



## **Faculty of Manufacturing Engineering**

# **SOLDER PASTE PRINTING YIELD IMPROVEMENT FOR SMT ULTRA FINE PITCH PRODUCT BY USING SIX SIGMA TECHNIQUE**

**Lim Kean Teik**

**Master of Manufacturing Engineering (Manufacturing System Engineering)**

**2016**

**SOLDER PASTE PRINTING YIELD IMPROVEMENT FOR SMT ULTRA  
FINE PITCH PRODUCT BY USING SIX SIGMA TECHNIQUE**

**LIM KEAN TEIK**

**A thesis submitted  
in fulfillment of the requirements for the degree of Master of Manufacturing  
Engineering (Manufacturing System Engineering)**

**Faculty of Manufacturing Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2016**

## DECLARATION

I declare that this thesis entitled “Solder paste printing yield improvement for SMT ultra fine pitch product by using six sigma technique” is the result of my own research except as cited in the references. This thesis has not yet being accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :  .....

Name : Lim Kean Teik .....

Date : 03-June-2016 .....

## APPROVAL

I hereby declare that I have read this thesis and it is sufficient in terms of the scope and quality to gain the award of Master of Manufacturing Engineering (Manufacturing System Engineering).

Signature : .....  DR. MOHAMAD BIN MINHAT  
Pensyarah  
Supervisor Name : ..... Fakulti Kejuruteraan Pembuatan  
Universiti Teknikal Malaysia Melaka.....  
Date : ..... 03-June-2016 .....

## **DEDICATION**

To my beloved mother and father

## ABSTRACT

Surface mount technology (SMT) is a method for producing electronic circuits in which the components are mounted directly onto the surface of printed circuit boards (PCBs). It has been emerged in the 1960s, gained momentum in the early 1980s and became widely used by the mid-1990s and is continually becoming more important as PCB assemblies become more advanced and compact with componentry real estate savings provided with SMT become more valuable and necessary. At presents, in the industry it has largely replaced the through-hole technology construction method of fitting components with wire leads into holes in the PCB because it allows for better electrical performance when compared to through-hole via and offers a conventional reflow processes compared to conventional wave solder. The majority of defects in PCB assembly are caused due to problem in the solder paste printing process or due to defects in the solder paste. There are various types of defects such as excessive solder paste, and solder melts and connects too many solder pads, which causes a short circuit. Insufficient solder paste result in incomplete circuits. When making PCBs, manufacturers often test the solder paste deposits using SPI (solder paste inspection). 3D SPI systems measure the volume of the solder paste printed on solder pads before the components are applied and the solder reflow process. SPI systems can reduce the incidence of solder-related defects to statistically insignificant amounts. Yield improvement requires increased focus on stencil technology, printer capability, solder paste functionality and under stencil cleaning. The term of fine pitch is defining as 0.5mm in pitch and ultra fine pitch is 0.2mm – 0.4mm in pitch (Surface mount council, 1999).

The two major responses from the experimentation are printing quality and SPI yield.

## **ABSTRAK**

*Surface Mount Technology* atau sering disingkat dengan sebutan *SMT* adalah satu kaedah untuk menghasilkan litar elektronik di mana komponen dipasang terus pada permukaan papan litar bercetak (*PCB*). Komponen elektronik yang dapat dipasangkan oleh mesin-mesin *SMT* adalah komponen khusus yang biasanya disebut dengan komponen *Surface Mount Device (SMD)*. Ia telah muncul pada tahun 1960, bertambah pesat pada awal 1980-an dan menjadi applikasi secara meluas pada pertengahan 1990-an dan berterusan menjadi lebih penting kerana pemasangan *PCB* menjadi lebih maju dan padat dengan simpanan harta componentry sebenar disediakan dengan *SMT* menjadi lebih berharga dan perlu. Pada masa sekarang, dalam industri ini ia telah banyak menggantikan kaedah pembinaan teknologi melalui lubang komponen sesuai dengan dawai membawa ke dalam lubang pada *PCB* kerana ia membolehkan untuk prestasi elektrik yang lebih baik jika dibandingkan dengan cara lubang melalui dan menawarkan proses reflow konvensional berbanding solder gelombang konvensional. Majoriti kecacatan dalam pemasangan *PCB* adalah disebabkan kerana masalah dalam proses percetakan pes pateri atau disebabkan oleh kecacatan dalam pes pateri. Terdapat pelbagai jenis kecacatan seperti pes pateri yang berlebihan, dan solder cair dan menghubungkan pad pateri terlalu banyak, yang menyebabkan litar pintas. Tidak mencukupi hasil timah dalam litar tidak lengkap. Apabila membuat *PCB*, pengeluar sering menguji deposit timah menggunakan *SPI* (pemeriksaan pes pateri). Sistem 3D *SPI* menyukat isipadu pes pateri yang dicetak pada pad pateri sebelum komponen yang digunakan dan proses reflow pateri. Sistem *SPI* boleh mengurangkan insiden kecacatan pateri yang berkaitan kepada jumlah statistik tidak penting. Peningkatan hasil memerlukan peningkatan fokus kepada teknologi stensil, keupayaan pencetak, fungsi pes pateri dan di bawah pembersihan stensil. Istilah padang halus mentakrifkan sebagai 0.5mm di padang dan padang halus ultra 0.2mm - 0.4mm di padang.

Kedua-dua jawapan utama dari uji kaji adalah kualiti pencetak dan hasil *SPI*.



## **ACKNOWLEDGEMENTS**

I would firstly express my sincere acknowledgement to my supervisor, Dr. Mohamad Bin Minhat from Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for his essential supervision, support, and encouragement towards the completion of this thesis. Dr. Mohamad has been supervising me and providing a lot of advice and suggestions for me in completing this project.

I would like to thank all my peers, my mother, father, and siblings for their moral support in finishing this degree. Last but not the least; I would like to thank anyone who had played crucial parts in the realization of this project.



## TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	viii
LIST OF ABBREVIATIONS	xi
<b>CHAPTER</b>	
<b>1. INTRODUCTION</b>	<b>1</b>
1.1 Overview	1
1.2 Problem Statement	2
1.3 Objectives	3
1.4 Outline of Thesis	3
<b>2. LITERATURE REVIEW</b>	<b>5</b>
2.1 Solder paste printing process overview	5
2.2 Printing machine	7
2.3 Typically important factor	8
2.4 Stencil	12
2.5 Squeegee	20
2.6 Solder Paste	22
2.7 Solder paste transfer efficiency	25
2.8 3D Solder paste inspection	27
2.9 Summary	29
<b>3. METHODOLOGY</b>	<b>30</b>
3.1 SMT process flow	31
3.2 Six Sigma	32
3.3 Solder paste printing machine parameter setting	37
3.4 Stencil test	39
3.5 Nimfron Squeegee blade test	41
3.6 Experimental Design	41
3.7 Summary	43
<b>4. RESULTS AND DISCUSSIONS</b>	<b>44</b>
4.1 SPI process specification validation (Define Phase)	44
4.2 Process mapping (Measurement Phase)	51

4.3	Printing parameter setting result (Analysis Phase)	54
4.4	Stencil test result (Analysis Phase)	60
4.5	Nimfron squeegee blade test result (Analysis Phase)	67
4.6	The best parameter setting, electro-form and Nimfron squeegee blade verification and validity test result (Improvement Phase)	76
4.7	The best parameter setting, electro-form and Nimfron squeegee blade implementation (Control Phase)	85
4.8	Summary	86
<b>5.</b>	<b>CONCLUSIONS AND FUTURE RESEARCH</b>	<b>87</b>
5.1	Conclusions	87
5.2	Future Research	89
	<b>REFERENCES</b>	<b>90</b>

## LIST OF TABLES

TABLE	TITLE	PAGE
2.1	The Area Ratios for different combinations of Aperture Widths and Stencil Thicknesses (Indium corporation, 2014)	20
2.2	Solder particle size (Tarr, Martin, 2010)	24
2.3	Solder paste alloy composition	24
3.1	Component assembly onto board	43
4.1	RPN score for Potential Causes of Failure	53
4.2	The DOE of solder paste printing yield of the printing speed, force and separation speed	54
4.3	The solder paste printing yield of the printing speed, printing force and separation speed	56
4.4	The DOE of solder paste printing yield of the stainless steel laser cut and electro-form stencil	61
4.5	The solder paste printing yield of the stainless steel laser cut stencil and electro-form stencil	62
4.6	The DOE of solder paste printing yield of the stainless steel and Nimfron squeegee blade	68
4.7	The solder paste printing yield of the Stainless Steel and Nimfron Squeegee blade	69
4.8	The investigation results of Significant Factor	75
4.9	The DOE of solder paste printing yield of the original parameter setting versus best parameter setting, electro-form and Nimfron squeegee blade	77
4.10	The solder paste printing yield of the stainless steel laser cut stencil with stainless steel laser cut stencil and electro-form stencil with Nimfron squeegee blade	78

## LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Solder Paste Printing Process Solder Paste Printing Process (R. Durairaj a,*, S. Ramesh a, S. Mallik b,1, A. Seman b, N. Ekere b, 2009)	7
2.2	Typical important factors for good printability (Koki company limited, 2014)	11
2.3	The aperture walls surface finish of chemically etched stencil	13
2.4	The aperture walls surface finish of laser cut stencil	13
2.5	The aperture walls surface finish of Electro-form stencil	14
2.6	Laser cut stencil technology	14
2.7	The cutting process of laser cut stencil	15
2.8	The coating is polymerized by light exposure	15
2.9	A negative image is created on the mandrel	16
2.10	The stencil is then grown by nickel electroforming	16
2.11	The features of the grown electroformed stencil are now revealed	16
2.12	Area Ratio for Square/Rectangular Apertures (Indium corporation, 2014)	18
2.13	Area Ratio for Circular Apertures (Indium corporation, 2014)	18
2.14	Type of squeegee	21
2.15	Nimfron squeegee blade	22
2.16	Solder Paste	22
2.17	Sn96.5/Ag3.5 solder paste	23
2.18	SAC305 solder paste	23
2.19	Solder Paste Printed on a PCB	23
2.20	Typical solder paste transfer efficiency – comparison between historical and “today’s” capabilities. (Mark Whitmore, Jeff Schake & Clive Ashmore, 2013)	25

FIGURE	TITLE	PAGE
2.21	Area Ratio requirements for current and future component technologies (Mark Whitmore, Jeff Schake & Clive Ashmore, 2013) (E.H. Amalu*, N.N. Ekere, S. Mallik, 2011)	27
2.22	Single-Sided Laser Triangulation Method	28
2.23	Shadow Effect	29
3.1	SMT Process Flow Chart	32
3.2	DMAIC Continuous Improvement Process (Ali Erdogana*, Hacer Canatanb, 2015)	33
3.3	Methodology (Tsung-Nan Tsai, 2011)	34
3.4	Cause and effect/fish bone diagram	36
3.5	MPM Ultraprint 2000 solder paste printer	38
3.6	Four phase-shifted fringe pattern scanning	39
3.7	Sinusoidal Fringe Pattern	40
3.8	TRI TR700 SII 3-Dimensional Solder Paste Inspection (3D AOI) machine methods	40
3.9	Stainless steel (a) versus Nimfron (b) squeegee blade	41
3.10	SMT Assembly Line	41
3.11	PCB layout	42
4.1	SMT Problem Identification	44
4.2	Comparison of solder paste printing offset (Left) versus good solder paste printed alignment (Right)	45
4.3	Insufficient solder volume as measured by SPI, which is $530,620\text{um}^3$	46
4.4	Good solder volume as measured by SPI, which is $858,487\text{um}^3$	47
4.5	Excessive solder volume as measured by SPI, which is $1,666,447\text{um}^3$	48
4.6	Cross section results for insufficient solder height, which is $20.7\text{um}$ solder thickness	49
4.7	Cross section results for good solder height, which is $31.7\text{um}$ solder thickness	50
4.8	Cross section results for excessive solder height, which is $54.7\text{um}$ solder thickness	50



<b>FIGURE</b>	<b>TITLE</b>	<b>PAGE</b>
4.9	Surface Mount Technology Process Flow Chart	51
4.10	Cause and effect/fish bone diagram	52
4.11	Pareto Chart of Potential Cause for Solder Paste Printing Yield Loss	53
4.12	Solder paste printing yield of the printing speed, printing force and separation speed	56
4.13	The Main Effects Plot for Yield	57
4.14	The box plot of eval 1, 2, 3, 4, 5, 6, 7, and 8	58
4.15	The Interaction Plot for Yield	59
4.16	Solder paste printing yield of the Stainless Steel Laser Cut and Electro-form	63
4.17	The Main Effect Plot for Yield	63
4.18	The box plot of eval 9, 10, 11 and 12	64
4.19	The Interaction Plot for Yield	65
4.20	The electro-form stencil solder paste printing release	66
4.21	The stainless steel laser cut stencil solder paste printing release	66
4.22	Solder paste printing yield of the Stainless Steel and Nimfron squeegee blade	70
4.23	The Main Effect Plot for Yield	70
4.24	The box plot of eval 13, 14, 15 and 16	71
4.25	The Interaction Plot for Yield	72
4.26	The Nimfron squeegee blade solder paste printing rolling effects	73
4.27	The stainless steel squeegee blade solder paste printing rolling effects	73
4.28	The Nimfron squeegee blade which surface overall has dimpled hollows covered with Nimfron-plating	74
4.29	The stainless steel squeegee blade	74
4.30	Solder paste printing yield of the stainless steel laser cut stencil with stainless steel laser cut stencil and electro-form stencil with Nimfron squeegee blade	79
4.31	The Main Effect Plot for Yield	80
4.32	The box plot of eval 17, 18, 19 and 20	81
4.33	The process capability of eval 17	82
4.34	The process capability of eval 18	82

<b>FIGURE</b>	<b>TITLE</b>	<b>PAGE</b>
4.35	The process capability of eval 19	83
4.36	The process capability of eval 20	83
4.37	The Interaction Plot for Yield	84
4.38	Defective rate for before and after improvement	85
4.39	Xbar-R Chart of Solder Paste Printing Volume	86
4.40	The Defect Point per Million levels for before and after the improvement	88



## LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
7QC Tools	7 principal of quality control tools
Ag3.5	Silver 3.5%
ANOVA	Analysis of variance
BGA	Ball Grid Array
CAD	Computer-aided design
DI water	Deionized Water
DMAIC	Define, Measure, Analyze, Improve and Control
DOE	Design Of Experiment
Dppm	Defect points per million
GR&R	Gage repeatability and reproducibility
IC	Integrated Circuit
IPC	Institute for Printed Circuits
KPIV	Key factor input values
KPOV	Key factor output value
MSA	Measurement system analysis
PCB	Printed Circuit Board
QFP	Quad Flat Package
RPN	Risk priority numbers
SAC305	Tin 96.5%, Silver 3.0% and Copper 0.5%

SMD	Surface Mount Devices
SMT	Surface Mount Technology
Sn96.5	Tin 96.5%
SPI	Solder Paste Inspection

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Overview**

At present, with efforts towards tools that held smaller, lighter and more functional; any small pieces of PCB use, creating a high density board with mixture of the components. These components can be composed of smaller components such as 01005 passives to fine pitch QFP / BGA device to a larger power supply devices. Number of solder alloy required to produce a reliable combined with lead-free processing and high processing needs to be a daunting challenge for process engineers. As indicated by the fact that industry reports about 70% of fine pitch Surface Mount Technology defects are related to the solders paste stencil printing process (IPC-7526, 2007).

Solder paste printing operation is widely recognized as a major source of defects in surface mount assembly. One approach to improving outcomes associated with solder paste deposition process is to detect print defects immediately after print operation and the reject defective board before component placement. This allows manufacturers to save time of wasted assembly defective board and avoid costly rework. Whether or not the reported defects in any particular site, SPC data can be collected and used for monitoring and correcting undesirable trends before they become critical to the process. 3D SPI system can be a tool to provide instant detection (Paul Haugen and Rita Mohanty, 2008).

The stencil itself is becoming increasingly critical as component size and density of placement increased. Main stencil factor could be material, fabrication methods, layout of the aperture, thickness, aperture geometry, aspect ratio, the size of the opening, the area ratio, taper and polish. Electroformed polished stencil with smooth aperture walls increases the paste

release. The recent innovation of stencil coating to improve repellence of solders paste from the stencil wall is gaining significant interest.

In order to secure a sufficient volume of solder paste, it is desirable to print solder paste by considering the process parameters need to be established for the assembly concerned. Stroke length, print pressure, print speed and print release from the stencil that is usually dialed in using automated inspection operations. Cleaning frequency is established based on the board design and manufacturing environment or based on how well the board, stencil and paste are interacting within the print process. Printing consistency is crucial to achieve printing repeatability and reproducibility.

## **1.2 Problem Statement**

The solder paste printing is known to be one of the most critical properties in Surface Mount Technology (SMT) to assure quality in the manufacturing of electronics. The challenge increases as the technology development moves toward a smaller chip components and finer pitch size of the solder pad on smaller and densely populated printed circuit boards. This study investigated the effects of printing critical factor that affected on solder print efficiency, defined as the volume ratio of printed solder to the solder pad size. Printed solder paste volume is measured by solder paste inspection (SPI). The test printed circuit board (PCB) in this study possessed 01005 and fine pitch package, and printability test pads printed using type 6 solder paste (Sn 96.5%, Ag 3.0%, Cu 0.5%, by weight). Various studies conducted to understand the behavior of solder paste stencil printing process. Solder paste has a range of factors that influence such as printing machine parameter, environment condition, stencil design and material, solder paste type and so on.

Thus intensive research is needed to understand the factors that most influence and how to overcome them. There is no any standard method for stencil printing process simulation using virtual flow. As such, this article can be the one to help researchers to simulate the solder paste printability in the future.

### **1.3 Objectives**

Regarding to the problems stated in the section 1.2, a few studies have been done to improve the solder paste printability to get better yield. The following objectives have been set to overcome the issues.

- a) To investigate the printing parameter setting such as printing speed, snap-off, separation speed and printing force and investigate its effectiveness in the printing process.
- b) To investigate the performance of two types of stencil, which are stainless steel laser cut and electro-form stencil, in stencil printing.
- c) To evaluate the Nimfron squeegee blade will be use to replace the conventional stainless squeegee blade.

### **1.4 Outline of Thesis**

The organization of this thesis is dividing into three main chapters. First chapter presents the background of the project and declares the objectives of the study. This chapter is concluding with the outline of the thesis.

Chapter Two reviews the basic and technology of solder paste printing operation concept. It also investigates the critical parameter that influence the solder printing process which involving of printing machine, type of stencil, solder paste, and the squeegee setting,

squeegee blade type and important of solder paste transfer efficiency. Furthermore, chapter two reviews the applications of 3-Dimensional Solder Paste Inspection (3D SPI) machine use to inspect the solder volume.

In Chapter Three, the methodology to improve the solder paste printing yield is presented by using Six Sigma Technique. It describes the study and development of printing parameter, stencil type and squeegee blade.



## CHAPTER 2

### LITERATURE REVIEW

This chapter describes the basic operation of a solder paste printing process. The typical important printing parameter that influence the solder paste printing performance has been identify and Electroform stencil and Nimfron squeegee blade is investigated. It also discusses the important of solder paste selection and transfer efficiency that influence the solder paste print onto the Printed Circuit Board (PCB). The 3-Dimensional Solder Paste Inspection (3D SPI) machine use to inspect the solder volume.

#### 2.1 Solder paste printing process overview

Circuit board manufacturing operations involve a stencil printer used to print solder paste onto a circuit board. A circuit board having a pattern of pads or other conductive surfaces onto which solder paste will be deposited is delivered into the stencil printer and one or more small holes or marks on the circuit board, called fiducial marks, is used to align the circuit board with a stencil or screen of the printer prior to the printing of solder paste onto the circuit board. After the circuit board is aligned, the board is raised to the stencil or in some configurations the stencil is lowered to the circuit board. Solder paste is dispensed onto the stencil, and a wiper blade/squeegee traverses the stencil to force the solder paste through apertures formed in the stencil and onto the board.

In some art stencil printers, a dispensing head delivers solder paste between first and second wiper blades, wherein during a print stroke one of the wiper blades is used to move or roll solder paste across the stencil. The first and second wiper blades are used on alternating boards to continually pass the roll of solder paste over the apertures of a stencil to print each successive circuit board. The wiper blades are typically at an angle with respect to the stencil



to apply downward pressure on the solder paste to force the solder paste through the apertures of the stencil. While in some other art stencil printers, the dispensing head is pressurized to force solder paste through the apertures, and the wiper blades are employed to scrape excess solder paste from the stencil during a print stroke.

Printer must be able to carry out several other operations to complete the print cycle, which comprises; loading with transport and mounting – Alignment (stencil to board) – The printing process (Squeegee) – Cleaning of the underside of the stencil (after some cycles) – unloading

The sequence of operations is as follows:

- i. Board moves to board stop (Conveyor system)
- ii. Board is clamped with board support (Snugger System)
- iii. Camera moves to fiducial 1/fiducial 2 and locates its position for board and stencil
- iv. Camera moves to rest position
- v. Board or stencil is aligned
- vi. Board moves up to stencil height with zero snap off
- vii. Squeegee operation commences with it pre-set Squeegee Pressure (Printing)
- viii. Board support moves down
- ix. Board is unclamped and moves out of machine.

The solder paste printing process illustration as shown in Figure 2.1 which begin with the stencil close to the board, squeegee move from left to right to make the solder paste rolling and at the same time allow the solder paste filling up the aperture. The solder paste printing

process finally will complete with board off from the stencil and make the aperture emptying to allow the solder paste completely transfers from the aperture.

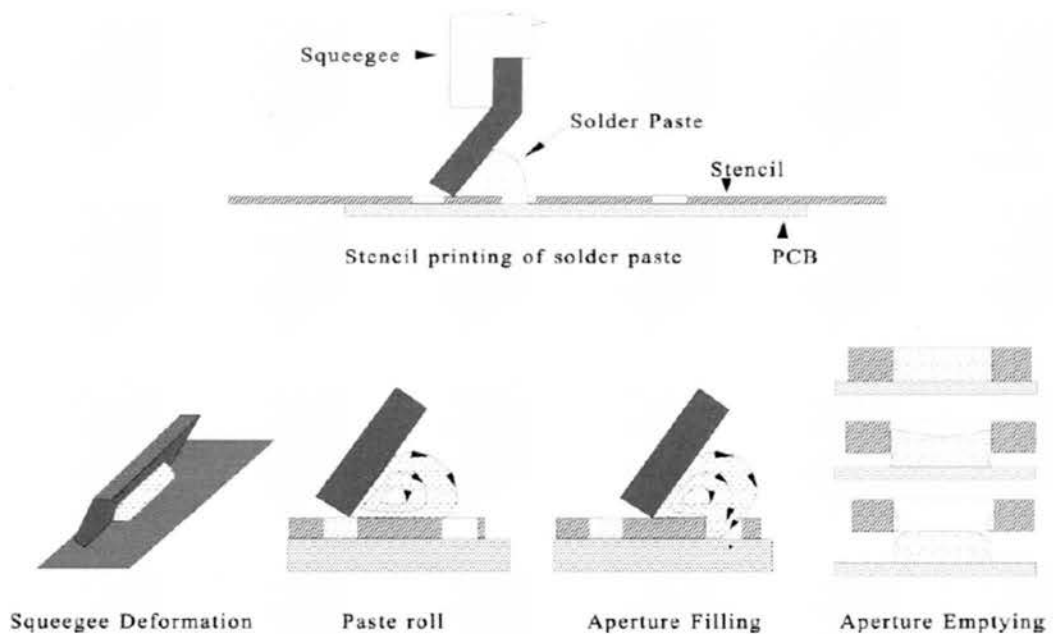


Figure 2.1: Solder Paste Printing Process (R. Durairaj <sup>a,\*</sup>, S. Ramesh <sup>a</sup>, S. Mallik <sup>b,1</sup>, A. Seman <sup>b</sup>, N. Ekere <sup>b</sup>, 2009)

## 2.2 Printing machine

As the electronics industry develops, there is a growing demand to increase the package density of components on a substrate area. Along with this, performance and quality requirements for solder pastes have become more demanding. With regard to fine pitch printing, what type of printing equipment and parameters to apply are one of the most crucial factors as well as the performance of the solder paste in order to achieve a high level of printability. This means that even if you have chosen the potentially high performance paste, it is very likely that you will end up with poor printing results because of inadequate parameter