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DESTRUCTIVE EXAMINATION OF SOLDER JOINTS ON AN SMT MANUFACTURING LINE

Elena MUNCUT (WISZNOVSZKY), Aurel Ion PERIANU, Valentin MULLER, Geza - Mihai ERDODI

Abstract: *The paper describes a line for soldering electronic components on PCBs and a method for optimizing solder joint parameters by destructive methods. A microscopic metallographic analysis, a tensile and bending tests and 3D simulations of mechanical tests are also performed. Finally, a method for determining dimensional non-conformities on the PCB manufacturing line by the SMT method is described.*
Keywords: *microscopic metallographic, tensile tests, bending tests, 3D simulation.*

1. INTRODUCTION

A surface mounted technology line (SMT) can differ greatly from one to another, it all depends on the factory and the final product. The first piece of equipment is a common and simpler one, a board loader, which inserts boards into the line from magazines or stacks of boards, being part of the handling equipment category.

Next comes a laser marking equipment, which marks the board with one or more data matrix to have traceability throughout the process, followed by a handling equipment that takes the board, transports it to the next step. This has a blowing system that cleans all impurities from the PCBs, both on the top and bottom.

The board goes to a printer, where having a template for each type of product, the paste is printed on islands (pads), to be inspected in the Solder Paste Inspection (SPI) which is placed after the printer. A handling equipment is attached to the SPI, which sends the compliant boards further and stores the non-compliant ones in a warehouse until they are checked. Next the pick-and-place comes planting modules using a vacuum-based system, which lifts the components from a dispenser and plants them on the board.

Next comes the second inspection system in the ideal line, an automatic optical inspection (AOI) with which we check the components to ensure that they are mounted where they should be and with the correct orientation before they are soldered, the repair cost being much lower at this stage. The oven is the next piece of equipment, which, through temperatures of hundreds of degrees Celsius, melts the paste and through cooling, the solders between the islands and the components are formed.

After the soldering is finished, a handling equipment cools the outgoing boards with the help of fans, but also has a magazine that can collect the boards if the next equipment is busy, this being the third inspection equipment, also an AOI, but now we also check the solders. The components have the solders under the body of the components, not visible to us, therefore the AOI is followed by an Automated X-Ray Inspection (AXI) [1].

1.2 The Solder Paste Inspection and 3D Measurement (SPI)

Most defects that occur in production (70%-80%) are due to incorrect printing of the solder paste, for this reason one of the important operations is the Solder Paste Inspection (SPI). The circuit board is a robust and reliable device.

The stretch knives are thin, which is why they wear out. A common damage is to the printing table that loses its flatness after a number of hours of operation. The template becomes thinner and we no longer have the desired volume of paste.

The control program is generated using a Gerber file. In this file we have all the necessary dimensions to be able to compare the obtained dimensions with those established, figure 1.

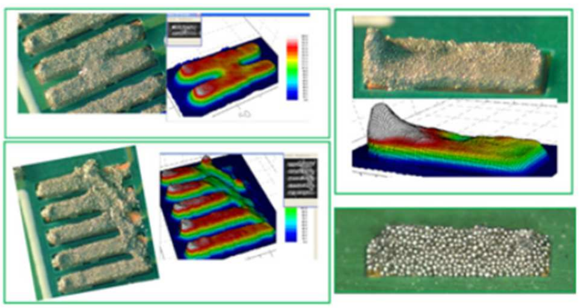


Fig. 1. Modelling of the determined dimensions during the process

In the Gerber file there is a 3D modelling with all the information regarding: board dimensions, position, shape and dimensions of the alloy islands and reference points. The thickness of the template is entered and the SPI will calculate the ideal amount of paste. The defects determined with the SPI are: volume, position, short circuit, shape, height, solder joint area.

The SPI control begins when a plate enters the conveyor belt, it is taken to a mechanical stop, a presence sensor detects the plate in the desired position, stops the conveyor belt, a system fixes the edges of the plate. The inspection head moves on the X and Y axes to the reference points, which are detected, the measured offsets are used to filter the results.

For the SPI, the last part of the settings remains that of tolerances and the choice of measurements. Here we have the following types of measurements and tolerances:

Volume – The ideal volume is calculated based on the length and width of the apertures, as well as the thickness of the template, and converted into a percentage that is 100%. A tolerance will be given to this, depending on the size of the apertures, the component package that will be mounted on the respective island/islands or other process requirements even the end customer. There are two types of tolerances, one called warning and one called error.

On the device we can set the following from the calculated volume:

- lower error limit at 60%
- minimum warning tolerance at 80%
- maximum warning tolerance 120%
- upper error limit 140%

A volume of solder paste between 80%-120% is accepted. If the pulp volume is between 60%-80%, respectively 120%-140% it is also accepted, but the data will be recorded as a process indicator.

If the pulp volume falls below 60%, the volume of solder paste is considered insufficient. And if the volume of solder paste is above 140% it is considered excess pulp. In both cases SPI stops the process.

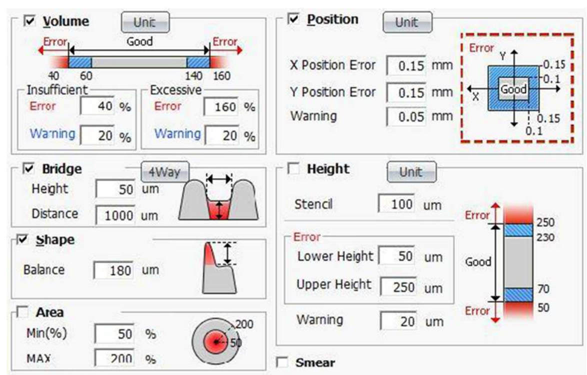


Fig. 2. Tolerances and the choice of measurements

Positioning – refers to possible offsets that occur during production. Normally, the paste deposit should be as centred as possible on the middle of the island. Here we can set the tolerance on the X and Y axes, with reference to the center of the island versus the center of the paste deposit, it can be set in microns or percentage, and we also have the possibility of setting the error tolerance and warning.

Short circuit – with this setting we check the short circuit between islands, having 3 simple settings, the minimum height from which a short circuit is considered, the maximum length and the search directions relative to the island (up, down, left, right).

Height – with reference to the thickness of the template, a lower and upper limit is set in percentage or microns.

Shape – compares two parts of the paste deposit, the top and bottom, taking the print directions as a reference. Tolerances are set in microns and refer to the maximum height difference between the two areas.

Area – the limits (lower and upper) are set in percentage; the 100% area being calculated from the aperture drawings in the Gerber.

Figure 2 illustrates the types of measurements and inspection tolerances.

2. OPTIMIZATION OF THE BONDING PROCESS EXPERIMENTAL RESEARCH

2.1 Microscopic examination

To examine the microstructures [2] of the soldered joints, figure 3, in order to analyse the possible cracks that they contain, it is necessary to adequately prepare the samples to be analysed.

The base material for the active part (contact pad): WCu/80.20 (DODUCO) with the commonly recommended filler material for soldering the CuCr + WCu/80.20 base material pair is the silver alloy BAg 45Cd (STAS 8971-87). This alloy will have to be replaced with a Cd-free alloy.

The sectioning should be performed with low-speed cutting devices to avoid inducing additional stresses.

The following solutions were used for the chemical attack of the section surfaces:

Performing microscopic analysis during bonding plays an important role in the visibility of micro cracks that otherwise cannot be determined, and the intermediate layers appeared during bonding by diffusion. Even if the base material does not melt due to the possibility of structural changes in this thermal example, it is possible to introduce.

- in the case of Pb-based alloys: a solution containing 2 ml of hydrochloric acid and 98 ml of industrial alcohol;

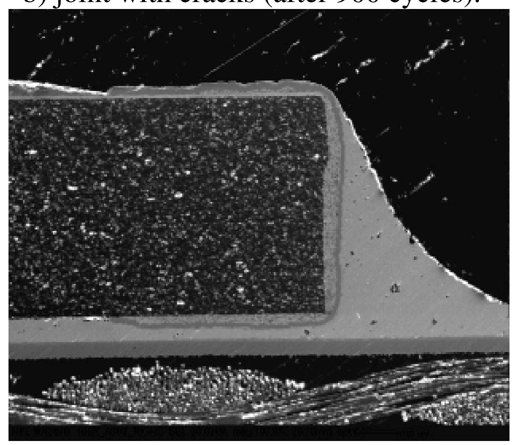
- in the case of Pb-free alloys: a solution composed of 2 ml of nitric acid, 2 ml of hydrochloric acid and 96 ml of distilled water; polishing is done as in the previous case

The sectioned samples are polished with abrasive paper with successive grain values between 15 μm and 0.25 μm, final polishing is done using a diamond paste with a grain size of 0.25 μm and are finally coated with epoxy resins.

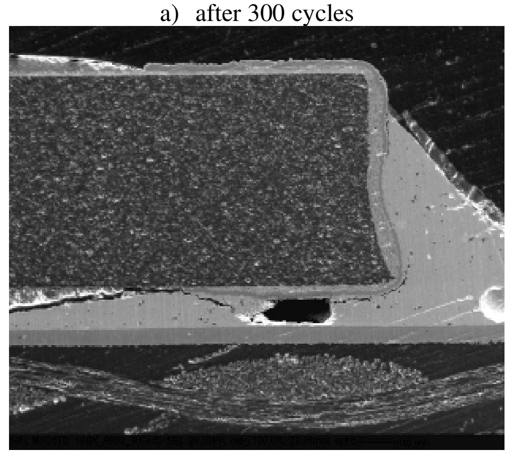
In figure 3, examples of analysed micrographs are presented:

- a) solder joint of a resistor, without cracks (after 300 cycles),

- b) joint with cracks (after 900 cycles).



a) after 300 cycles



b) after 900 cycles

Fig. 3. Micrographs of the soldered joint

For microscopic analysis (under an electron microscope) it was necessary to deposit conductive layers (AuPd, Au or Cu) on the surface of the samples. It is mentioned that the microstructural analysis technique is useful for evaluating the degradation mode of the joints, but is not relevant for quantitative assessments of crack propagation in the bonded joint.

2.2 Examination with penetrant liquids

This is another non-destructive examination technique used to locate and assess the extent of cracks, [3]. The working procedure was as follows:

- cleaning the samples in an ultrasonic bath in a solution of 50% water and 50% isopropyl alcohol;
- after drying with compressed air, they were placed in a vacuum container and coloured penetrant was applied. Partial vacuum was applied for 15 minutes;

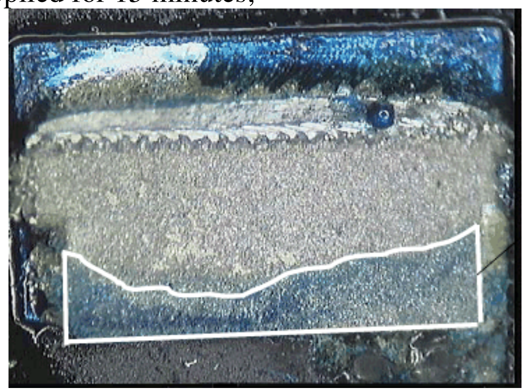


Fig. 4. Liquid penetrant examination of a soldered joint

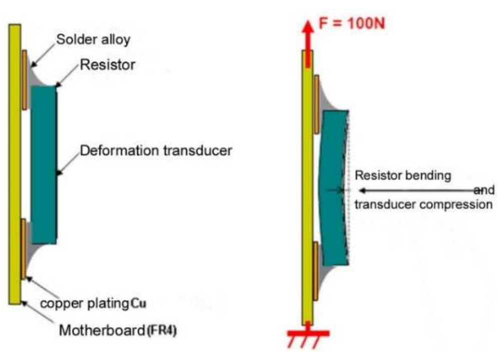
- the samples were placed in a convection oven, 10 minutes at 50^0C;
- the components were extracted from the base plate and the joints were analysed under an optical microscope.

A specific image analysed in the case of liquid penetrant examination is shown in figure 4. The area delimited by a white outline is the area with cracks.

The area of the cracked zone was determined, depending on the number of cycles supported by the tested plate, by counting the pixels in the selected area of the image.

2.3 Mechanical tests

Mechanical tests [4], [5] were applied to investigate the deformations of the soldered joint as a function of time under the action of external stresses.



a) Mechanical test configurations for tensile testing

b) Tensile testing device

Fig. 5. Mechanical test configurations and device for tensile testing

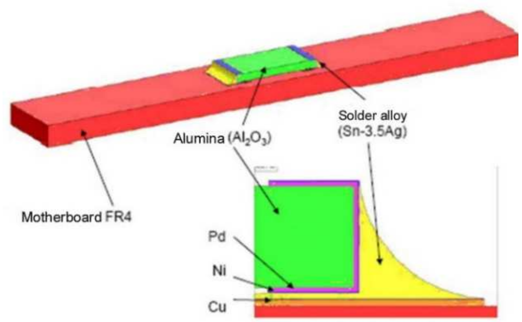
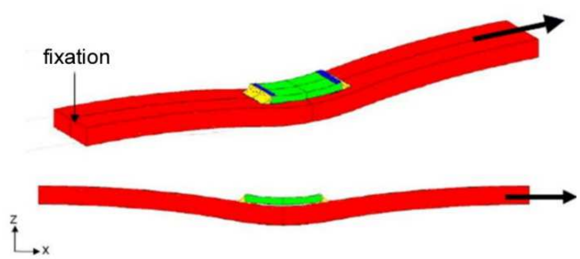


Fig. 6. Mechanical test setup



a) Bending test configurations

b) Shear testing device

Fig. 7. Bending test configurations and shear testing device

Next, configurations are presented in figure 5, figure 6 and figure 7 and experimental results.

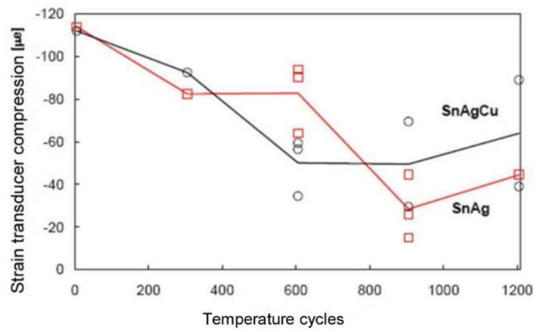


Fig. 8. Experimental results in compression

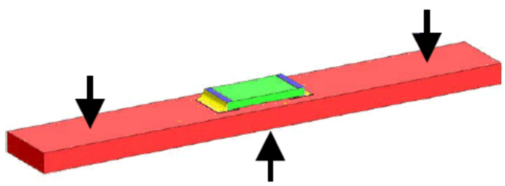


Fig. 9. Configuration for 3-point bending test

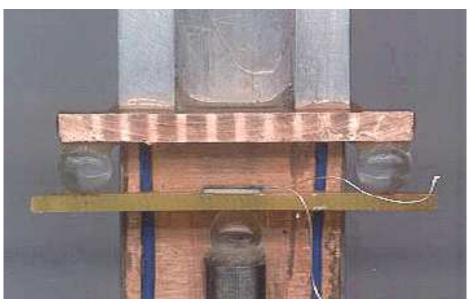


Fig. 10. 3-point bending test fixture

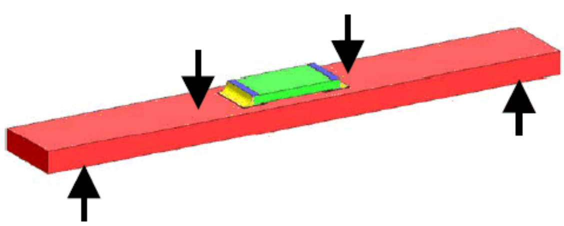


Fig. 11. Configuration for 4-point bending test

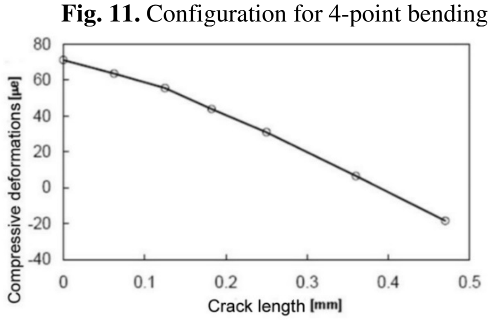


Fig. 12. Experimental results of the compression test

The tests were performed on resistors soldered on FR4 base plates, and the measurements of the quantities of interest were recorded after 0, 300, 600, 900 and 1200 stress cycles.

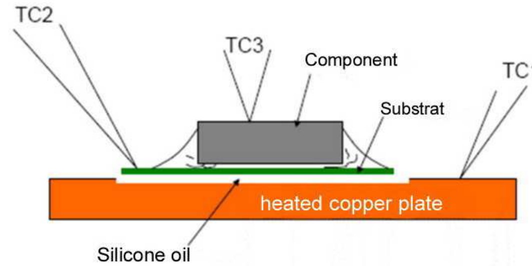


Fig. 13. Experimental setup for heat transfer monitoring (TC1, TC2, TC3 – thermocouples)

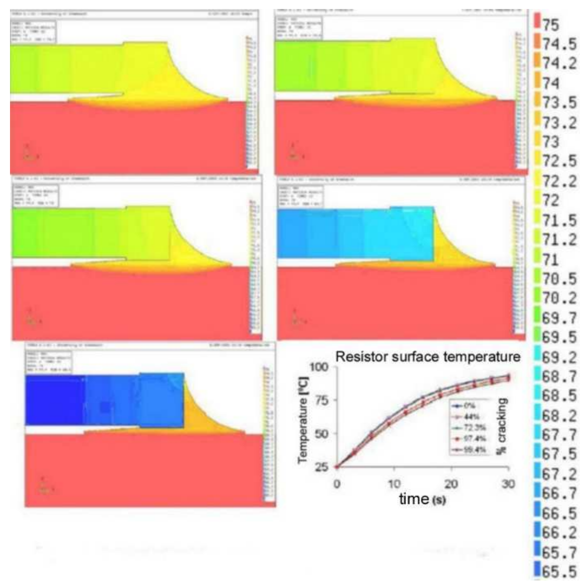


Fig. 14. Bonded joint patterns (with percentage length of crack length) following exposure to 100^{0}C for 12 seconds

3. CONCLUSIONS

The microstructural examination after sectioning proves to be the most effective method for identifying and locating cracks and analysing microstructural changes produced by thermal cycling. The drawback represented by the difficulty of locating long cracks in small joints can be eliminated if the analysis is performed under an electron microscope (instead of an optical microscope). The method is recommended for quantitative evaluations of glued joints over their entire service life.

The liquid penetrant examination has advantages in the analysis of cracks in glued joints and can be applied to analyse the entire area of cracks. The applicability of the method is not dependent on the positioning of the sectioning plane, as in the previous case.

The shear test is used both to assess the degree of crack propagation and to assess the strength of the joint.

Bending (3 and 4 point) and tensile tests depend largely on experimental conditions and operator experience, and may lead to additional degradation during the test. For these reasons, it is considered that further refinement of these procedures is necessary before they can be recommended for effective use as methods for evaluating the integrity of soldered joints in the field of electronic circuits.

4. REFERENCES

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Examinarea distructivă a îmbinărilor lipite pentru optimizarea parametrilor pe o linie de fabricație SMT

Lucrarea descrie o linie de lipire a componentelor electronice pe PCB și o metodă de optimizare a parametrilor îmbinării lipite prin metode distructive. Analiză metalografică microscopică, încercări de tracțiune și încovoiere. Sunt realizate și simulări 3D ale încercărilor mecanice. În final se descrie și o metodă de determinarea a neconformităților dimensionale pe linia de fabricație a PCB prin metoda SMT.

Elena MUNCUT (WISZNOVSZKY) [0000-0002-4097-8500], Associate Professor, “Aurel Vlaicu” University Arad, Faculty of Engineering, Dept Automat Ind Eng. Text Prod & Transport, Romania, Arad, Email: muncutstela@yahoo.com, Phone: 0746491247, Home Address: str. Lungă, nr.21, Romania, jud. Arad, Șeitin.

Aurel Ion PERIANU, INCD ISIM Timișoara, Home Address: Email: aperianu@isim.ro, Phone: 0740138473

Valentin MULLER [0000-0002-6890-0473], Associate Professor, “Aurel Vlaicu” University Arad, Faculty of Engineering, Dept Automat Ind Eng. Text Prod & Transport, Romania, Arad, Email: valentinmuller7@yahoo.com.

Geza-Mihai ERDODI, lecturer, “Aurel Vlaicu” University Arad, Faculty of Engineering, Dept Automat Ind Eng. Text Prod & Transport, Romania, Arad, Email: geza.erdodi@gmail.com, Home Address: Bld. Iuliu Maniu, bl.36, et.3, ap.13, Romania, Arad, Phone: 0744703717