iNEMI

International Electronics Manufacturing Initiative

Solder Paste Deposition Project Report

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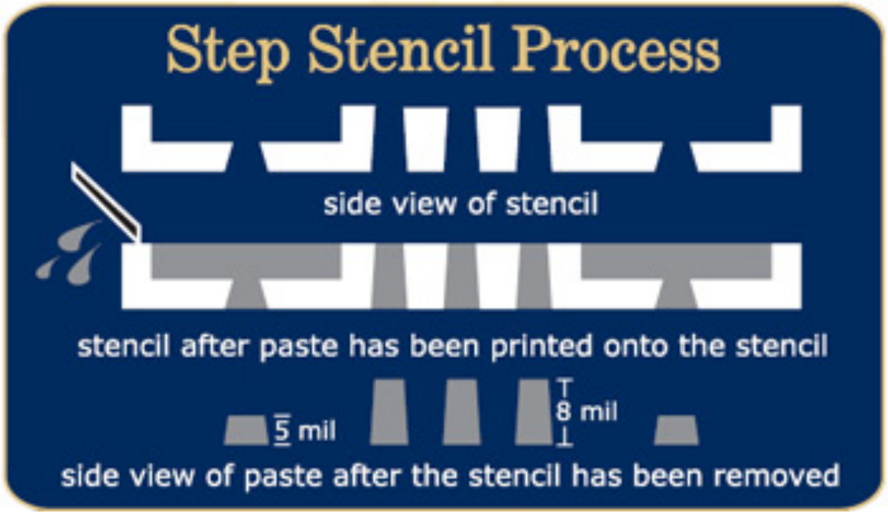
Advancing manufacturing technology

Outline

- Introduction
- Objective
- DOE Design
- Experiments
- Results and Analysis
- Conclusions
- Acknowledgements

Introduction

- The mixed technology on a PCB is creating unique challenges for board assemblers
- Solder paste volume requirement for castle like component and miniature components vary widely
- There are several approaches to solve this problems
- They are:
  - Dual print
  - Printing/dispensing
  - Overprinting
  - Hybrid approach
  - Step stencil



http://www.laserstentech.com/040~Stencils/030~Step_Stencils/

Introduction Continued…

- Solution approaches:
  - Dual print
    - Printer one prints miniature components using a thin stencil then printer tow prints the larger components using a pocket stencil
  - Printing/dispensing
    - Printing is done using an uniform thickness stencil then the larger (or smaller) pads are supplemented by dispensing additional paste
  - Overprinting
    - A thinner stencil is used to meet the need of smaller components while the larger components are over printed to deliver more paste
  - Hybrid approach
    - Conventional printing is combined with jetting to meet the process requirements
  - Step stencil
    - Steps are created to accommodate both larger and smaller components.

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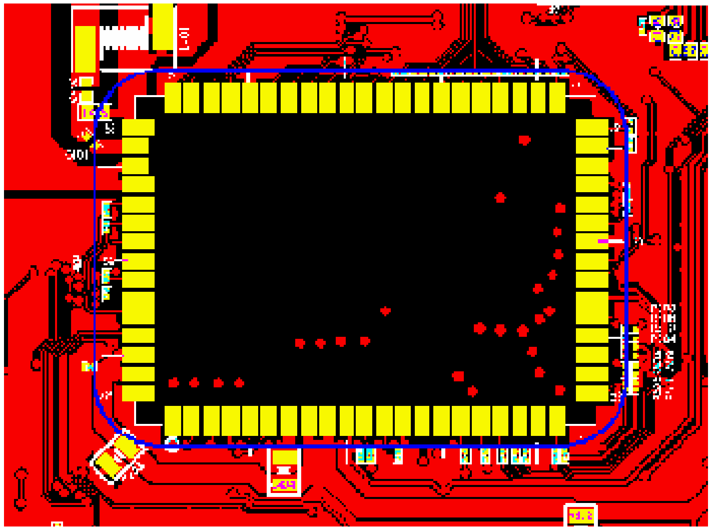
Objective

- Investigate the use of step stencil for depositing different volumes of solder paste on the same board for high-density layout.
  – Study the major factors and their impact to step stencil printing quality.
  – Investigate the possibility of reducing the keep-out distance per the recommendation of IPC-7525 Stencil Design Guidelines

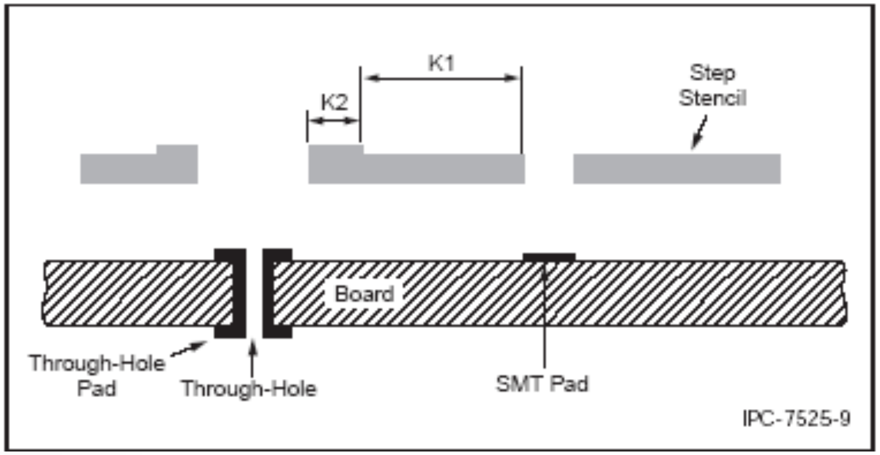


Miniature components close to the castle-like components

IPC-7525 Stencil Design Guidelines

- The widely recognized industry standard IPC-7525 has been used as the starting point for this project that explores the effect of varying the keep out distance for small components 0201 and 0402 chips, 0.4mm CSP and 0.4mm SOP. Large component is represented by CCGA.

- IPC-7525 specifies for every mil step thickness a minimum keep-out distance (KD) of 36mil is required to get good paste deposition(36h-h is the step thickness).



http://www.laserstentech.com/040~Stencils/030~Step_Stencils/

Solder Paste Deposition Project
Project Members

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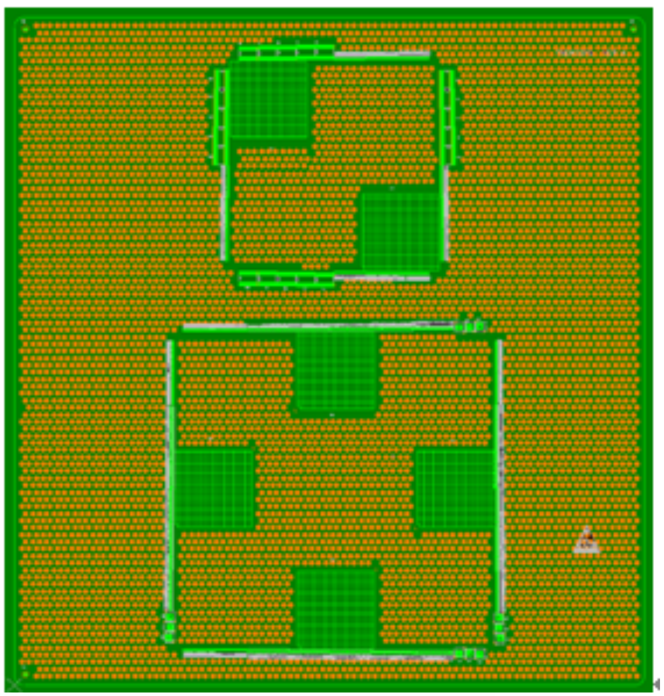
Experimental Approach

- The experiment was divided into three phases:
  - Phase I – Printing study-Conducted at Speedline, US
    - Understand the effect of various printing and board design factors on the overall printing performance
  - Phase II – Printing validation study-conducted at Speedline, US
    - Validate the results for phase I study by repeating selected runs
  - Phase III – Assembly study-conducted at Huawei, China
    - Conduct assembly study by selecting critical factor combination as determined by phase I and II.

Test Board

Test Board Spec

Size	360.0mm×340.0mm×2.5mm
Layer	4
Surface finish	OSP
Material	FR-4



Board Layout

Component	KD/mil	KD level	Layout
0201	24，32，40，43，48，51，56，59，67，75	10	Outside
0402	24，32，40，48，56，64，72，80，88	9	Outside
0.4mm pitch SOP	24，32，40，48，56，252，260，268，276，284	10	Outside
0.4mm pitch CSP	Min 24，Max 184，Step 8	21	Outside
1.27mm pitch CCGA	/	/	Inside

Experimental Design

Phase I

Purpose of test: To establish optimum printing parameters for mixed component board

Date: 03/26/08 | Engineer:

Experimentation Type: Screening | Fractional Factorial (2_{IV}^{5-2}), 2 Levels

Factor	Parameter	LEVELS (-)	LEVELS (+)	Comment
SPT	Solder	Pb-free	SnPb	
SP	Solder pwoder	Type 3	Type 4	
SLP	Stencil type	Laser cut SS	Efab Nickle	
STP	Step	Step down	Step up	
STK	Step thicknes	0.03mm	0.06mm	

Response: Transfer Efficiency (TE), pad height (PH), pad area (PA), visual

Board Qty	Treatment order	Run order	SPT	SP	SLP	STP	STK	Y1, TE	Y2, PH	Y3, PA
3	1	1	-1 (Pb-F)	1 (T-4)	-1 (laser)	-1 (S-down)	-1 (0.03)			
3	2	2	1 (SnPb)	-1 (T-3)	-1 (laser)	-1 (S-down)	-1 (0.03)			
3	3	3	1 (SnPb)	1 (T-4)	1 (Efab)	1 (S-up)	1 (0.06)			
3	4	4	-1 (Pb-F)	-1 (T-3)	1 (Efab)	1 (S-up)	1 (0.06)			
3	5	5	-1 (Pb-F)	1 (T-4)	-1 (laser)	1 (S-up)	1 (0.06)			
3	6	6	1 (SnPb)	-1 (T-3)	-1 (laser)	1 (S-up)	1 (0.06)			
3	7	7	1 (SnPb)	1 (T-4)	1 (Efab)	-1 (S-down)	-1 (0.03)			
3	8	8	-1 (Pb-F)	-1 (T-3)	1 (Efab)	-1 (S-down)	-1 (0.03)			
3	9	9	-1 (Pb-F)	-1 (T-3)	-1 (laser)	1 (S-up)	-1 (0.03)			
3	10	10	1 (SnPb)	1 (T-4)	-1 (laser)	1 (S-up)	-1 (0.03)			
3	11	11	1 (SnPb)	-1 (T-3)	1 (Efab)	-1 (S-down)	1 (0.06)			
3	12	12	-1 (Pb-F)	1 (T-4)	1 (Efab)	-1 (S-down)	1 (0.06)			
3	13	13	-1 (Pb-F)	-1 (T-3)	-1 (laser)	-1 (S-down)	1 (0.06)			
3	14	14	1 (SnPb)	1 (T-4)	-1 (laser)	-1 (S-down)	1 (0.06)			
3	15	15	-1 (Pb-F)	1 (T-4)	1 (Efab)	1 (S-up)	-1 (0.03)			
3	16	16	1 (SnPb)	-1	1 (Efab)	1 (S-up)	-1 (0.03)			

Fixed factors

Equipment

MPM printer, Koh Young & Cyber Optics SPI

Print speed, Print pressure, and Separation method,

Optimize for each stencil type

Solder Paste

Indium

SnPb: NC-SMQ92H with Sn63

Lead-free: 8.9 with SAC305

Design Factors Explanation

Factor	Level	
Solder paste	Tin-lead	Lead-free
Powder size	Type 3	Type 4
Stencil fabrication	Laser-cut	Electroformed
Step type	Step-up	Step-down
Step thickness (none-step area thickness is 0.12mm)	0.03mm	0.06mm

DOE Matrix

Run order	Solder type	Solder particle size	Stencil fabrication	Stencil type	Step thickness/mm
1	Lead-Free	Type 4	Laser-cut	Step-down	0.03
2	SnPb	Type 3	Laser-cut	Step-down	0.03
3	SnPb	Type 4	Electroformed	Step-up	0.06
4	Lead-Free	Type 3	Electroformed	Step-up	0.06
5	Lead-Free	Type 4	Laser-cut	Step-up	0.06
6	SnPb	Type 3	Laser-cut	Step-up	0.06
7	SnPb	Type 4	Electroformed	Step-down	0.03
8	Lead-Free	Type 3	Electroformed	Step-down	0.03
9	Lead-Free	Type 3	Laser-cut	Step-up	0.03
10	SnPb	Type 4	Laser-cut	Step-up	0.03
11	SnPb	Type 3	Electroformed	Step-down	0.06
12	Lead-Free	Type 4	Electroformed	Step-down	0.06
13	Lead-Free	Type 3	Laser-cut	Step-down	0.06
14	SnPb	Type 4	Laser-cut	Step-down	0.06
15	Lead-Free	Type 4	Electroformed	Step-up	0.03
16	SnPb	Type 3	Electroformed	Step-up	0.03

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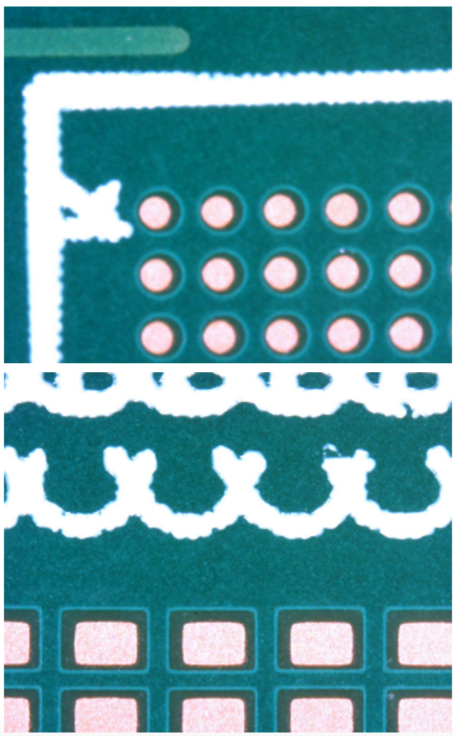
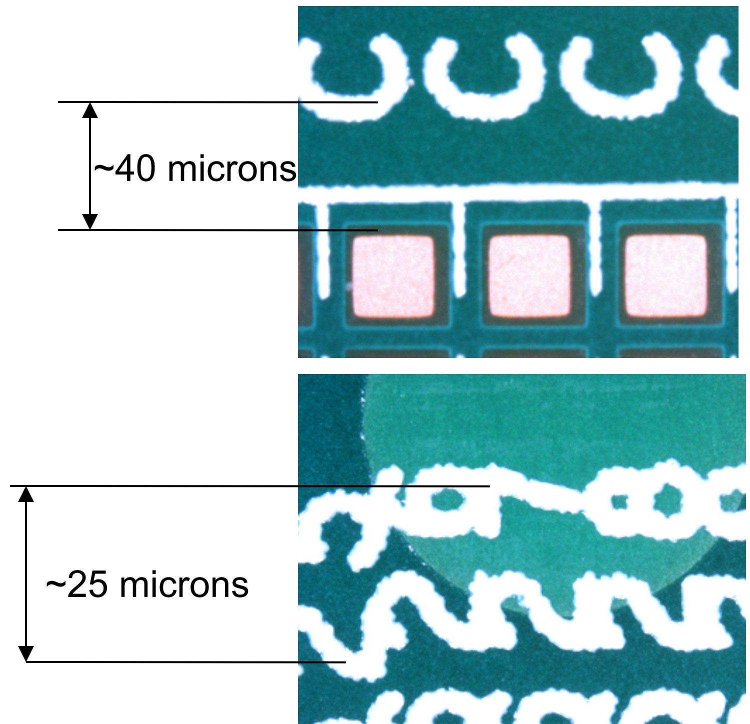
Pre-DOE Investigation

- Prior to running the DOE, the following studies were conducted
  - Visual inspection of the board and stencil
  - OSP thickness measurement
  - Gage repeatability for both SPI systems

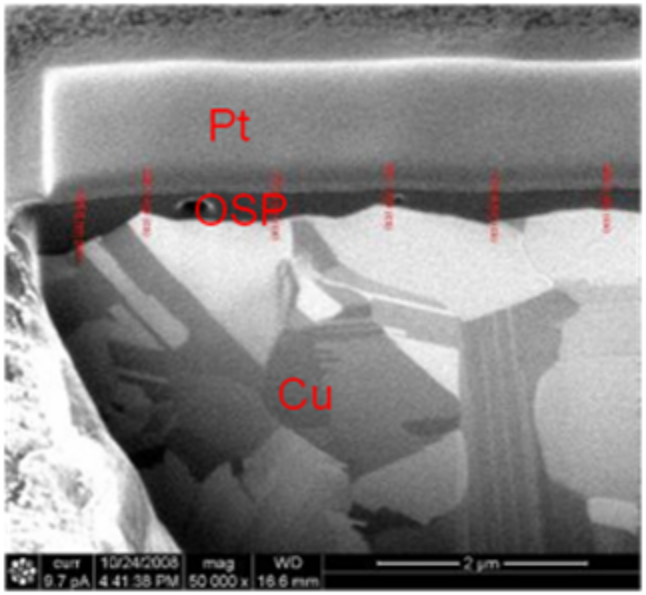
Visual Inspection of the Board

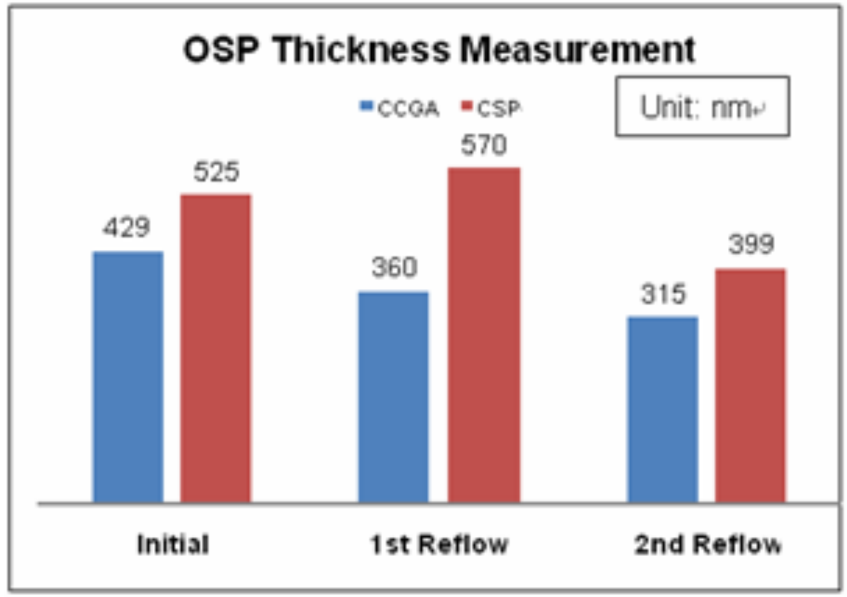
- Optical inspection of the board showed the silk screening had a variation of over 25 microns and the height difference between bare board to the silk screen was over 40 microns
- We should recognized, this variation may influence the printing results





OSP Thickness Measurement





- OSP Type - High Temperature
- Measurement tool - Focused Ion Beam (FIB)
- The difference of pad thickness - < 0.5 µm
- After double reflow, the OSP still met solderability requirements.

Gage Repeatability

Precision to Tolerance ratio with a specification of ± 40% for the TE was used to access the Gage repeatability of each SPI system

$$P/T = 6 \frac{\sigma_{\text{measurements}}}{\text{USL-LSL}}$$

Acceptance criteria:

$P/T \leq 10\%$ Highly capable gage

$10\% \leq \frac{P}{T} \leq 30\%$ Accepatable

$P/T \geq 30\%$ Unaccepatable

Cyber Optics

P/T for SE300 – 11.65%

Koh Young

P/T for KY-3020 – 6.37%

Based on the P/T ratio, both systems were considered to be capable of inspecting paste volume

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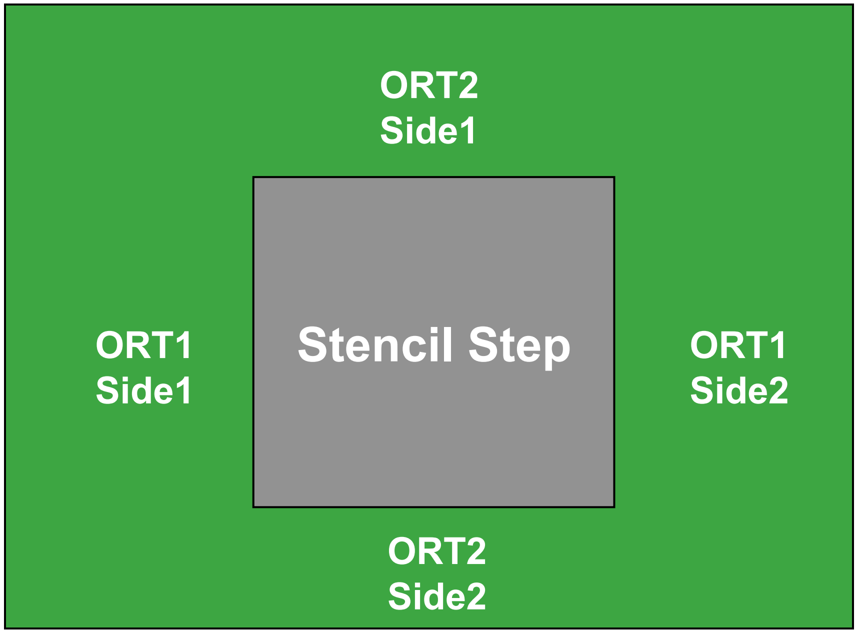
Result and Analysis



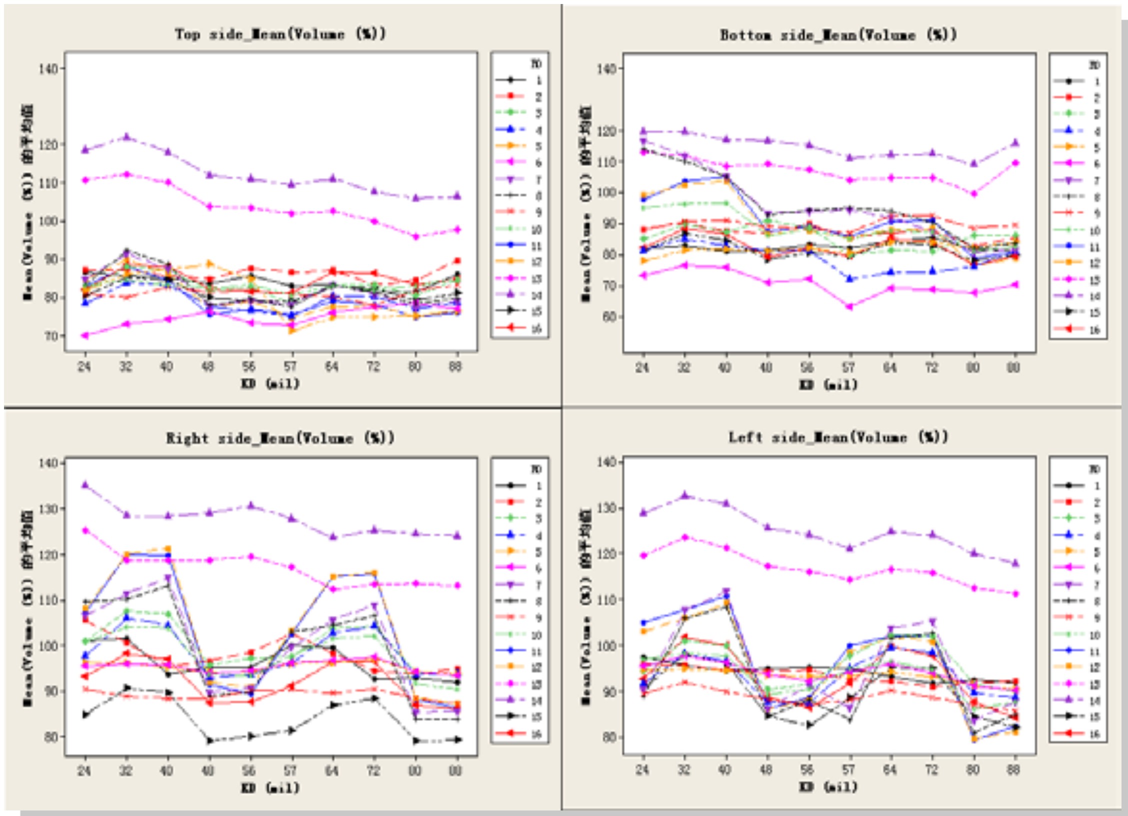
Analysis method:

- Volume and height data for each component surrounding the steps were analyzed using JMP and Minitab statistical software.
- Components included, 0402, 0201, 0.4mm CSP and 0.4mm SOP

Keys:
ORT – pad orientation
1 – left or top based on ORT
2 – right or bottom based on ORT

Typical Trend Analysis-TE

KD trend analysis of 0402 Average TE for all 4 sides

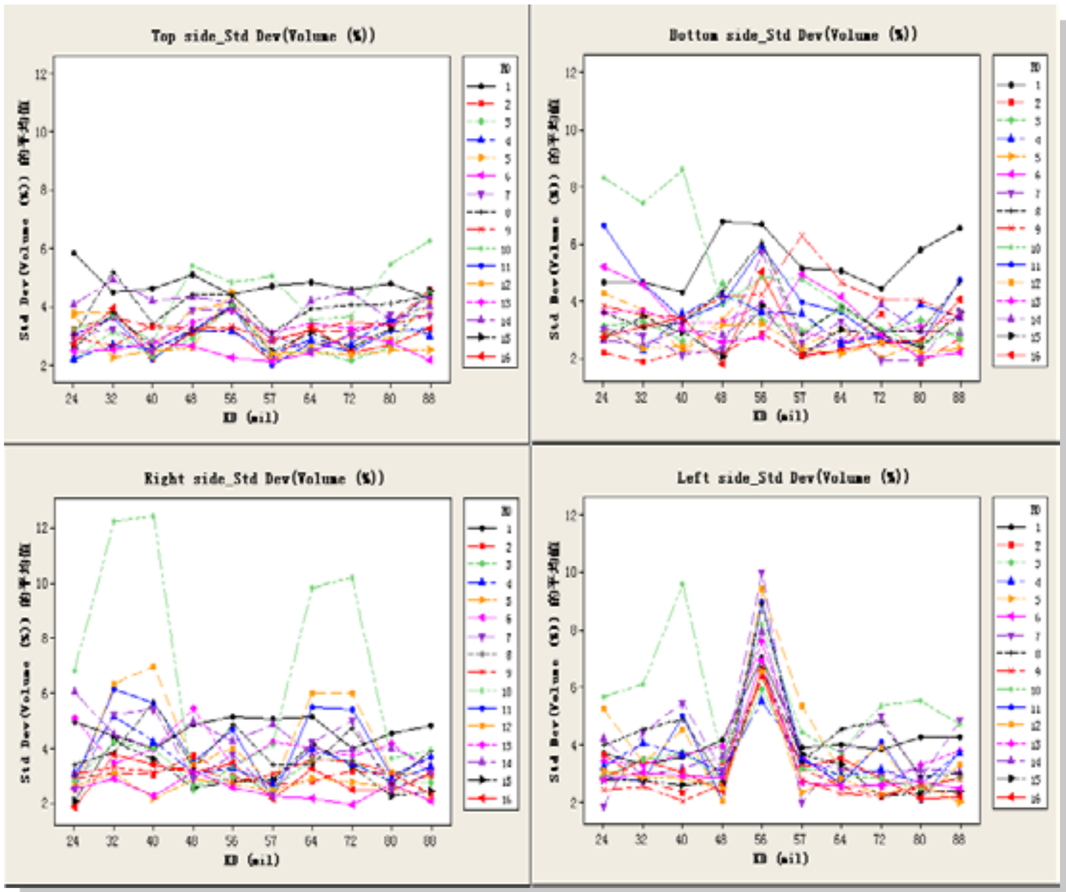


0402 TE vs. KD

- KD may not be the most significant factor in a single run, because TE varies little with increasing KD
- TEs differ between some runs, especially Runs 13 and 14 which have TE values higher than other runs.

Typical Trend Analysis -Stdev

KD trend analysis of 0402 stdev of TE for all 4 sides



0402 Stdev vs. KD

- Standard Deviation analysis shows that the KD is not the most significant factor driving TE variation.
- With the exception of RO 10, most all Stdev falls below 10%

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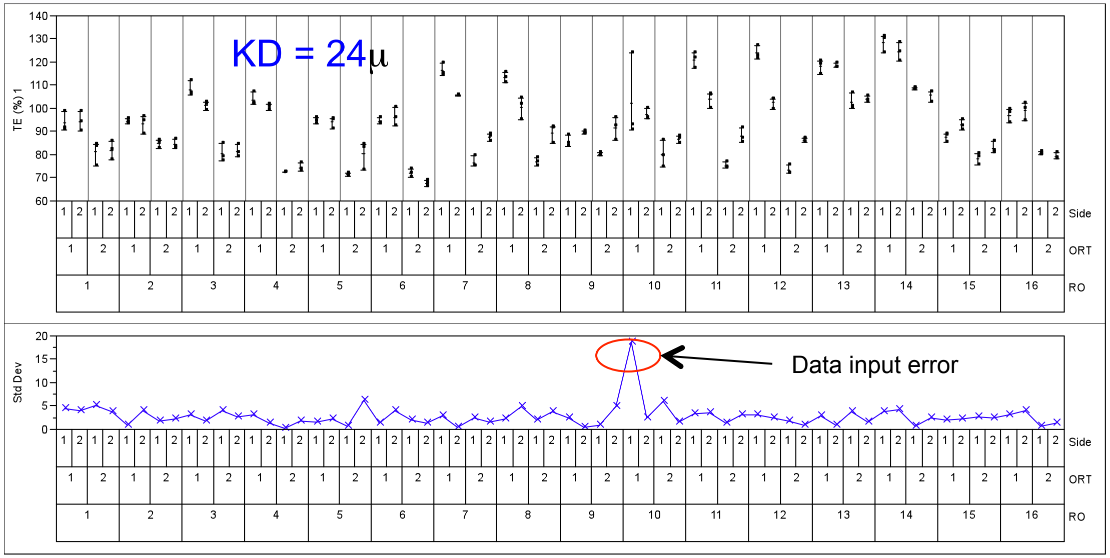
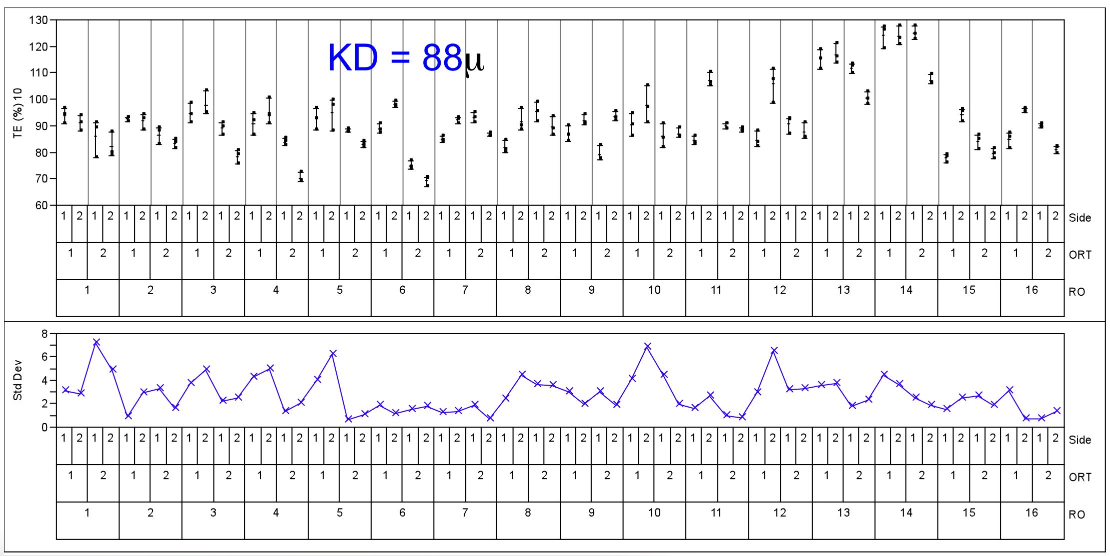
Typical Box Plot of TE- 0402

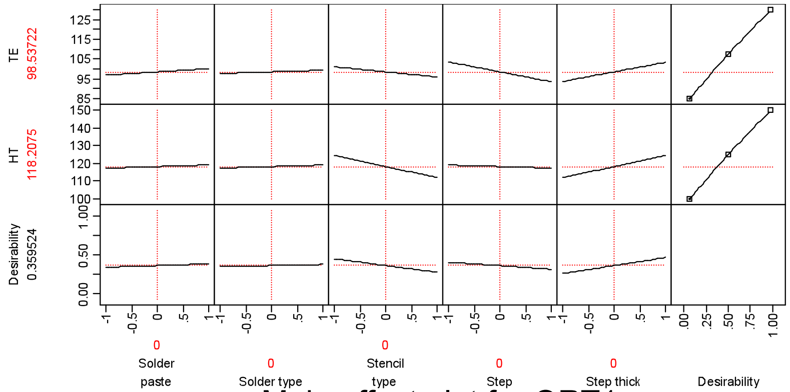




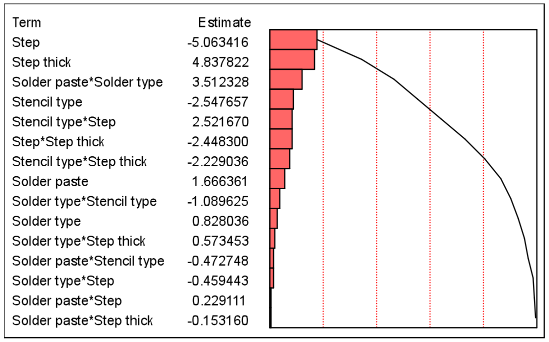
The Box Plot shows:

- Side to side variation is minimum regardless of the KD distance. Hence the data can be combined
- Orientation appears to have a significant effect, hence need to be treated separately
- Run order shows significant effect on the TE, which implies factors and levels included in the DOE was appropriate
- Standard deviation was found to be bellow 10%, which meets the set criteria

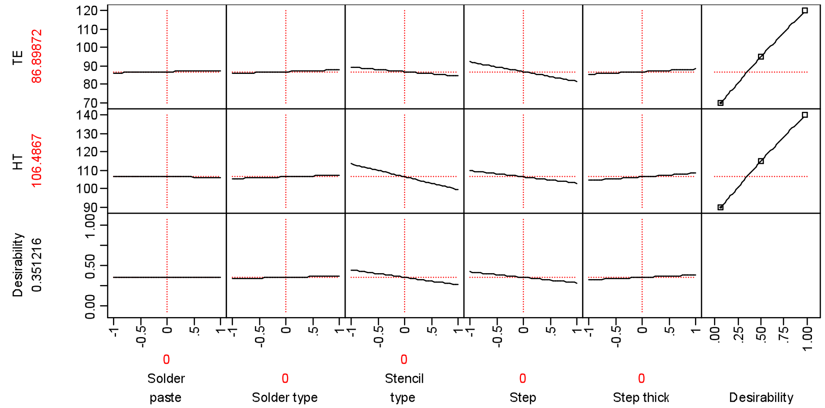
Typical DOE Analysis-0402 (JMP)



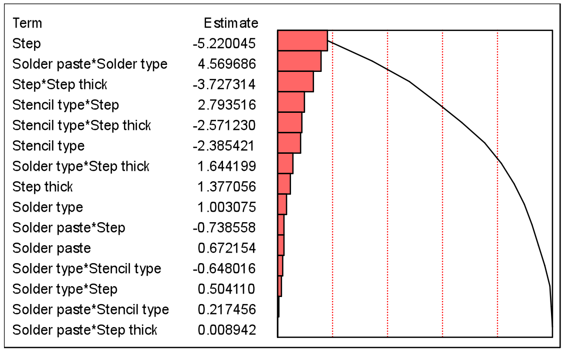
Main effect plot for ORT1



Pareto plot for ORT1



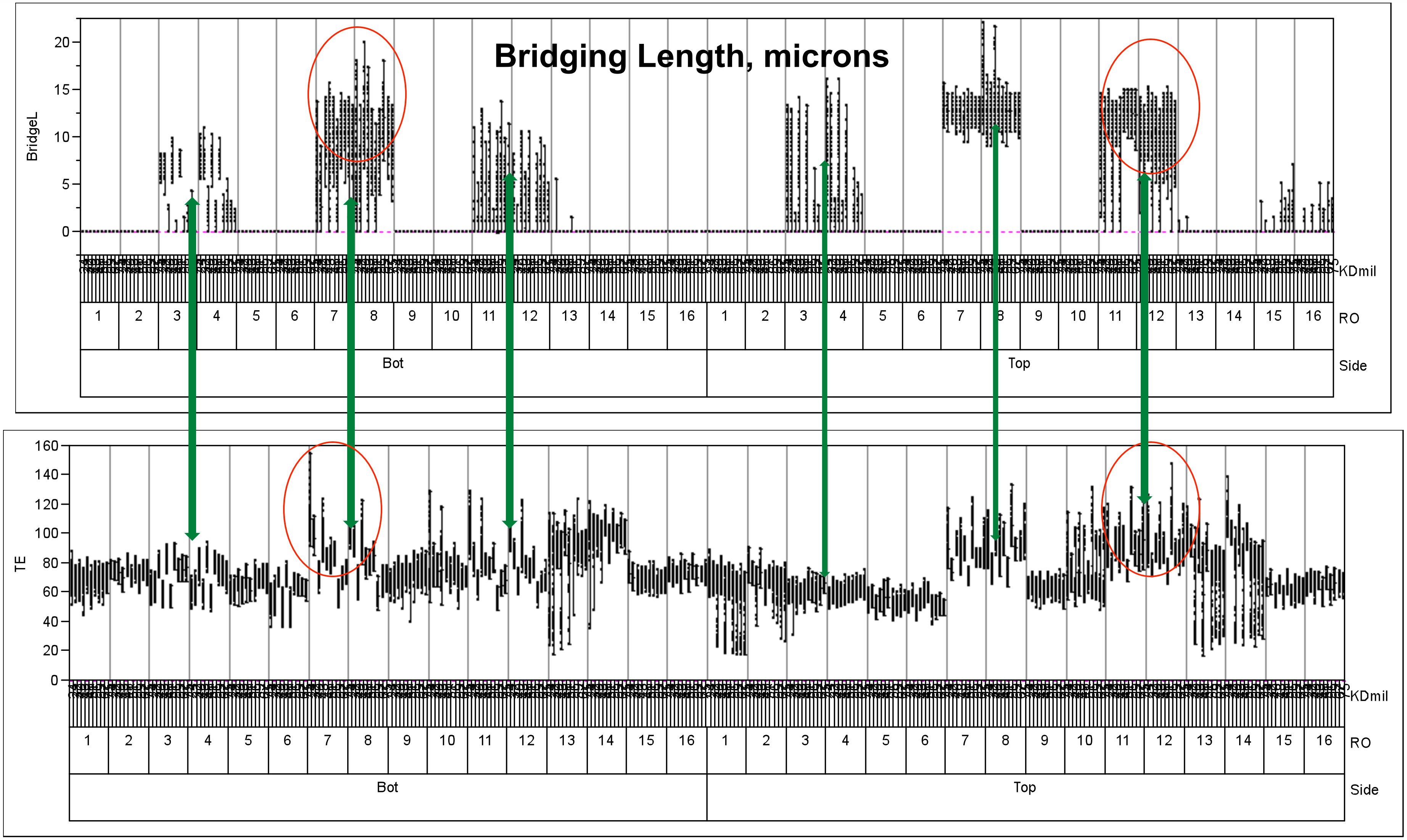
Main effect plot for ORT2



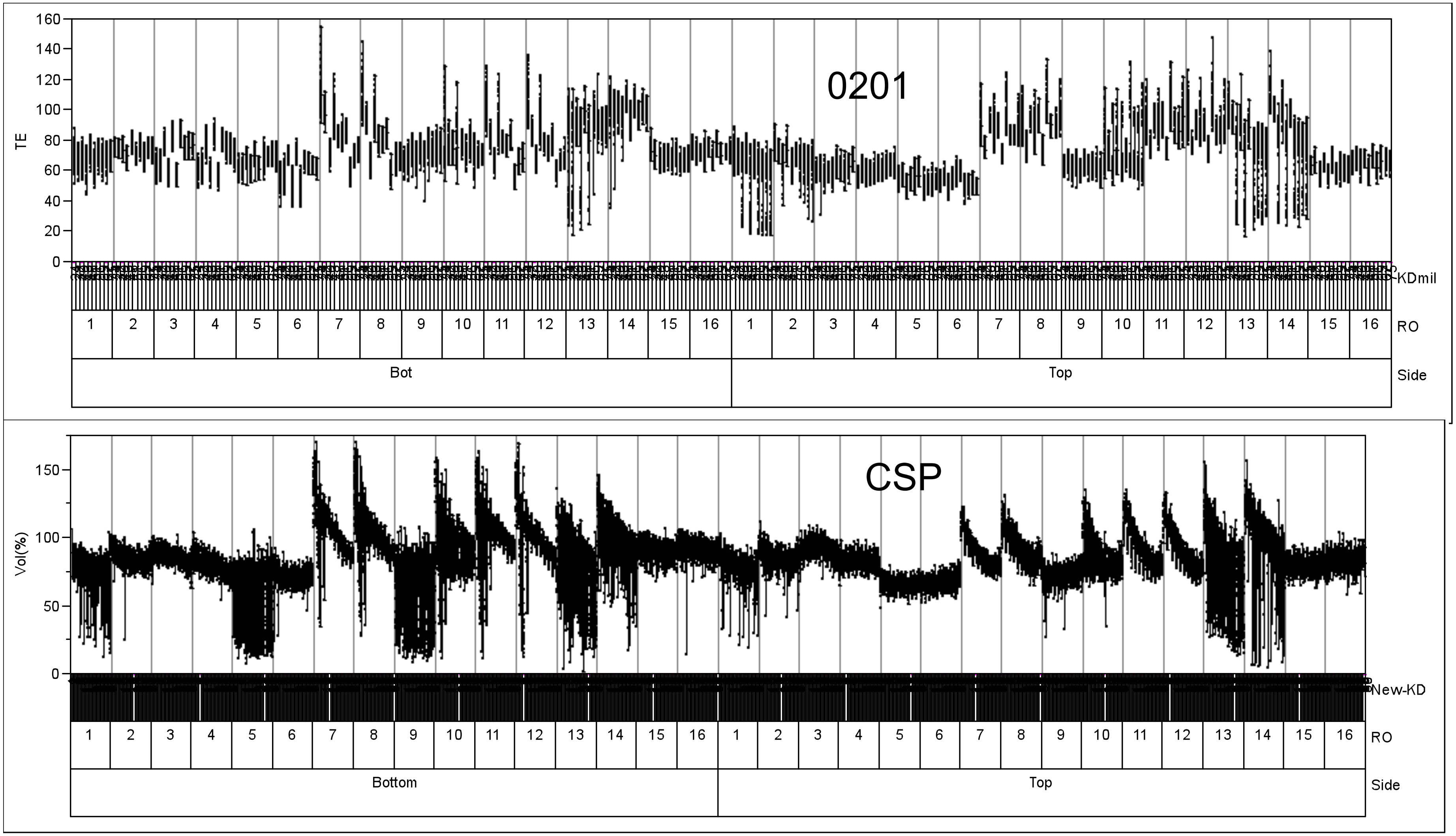
Pareto plot for ORT2

DOE analysis shows step type, stencil type, and step thickness have significant effect on TE regardless of the orientation. In addition, there are some complex interaction between some factors

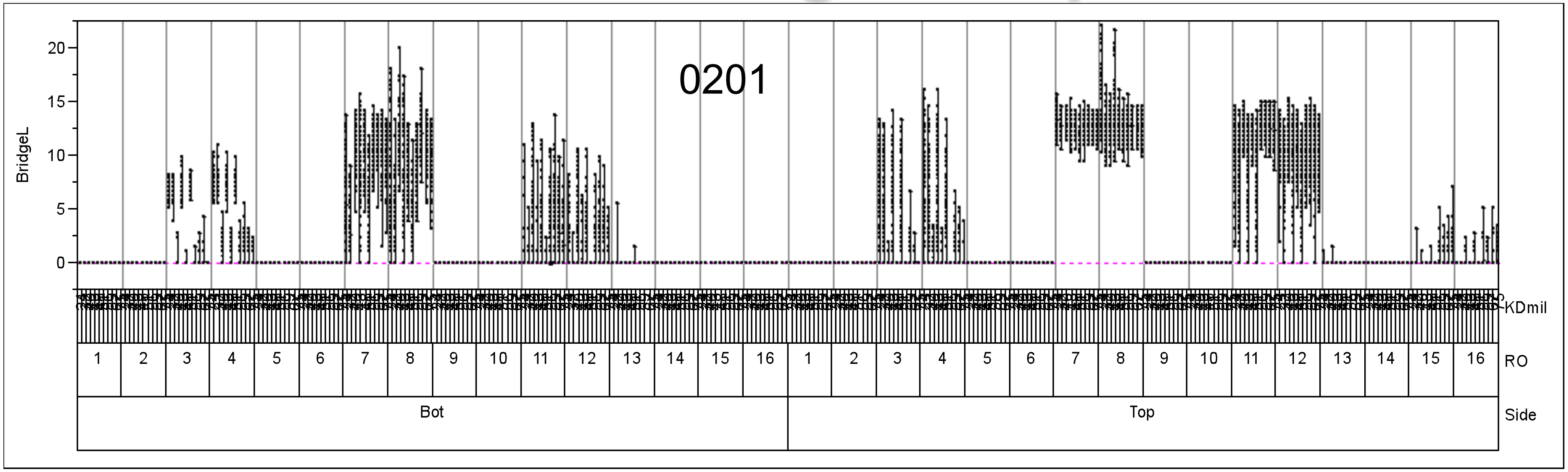
Typical Box Plot for 0201

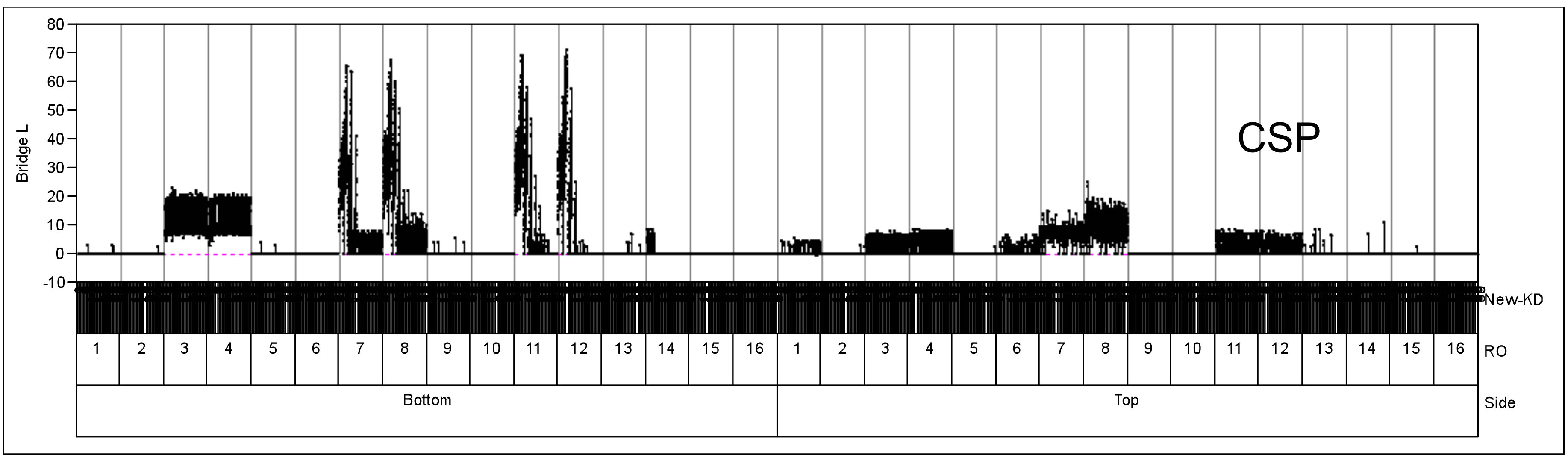


CSP-0201 TE Comparison

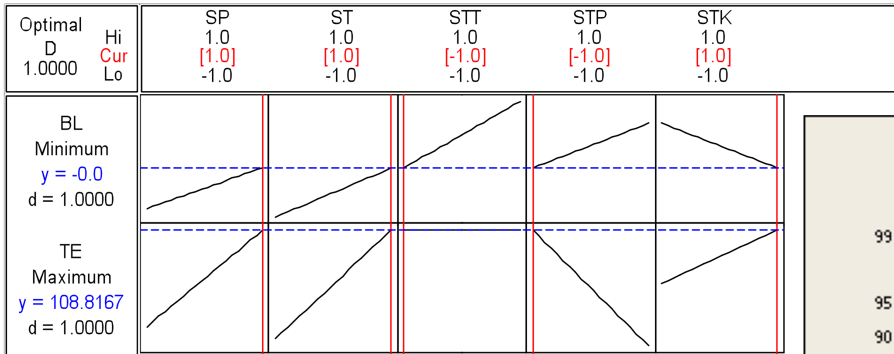


CSP-0201 Bridge Comparison



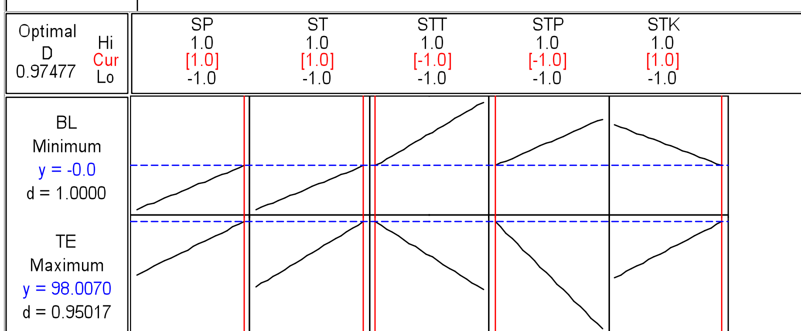


DOE Results-0201(Minitab)



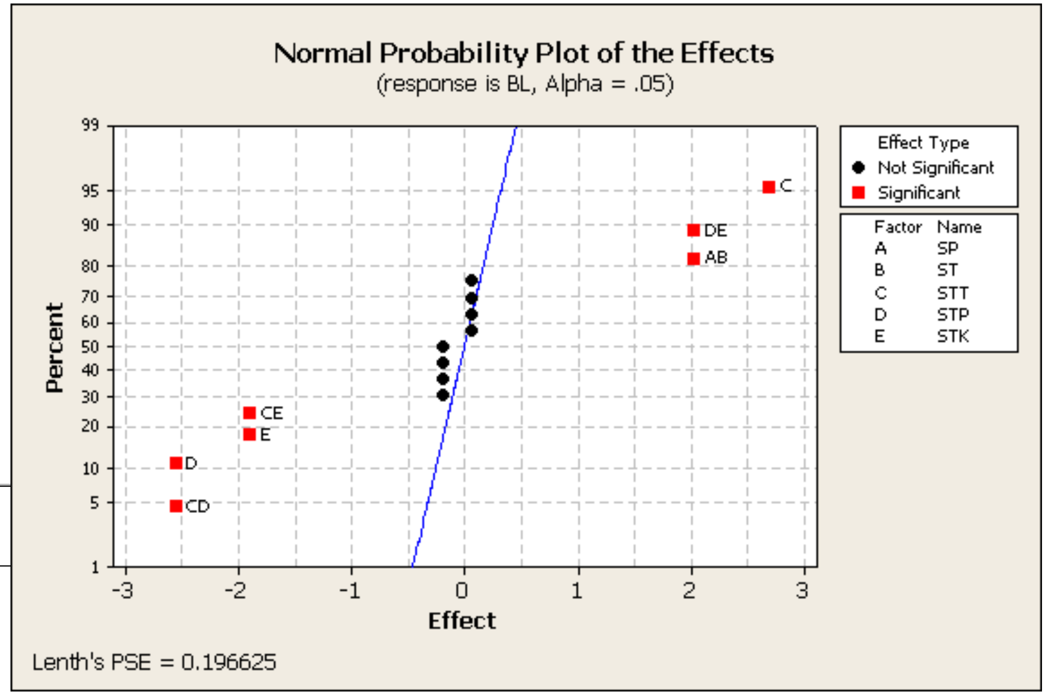
KD24-Bottom

Optimum run is to RO14



KD75-Bottom

Optimum run is close to RO14



Minitab analysis shows that regardless of the keepout distance, step size, stencil type and step thickness has the most significant effect

Phase I Summary

- Step type, Step thickness and stencil type has significant effect on the print quality for miniature components.
- Laser cut, step down stencil with 0.06mm step provided the best quality print (RO 14)
- Solder type and powder size has minimum effect on the print quality
- DOE shows complex factor interaction, which needs to be further investigated
- The effect of KD is not clear

Phase I Summary Continued…

Component	Transfer Efficiency	Standard Deviation
0201	No clear trend in a single run; Notable differences between runs.	No clear trend in a single run; Notable differences between runs
0.4mm pitch SOP	In a single run TE clearly reduces with increasing KD; Notable differences between runs.	No clear trend in a single run; Not much difference between runs
0.4mm pitch CSP	Considerable variation in TE with increasing KD in some runs; The trend is more consistent between runs, that is, the trend of TE with increasing KD although there are still large differences in the absolute values.	No clear trend in a single run; Not much difference between runs

Phase II- Verification Runs

- Based on the TE and Bridging data, the highlighted runs were considered to be of interests. Verification runs, (Phase II) and the assembly study was conducted by repeating the following 7 runs

RO	Solder paste	Solder particle	Stencil type	Step type	Step thickness	Group	BBL	BTE	TBL	TTE
2	SnPb	Type 3	Laser-cut	Step-down	0.03	1	P	P	P	P
15	Lead-Free	Type 4	Electroform	Step-up	0.03	1	P	P	P	P
16	SnPb	Type 3	Electroform	Step-up	0.03	1	P	P	P	P
7	SnPb	Type 4	Electroform	Step-down	0.03	2	F	F	F	M
8	Lead-Free	Type 3	Electroform	Step-down	0.03	2	F	F	F	M
11	SnPb	Type 3	Electroform	Step-down	0.06	2	F	F	F	M
12	Lead-Free	Type 4	Electroform	Step-down	0.06	2	F	F	F	M
3	SnPb	Type 4	Electroform	Step-up	0.06	3	F	P	F	P
4	Lead-Free	Type 3	Electroform	Step-up	0.06	3	F	P	F	P
1	Lead-Free	Type 4	Laser-cut	Step-down	0.03	4	P	F	M	F
6	SnPb	Type 3	Laser-cut	Step-up	0.06	4	P	M	M	M
5	Lead-Free	Type 4	Laser-cut	Step-up	0.06	5	P	F	P	M
9	Lead-Free	Type 3	Laser-cut	Step-up	0.03	5	P	F	P	M
10	SnPb	Type 4	Laser-cut	Step-up	0.03	5	P	F	P	M
13	Lead-Free	Type 3	Laser-cut	Step-down	0.06	6	P	F	P	F
14	SnPb	Type 4	Laser-cut	Step-down	0.06	6	P	F	P	F

- **Keys:**
  - **BBL :**Bottom side Bridge Length ; **BTE :** Bottom side Transfer Efficiency
  - **TBL :** Top side Bridge Length ; **TTE :** Top side Transfer Efficiency
  - **P :** Pass ; **F :** Fail ; **M** : Marginal – around pass/fail boundaries

Assembly Study

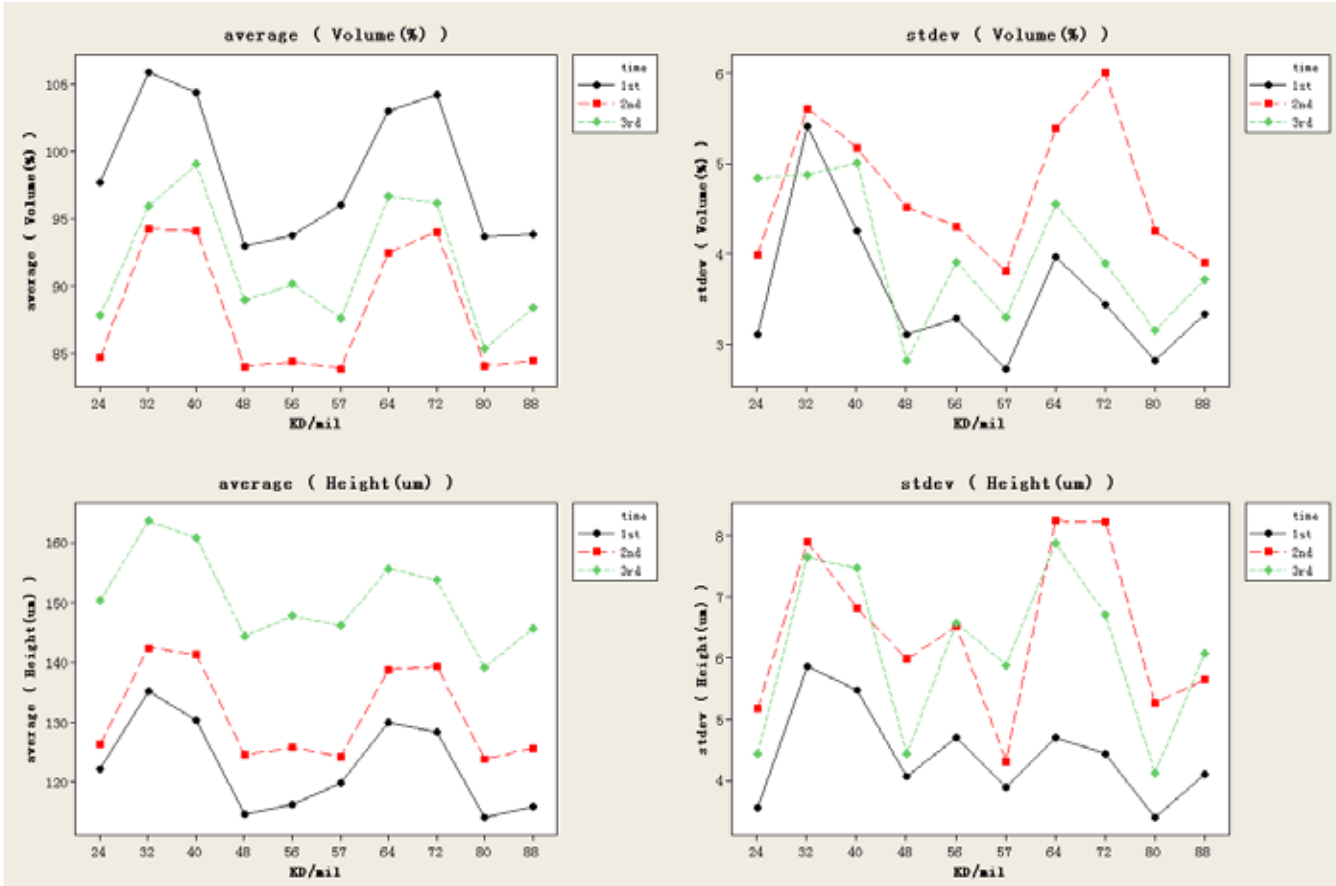
- The assembly study was conducted by assembling the boards from the 7 selected runs from Phase I study.
- 3 replicate per run was collected to reduce the effect of noise
- Each pad was inspected with 3D SPI. The paste volume, transfer efficiency (TE), paste height, and bridge information were recorded for further analysis

Print → 3D SPI → Pick-and-Place → Pre-reflow AOI → Reflow → Post reflow AOI

Analysis Method

- The average transfer efficiency and standard deviation for each run was compare with the two previous experiment to learn the stability of each chosen factors
- Defect data from before and after reflow was compare to understand the effect of print defects on the assembly defect

Typical Print Trend Analysis-0402



Both mean and Stdev for TE and Height shows similar trend among the 3 sets of experiment. As one would expect, absolute values are somewhat different

Typical Defect Inspection Data*

RO	Board No	Component Type	SPI				Pre-reflow			Post-reflow				Microscope (Visual Inspection)		X-ray
			No Solder	Bridge	Misalignment	Excess	Misalignment	Bridge	No Solder	No Solder	Bridge	Dryjoint	Misalignment	Bridge	No Solder	Bridge
6	1	0201	5/500 C648/ C851/													
		0402	1/500 C148									1/400 C97				
		SOP								1/8 U14		1/8 U17				
		CSP	2/12 U32/U										1/8 U37			
	2	0201	13/500 C626/ C631/ C632/ C635/ C638/ C639/													
		0402	2/500 C17/C							1/400 C69						
		SOP	1/20 U18				1/8 U20									
		CSP	2/8 U32/U										1/8 U33			1/8 U34
	3	0201	1/500 C859				1/500 C909									
		0402	2/500 C17/C													
		SOP														
		CSP	2/12 U32/U													
11	4	0201														
		0402				1/500 C283										
		SOP		4/20 U1/U2 /U3/U				1/8 U20			1/8 U20			3/8 U1/U2 /U20		
		CSP		1/12 U35												8/8 U27/U 28/U3
	5	0201														
		0402														
		SOP		3/20 U1/U2 /U6										4/8 U1/U2 /U6/U		
		CSP		1/12 U35		1/12 U35										8/8 U27/U 28/U3
	6	0201														
		0402					2/400 C500/									
		SOP		3/20 U1/U2 /U3/U										3/8 U1/U2 /U20		
		CSP		1/12 U35		1/12 U35										8/8 U27/U

Shows some defect counts for two typical runs-RO 6 and RO11

** Doesn't include all defects.*

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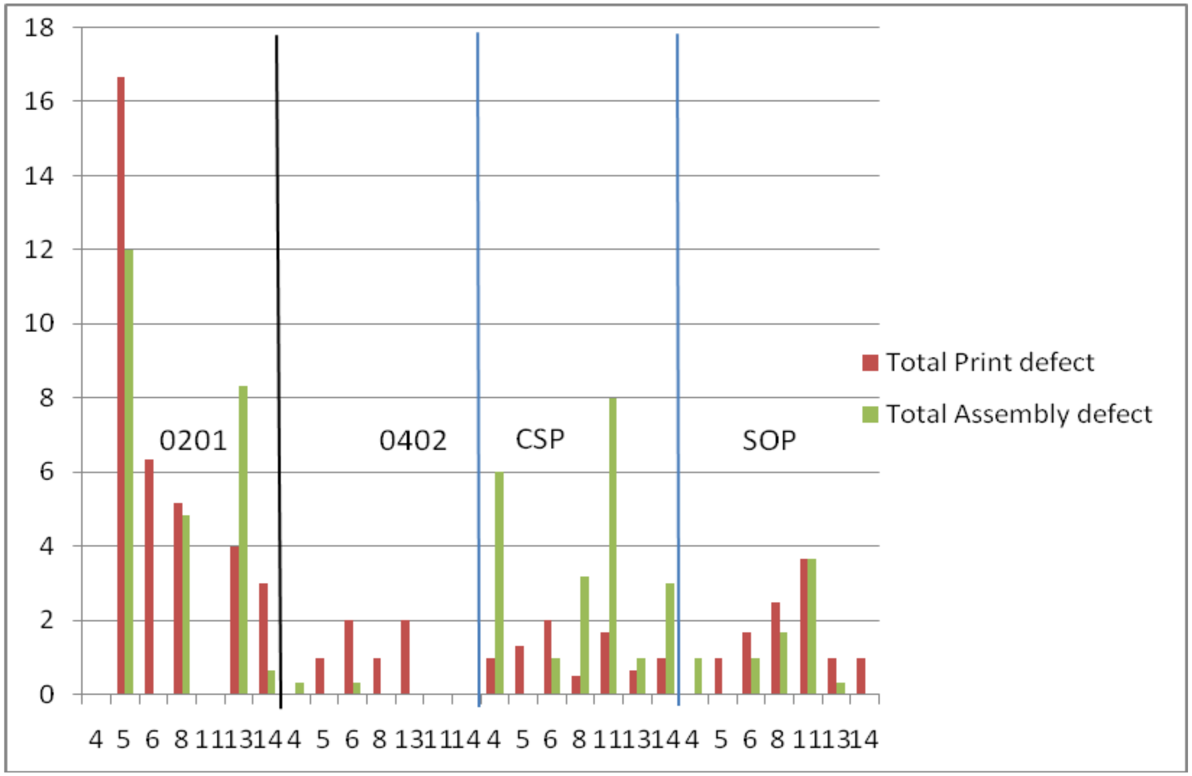
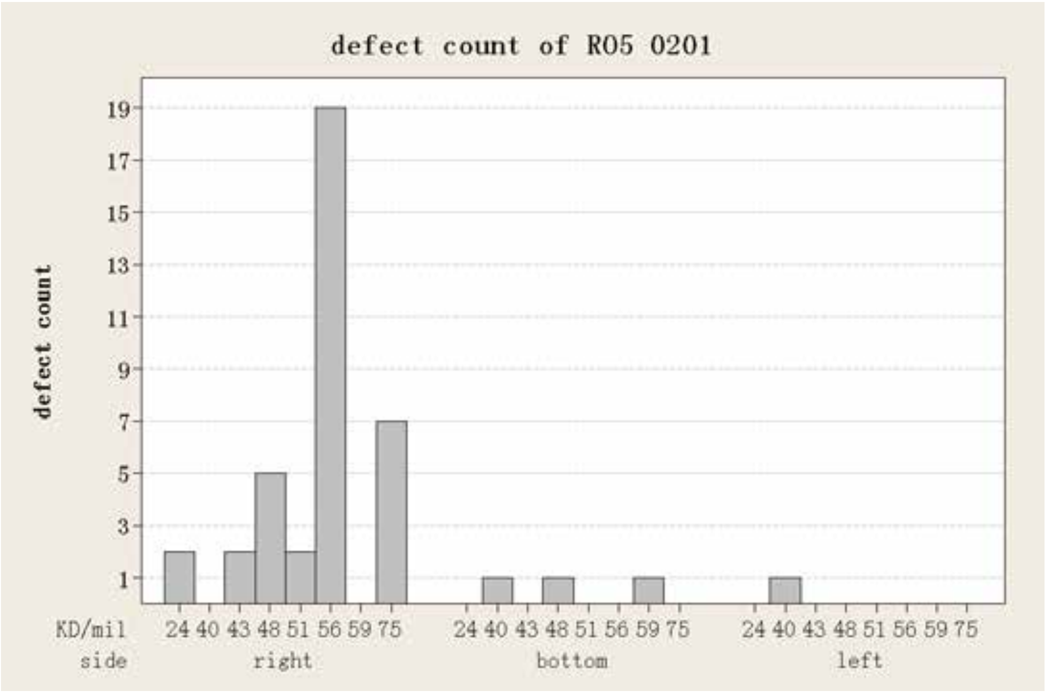
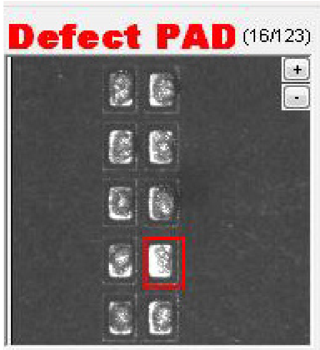
Printing & Reflow Defect Correlation



- In general, 0201 shows higher level of print defects that diapers' after reflow
- 0402 shows hardly any assembly defect
- CSP and 0201 show most assembly defects

Typical Defect Correlation..





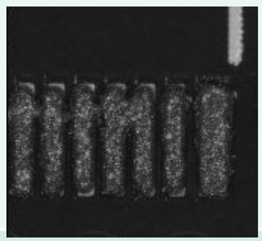
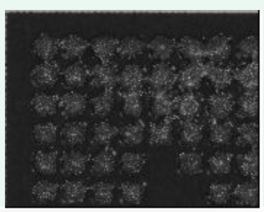
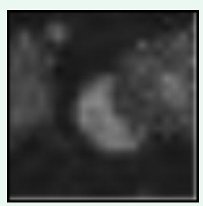
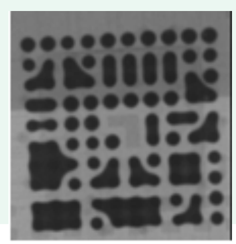
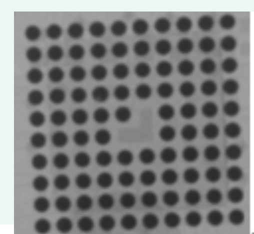
SPI

After Reflow

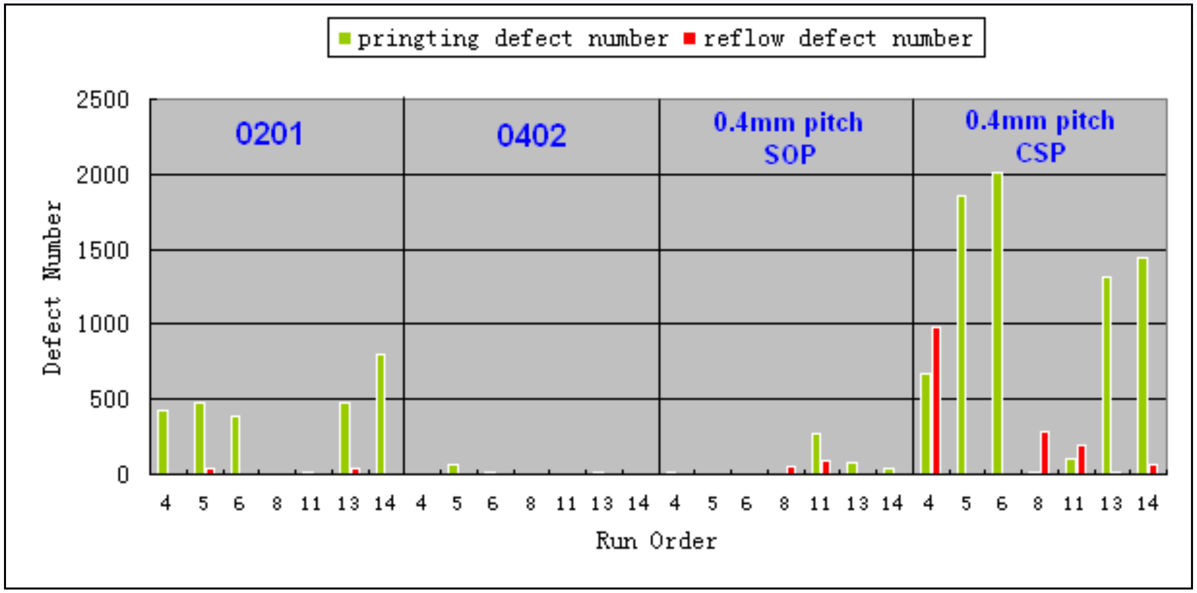
"Lack of solder" from SPI inspection shows "no solder" after assembly as well

Data Analysis

- **Defects comparison after reflow and printing**

Components		Bridge / Open Solder joints	Good Solder joints
0402			
0.4mm pitch SOP			
0201			
0.4mm pitch CSP	 		

Data Analysis



- For 0402, the closest KD is 24mil which in-addition is the smallest KD set in the experiment design.
- For 0.4mm pitch SOP，when the KD is larger than 32mil, in some ROs the closest KD may be 24mil.
- In RO5 and RO13，the closest KD of 0201 is 75mil. There are no defects occur in other ROs after reflow.
- For 0.4mm pitch CSP, only RO5 has no reflow defects.
- There are reflow defects in other 6 ROs because the KDs set in this project is not large enough.

Outline

- Introduction
- Objective
- DOE Design
- Experiments
- Results and Analysis
- Conclusion
- Acknowledgements

Conclusions

1

The results shows that 0402 passives are not sensitive to the factors under study here. The minimum KD selected is 24mil, and the maximum step thickness is 2mil. Based on this findings, we can conclude that for 0402, the minimum KD can be as low as 12h(h is the step thickness). This minimum KD reduction may be applicable to all larger components, such as 0603, 0804 etc.

2

For 1mil step thickness and electroform step-up stencil (RO 15 & 16), we found that challenging component such as 0.4mm CSP does not show defect in terms of bridge and transfer efficiency. Therefore, for electroform step-up stencil, the minimum KD can be reduced from 36h to 24h. This minimum KD reduction may not be applicable to components with <0.4mm CSP in terms of printing.

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