ELEC 6740 Electronics Manufacturing
Chapter 9: Solder Paste and Its Application

R. Wayne Johnson
Alumni Professor
Auburn University
334-844-1880
johnson@eng.auburn.edu

Outline

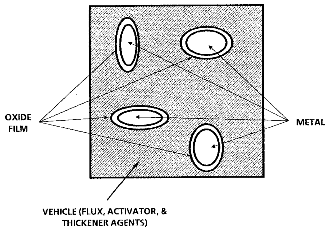
1. **Introduction**
2. **Solder Paste Properties**
3. **Solder Paste Printing Equipment**
4. **Solder Paste Printing Processes**
5. **Paste Printing Defects**
6. **Paste Printing Variables**
7. **Printing for Different Types of Components**

Introduction

- **Solder paste printing is a critical step in the SMT process**
  - **Solder paste**
  - **Printers**
  - **Process**
  - **Defects**

Solder Paste Properties

- Solder particles in a thickened flux/solvent vehicle



Metal Composition - Selection

1. Materials of the substrate & surface mount components
2. Compatibility of the solder with the metallization on the substrate (Au embrittlement, Ag leaching)
3. Solder strength as a function of temperature
4. Cost (%Ag)
5. Lead free

Solder Alloys

Alloy	Range (c)	Difference	Properties
75Pb/25In	250S-264L	14	Less gold leaching, more ductile than Sn/Pb alloys: Die attachment, closures, and general circuit assembly
50Pb/50In	180S-209L	29	
25Pb/75In	156S-165L	9	
37.5Sn/37.5 Pb/25In	134S-181L	47	Good wettability, not recommended for gold
80Au/20Sn	280E	0	Highest quality for Au surfaces: die attachement & closures

Solder Alloys

Alloy	Range (c)	Difference	Properties
63Sn/37Pb	183E	0	Widely used tin-lead solders for SMT and general circuit assembly: Low cost and good bonding properties: Not recommended for Ag and Au soldering because of high leach rate.
60Sn/40Pb	183S-188L	5	
50Sn/50Pb	183S-216L	33	
10Sn/90Pb	268S-302L	34	
5Sn/95Sn	308S-312L	4	

Solder Alloys

Alloy	Range (c)	Difference	Properties
62Sn/36Pb/2Ag	179E	0	Tin-lead solders containing small amounts of Ag to minimize leaching of Ag conductors and leads: Not recommended for Au: Sn/Pb/Ag (62/36/2) is strongest tin-lead solder.
10Sn/88Pb/2Ag	268S-290L	22	
1Sn/97.5Pb/1.5Ag	309E	0	

Solder Alloys

Alloy	Range (c)	Difference	Properties
96.5Sn/3.5 Ag	221E	0	Widely used tin-silver solders providing very strong, lead free joints: Minimizes Ag leaching: Not recommended for Au
95Sn/5Ag	221S-240L	19	
42Sn/58Bi	138E	0	Low temperature eutectic with high strength

Metal Content

Metal Content (wt. %)	Wet paste thickness (in.)	Reflowed solder (in.)
90	0.009	0.0045
85	0.009	0.0035
80	0.009	0.0025
75	0.009	0.0020

Particle Size

$$\text{Ratio} = \frac{\text{Surface Area}}{\text{Volume}} = \frac{\Pi R^2}{(4/3)\,\Pi R^3} = 3/4R = 1.5/D$$

Particle Size

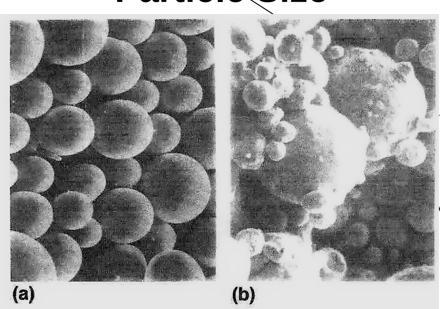
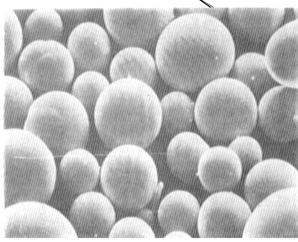


Figure 9.2 (a) Perfectly spherical and (b) unacceptable solder particles in solder paste.

Solder Paste



Type 3 Paste: 25-45µm particle size range

Paste Types

Type	None Larger Than (um)	Less Than 1% Larger Than (um)	80% Minimum Between (um)	10% Maximum Less Than (um)
1	160	150	150-75	20
2	80	75	75-45	20
3	50	45	45-25	20
4	40	38	38-20	20
5	30	25	25-15	15
6	20	15	15-5	5

Solder Powder Mesh Designation

Designation J-STD-005	Mesh ASTM B214	Particle Size (µm)	Ave. Particle Size	Surface Area Ratio
Type 2	-200/+325	75-45	60	1
Type 3	-325/+500	45-25	35	1.71
Type 4	-400/+500	38-20	31	1.93
Type 5	-500	25-15	18	3.33

Type vs. Pitch

Component pitch (in.)	Stencil aperture (in.)	Max. Powder size (µm)	Stencil Apeture/ Max PS	Desired Paste Type
0.050	0.025	80	8	2
0.025	0.014	50	4.3 or 7	2 0r 3
0.020	0.010	50	5	3
0.015	0.008	40	5 or 6.6	4 or 5
0.010	0.006	30	5	5

Flux Activators and Wetting Action

- **The activators in the flux promote wetting of the molten solder to the surface mount lands and component terminations by removing oxides and other surface contaminants.**
- **Fluxes are generally mild acids**

J-STD-004

- **Rosin based**
- **Water soluble**
- **Low residue or No-clean**

Rosin

- Rosin flux is primarily composed of natural resin extracted from the oleoresin of pine trees and refined.
  - Rosin (R)
  - Rosin, mildly activated (RMA)
  - Rosin activated (RA)
    - Rarely used, very high activity level

Water Soluble

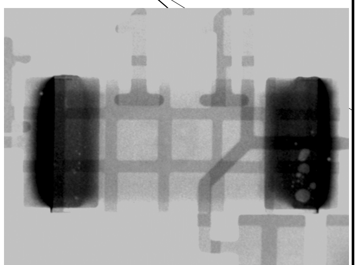
- Organic acids (OA)
- Must be cleaned after soldering
- Formulated with a glycol base

No-clean

- Natural resins other than rosin types and/or synethic resins
- Varying 'solids' content
  - Impacts amount of flux residue
  - Some leave no visible residue
- Residue is non-corrosive, non-conductive and can be left on the board

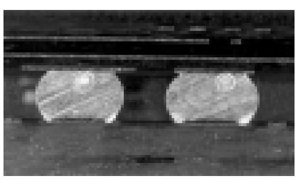
Void formation

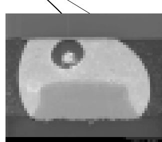
- If the solvent in the paste does not evaporate before the solder melts, gas bubbles can be entrapped in the molten solder creating a void.

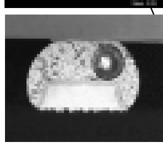


SOLDER BALL VOIDS

Area Array Packages







Rheology Properties

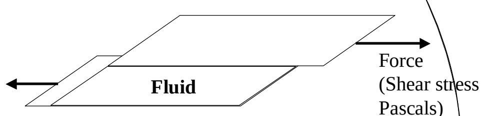
- Viscosity
- Slump
- Tackiness
- Working life

Viscosity

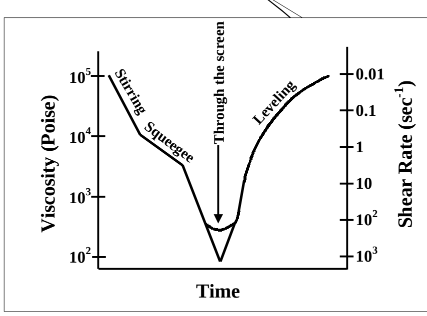
- Viscosity = Shear Stress/Shear Rate (Pascal-seconds)
- The internal resistance exerted by a fluid to the relative motion of its parts

Viscosity

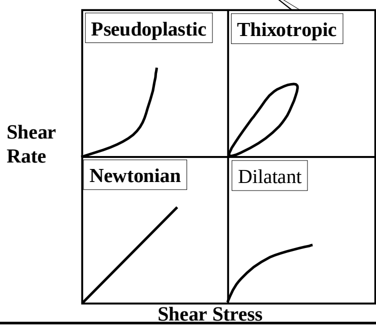
- Shear rate (sec^{-1}) is the rate of travel of the two parallel plates separated by fluid divided by the distance between the plates (cm/s/cm)



Viscosity as a Function of Process



Response of Fluids to Shear



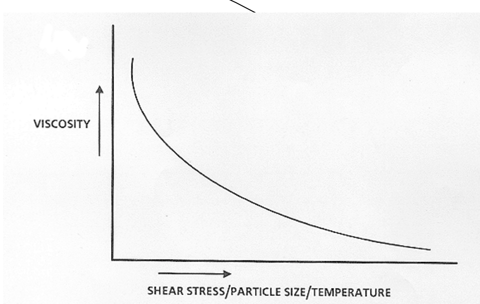


Figure 9.4 Impact of increasing shear force and temperature and particle size on solder paste viscosity with identical metal content and flux vehicle.

Viscometer

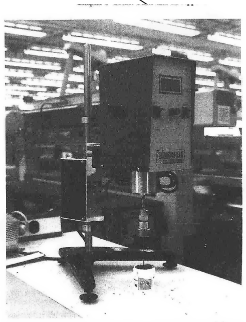


Figure 9.5 Brookfield viscometer. (Photograph courtesy of Intel Corporation.)

Spiral (Malcom) Viscometer

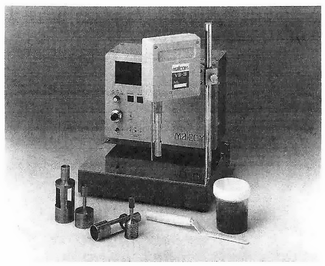


Figure 9.6 Photograph of spiral (Malcom) viscometer. (Courtesy Malcolm Instruments Corporation.)

Schematic of Spiral Inductor

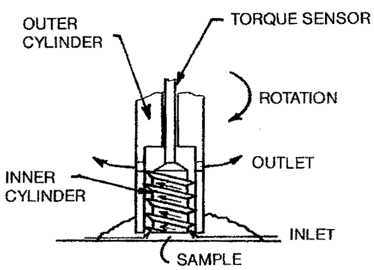


Figure 9.7 Schematic of spiral (Malcom) viscometer.

Shear Rate

Table 9.6 Shear rates corresponding to various rotational speeds for Malcom viscometer [11].

ROTATION SPEED (RPM)	SHEAR RATE (SEC^{-1})
5	3
10	6
15	9
20	12
30	18

Solder Balls

1. **Solder balls are formed by very fine powder particles in the solder paste.**
   - **They are carried away from the main solder deposit as the flux melts and flows before the solder itself melts.**
   - **This happens especially when the paste is deposited outside the land area either by design or misregistration**
   - **These smaller particles lose contact with the larger solder paste deposit and when the solder melts, each particle becomes a small solder ball at the periphery of the original paste deposit**
   - **A collectionm opf small solder balls around the main solder deposit is called a 'halo'.**

Solder Balls

2. **Solder balls are also formed when the oxide layer on the nsurface of the solder powder particles is so thick the flux and any activator in the paste are not sufficient to remove it.**
   - **Since the oxide cannot melt at soldering temperatures, they are pushed aside as a solder ball by the surrounding oxide-free molten solder.**
   - **Solder balls formed in this manner are larger than those formed by the 1st mechanism because of the presence of surface oxide which is less dense than the metal.**

Solder Balls

- **Improper handling**
- **Excessive baking/preheat prior to reflow**
- **Particle rubbing (Fretting corrosion)**
- **No-clean more likely to have solder balls**
  - **Less aggressive flux**

Testing

- Print paste onto non-metallic substrate (ceramic, glass, FR-4)
- Reflow
- Inspect for solder balls

Solder Balls

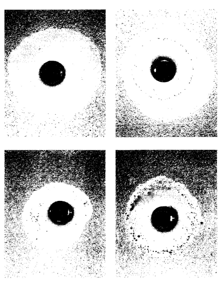


Figure 9.8 Solder ball formation during solder ball test for determining the suitability of solder paste. No solder ball (top left) is preferred, but a minor occurrence of very fine solder balls (top right) is also acceptable. Clustered solder balls (bottom left) and a solder ball halo ring with numerous solder balls (bottom right) are unacceptable [1].

Printability

1. Weight 5 clean dummay boards (W1) and after (W2) the paste is printed.
2. Determine the weight of paste deposited (W2-W1)
3. Measure and record the height at 4 predetermined points on each substrate
4. Perform steps 1-3 for freshly removed solder paste and solder paste exposed to the atmosphere for 4 hours.

Printability

1. The solder paste weight should not vary by more than 10% among the average measurements taken on one substrate
2. The paste height should not vary by more than +- 1mil among the average measurements taken on one substrate
3. The solder paste pattern should have uniform coverage, without stringing and without separation of flux and solder, and should print without forming a peak.

Printing Equipment

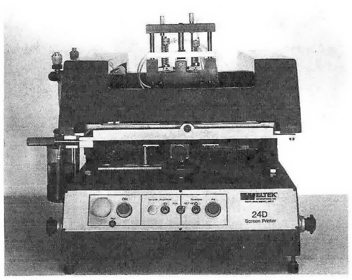


Figure 9.9 Laboratory model solder paste screen printer. (Photograph courtesy of Weltek International.)

Printing Equipment

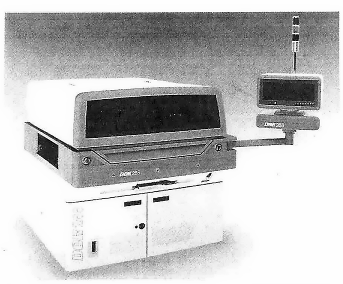


Figure 9.10 An example of an automatic screen printer. (Courtesy of DEK Corporation.)

Printing Equipment

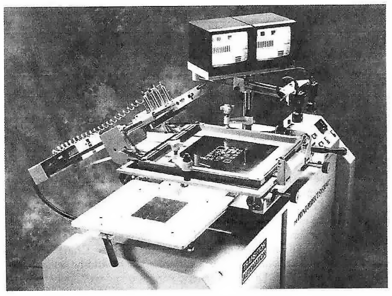


Figure 9.11 An example of a semi-automatic printer. (Courtesy of Transition Automation.)

Printer Selection

- Manual vs. computer control of parameter
- Stencil size
- PWB size
- Print mode
- Alignment

Print Variables

Table 9.7 Solder paste printing equipment variables [15]

- Structural
  - Stiffness
  - Parallelism
  - Precision of mechanical parts (fit and movement)
- Squeegee
  - Velocity
  - Acceleration
  - Deceleration
  - Pressure (down force)
  - Stroke parallelism
  - Parallelism in substrate
  - Down stop
- Modes of operation
  - Contact/Off-contact
  - Bi-directional/unidirectional printing (flood/print or print/print modes)
  - Flood bar
  - Multiple wet pass
- Screen holder
  - X axis
  - Y axis
  - Z axis
- Rotation (Theta)
- Peel off
- Snap off

Printing Parameters

Table 9.8 Solder paste printing parameters (will vary with equipment)

MACHINE VARIABLES	RECOMMENDED SETTINGS
Squeegee material	Rubber or metal
Squeegee Pressure[a,b]	
• Screens with rubber squeegee	15–25 lb.
• Stencil with metal squeegee	10–20 lb.
• Stencil with rubber squeegee	30–40 lb. (1.5–2.5 lb./inch of squeegee length)
Squeegee Speed[a]	
• Stencil for 50 mil pitch components	2.0–4.0 inches/second
• Stencil for fine pitch components	0.5–1.5 inches/second
Snap-off distance[a]	0.020–0.040 inch (zero for on-contact printing)
Angle of attack	45° or 60°
Leveling of screen/stencil: front/back and side to side alignment	Adjust so it is parallel Repeated passes will bring the pad openings of the screen or stencil in line with the solder pads on the substrate; align with micrometer or screws or visually (manual printers) or with vision (automatic printers)

[a] Critical printing parameters.

[b] Start with low pressure and then gradually increase pressure until clean sweep is achieved on the stencil.

Screens & Stencils

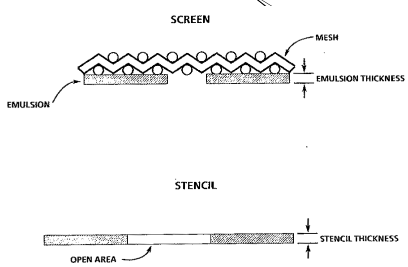


Figure 9.12 Cross-sectional views of stencils and screens for solder paste printing.

Stencils & Screens

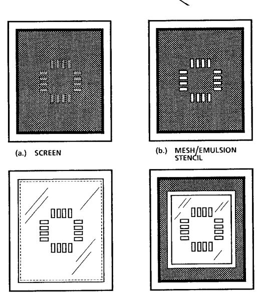


Figure 9.13 Construction of screen (a), mesh/emulsion stencil (b), all metal mask stencil (c), and flexible metal mask (d).

Stencils & Screens

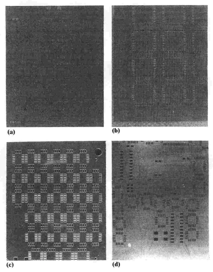
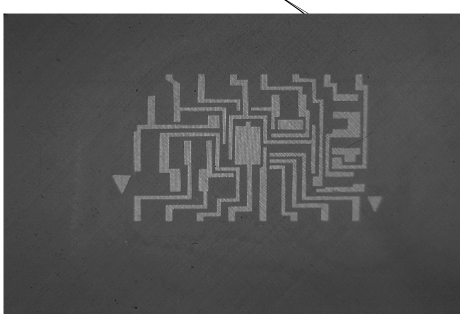
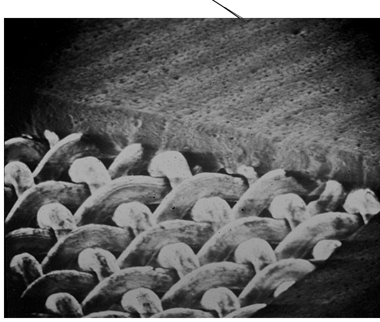


Figure 9.14 Close up views of openings in screen (a) and three different stencil types: mesh/emulsion stencil (b), all metal mask stencil (c), and flexible metal mask stencil (d), which correspond to the diagrams of Figure 9.13. (Photographs courtesy of Intel Corporation.)

Screens



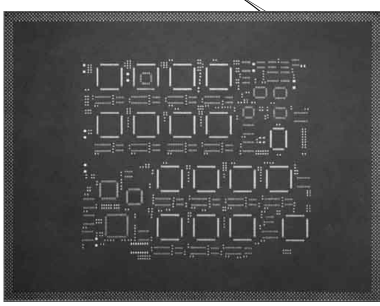
Screens



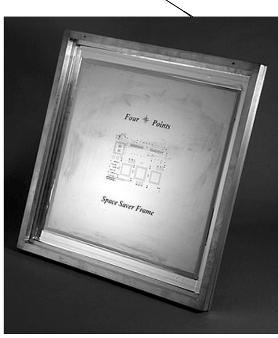
Stencils

- Stainless steel
- Nickel
- Brass

Stencils



Stencils



Flexible Metal Mask Stencil

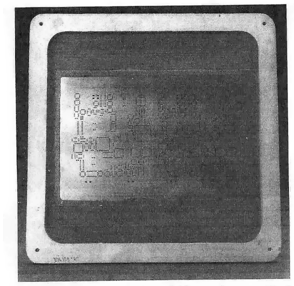


Figure 9.15 A flexible metal mask stencil. (Photograph courtesy of Intel Corporation.)

Frame for Stretching Stencils

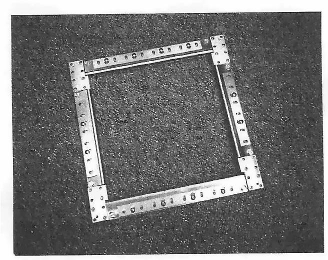


Figure 9.16 Frame for stretching stencils without frames. (Courtesy of SMT Division of Alpha Metals, Inc.)

Stencil Storage

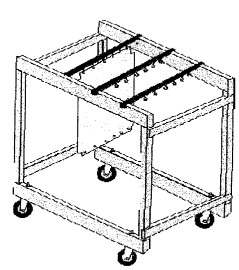
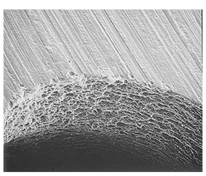


Figure 9.17 Storage rack for stencils without dedicated frames. (Courtesy of SMT Division of Alpha Metals, Inc.)

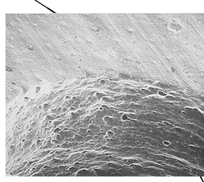
Stencil Forming

- Chemical Etch
  - Electropolished
  - Ni Plated
- Laser Cut
  - Electropolished
  - Ni Plated
- Ni Electroformed

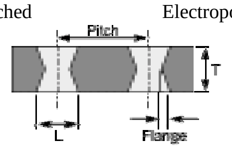
Chem Etch



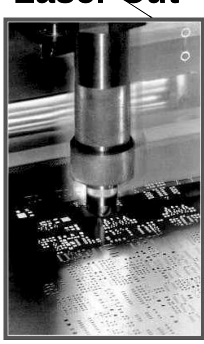
As-etched



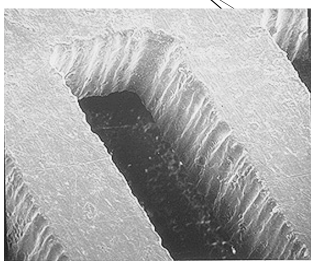
Electropolished



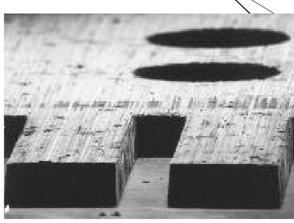
Laser Cut



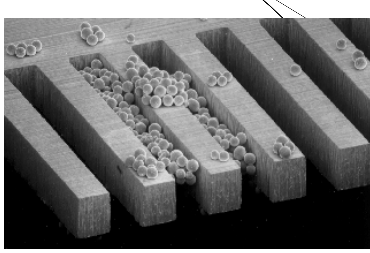
Laser Cut Aperture



Ni Electroformed



Comparison of Apertures to Solder Particles



Print Resolution

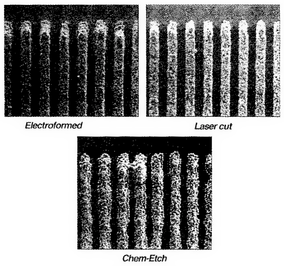


Figure 9.28 Ultra fine pitch paste deposited through 4.5 mil apertures made by electroformed, laser cut, and chemically etched stencils. (Courtesy of AMTX, Inc.)

Stencil Type

Stencil Type / Key Features	Chemically etched Stencils	Laser cut Stencils	Electroformed Stencils
Aperture size control	△	○	◇
Aperture wall smoothness	○	△	◇
Aperture wall shape control	△	○	◇
Step stencil capability	◇	△	△
Foil strength	◇	◇	○
Gasketing effect	△	○	◇
Ultra fine pitch application	△	○	◇
Cost	Low	Medium	High

◇ = VERY GOOD ○ = GOOD △ = FAIR

Figure 9.29 The key features of chemically etched, laser cut, and electroformed stencils

Printing

1. **No matter which method of application is used, be sure that the solder paste has been stored properly. A tightly sealed, unopened container of solder paste generally can be stored for 6 months at 4-29°C. Shelf life is flux dependent. It is better to use the freshest paste possible. If opened, store in a refrigerated environment.**
2. **Use only fresh paste every day. To accomplish this, use small jars that contain only 1 day's worth of paste or transfer paste from large jars as needed for the day and put the rest back in the refrigerator. This helps improve paste-related yield.**

Printing

3. **Allow refrigerated container to reach room temperature before use. It may ber advisable to take the paste out of the refrigerator the night before for the next day’s use to avoid the wait.**
4. **Check the solder paste for solder ball characteristics and viscosity.**
5. **When all solder paste printing is complete, wash the screen or stencil with the appropriate solvents.**
6. **Discard (hazardous material) any used paste.**

Screen Printing

- **Typically off-contact**
- **Lower viscosity for flow through wires**
- **Screen and PWB should be parallel within 0.002”**
- **Snap-off distance set to 0.030” (typical)**

Screen Printing

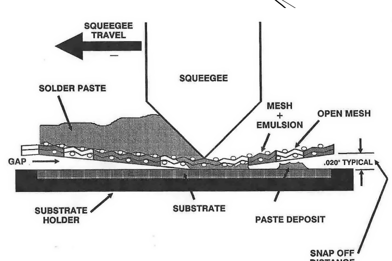
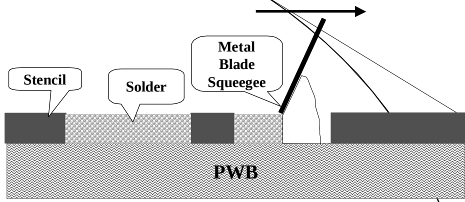


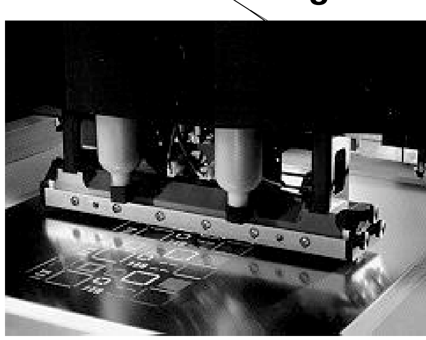
Figure 9.18 Applying solder paste on a substrate by squeegee in a screen printing process: schematic view.

Stencil Print

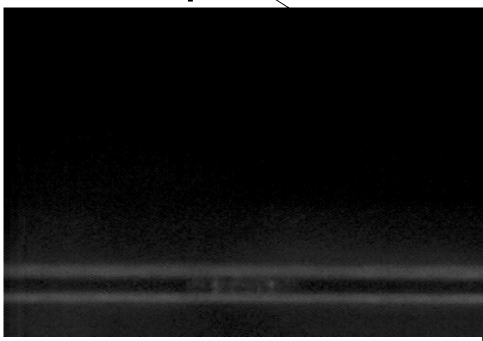


Stencil Printing

Stencil Printing



Separation



Step Stencil

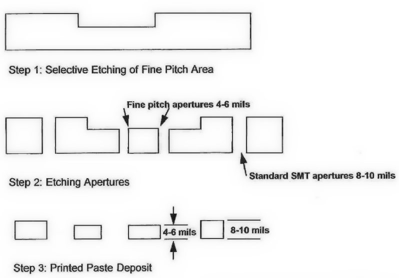


Figure 9.20 A schematic of a multilevel stencil for dual-thickness printing.

Step Stencils

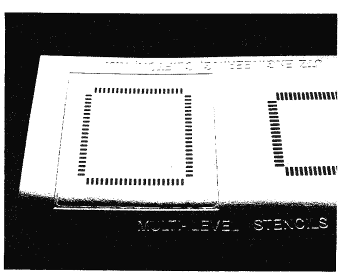


Figure 9.21 Multilevel or selective etching in a metal mask stencil for depositing different solder paste thicknesses on the same board. (Photograph courtesy of Intel Corporation.)

Stencils vs. Screens

Table 9.9 Advantages and disadvantages of screens and stencils

STENCILS	SCREENS
ADVANTAGES	DISADVANTAGES
• Easy to set up	• Harder to set up
• On-contact and off-contact printing	• Off-contact printing only
• Can print by hand	• Cannot print by hand
• Wider usable viscosity range	• Narrow usable viscosity range
• More durable	• Less durable
• Do not plug easily	• Plug easily
• Easy to clean	• Hard to clean
• Allow multilevel printing	• Do not allow multilevel printing
DISADVANTAGES	ADVANTAGES
• Higher cost	• Lower cost

Dispensing

- **Low volume, slow**
- **Repair**
- **Special requirements**
- **Clogged needles**
  - **Lower viscosity**

Printing Defects

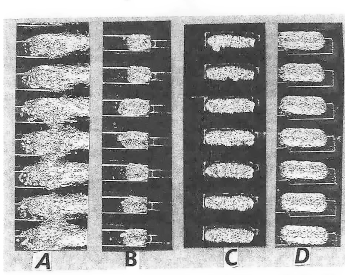
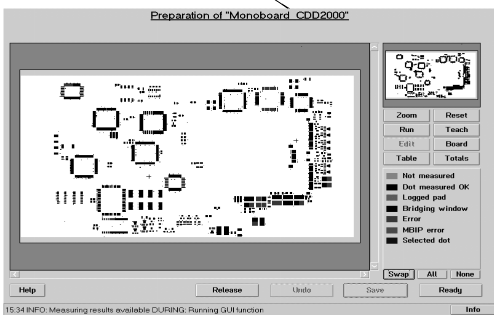
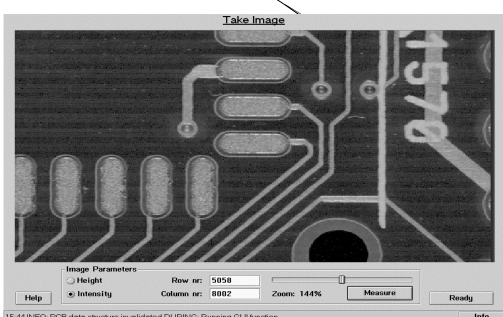


Figure 9.22 Common print defects during solder paste application: (a) smeared print, (b) skipped print, (c) print with ragged edges, and (d) misaligned print. (Photograph courtesy of Intel Corporation.)

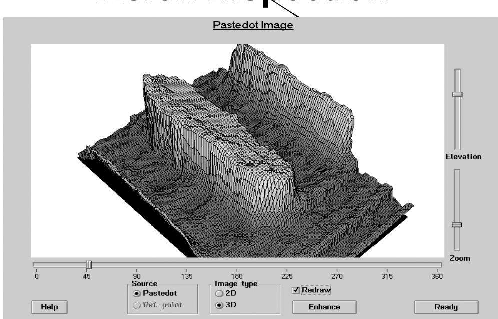
Visual Inspection



Visual Inspection



Vision Inspection



Solder Paste Viscosity

- Dispensing: 200,000 – 450,000 (centipoise)
- Screening: 450,000 - 800,000 cP
- Stenciling: 750,000 – 950,000 cP (50mil pitch)
- Stenciling: 900,000 – 1,200,000 cP (fine pitch)
- Temperature effects
- Paste shearing
- Moisture (water soluble paste)

Print Thickness

- Stencil thickness
- Pressure
  - Scooping
- Blade type
  - Metal
    - Stencils
  - Rubber
    - Screens & Stencils

Squeegees

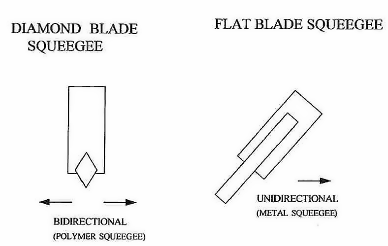


Figure 9.24 Bidirectional and unidirectional rubber squeegee blade configurations.

Print Orientation

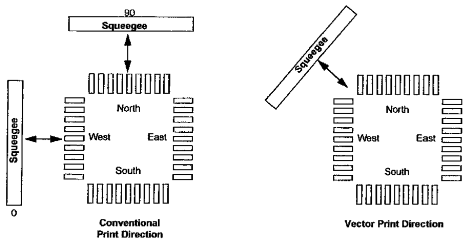


Figure 9.25 Vector printing—squeegee at an angle for uniform paste printing [17].

Print Speed

- Function of paste
- Fast print speed can cause planing of the squeegee, resulting in skips
- Slow speed generally provides better prints, but can lead to ragged edges or smearing of too slow.
- Production favors fast speeds

Stencil Aperture

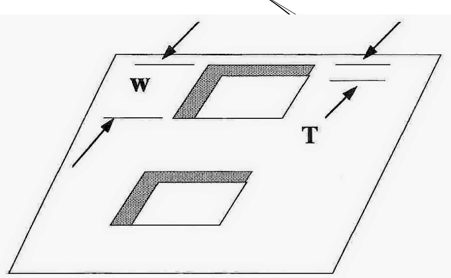


Figure 9.26 Stencil aperture width versus thickness for good print with minimum aspect ratio (W/T) of 1.5.

Print Thickness

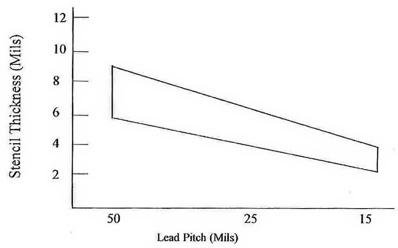


Figure 9.23 Recommended range of stencil thicknesses for various lead pitches.

IPC Stencil Design Rules

Part Type	Aspect Ratio Range	Area Ratio Range
PLCC (50 mil pitch)	2.3 to 3.8	0.88 to 1.48
QFP (25 mil pitch)	1.7 to 2.0	0.71 to 0.83
QFP (20 mil pitch)	1.7 to 2.0	0.69 to 0.83
QFP (16 mil pitch)	1.6 to 2.0	0.68 to 0.86
QFP (12 mil pitch)	1.5 to 2.0	0.65 to 0.86
0402	N/A	0.84 to 1.00
0201	N/A	0.66 to 0.89
BGA (50 mil pitch)	N/A	0.93 to 1.25
BGA (40 mil pitch)	N/A	0.67 to 0.78
BGA (20 mil pitch)	N/A	0.69 to 0.92

Definitions

Area Ratio

$$\frac{\text{Area of Aperture Opening}}{\text{Area of Aperture Wall}}$$

Aspect Ratio

$$\frac{\text{Width of Aperture}}{\text{Stencil Thickness}}$$

Rule of thump:

Area Ratio > 0.66

Paste in Hole

$$RVP = \text{Required paste volume} = 2x\prod(D_h^2 - D_l^2)x(T/4)$$

D_h = plated through hole diameter

D_l = lead diameter

T = the board thickness

Hole should be 0.012” bigger than lead diameter
or 0.010” bigger than the diagonal dimension of the lead.

Paste in Hole

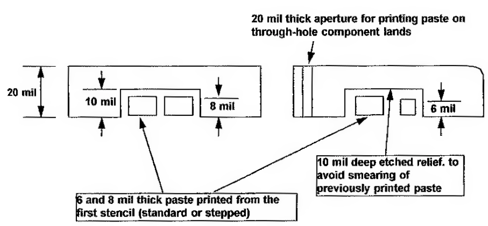


Figure 9.30 Schematic of a step stencil for printing on through-hole lands in a mixed assembly.

Paste in Hole

- **Aperture larger than PWB pad**
  - **Printing on solder mask**
- **Potential for solder balls**