Manufacturing Science and Education 2025

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 68, Issue Special II, Month July, 2025

STUDY ON THERMAL CONTROL OF TECHNOLOGICAL FLOW IN SURFACE-MOUNT TECHNOLOGY SOLDERING OF ELECTRONIC COMPONENTS

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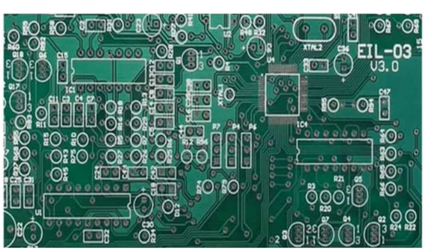
Abstract: *The paper presents an industrial application of research on the occurrence of cracks in joints made with Pb (Lead)-free alloys, with an experiment carried out on a printed circuit board type with rigid FR4. FR4 is a composite material composed of woven fiberglass cloth with an epoxy resin binder that is flame resistant. The base plate is 1.6 mm thick, plated with a 35 μm thick copper (Cu) layer and a gold (Au) and nickel (Ni) -based finishing layer. The experimental part is a comparative study in the case of shear tests, for 5 samples having joints soldered with alloys containing Pb and 5 samples having joints soldered with alloys without Pb. The study of crack occurrence was based on subjecting the joint to a set of 200 thermal cycles and inducing local stresses by acting on the components and the temperature of the joining alloy in the first case being maximum 240^{0}C. The results are applied industrially on machines for placing components on through-hole boards with wave soldering or Surface-Mount Technology (SMT) assembly machines with soldering in a complex thermal cycle oven: heating in several stages to the soldering temperature and finally cooling.*

Keywords: *printed circuit board, components, Surface-Mount Technology (SMT) assembly, shear tests, tin-lead (SnPb), without lead (Pb)*

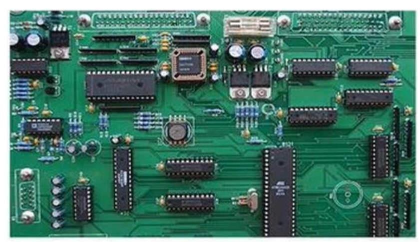
1. INTRODUCTION

The printed circuit board (PCB) pick-and-place machine (P&P) is a robotic equipment that is used to take electronic components from a tape and place them on the surface of a printed circuit board, figure 1, [1].

There are machines for placing components on through-hole boards or Surface-Mount Technology (SMT) assemblies that can be served by two different types of pick-and-place machines, as well as sequential arrangement machines, [2].



a) Initial PCB



b) PCB in final assembly

Fig. 1. Component placement

The high-speed „pick-and-place” machines were built around a single turret design that could mount two dozen stations. The turret rotates, the stations pass through the back of the machine picking up parts from belt feeders mounted on a moving cart. The station advances and passes an optical station that calculates the angle at which the part was picked up, allowing the machine to compensate for the deviation. When the station reaches the front of the turret, the board is moved into position, the nozzle is rotated to place the part in the proper angular orientation, and the part is placed on the board.

The components for the Surface-Mount Technology system are mechanically designed with two metal lugs or end caps that can be soldered directly to the surface of the printed circuit board.

The Wave Soldering Machines are equipment used in the process of soldering electronic components using Through-Hole Technology (THT), ensuring a solid connection between components and PCB. Their process is automated, and has few errors and high efficiency. Soldering is by immersion, the PCB passes through a wave of molten alloy [3 - 4].

2. THE EXPERIMENT

The present study obtained in the case of shear tests, for 5 samples having joints soldered with alloys containing lead (Pb) and 5 samples having joints soldered with alloys without Pb.

Table 1

Experimental results of shear force

No. of samples	Shear force, [N]			
	Before temperature cycles		After temperature cycles	
	SnPb	*Without PB*	*SnPb*	*Without PB*
1	69,7	64,6	60,5	53,4
2	73,6	75,4	56,1	53,4
3	65,6	71,2	62,9	54,7
4	68,5	69,8	62,3	62,4
5	69,6	69,1	59,7	54,2

The samples subjected to the shear test are represented by soldered joints, with Tin-Lead-Copper (SnAgCu) and Tin-Lead (SnPb) type alloys, of electronic components on printed circuit boards (the temperature of the joining alloy in the first case being maximum 240^{0}C, and in the second case maximum 260^{0}C), the temperature values that characterize thermal cycles are between 65^{0}C ÷ 150^{0}C.

Table 2

The average resistance of joints subjected to temperature cycles

Joint type	Average joint strength (N)		Percentage change (%)	Assessment
	Before temperature cycles	After temperature cycles		
SnPb	69,4	60,3	13,11	accepted
without Pb	70,0	55,62	20,54	accepted

Table 3

Joint strength after thermal cycling

Joint type	Average joint strength (N) after 200 temperature cycles	Percentage change (%)	Evaluation
SnPb	60,30	7,76	accepted
without Pb	55,62		

The experimental results are presented in Table 1.

The values of the bond strength before and after subjecting the samples to 200 temperature cycles are presented in Table 2.

Table 3 presents, for comparison, values of joint resistance after subjecting the samples to 200 temperature cycles.

3. METHODS FOR DETECTING CRACKS IN SOLDERED JOINTS

To examine the functional integrity of conventional SnPb type joints, a series of investigation techniques are used, the applicability of which is considered to be extended to joints based on Pb-free alloys.

The results obtained within the integrity examination programs of conventional bonded joints have demonstrated that failures in the case of these joints are not short-term processes, but are due to gradual evolutions of degradation, especially the development and propagation of cracks. A typical example of a soldered joint, from the composition of electronic circuits, with cracks, is shown in figure 2.

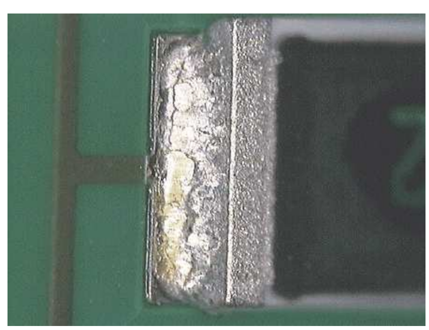


Fig. 2. Bonded joint containing cracks

The resistance of soldered joints is affected especially, in cases where they incorporate rigid ceramic components (resistor type), soldered on substrates (motherboards) of the type of printed circuits. We consider the most unfavorable case, the integrity assessments were performed on a set of resistors soldered on FR4 type boards (glass fiber construction, plated with a layer of copper). Figure 3 shows such an assembly subjected to tests, in which the baseboard is 1.6 mm thick, plated with a layer of Cu having a thickness of 35 μm and a deposited layer, for finishing, based on Au and Ni.

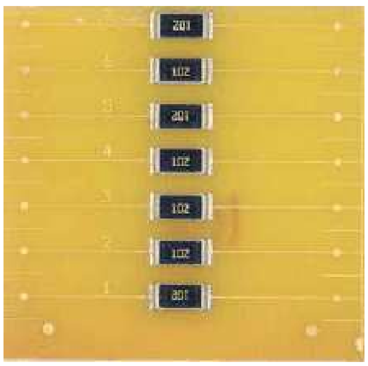


Fig. 3. Motherboard + electronics assembly

The solder alloys (without Pb) used were of the 95.5Sn3.8Ag0.7Cu (95.5Tin 3.8Silver 0.7Copper) and 96.5Sn3.5Ag (96.5Tin 3.5Silver) type.

The usual technique applied for generating (inducing) cracks in soldered joints consists of applying thermal cycles, which generate shear stresses, [6].

The parameters of the applied temperature cycles are presented in figure 4.

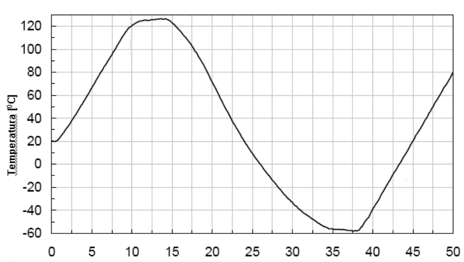


Fig. 4. Thermal cycles

In the case of the tested circuits, the thermal expansion coefficients of the materials in the soldered joint had the following values:

- alumina: $6,5x10^{-6}/^{0}C$;
- solder alloys: $21 \div 25x10^{-6}/^{0}C$;
- (Cu) copper cladding layer: $17,6x10^{-6}/^{0}C$;
- FR4 base plate: in the x-y plane, $12 \div 18x10^{-6}/^{0}C$, and in the z direction $650x10^{-6}/^{0}C$;

All of the above expansion coefficients are, temperature dependent.

4. THE INDUSTRIAL APPLICATION OF THE RESEARCH

The process begins with PCB design, PCB fabrication and preparation, solder paste application, SMD (Surface-Mount Devices) component placement and reflow soldering. After that, the assembled boards are inspected and tested to detect defects and ensure quality standards.

4.1 Equipment required for the SMT process:

Magazine loader, in figure 5, there is an equipment that is used to load and unload printed circuit boards into and out of different stages of the assembly process on the SMT line.

Fig. 5. Magazine loader

The laser marker is a piece of equipment, figure 6, used in the electronic component assembly industry that uses a laser beam to etch a QR (Quick Response) code onto PCBs. The markings include: serial numbers, logos, production dates or other information needed for traceability and identification.

The role of the laser marker is:

a. Traceability: QR codes for tracking and managing products throughout the supply chain and during the product lifecycle,

b. Identification: serial numbers, company logos and other identification marks on individual components or PCBs,

c. Quality Control: data marks to monitor production batches and ensure compliance with quality standards,

d. Personalization: customer-specific markings, such as product name or technical specifications.

Fig. 6. Laser Marker

The main printer, figure 7, is designed to evenly apply solder to the PCB surface.

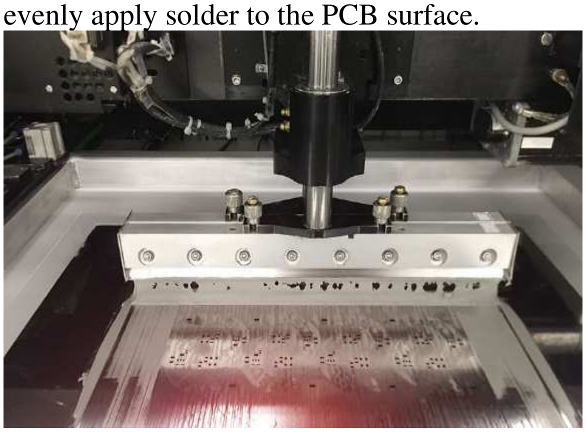


Fig. 7. Printer SMT

The SMT printer uses a stencil (template) to determine the exact locations where the solder should be applied. The stencil has openings that correspond to the solder points on the PCB. The precise alignment between the stencil and the PCB is crucial. The modern SMT printers use optical systems and cameras to ensure that the stencil and the PCB are aligned correctly. These are controlled by software, which allows precise programming of the mark type, the location and other parameters.

The solder alloy used is SAC305SnAgCu with low-voiding properties and grain size 4. It has the following chemical composition: Tin (Sn) 96.5%, Silver (Ag) 3.0% and Copper (Cu) 0.5%. It does not contain lead according to global requirements in the field, [5].

The melting point of the alloy is 217-220°C, comparable to traditional Pb-Tin based alloys. The solder has tensile and torsional strength at the value required for electronic connection applications. The alloy is reliable under operating conditions of thermal cycling and exposure to humid environments. Due to the silver content, it has good electrical and thermal conductivity which is important for the electronic performance of the assembled components, [6].

The pick-and-place equipment, figure 8, is an automated device used in the assembly of printed circuit boards. They consist of a movable head equipped with multiple suction nozzles that pick up electronic components from the supply strips and place them on the PCB. The nozzles are interchangeable and can handle various sizes and shapes of components.

Fig. 8. Automatic Pick and Place Device - Component Feeding Area

The pick-and-place equipment is equipped with cameras and sensors that help to identify and correctly orient components. The vision system checks the exact position of the components and the adjustments needed for precise placement. The electronic components are supplied to the pick-and-place equipment by conveyor belts. The conveyors are mounted on the machine and are configurable to handle multiple types of components simultaneously.

The equipment head moves from the feeder to the exact location on the PCB where the component needs to be placed, the speed and accuracy of movement are essential to ensure quality placement and soldering. The pick-and-place equipment is controlled by software that allows the paths and positions of the components to be programmed. The software can optimize the path of the pick head to minimize the cycle time and maximize the efficiency.

The Panasonic PanaCIM Manufacturing Execution System (MES) has an integrated management system that controls pick-and-place equipment and the reflow ovens, optimizing the production flow and ensuring traceability of components and processes. It allows programming and configuring the process of placing components on PCBs. The program works in X, Y, Z coordinates for each component. There is also a stage for calibrating the equipment ensuring precision for component placement and temperatures in the reflow ovens.

The reflow oven has a program that allows setting and monitoring the thermal profile, ensuring correct heating and cooling of PCBs in the same time provides real-time monitoring of production status and equipment performance and generates detailed reports on production, defects and equipment maintenance.

The program integrates the data and processes with production management systems to ensure efficient coordination of the entire production flow.

The maintenance for pick and place equipment is important to ensure optimal performance, accuracy and reliability in the placement of printed circuit boards (PCBs) using surface mount technology (SMT).

The Reflow Oven, figure 9, is the essential equipment used in the reflow soldering process for printed circuit boards in surface mount technology (SMT) assemblies. The 7-zone ovens are designed to provide precise thermal control, essential for achieving quality solder joints and avoiding defects in the electronic component assembly process.

The zones in the oven are as follows:

Preheat: The first 2-3 zones are dedicated to gradually heating the PCBs to prevent thermal shock and ensure uniform heat distribution;

Soak: The middle zones maintain a constant temperature to allow the flux from the solder to activate and even out the temperature across the entire PCB surface;

Reflow: 1-2 central zones where the PCBs reach the solder paste melting temperatures (typically 217-250°C for SAC305), effectively bonding the components;

Cooling: The last 1-2 zones gradually cool the PCBs, solidifying the solder and forming solid and reliable connections.

Each zone is equipped with temperature sensors and controllers to maintain precise temperatures according to the preset thermal profile. This thermal control is crucial to ensure that the solder reaches and maintains the correct temperature for an adequate period of time and the speed of the PCB conveyor belt is controlled and uniform. The conveyor speed is continuously variable and allows for customized thermal profiles to be created according to the specific requirements of the soldering process.

Fig. 9. SMT Reflow Oven with 7 work zones

The REFLOW ovens provide precise temperature control for each zone, achieving uniform and resilient soldering of SMT components.

5. CONCLUSION

The change in strength in both cases is less than 30% after 200 temperature cycles

The strength of the Pb-free alloy joint is less than 10% lower than that of the Pb alloy, after 200 temperature cycles.

Local stresses can also be induced mechanically, by acting on the components, as well as due to the differences between the values of the thermal expansion coefficients of the materials that make up the soldered joint subjected to temperature variations.

The ability to adjust temperatures and conveyor speed allows use for a wide range of PCBs.

7-zone ovens are reliable for mass production, reducing defect rates and improving the quality of the final product.

The optimization of the thermal field contributes to the efficiency of the soldering process, saving time and energy and reducing operational costs, visible in the work [7]. All this shows that the ovens contribute significantly to improving the quality and efficiency of production processes.

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Studiu experimental privind controlul termic a fluxului tehnologic la lipirea SMT (Surface-Mount-Technology) a componentelor electronice

Abstract: Lucrarea prezintă o aplicație industrială a cercetărilor privind apariția fisurilor în îmbinările realizate cu aliaje de lipire fără plumb (Pb), cu un experiment efectuat pe o placă de circuit imprimat de tip FR4 rigid, un material compozit alcătuit din inserție din fibră de sticlă cu un liant din rășină epoxidică rezistent la flacără. Placa de bază are o grosime de 1,6 mm, fiind placată cu un strat de cupru (Cu) de 35 μm grosime și un strat de finisare pe bază de aur (Au) și nichel (Ni). Partea experimentală este un studiu comparativ în cazul testelor de forfecare, pentru 5 probe având îmbinări lipite cu aliaje care conțin plumb și 5 probe având îmbinări lipite cu aliaje fără plumb. Studiul apariției fisurilor s-a bazat pe supunerea îmbinării la un set de 200 de cicluri termice și inducerea unor solicitări locale prin acțiunea asupra componentelor, iar temperatura aliajului de îmbinare fiind de maximum 240°C. Rezultatele sunt aplicate industrial pe mașini pentru plasarea componentelor pe plăci cu găuri străpunse cu lipire cu val sau pe mașini de asamblare cu tehnologie de montare pe suprafață (SMT) cu lipire într-un cuptor cu ciclu termic complex: încălzire în mai multe etape până la temperatura de lipire și în final răcire.

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