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PROCESS CONTROL AND RELIABILITY OF REWORKED BGA SOLDER JOINT

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ABSTRACT:
One of the key aspects in electronics manufacturing is to ensure that the soldering specifications defined by the package manufacturers is fully implemented in production and a process is in place to maintain the reliability and repeatability of soldering. When re-working or replacing a part due to manufacturing or part defect, the work is typically done by hand soldering, a manual process that is then verified by the operator through manual inspection. In the case of BGA rework, it is a challenge to provide the same level of soldering conditions as the original soldering due to different architecture of the rework equipment. This challenge is further compounded with the smaller footprint packages such as micro BGAs, QFNs and LGAs. Minimal amounts of solder in small packages and handling of parts on the rework equipment reduces the process window. It is important that a process control is in place to maintain the amount of solder paste and suitable reflow condition to ensure a reliable reworked solder joint.

This paper discusses the work done in identifying the key features for the right BGA rework equipment and the aspects important for a reliable and repeatable rework process for BGAs and bottom termination components. The work includes:

- leaded and lead-free BGAs
- achieving and replicating reflow conditions of a standard reflow oven in a BGA rework machine
- working with or without solder paste
- review of post reflow solder joint analysis

Key words:
BGA (Ball Grid Array); QFN (Quad Flat No-Leads); LGA (Land Grid Array); Rework; Repair; Profile, IMC (intermetallic compound)

INTRODUCTION:
The lead-free solder does not wet metal surfaces as well as the traditional tin-lead metallurgy. This narrows down the process window for lead-free solder as compared to leaded solder. Due to the shrinking form factor of the parts and the boards, rework process has to be focused on the component being worked on without damaging the board surface and surrounding components. The bottom termination packages, high density BGAs and micro BGAs cannot be inspected for the inner rows of solder balls and if tomography or another 3D x-ray technique is not being used, the verification relies on the visual inspection of the periphery solder balls only.

The paper is divided in five sections:
- Selection of equipment: It should be capable of accurate placement and replicating reflow oven heating conditions. - Board Preparation: It is important that the rework will not cause defect or board damage.
- Development of reflow profile: Identify correct location for attaching thermocouple and heating conditions and ensure uniform heating.
- Techniques for successful Rework process: Selection of gel flux or solder paste as the medium of soldering. - Verification and validation of rework: To validate the integrity and reliability of the reworked solder joint.

SELECTION OF REWORK EQUIPMENT:
The factors to be considered for BGA rework equipment are:

- Proper reflow conditions and reflow temperature for rework can be achieved with an effective heating method. Most of the machines support bottom side heating to raise the temperature in the target reflow time and retain the heat. Manufacturers have used convection and Infrared (IR) heaters or both of them for bottom heating. The IR heater has the advantage of uniform heating over a larger area of the board without air flow management and it works better for general heating of the board. The top heater can be used for focused heating of the part and control of the profile curve.
- The machine software should provide the feature to set up and program the machine for a new board or a new part based on the user's defined parameters of temperature and time.
- System needs to be capable of handling all board sizes and packages (from small 0402 size to 50mm square)
- The equipment should have an accurate optical alignment capability and placement accuracy.
- The heater should be capable of handling RoHS compliant parts that require higher reflow temperatures.
- The equipment should support site cleaning for removal of excess solder and smoothening the surface after removal of a part.

- The calibration features should be defined and the equipment should be easy to calibrate and maintain.
- The equipment should support high volume rework of BGAs if used in a high production environment. The feature may include automatic residual solder removal from pads, flexibility in vision camera alignment to place parts at different locations and reflow multiple components simultaneously.
- It is important that the supplier should provide technical support and local maintenance.
- The equipment should be reasonably priced.

Figure 1. BGA rework machine

PREPARING THE BOARD FOR BGA REWORK:

For successful BGA rework on a fully assembled board, the board should be pre-conditioned by baking it as per JEDEC033 specifications to eliminate any moisture accumulated over time in the assembly. This moisture can cause delamination or other catastrophic failure of the assembly.

Unless the MSP level of the part and the board condition are known to be of low MSP level, it is a good practice to bake the board before it is heated for rework.

To reduce the number of heat cycles, it is preferred to remove the suspected defective component at the same time as when the rework recipe is developed.

DEVELOPING THE REFLOW PROFILE:

The reflow profile is the most critical element of a good and reliable rework. The reflow profile has to achieve two primary objectives:

- the heat conditions of the package and the board, i.e. temperature, heating and cooling rate
- maintain the heat conditions for the specified time, i.e. time above liquidous, total profile time

Source of Input for Reflow Profile Development:

To develop a robust and reliable profile, the data should be taken from:

- Component parameters, provided by the manufacturer on the data sheet under the process considerations for soldering
- Solder paste/gel flux processing conditions
- Characteristics of the board/assembly: thickness, materials, Thermal glass transition rating, critical component located in close proximity of the part to be reworked
- Heat-transfer device (rework machine) parameters

After the above are addressed, a starting point for the profile can be established.

Mechanics of Profiling

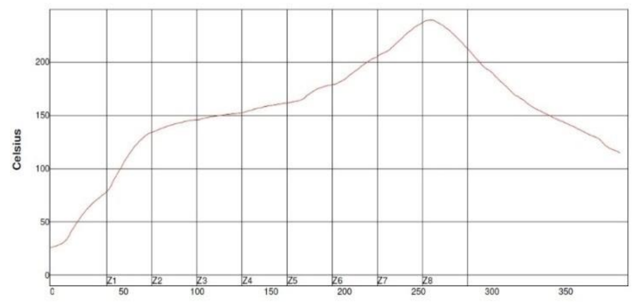
At least one thermocouple should be placed under or very close to the BGA in order to probe the package for attaining the recommended soldering conditions. For large BGAs (>40mmx40mm), it is recommended to have two probes placed, one in the middle and one on the corner of the BGA to monitor the ΔT. If the device has any specific thermal characteristic that has to be monitored, then an additional probe has to be placed accordingly.

The system provides measurement capability with the thermocouple interface; thermocouples are attached to the equipment to independently monitor the temperature and time curve. Limits should be checked for peak temperature, max rising slope, total time above liquidous and cooling slope to ensure that they conform to the part and solder paste manufacturer specifications. Equipment settings should be edited and the rework profile repeated until all parameters are within the specified range.

Profile Verification

The initial verification of a successful rework is through visual inspection for alignment and solder ball shape and finish. The package should be further verified through x-ray inspection. The integrity of the rework is verified through comparison of the profile curve of the BGA rework with the manufacturer's specifications and the profile curve of the reflow oven. The two profile curves should be compared for initial ramp from ambient to about 120C, soak time up to 200C, time above liquidous of 217C and cooling rate. Both the curves are very similar in these characteristics.

Figure 2. Typical lead-free BGA rework profile, developed



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on semi-automatic BGA rework equipment **Figure 3.** Typical lead-free reflow profile, developed on an 8- heat zone convection reflow oven

REWORK TECHNIQUES AND BENEFITS:

The operator or the engineer has many choices in the process they will use to rework a board. Some of the factors which affect the reliability of the solder joint are:

- Choice of gel flux or solder paste as the soldering medium
- Solder paste application techniques
- Methods for achieving higher volume of boards for rework
- Rework of POP

Rework Using Gel Flux Deposition for BGA

For most of the BGAs (>10mmx10mm) and for occasional rework due to normal process fall-out, gel flux will be sufficient to ensure a good soldering medium for a reliable solder joint.

Gel flux is a viscous material that is easy to apply, does not flow after it is applied on the board and does not easily evaporate at higher temperatures. It exhibits the characteristics of the flux in the solder paste as it becomes active at the right temperature during reflow and promotes soldering. Its tackiness is important for securing the part so that it is properly aligned on the pads/contacts. It is readily available in both no-clean and water-soluble chemistry to fit the requirement of the assembly initially built on the SMT line.

Gel flux application is done by using a small brush; a thin film layer spread evenly across all pads is performed under a microscope to ensure no pad is left without flux.

The flux should be kept within the area where needed as it will usually thin out during reflow and spreads outwards. Its downside is that it results in higher flux residues, which is not easily removed in the case of no-clean gel.

Figure 4. Gel flux application on pads using a brush

Normally, gel flux is recommended mostly for low volume to support smaller quantity of production fallouts or prototyping. It is an economical method for replacing BGAs in common packages such as plastic BGAs, where size or the thermal mass of the part is not a concern.

Gel flux is not recommended for reworking non-BGA parts (bottom terminations).

Rework using Solder Paste Deposition

Micro BGA packages typically less than 7mmx7mm would be moved by the airflow from the equipment and will cause misalignment of the part to the board, whereas bottom termination components do not have any solder and solder paste will be the only option to introduce solder to the joint. The solder paste can be introduced by printing solder on the board or on the part. It is not possible to position a ministencil on a densely assembled board for printing solder paste. The better choice is to print solder on the part and place it on the board using the BGA rework machine.

There has been much debate about whether adding solder paste during BGA rework will significantly strengthen the solder joint and enhance its reliability. By comparison, the amount of solder from the ball itself is much bigger compared with the amount of solder paste added. However, it is considered that the extra amount of solder will result in a more reliable, stronger solder joint.

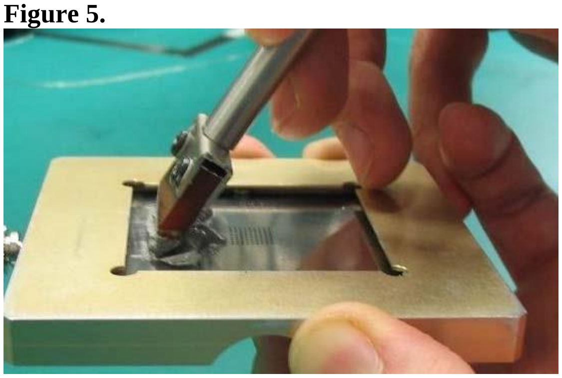
Adding solder paste can also be beneficial to compensate for small irregularities left from cleaning the old solder from the pads or from co-planarity concerns on the new packages, especially if it is a re-balled package, and there could be a variation on the height of the solder balls.

Solder paste can also help during the rework process when the flatness of the PCB is not perfect; therefore a board support system is essential for larger boards during rework.

The use of solder paste for rework has become more predominant in the last few years, with the emergence of numerous lead-less packages and to enhance the reliability of the solder joints, especially with the introduction of RoHS.

The printing of solder paste can be achieved by using a mini-stencil, with the aperture openings the same as the part pad dimensions or PCB land pattern.

Figure 5.



Depositing solder paste on the new part (LGA, QFN, BGA) before placing on the board at the rework system

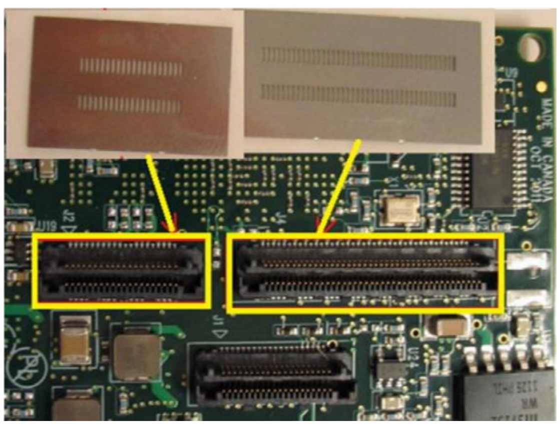


Figure 6. Use of mini-stencils for rework/replacement of SMT fine connectors

A rework involving the solder paste has the advantage of replicating the exact same conditions as in the original part placement, SMT printing and reflow in the oven.

Besides BGA packages, solder paste for rework/repair is recommended for:

- Larger volume repairs
- After-market services
- Very complex, high-dollar value parts
- Customer specifications
- LGA, QFN, modules, SMT fine connectors, where solder paste needs to be added
- Board upgrade/retrofit using an adapter, due to unavailability of the original part (see Fig. 8)

SPECIAL REWORK TECHNIQUES:
Achieving High Volume On Rework

- For high volume production and average fall-out, the number of boards to be repaired for BGAs could be in 100s of boards per day. To keep up with the work and production, techniques should be used for efficient and mass rework of BGAs efficiently. The techniques for handling higher volume can be achieved through:
- Set up multiple BGA rework stations to work in parallel
- While one board is being reflowed, the operator can load and unload on other machines.
- Use multi nozzle head to concurrently remove and reflow parts on a panel
- Use custom shape and sized nozzle to work on multiple odd-shaped or de-panelized boards concurrently

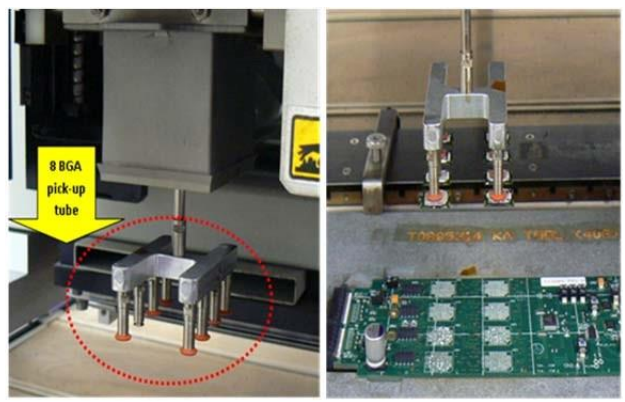


Figure 7. Multiple BGAs being reworked simultaneously with a custom pick-up nozzle

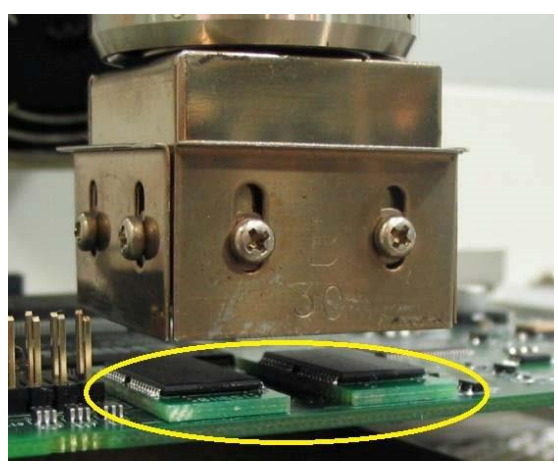


Figure 8. Special rework - reflow retrofit adapter modules using the rework machine

Rework of Package-on-Package (POP) Devices

To remove and replace a POP device, it is advisable to remove both the parts from the PCB and replace with new parts. Any attempt to work on only one package may result in defects on the other part due to removal and placement of the other part.

Similar to the original reflow considerations for the very thin and heat sensitive POP devices, a well-controlled rework process should be developed for removal as well as placement during rework.

The process should be to reflow and remove both the parts from the board and clean the excessive solder off the pads. Experiments with solder paste printing on the balls and gel flux printing on the pads have been conducted and they are both successful.

Similar to the options mentioned in the original placement methods, rework can also be implemented through prestacking and reflowing both the packages and then placing and reflowing them on the board. The other option is to apply gel flux on the main board, place the lower BGA, apply gel flux on the balls of the upper package and place it above the lower package. This combination can then be reflowed in one pass. Experiments have shown good results on the repaired boards using the latter method.

VALIDATION OF REWORK PROCESS AND SOLDER QUALITY:

Upon completion of the rework process, a visual inspection around the periphery of the newly installed part (where clearance allows) combined with a 2D X-ray inspection should be sufficient to validate that proper reflow conditions have been achieved and that quality standards are met. Although not necessary, a more detailed verification can be done though cross-sectioning that will look at the metal structure of the newly formed solder joints. This is typically required for process development.

During the lab analysis, the shape, size, voids and the structure of the solder joints are verified and measurement on the Intermetallic compound can conclude the quality of the solder joints.

From experiments, two identical parts were tested; one BGA was reworked with gel flux applied on the PCB pads, and the second identical board was reworked by adding solder paste, which was deposited on the part's solder balls. Both samples have undergone identical reflow conditions, with lead-free and no-clean chemistries.

Based on the pictures and the measurements taken, there was no significant difference between the two. Both exhibited good solder joint consistency and the shape of the collapsed solder joints was equally good.

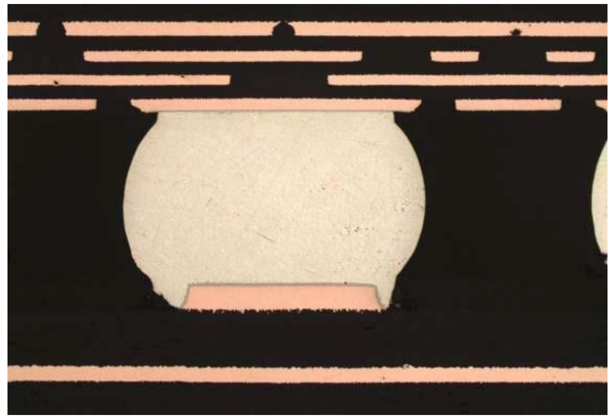


Figure 9. Cross-sectioning for a BGA solder joint reworked using gel flux

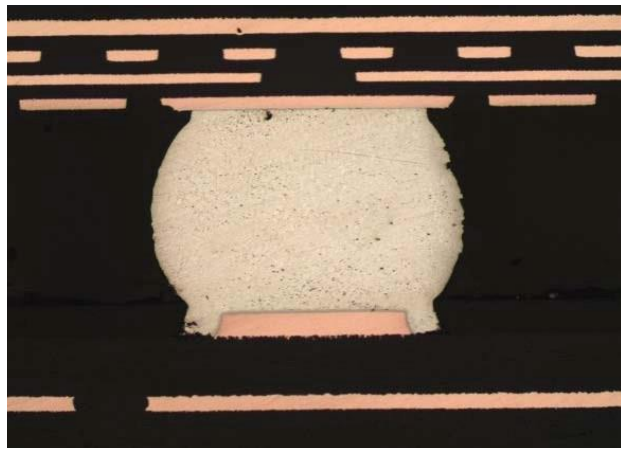


Figure 10. Cross-sectioning for a BGA solder joint

reworked using solder paste

The IMC measured had comparable results, varying from 0.03-0.11mils for the sample reworked with gel flux and 0.05-0.13mils for the sample reworked with solder paste.

CONCLUSION:

With the introduction of the BGAs and leadless bottom termination components, the BGA rework systems have become a very important piece of equipment which every manufacturer has to depend on, not only for repairing regular fall-out, but increasingly for providing independent localized BGA reflow, when mixed BGA/CSP packages are being used on the same board.

It is very critical to target and achieve higher workmanship standards and a robust, repeatable and reliable rework process for rework of BGA and bottom termination components.

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- Solderability Testing and Solutions, Inc. (ST&S Group) for micro-sections pictures and report of Creation boards

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