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DESCRIPTION AND OPTIMIZATION OF AN SMD PRODUCTION LINE: PROCESSES, THERMAL CONTROL AND AUTOMATED INSPECTION

Erdodi Geza [1], Wisznovszky Elena Stela[2] and Culda Lavinia Ioana [3]
[1]Universitatea Aurel Vlaicu din Arad, ORCID 0009-0001-1917-871X, geza.erdodi@gmail.com
[2] Universitatea Aurel Vlaicu din Arad, ORCID 0000-0002-4097-8500, stela.muncut@uav.ro
[3] Universitatea Aurel Vlaicu din Arad, ORCID 0000-0003-4230-5390, lavinia.culda@uav.ro

ABSTRACT: The SMD (Surface-Mount Devices) production lines are essential infrastructures in modern electronics manufacturing, due to their flexibility and high level of automation. The typical process includes steps such as stencilling, pick-and-place, reflow soldering and post-process inspections. Optimizing the technological flow aims to increase yield, reduce defects and lower production costs. The thermal control is a critical element, as the reflow profiling must be adapted to the board topology and component characteristics, ensuring a controlled temperature ramp, adequate time above the melting point and uniform cooling. Parameters such as “time above liquids”, ramp speed and peak temperature directly influence the formation of solder joints and the reliability of the final product. The automated solder paste inspection (SPI), automated optical 2D/3D inspection (AOI 2D/3D) and the automated X-ray Inspection (AXI) plays a central role in early detection of defects, allowing for rapid corrections and reducing the rework rate. The integration of these systems into a statistical process control (SPC) framework and digital traceability contributes to optimizing quality and increasing the performance indicators like the overall equipment effectiveness indicators (OEE), first pass yield (FPY) indicators, and defects per million opportunities (DPMO) indicators. Thus, an optimized SMD line combines well-defined processes, rigorous thermal control and advanced automated inspection, resulting in electronic products with high reliability and competitive manufacturing costs.

KEYWORDS: SMD, optimization, thermal processes, control, automation

1. INTRODUCTION

In the modern electronics industry, automated SMD component assembly lines are an essential part of the manufacturing process. These lines integrate advanced equipment such as automatic PCB loaders, solder paste printers, high-speed pick-and-place machines, reflow ovens, and (AOI) systems.

The process automation ensures a high quality and increased productivity, which are critical aspects in an area where circuit complexity is constantly increasing.

The automated inspection plays a crucial role in this domain, quickly identifying assembly or soldering defects immediately after each critical step. Thus, AOI not only significantly reduces the risk of delivering non-conforming products, but also optimizes the remediation process, preventing the accumulation of errors in the flow.

A vital aspect within these processes is the control of thermal effects on electronic components and printed circuit boards (PCBs). Excessive temperatures or incorrect thermal profiles during the reflow process can cause damage to sensitive components, PCB delaminating, solder defects or internal stresses that affect the long-term reliability of the final product. Therefore, optimizing the thermal parameters – such as the oven temperature curve and heat exposure time – is fundamental to maintaining the physical and electrical integrity of electronic assemblies.

2. DESCRIPTION OF AN S.M.D. PRODUCTION LINE

The SMD production line is an automated assembly of equipment used to mount electronic components onto printed circuit boards (PCBs). It is designed to ensure a continuous, accurate and controlled flow of the electronics manufacturing process.

The typical process flow of the SMD production line consists of:

-PCB reception and preparation — quality control, cleaning (if necessary), fiducially marking application.

-Solder paste printing inspection (SPI before/after) — stencil, paste application on pads.

-Pick & Place — optimized feeders, part sequencing, dosage control, fiducially verification.

-Pre-reflow inspection (AOI at print/placement verification) — detection of missing paste or wrong placements.

-Reflow soldering — tunnel/oven with 4–8 zones (preheat, soak, ramp, peak, cool).

-Post-reflow inspection — AOI (2D/3D) + AXI of ball grid array/micro ball grid array (BGA/µBGA).

- Defect detection & rework—thermally controlled rework stations.

-Functional in circuit testing (ICT)—electrical tests, programming.

-Packaging / delivery.

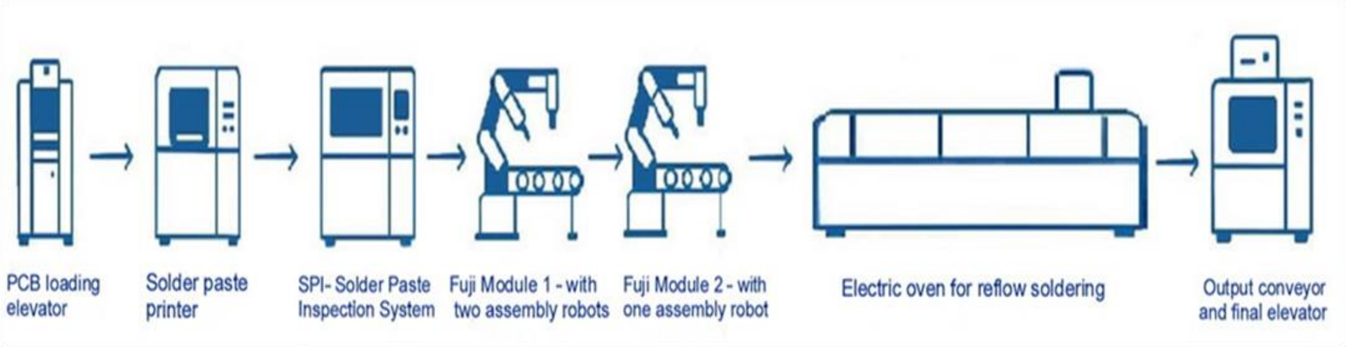

Figure 1 Description of an SMD production line

2.1 PCB loading elevator

The process begins with the loading elevator, which automatically feeds the blank PCBs into the production line. This ensures efficient transfer and a constant feed to the line.

Figure 2 PCB loading elevator

2.2 Solder paste printer

In this step, solder paste is applied to the surface of the PCB using an automatic printer. This is deposited through a stencil in the specific areas where the SMD components are to be mounted.

The quality of the paste application is essential for the reliability of the solder joints.

Figure 4 shows a squeegee system that applies paste over a stencil.

Figure 3 Solder Paste Printer

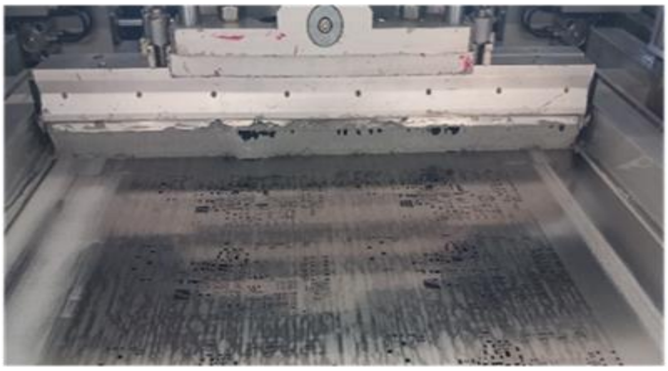

Figure 4 Solder Paste Printer

Figure 5 Solder paste

As a raw material, the printer can apply tin paste or adhesive (glue)

In this stage, solder paste is applied to the surface of the PCB using an automatic printer. This is deposited through a stencil in the specific areas where the SMD components are to be mounted. The quality of the paste application is essential for the reliability of the solder joints.

The solder paste has an optimal viscosity that depends on the temperature.

Required control: The room temperature is maintained between 22°C and 26°C for the stability of the paste. The solder paste should be brought to room temperature before use (after being removed from the refrigerator) to avoid condensation and viscosity variations.

2.3 Solder pastes printing inspection (SPI)

Immediately after the printer, the line includes an SPI device, which analyses the uniformity, quantity and positioning of the solder paste.

It provides automatic feedback to the printer, adjusting its parameters to correct any deviations and to ensure optimal paste application before mounting the components.

The error that occurs appears in the form of:

- No paste / clogged foil error
- Excess solders paste error
- Error frequency report

2.4 SMD mounting machine

The assembly machine consists of two modules:

-Fuji Module 1 – with two vacuum-based assembly robots.

This module is equipped with two high-speed robots, which mount small and medium-sized SMD components on the PCB.

The second assembly module, equipped with a single robot, is used for placing larger components or those that require high positioning accuracy.

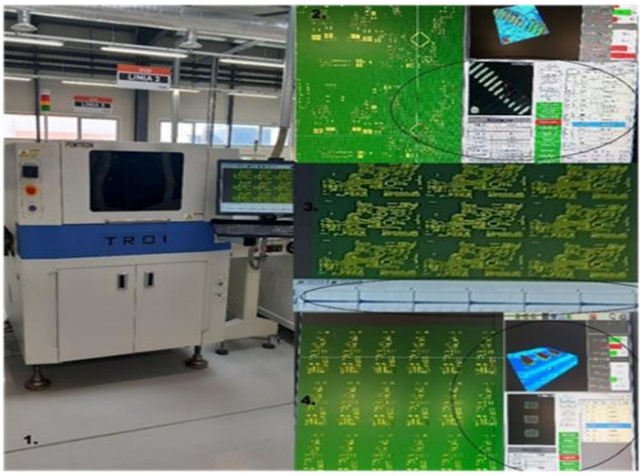

Figure 6 Solder Paste Inspection System

Thanks to the two robots, an increased assembly rate and increased efficiency are ensured.

-Fuji module 2– with a vacuum-based assembly robot.

-Although the component placement is not a direct thermal process, the ambient temperature can affect:

Figure 7 Assembly machine

The stability of component placement (minor PCB expansions due to temperature differences).

- The accuracy of cameras and optical systems (through expansions).

The control required in this area refers to maintaining constant operating temperatures in the production hall to reduce temperature variations through the air conditioning system linked to the chillers.

2.5 Transfer conveyor belt

The transport between equipment is carried out by a conveyor belt that ensures continuity and precise alignment of the plates throughout the entire process.

Figure 8 Transfer conveyor belt

2.6 The electric oven for reflow soldering TSM N70-i123MH

Thermal influence: This is where the critical controlled heating process takes place:
After mounting the components, the PCBs enter in an electric reflow oven. This is composed of several thermal zones that follow a rigorous temperature profile: preheating, activation, melting the paste (reflow) and cooling.
The heating study of the PCB is fundamental to obtain solid solder joints, and avoiding defects such as micro cracks or tombstoning.

Figure 9 Electric reflow soldering oven TSM N70-i123MH

The tombstoning is a soldering defect during the reflow process where a surface-mount component partially or completely lifts off one pad while the other end remains soldered, resembling a tombstone. It is caused by unequal wetting forces from molten solder, often due to thermal disparities between the pads, resulting in a dislodged component that creates a faulty connection and can lead to device malfunction.

Figure 10 Oven

Figure 11 Control panel

2.7 Output conveyor and final elevator

After the bonding process, the boards are transported to an output conveyor and stored in a final elevator, ready for the inspection stage.

Figure 12 Output conveyor and final elevator

2.8 AOI – Automatic optical inspection

The AOI system analyses each board to detect solder defects, missing, inverted or misaligned components. After inspection, the PCBs are automatically sorted into two groups:

Figure 13 Automatic optical inspection

Pass – compliant boards, meeting quality standards.
Fail – boards with detected errors, sent to a dedicated elevator for repair or reanalysis

Figure 14 Plate validation

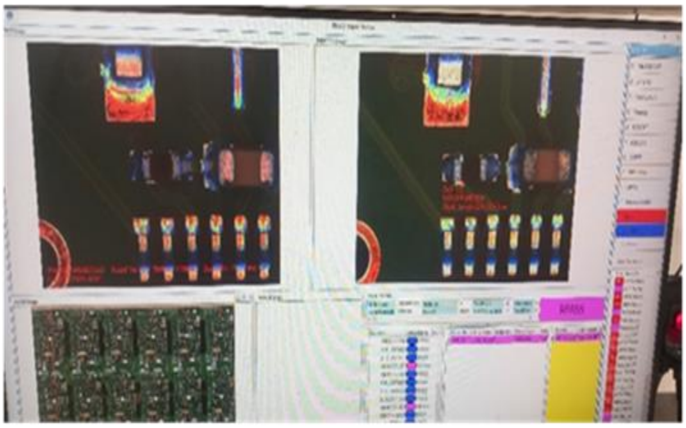

Figure 15 Analysis and confirmation of false errors given by AOI

Figure 16 Checking the solder under a microscope

3. REPRESENTATION OF TEMPERATURE GRAPHS FOR A 15-ZONE ELECTRIC REFLOW OVEN

The temperatures gradually increase from ~80°C to a maximum of ~200°C over a period of at least 3 minutes. The adhesive is used on partially assembled PCBs.

Some productions require assembly of through-hole technology (THT) components or can also be used as reinforcement for large components.

In some SMD applications, especially when it is desired to temporarily fix the components before the final soldering process, special adhesive is used.

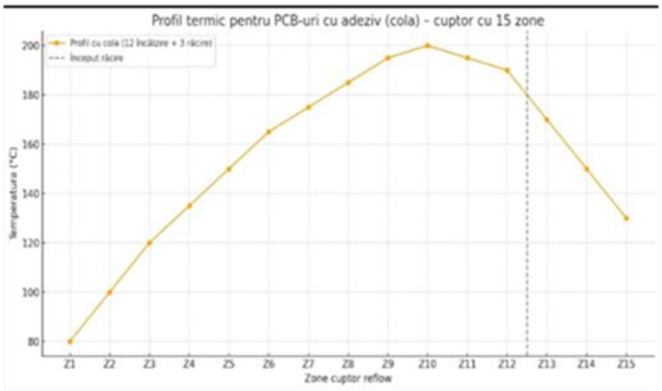

Figure 17 The control chart

It is applied point wise under the components and requires a distinct heat treatment from the solder paste, with the purpose of hardening the adhesive. In this case we have a circuit that contains solder paste and adhesive for reinforcing.

The reflow process for adhesive boards involves a slower thermal profile, with moderate temperatures gradually distributed across the 12 zones of the oven.

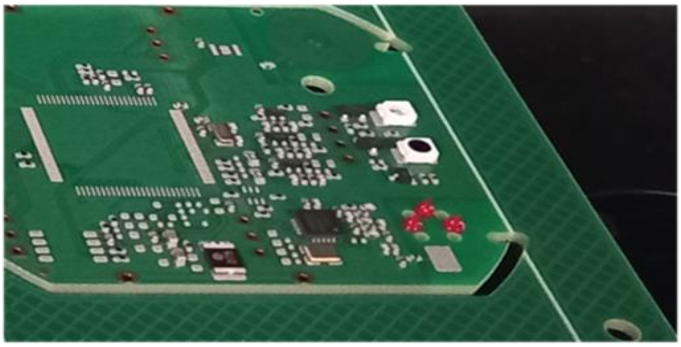

Figure 18

The goal is to avoid degradation of the adhesive while ensuring effective bonding of the components in the correct position.

Profile features:

-Avoid reaching the melting temperature of the solder paste, as this stage is only aimed at curing the adhesive.

-After the thermal peak section, the temperature decreases in a controlled manner to prevent thermal stress on the components.

-Using the appropriate thermal profile for adhesive boards is essential to prevent defects such as component displacement, adhesive burn-in, or insufficient adhesion during the final reflow oven.

4. WEEKLY REFLOW OVEN TEST REPORT

These tests are performed weekly to ensure the proper functioning of the heating resistors, temperature sensors and fans.

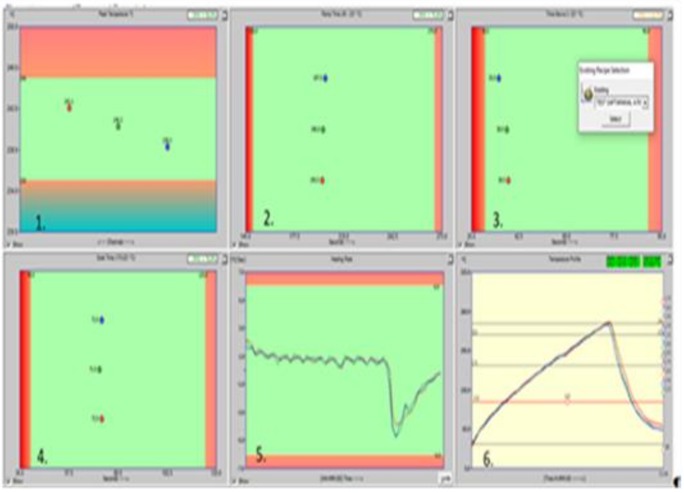

Figure 19 Weekly testing

For certain productions, this test is performed every time at the beginning of production and is recorded based on the batch number.

Graphic description:
1. Maximum temperature reached
2. Paste preheating time
3. Liquid paste time
4. Period in which the paste becomes liquid
5. Temperature by areas taken by the PCB (3 temperature sensors)
6. Oven profile temperature

The detailed report includes all the information concerning the times and temperatures in the oven.
All temperature tests were performed on a TSM N70-i123MH reflow oven with SolderStar Delta test equipment.
Equipment included:
-25mm Reflow Heatshield DeltaProbe Adapter (fitted to shield)
-3 x Matched DeltaProbe sensors
-Adjustable Carrier
-Tolerance Software Module
The SolderStar DeltaProbe is a reflow soldering accessory that works in conjunction with the SolderStar Pro temperature profiling system. It effectively removes the need to use fragile test boards for periodic profiling required for ongoing control of the reflow process.
With fixed sensors and no test card or long trailing wires, the SolderStar DeltaProbe is a fixed, robust and convenient platform for generating highly repeatable results.
Although process setup requires a temperature profile captured from a real test PCB, ongoing process monitoring can be achieved by measuring the difference from an established process baseline.

5. STUDY OF SOLDERING TEMPERATURES DEPENDING ON PCB THICKNESS

The reflow soldering process involves the controlled heating of the PCB board to melt the solder paste or adhesive and ensure a solid connection between the pads and the electronic components. The efficiency of this process directly depends on the thickness of the PCB, the temperature profile set in the reflow oven, as well as the speed of the conveyor belt.
Thicknesses analysed:
- 0.7 mm (thin)
- 1 mm (medium)
-1.6 mm (industry standard)
Explanation for the comparative thermal profile between 0.7mm, 1.0mm and 1.6mm PCBs:
This graph illustrates the thermal behaviour of PCBs with different thicknesses during a standard reflow cycle.

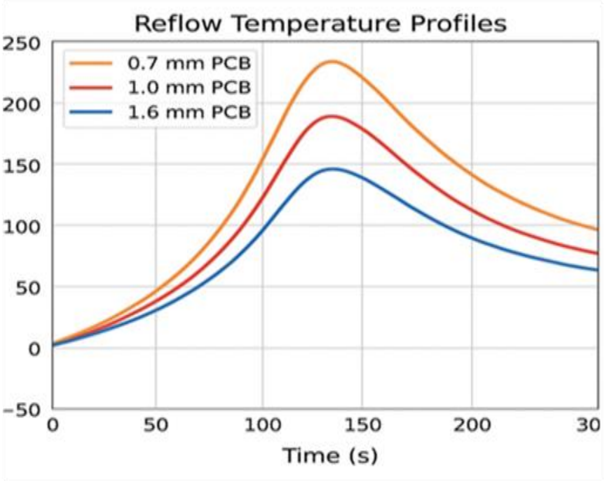

Figure 20 Reflow temperature profiles

It is observed that the 0.7 mm PCB reaches peak temperature quickly due to its low thermal mass, but is also more susceptible to thermal shock and warping.
Advantage: Heats up quickly to reflow temperature.
Risk: Overheating of sensitive components; increased risk of component lift and paste leakage if the profile is not adjusted properly.
Recommendation: Reflow temperature reduced by approximately 5–10°C compared to standard and faster pass speed.
The 1.0 mm PCB exhibits a balance between rapid heating and structural stability.
Intermediate behaviour: Requires careful balancing between preheat time and peak temperature.
Risk: If the heating is too slow, cold or insufficient solder joints may occur.
Recommendation: Slightly extended preheat time and standard reflow profile (about 230–240°C for 30–60 seconds).

1.6 mm PCB has a higher thermal inertia, heating and cooling more slowly, which reduces the risk of cracks or delimitation during repeated temperature cycles.
Advantage: Good thermal inertia, high stability during reflows.
Risk: Slow heating can lead to insufficient soldering, incomplete heating of the PCB (in the case of multilayer) or elimination at too high temperatures.
Recommendation: Extended preheat and higher peak temperature (240–250°C), with reduced conveyor speed to allow heat penetration.
Note: Choosing the right PCB thickness based on the thermal profile is essential to ensure the reliability of the final product.
It is worth mentioning that all PCB batches come with a complete test report, but we will focus on the soldering test and the thermal stress test.
This document certifies that the tested boards have passed the bonding and thermal stress test according to the IPC J-STD-003C standard. The material demonstrated complete bonding, without any delaminating or non-adhesion defects, and all measurements and test conditions were met.


THERMAL STRESS TEST

SOLDERABILITY TEST

Figure 21 Compliance document

<u>Conclusion</u>: The tested PCB has excellent bonding, suitable for use in electronics manufacturing.
Possible defects caused by improper settings:
-Tombstoning - thermal imbalance between the ends of the components.

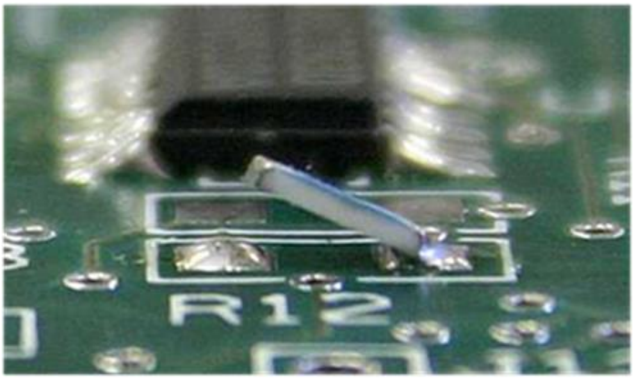

Figure 22 Trombstoning – thermal imbalance

-The problem is most common with SMDs, such as resistors and capacitors, due to their light weight, although technically larger components may suffer minor warping or deformation leading to open circuits. When the solder on one side of the component melts earlier than the other side of the component, the component can lift off its supports, as shown in the image above.
-Cold solder joints – insufficient temperature or too short reflow time.

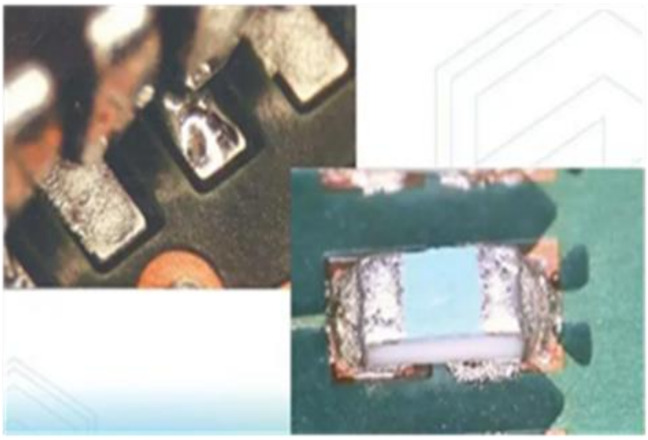

Figure 23 Cold solder joints

-Delimitation – excessive temperature or its sudden increase.

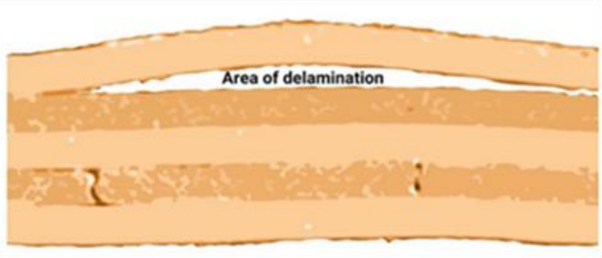

Figure 24 Delimitation – excessive temperature

Component shifting – too short time before the paste hardens or most of the time this is related to components floating on the molten solder and the equipment has some vibrations that could affect the position of those components. The same problem can also occur if the printer does not position the paste on the pad well.

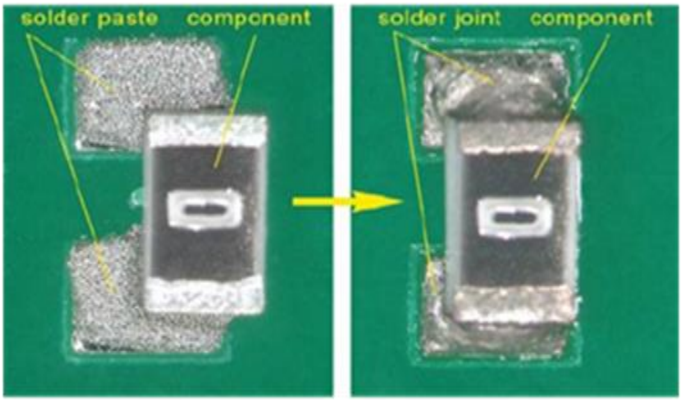

Figure 25 Component shifting

Notes: The temperature is controlled from storage to final processing.

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