

Novel Approach Solder Paste Printing on 90 μ m Pitch Application

B. Senthil Kumar, Lim Chze Min Jason, Yam Lip Huei, Zhang Rui Fen, Edrina Risson Olakkankal, Zhang HanWen & Kang Sungsig SS,
Heraeus Materials Singapore Pte. Ltd., Pioneer Crescent, Block 26 #06-11/12, Singapore-628558
Email: senthilkumar.balasubramanian@heraeus.com

Abstract

Smaller components in system in a package (SiP) addresses the needs of miniaturization by using cutting edge technology in advanced packaging applications, which involves integration of passive components, flip-chips, integrated devices, etc. Increasing demands for a reduced footprint requires solder paste technology to constantly reinvent SAC305 solder paste. The Type-7 (<11 μ m) powders were processed by Welco™ technology and formulated into water soluble (WS) solder paste that provided consistent print volume and prints for stencil opening ($\geq 55\mu$ m) and pitch ($\geq 90\mu$ m).

Even though solder pastes can achieve the 90 μ m pitch capability, other factors significantly contribute to printing defects such as substrate quality, printing parameter, printing accessory and equipment process capability limitation. The present paper discusses critical challenges contributing to printing defects in the 90 μ m pitch stencil printing application and provides a detailed explanation and control guidelines.

Key words

System in a package (SiP), Flip-chips. SAC305 solder paste, Stencil printing and Solder paste Inspection (SPI).

I. Introduction

The miniaturization of electronic components is a critical aspect of modern technology, allowing for more compact and efficient devices. SiP technology is at the forefront of this trend, integrating various components such as passive elements, flip-chips, and integrated devices into a single package. Solder paste stencil printing of Cu pillar bump interconnect is a promising, yet cost effective and high yield solution, especially as bump pitch shrinks [1]. This integration necessitates the evolution of solder paste technology, particularly the SAC305 solder paste, to meet the demands for smaller footprints. The development of ultra-fine Type-7 powders, with particle sizes 2 to 11 μ m and high sphericity, processed using Heraeus's proprietary Welco™ technology as shown in Fig1, has led to the creation of water-soluble solder pastes that ensure consistent print volumes and adherence to the stringent requirements of stencil openings and pitches. However, achieving a 90 μ m pitch capability with solder pastes is only one piece of the puzzle. Other factors include the design of the stencil, the precision of the stencil manufacturing process, the quality of the substrate, and the parameters and capabilities of the printing process itself.

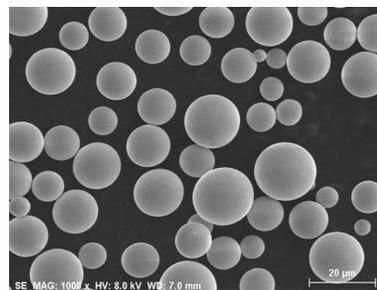


Fig.1 Welco™ Solder powder Type 7 (SAC305 alloy), Powder size distribution (PSD) >90% and powder size 2-11 μ m

To address these challenges, a comprehensive approach is necessary, encompassing:

- The control of substrate tolerance, which includes the management of pad size and pitch, as well as the mitigation of warpage.
- The limitations of Solder Paste Inspection (SPI) equipment, particularly in inspecting the fine 90 μ m pitch.
- The optimization of printing parameters, such as printing pressure and speed, separation speed and distance, and application of gap printing techniques.

By focusing on these areas, it is possible to significantly reduce the incidence of printing defects and enhance the reliability of the SiP technology. This detailed examination and the establishment of control guidelines are essential for advancing solder paste technology to maintain the pace of miniaturization in electronic packaging applications.

II. Paste & Flux Design Concept

Paste release performance is affected by factors such as flux rheology, stencil design, stencil thickness, area ratio of stencil apertures, printing parameters, and paste rheology [2]. Rheology is fundamental as the flow and deformation affects the print quality and post-print behavior of the solder paste [4]. The rheological characteristics of a paste are important and greatly influence application performance. This is due to the varying forces exerted on the paste by different application techniques. For optimal performance, it is essential to tailor the paste's rheological properties to suit the specific application method by controlling the flow and deformation. This in turn, affects the quality of printing and the behavior of the solder paste after printing. Viscosity, thixotropy, and yield stress are three primary rheological measurements that characterize a material's behavior. A concise explanation of these terms is as following:

- Viscosity refers to the measure of a material's internal frictional resistance when it flows against itself.
- Thixotropic behavior is indicated by the shear stress response relative to the applied shear rate and is a time-dependent property where the fluid's viscosity lessens with prolonged shear and slowly recovers once the shear ceases.
- Yield stress is the minimal force necessary to transition a material from elastic to plastic deformation.

Solder paste is a mixture predominantly consisting of solvents, rosin, activators, rheology modifiers, various additives, and alloy powders. The proportion and molecular architecture of each component of the paste can significantly affect its rheological properties. For instance, identical quantities of different solvents can exhibit different rheological behaviors if their molecular structures differ, ranging from short-chain to long-chain, or branched configurations. Similarly, the use of diverse rosins or thickeners, can lead to marked changes in rheology. The polarity of the paste's constituents is another critical factor.

Many activators and rosins are polar forming intermolecular forces that create networks that further impact the rheology. Rheology modifiers operate by intertwining with solvents and altering the flux network significantly and thereby modifying the rheology.

The role of alloy powder in shaping the product's rheological properties is equally significant. Within the paste, the powder forms the solid framework and introduces stiffness, while encapsulated by flux which imparts liquidity to the paste. The powder's function is to impede the flow of material; as the size of the powder decreases, its surface area increases, leading to enhanced friction between particles during movement, thereby increasing the paste's viscosity. Conversely, assuming a constant powder size, higher powder content results in increased inter-particle friction and thus, greater viscosity. Fig.2 illustrates the correlation between the paste's powder volume% and its weight%. Owing to the different densities of flux and powder alloy, changes in powder volume% do not linearly correlate to powder weight%. For instance, when powder weight% is increased from 80% to 90%, it results in a sharp rise in volume% from 35% to 55%. Conversely, lowering the powder weight% in the paste's formula raises the volume% of flux. Fig. 3 is a schematic of the paste's internal structure at varying metal volumes.

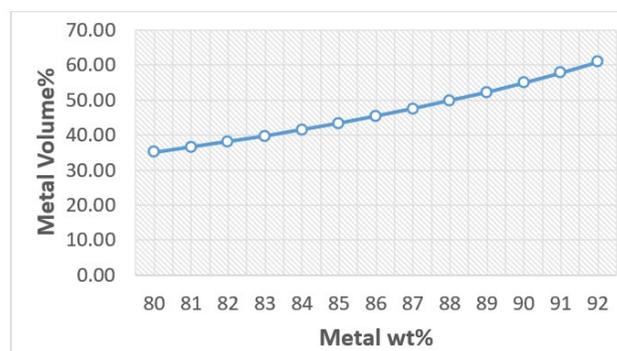


Fig.2 Typical relationship of powder volume% vs powder weight% in solder paste [4].

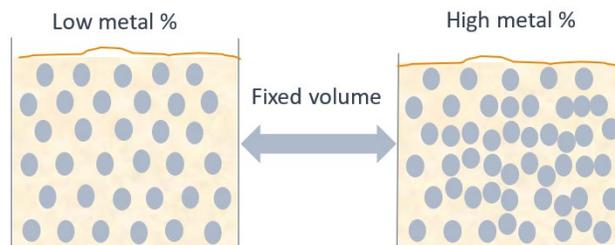


Fig.3 Schematic diagram of paste internal structure with different metal volume% with fixed flux volume [3].

When subjected to external forces, the paste transitions from a solid to a liquid state due to the reorientation of the flux's long-chain or entangled molecules. During the printing process, as the paste moves through the stencil opening under pressure, and the flux's malleability allows pastes with higher flux volume% to pass through smaller openings readily.

Additionally, the powder volume% affects the solder volume; a set paste volume and a higher metal% yields a larger solder volume post-reflow.

The new solder paste formulation, referred to as Welco™ AP520 T7, has been developed by adjusting flux and metal volume% to enhance the paste's rheology and improve its release efficiency when used with a 55µm stencil aperture. To overcome the paste release challenge, the selection of appropriate stencil design, stencil thickness, printing parameters, and paste type will be critical [5].

III. Experimental with Results & Discussion

A. Substrate warpage

The impact of substrate warpage on ultra-fine pitch stencil printing is a critical aspect of modern electronics manufacturing, where precision and reliability are paramount. Ultra-fine pitch printing refers to the application of solder paste through stencils with very small apertures, which is necessary for the assembly of high-density electronic components. Therefore, understanding the relationship between stencil printing parameters and substrate warpage is essential for optimizing the manufacturing process.

The printing test was carried out on a DEK Galaxy printer with optimized printing parameter shown in (Table 1). The pastes were printed on an in-house Electroless Nickel Immersion Gold (ENIG) substrate which were then sent for optical inspection using KEYENCE VHX6000 optical microscope to screen for print defects. Several factors influence the relationship in stencil printing, especially when dealing with substrate warpage. These factors include board support method, stencil thickness, aperture size and shape, and the type of solder paste used.

Proper stabilization of the board during the squeegee stroke action is crucial. This involves selecting an appropriate squeegee length that matches the board support and ensuring that both the board and stencil remain stationary during printing. Two types of board support such as Vacuum Pins Support (VPS) and Universal Vacuum Pallet (UVP) were evaluated. VPS provides only point contact with minimal mechanical rigidity to the warped substrate during the stencil printing process.

Table.1 Optimized Printing Parameters.

Printing parameter	Welco™ AP520 T7
Printer	ASM Galaxy
Room Temp °C	23°C
Room RH %	58%

Stencil thickness	25µm
Printing Speed	25mm/s
Printing pressure	4kg
Printing gap	0mm
Separation speed	10mm/s
Separation Distance	10mm
Sq. length	170mm
Sq. Angle	60 degrees
Dwell Height	40mm

However, this approach can lead to printing defects and challenges in optimizing the printing process. UVP however, offers extensive mechanical rigidity support. By holding the substrate flat during printing as shown in Fig. 4(a), UVP reduces the likelihood of warpage by maintaining the alignment of the stencil with the substrate and ensuring more accurate and consistent deposition of solder paste. This results in more accurate and consistent deposition of solder paste. When the board warpage pattern is concave (as seen in Fig. 4(b), the center portions corresponding to locations Square “D”, “E”, and round aperture “A” and “B” on the board), UVP is effective in mitigating warpage-related challenges.

Board warpage significantly impacts printing performance, as shown in Table 2. When using UVP support, printing defects have reduced to zero compared to the location-based defects observed with VPS due to board warpage, as an illustrated in Fig. 5. Additionally, vacuum pallets can reduce the occurrence of solder bridging and insufficient solder deposits, which are common consequences of substrate warpage. Integrating vacuum pallets into the printing process is a proactive approach to address substrate warpage issues, ultimately enhancing assembly yield.

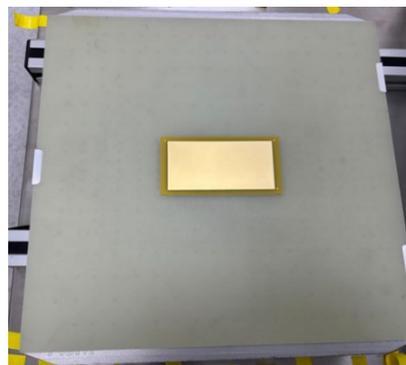


Fig.4(a) Universal vacuum pallet



Fig.4(b) Vacuum Pins Support with printing location

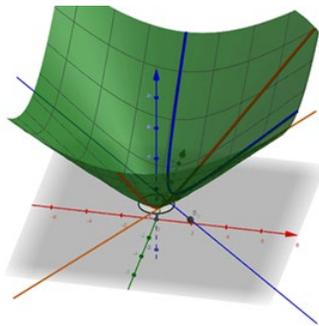


Fig.5 Typical Concave board warpage occurred in substrates as an illustration explained four corner points higher than center of board.

Table 2. Printing results comparison of UVP Vs VPS.

	Stencil aperture opening : 55µm and Line Spacing LS: 35µm									
	Square					Circle				
	A	B	C	D	E	A	B	C	D	E
Vacuum Pins Support										
Defect rate	2%	4%	2%	0%	0%	0%	0%	2%	1.5%	2%
Universal Vacuum Pallet										
Defect rate	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

B. Solder paste inspection (SPI) equipment limitation

SPI equipment faces challenges in accurately measuring small volumes, particularly for deposits as fine as 55µm. The limitations come from the equipment's resolution and the ability to discern fine details at a small scale. Advancements in SPI technology has been made, such as the introduction of height threshold method which offers improved accuracy by capturing the height of the solder paste deposits. Additionally, the upgraded pixel size from 5µm to 3.5µm can improve measurement repeatability.

In the process of SPI, a critical step involves the assignment of specific data to each pixel. This data encompasses various attributes such as height, visual characteristics, and color. Segmentation, a pivotal technique in this process, operates by labeling each pixel based on the assigned data and determines whether a pixel represents solder material.

However, challenges arise in fine pitch applications where the segmentation method may erroneously classify solder pixels as 'non-solder, leading to an underestimation of the solder height as shown in Fig.6. An alternative approach, the height threshold method, considers any pixel exceeding a certain height as solder, with the minimum threshold set at 5µm and adjustable in increments of 5µm. For precise applications, setting the threshold at 5µm has proven to yield the most accurate representation of the actual solder paste height as shown Fig.7.

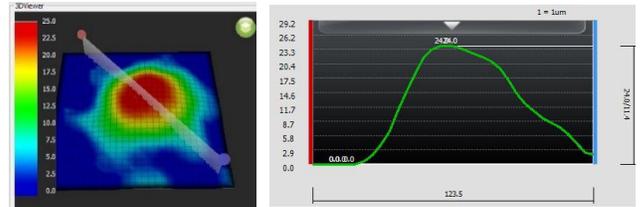


Fig.6 Segmental methods and noticed solder deposit average height 21.8µm from SPI measurement with 55 µm bump and stencil thickness 25µm.

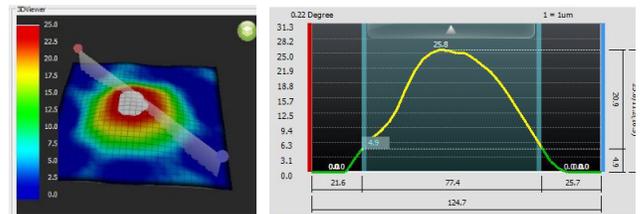


Fig.7 Height threshold methods and noticed solder deposit average height 23.5µm from SPI measurement with 55 µm bump and stencil thickness 25µm.

A smaller pixel size translates to higher resolution, which allows for more detailed inspection of the solder paste print quality, especially for fine-pitch applications where the margin for error is minimal. Fig.8(a) &(b) compares the 5µm pixel resolution with the 3.5µm pixel resolution. With a 3.5µm pixel resolution, there are 175 pixels available to compute the results, leading to better repeatability and accuracy for a 50µm pad size. On the other hand, with a 5µm pixel resolution, only 78 pixels are available, which results in poorer repeatability and accuracy.

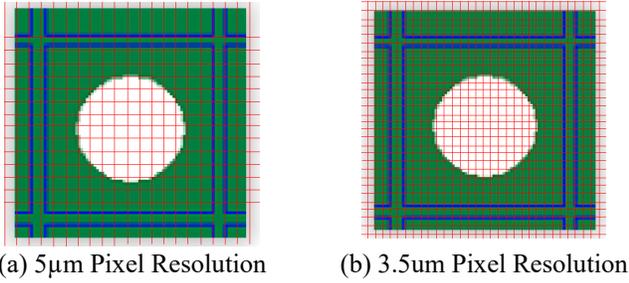


Fig.8(a) On the 5µm resolution, 50µm pad size. Total 78 pixel consider in the measurement.

Fig.8(b) On the 3.5 µm resolution, 50µm pad size. Total 175 pixel consider in the measurement.

The pastes were printed on an in-house Electroless Nickel Immersion Gold (ENIG) substrate with a 25µm stencil thickness using Welco™ AP520 T7 solder paste. Their paste volume% was measured using the KOH YOUNG solder paste inspection system, and the results were plotted in a box graph as shown in Fig.9. A significant volume difference was observed between the segmental and threshold height settings. The average paste volume% was more than 30% higher with the threshold height method than with the segmental method for both circular and square apertures. The pixel effect was significant, with a 3.5µm pixel size showing a 10-15% higher volume than a 5µm pixel size.

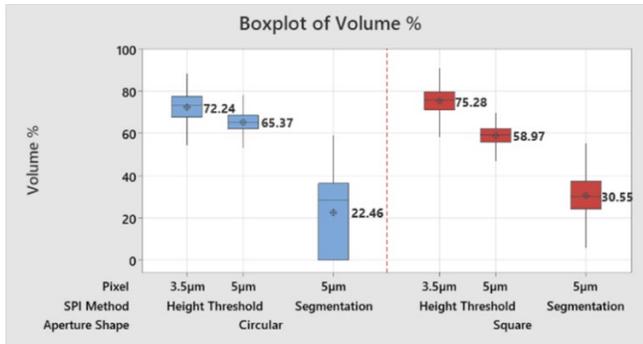


Fig.9 Comparison of % Paste volume result Segmental Vs threshold hight method and 5µm pixel Vs 3.5µm pixel

C. Printing parameter DOE

In microprinting, for example with small stencil apertures opening of 55µm and pitches of 90µm, the precision of printing parameters is vital to avoid defects such as bridging and incomplete patterns. Printing speed affects the time the solder paste is in contact with the stencil, influencing the transfer efficiency and the definition of the printed pattern. A slower speed may improve print definition but can also increase the risk of smearing or slumping. Conversely, a high printing speed might not allow sufficient paste transfer, leading to incomplete patterns. Printing pressure is another critical parameter; too

much pressure can cause the paste to squeeze out and create bridges between pads, while insufficient pressure may not adequately fill the apertures, resulting in incomplete deposition. Separation speed and distance affects the stencil's withdrawal from the PCB; a rapid separation can lead to stringing or snapping of the paste, which contributes to bridging. A slow separation might minimize this risk but can also cause smudging if the paste is tacky. The separation distance must be enough for the paste deposit to clear the stencil. It is a delicate balance where each parameter must be optimized according to the specific requirements of the printing process and the properties of the solder paste used. Optimizing these parameters requires a thorough understanding of the solder paste's properties and the printing environment, as well as a meticulous approach to the design and execution of the printing process.

The optimization printing parameters was conducted using the Response Surface Method (RSM) design of experiment (DOE) method with three factors: printing pressure, printing speed, and separation speed, along with two replicates. RSM is a series of mathematical and statistical techniques used for modeling and analyzing problems and have the objective of optimizing the responses [6]. A total of 30 runs were validated. The factors and parameter window are listed in Table.3.

Table.3 DOE factor and low and high parameters value.

Factor	Name	Low	High
A	Pressure	3	7
B	Speed	15	35
C	S Speed	2	20

During the DOE runs, the separation distance was fixed at 10mm. All DOE legs were inspected using a KEYENCE VHX6000 optical microscope to check for print defects. The analysis of the response optimization was performed, and the optimal printing parameters are displayed in Fig.10.

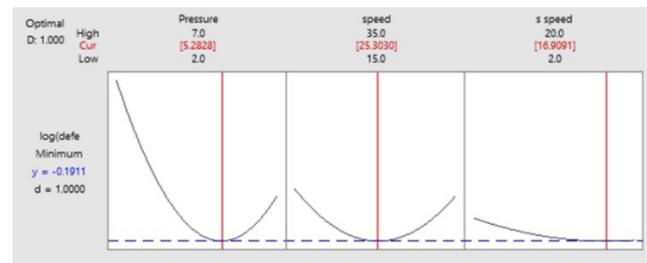


Fig.10 Response optimizes analysis for 20 runs DOE.

It was observed that lower settings of printing speed, pressure, and separation speed increased the occurrence of printing defects. Lofti and Howarth (1998) stated that squeegee pressure, and squeegee speed are essential for enhancing printing performance [6].

A contour plot analysis, as shown in Fig.11, was carried out to obtain the process window. The optimal printing parameters suggested to achieve zero print defects on both square and circular apertures (with square opening (SO) of 55um and line spacing (LS) of 35um) using Welco™ AP520 T7 paste were determined using the surface response method.

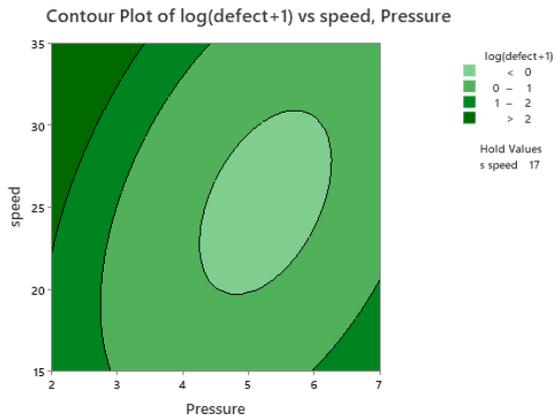


Fig.11 Contour Plot analysis for process window predication

IV. Conclusion

Several factors influence the printing performance of solder paste. It has been established that substrate warpage significantly affects printing defects, particularly in stencil openings as small as 55 μ m with a 90 μ m pitch. To mitigate this, it is recommended to use a universal vacuum pallet support during printing.

Additionally, SPI equipment has limitations in measuring paste volume due to pixel size and algorithm constraints. The pixel size of the SPI equipment is crucial for ensuring the quality of 55 μ m solder paste printing. Thus, selecting SPI equipment with a 3.5 μ m pixel size is vital for manufacturers striving for high throughput and reliability in their solder paste printing processes.

To address measurement errors, the threshold method is necessary. For a solder volume requirement of 55 μ m, a 3.5 μ m pixel size and a threshold height method are advised. Design of Experiments (DOE) has determined the optimal parameters for zero defects in Welco™ AP520 T7 solder paste for a 55 μ m stencil opening and 90 μ m pitch.

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