EVALUATION OF THE PRINTABILITY OF LEAD VERSUS LEAD FREE SOLDER PASTES

By

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ABSTRACT

Evaluation Of The Printability Of Lead Versus Lead Free Solder Pastes

Ryerson University

As the global marketplaces consider mandating lead-free equipments, many questions arise about the impact and feasibility of replacing lead in printed circuit boards soldering applications. In this project, the results presented of a study on comparing the process of screening lead paste versus lead free paste parameters for regular stencil printing using standard manufacturing methods.

The key process parameters studied were: squeegee speed, squeegee pressure, and screening yield for both types of pastes. Two solder paste formulations (lead paste and lead – free paste) were evaluated in this study.

The analysis of the pastes deposit volumes showed that for normal manufacturing range of printer (screener) settings (speed and pressure) tested the two pastes performed the same. The results also showed that the squeegee speed has a greater effect on the printing process than the squeegee pressure. The tests clearly showed that the lead paste was affected more by setting changes compared to the lead free paste. Varying the print speed and pressure for type of pastes by observing the resulting printed paste volumes optimized screening parameters. This study confirms that a new stencil or stencil design is not needed for the lead free paste. However, this study recommends a change to the sitting of the screening print process.

Stencil cleaning frequency is one of the main factors that impact the production rate in an SMT line. The project highlights new results that lead free paste throughput will be less compared to lead paste at the screening step. The number of rejected boards screened with lead free- paste exceeded normal manufacturing standards. As stencil cleaning is a must function, it was recommended to increase stencil wiping frequency when lead free paste in use in order to obtain a consistent volume with less screening defect.

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CHAPTER I

INTRODUCTION

The production of electrical and electronic equipment is one of the fastest growing domains of manufacturing industry in the Western world. Both technological innovation and market expansion continue to accelerate the replacement process. New applications of electrical and electronic equipment are increasing significantly. There is hardly any part of life where electrical and electronic equipment is not used. This development leads to an important increase in waste electrical and electronic equipment (WEEE). The WEEE stream is a complex mixture of materials and components. In combination with the constant development of new materials and chemicals having environmental effects, this leads to increasing problems at the waste stage. The WEEE stream differs from the municipal waste stream for a number of reasons: the rapid growth, and because of their hazardous content.

Lead (Pb) has been widely used in the industry for a long time. Of the approximately 5 million tons of lead consumed globally every year, 81% is used in storage batteries. The lead consumption in the electronic assembly industry is about 0.5 %. However, despite the long-term acceptance of lead by human society, lead poisoning is now well recognized as a health threat. Storage batteries, due to the almost 100% recycling practice, do not contribute to the pollution or contamination. On the other hand, although solder is only a small percentage by weight of electronic products (TVs, PCs, phones etc.), this equipment often ends up in landfill after being disposed, and the lead is leached out into the water supply [1].

North American legislations were intentioned to ban all lead-alloys from electronic solder by 2006-2008.There are impending producer responsilities laws for electronic equipment to use lead free solder by that date. Since 2001 the leading Japanese electronic manufacturers started introducing products which contain no Pb in the interconnect system. Therefore, North American electronics manufacturers need to be working hard on qualifying their processes and machines and make them lead free ready. Furthermore, the logistics and economics of specifying a particular alloy must be considered.

Stencil printing is a critical first step in surface mount assembly. It is often cited that about 50% or more of the defects found in the assembly of PCBs are attributed to stencil printing [2]. A thorough understanding of lead free stencil printing process would facilitate the design of printers, stencils and pastes, and would ultimately permit the extension of reliable print techniques to the very fine print arena when this new paste would be implemented. The focus of this study is a comparison of volume release between the two pastes and the effect of different parameters like speed, pressure on each type.

This project has the following structure: Section 1 provides a wide introduction to the surface mount technology (SMT) process and machines. Section 2 contains details of various emerging alternatives for lead free paste. General technical guidelines for the different types of lead free paste, field of applications, and chemical contents. Chapter 3 will detail the experiment settings, machines, parameters, and results; like screener and paste inspection machine. Section 4 describes the results and the recommendations for future work in this direction to enhance the new process and enrich manufacturing and engineering practice.

This chapter will outline the electronic manufacturing services (EMS) process as well as the solder paste printing process.

1.1. Electronic Manufacturing Services Overview

The manufacturing of an electronic product is a complex process in which services must be offered across the entire product cycle from its initial design to system build, from customer fulfillment to logistics. The overview will outline and explain the process for getting an electronic product into high volume manufacturing and then sustaining the manufacturing process for the product's entire life cycle. In order to fully support this process the EMS (Electronic Manufacturing Services) must have the following core competencies in place (Fig. 1.1) [3]:

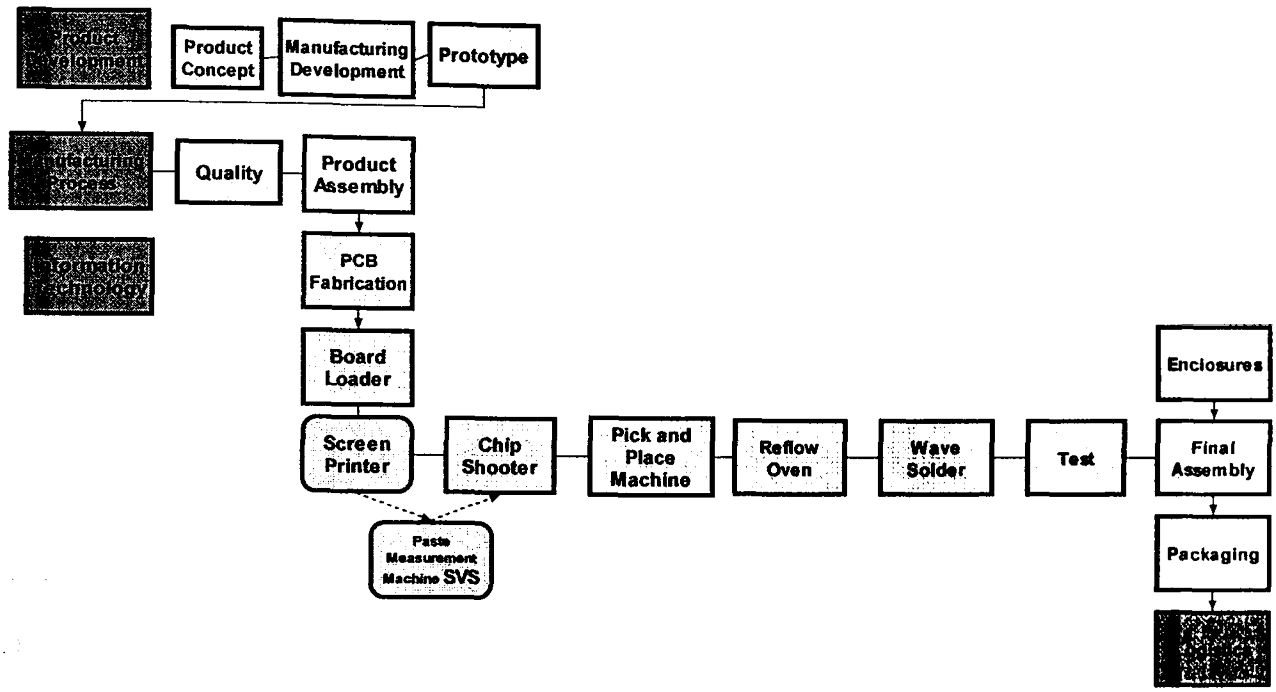

Figure 1.1: Electronics Manufacturing Process

1.1.1. PRODUCT DEVELOPMENT

The development phase converts a product concept to a proven product ready for manufacturing. This phase consists of four main parts:

1.1.1.1. Product Concept

The OEM (Original Equipment Manufacturer) prior to approaching the EMS with the product idea typically performs this part of the development phase. During this phase the OEM puts into place the following criteria: a conceptualized design, marketing plan with market survey and identified user, a business plan with projected cost to manufacture, projected selling prices, projected time-to-market, and projected demand plan, a preliminary definition of the software design, a set of preliminary electrical drawings, a set of preliminary mechanical drawings of the piece parts (e.g., sheet metal components, product layout plastic components, etc.)

At the completion of this part of the development phase, the OEM can proceed with the prototyping of the product. However, if the OEM does not have a sufficient hardware development/design staff in place, the OEM will contract the EMS provider to complete the design with oversight performed by the OEM development group [3].

1.1.1.2. Product Design

An integral part of a good manufacturing system is to have a design business unit that is responsible for the following areas: Industrial design (Industrial designers generate concepts and solve problems in an effort to develop possible and desirable electronic products. The EMS assigns cross-functional teams to explore preliminary concepts and development. The industrial design team will then refine the form and function of the product and present their designs to the OEM for approval, mechanical engineering design (Mechanical engineers provide concept exploration, material and process research in addition to component research and selection). The EMS will design all of the mechanical components for the product using a Computer Aided Design (CAD/CAM) system. This system will create a 3D model and verify all of the component parts that will be needed for the final product. Further, this system will aid in the design of the sheet metal components, plastic components and enclosure design.

Electrical & component engineering (As the industrial design and mechanical engineering takes shape, electrical engineers concurrently develop original product concepts, feasibility studies and full turnkey electrical system design. The EMS makes sure that the development of electrical specifications, firmware development, electrical prototypes and performance simulations meet the requirements of the OEM), Software design (The software design for the product will specify the user interface, functional expectations of the product defining the stimulus and response for each action the product should perform, display characteristics, interface to other equipment, and the human factors of interface. All of these items could be defined/created by the OEM prior to presenting the product concept/design to the EMS or may be developed jointly by the EMS and OEM. The EMS will utilize the software performance criteria from the OEM to develop software in conjunction with the electronic hardware that will meet the functional requirements for the product), PCB (Printed circuit board) layout, RF (radio frequency) design, Quality assurance, Design validation testing engineering. These pre-production design services are performed concurrently allowing the EMS to handle every phase of production in-house and bring new product categories to market faster. Further, these design services help an EMS provider get involved in an OEM's manufacturing program before production begins [3].

1.1.1.3. Manufacturing Development

An integral part of a good manufacturing system is to have a manufacturing process development section within the design and engineering unit. This part of the development phase is conducted concurrently with the prototype phase. This group is responsible for the following areas:

- Finalize product design
- Design tooling for assembly, plastic moulding, sheet metal fabrication, etc.
- Develop processes for product assembly including projected time studies, process documentation, projected cost analysis, etc.
- Create a bill of materials (BOM) and assembly structure
- Create quality plans and procedures
- Analyze components in design
- Define manufacturing equipment needs for high volume production

1.1.1.4. Prototype

A pre-production prototype is an essential step in the New Product Introduction (NPI) process. The prototyping stage serves to validate a whole series of assumptions prior to high volume manufacturing:

- Industrial design
- Electrical design
- Mechanical design
- Software design
- Availability of component parts and other materials
- Assembly sequence and methods
- Test procedures
- Training of production staff

Building a production prototype is the final major step in the product integration cycle. It really answers the question, "How well do all the individual components and subassemblies come together to form a real product [3].

1.1.2. MANUFACTURING PROCESS

The manufacturing process consists of quality systems, product assembly and packaging of electronic products such as cell phones, routers, internet switches, and PCs. The full system assembly of a handheld for example involves assembling a PCB, placing the board inside a plastic enclosure, adding the necessary peripherals, screwing the "box" or enclosure together, and downloading the appropriate software. Next, the fully assembled product is placed inside a cardboard box and shipped to its desired destination.

1.1.2.1. Quality Systems

Quality is defined as a high degree of excellence. From the customer's point of view, it is a product or service that meets expectations, yet exceeds requirements. Quality has become a crucial characteristic that must be integrated within an organization's operations. Further, quality allows for a strong and competitive position in today's challenging market place. Some of the benefits associated with high quality include cost savings, higher productivity, less raw material consumption, greater profit, and a larger, more loyal customer base. Within the EMS organization, there are many different certifications that may be achieved. Most specific to the industry is the ISO 9000 certification series. ISO, International Organization for Standardization, is an organization formed by members from 20 various countries with affiliates worldwide who have established a set of standards that must be adhered to by all participating organizations. The need for these standards becomes apparent when trade shifted to a global level making it more difficult to assess the performance of one company versus another. These standards were established as a minimal set of requirements that must be met by each company therefore establishing a basis in which they could be compared [3].

Most ISO standards are very specific and technical. The importance of the ISO 9000 certification is that it demonstrates to the customer that quality is a strong value for any organization. The ISO 9000 series of standards apply to various functions within an organization that includes design, process control, purchasing, after-sales service, inspection, testing and even training.

1.1.2.2. Product Assembly and SMT Process

Product assembly or full system assembly is the primary operation that occurs in the manufacturing process stage. This operation consists of three main functions: electronic assembly, enclosures, and final assembly. Essentially, product assembly is the operation where raw materials and purchased components are assembled together to make the electronic product.

(i) Electronic Assembly

World-class manufacturing (WCM) is a term that captures the EMS industry and the major companies involved in manufacturing electronic products around the world. Electronic assembly or high volume manufacturing is the core element of the turnkey process where Surface Mount Technology (SMT) lines attach components and devices onto the surface of printed circuit boards (PCBs). These production lines are approximately 280-ft.-long and are comprised of multiple SMT machines that place components on to the circuit boards in addition to heating, cleaning and testing.

A turnkey is a type of outsourcing method that turns over to the subcontractor all aspects of manufacturing, such as: material acquisition, assembly and testing. Its opposite is consignment, where the outsourcing company provides all materials required for the products and the subcontractor provides only assembly equipment and labour solution is always a complete system. The SMT line consists of a basic "board handling" structure that begins with a board loader and ends with a wave solder and test machine, preparing the board for final assembly and distribution [3].

A typical basic SMT (SMT is a collection of scientific and engineering methods needed to design, build, and test products made with electronic components that mount to the surface of the printed circuit board without holes for leads) line consists of the following machines from start to finish.

Screen printer:

As a first step, the board moves into a screen printer (Transfer of a pattern onto a surface by forcing a suitable material through a screen with a squeegee) or solder paste application machine. This machine utilizes a stencil (A thin sheet of brass or stainless steel with openings that match the land pattern of the printed circuit board. During printing, adhesive or solder paste (A homogeneous combination of solder particles (ranging in diameter from about 4 to 40 microns), flux, solvent, and a suspension agent used in the surface mount reflow soldering process. Solder paste has a high viscosity of approximately 900,000 centipoises. Solder paste is commonly applied by printing, dispensing, performs, and manual methods (is forced through these openings onto the printed circuit board) screening process to apply the solder in the form a paste to the locations on the board where all the SMT components will be electrically connected. Interesting enough, no one alive can claim the invention of solder paste. Screen-printing has become the universal method for dispensing adhesives in the EMS industry. Actually, the process is very similar to silk-screening tee shirts, with an application accuracy of 1000th of an inch.

Paste Measurement Machine SVS:

Exiting the screen printer, a paste measurement machine is next to measure paste volume and screening defect using laser scanning system.

Chip shooter:

Next, the board enters a "chip shooter," an SMT machine that rapidly places components such as resistors, capacitors and ICs (Integrated Circuit) on to the circuit board. The placement of components on the board can reach a rate of more than 40,000 chips per hour (or higher). However, back in the early days of surface mount assembly (1981), the smallest component available for automatic placement was the 1206 chip (0.12" x 0.06" in length and width). At the time there were no widely available large parts like SOIC's (small outline integrated circuits). The first placement machines were "Pick-and-Place" machines with mechanical centering to accurately locate the component on the end of a vacuum nozzle. The machines were noisy and, by today's standards, slow at 0.6 seconds per placement (6,000 placements per hour). As time passed available packaging got smaller so that second generation machines needed to place 0805 components (0.08" x 0.05"). The machines ran at a rate of 0.4 seconds per placement. Accuracy of these early machines was usually somewhere around ± 0.004". Currently, the smallest part available for placement is the 0201 chip (0.02" x 0.01"). The early "Pick-and-Place" machine has evolved into a high-speed placement machine now named a "chip shooter." Chip shooters use one of two basic designs to place components: The most common is a turret drive with multiple heads around the outside of the turret. It looks kind of like an old-fashioned machine gun aimed down. A feeder carriage is place in the back of the machine that moves back and forth to put the correct component under the turret. As the turret spins, the component is picked up from the feeder carriage and is brought to the front for placement. The advantage of the turret design is speed since many components can be on the turret in process at the same time. The circuit board being assembled moves around under the front of the turret to position the component correctly. Placement times for turret machines have dropped to around 0.1 seconds per placement or 36,600 per hour. A second type of chip shooter is a gantry system. The circuit board is held stationary, or moved in only 1 axis, and the head goes to the feeder to get the component and moves to the proper location for placement. Also, unlike the turret type machine, the feeder assembly usually does not move. This is normally slower than a turret machine but some companies have developed machines that use multiple heads and build several boards at the same time. This lowers the effective placement time so much that some machines are capable of over 80,000 placements per hour.

Pick-and-Place:

If large components (normally more than 30 by 30 mm size) are needed in the assembly production, "flexible placement" or "fine pitch" machines are placed in line after the chip shooter. These modern Pick-and-Place machines are usually gantry type machines, that is, the head moves to a fixed feeder location to pick up a component and then moves to the board to place the component. Multiple cameras are typically used to locate the circuit board and inspect the component so the component can be placed exactly where it belongs. With lead pitch as small as 0.012", mechanical centering of components on the nozzle lacks in speed and accuracy.

Reflow oven:

Next, the board is transported to a reflow oven that melts the solder paste and bonds the components onto the board at temperatures above 183 degrees Celsius. The term solder reflow describes a heating process with pre-placed flux and solder. A pre –placed flux is a material used in conjunction with soldering that removes oxidation on surfaces to be soldered and prevents re-oxidation during the formation of a solder joint. The oven typically operates in air, nitrogen or any other gas. In any soldering operation there are three major elements that facilitate the bond formation and allow the solder paste to form a solder joint: the flux, the solder alloy, the heat

The order in which these parameters are applied varies from process to process. With the heat, the flux becomes very active, cleaning off any tarnish. Within this process the solder melts thus wetting the surfaces. Upon cooling, the fillet solidifies allowing for a solder joint.

Wave solder:

The board with through-hole is a plated-through hole (PTH) is one formed by a deposition of metal on the inside surface of a through-hole (also known as a supported hole). The configuration is used to provide additional mechanical strength to the soldered termination or to provide an electrical interconnection on a multi-layer printed circuit board) components in now ready for the wave solder machine. This step of the electronics assembly process only occurs when there are through-hole components on the PCB board. A Wave Solder Fixture is fixed around the board before it enters the machine. This fixture holds the board through the wave solders process in addition to protecting any area on the board that should not be exposed to the molten solder. Once the wave solder machine electronically senses the PCB board within the machine, flux is applied to the bottom-side of the board via a spray application.

As the board continues to move up the conveyor toward the molten solder it passes through an oven, or a series of ovens, that pre-heat the board to a certain level specified by the OEM and the flux manufacturer. This pre-heat process prepares the board for the molten solder, which the board will pass over. Through-hole component cavities are filled with solder as the board continues along the conveyor and over the top of the molten solder. The wave solder process is now complete as the board exists the machine at which time the board may be cooled by a series of fans before an operator picks up the board for inspection.

Test:

The board is then transported to a continuity testing process that tests the board for low-level functionality and helps ensure that there are no shorted or open connections on the board. This process is typically performed on a "bed-of- nails" tester in which the ends of the gold-plated pins contact specific points on the PCB. Other possible tests include:

- *Functional text*: The electrical testing of an entire assembly that simulates the intended function of the product.
- *Flying probe*: A rigid, pointed, metallic, wire-shaped device used for making electrical contact to a circuit pad for electrical test purposes.
- *ICT*: In-Circuit Test
- *Burn-in*: The process in which a device is electrically stressed by subjecting it to an elevated temperature and voltage for an adequate period of time to cause the failure of a marginal device.
- *X-ray*: A ray or radiation of very short wavelength that can penetrate solid substances.
- *Parametric*: The testing of specific parameters for different inputs and outputs.
- *ESS*: Environmental stress screening.

(ii) Enclosures

The plastic moulding and assembly process consists of four major sections:

-Supply of plastic raw material

-Plastic moulding tooling

-Plastic moulding press

-Secondary operations

The plastic raw material is usually supplied in palletized form after being dried to ensure that there is no moisture in the material. The drying process is required for materials that are hydroscopic. This material is fed into the moulding press and moulded depending on the tooling installed in the press. A computer-controlled process is used to ensure consistent product quality. At the completion of the moulding operation the plastic parts are fed to the plastic secondary operation where the plastic sub-assemblies are constructed. The completed plastic assembly is then sent to the final assembly operation where it is attached to all of the other components to make the finished product [3].

(iii) Final Assembly

Final assembly is the last stage of the full system assembly process. During the final assembly stage, the subassemblies produced during the electronic, sheet metal and plastic assembly operations will be assembled into the final product, known as "box build." Following the box build, the finished product will be functionally tested to ensure that it meets and/or exceeds the specification requirements. At the completion of the functional test the product is packaged in the distribution/sales packaging and is ready for distribution [3].

1.1.2.3. Packaging

The packaging for the product is an important final step in the whole manufacturing process. The product is packaged and then shipped to its desired location(s).

The packaging for the product for distribution and shipment to commercial customers must be capable of protecting the product during shipping and subsequently handling at the commercial site, as well as displaying and advertising the product on a display rack. Final packaging is single use packaging; once it gets to the end user it is usually discarded. Because of single-use for this packaging, it should be designed to ensure that the materials used would minimize the percentage of the packaging that goes to the landfill.

1.1.2.4. Logistics

When examining the processes from design to delivery within the supply chain, it becomes clear that logistics management is the thread that ties the whole process together. Logistics is the efficient and timely movement of materials and information, and has become the integrator of all processes from design to procurement to manufacturing to customer delivery. Merging manufacturing and logistics has transformed the EMS industry allowing for the design, assembly and distribution of product to be completed with fewer touches, less cost and quicker time-to-market.

It is well documented that most supply chains today are riddled with redundancies and latency. Further, there are many solutions from software companies, service providers, OEMs and distributors that address these issues. A strong set of solutions offered by leading EMS providers involves three key dimensions that are systemically linked together. These three dimensions include: low cost operations & global network, demand pulls inventory management and finished goods distribution [3].

1.1.3. INFORMATION TECHNOLOGY

The information technology system implemented by the EMS improves time-to-market and lower costs for the OEM. Through worldwide network configurations and integrated e-commerce systems, the EMS Company can monitor the entire process of manufacturing that include the following:

- Design and documentation
- Supply chain planning
- Order processing
- Procurement
- Assembly

- Logistics

The EMS' I.T. system allows the collection and reporting of production data and efficient lines of communication between supplier, OEM and EMS [3].

1.2. SOLDER PASTE PRINTING

1.2.1. MACHINE OVERVIEW

In the printing process, solder paste is printed through a metal stencil onto the PCB solder pads. The stencil printing of solder paste is the most important stage in the modern assembly process. If the process is not set up or operated correctly then the final assembly yield will not meet the needs of the industry. This specification defines the procedures to be used in the stencil printing process. To achieve a good soldered joint, it is essential to print accurately and with a consistent thickness of solder paste on each of the pad surfaces of the circuit boards. To reach this objective, the solder paste print must be aligned correctly, the correct amount of solder paste for each joint must be present and the print should form an even layer of paste for perfect component placement. Solder paste is a mixture of very small balls of solder and flux. It is sticky so that components placed into the paste will remain on the board. In the oven, the solder paste reflows or melts to form a solder joint between the components lead and PCB pad. [4].

1.2.2. PRINTING (SCREENING) FACTORS

When screening paste onto a PCB there are a lot of factors to consider. In the listing below (Table 1.1) the most essential factors are mentioned.

Table 1.1: Screening variables

Equipment&Tooling	Methods	Materials	Environment	Operators
Stencil	*- Process parameters*	*- Solder paste*	- Air humidity	- Skills
- Polish	- printing speed	- Alloy composition	- Air circulation	- Training
- Thickness	- Squeegee pressure	- Viscosity	- Temperature	- Authority
- Design	- Separation Speed	- Flux	- Air quality	- Handling
- Aspect Ratio	- Cleaning	- Alloy particle size		- Discipline
Screener	- Snap off	*- PCB*		
- Squeegee	*- Setup*	- Pad flatness		
- Repeatability	- Stencil storage	- PCB flatness		
- Accuracy	- Paste storage	- Pad finishing		
Cleaning	- knead parameters	- Pad planarity		
- Frequency		- Support		
- Chemistry		- Masking issues		
- Procedures				

All the factors in the five groups are differently important but all play a role in the final result and it is important to consider all aspects to reach the quality needed in the products produced.

1.2.3. PRINTING EQUIPMENTS

The main input in the screening process are: PCB, solder paste, stencil, squeegee blades and the printer.

- <u>*Stencil printer machine type MPM 3000*</u>

The main function of the machine is to accurately apply solder paste and applies solder paste in a controlled manner (Fig.1.2) [23]

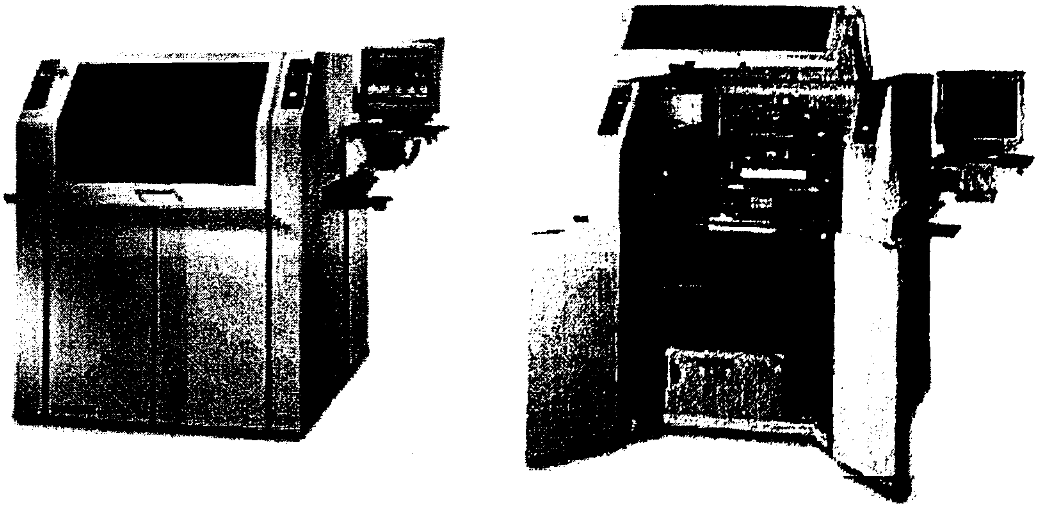

Figure 1.2: Stencil printer machine

Machine Dimensions: 63.24 in (1606.3 mm) wide x 46.0 in(1168.4 mm) deep x 64.44 in (1636.78 mm) high

Print Area: 18in x 16 in. (457mmx406mm)(X, Y)

Board Size: 2" x 2" (50.8 x 50.8) to 20" x 16" (508mm x 406.4mm)

Snap of: -0.05 in to +0.1 in. (-1.3 to 2.5 mm)

Squeegee Pressure: 1lb to 60lb. (0.4 to 27 kg)

Squeegee Speed: 0. 25 in/sec to 12 in/sec (6.35 to 305 mm/sec)

Fiducials Type: All conventional fiducials accepted

Board Size: max=20 x 16 in. (508x406 mm), min=2x2 in.(50x50mm), thickness,0.015 to 0.5 in.(0.381 to 12.7 mm)

Method of Support in Print: Magnetic pins, workholders

Method of board hold- down: Underside vacuum, Y-axis snuggers and Z-axis clamps

Alignment Repeatability: ± 0.0005 in. (± 0.0127 mm)

Alignment Accuracy: ± 0.0001 in. (± 0.0025 mm)

- *Squeegees*

They Driven across stencil, forces solder paste onto board, creates a uniform contact line with the substrate, and provides proper balance and pressure (Fig. 1.3) [13,14].

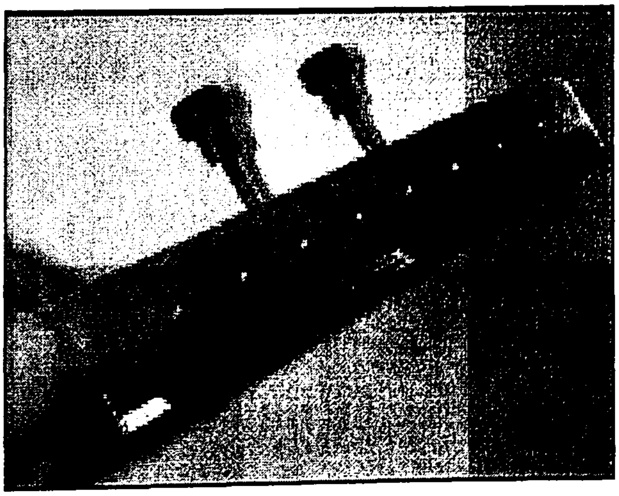

Figure 1.3: Squeegee

The printing squeegees can have different designs and made of different materials; e.g., square rubber rods, thick rubber plates, flat metal plates or other combinations. Today, the commonly used squeegees, for metal stencil printing, are made of thin metal. The squeegees must have a very smooth and non-sticking surface and at all times a sharp printing edge. This will ensure that the solder paste will roll more easily on top of the stencil and help prevent clogging of the stencil apertures. To make a perfect solder paste print, the PCB support must hold the PCB in a locked position and absolutely parallel to the stencil.

- *Stencil*

The main method used to print solder paste onto PCBs is stainless steel stencil (Fig. 1.4). It should have strong base with excellent stability. Stencils have thickness from 0.004" to 0.010"; aperture size is determined by component pitch, paste flows freely and uniformly. There are three different metal stencil-manufacturing methods: etching, electroforming and laser cutting.

The apertures in both laser-cut and electroformed stencils have very sharp edges and are slightly conic. This makes the solder paste easily slip of the aperture edges and thereby secures a uniform print. The metal stencil is attached to the printing frame using tensioned mesh or directly using a special frame with a gripping system. Mesh attachment is a little more expensive but handling the loose stencils, for the direct attachment systems, easily damages the stencils and thereby results in poor printing quality. If properly handled a stainless steel stencil will last more than 10,000 prints. The stencil thickness should be chosen depending on the job in hand. For very fine pitch such as 0.3 mm lead pitch, 100 or 125-micron stencil could be used and for lead pitch down to 0.5 mm 150 micron stencils can be used. The stencil thickness together with the aperture sizes also determines the amount of solder paste present to form each solder joint during reflow soldering. As a guideline the minimum stencil aperture width must be at least 3 times (preferable 5 times) the diameter of the largest solder particle and the stencil aperture width should also be larger than the stencil thickness. Rounded aperture corners will reduce clogging of fine pitch apertures and smearing. The top surface of the metal stencil should be slightly roughened to make the solder paste roll perfectly during printing [10].

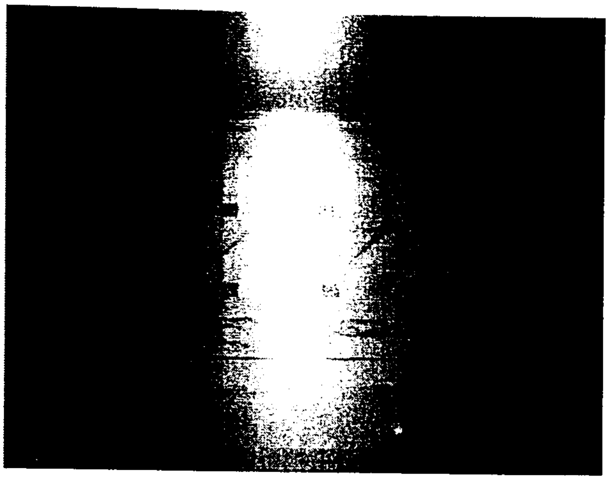

Figure 1.4: Stencil

- *Printed circuit board*

Rigid laminate material (FR4) consisting of a glass epoxy clad with copper on two sides for double side board (Fig. 1.5).

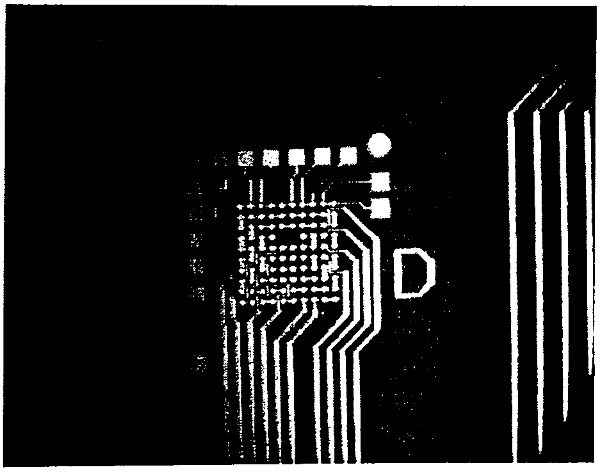

Figure 1.5: Printed circuit board

The flatness of the PCBs and the solder land flatness are both essential to the printing quality. If the PCBs are bent or twisted, the result can be large variation in the solder paste layer. And especially for fine pitch printing, the solder land flatness is important. The PCB has OSP (organic surface polishing) pads. The PCBs must also be clean and without fingerprints that will cause poor wet-ability in the reflow process. Fingerprints on the solder lands can also result in too little solder paste or none solder paste, because the solder paste will not stick to the surface and are left inside the stencil apertures. Especially PCBs with NiAu and OSP surface are sensitive to these problems.

- *Solder Paste*

The solder pastes function is basically to supply solder material to the soldering spot, hold the components in place prior to soldering, clean the solder lands and component leads and finally to prevent further oxidation of the solder lands. More details about this material will be presented in the next chapter.

1.2.4. PRINTING MECHANISM

The main reason for printing solder paste onto the PCB is to supply solder alloy for the solder joints. To reach this objective, the solder paste print must be aligned correctly, the correct amount of solder paste for each joint must be present and the print should form an even layer of paste for perfect component placement. The solder paste on top of the stencil is partly rolled and pressed into the stencil apertures and onto the PCB solder lands by a moving and angled squeegee (Fig.1.6) [16,17]. The squeegee angle must be between 45 to 60 degrees (usually not adjustable) and the rolling solder paste should have a diameter of 15 to 20 mm for optimum conditions. Several items are important to reach a good result when printing solder paste onto PCBs. The parameters squeegee down stop, squeegee pressure, printing speed, snap off, separation speed, printing area and stencil cleaning are explained below. The printer uses a vision system to accurately deposit solder paste onto the proper locations on the PCB. Once the board enters the printer, a camera is used to look at the reference points (fiducials) on both the stencil and the board. The printer then moves the stencil to align the stencil fiducials to the board fiducials. As a result, the stencil apertures are then lined up over the proper locations on the PCB. The solder is then deposited.

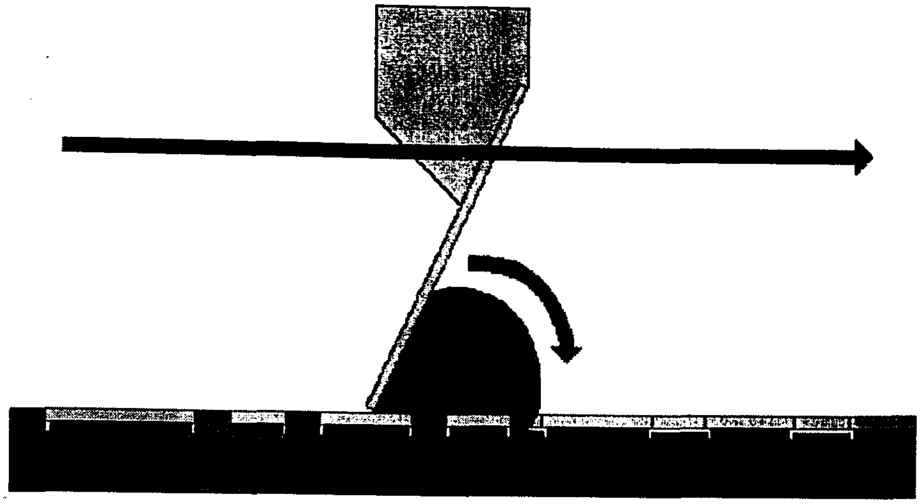

Figure 1.6: Printing Mechanism

- *Squeegee down stop*

The squeegee down stop is a mechanical stop that prevents the squeegees to move further down. It must be adjusted only to just touch the stencil surface. However, if the squeegee axis and the stencil are not perfectly parallel, it can be necessary to over-adjust the down stop to compensate. But, if the down stop is adjusted too far down, both stencils and squeegees will wear out rapidly.

- *Squeegee Pressure*

The squeegee pressure should be as low as necessary to scrape the stencil clean of solder paste particles when printing. If adjusted correctly, a thin layer of flux will remain on top of the stencil [1]. The amount of pressure is determined by printing speed and stencil type. As a manufacturing practice the pressure is adjusted to be equivalent to the squeegee length. For example, a 9 lb pressure should be applied when the blade in 9in in length.

Printing Speed

Usually the solder paste manufacturer gives a hint towards the printing speed window; typically between 1 and 1.5 inch per second. The possible printing speed is determined by the solder paste's behaviour. The solder paste must be soft and fluid when printed but jelly-like and stable when printed onto the PCB solder lands. The more fluid the paste is when moved and rolled the higher print speed can be used. The printing speed is a major factor in the printing cycle time and one is therefore interested in the highest speed possible without compromising the print quality [1].

- *Snap off*

Snap off is the distance between the stencil underside and the PCB placed in print position but without the squeegee touching the stencil. For best stencil printing, the snap off should be zero. This is also called contact printing. Here, the snap off plays a role in the amount of solder paste printed onto the solder lands. A high snap off will result in a thicker layer of solder paste [1].

- *Separation speed*

The speed of separation between stencil and PCB after printing is important. A too rapid separation speed when printing fine pitch will result in clogging of the stencil apertures. A too fast separation will also result in tailing and form high edges around the solder paste deposits. The ideal separation speed depends on the solder paste and the stencil aperture wall smoothness. On the other hand, a slow separation speeds will slow down the printing cycle time [1].

- *Printing area*

To ensure that the solder paste is rolling correctly before the aperture pattern is reached, the squeegee movement should start 80 - 100 mm or 2 times the solder paste circumference outside the pattern area. To the sides, the squeegee overlap should be a minimum of 20 mm [1].

- *Stencil cleaning*

In general, if all printing parameters are in control, stencil underside cleaning should not be necessary. Stencil underside cleaning can be done by hand or automatic. The wiper does not clean the stencil underside but simply moves the solder paste particles from around the apertures to the complete stencil underside. And when performing the next print the solder particles are transferred to the PCB where they are found all over the surface. Stencil cleaning prior to use is important to prevent dust and dirt to enter the solder joints. The stencil should also be cleaned for solder paste after use [1].

1.2.5. ENVIRONMENT

Dust and dirt from the air that ends up on the PCBs and stencils can cause defects such as bridging and poor wet-ability in the reflow soldering process. A small piece of fibre or hair between two fine pitch solder pads can easily cause bridging. It is therefore very important that the PCBs are stored in sealed packages and if necessary cleaned before use.

Air draught in the production area can speed up evaporation of the solvents in the solder paste and thereby make the solder paste dry out. Also a high temperature will make the solder paste dry out quickly. If the room temperature in the production area varies a lot, it will be very difficult to control the printing process. The viscosity of the solder paste changes with the temperature and the solder paste print will sometimes be perfect and other times the paste will slump and result in bridging. Solder paste supplier's data for the temperature window should be checked [18].

Solder paste printing performance, tack life, and reflow characteristics can be greatly affected by the temperature and humidity characteristics of the manufacturing environment. The recommended temperature the solder paste should be at when printing is 70-77°F. The recommended humidity is between 35-65% RH. Ideal temperature storage for solder paste is typically 32-40°F, but some newer formulas do not require refrigeration (it actually makes the solder paste perform poorly) [5].

1.2.6. SVS PASTE MEASUREMENT MACHINE

The paste volumes deposited on the board can be measured using an SVS paste measurement machine. The basic function of this machine is early defects detection. Paste defects are detected as they occur, allowing for the remove of defective boards before placement. Solder paste defects, such as low or high paste volume or bridging between pads, are the leading cause of SMT board defects.

Studies have shown that correct solder paste volume is the most important variable in producing solder joint quality. Joints produced with low paste volume may appear adequate and may pass a functional test, but can result in field failure. Up to 80% of SMT board defects can be traced to the paste application process. SVS machine technology enables precise height and volumetric measurements, the best indicators of final solder joint quality. This allows for instant identification of out-of-range conditions for immediate action.

The key component in data acquisition and image processing system is the solid-state 3-D scanning laser, which provides millions of highly accurate and repeatable height data points per second. The laser's speed is achieved as the beam sweeps back and forth over the board in a scan patch, minimizing the amount of mechanical positioning required measuring the PCB. As the laser beam sweeps over the PCB, a series of 3-D images is created. To guarantee measurement accuracy and repeatability, the inspection system establishes a zero reference plane for each image, using metal circuit trace information, which eliminates the effects of board warp and tilt on height and volume measurements. The inspection system's high-speed image processing hardware and software are especially suited for high-density images, such as BGA's and fine pitch component sites. These results in 100% PCB process measurement at in-line speeds for both solder paste after printing and component position after placement.

A single height measurement is made when the laser scanner projects a laser light beam onto the subject to be measured. The light is reflected onto the two position-sensitive detectors. Changes in height are measured as changes in the location of the reflected beam on the detectors. Triangulation is used to combine the position data from the two detectors to produce a single height data point. Millions of height measurements are made per second, and the resultant data points are mapped into image arrays, creating 3-D images [6].

CHAPTER II

LEAD FREE PASTE VERSUS LEAD PASTE

2.1. LEAD FREE DRIVING FORCES

There has always been a substantial pressure from environmental agencies around the world for the complete replacement of lead or to regulate its use. Collaborative industrial and organizational efforts of the electronics industry to resist these types of pressures have been successful in the past. Recent legislation and market pressures around the world to eliminate lead from electronic products are increasing and show no sign of subsiding. Theses types of environmental and legislative calls or forces trying to replace lead are identified as the driving forces.

Increasing use of PCBs in everything people use is leading to more electronics in landfills (Fig. 2.1)

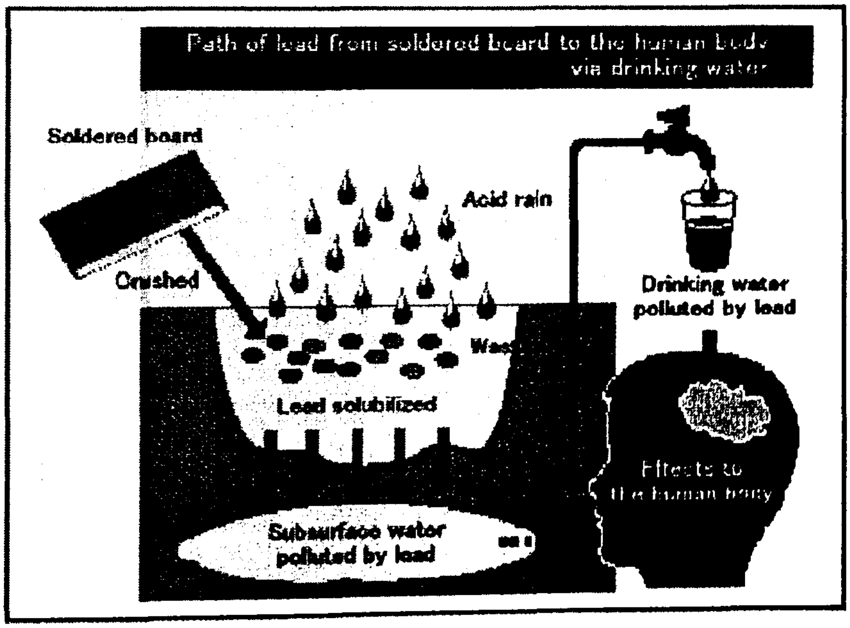

Figure 2.1: Path of lead from soldered board to the human body [2]

International pressure to eliminate/reduce the use of lead in electronic assemblies is accelerating due to the European Directives - WEEE (Waste Electrical and Electronic Equipment) and RoHS (the Restriction of the use of certain Hazardous Substances in electrical and electronic equipment) that will be effective August 2005 and 1st July 2006 respectively.

Asia

The lead-free initiatives in the Japan OEM segment continue to be the most advanced in the industry.

• Key OEMs driving lead-free technology throughout their manufacturing operations.

• China "Management Methods for the Prevention and Control of Pollution Caused by Production of Electronic Information Products" In draft form for consultation and relates to production of EEE.

Europe

Led by the major European and Japanese OEMs, Europe's electronics market will be the second most prevalent global lead-free market by 1/7/06 behind only Japan.

• Installation and commissioning of lead-free manufacturing processes is the number one issue for European producers of Electrical and Electronic Equipment (EEE).

North America

In Canada and the United States, the lead-free activity, although in its infancy, is accelerating due to a combination of environmental and competitive pressures in the industry.

2.2. ELECTRONICS INDUSTRY LEAD (Pb) CONSUMPTION

Lead has been used in industry for decades, and in some applications for centuries. The amount used in electronic solder is relatively minor. Table 2.1 details the percentages of lead are in use in our present industry. However, the percentage of lead in electronic manufacturing products is not significant, international agencies are demanding its elimination>The reason for such awareness is the lack of recycling facilities and procedures for electronic manufacturing products, when compared to storage batteries in the automobiles sector.

Product	Consumption (%)
Storage batteries	80.81
Other oxides (paint, glass and ceramic products, pigments and chemicals)	4.78
Ammunition	4.69
Sheet lead	1.79
Cable covering	1.40
Casting metals	1.13
Brass and bronze billets and ingots	0.72
Pipes, traps, other extruded products	0.72
Solder (non-electronic)	0.70
Electronic Solder	0.49
Miscellaneous	2.77

Not very significant in the total picture.

Table 2.1: Lead consumption in the industry [2]

2.3. TIN-LEAD SOLDERS

Tin/lead solder is the most widely utilized soldering alloy. The popularity of this alloy is due to its relatively low melting temperature, aggressive bonding characteristics, good wicking tendencies, good electrical continuity, and low cost. The low melting point of tin/lead solders is often preferred because of the reduced probability of thermal shock to soldered assemblies during high speed soldering operations.

Tin/lead solder electroplate will also protect copper circuit boards from oxidizing allowing them to be stored for long periods of time.

The phase diagram for the tin/lead system is shown in figure 2.2; the white areas represent all the temperatures at which combinations of lead and tin are "mushy". In theory, the useful temperature range for soldering is defined by the liquidus temperatures, but in practice recommended soldering temperatures should be 30-80 °C above this to ensure good alloy fluidity and wetting characteristics. The eutectic composition (c) would be the stoichiometry most common for wave soldering.

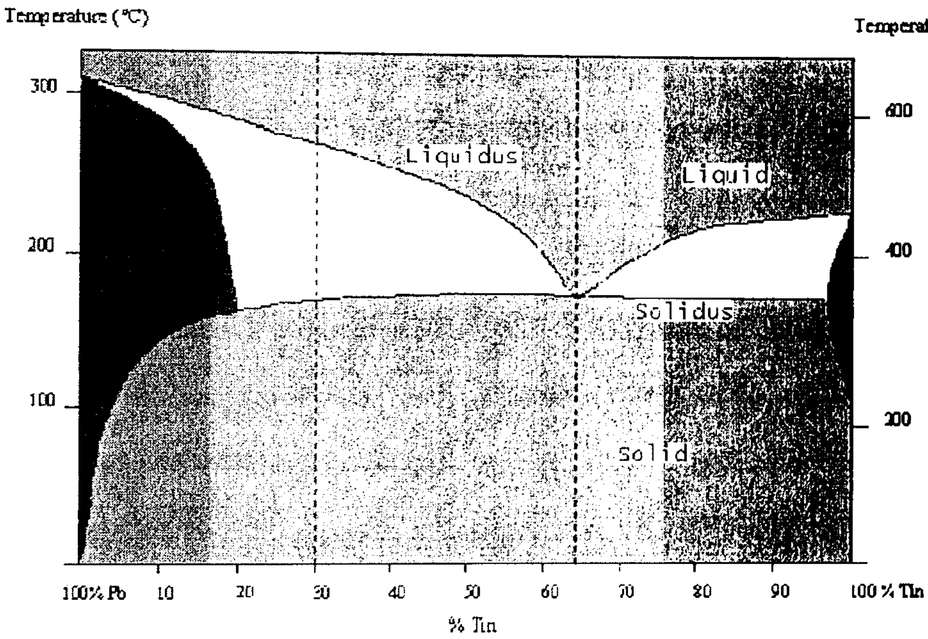

Figure 2.2: Phase Diagram of the Tin/Lead Solder Alloy System [7]

The lead component of tin/lead solders is regarded as a filler metal. Although many other metals can be combined with tin to produce solder, in the case of non-electronic solders lead is used primarily because of its low price. It also is easy to manipulate (i.e., it has a low melting temperature) and it dissolves tin readily (in the liquid state) so that both the tin and lead components remain well mixed. For electronic solders, however, lead plays an important role in a low melting point (eutectic) alloy, while preserving acceptable and necessary mechanical and electrical properties in the soldered joint.

Tin/lead alloys are subject to "tin pest", an embrittling reaction that results from the tin component in the solder converting allotropically from white (beta) tin to grey (alpha) tin. The reaction may have significant incubation times but will occur at temperatures lower than 13.2 °C. This reaction is accompanied by a 26 % increase in volume, which results in the tin component of the solder turning into powder. Additions of each element to the tin/lead alloy may have beneficial or detrimental effects on properties such as strength, creep, thermal fatigue properties, the scavenging of base metals, Intermetallic growth, viscosity, surface tension, etc. Each addition must be carefully evaluated to optimize the desired properties.

Perhaps the most important disadvantage of tin/lead solders is their high solubility for precious metals, particularly gold. Both tin and lead can combine with gold to form intermetallic compounds: the reaction rate growth kinetics for compound formation is high. These compounds when present at the older/substrate interface significantly embrittling the solder joint and result in very poor mechanical integrity. Tin also reacts with copper to form similar copper/tin intermetallic compounds. In the case of copper, however, the melting point of the compounds is higher than that of the tin/gold intermetallic and the reaction rates for growth are much slower. If, however, the copper/tin solder bond is subjected to even moderately elevated temperatures, continued growth of this phase will occur resulting in decreased bond strength [7]

2.4 SOLDERING METHODS

Currently, a number of soldering methods are used for making interconnections. Wave soldering, also known as flow soldering, is a low cost method commonly used for through-hole (TH) and bottom side surface mount discrete assembly. It supplies both the solder and heat in one step. The function of solder in TH assembly is to provide reliable electrical contact; the component is supported mechanically by lead crimping, screws, heat-staked pins, etc. Reflow soldering, most commonly used for surface mount (SM) assembly, consists of two operations; first, that of adding solder and second, applying heat to cause melting. The functions of solder in SM assembly are to secure the components to the substrate board as well as to provide the electrical contact. Thus SM assembly requires better mechanical performance from the solder than TH assembly. A mixed technology soldering combines SM and TH on the same circuit board.

- ***Wave Soldering***

The fluid dynamics of molten solder and the flux, oxide and relative motion of the board to solder at the "peel back" exiting position in the solder wave has been exhaustively studied to improve results. Circuit board fixtures and machine components use materials that are compatible with molten 63/37 Sn /Pb in contact with soldering flux. Specifications precisely define the maximum limits for the build up of contaminants in the solder for optimum performance, beyond which the solder must be changed. Typical wave soldering conditions are a wave temperature of 235-245 °C, a conveyor speed of 4 to 7 feet/min., and a time above the liquidus of approximately 5 seconds. The preheat temperature is typically adjusted to heat the soldered side of the PWB so that that the temperature difference between the solder wave and the PWB is less than 100 °C. Wave soldering parameters must be capable of dealing with the thermal limitations of ceramic discrete resistors and capacitors, Small Outline Transistors (SOTs) and Small Outline Integrated Circuits SOICs on the bottom side of assemblies. The major limiting factor in wave soldering of mixed technology circuits is that of excessive expansion per unit time, which can cause device cracking. The component-heating rate when immersed in molten Sn/Pb solder is in excess of 300°C second, and this is unlikely to differ significantly for other liquid metals. This defect mode is negligible when (1) the temperature differential between the preheat and solder wave is kept below 100°C and (2) only process qualified components are used.

- ***Reflow Soldering***

Solder paste is widely used for SM assembly, where it is applied by dispensing and screen or stencil printing. The paste is a mixture of solder particles (powder) and solder-paste flux. The oxide free solder particles are generally spherical in shape of 15 to 150 microns in size. The size and size distribution of the particles are critical to the performance of solder paste during assembly. Solder-paste flux is a uniquely tailored mixture of flux, thixotropic vehicles to control printability, elements to control drying rate and tackiness, etc. This material is mixed with the powder to provide a material having unique properties. Solder-paste flux must meet rigid electrical and chemical requirements to assure long term reliability, while also providing good wetting to the paste powder, substrate pads, and component surfaces.

The methods of forced convection heating are widely used for electronic assembly. High volume assembly with convection heating is generally performed with in-line, conveyorized equipment. Most of these machines provide convection modes of heat transfer. The heating rates, at about 1.5 °C per second, are two orders of magnitude lower than wave soldering. To prevent damage to FR-4 epoxy glass substrates in the form of discoloration, delamination, or measling, the maximum temperature is limited to 235 °C and the maximum time above the liquidus is about 2 minutes. Many of these soldering facilities are now introducing nitrogen into the reflow zones to reduce the oxygen level to below 100ppm: this provides a non-oxidizing environment in which a low residue solder paste can form acceptable solder joints. Such an environment can also reduce flux residues with solder paste materials designed for such use.

2.5. FLUXES AND FLUX REMOVAL

The solder paste consists of tiny solder balls made from the selected material (solder matrix) and is encased in a flux matrix. Fluxes serve a number of functions: to remove tarnish films, to protect the surface from re-oxidation, to remove reaction products so solder may come into intimate contact with the surface, and to assist transfer of heat to the joint. In the 1970's the vast majority of wave soldering operations relied on rosin-based fluxes and subsequent cleaning with chlorofluorocarbon (CFC) or chlorohydrocarbon (CHC) based solvents. The need for improved soldering yields and quality, and pressure to eliminate the use of environmentally hazardous materials, have resulted in a move toward water soluble flux (WSF) with water cleaning, aqueous detergent and semi-aqueous cleaning for rosin fluxes, and low solids flux (LSF) with "no clean". Generally, mildly activated rosin fluxes provide satisfactory soldering yields or standard TH products having components with good solder ability these fluxes are not capable of providing the low defect levels that are required for high density circuitry with SM components on the bottom side. As a result, many manufacturers have elected to use highly activated WSF to reduce solder defects and broaden that solder process window. Because of the high activity level of WSFs it is critical to have an effective and well-controlled aqueous cleaning process. A major drawback of this technology is the need to qualify assemblies for exposure to water; thus, the interest in "no clean" LSFs. There is still a good deal of ongoing development associated with these materials. Because the amount of residue remaining after soldering is related to the amount applied, it is important to control the flux application process. In addition, the small amount of flux solids available for soldering and the lower flux activity creates a smaller process window and requires better control of soldering parameters. There are similar flux considerations for reflow soldering. Historically, the fluxes used in solder pastes have been rosin based. The extent of cleanliness required depends on the factors cited in the previous section. There is current interest in developing reflow technology that leaves little or no solder paste residue. The solder pastes generally contain constituents that decompose during exposure to reflow temperatures. Successful low residue reflow has been achieved using LSF based solder pastes and nitrogen inerted reflow. Efforts are being directed at developing low residue pastes that perform well in an air environment [7].

2.6. PERFORMANCE CHARACTERISTICS OF SOLDER

The melting temperature of solder is usually the fundamental performance characteristic. Some soldering applications may call for a low temperature solder if the parts to be bonded cannot tolerate high levels of heat (most plastics found in printed circuit boards break down at temperatures over 270 °C). Other applications may call for a solder that can be heated to a "mushy" state such that the solder can be manipulated to fill gaps. By choosing eutectic type solders that are off stoichiometry with respect to the eutectic composition, the melting range and hence the degree of "mushiness" can be controlled.

The basic objective of the soldering process is to cause solder to properly wet the surface of each part to be joined. In reaching this objective solder will spread on each part to form a thin continuous film, which alloys with the base metal of each part to be joined. From the definition of soldering it is seen that the basic solder process depends on wetting for the formation of a solder to metal contact. This process of wetting of a liquid to a solid is influenced by tarnish products (oxides, sulfides, etc.) present on the surface of both the liquid solder and the solid base metal. These nonmetallic corrosion products must be removed by appropriate fluxes to ensure good wetting (low dihedral angle) between the liquid solder and the solid interface. The dihedral angles should be less than about 75°C to ensure high quality and reliability in the solder/substrate bond. The dihedral angle is influenced both by the cleanliness of the base metal/solder surfaces and by the chemical affinity between the solder elements and the base metal substrate. The larger the difference in surface tensions between the solder and the base metal the greater the affinity for the solder to wet the surface. For copper substrates, bismuth will exhibit better wettability, (i.e., a lower dihedral angle) than either tin or indium.

In electronic assemblies, solder joint failure can be caused by a number of mechanisms including (1) vibration, (2) mechanical shock, (3) thermal shock, (4) differential thermal expansion, (5) mechanical over stress, and (6) creep. These failure mechanisms, as well as low temperature cycling are primarily stress driven and hence the resistance to such failures is highly dependent on the strength of the solder alloy. Tensile and shear strength properties of solder alloys are highly dependent on temperature, strain rate, and test specimen geometry; hence prediction of solder joint characteristics from bulk material properties may incur a high degree of uncertainty. Alloys must be compared under similar test and joint configurations.

For surface mount assemblies, where the joint integrity is of utmost importance, the critical mode of failure is that of poor fatigue resistance at typical operating temperatures. The fatigue failures are generally strain induced and can be minimized by reducing the cyclic fatigue damage. Cyclic fatigue damage in SM assemblies can be minimized by reducing and/or accommodating the cyclic thermal expansion differences between (1) the SM components and the substrates to which they are solder attached, and (2) the solder alloy and the lead or circuit-board-land to which it is joined. Cyclic thermal excursions generally result from differences in temperature due to power dissipation internal to the component, and system load fluctuations and or seasonal changes external to the component.

The difference in coefficient of thermal expansion, CTE, between the solder alloy and the component lead material is normally only a contributing factor to fatigue failure, but is can be a primary cause when the difference in CTE is large and the use environment is severe, particularly in the presence of stress concentrations at the brittle intermetallic commonly found at joint interfaces.

The underlying mechanism causing long-term solder joint cyclic fatigue damage is the creep and stress relaxation behavior of solder. Solder often operates at temperatures in excess of 60% of its absolute melting point. Thus, solder undergoes significant stress relaxation and creep - processes that convert elastic strains to plastic strains. These processes are very time, temperature, and stress dependent. The fatigue damage due to plastic strains is significantly larger than damage from elastic strains.

The primary purpose of compliant leads to reducing the stress level at the solder joint significantly below the solder yield strength to reduce the cyclic hysteresis loop area and the cyclic fatigue damage. At lower stress levels, the visco-plastic flow slows significantly. A reliability benefit can result if stress levels are reduced to a point where the conversion of the elastically stored strain energies to plastic deformations in solder due to stress relaxation or creep is retarded to such an extent that stress relaxation is still significantly incomplete even for operational cycles.

Solder grain structure is inherently unstable and will coarsen with time and temperature, particularly in the presence of cyclic strains. Fine grain structures in the solder at the time of accelerated testing give false indications since grain size will coarsen in use [7].

2.7. LEAD FREE SOLDER PASTE

There are numerous lead-free alloys available today, some of which have already been used for decades in high temperature applications. Consensus is that Tin (Sn) with additives to improve wetting, strength, reliability and process yield is the only viable alternative to replace Lead (Pb) Primary alternatives are typically >95% Sn plus elemental additives to offer the best match to the current Tin-Lead alloys [2].

If an alloy contains two elements, it is referred to as a eutectic alloy, for example tin-lead solders. Similarly, it is referred as ternary for having three elements and quaternary for having four elements. Any replacement solder alloy usually contains tin (Sn) with on or more than one of these elements: lead (Pb), silver (Ag), copper (Cu), indium (In), bismuth (Bi), zinc (Zn), germanium (Ge) and antimony (Sb). Properties of a solder alloy depend upon its constituent element. The following are the most desirable attributes of any solder replacements:

1- No element in the selected solder alloy will have a significant negative environmental impact now or in the future.
2- It should be available in sufficient quantities, now and in the future.
3- Melting temperatures should be similar to tin-lead solder, preferably close to 183 °C.
4- Wetting behavior should equal to or better than tin-lead solder on variety of surface finishes. Pasty range, which is defined as the transition phase from complete solid to

complete liquid, should be as small as possible. Eutectic alloys such as possible. Eutectic alloys such as tin-lead solder have no pasty range but non-eutectic alloys have a pasty range.

5- Thermal and electrical conductivity should be similar or better than of tin –lead eutectic solder.

6- It should exhibit good reliability in terms of adequate joint strength and thermal fatigue resistance. Reliability performance should be at lease as good as Sn/Pb in thermal cycling and end-use environmentally.

7- It must be easy to rework and should be lower than or similar to tin lead solder.

8- Replacement alloy cost should be lower than or similar to tin-lead solder.

9- It must reflow with the existing equipment [2]

Table 2.2: Pb Free alloy overview [2]

	Constituents (Ranges NOT specifications)							CELSIUS		Raw Material Cost
Name	Sn	Ag	Cu	Sb	Bi	Zn	In	Solidus	Liquidus	Sn63/Pb37=1
Tin Silver Eutectic	96.5	3.5						221	221	3.0
Tin Copper Eutectic	99.3		0.7					228	228	1.5
Tin Zinc Eutectic	91					9		199	199	1.4
SAC	Bal	3-4	0.5-1					217	221	2.7
SAB	Bal	2-4			<5			205	210	2.6
SACX	Bal	0.3	0.7					217	228	1.6
SACSB	Bal	2.5	0.5	0.12	1			213	221	2.5
SACI	Bal	4.1	0.5				4	205	210	7.2
SZB	89				3	8		189	199	1.4

Tin Silver Eutectic: Higher solidus/liquidus than SAC (Table 2.2) will pick up Cu from boards at a rate of around 0.03%Cu/1000 boards - will become a SAC alloy in use. Has poorer wetting than SAC and considered too high liquidus for reflow applications.

Tin Copper Eutectic: This alloy has lower metal cost than silver containing alloys. The main disadvantages; are higher liquidus than SAC (Table 2.2), too high for reflow usage, high level of bridging in wave and thermal fatigue concerns (cracked joints).

Tin Zinc Eutectic: This alloy has lower metal cost than silver containing alloys. Low liquidus temperature. Could offer a similar reflow profile to SnPb. On the negative side of it; Zinc is highly corrosive, oxidizes very readily. Poor fluidity/drainage excludes from wave. Requires very active flux/coated powder/nitrogen atmosphere - question reliability.

SAC: This is an ideal alloy for high temperature applications. It contains widely available materials and a good contender for reflow soldering. The alloy has lower liquidus than SnCu, SnAg - Reflow OK. Good fluidity, low level of bridging (Table 2.2).

Low copper leaching compared to SnAg. Rapidly becoming the "Standard" lead free (LF) alloy.

SAB: This alloy has Lower liquidus than SA, SAC and SC alloys. Increased fillet lifting caused by SnBi phase. Test showed reliability hazard with Lead on components (96oC Melting Point phase) (Table 2.2).

SACX: Lower raw material cost than SAC305/405, yield equivalent to SAC305, much superior to all Sn/Cu based alloys but joints are duller than Sn/Cu (Table 2.2).

SACSB: Lower solidus temperature than SAC, Lower Silver content and hence material cost. On the disadvantages side Bismuth content high enough to cause problems if there is low melting phase of Sn/Pb/Bi at 96 °C (Table 2.2).

SACI: For this alloy the liquidus temperature of 210 °C. However it has very high raw material cost and prohibitive for Wave Solder and for Reflow (Table 2.2).

SZB: On the plus side of this alloy lower cost than SAC alloys, and lowest solidus/liquidus temperatures. The main disadvantages are; Zinc is highly corrosive, oxidizes very readily. Poor fluidity/drainage excludes from wave (Table 2.2).

The industry focus is on the SAC alloy because of its obvious advantages over other types.

SAC Alloy meets the Following Requirements

- Reflow liquidus temperature approximately 220 °C.
- Wide process capability alloy without a large performance detractor.
- Good thermal fatigue resistance.

All other alloys have at least one major drawback.

- Tin-Silver has a reflow temperature that may be undesirable for some surface mount applications and poorer wetting performance.
- Tin-Copper does not produce acceptable production or reliability performance.
- Tin-Zinc alloys do not generally have acceptable shelf life properties due to alloy corrosiveness.
- Tin-Silver-Bismuth alloy has a hazard of generating a low melting point phase within the alloy.
- Tin-Zinc-Bismuth: Zinc is a highly corrosive material-making product difficult to work with.
- Indium containing alloys are very expensive.
- Wetting and spread are often confused in discussions about Lead-Free solder.
- <u>Definitions</u>:

(i) Wetting performance is measured as time to wet and wetting force and is evaluated using a wetting balance. This is a indicator of the magnitude of the interfacial energies between the solder and contact surface. Faster wetting speed and higher wetting force are desirable (the attractive force between the two materials is greater).

(ii) Spread is measures of the movement of the solder during reflow to cover the contact surface and the extent of spread is determined by the interaction of the wetting forces (above) and the surface tension (forces) of the liquid solder.

• The surface tension of Lead-Free solders is greater than that of Sn63/Pb37, therefore even though the wetting forces are high for Lead- Free alloys (particularly SAC) this results in less spread of the liquid alloy when compared with Sn63/Pb37. Traditionally in Tin/Lead soldering poor spread has been an indicator of "poor wetting" this is not the case with Lead-Free alloys.

Table 2.3: Physical Properties Sn63/Pb37 versus SAC Alloy [2]

Physical Properties	**Sn63/Pb37**	**SAC Alloy**
Melting Point [°C]	183	217
Electrical Conductivity %IACS	11.9	13
Electrical Resistivity [μΩ.cm]	14.5	13
Brinell Hardness HB	17	15
Density [g/cm3]	8.4	7.5
Tensile Strength [N/mm2 at 0.004/s strain rate, 20°C]	40	48
Joint shear strength [N/mm2 at 0.1mm/min, 20°C]	23	27
Joint shear strength [N/mm2 at 0.1mm/min, 100°C]	14	17
Creep Strength (Shear stress for 1000 hours to failure) [N/mm2, 20°C]	3.3	13.0
Creep Strength (Shear stress for 1000 hours to failure) [N/mm2, 100°C]	1.0	5.0

Fundamentally the physical properties of Sn63/Pb37 and SAC alloys are very similar.

Considerations when making alloy selection:
There are a number of different alloys available for Lead-Free soldering, and they have differing fundamental properties. During selection consideration should be given to:

- Melting point (solidus/liquidus temperatures).

- Wetting speed and force.
- Thermal fatigue resistance.
- Mechanical Strength.
- Rate of oxidation.
- Fluidity (drainage for wave solder).
- Potential to form low melting point phase when Lead is present.
- Raw material cost.

SAC Alloys have no major flaw and are the most popular Lead-Free alloys currently in use [19].

CHAPTER III

3.1. EXPERIMENT METHODOLOGY

3.1.1. OVERVIEW

The goal of the solder paste printing process is to consistently deposit a precise amount of solder paste onto specified areas of a substrate. Therefore, the print performance (printability) of a solder paste ultimately has to be measured by its ability to create depositions of consistent volume.

To investigate the lead free paste printability and compare it to the regular lead paste, a test vehicle was used that included very fine pitch type of pads (micro ball grid array pads). In the experiment, one type of pad finishing (copper finished) was used as test vehicles.

One of the main goals of this experiment is to find out the appropriate machine settings for each paste for optimum coverage on different settings. The goal of the solder paste printing process is to consistently deposit a precise amount of solder paste onto specified areas of a substrate and to determine how the lead and lead free pastes will react under changing pressure and speed of printing.

All printing should be done using typical, best practice production parameters, (on-contact printing, metal squeegee, squeegee pressure 1-2 pounds per linear inch, 5-6 mil thick laser-cut stencil, print speed of 1- 1.5 inches per second).

Release from the stencil determines the deposition volume of solder paste. As several factors can influence the release characteristics of a solder paste, great care should be taken to keep these factors consistent when comparing solder pastes.

3.1.2. SELECTION OF EXPERIMENTAL PARAMETERS

The results of the experiments in the effect of key control factors on paste volume and print quality concluded that squeegee speed and pressure are the most dominate factors in this process. The length of the PCB to be screened determines the proper length of the squeegee. In addition, the available standard squeegee blades on the floor, table 3.1, also control the blade selection. There are different sizes on the market, but this is the normal size used in printing. The next dimension to consider is length. The simple answer to this selection is that it should be long enough to overlap the board by a comfortable margin, usually a half-inch or more, depending on the size of the printed board. If your squeegee is too short, there's a chance it will drift off to one side or the other during the print stroke and leave part of the image unprinted. A blade should extend 0.5 to 1.5 inches beyond each end of the PCB. In this case a standard blade length of 9-inch for an 8-inch board length was used (see table 3.1). The squeegee pressure for metal blades is 1-1.5 lb per liner inch of blade as per our process guidelines. So as an initial pressure operator in this case is start applying is 9 lb and may go up to 13.5 lb. Regarding the speed, it is very paste dependent. Most paste vendors are recommending starting with speed 1 in/sec (in case of no clean paste and not water soluble type). Manufacturing operator's process to use 1-1.5 in/sec for most the used paste at this time. Both initial pressure and speed were selected according to the electronic manufacturing assembly standard [20,21].

Simulating manufacturing practises was a key factor in parameter selection in this project. When screening results are not satisfactory, the EMS operators change randomly one of the two parameters (speed and pressure}. They may ending up changing both of them in order to get the best paste height or volume. The idea was to measure the effect of each one of the parameters on the paste volume in case of increase or decrease and improve the printability. The two most significant parameters were chosen in the printing step and optimized according to each of the two experimental pastes. Changing one parameter at a time was maintained constant to eliminate any variability in the data.

Table 3.1: Manufacturing standard squeegee blade lengths

Squeegee blade length (in)	Intial pressure (lb)	PCB length (in)
6	6	less than 6
9	9	less than 8 up to 6
12	12	less than 11 up to 9
16	16	less than 15 up to 12
19	19	less than 18 up to 16
21	21	less than 20 up to 19

3.2. EXPERIMENT EQUIPMENTS AND MATERIAL OVERVIEW

3.2.1. STENCIL

One laser cut stainless steel stencil was tested in the experiment .The opening size and thickness of each component pad determine the volume of paste to be deposited at each location. As the screen printer squeegee passes over the opening, solder paste is forced onto the PCB. The volume of paste required depends on the individual component and lead size. The fine pitch applications are typically defined as having area ratios smaller than 1.1 (where area ratio= area of the aperture/ area of the aperture walls). The stainless steel stencil was provided with a special coating to smooth over rough edges produced during the stencil manufacture. The main design features for the project stencil are:

1- Size 29"x29"

2- Foil thickness: 5 mil (0.005")

3- Laser cut

4- Stencil aperture opening made rounded as the same pad shape

5- The ratio of aperture to pad size is made 110%

3.2.2. SOLDER PASTE

The solder pastes used in this work were obtained from regular solder manufacturers as follow

1- Lead paste: Eutectic (Sn63/ Pb37), no clean, with particle size type 3

2- Lead free paste: (96.5 Sn/ 4 Ag/ 0.5 Cu), no clean, with particle size type 3

Both pastes were treated in the same manner to allow for direct comparison of the results. Each paste was brought to room temperature prior to any testing. Prior to using any type of paste, a through manual kneading operation was carried out before applying it on the surface of the stencil.

The SnAgCu lead-free solder paste obtained from the solder manufacturers were in a large part new developmental paste so there would necessarily be some differences between their performance and those of tin-lead pastes. Improvements would be made with increased usage of these lead-free products. For Type 3 paste the maximum size solder particle in this paste is 0.0017" in diameter; therefore, the minimum aperture width should be 0.0085".

3.2.3. TEST VEHICLE

The test vehicles contained eight micro BGA's (A-B-C-D-E-F-G-H), with 0.5 mm pitch between pads, and solder mask defined. The boards have four-layers FR-4 with a copper pad finishing. The PCB size is 8"x4.5"x0.6".

3.2.4. PRINTER (SCREENER)

The screening equipment used in this project is the MPM Ultraprint 3000 series. It is a fully automatic screen printer. The machine consists of the following elements:

Slide shuttle configuration to allow the operator access to the print head, the universal nest and all related set up adjustments. Video camera systems with cross hairs to provide a visual aid for fast and accurate initial alignment. During production operation, the video system shows the operator the best fir alignment at a glance [22].

Controls and instrumentation for critical process parameters such as squeegee speed, snap off (which is zero in this experiment), print mode and vacuum rates.

Motorized squeegee drive and shuttle cam followers to ensure registration control and repeatability.

Dual squeegee to place the solder paste on the appropriate pads.

Specifications for metals squeegee blades and the initial operation conditions were as follows (see figures 3.1 and 3.2):

a- Total Force 9.0 lb.

b- Balance 50/50

c- Print Speed 1.0"/second

d- Printing Conditions: room temperature is 22° C and humidity is 50%

e- Snap off was set to zero for all runs

f- 9" metal squeegees with no damage or wear (60 degrees with PCB)

g- Stencil separation speed: low

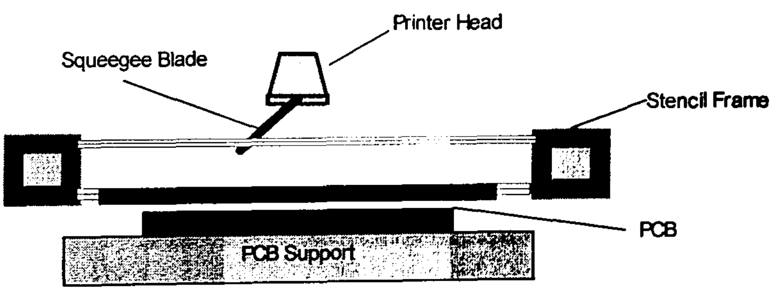

Figure 3.1: Stencil Printer Schematic

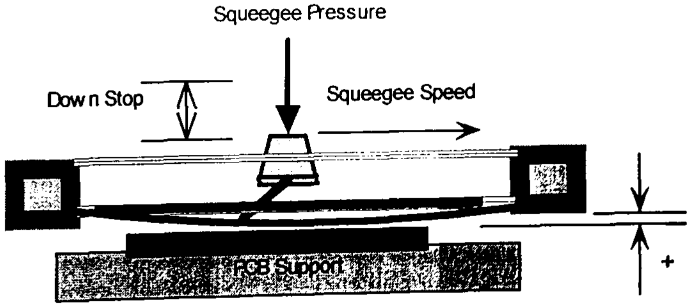

Figure 3.2: Key Variables

3.2.5. PASTE VOLUME MEASUREMENT MACHINE

The SVS 8100 machine was used to measure the paste volume and height. SVS measurements must be >70% of expected volume (as calculated from the volume inside the aperture). All of the pastes met this criterion, although volumes did fluctuate more on some samples than others [21,22].

3.3. VARIABLES

Pressure and print speed were identified as the two factors that are most significant on printability and the goal is to determine which levels of these factor combinations should be selected to optimize the response.

The following parameters were taken into consideration in these experiments: screenings speed and pressure.

Total force: is the force applied to the squeegee blades by the screen printer. This setting should be just high enough to ensure that no paste residues are on the stencil during the print stroke. Due to the flexibility of squeegee blades, an increase in total force would result in an inadvertent increase in chamber pressure.

Print speed: is the speed at which the squeegee head travels across the top of the stencil during the print stroke. Slower speeds result in more "time over aperture" and more paste deposited on the pad (which allows the paste time to flow into the apertures). Faster speeds decrease "time over aperture" and result in less paste deposited.

Parameters and General Experimental Procedure:

1- Start with freshly opened solder paste.

2- Both types of solder pastes (Type 1, lead free paste and Type 2; lead paste) are brought to and stabilized at ambient (approx. 22° C, 50% RH) temperature for at least four hours.

3- Pastes are thoroughly mixed using a plastic spatula for 30 seconds.

4- Machine set up and screening conducted by the same personnel.

5- Begin the test by depositing sufficient solder paste to print approximately 10 boards (175-200 grams -there is NO paste replenishment during the test).

6- Three boards are printed of each paste at one time and at the same speed and pressure. Boards screening intervals were kept the same for each patch 45 seconds between boards.

7- Each board is clearly marked as to its printing sequence.

8- There should not be any intermittent bottom side wiping between boards in the same batch.

9- After screening three boards the stencil is thoroughly cleaned manually using isopropyl alcohol (IPA) and dried between samples to ensure there was no paste build-up in the apertures.

10- Examine the screened boards under a 30 X magnification microscope.

11- Immediately after examination perform the volume measurements using SVS machine.

12- Testing all boards done quickly to minimize pastes sensitivity to environmental changes[22].

3.4. EXPERIMENTAL RUNS

The experiments were run in two different phases. In each phase, there were five runs. The experimental runs were completed in sequence depending on the type of solder paste alloy due to practical reasons. Limited amount of time and availability of only one stencil printer during the experiment were the main reasons for this sequencing. All the lead free PCBs were numbered from Type1 A to Type1 P. While all the lead paste PCBs were numbered from Type2 A to Type2 P.

The sequence of screening started with leaded paste Sn63/Pb 37 followed by the SAC lead free paste. Every time the solder paste was changed, the stencil and squeegee blades were cleaned properly to avoid any contamination. Table 3.2 shows the exact experiment run for Type 2 lead paste.

Table 3.3: Experimental runs for Type 2 (phase 1) lead paste

Lead Paste Sn63Pb37	TYPE 2			
	Run 1	Type2 A	1	9
		Type2 B	1	9
		Type2 C	1	9
	Run 2	Type2 D	1.1	9
		Type2 E	1.1	9
		Type2 F	1.1	9
	Run 3	Type2 G	0.9	9
		Type2 H	0.9	9
		Type2 I	0.9	9
	Run 4	Type 2 J	1	9.9
		Type 2 L	1	9.9
		Type 2 M	1	9.9
	Run 5	Type 2 N	1	8.1
		Type 2 O	1	8.1
		Type 2 P	1	8.1

Method of Calculation Paste Average Volume

The paste measurement machine (SVS) was calculates the observed paste volumes (Obs. Vlu.). Each of these volumes is represents the average of paste deposited on one pad of each micro BGA (Ball Grid Array). The board has 8 locations (A-B-C-D-E-F-H). Each location has 98 pads. For example the average was calculated at reading Run 1 location A-KG, table 3.2 as the sum of volumes on all pads at location A-KG divided on the number of pads on that location.
The readings were collected three times and at the end of Table 3.2 an average of three reading was calculated.

Table 3.2: Example of Calculation of Paste Average Volume

	Obs. Vol.Cumil			
Device Name	Reading 1	Reading 2	Reading 3	Average
A-KG	459	405	419	427.67
B-KG	467	387	395	416.33
C-KG	501	430	419	450.00
D-KG	330	318	346	331.33
E-KG	489	410	439	446.00
F-KG	413	349	351	371.00
G-KG	417	386	397	400.00
H-KG	393	355	426	391.33

Phase 1

The print results (Type 1 Run 1 to Run 5) for the lead paste using different machine printer settings as shown in Table 3.3. An exact amount of lead paste (100 grams of paste) was placed on top of the stencil for screening. After screening three good boards and examining them using microscope, they were taken to the SVS for paste volume measurements. In Run 1 the speed and pressure was kept at the nominal values 1 in/s, 9 lb respectively.

In this phase, there were five trials (Run 1 to Run 5). In each run, a total of three boards were screened and inspected visually and measured by SVS at normal rate of one card per minute. In case of Run 1, a normal production setting used to screen the initial 3 boards (Type 2 A-B-C) with speed of 1 in/s and pressure of 9 lb, which equal to the pressure length. Paste printability and consistency was good in Run 1 as shown in Figure 3.4, there were enough of paste volume on each location except location D that would show similar results on all runs due to card support issue underneath that location. The test data (paste volume) was averaged by the SVS on each micro BGA (98 balls on each one, Figure 3.3).

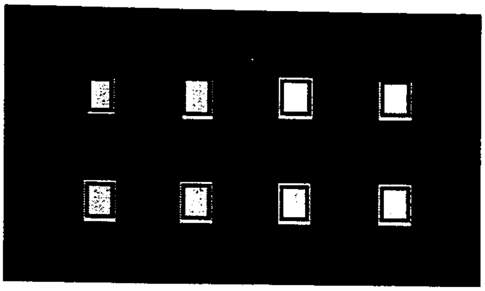

Figure 3.3 (a): The micro BGA pads

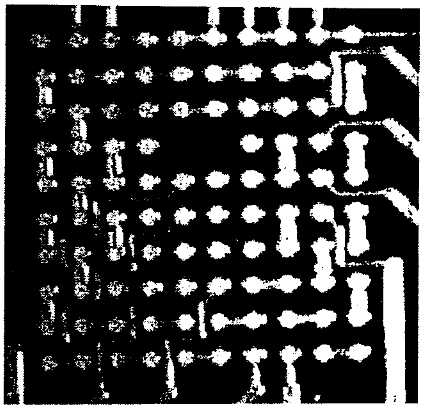

Figure 3.3 (b): Test Vehicle

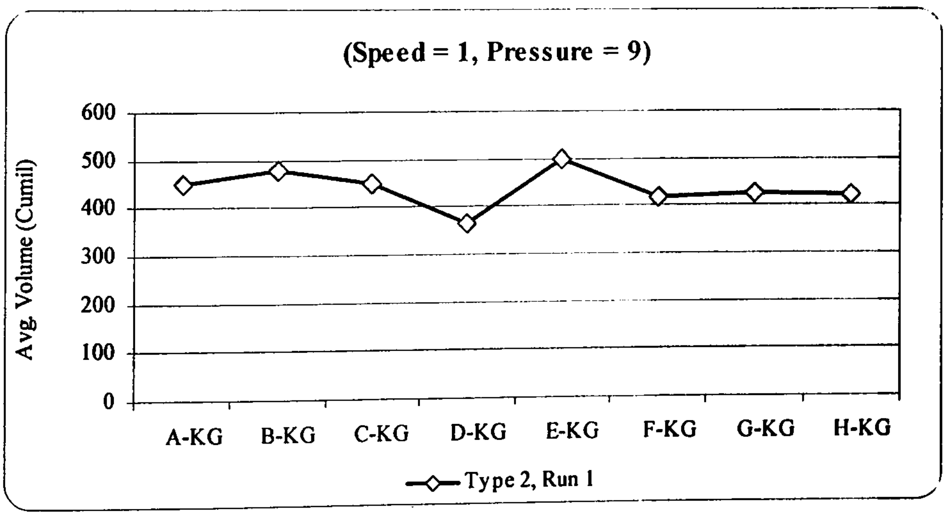

Figure 3.4: Type 2 (lead paste), Run 1

After this run, the stencil was cleaned manually using wipes and IPA. Paste remains on stencil. The printing speed was increased by 10 % to 1.1 while the pressure kept the same at 9 lb. Another three boards were screened Type 2 (D-E-F) Table 3.2. Boards are run through the SVS system and volumes at pads noted, the results are shown in Figure 3.5.

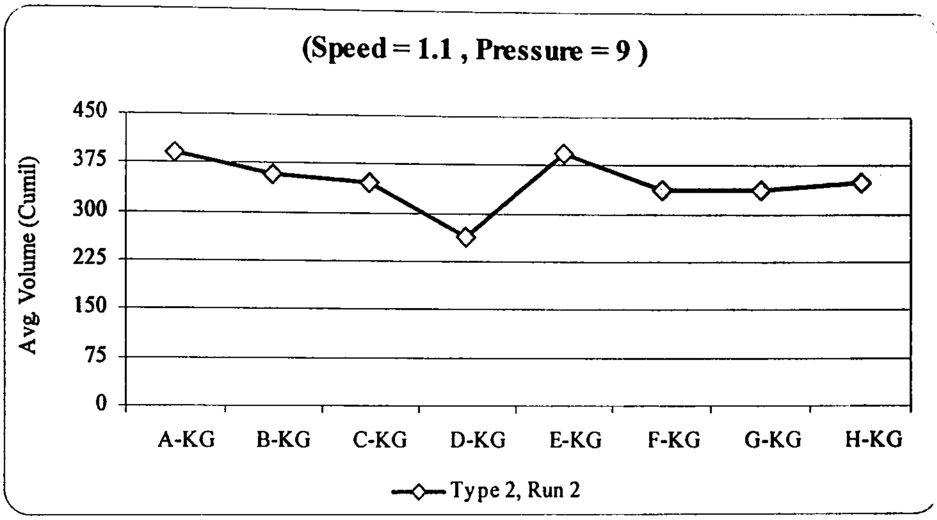

Figure 3.5: Type 2 (lead paste), Run 2

Figure 3.5 shows clearly that increasing printing speed is a definite factor to decrease the deposited lead paste volumes on pads. The relatively higher squeegee speed 1.1"/s did shown low paste volumes and consistency at some points.

On the other hand, Figure 3.6 introduces the results for the lead paste (Type 2) with slower screening speed (Run 2). More time was given to the squeegee to flow the paste into the apertures; consequently the volume is 6% bigger compared to the previous two runs.

Now the time to see closer the effect of total force applied to squeegee blades by the screen printer.

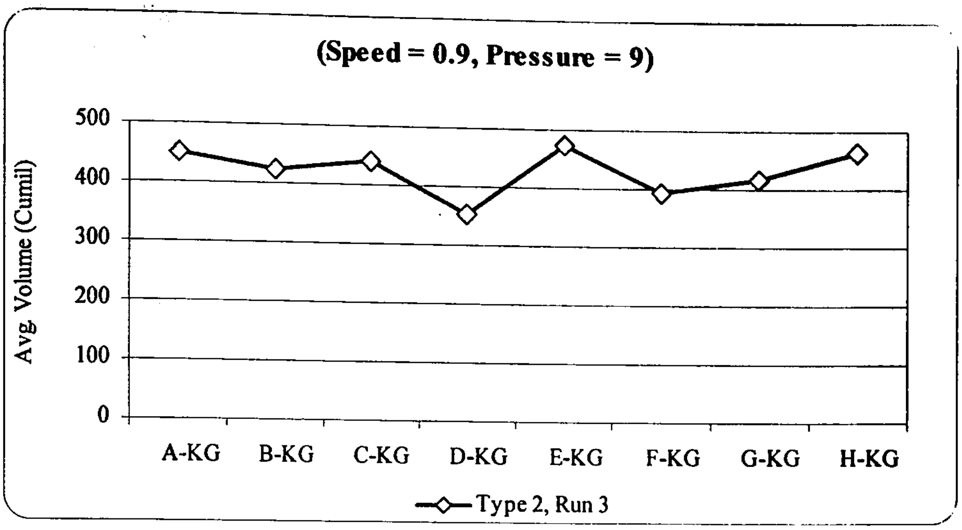

Figure 3.6: Type2 (lead paste), Run 3

For Type 2 Run 4 the pressure was increased by 10% to 9.9 while the speed of the squeegee kept the same at the nominal value of 1 in/s. Figure 3.7 shows the results of such settings. The paste volume starts decreasing. This decrease in volume may show that scoping effect may start to occur when squeegees are forced to go beyond the stencil surface. Greater force results in excess paste scooping. Scooping effect occurs when excessive pressure applied to the stencil through the squeegee forcing the paste to come out of the apertures.

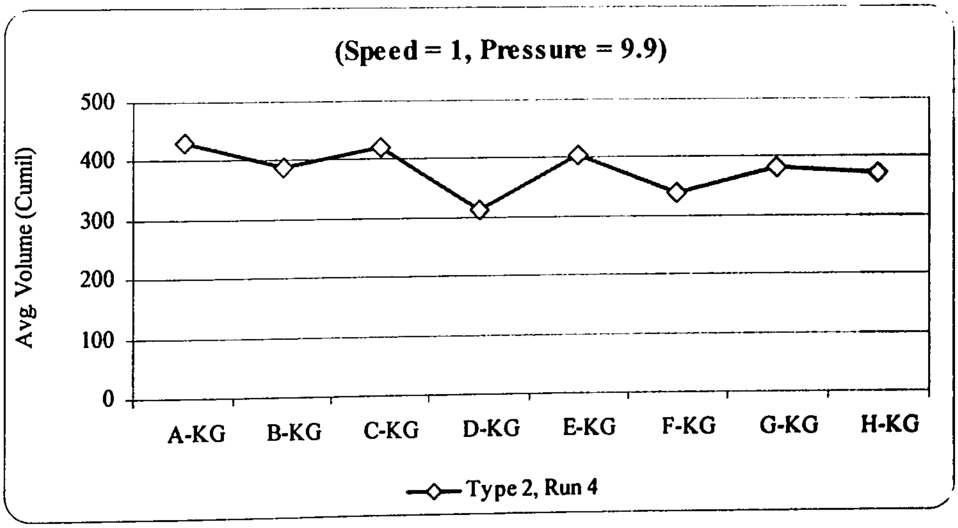

Figure 3.7: Type 2 (lead paste), Run 4

Figure 3.8 Type 2 Run 5 shows the graphical results of screening paste Type 2 with less pressure by 10% and same blade speed at 1" /S, the paste volumes less than Run 1but by very small percentage. From pressure setting, the optimal pressure force was 9 lb in this case. The optimal parameter is considered to be the one, which may give the desired paste volume. The desired optimal paste volume was calculated by multiplying the area of the pad by the stencil height (5 mil) .The optimal volume is the one which is close to the theoretical programmed value.

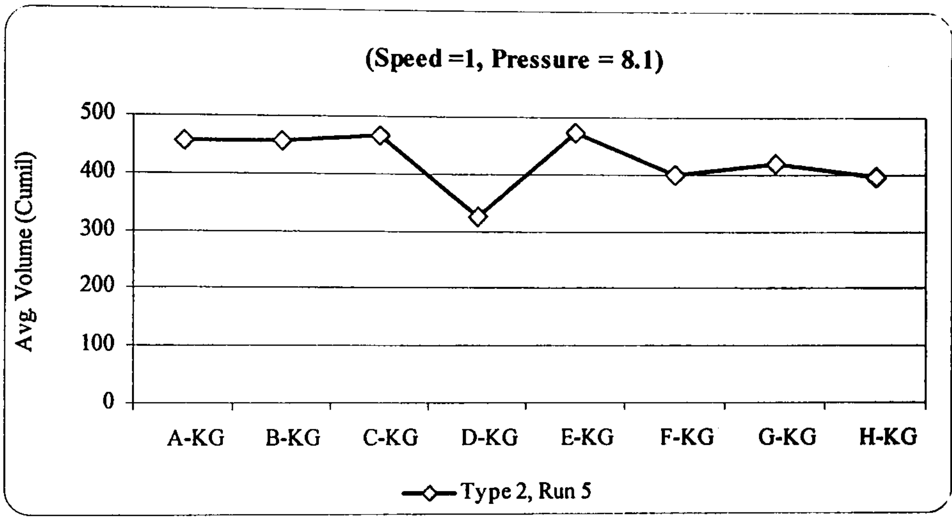

Figure 3.8: Type 2 (lead paste), Run 5

SUMMARY (Phase 1)

Comparison of all five runs of Type 2 paste is presented in Figure 3.9. This figure shows printing quality regarding paste volume at three different settings of speed and pressure. These results clearly present data towards optimizing machine setting and the level of changing these variables. For example, screening with slower speed than 1"/s is giving more consistent paste for all three board while the nominal setting tends to give less paste volume by the third board. Increasing the squeegee speed showed less volume on the micro BGA pads. Print quality data such as paste volumes and visual appearance of solder paste deposits were less affected by pressure changing than that of squeegee speed. Paste consistency could be defined as is the ability of the screening machine to deposit desired of volume of paste with no screening defects such as bridging, insufficiency, and missing.

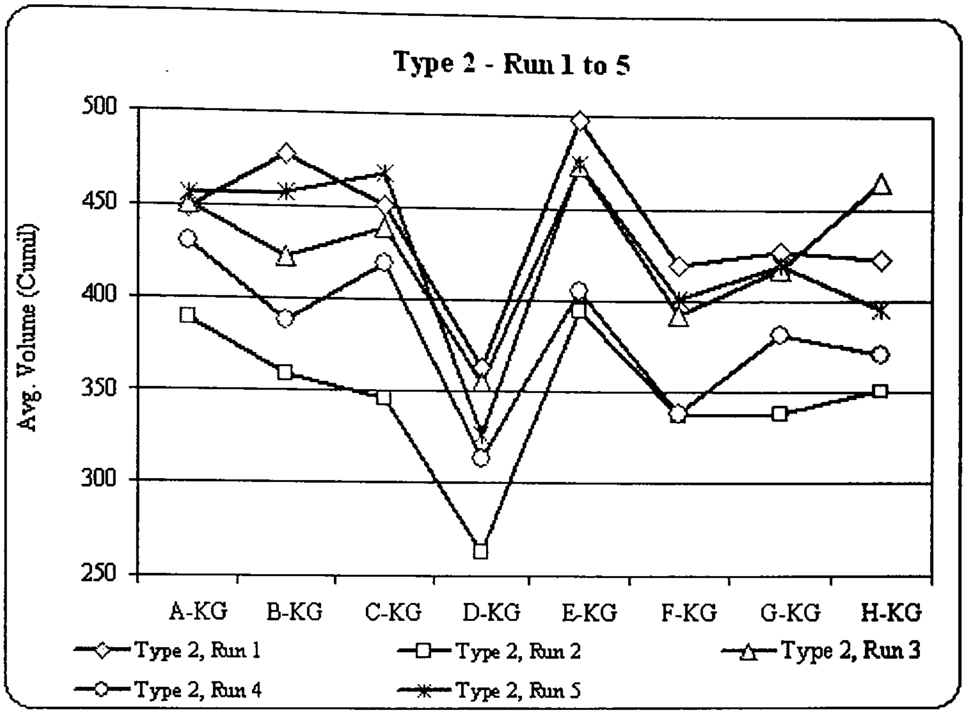

Figure 3.9: Type 2 (lead paste),Runs 1 to 5

Phase 2

The second phase of experiment investigated interaction between the same process variable (speed and pressure) but using lead paste (Type 1). For each phase of experiment, a full sequence was designed and run as indicated in Table 3.4. After washing the stencil and thoroughly cleaning the squeegees the same amount of 100 grams of lead free paste this time applied on top of the stencil to start phase2.Figure 3.10 Type1 Run1 represents the results of using lead free paste with the nominal screening speed of 1"/s and pressure of 9 lb. The paste deposited volumes were normal and acceptable to the SVS machine.

Table 3.4: Experimental runs for Type 1 (Phase 2) Lead Free Paste

Lead Free Paste Sn95.5 Ag4 Cu0.5	TYPE 1			
	Run 1	Type1 A	1	9
		Type1 B	1	9
		Type1 C	1	9
	Run 2	Type1 D	1.1	9
		Type1 E	1.1	9
		Type1 F	1.1	9
	Run 3	Type1 G	0.9	9
		Type1 H	0.9	9
		Type1 I	0.9	9
	Run 4	Type 1 J	1	9.9
		Type 1 L	1	9.9
		Type 1 M	1	9.9
	Run 5	Type 1 N	1	8.1
		Type 1 O	1	8.1
		Type 1 P	1	8.1

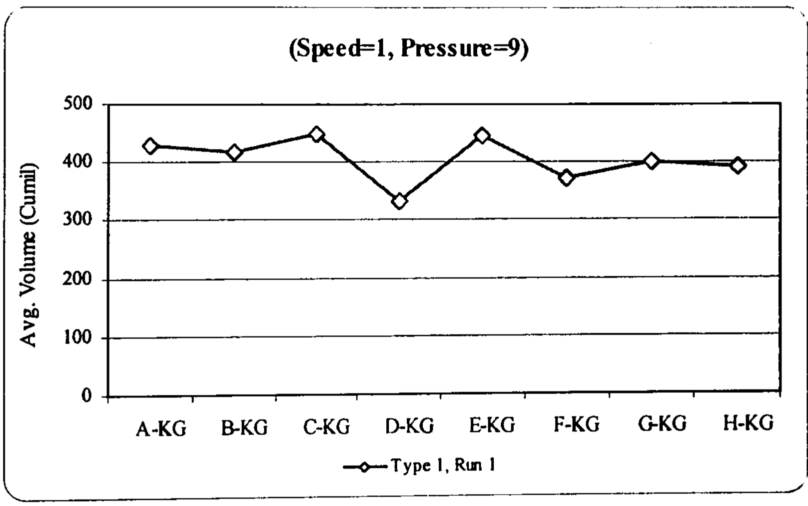

Figure 3.10: Type 1 (lead free), Run 1

The stencil was cleaned and with the same time intervals continue screening cards with labels Type 1 D-E-F. The machine setting has changed to speed 1.1"/S, pressure 9 lb. Paste measurements were taken for three boards, result are illustrated in Figure 3.11 Type1 Run 2. Deposited paste volumes were less than Type 1 Run 1as speed was increased but fractionally.

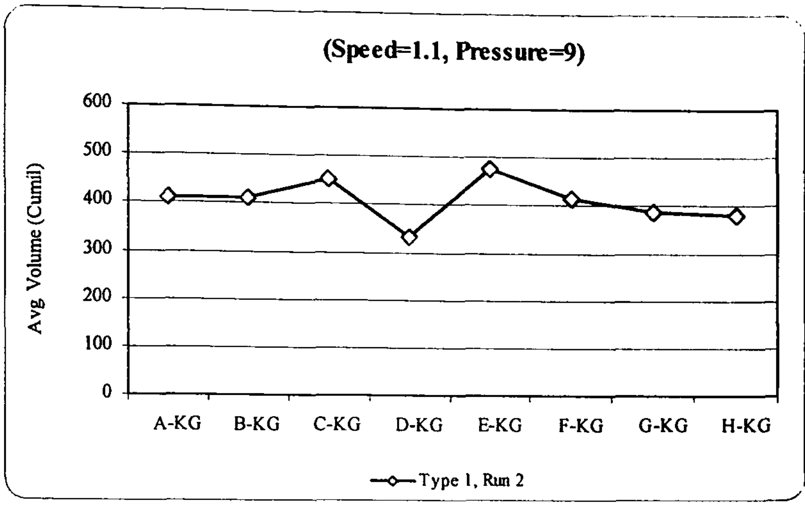

Figure 3.11: Type 1 (lead free), Run 2

For new group of boards Type 1 Run G-H-I, the screening speed was set down to 0.9 while pressure was fixed. Figure 3.12 shows the measured volumes on the SVS, a noticeable increase in deposited paste as screening speed went down by 10%.

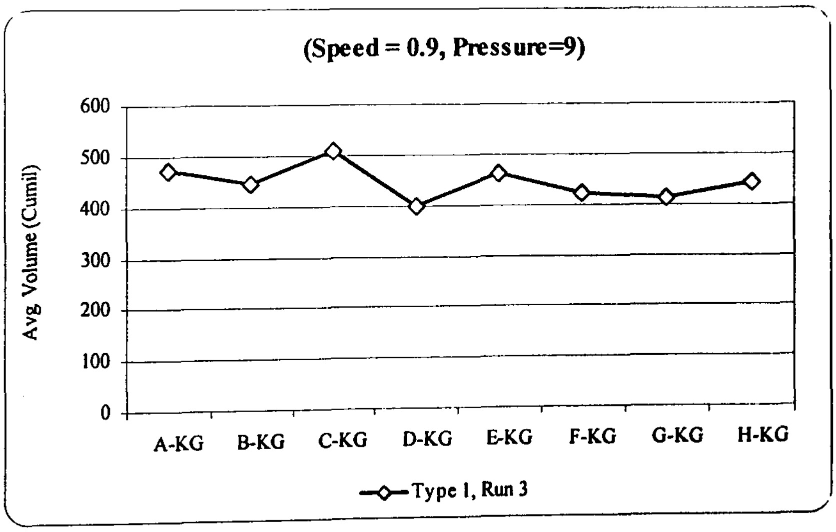

Figure 3.12: Type 1 (lead free), Run 3

With fixed speed at 1"/S, and pressure was set higher to 9.9 lb, three board (Type 1 Run J-L-M) were screened and measured. In Figure 3.13, lead free paste volumes was noticed getting less but in very small numbers compared to the volumes in Type 1 Run 1.

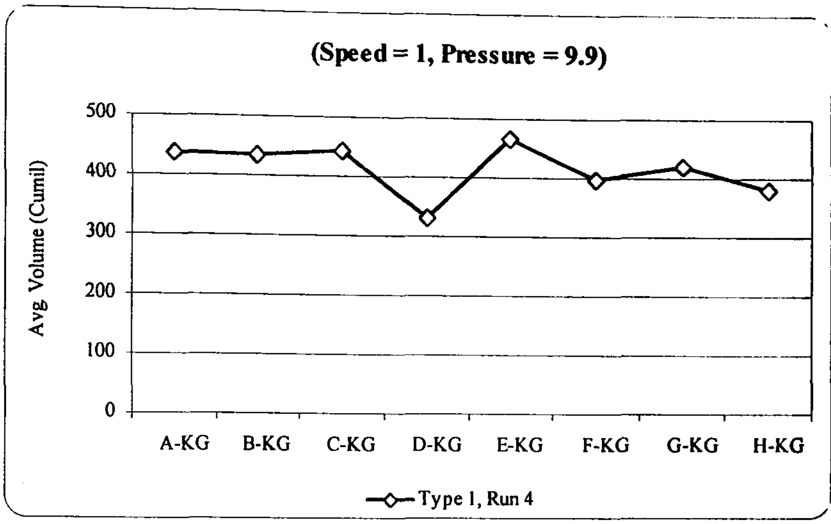

Figure 3.13: Type 1 (lead free), Run 4

Decreasing the pressure to 8.1 lb with fixed speed of 1"/s the volumes was increased slightly comparing to paste volumes in Type 1 Run 1. Less pressure (Figure 3.14) in this case gave more paste on pads than Run 4 on the previous run.

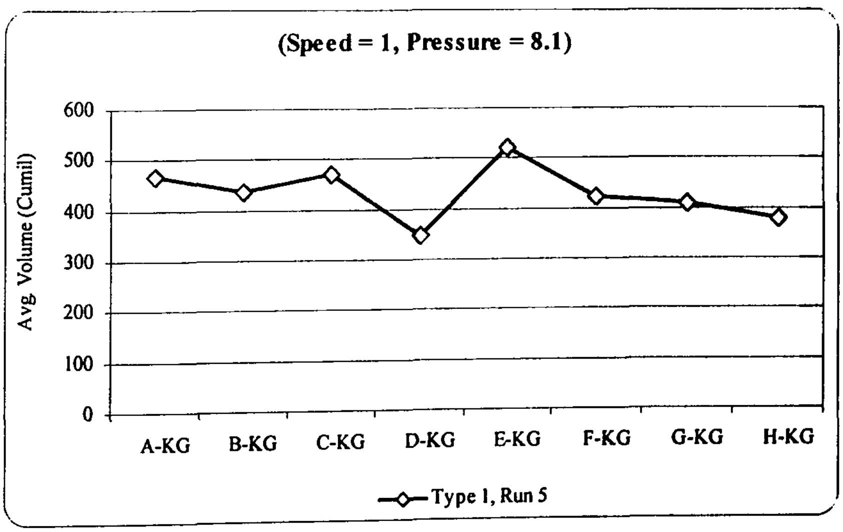

Figure 3.14: Type 1 (lead free), Run 5

Figure 3.15 indicates how the lead free paste behaved with changing variables, it is also shows all five runs and their experimental conditions.

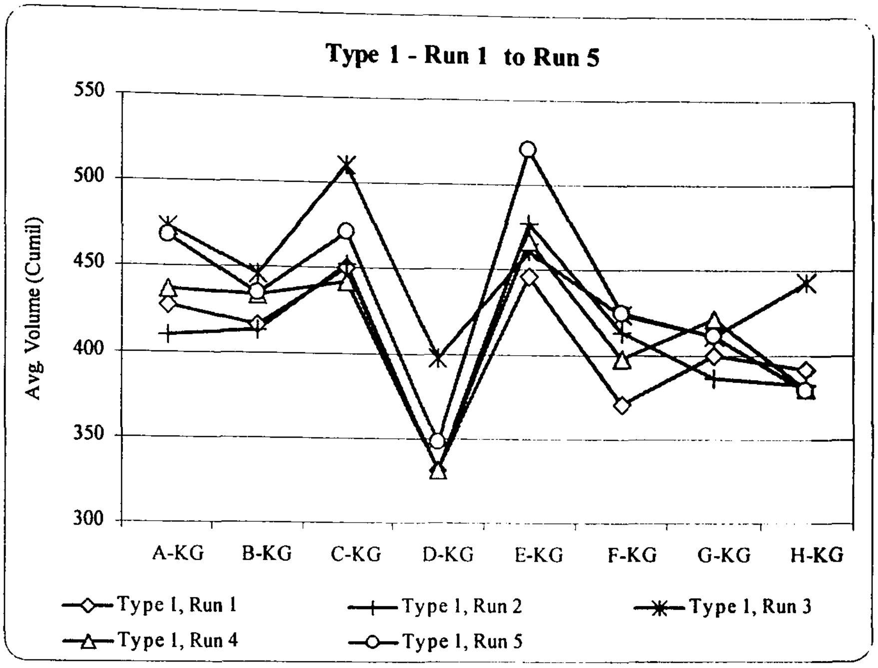

Figure 3.15: Type 1 (lead free), Runs 1-5

Figure 3.15 highlights that changing squeegees pressure had more effect on increasing paste volumes than changing speed. Figure 3.15 shows that lead free paste is less affected by changing of variables (speed and pressure) than the lead paste Figure 3.9.

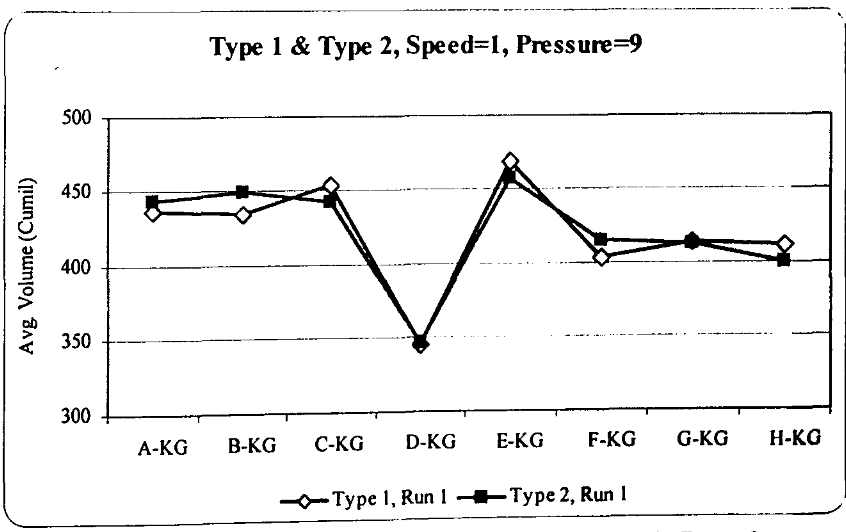

Figure 3.16: Types 1(lead free), Type 2 (lead paste), Runs 1

Summary (Phase 2)

Comparisons of the screening results of both Type 2 (lead paste) and Type 1 (lead free paste) at normal speed of 1"/s and pressure of 9 lb, illustrated in Figure 3.16, clearly demonstrates that deposited volumes were the same in both cases. This result answers to electronic manufacturing service companies that old stencils are valid to with lead free paste. Each of EMS companies already has thousands of stencils for their production lines. Now with just moving to a regular type 3 paste (mesh size –325+500) lead free paste would guarantee having enough paste volumes screened with the old nominal conditions. But the coming results set more cautious action to be taken in manufacturing areas.

The comparative figure (Figure 3.17), between type 1 and type 2 pastes at run 2 conditions shows that lead free paste deposited volume is higher by 3% compared to the lead paste.

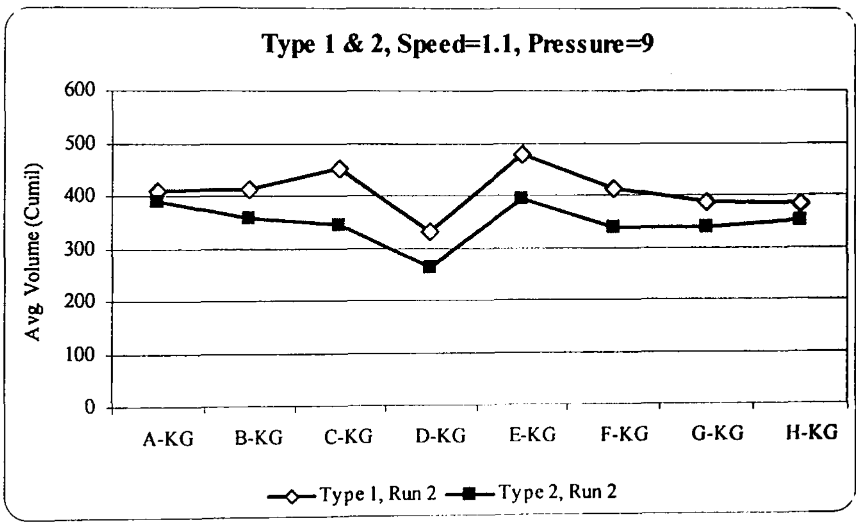

Figure 3.17: Types 1(lead free), Type 2 (lead paste), Run 2

This increase is speed shows some differences in deposited volumes, the lead free paste volumes on pads are more than the lead paste. Higher speed affected both Types1, and 2 by lowering the paste volumes but Type 1 paste illustrated poor results comparing to Type1.

By comparing the two pastes with speed less by 10 % under in Run 3 conditions (Figure 3.18), the deposited average volume was noticed to increase as an overall average compared to the previous runs by 4%. By comparing the overall paste volume deposited on both boards screened under less speed by 10 % gave such a percentage of paste increase.

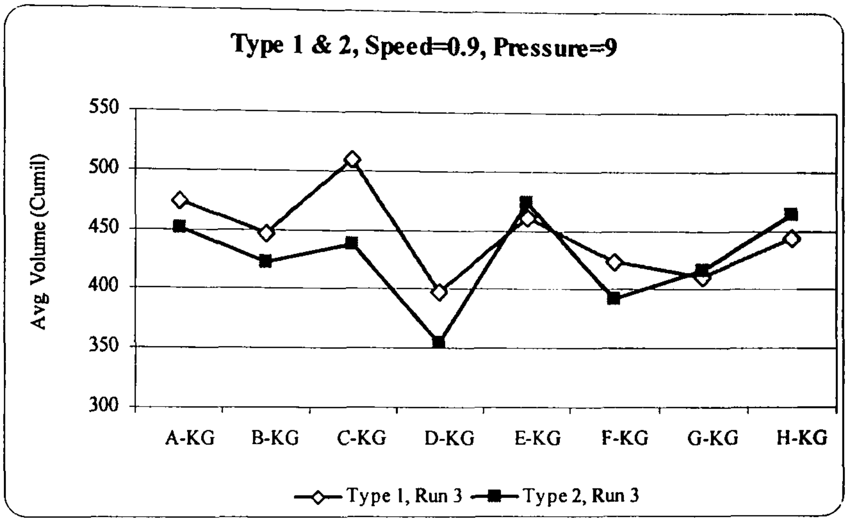

Figure 3.18: Types 1 (lead free), Type 2 (lead paste), Run3

The paste volumes data collected for both Types 1, and 2 at Run 4 conditions shows decrease in volumes for both types but the lead free paste is less affected by the 10 % increases in squeegees pressure Figure 3.19

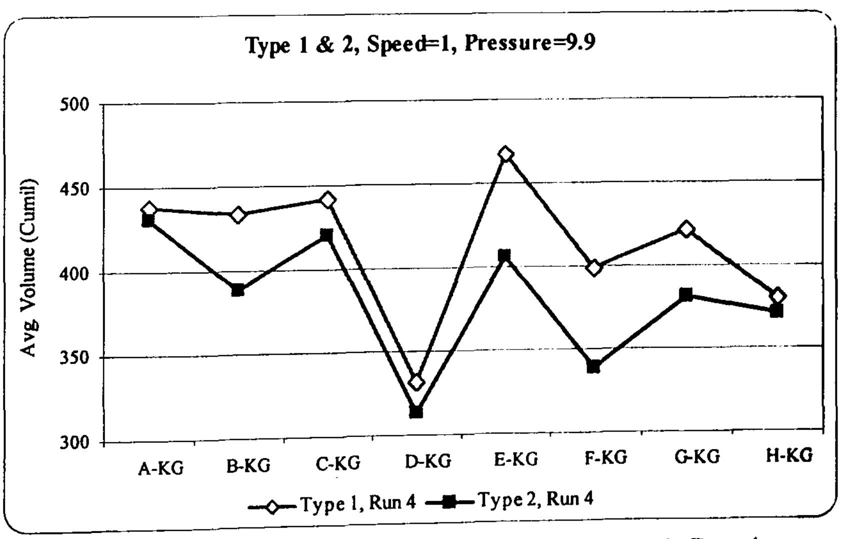

Figure 3.19: Types 1(led free), Type 2 (lead paste), Run 4

As pointed earlier, pressure settings at the nominal values give better results in term of paste volumes for both pastes. When decreasing the pressure by 10% both Types 1, and 2 reacted the same; similarly deposited volumes were less but lead paste was in general slightly less than the lead free paste Figure 3.20.

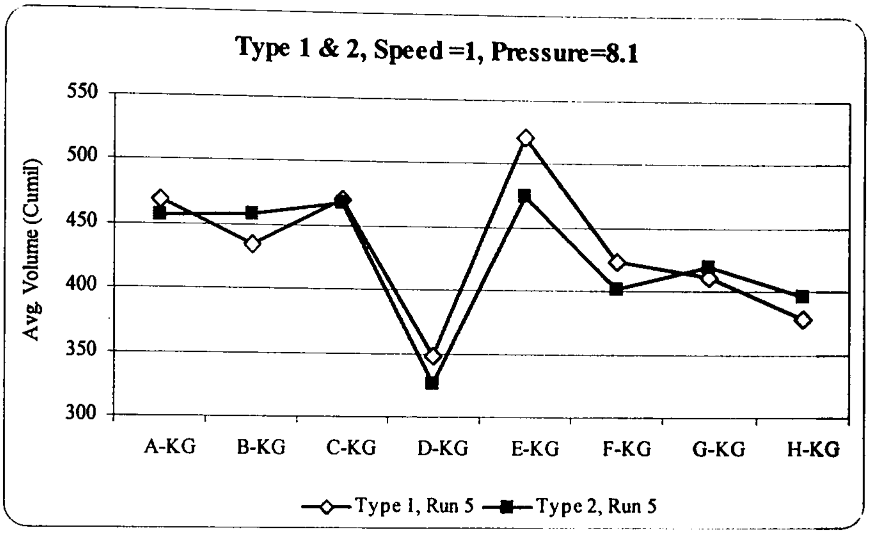

Figure 3.20: Types 1 (lead free), Type 2 (lead paste), Run 5

3.5. RATE OF BOARDS REJECTION

Part of this project is to optimize the new paste and find out any discrepancies that may appear during the screening process. Stencil printing has moved from simple to complex as smaller components finer pitch parts are used. Reduced lead pitches are demanding that stencil printing be more precise in terms of volumes and accuracy. If apertures are clogged, or if solder paste remains on the bottom of the stencil, printing defects will increase and consequently the boards have to be washed. Previous experiments concentrated more on the transfer rate. The transfer efficiency of a particular print is defined as the ratio of the volume of paste deposited on the substrate to the volume of the stencil aperture. Transfer rate is an important way to find out a rejected board, but there are some other defects that SVS machine is not able to detect other than paste volume like bridging, slump, incomplete paste deposition and insufficiency, solder balling, smudged print, uneven print [6,13].

In the SMT arena, any new solder paste printing has to produce yields that are comparable or better to those of currently used paste technologies in order to compete. Stencils need frequent cleaning to ensure a specific amount of paste deposition and to minimize the rate of rejection due to paste defects. It is very important to detect as early as possible any printing errors and causes of other defects due to degradation of the quality of the solder paste, loss of working viscosity point [23,24].

Normally, each screener machine has its own stencil wiping system a special tool designed to clean the underside of the stencil.

A new set of boards were set for new experiment to find out what are the major differences between Type 2 lead paste and Type 1 lead free paste in terms of number of rejected boards. The print parameters were left the same in a qualitative manner by varying the print speed and blade pressure while observing the resulting print under a microscope. The quality of the print, slump, bridging, uneven paste, and smudging and best brick like definition were used to judge the prints. The same print conditions were then used for the three sets of print tests. SMT throughput and cycle time are very effected by the solder paste printing process.

The screener wiping system (Figure 3.21) is vital to consistent good print; therefore, the machine is equipped with an on-board wiping system. The system is fully programmable and it includes wet, dry and vacuum cleaning options. Most companies are using the dry option. In addition to this wiping system, stencils are also washed from time to time and between batches using a special washing machine using solvents or aqueous detergents [25,26,27].

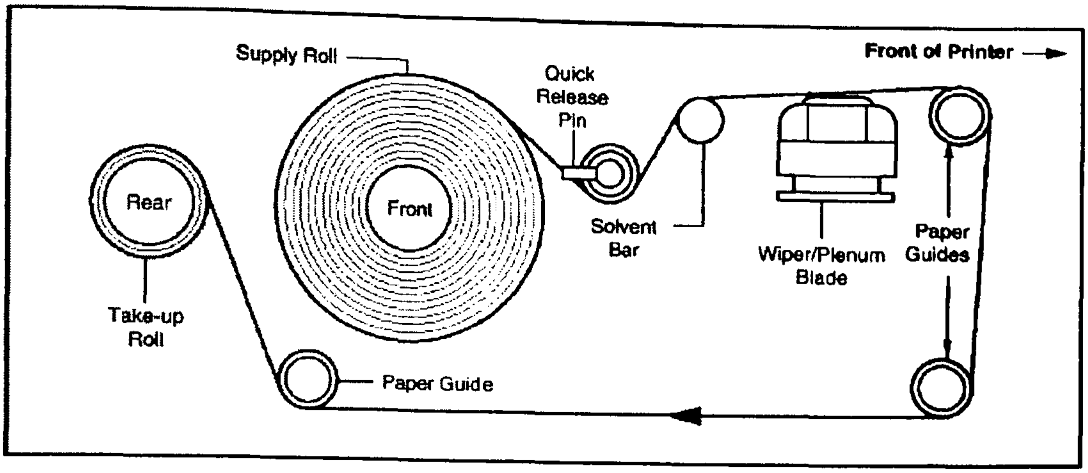

Figure 3.21: Screener wiping system [2]

3.5.1. EXPERIMENT PARAMETERS

In this sector, the same raw cards, stencil, machines, and variables were used to conduct the test. Thirty cards in three batches of ten cards were screened at the nominal variables of speed 1"/S, pressure 9 lb. After screening, the cards were taken to a microscope for printing defects investigation. All results were recorded, the stencil was cleaned manually as the machine has no wiping system and another ten boards screened with out stopping until finishing the 30 cards for that paste and for that variable.

In case of changing the pressure variable and maintaining the sequence of screening and speed, results of screening defects for both Type1 and Type 2 paste are shown in table 3.5.

Table 3.5: Experimental Parameters, Types 1 (lead free), Type 2 (lead paste)

Paste	Pressure	No of boards	No of fails	% of Failed Boards
Type 1	8.1	30	5	17%
Type 1	9	30	6	20%
Type 1	9.9	30	8	27%
Type 2	8.1	30	4	13%
Type 2	9	30	4	13%
Type 2	9.9	30	5	17%

As illustrated the lead paste (Type2) has much better throughput than lead free paste (Type1) in all three cases, nominal pressure, low and high. Figure 3.22 shows that the frequency of underside stencil wiping or stencil cleaning should changed to be more frequent than the lead paste. Lead free paste is showing very poor results especially in terms of squeegee pressure increase. Due to a large volume of dispensed paste or viscosity effect, the lead free paste tends to bridge between fine pitch pads.

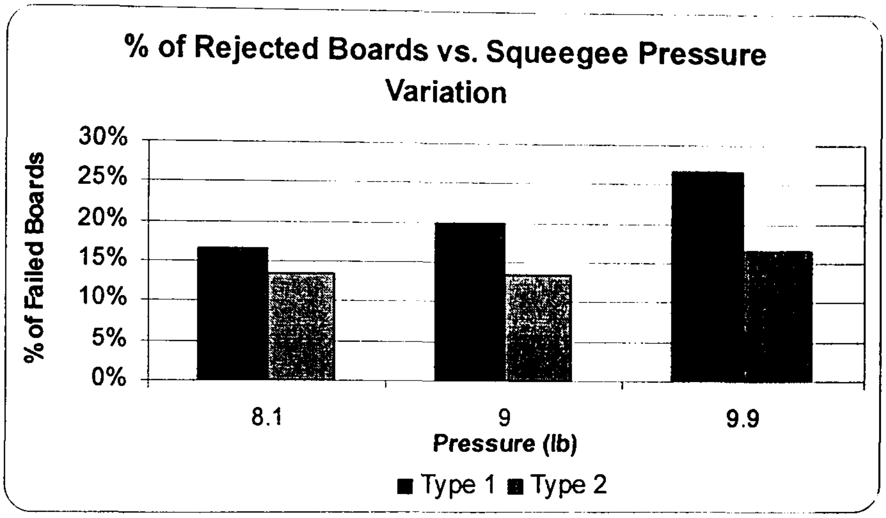

Figure 3.22: Percentage of rejected boards in case of pressure variances, Types 1 **(lead free),** Type 2 (lead paste)

The next phase is to screen another 30 boards with lead paste using Run 1,2 and 3 **variables** (speed change). At the same time, 30 boards screened with lead free paste **for each set of Run 1,2** and 3. The sequence of screening is illustrated in table 3.6.

Table 3.6 – Sequence of screening, Types 1(lead free), Type 2 (lead paste)

Paste	Speed	No. of boards	No. of fails	% of Failed Boards
Type 1	0.9	30	6	20%
Type 1	1	30	5	17%
Type 1	1.1	30	7	23%
Type 2	0.9	30	3	10%
Type 2	1	30	4	13%
Type 2	1.1	30	5	17%

The lead free paste shows also weaker yields for case of changing the squeegee speed. Yield was found to deteriorate more significantly for cases of slower and high speeds. Such behaviour may be attributed to viscosity and fluidity of the lead free paste causing more bridging between pads. Figure 3.23 shows that the frequency of stencil cleaning in case of using lead free paste has to be much bigger that the old setting used with the lead paste.

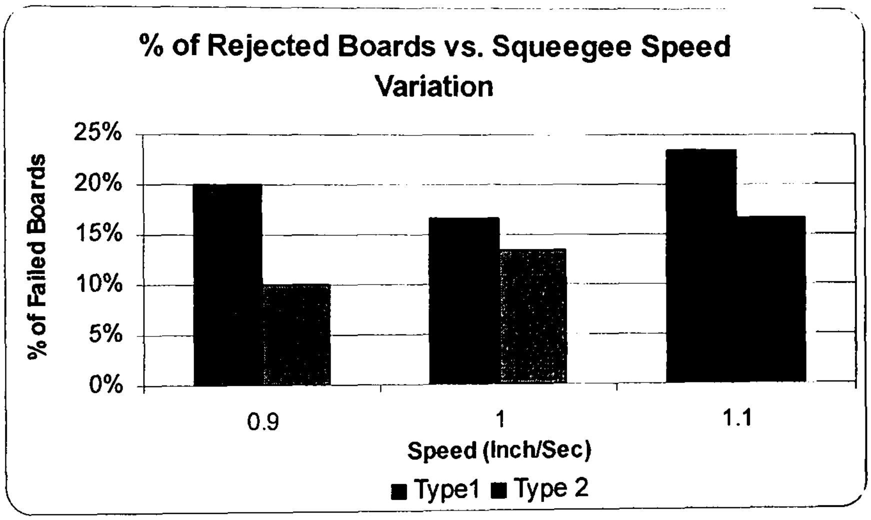

Figure 3.23 - Percentage of rejected boards in case of speed variances, Types 1 (lead free), Type 2 (lead paste)

CHAPTER IV

RESULTS AND RECOMMENDATIONS

4.1. PURPOSES

To present global trends regarding lead free printing qualification and technology, this project presents a new experiment comparing the old (present) and new (coming) paste. Emphasis is placed on processes, design of stencils, paste dispensed volumes, and consistency of screening. How the new material and general paste-printing parameters affect the process is also reviewed. The new paste material will bring with it totally new process change sand challenging to the EMS industry.

4.2. CONCLUSIONS

This experiment was done primarily to compare paste volumes of the lead and lead free pastes deposited on a PCB. The effect of screening speed and squeegee pressure were studied carefully in this project. At normal screening conditions, both pastes (lead and lead free) behave the same. The printability experiment was used successfully to determine that equal paste volumes were printed from the same stencil apertures at normal speed and pressure from both types of pastes. These results mean that there is no need for new stencil design or changes may be needed for the new generation of paste. Millions of dollars would be involved for any manufacturing facility in case of stencils new design and manufacture.

In case of screening speed change, paste volume consistency for both types of paste changed. The interaction between the screening speed and paste volume was significant. The percentage of decrease of the deposited paste went down to over 17% when the speed decreased by 10 %.

While manufacturing EMS guide line allow operators to change the screening speed to go up to 40% that may indicate the effect of speed on quality and yield at the same time. For example, in case of increasing the screening speed by 10%, deposited paste volume decreased by 17.4% for lead paste. In general, at low squeegee speed paste volumes increased, and volumes decreased when squeegee speed increased from the nominal value for both pastes, Fig (4.1).

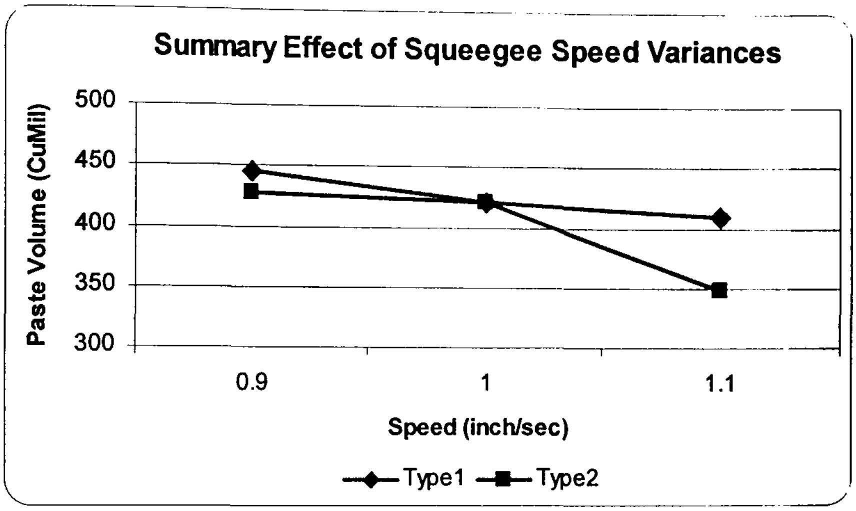

Figure 4.1: Effect of squeegee speed on pastes volume, Types 1 (lead free), Type 2 (lead paste)

Transfer rate of lead paste increased by 1.5 % compared to a 6 % increase in lead free paste when squeegee speed was decreased by 10 %. At the same time, when speed of the squeegee increased by 10 % a significant decrease in paste deposition of the lead paste up to -17.4%, while the lead free paste volume was less by 2.8 % figure 4.1. For both types of pastes slower squeegee speed allows more time for both aperture filling and for the squeegee to compact the paste into the aperture. Higher squeegee speed will result less deposited paste is not preferred for fine pitch and discrete parts application because there is less time for the solder paste to fill the apertures.

The results show that the effect of squeegee pressure is important and have a direct impact on deposited paste volumes for both types of pastes. However the pressure has less impact on paste volume but it is still to be considered one main factor of the machine settings for screening optimization. Figure 4.2 describes the relation between squeegee pressure and paste volumes for the used pastes in this project.

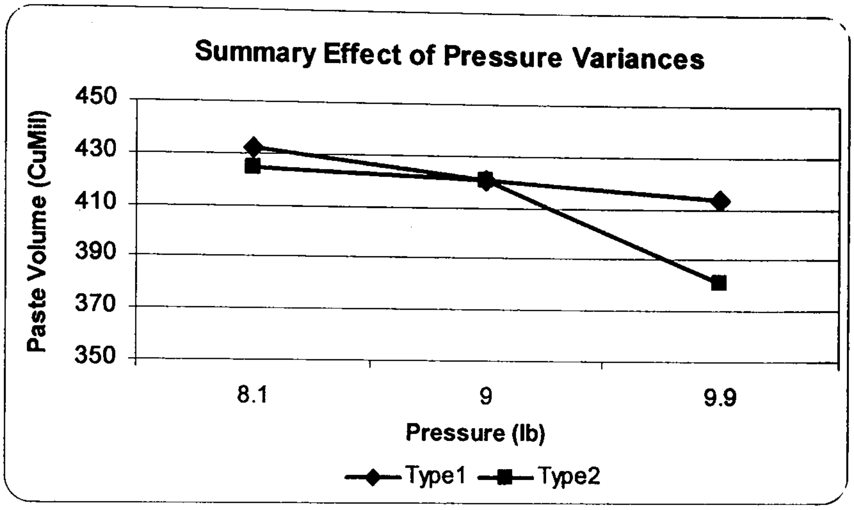

Figure 4.2: Effect of squeegee pressure on pastes volume, Types 1 (lead free), Type 2 (lead paste)

Lower squeegee pressure by 10% in case of lead paste increased the deposited paste volume by 1.7 % while the lead free paste increased more for this setting by 2.72%.

However, the deposited paste volume was decreased when squeegee pressure increased by 10 % for type of pastes. The lead paste volume reduction impact was much higher and decreased by -9.4% comparing to a reduction of –1.62% in lead free paste. Higher squeegee pressure scoop out the paste from the filled apertures and the viscosity factor plays a big roll between the two experimental types and shows a big difference in any setting changes.

Higher speed and pressure setting gave lower paste volumes in this experiment for both types of pastes. At the same time lower settings gave more paste but at lower percentages compared to decrease case.

Optimization of machine speed and pressure settings in screening the lead free paste or the regular lead paste is different. In order to give manufacturing more detailed and clear directions about their new and old pastes and how they would react under setting change table 4.1 was created as final conclusions.

Table 4.1: The relation between paste volume and squeegee speed and pressure variation, Types 1 (lead free), Type 2 (lead paste)

	Speed Variation		Pressure Variation	
	+10%	-10%	+10%	-10%
Paste Volume (Type 2)	-17.40%	6%	-9.40%	1.70%
Paste Volume (Type 1)	-2.80%	1.50%	-1.62%	2.72%

One of the main result this experiment have demonstrated that new stencils are not in need for the lead free paste; however, engineers, technicians training upgrade in addition to process change is essential for the lead free paste.

All solder paste printing processes will require the stencil to be cleaned at some determined frequency.

All solder paste printing processes will require the stencil to be cleaned at some determined frequency. The other essential part of the experiment results was highlights that the throughput of the screeners using lead free paste is less by 7 % or in other words the rejected boards with lead free paste is more by 7 % in normal screener settings. Throughput of the screener was less by 5 to 7 % at other setting change of pressure and speed in lead free paste case.

These results can be used to improve and determine the impact of lead free paste on SMT yield performance. Additional control and monitoring of the process and effectively increases the process yield and improves the amount of good boards produced in any given time period. More rejected boards mean more frequent stencil cleaning subsequently the line down time will be more.

The most appropriate solution for the throughput issue is a well trained, disciplined; conscientious operators and process control will be a major contributor to the performance of the solder paste printing process.

Based on the results it can be concluded that by implementing lead-free paste PCB assemblies with less or similar percentage of defects than the existing lead paste can be obtained.

As part of the recommendations for future work in this direction we suggest the following:

1- Investigating more lead free materials alternatives of solder alloys and components.

2- Perform the tests with different PCB material finishing.

3- Complete the current study through conducting further experiments by changing the speed and the pressure simultaneously with various range of increments other than the 10% increment used in this project.

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