temperature and suitable soldering tip shape. Simultaneous heating from underside to pre-heat assembly

Note:
Use of circuit board materials with high T_D value could reduce this effect.

Source: Fraunhofer ISIT

Fig. 97: Pad lifting due to excessive soldering tip temperature



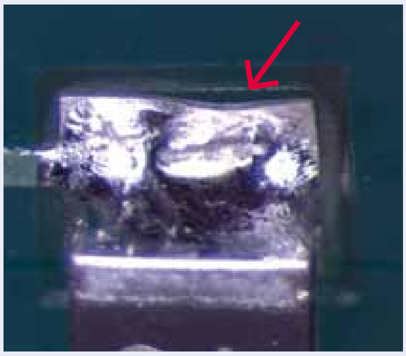
Cause:
Soldering tip temperature too high and/or contact period too long

Prevention:
Training. Controlled soldering tip temperature and suitable soldering tip shape. Simultaneous heating from underside to pre-heat assembly

Note:
HF-capable circuit board materials in particular tend to have reduced bond strength (peel strength).

Source: Fraunhofer ISIT

Fig. 98: Pad lifting due to excessive mechanical pressure



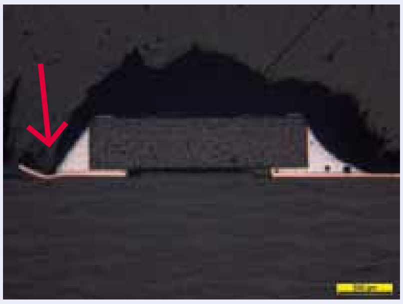
Cause:
Excessive pressure whilst applying solder and/or contact times too long

Prevention:
Training. Suitable soldering tip geometry; ideally, monitor heat exposure through the molten solder.
Simultaneous heating from underside to pre-heat assembly

Note:
HF-capable circuit board materials in particular tend to have reduced bond strength (peel strength).

Source: Fraunhofer ISIT

Fig. 99: Pad lifting (cross-sectional view) due to excessive mechanical pressure



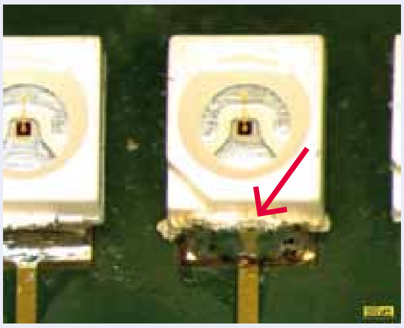
Cause:
Excessive pressure on soldering tip whilst applying solder

Prevention:
Training. Suitable soldering tip geometry

Note:
HF-capable circuit board materials in particular tend to have reduced bond strength (peel strength).

Source: Fraunhofer ISIT

Fig. 100: Component body melted by excessively long soldering time



Cause:
Excessive contact time leads to irreversible damage to the component

Prevention:
Training. Monitor times in process control and use suitable soldering tip shape.

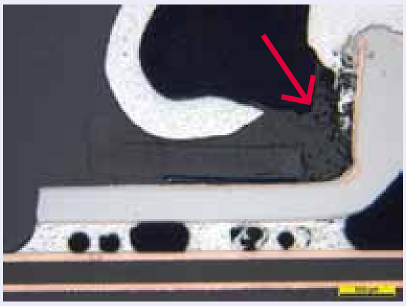
Note:
One might expect similar effects from excessive soldering tip temperatures; this however would also tend to result in burns and carbonisation. If necessary, the hand soldering station's dynamic control behaviour should be checked.

Source: Fraunhofer ISIT

Fig. 101: Electrolytic capacitor, component body undamaged

Source: Fraunhofer ISIT

Fig. 102: Electrolytic capacitor, component body internally melted by excessive soldering time, not visible from the outside



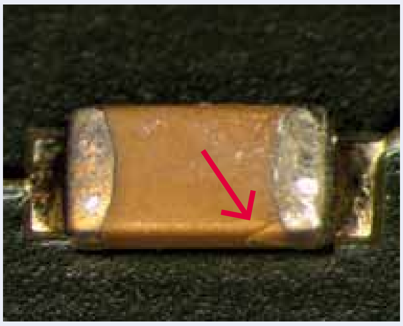
Cause:
Critical thermal exposure along the capacitor's connection surfaces

Prevention:
Training. Suitable soldering tip geometry. Preferably, heat input through the molten solder; situationally adjust heat bridge (pad - solder - component connection)

Note:
Of particular importance here is the design of the landing area (pad geometry), in order to achieve an optimal thermal coupling by heat conduction.

Source: Fraunhofer ISIT

Fig. 103: Ceramic body destroyed by temperature shock on contact with soldering iron tip



Cause:
Critical thermal exposure along the capacitor's connection surfaces

Prevention:
Training. Suitable soldering tip geometry. Situationally adjusted heat bridge
(pad - solder - component connection)

Note:
Of particular importance here is the design of the landing area (pad geometry), in order to achieve an optimal thermal coupling by heat conduction.

Source: Fraunhofer ISIT

Fig. 104: Excessive amounts of solder and flux, cone formation on the solder joint, solder in improper contact with component body, burned flux elements

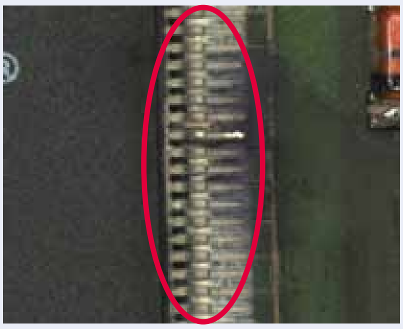
Cause:
Unprofessional, procedurally uncoordinated thermal input

Prevention:
Training.

Note:
No matter what the thermal power or rule behaviour of hand soldering stations employed, the operator still represents the dominant process variable in hand soldering.

Source: Fraunhofer ISIT

Fig. 105: Unacceptable flux residues after manual cleaning



Cause:
Unsuitable cleaning agents or processes lead to an incomplete cleaning/removal of flux residues.

Prevention:
Adjust cleaning media to the characteristics of the flux residues.

Note:
Residues from no-clean processes are worthy of separate consideration, as they were not originally intended to be cleaned. Compatibility in this regard should not be deduced merely from visual inspection, but in case of doubt should be corroborated chemically.

Source: Fraunhofer ISIT

Soldering with rework systems / Defect - Causes - Prevention

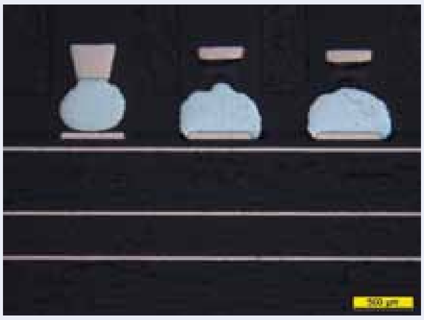
In contrast to hand soldering processes, primary factor is the operator (besides the basic device power parameters) modern rework systems are generally aimed toward operator-independent output scatter.

The stated process goal is primarily the correct, sequence-compliant operation and prudent thermal profiling as a function of the component(s) in need of rework.

While some defect patterns can appear in the domain of rework systems and manual soldering, most aspects of defect causes and prevention do diverge.

Defect type: Coplanarity

Fig. 106: Coplanarity



Source: Fraunhofer ISIT

Cause:

Following mechanical deformation (e.g. on QFP connections) or inconsistent heat input, the result may be local deformities, twisting or warping of most large-surface components and their connection geometries.

A result (and unacceptably wide) gap between component and circuit board (e.g.: with BGA, BTC, etc.) or between component connection and landing area is recognisable.

During the soldering process, this gap might not be closed, or will be insufficiently closed, by liquid solder; open or defective solder joints can impact the result.

This phenomenon can occur in rework as well as in the inline process itself. Large components, in particular (e.g. BGA sockets, long connector strips), are most susceptible.

Prevention:

Avoid inconsistent heat input, for example by using nozzles customised for the component or a sufficient amount of bottom side heating for profiling.

When designing profiles, it is important to pay attention to the component's colour (e.g.: brightness, reflective surfaces), particularly in primarily radiation-based systems.

The effect is reduced by implementing local, close interval temperature measurement on critical components and by physically supporting the circuit board during the rework process.

With very delicate connection geometries, it may be necessary to by-pass mounting the component from the typical component pick position, and instead (if possible) process it directly out of the manufacturer's packaging (tray, etc.).

Vacuum pipettes or axis-guided nozzles are preferred in lieu of tweezers or other (clamping) tools.

Defect type: Twisting/Bowing

Fig. 107: Bowing

Source: Fraunhofer ISIT

Cause:
In general, a distinction must be made between two assembly states:

1. The assembly/circuit board is already bowed or warped prior to reworking.
2. The assembly does not experience torsion/bowing until reworking.

The conditions in Category 1 do not lend themselves to correction by rework, as the causes for this lie either in a preceding soldering process or in the condition in wich the circuit boards were delivered.

Regarding 1: Under solder heat bombardment, the firmly bonded circuit board materials become heated (often considerably) above T_G, disrupting the (initially stable) PCB geometry by unbalancing the prevailing internal stresses in the materials. The release of previously contained internal stresses represents the dominant factor in the type and form of the resulting torsion or bowing.

The causes of the internal stresses themselves may stem from sub-optimal materials combinations, asymmetric design, incorrect thermal process control, insufficient support effect (centre support), etc.

Regarding 2: Primarily heavy, large-format assemblies require sufficient support, such that during the soldering process the distributed load of the populated assembly does not cause sagging. A sag could even become "frozen" after rework is finished (with regard to the stresses in the solder joints or within the circuit board itself).

In addition to deformations resulting solely from the assembly's own weight, a common cause of pronounced torsion and bowing is the state of clamping forces and tension within the assembly receptacle (especially for relatively thin circuit board substrates).

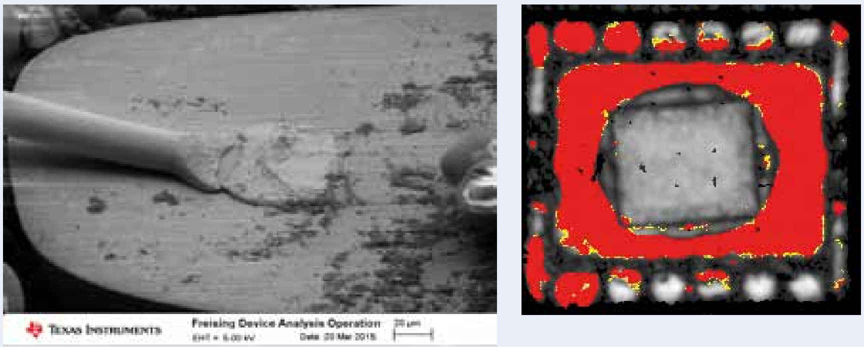
In this situation, the assembly is held firmly in the x-y direction (at room temperature) by the rework system's clamping frame or holding apparatus. When heated it becomes pressed (particularly clearly at $T > T_G$) against the immovable clamping points; the circuit board must either move the holding apparatus, or else it will not withstand the thermally induced stresses at the clamping points and thus yield to the load by twisting or bowing:

Prevention:
Regarding 1: Not within the scope of this manual.

Regarding 2: Application of board centre support devices, non-rigid framing or clamping devices; and if possible, use of guided circuit board receptacles and not only of gravity-assisted solutions.

Defect type: Popcorning

Fig. 108: Bond tearing off (left image) and surface delamination (right image) following popcorning



Source: Texas Instruments

Cause:
Almost all plastics used inside component housings are hygroscopic. Depending on hygroscopic behaviour the result is a more or less pronounced accumulation of water (absorbed mostly in the form of water vapour from the environment) in the component's interior.

The affinity of this water molecule transport in any given component is accounted for mostly indirectly with the MSL (moisture sensitivity level).

When exposed to solder heat, the moisture trapped in the component is unable to escape without causing damage. Should the vapour pressure of the trapped water cluster (water nest) rise above a certain level, the result is either an "unspectacular" (i.e. invisible from the outside) release along a path of least resistance or a bloating of the casing due to the enormous pressure inside. The latter effect is often known as popcorning.

It is especially tricky to diagnose the extent of popcorning, since these events are frequently not pronounced on the surface, yet cause massive damage (for instance, bond tears) to the component internally.

Prevention:
Bear in mind the necessity of re-drying moisture-sensitive components (MSL label) and populated assemblies in the case of a rework.

It is now prudent to explore exactly which sub-sections of the assembly will undergo a reflow stress.

The re-drying requirement is always determined by the most temperature sensitive component (highest MSL value).

Defect type: Loss of solderability

Fig. 109: Loss of solderability due to solder residue removal

Source: Fraunhofer ISIT

Cause:
During the removal of solder residue the affected landing surfaces suffer undesirably high erosion into the interface of the intermetallic zone.

The coating of solder residue required to maintain solderability is no longer stably present, resulting in the non-wetting or dewetting of the affected areas.

This most often occurs in connection with a mechanical removal of solder residue, for example as a result of using solder wicks. Here, two main factors have a decisive impact on the result:

1. Affinity of the solder to preferentially wet the hotter (compared to the landing surface), flux-soaked copper braid.

2. User-dependent and highly variable effect due to direct, force-independent mechanical interference from soldering iron to solder wick to landing area.

Prevention:
Implement solder removal preferably with force-controlled or so-called force-free systems, for example hot gas vacuum tools.

Use concave tip geometries in place of solder wicks (where possible) along with sufficient quantities of flux in order to generate the most uniform solder formations possible at stable planarity.

Defect type: Torn (away) pads

Fig. 110: Torn (away) pads

Source: Fraunhofer ISIT

Cause:

1. During solder residue removal, non-molten (at least locally) solder joints cause an inadmissibly high application of force to the affected landing areas; coupled with motion of the component or soldering tool, this can result in pad loss - indicates that process control is locally not hot enough.
2. Equally possible is the loss of a landing surface due to severe overheating at clean-up or during the soldering process - indicates that process control is locally too hot.

Here, it is almost exclusively the interfaces between the copper of the connection surface and the circuit board substrate which are affected.

Most affected by this are: small-footprint, not electrically attached landing surfaces (where it must also be said that the circuit board bond strength and peel strength have a significant influence).

Prevention:

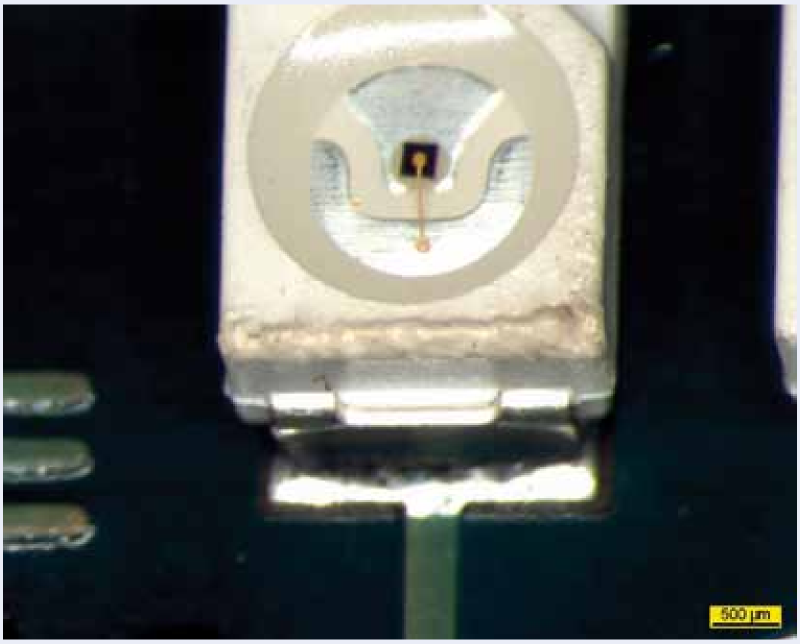
Strict compliance with thermally calibrated profiles, in order to rule out processes that are either too hot or too cold. Particularly with thermally inhomogeneous circuit board designs must measurements must be taken at all critical points.

In addition to the challenges originating from the circuit board's design, it is also worth considering the particularities of some component types, as large BGAs and BTCs do not experience the same temperatures on all of their leads during soldering.

Besides temperature profiling, it is also advisable use a time- or temperature-guided control to run rework system processes such as "lift component", so that components are not moved into the too-cold environment of the assembly, which would damage individual pads.

Defect type: Thermal overload to component

Fig. 111: Thermally overloaded component



Source: Fraunhofer ISIT

Cause:

During the actual rework process, a thermally secured component corridor becomes (mostly locally and briefly) improperly overloaded.

The parameters of this component-specific acceptable corridor are characterised by maximum allowable temperature and time; even if only one of these limits is exceeded, the process --and the result -- can no longer be considered reliable.

The causes often lie in defect to consider the prevailing thermal requirements of the assembly in context (shadows from other components, surfaces, default profiles for components, etc.); and in the lack of thermal profiling at critical points.

Most often forgotten when reworking fully populated assemblies are separate, individual reflow fitness tests on all components which will be exposed to heat (for example electrolytic capacitors, transformers, or THT press-in connectors).

Of particular importance is --in addition to unflagging observance of thermal limits-- the components' durability in the face of repeated soldering heat stress, i.e. the frequency of the maximum allowed heat bombardment on components. Within the categories of housing classified according to J-STD-020 [3], a reflow solder heat stress resistance is assumed to be guaranteed for three passes.

Prevention:

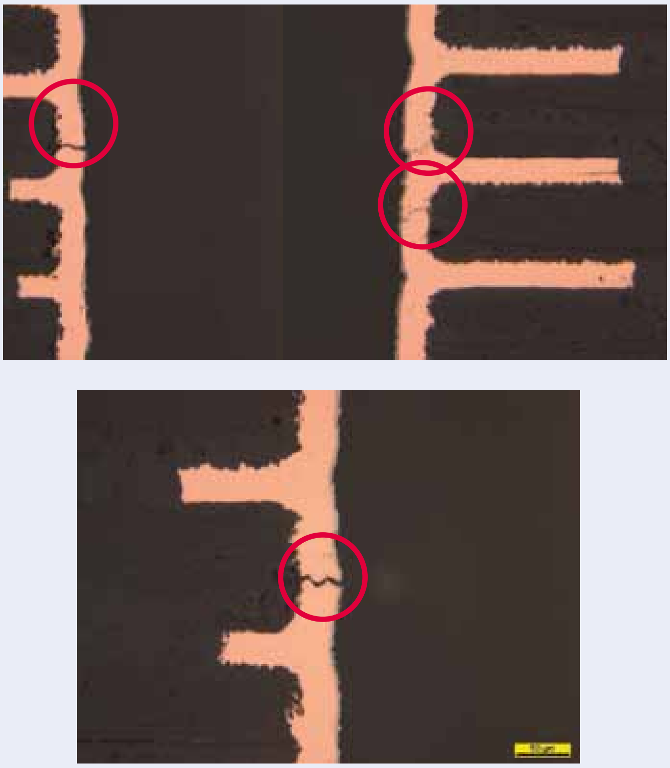
Holistic consideration of the assembly area exposed to soldering heat, in particular of the neighbouring components which have no identified level of reflow fitness.

Observance of allowable thermal component limits both on components directly under rework as well as on components at some remove from the rework.

In the case of repeated solder heat exposure (particularly on thermal overlaps), the number of repetitions should be checked.

Defect type: Thermal overload to circuit board

Fig. 112: Thermally overloaded component



Source: Fraunhofer ISIT

Cause:

During rework (depending on the assembly- and component-specific thermal requirements), the assembly (and therefore necessarily the circuit board as well) is locally not only heated inconsistently but may also be exposed to repeated solder heat stresses.

Depending on design, process control, rework position and rework frequency, damage to the circuit board may result. Besides superficial obvious damage, the circuit board may also be damaged internally.

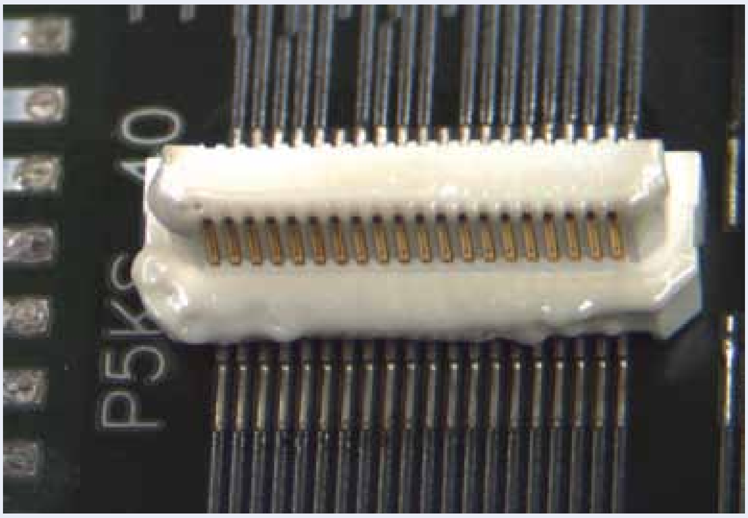
Particularly in areas of thermal overlap, overloads to the circuit board can occur due to repeated heat stresses as a result of multiple exposures to soldering heat; necessary multiple heat stress durability specifications should be requested individually from the circuit board manufacturer.

Prevention:

1. Rework systems: Strict observance of defined/calibrated profiles at the respective reworking points.
2. Circuit board specifications: Prior to rework, one should check the allowable number of rework steps explicitly specified by the manufacturer.
3. Design: If there is assumed to be an increased probability of rework on an assembly, the choice of materials in such a circuit board should be considered separately (see section 2.7).

Defect type: Thermal overload
Housing & push-on connector(s)

Fig. 113: Thermal overload to housing & push-on connectors



Source: Fraunhofer ISIT

Cause:

During reworking, temperature-sensitive housings (with often unspecified solder temperature and time boundaries) are exposed to inadmissibly high heat input, thermally overloading the housings.

Causes in the case of rework systems are often related to the method of thermal input. Particularly vulnerable are neighbouring areas/housings which are not in fact the focus of rework, but whose positions relative to the heat input (beam path or flow direction) are unfavourable.

For example, if not given proper consideration, tall black plastic housings in the immediate area of the component under rework are particularly endangered by the use of radiation-based rework systems.

An very specific danger exists in cases of uncontrolled solder heat exposure to areas containing press-in components; this is due to the fact that while their housings may not take any visible damage, the associated bonded connection zones may become damaged.

Prevention:

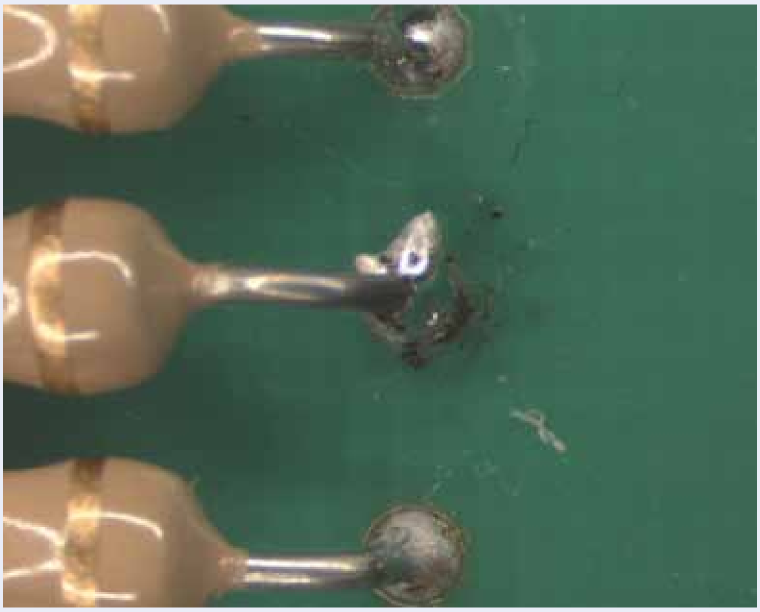
Observance of each component's and neighbouring component's resistance to soldering heat; compatibility checks for connection technologies (soldering and press-in techniques). Visual checks are not always enough to verify intactness.

Adequate shielding plates, screens or heat conducting devices can reduce unwanted local collateral heat exposure; for borderline temperature-time limits, evidence should be provided by means of temperature profiling.

Particularly for nearby press-in connections on heavy assemblies, a ban on rework with rework systems altogether can be the result, if the acceptable temperature-time corridors are exceeded.

Defect type: Inadmissible residues (particulate, flux, unsuitable cleaning process/cleaning chemicals etc.)

Fig. 114: Residues from rework



Source: Fraunhofer ISIT

Cause:

During rework, either too much flux is applied or it is applied in the wrong places; often this cause leads to uncertainty over the effectiveness or capacity of flux systems. The consequence can be residues that fail to meet requirements for visual or technological characteristics.

If attempts are made to clean these flux residues with improper cleaning processes or substances, a "cocktail" of reaction products and cleaning substances may develop that is no longer easy to classify.

During re-melting of the soldering paste and dynamic leakage of process gases from solder joints, solder spatters or particles in the region of the component under rework may occur.

Purely manual cleaning always requires particular consideration that cleaning may displace residues loosened *in situ* into other places in the assembly.

Prevention:

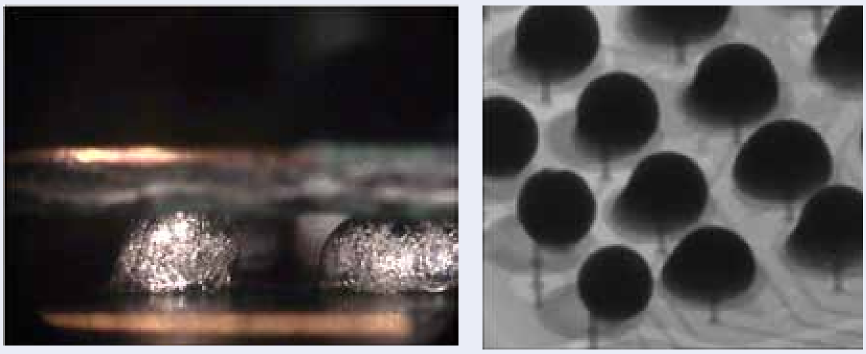
Observe classification and compatibility of flux systems with cleaning media and cleaning processes.

These considerations must be made into account prior to rework, since no flux material necessarily has the perfect cleaner; furthermore, cleaning options for the assembly in its fully populated state should be reviewed.

Possible particle displacements or emergent reaction products from an unauthorised cleaning process should be individually checked for type and possible hazard to the assembly (form, fit and function); their innocuousness must be checked in cases of doubt.

Defect type: Inconsistent heat distribution (BGA solder)

Fig. 115: Result of uneven heat exposure



Source: Fraunhofer ISIT

Cause:

In the flat array of balls and their associated landing surfaces, a sufficiently even heating condition is not achieved during rework.

Here the primary risk does not involve exceeding the acceptable component temperature, but rather a thermal inhomogeneity in the region of all connections or circuit board landing surfaces; as a result of this, incompletely re-melted areas often emerge in the transition between soldering paste and ball.

Prevention:

Observe thermal requirements of the circuit board and component; observe thermal fluctuations resulting from process-dependent variance in heat transfer.

This variance can be triggered by the use or non-use of soldering paste or by coplanarity effects.

Make control measurements with temperature sensors, and retain associated process parameters by means of individualised soldering programs.

Define solder programs on the basis of descriptions of component position and soldering mode (soldering on / de-soldering, with or without soldering paste, partially or fully populated assembly, etc.), which can be clearly categorised.

5.2 Electrochemical Migration (ECM)

5.2.1 Conditions for the emergence of electrochemical migration

The essential factor in the growth of electrochemical bridges is the presence of moisture, because it facilitates corrosion. Moisture can build up on the assembly in a number of ways, first as a moisture film adsorbed on the surface, and secondly as condensation.

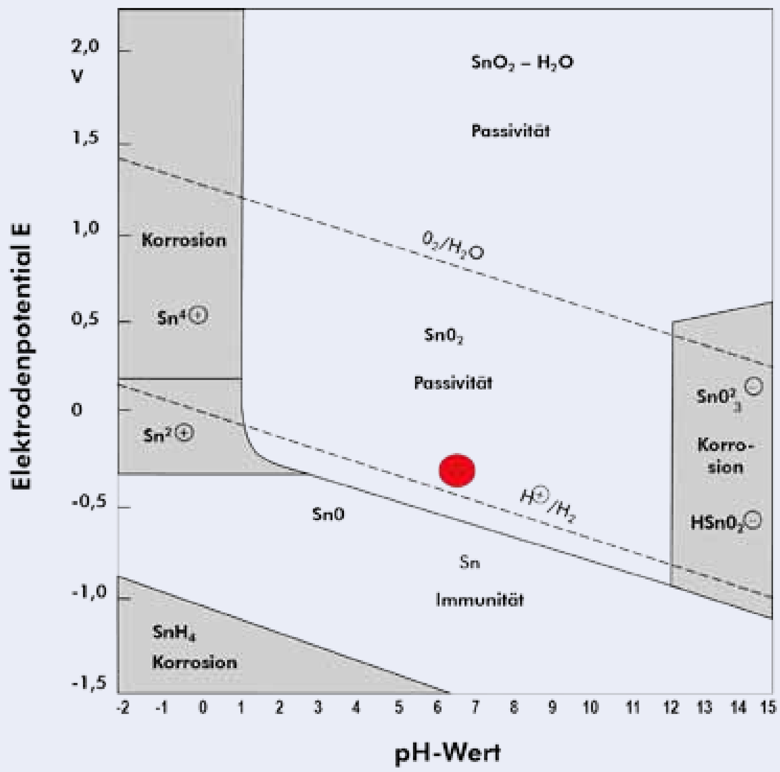
The critical air humidity level necessary for adsorbed moisture films is strongly dependent on the surface energy and surface polarity, i.e. on the material, particularly on the solder resist mask and its degree of filling. This is why adsorption can occur even at air humidity levels significantly below the dew point, that is, the temperature difference at which water drops begin to form on the surface. Film thicknesses of a few monolayers are sufficient to induce corrosion.

In addition to adsorbed moisture films, condensation induced by temperature cycling can also lead to electrochemical migration. As opposed to moisture films, condensation collects on the spots with higher thermal mass, such as metallised areas or hygroscopic points, like impurities. Organic acids or halide salts, as typical solder resides can often pull the local condensation point down as far as 60 percent of the relative humidity.

Another important factor is the raw material used. Layer counts sufficient for moisture films form for example on metals or metal oxide surfaces beginning at a critical humidity of 60 to 70 percent RH (relative humidity), or on quartz-filled solder resist masks. Corrosive gases such as nitrogen compounds, H_2S and CO_2 have similar effects and also dissolve in moisture films. This is attained only at or above 90 percent RH on aluminium oxide ceramics or unfilled non-polar solder resist masks. At constant climate, humidity adsorbs on Sn-metallised epoxide resin substrate, that is, on circuit carriers, preferentially on synthetic resin surfaces. It is adsorbed and retained until partial pressure equilibrium is reached.

Furthermore, there must be present a metallisation or solder material which makes electrochemical migration possible in the first place. This means that the mate-

Fig. 116: Corrosion behaviour of Sn



Source: Zestron

rial must exhibit an active range in alkaline electrolytes (see grey areas in Figure 116). In distilled water, for example, silver, copper, lead, tin and cadmium will migrate well. The bridging propensity varies noticeably with the potentials of the electromotive series and the narrowing of the material's passive behaviour in the alkaline range. With nickel, for example, migration or corrosion does not occur under conditions of condensed water. The susceptibility of an component to electrochemical migration can be estimated with the aid of pH-potential, or so-called Pourbaix diagrams.

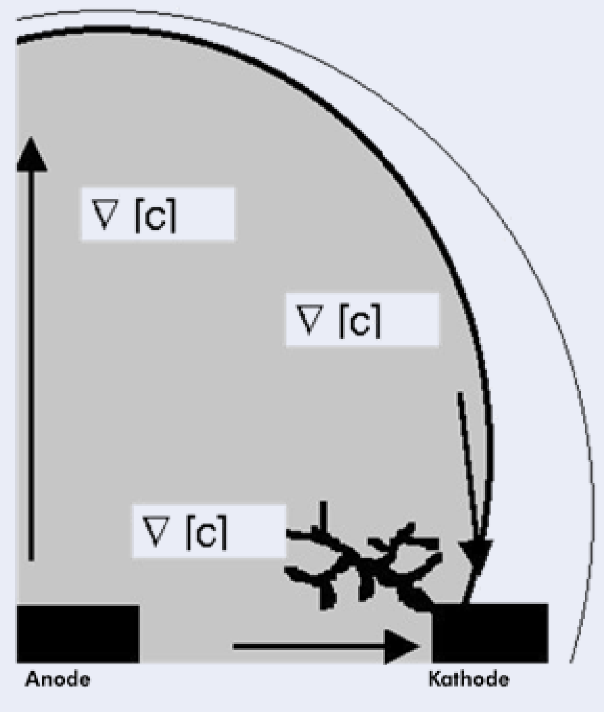
In addition to moisture and material, residues and impurities on assemblies have a considerable effect on the emergence of electrochemical migration. Condensation is most favoured when hygroscopic flux residues, dust or salt crystals are present on surfaces, acting as condensation points or condensation seeds for humidity and corrosive gases. Adsorption potential is further increased when such surface impurities act as moisture reservoirs, so that the otherwise rapid re-drying of polymers, for example, is only guaranteed at below 30% RH.

5.2.2 Mechanism behind formation

As a result of the moisture film adsorbed on the assembly surface, there is a reduction in surface resistance and thus in the necessary insulating capacity of the solder resist masks or circuit carriers. Beyond a critical film thickness the intrinsic conductivity of the adsorbed water film enables the protolysis of pure water. This leads to a strong local alkalinisation of the anode, i.e. of the voltage supply (VCC) or signal leads. Because the pH level has been increased, silver, copper, tin and lead in particular (currently the most commonly used elements in metallisation) are polarised in an electrochemically active range.

The anode surface will dissolve in proportion to the protolysis flow between contact and ground. Propagation or dendrite growth overwhelmingly follows the direction of the concentration gradient (see Fig. 117).

Fig. 117: Concentration-dependent dendrite growth



Source: Zestron

The actual bridging takes place either through galvanic deposition, proceeding from the cathode (GND); or less commonly through the transition of hydroxides/complexes to salts, the so-called staining from the anode (VCC or signal contact).

At higher ion concentrations or gradients, smoother growth structures are favoured. Bands or fibre bundles form (Figure 118).

5.2.3 Consequences of electrochemical migration

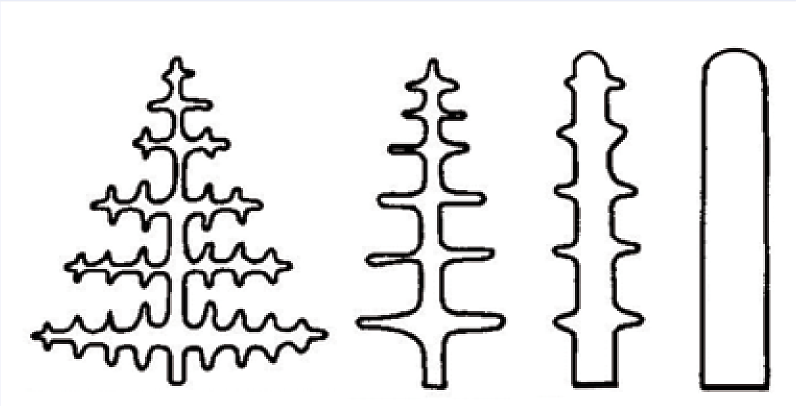
It is often very difficult or impossible to prove that electrochemical migration (ECM) is the cause of damage or defect. When small dendrites appear over short condensation times of typically a few minutes, these are not conductive and burn off immediately. Even so, resultant short-term malfunctions lead to dissatisfaction on the part of the end user and thus to loss of reputation, and depending on application, to high secondary costs from the defect. In order establish electrochemical migration as the problem, the affected circuits must be recalled from the field and checked for evidence of ECM with scanning electron microscopy. Logistical considerations alone often make this impossible. As a result, these defects are thus mistakenly interpreted along with software glitches and current leakage effects as vague "malfunctions".

When stable dendrites --having current carrying capacity-- form, temperatures of 600 °C (1110 °F) and higher can occur (Figure 119).

If the circuit does not have a suitable protection or cut-out, these temperatures can start fires. But since this destroys the circuit, one can often only speculate as to whether the cause had been electrochemical migration or electrical breakdown, for example.

The three most important factors behind the emergence and extent of electrochemical migration are moisture risk, degree of impurity, and electrical design of the assembly. As such, the user / operator cannot change or control all the relevant factors. Because of the complexity of the mechanism, estimating risk on a case-by-case basis is difficult. A coating will not prevent electrochemical migration in every case. However, integrating a cleaning process prior to coating is a prudent and reliable preventative measure.

Fig. 118: Growth formation as a function of ion concentration.



Source: Zestron

Fig. 119: Dendrite, the formation of yellow and red tin oxide, indicates high temperatures

Source: Zestron

5.2.4 Qualification of residues after rework

To assess post-rework risks, test assemblies from various rework processes, making up a representative sample of possible residues, were investigated for assessment-critical impurities. These are to be evaluated primarily on the basis of impurity-induced isolation defects, electrochemical migration and creeping corrosion.

In the years during the switch to lead-free solder, electrochemical migration more frequently became the cause of defects, especially in climate stress tests. This is explained by the fact that silver is capable of migration capable at relative humidity as low as around 65 percent, and the fluxes in use at the beginning of the transition had higher activator content. The activators adsorbed additional moisture from the air due to their hygroscopy and retained it stably, causing the development of critical, i.e. dendrite growth-friendly moisture films on assembly surfaces. Risk of assembly defect due to electrochemical migration can be contained by further adapting fluxes to lead-free solder, and by following the trend to alloys with markedly lower silver content. At high humidity levels during operation, leakage current is once again to be considered the main risk of defect.

Whilst the high package density of electronic assemblies admitted increases the base risk of leakage current defects, this risk is largely compensated for in practice by robust electrical design, continuous advancements in no-clean production and high self-drying potential from dissipated heat. Only through the growing focus on circuits' power consumption and the move to component elements with increasingly high input impedances did the number of defects due to leakage current rise in stress tests and thus in operation as well. A significant number of circuits today malfunction in the presence of leakage current in the range of a few hundred (100) milliamps. Using Tautscher's exemplary account of the combined effect of moisture adsorption and impurity, one can roughly estimate the expected surface resistance. Based on his measurements Tautscher assumes a worst-case SIR drop of three orders of magnitude for humidities between 60 percent and condensation. He expects a maximum SIR drop of another five orders of magnitude as a result of impurities. This means that the insulation resistance of a solder resist with 10^{12} Ohm/cm can drop to 10^{4} Ohm/cm. It is readily apparent then that these low resistances allow leakage currents far in excess of the specified limits. Besides the choice and processing of the solder resist, the reduction and monitoring of impurities on the assembly is therefore a key point in preventing defects due to current leakage.

Corrosion creep is also increasingly deserving of mention in connection with halide residues. Copper in particular likes reacting with chlorides and bromides, which (among other ways) get onto component surfaces through flux. Copper on various metallisations in the assembly should ordinarily not be exposed to the environment. It should be covered with tin (for example) on solder contacts and by the solder resist mask on circuit paths. In practice there are always discrepancies from process errors or insufficient component specifications, which in the presence of increased environmental humidity can lead to copper corrosion. Here, low-impedance leakage current bridges develop, which can stretch up to several centimetres.

Because a great range of fluxes and pastes is utilised throughout the rework process, as in standard production, the real risk from residues can't be predicted from data sheets. Of course, a low activation level (L), as well as minimal halide content (0), is more favourable than (H1)-activated. However, with designations one should pay careful attention to the standard used since, with respect to the acceptable halide content at L0 the DIN EN and ANSI J-STD, standards can differ by up to a factor of five (Table 4). Also, and especially with ROL0, pastes can split off hygroscopic short chain multi-carboxylic acids from the resin, as research from Denmark Technical University (DTU) has shown. While this is good for soldering behaviour, it also creates the risk of critical residues.

When deciding whether or not critical residues are present, it is recommended to follow the standards. The most well-known parameter, the so-called ion equivalent, can be found in Chapter 8 of J-STD-001 [8]. Here a threshold of 1.56 µg/cm² is indicated for ROL0 and ROL1. However, this value hasn't been updated since the 1970s. For this reason it is advisable to follow the recommendation in the J-STD-001 [8] and work with the manufacturer and user to set a threshold. That determination should be justified on the basis of history or tests. The IPC-9202 [34] gives the baseline specifications for carrying out such tests, and also defines the methods for determining the ionic residues. Limit values and orientation are provided in the table in IPC-CH65 [3], which also quantifies the amount of allowable organic acids. The provision for organic acids also allows for an improved risk analysis. Should primarily water-soluble acids be found here --and also exhibit a large hygroscopic potential-- the risk of leakage current should be checked. Location-specific colour tests can determine whether acids are forming bridge-building structures between sensitive signal inputs or on contacts with high voltage differences (e.g. between ground and voltage supply). Analogue colour tests are also available for visualising halide distributions. Potentially critical points identified in this way can now be stressed using local moisture strain, and circuit function under stress can be checked.

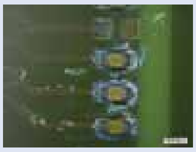
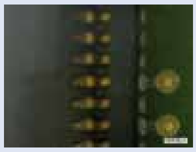
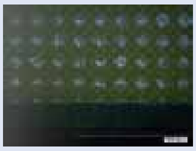
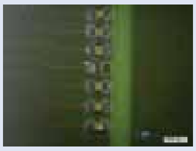
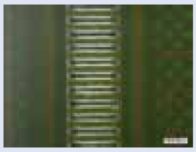
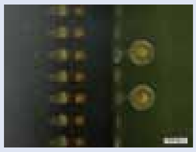
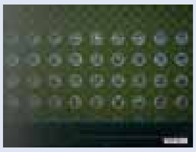
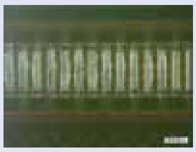
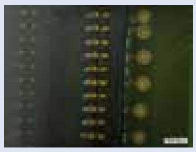
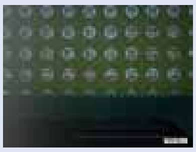
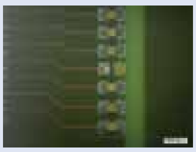
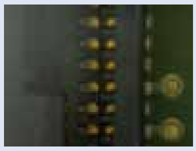
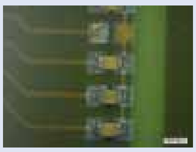
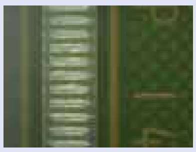
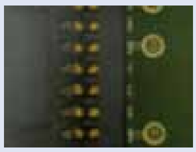
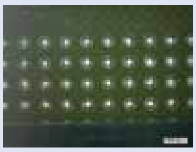
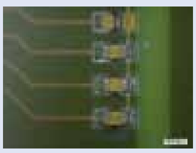
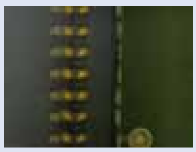
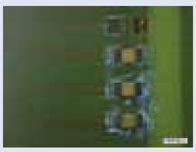
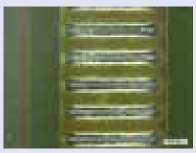
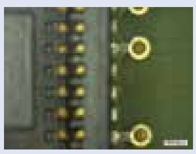
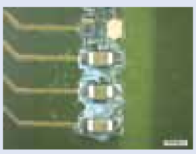
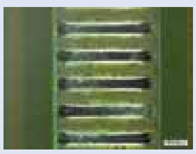
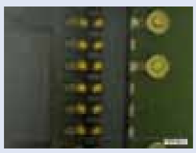
When assessing operational safety after the rework process, another consideration is that there may be other factors besides flux residues. Among other factors, the significance of imported impurities grows with components and other outsourced parts, with outgassing from polymer materials under solder heat as well as with the human factor in handling and logistics. Therefore, appropriate supply chain management is important to the rework process.

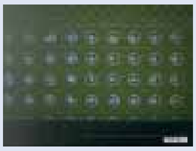
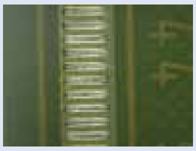
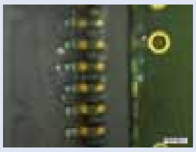
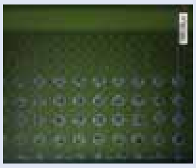
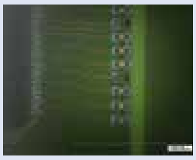
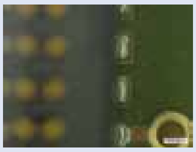
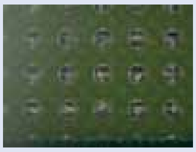
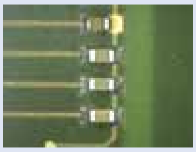
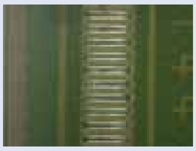
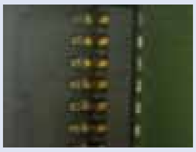
In the creation of this manual, research was limited to the contaminating effects of flux on un-cleaned assemblies. Twelve different residue combinations from primary and rework processes were surveyed by means of ion equivalent and flux test, and visually examined in accordance with IPC-A-610 [24]. For un-cleaned test assemblies the ion equivalent scattered between 0.58 and 1.67 µg/cm². The flux test corroborated that there were free carboxylic acids on all test assemblies. With regard to the in-circuit testability and the resin residues on test points, the results varied between acceptable and unacceptable. This can be traced back to a surplus of resins from rework. If a cleaning process is used, flux contamination and other residues from handling and supply chain can be eliminated.

The investigation carried out here is intended to be, and indeed can only be treated as a rough introduction to assessing risk potential. In individual cases it is recommended to carry out the audit in accordance with the above-mentioned standards. Because manual cleaning steps are often employed in rework, their results as well should be checked on the basis of the standards mentioned; and these manual cleaning procedures should be monitored and taught analogously to manual soldering processes.

5.3 Overview of test results

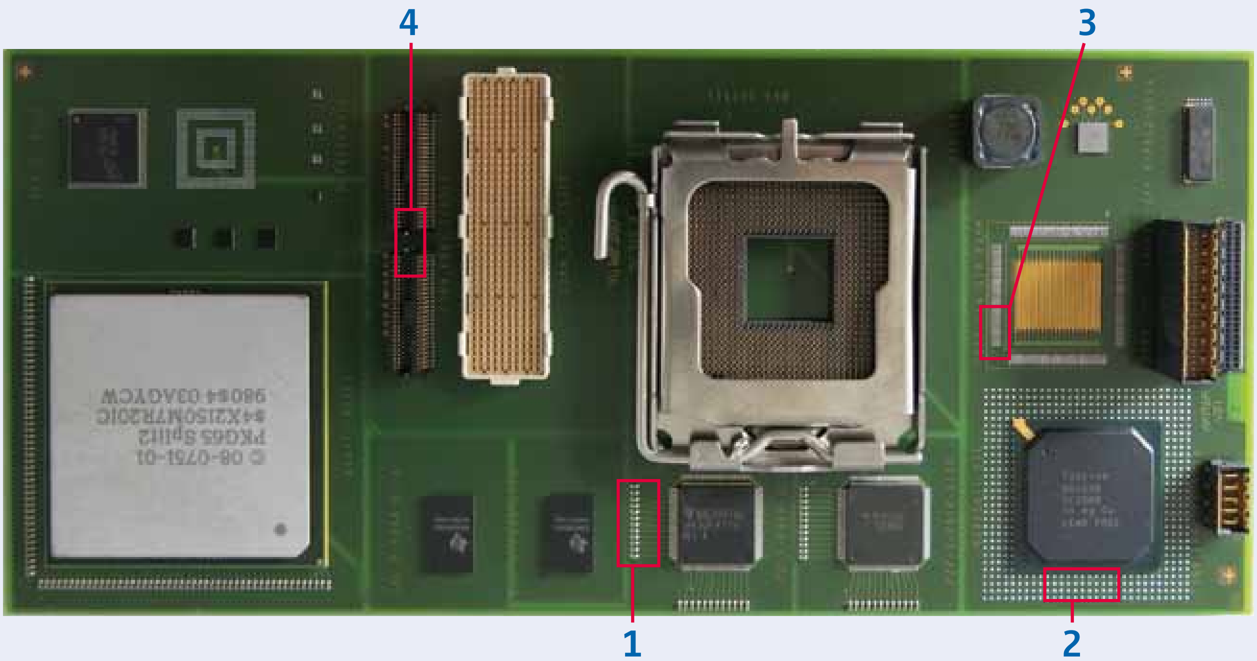
Tab. 19: Residue spectrum after rework

Test board ID	Flux test		Resin test		Ionic contamination
	1	2	3	4	
25					1.677 µg/cm² equiv. NaCl
26					0.861 µg/cm² equiv. NaCl
27					0.586 µg/cm² equiv. NaCl
28					0.946 µg/cm² equiv. NaCl
29					0.896 µg/cm² equiv. NaCl
30					0.881 µg/cm² equiv. NaCl
31					0.876 µg/cm² equiv. NaCl
32					0.824 µg/cm² equiv. NaCl

33					0.746 µg/cm² equiv. NaCl
34					0.835 µg/cm² equiv. NaCl
35					0.614 µg/cm² equiv. NaCl
36					0.870 µg/cm² equiv. NaCl

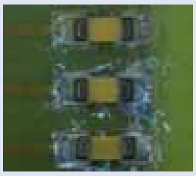
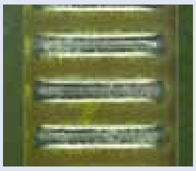
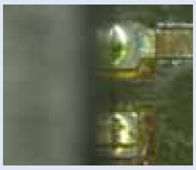
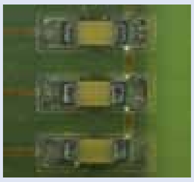
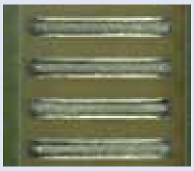
Source: Zestron

Fig. 119: Test board



Source: Zollner

Tab. 20: Effect of cleaning

Label	Flux test		Resin test		Ionic contamination
	1	2	3	4	
31 Prior to cleaning					0.876 µg/cm² equiv. NaCl
32 After cleaning					0.128 µg/cm² equiv. NaCl

Source: Zestron

Cleaning parameters:
50 °C (122 °F) / 20 min / ultrasound

Cleaning medium:
Zestron FA+

Rinsing parameters:
De-ionised water / RT / 10 min. / ultrasound
De-ionised water / RT / 10 min. / flow-around

Drying parameters:
60°C (140 °F) / 20 min.

6 Conclusion/Outlook

In the following, the core discipline of criticality analysis (thermal processing) will be summarised, bearing in mind the product quality (reliability) in a rework context.

This comprehensive weighing of multiple factors will allow us to identify (and if needed, to implement) which rework processes ensure a reliable operating condition even in later assembly applications.

6.1 Reliability

The results gained from visual inspection and cross-sectional analysis show in principle that after a carefully controlled rework, no adverse effect to the reliability of the solder joints or assembly can be expected.

In addition to the present results, the issue of possible solder junction embrittlement (initiated by growth of intermetallic phases) should be considered for more rigid solder joints possessing a relatively small solder gap (e.g. ceramic chip components).

The increase of intermetallic phases observed in cross-section (because of additive solder heat exposure) can certainly be metallurgically calculable and is typically categorisable, but there are occasionally critical assembly configurations for which a separate verification of reliability would seem sensible.

The maximum attainable assembly reliability is always limited by the respective reliability levels of the individual components involved. The cumulative reliability is decisively impacted by the circuit board, as this single assembly component must withstand the collective heat of all rework soldering processes (see section 2.7).

In order to be confident in a product-specific statement of reliability with respect to reliability on the assembly level following rework, it is recommended to provide individual qualification on the assembly level.

**Concerning this,
the following are essential:**

- Assembly under consideration, in its initial condition
- Assembly in post-rework condition for assessment
- Environment simulation according to individual mission profile
- Comparative visual and destructive inspection of initial and post-rework condition
- Detailed consideration of all areas exposed to solder heat
- Documentation and conformity assessment in accordance with agreed-upon specification(s).
- Release/rejection of product-specific rework process

6.2 Thermal processes

6.2.1 Rework / Component-process preference table

In the context of the investigations conducted, certain rework configurations proved to be particularly suitable. The knowledge gained of component-specific properties, heat transmission methods and advisable process options is laid out in the table below.

Mandantory recommendations cannot be derived from Table 21 for every application of the assemblies under consideration. Table 22 contains key process control recommendations for rework of typical component types, with a focus on component replacement.

The focus is on the exchange of components. When only reworking single solder joints with a view to correcting too much / too little solder, hand soldering is recommended in most cases. However, hand soldering is counter-indicated for rework on BTC and BGA component types.

Tab. 21: Component process recommendations, based on test assembly

Mounting location	Component form	Features	Contact soldering	IR system	Hot gas	Addtl. steps	Reballing	Visual inspection	X-Ray
Inductor	2-pole	High thermal mass	X (T)	X	X	Pre-heat component	-	X	(P)
Res_xxx	2-pole	01005-0402	X	X	X	-	-	X	(P)
Ceramic capacitor_xxx	2-pole	01005-0402	X[1]	X	X	Pre-heat component	-	X	(P)
xx-PQFP	QFN	Pitch 0.5mm	X	X	X	Soldering tip with cavetto	-	X	(P)
Conn-xxx	Connector	THT – SMT Mix	-	R	X	mount heat shield if required	-	X	X
BGA-xx	Ball Grid Array	various pitch	-	X	X	-	X	R (S)	X
Conn-FCI	MEG Array	Ball Grid Array	-	X	X	Modify placement aid	X	R (S)	X
BGA socket	Socket 775	Ball Grid Array	-	X	X	Pre-heat assembly	R	R (S)	X

[1] Ceramic capacitors: Contact soldering not recommended due to temperature gradient sensitivity; better to use hot gas device.

X = standard process
R = with restrictions
P = process qualification
T = soldering tweezers
S = special optics

Tab. 22: Component type process recommendations

Compo-nent type	Features	Supporting documentation	Contact soldering	IR system	Hot gas	Additional steps	Visual in-spection	X-Ray Q	X-Ray X	X-Ray C
2-pole (chip-compo-nent)	01005-0402	J-STD-075 [5]	R	X	X	Expanded employee qualification, observe temperature gradient	X	-	-	-
2-pole (chip-compo-nent)	>0402	J-STD-075 [5]	X/T - Caution - ceramic cap dan-ger, see Tab. 21	X	X	Observe temperature gradient	X	-	-	-
Tantalum capaci-tors	-	J-STD-075 [5]	X	X	X	Observe peak temperature / hold times	X	-	-	-
MELF	Vitrous body	J-STD-075 [5]	H	X	X	Observe temperature gradient	X	-	-	-
SOT/ SO-IC	-	J-STD-020 [3] J-STD-033 [4]	X/H	T	T	-	X	-	-	-
SOT/ SO-IC	Heat dissipa-tion surface	J-STD-020 [3] J-STD-033 [4]	H	T	T	Special nozzle	X	-	-	√
Gullwing	Pitch ≤0.65 mm	J-STD-020 [3] J-STD-033 [4]	X	T	T	Soldering tip with cavetto	X	-	-	-
Gullwing	Pitch ≤0.65 mm thermal pad	J-STD-020 [3] J-STD-033 [4]	H	T	T	Soldering tip with cavetto	X	-	-	√
J-lead	-	J-STD-020 [3] J-STD-033 [4]	X	T	T	-	X	-	-	-
BGA, CSP	Re-melting balls, various pitch	J-STD-020 [3] J-STD-033 [4] IPC-7095 [6]	-	X	X	Reballing possible	R (S)	√	√	√
BGA, CGA	Non-remelting connections, various pitch sizes	J-STD-020 [3] J-STD-033 [4] IPC-7095 [6]	-	X/R	X	Limited reballing, additional deposit of soldering paste necessary	R (S)	√	√	√
DPAK	Heat dissipation/sur-face thermal pad surface	J-STD-020 [3] J-STD-033 [4]	-	T	T	-	X	-	-	√
BTC	-	J-STD-020 [3] J-STD-033 [4] IPC-7093 [7]	-	T	T	-	X/R	√	-	√
Connector	In SMT, through-hole	J-STD-020 [3] J-STD-033 [4]	X	X	X	Special nozzle, placement aids, pay attention to printed circuit board bowing	X	-	-	-
Connector	In SMT, BGA	J-STD-020 [3] J-STD-033 [4]	-	X/R	X/R	Special nozzle, placement aids, pay attention to printed circuit board bowing	X	√	(√)	√

X = standard process
R = with restrictions
P = process qualification
T = soldering tweezers
H = hot gas pen

S = special optics
TP = temperature profile required
C = client-specific
Q = solder junction quality

In rework terms, the key technological factors can be attributed either to thermal parameters (component and circuit board level), or else to chemical interactions (with a focus on residue analysis), such as the following:

- Multiple solder heat stress situations resulting from thermal overlaps (see sections 2.4 and 4.4)
- MSL (particularly when history of moisture exposure is unknown - see sections 2.9 and 5.1)
- Flux compatibility (chemical and thermal - see sections 2.4 and 5.2)

While implementing the above considerations during a rework in principle cause extra costs, the underlying limits, corrective actions and tolerance ranges are for the most part sufficiently defined.

In rare, product-specific incidents, borderline cases may still occur despite taking account of and compliance with all required parameters (both technologically adequate as well as authorised in the sense of a prior tuned customer-supplier agreement). Such instances must be examined on a case-by-case basis.

In such a case, the clear classification with respect to the controllable as well as fully authorised rework process must, if necessary, be checked for assignment to the repairs department.

The deciding factor in whether rework or repair is called for is first to clarify to what extent corrective measures can restore full the item's full conformance with its respective specifications or drawings.

6.2.2 Repair / component process

In accordance with the definitions of rework, modification or repair laid out in section 2.1, it is certainly possible to classify corrective measures, but on short notice it is often not possible to gather all the detailed information for an unambiguous classification.

Here a premature categorisation as rework must be ruled out, because ostensibly minor details must often be considered, whose salience cannot be reduced to thermal parameters alone.
The essential criticality does not necessarily lie in insufficient technological compatibility of the corrective procedure, but frequently rather in product conformities which are not 100 percent met.

Key questions on this matter (some of which were already addressed in section 2.1) are recapitulated as a basis for improving risk assessment in terms of deciding between rework and repair.

Do corrective measures merely represent an unscheduled and temporary measure or are they in danger of becoming routine?

- As a rule, solder joints from in line soldering processes with acceptable amount of solder produce acceptable assembly properties, inasmuch as the underlying design and class division are consistent.
- Prior to a routine corrective intervention, which gives the solder joints an "extra portion" of solder, it should be warned that the expected gains in reliability or admissibility are not always commensurate to the risk and/or effort involved.

Does the modification come with caveats (quality, reliability), and if so, how great are they?

- The answer to this question is can usually be carried out in consultation with the client, as the actual implications for product characteristics are generally not possible to ascertain through visual inspection or X-ray diagnosis.
- Special attention must be paid to assemblies which feature multiple joining technologies; for example, a thermally ideal BGA replacement (see Chapter 2.2) is not perfectly admissible when a press fit connector is located nearby.
- Are there other thermal limits besides the actual SMT or THT components which should be considered separately?
  - Conformal coatings, for example, do not always respond to excessive heat input with burn effects visible to the naked eye.
  - The danger of (often only local) delamination of protective coatings as a result of increased heat input must be checked for separately, as critical microclimates can develop along the interface between component (printed circuit board) and protective coating.

From the customer point of view, is an additional procedure even permitted?

- Here, a distinction should first be made, whether and to what degree corrective measures are permissible and sensible in the first place.
- Often minor corrections with hand soldering irons are allowed, while a BGA replacement is considered out of the question.
- A disallowed or incorrectly applied procedure (especially with seemingly "simple" component types) can lead to degradation or loss of function. For example, fractures in glass diodes can result from use of a soldering iron, while the client would have permitted the use of a hot gas pen.

Are there restrictions with respect to moisture-sensitive components (MSL)?

- This theme appears at various places in this guideline and is discussed with acknowledgement given to the typical MSL representatives.
- The danger to the component or to the assembly increases tremendously once the classical MSL attributions can no longer be applied with confidence (e.g. due to incomplete data sheets), or if standard re-drying recommendations (according to J-STD-020) no longer fit the assembly's development or integration condition of construction.
- The same things that are described and classified purposely for moisture-sensitive also applicable in a modified form to some moisture-sensitive circuit board materials, but in these cases an authoritative classification is not possible.

In summary, both reworking and repair are suitable measures for guaranteeing or restoring an assembly's integrity where necessary, either as part of the running production process or in the event of delayed corrections.

In addition to basic considerations of capability, the technologies and concepts to be applied in practice continuously require authorisation from the customer: Even minor corrections are not necessarily permitted unless they are explicitly defined in advance.

7 Closing Remarks

The reworking process is a controllable one, provided it is diligently carried out and all boundary conditions for components, printed circuit board and soldering process as well as handling thereof (as set forth in this guideline) are observed and complied with.

The right rework process can produce qualitatively consistent and equal products. In addition to a customised thermal profile, a qualified and reproducible rework process sequence are indispensable parameters in achieving this.

The foundation for this - in the sense of fundamentally safe and feasible rework processes - is a suitable choice of printed circuit board material in light of the additional thermal demands represented by the rework process.

Given the use of stable processes and situatively customised rework procedures, the same requirements on qualitative execution and product quality apply in rework as in the line process.

Particularly applicable are the same acceptance and testing accuracy criteria, as well as the rigorous compliance with all secondary aspects with regard to form, fit and function.

Always required is a demand-oriented and calculating review of the essential necessity (particularly with respect to kind and extent) of rework steps.

Besides just successful rework procedures, the focus is also on implementing safe process control as a rework process window.

Purely cosmetically motivated corrections to solder joints are explicitly discouraged.

8 Corporate and Research Partners

Fraunhofer Institute for Silicon Technology (Fraunhofer-Institut für Siliziumtechnologie)

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10 Glossary

A

B

BGA

Ball Grid Array - surface-mounted housing with ball-shaped connection points arranged on the underside of the unit in a two-dimensional array.

There are typically two variants recognized: either with "low-melting" or "high-melting" balls. After melting during the reflow process, the low-melting balls change from their original ball form into a barrel shape once the solder deposit is fully integrated. High-melting balls (e.g. of PbSn10) mostly maintain their original form, even after the reflow process, changing unsignificantly as they melt locally in the solder joint area.

BTC

Bottom Termination Components - Components with bottom connections.

C

CAF

Conductive Anodic Filamentation - Formation of copper filaments in the base material, growing from the anode to the cathode (effect taking place within the circuit board in the direction of fibre orientation)

Cleanable

A state or quality of flux residue after soldering (in accordance with the soldering procedure approved by the flux manufacturer) generally requiring cleaning, because the residues are (at least under some conditions) categorised as corrosive.

Convection

Commonly used method of heat transfer within soldering systems (primarily in so-called reflow full convection soldering systems) as well as rework systems in the form of hot gas variants

Conduction

(aka thermal conduction) Another commonly used physical method of heat transfer, primarily in hand-held solder devices (solder tip). Also indirectly used transfer heat energy using molten solder.

Condensation

Another method of heat transfer in which heat can be transferred relatively quickly and efficiently by depositing latent heat through a state-of-matter transformation (vapour to liquid). In use in soldering systems, favoured in so-called vapour phase soldering systems; however, such systems are not covered in detail in this manual.

D

DFN

Dual Flat No Lead - Component type belonging to the BTC family.

Daisy chain

Daisy Chain is a wiring scheme wich allows to monitore component connections, including solder joints, via Ohm mesurement.

DICY

Hardening mechanism for circuit board materials (relating to the resin system(s) used)

DIN

German Institute for Standardisation (German: *Deutsches Institut für Normung*)

DMA

Dynamic Mechanical Analysis - Measurement method for electronically determining modulus of elasticity.

E

Eutectic

Describes an alloy which at its current eutectic percentage ratio of constituents yields the lowest melting point for that alloy; in a eutectic ratio the liquidus line and the solidus line meet to a point.

The alloy thus no longer has a melting range, but instead only a melting point.

ECM

Electrochemical Migration - build-up of (conductive) dendrites in the presence of ionic contamination, moisture and difference in potential

ENIG

Electroless Nickel / Immersion Gold - circuit board surface

ECSS

European Cooperation for Space Standardisation

EN

European Standard (German: *Europäische Norm)*

EIA

Electronic Industries Alliance

F

G

Gull wing

Designation for a type of connector; name based on resemblance to a gull's wing. Common examples of components which use this connector shape include QFP, SOT, etc.

H

Heat trensfer - see section 2.12 for additional information

I

IST

Interconnect Stress Test - accelerated reliability test for scoring how resilient plated through holes and PCB interconnects are to repeated thermal cycling. The test uses the self heating of structures of the pcb.

IPC/JEDEC J-STD-020 [3]

Moisture/reflow sensitivity classification for nonhermetic surface-mount devices

IPC

Originally Institute for Printed Circuit; now Association Connecting Electronic Industries

IPC/JEDEC J-STD-033 [4]

Standard for handling, packing, shipping, and use of moisture/reflow sensitive surface-mount devices

IEC

International Electrotechnical Commission

J

J-STD

Refers to publications from the American organisation Joint Industry Standard

J-STD-001 [8]

Requirements for Soldered Electrical and Electronic Assemblies

J-STD-002 [36]

Solderability Tests for Component Leads, Terminations, Lugs, Terminals and Wires

J-STD-003 [37]

Solderability Tests for Printed Boards

J-STD-004 [20]

Requirements for Soldering Fluxes

J-STD-075 [5]

(EIA/IPC/JEDEC) Classification of Non-IC Electronic Components for Assembly Processes

JEDEC

Solid State Technology Association (formerly Joint Electron Device Engineering Council – JEDEC) - American organisation for the standardisation of semiconductors

K

L

LGA

Land Grid Array - component type, belonging to the BTC family

Liquidus

Temperature under which all elements in an alloy begin to solidify

M

Modification

Overhaul of a product's operational capacity in order to satisfy new acceptance criteria. Changes are generally necessary in order to reflect design changes present in blueprints, change requests and the like. Changes can be carried out only with express authorisation and detailed description in the relevant documentation changes.

Modification

The modification of a printed circuit assembly shall be the revision of interconnecting features by interrupting conductors or adding components as well as wire connections (ESA)

Microvia

Vertical connection hole (usually laser-drilled), executed as a blind hole for electrically connecting two directly superimposed layers by means of metallisation.

MSL

Moisture Sensitivity Level - describes the level of sensitivity of certain water-absorbing component types, which must be dried prior to solder heat stress, so as to avoid internal component damage.

N

No clean

The state or quality of flux residue after soldering (in accordance with the soldering procedure approved, by the flux manufacturer) which generally does not require cleaning, because the residues are not categorised as corrosive.

O

P

PQFP
Plastic Quad Flat Pack(age) - surface-mounted package type with gullwing-style leads

Pin in paste
Processing of component parts for through-hole mounting within a reflow-based production procedure, in which a customised solder deposit is used with the goal of supplanting the original (and more costly) wave soldering process. Here, the stability of reflow heat on the affected component is crucial.

Phenolically hardened
Hardening mechanism for circuit board materials (relating to the resin system(s) used)

Q

QFP
Quad Flat Pack(age) - surface-mounted package type with gullwing-style leads

QFN
Quad Flat No Lead - Component type belonging to the BTC family.

R

Reballing
Process which serves to exploit other alloy properties (e.g. lead-free or lead-containing) by replacing balls, especially of BGAs, substrates or other component designs; or to restore the original ball matrix.

Rework
Reworking / refinishing of non-conforming items with original processing or equivalent thereof in order to ensure that the item is fully compliant with its respective blueprints or specifications

Rework (according to European Space Agency - ESA)
Process of reworking of a defective solder joint (without changing the component) as a consequence of the repair or modification process or for restoring good workmanship of potentially defective solder joints

Rework system
This designation encompasses all systems and machines whose operation is (at least partially) automated through programming and/or user guidance, and which, compared to a purely manual mode of operation, enable an improved, reproducible process design. This type of apparatus is also characterized by a distinct component- or assembly-specific thermal profile and an on-demand accessible program.

Repair (ESA)
Change of a component with all its associated connections, including the fixing down of a lifted pad or track or any similar procedure described in this Standard

NOTE 1 Changing of components for tuning, i.e. desoldering and changing component value is not considered a repair, rework or modification operation.

NOTE 2 During tuning, solder jointing is achieved with a minimum of solder, just enough to ensure contact.

Repair
Restoration of a defective item's functional capacity in such a way that does not ensure that the item is fully compliant with its respective blueprints or specifications.

Radiation
Physical method of heat transfer in which surface temperature of the radiating body and the surface colour of the receiving body significantly affect heat transfer rate.

S

SIR
Surface Insulation Resistance - this is a key parameter particularly in the qualification of fluxes or impurities (no clean or cleanable).

Solidus
Temperature at which all elements in an alloy are solid

SAC305
Name for one of the most commonly used lead-free soft-solder alloys, composed of tin (Sn), silver (Ag) and copper (Cu). SAC305 is so called for its Sn-Ag-Cu composition of 3.0% Ag and 0.5% Cu, the remainder being tin.

SnPb37
Eutectic tin-lead solder with 63% Sn and 37% Pb

SAC solder
General term for derivations of the tin-silver-copper (Sn-Ag-Cu) solder formula

SMD
Surface Mount Device

SMT
Surface Mount Technology

T

THD
Through Hole Device

THT
Through Hole Technology

TGA
Thermogravimetric Analysis - measurement method for determining temperature-dependent mass loss (e.g. of circuit board materials)

TMA
Thermomechanical Analysis - measurement procedure for determining a material's deformation under a defined application of force

U

V

W

X

X-Ray
Band of the electromagnetic spectrum including waves of 0.1 to 10 nm with energy levels typically in the keV range. Also an established method of non-invasively diagnosing internal component elements (for instance copper conducting paths) and solder joints not amenable to visual inspection (BTC, BGA etc.). A variety of guidelines, standards and practices reference this type of diagnosis.

Y

Z

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