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INVESTIGATION THE SOLDER JOINT QUALITY OUTPUTS USING DESIGN OF EXPERIMENTS TECHNIQUES

Наведено результати досліджень для покращання якості паяних з'єднань під час зборки. Експерименти та моделювання над розподіленими об'єктами були застосовані для підбору оптимальних умов. Досліджено найбільше критичні параметри, які впливають на якість паяних з'єднань. Дані про вплив поперечної сили порівнювали для різних профілів поверхні.

This work presents the results obtained using methodology for quality improvement of solder joint in different components during the assembly processes. DOE experiments and simulations were employed to solve the problem and identify optimal processing conditions. The most critical parameters peak temperature and time above liquidus during the reflow process, impacting solder joints quality are studied. The shear force data are compared across the different profiles.

1. Introduction

Solder paste printing is one of the critical steps in surface mount manufacturing affecting directly the yield and quality of assembly, especially in this era of fine pitch technology. When we want to assemble fine pitch surface mounted components on a populated printed circuit board (PCB), the completed PCB should be inspected for poor solder joints, solder bridges, or other anomalies.

Reflow profile has significant impact on solder joint performance because it influences wetting and microstructure of the solder joint. One high-volume manufacturer's six-month study indicates the average percentage of defect opportunities from the screen-printing reflow process 84.08% [1]. Even a marginal improvement in defect reduction in the solder paste printing process will provide a significant improvement in the overall process quality and first pass product yield [2]

Experiments are often conducted to determine if changing the values of certain variables leads to worthwhile improvements in the mean yield of a process or system. Another common goal is estimation of the mean yield at given experimental conditions [3]. In practice, it is difficult to fit an accurate and interpretable model to the data, which can attain both goals. A certain manufacturer of assembled electronic circuit boards was suffering from severe quality problem in terms of high percentage of solder joint defects [4].

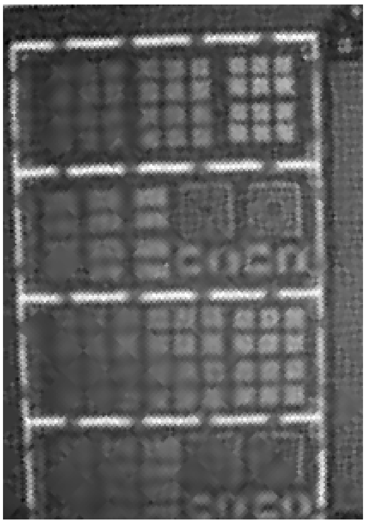


Fig. 1. View of the test vehicle

Design of experiments (DOE) has become an essential tool for the validation of electronics assembly manufacturing processes. A good description of why this statistical technique should be used is the assertion that processes "should be challenged to discover how outputs change as variables fluctuate within allowable limits". As an example of the benefits that such a validation tool can provide, this article describes a DOE that was run on any electronics assembly process for improving solder joint quality.

2. Experiments preparation

By focusing predominantly on soldering processes and joint performance, solder paste vendors are closing in on a small number of suitable paste formulations that will meet reflow and electrical/mechanical performance criteria.

Effective transition from SnPb soldering to the lead-free soldering requires key implementation issues to be addressed in the electronics industry. One of the critical issues is the effect of reflow profile on lead-free solder joint and quality since reflow profile would influence wetting and microstructure of the solder joint. Solder paste needs adequate reflow temperature to melt, wet, and interact with the copper pad or other board metallization and component metallization to form the solder joint.

The intermetallic layers will form during the reflow and cooling process. A suitable reflow profile is essential to form a good solder joint.

Before embarking on the Design of Experiments described in this paper, the machines was calibrated mechanically. Using the manufacturer's defined procedure, we verified that *Cp* and *Cpk* values passed the minimum 1.6 value. To reduce the amount of statistical "noise" the same machines, interface and transfer head throughout the experiment were used. We also used the same substrate throughout, for measurement purposes.

Software STATISTICA© is used for design of our experiments. The experiments were run on equipment of Curtis/Balkan Corp. The test vehicle designed for chip scale capacitors/resistors (the outside dimension is 5 x 7" with 0.030" thickness) is shown in Fig.1. The board material of all experiments is FR-4. A standard assembly line consists of a solder paste printer, a pick-and-place machine, and a nine-zone reflow oven. An electroform stencil of 0.005" thickness and 1:1 ratio (between the aperture size and pad size) is used. During the investigations the forth phases in DOE are performed: planning, screening, optimization and verification.

In the course of the experiments defects included bridging, tombstones, edge-standing parts, missing parts and upside-down parts are marked. Bridging and tombstones were the most common defects, accounting for 68 % of the total 7,94%. Tombstones were most often linked to pads with vias, especially if only one of the two pads had a via. Although the orientation of the resistors had no affect on the number of tombstones that occurred, the tombstone rate increased significantly as the pad size increased. Pad 7.2 mils wide and 7.8 mils long produced the least amount of tombstones. Solder mask misalignment increased the rate of tombstones, and the quick-ramp profile produced fewer tombstones than the soak profile.

Among many developed lead-free solder alloys, SnAgCu lead-free solder alloy is considered by the electronics industry to be the best alternative to eutectic tin-lead solder [5]

For SnAgCu reflow soldering, a commonly accepted minimum peak temperature of 230°C is necessary to achieve acceptable solder joints. The maximum temperature, on the other hand, depends on the board size, board thickness, component configuration, material thermal mass, oven capability, and etc. These factors result in different temperature delta crossing the board, which can sometimes be as high as 20 – 25°C.

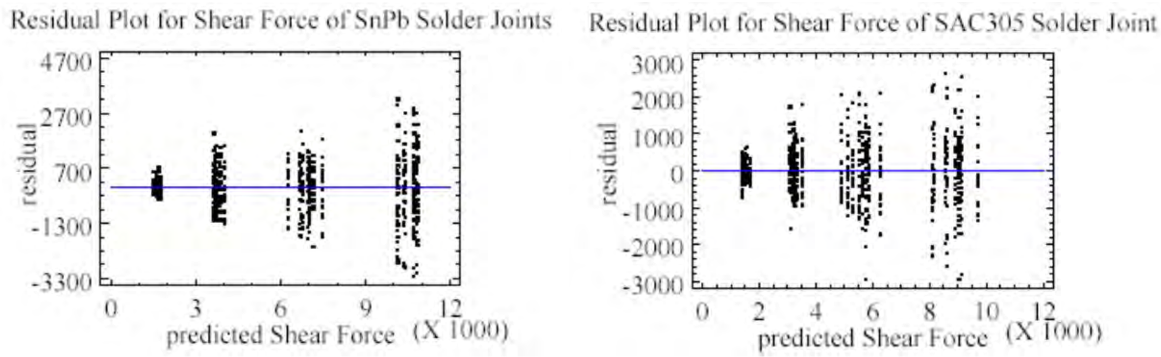
3. Reflow Soldering

The purpose of this experiment is to study the effect of the reflow Peak Temperature. Nine reflow profiles for 96.5%Sn 3.0%Ag 0.5%Cu (SAC 305) and nine reflow profiles for Sn63Pb37 have been developed with three levels of Peak Temperature and three levels of Time above solder liquidus temperature. A 3^2 factorial design with three replications was selected in the experiment. The Peak Temperature and Time above liquidus are two input factors and each factor has three levels as shown in Table 2. The 18 reflow profiles were developed using three thermal couples attached to the test vehicle where covered the diagonal corners of the board and the center. A linear ramp-up method was used for developing reflow profiles [6]. 27 boards were assembled using SnPb paste and 27 boards using SAC305 paste, respectively. The assembly sequence was randomized to minimize the nuisance factors such as room temperature, humidity, and other conditions. To be consistent, the process parameters for the stencil printing and pick & place were the same. The only variable is the reflow profile. All boards were visually inspected after stencil printing, after pick and place, and after reflow. The only difference between SnPb solder joints and SAC305 solder joints after reflow is that SnPb joints look shiny and SAC305 joints look dull.

Table 1. Experiment factors

Time above Liquids, *sec*		30	60	90
Peak Temperature, ^oC	SnPb	195	205	215
	SAC305	230	240	250

Shear test was performed using shear tester and the peak shear force and failure modes were recorded. It should be noted that only two failure modes were observed during the shear testing. They are fracture at the solder joint and component failure. For most of the samples the fracture mode was at the solder joint interface. The shear force of samples where the component failed was not considered. Only the shear force data with solder joint fracture were analyzed using analysis of variance (ANOVA).



a) *b)*

Fig. 2: a) Plot of residuals versus predicted shear force of SnPb joints;
b) Plot of residuals versus predicted shear force of SAC305 joints

First, the validity of three assumptions (normally, independently, and constant variance of the residues) of ANOVA was checked. As shown in Fig. 2a and b, the residual vs. predicted shear force plots show that the residual variances are not constant. In order to make the ANOVA analysis valid, a transformation is necessary. We found the square root transformation (SQRT) is appropriate in this case.

The ANOVA table for the square root of the SAC305 shear force (shear force after transformation) is shown in Table 2. The P-value of less than 0.05 indicates that the factor has statistically significant effect at the 95% confidence level. This table shows that the component size, reflow Peak Temperature and Time above liquids have statistically significant effect on the shear force. It is intuitive that component size has significant effect on the solder joint shear force since big components have larger contact areas.

Table 2. ANOVA results for the SAC305 shear force

	A	B	C	AB	AC	BC	Residual	Total (corrected)
Sum of squares	267930	947,76	895,531	241,806	428,161	160,009	16478,4	287082
Df	3	2	2	6	6	4	624	647
Mean square	89310,1	473,88	447,766	40,310	71,3602	40,0022	26,4077	
F-Ratio	3381,98	17,94	16,96	1,53	2,70	1,51		
P-value	0	0	0	0,1670	0,0134	0,1962		

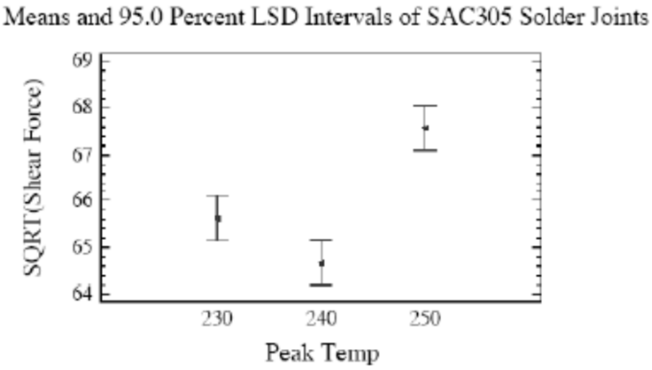


Fig. 3 Effect of Peak Temperature on SAC305 Solder Joint Shear Force

Figure 3 shows that the Peak Temperature of 250 ^oC results in the highest shear force while there is no significant difference on shear force between the Peak Temperature of 230 ^oC and 240 ^oC. Figure 4 shows Time above liquids of 30 *sec* results in the highest shear force while there is no significant difference on shear force between the Time above liquids of 60 sec and 90 sec.

The ANOVA table for the square root of the SnPb shear force (shear force after transformation) is shown in Table 3. It shows that only the component size and the peak temperature have statistically significant effect on the shear force. Time above liquids (TAL) does not have statistically significant effect on the SnPb solder joint shear force. Fig. 4 shows that the Peak Temperature of 215 ^oC results in a slightly highter shear force while there is no significant difference on shear force between the Peak Temperature of 195 ^oC and 205 ^oC.

Table 3. ANOVA results for the SnPb shear force

	A	B	C	AB	AC	BC	Residual	Total (corrected)
Sum of squares	345244	189,029	51,9084	349,653	358,652	135,373	17903,4	364232
Df	3	2	2	6	6	4	624	647
Mean square	115081	94,5145	25,9542	58,2755	59,7754	33,8432	28,6914	
F-Ratio	4011.01	3,29	0,90	2.03	2,08	1.18		
P-value	0	0,0377	0,4052	0,0596	0,0533	0,3186		

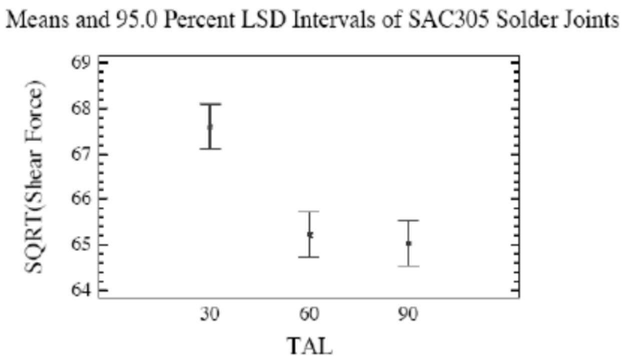


Fig. 3 Effect of Peak Temperature on SAC305 Solder Joint Shear Force

In this investigation, ANOVA for different component size was conducted as well. To understand the experimental results, failure analysis using Scanning Electron Microscopy was performed.

Since the shear area in termination metallization varies from different components and component sizes, this is the reason why the effects of the Peak Temperature and the Time above liquids are not consistent for different component sizes and for the SnPb and SAC305 joints.

4. Conclusions

Reflow profile has significant impact on solder joint performance because it influences wetting and microstructure of the solder joint. The degree of wetting, the microstructure (in particular the intermetallic layer), and the inherent strength of the solder all factor into the quality of the solder joint.

It has been shown in this paper that it is possible to obtain a Lead Free soldering process that is defect free and exhibits a better reliability profile than that of the baseline Tin Lead.

The effects of the Peak Temp and the Time above liquidus are not consistent for different component sizes and for SnPb and SAC305 solder joints.

The shear force of SnPb solder joints is higher than that of SAC305 solder joint because the wetting of SnPb is better than that of SnAgCu.

Additional work is needed to complete the quality study of this project, especially in studying the inter-metallic structure of the alloys.

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OPTICAL WAVEGUIDE TEMPERATURE SENSOR WITH LIQUID CRYSTAL

Наведено результати розроблення та дослідження сенсора температури на основі пластикового оптоволокна та нематичного рідкого кристала. Сенсор характеризується простою конструкцією і легкою адаптацією до різних умов. Використання термо-оптичних ефектів в сенсорах є дуже зручним під час роботи з агресивними середовищами.

The construction and obtained results of temperature sensor operation based on plastic optical waveguide and nematic liquid crystal have been presented. Such sensor is characterized by simple construction and easy sensory adaptation. Using thermal-optical effects in sensor part is very useful for application in disturbed environments, etc.

1. Introduction

The optical waveguide sensors have a strong positions in metrology as well as their undeniable advantages like immunity on electro-magnetic disturbances make such devices very useful for selected applications. The construction of temperature sensor where the temperature influence on optical properties of liquid crystal was used has been presented in this paper.

Nematics – as one-axial crystal – have two main refraction coefficients $n_0 = n_I$ i $n_e = n_{II}$. Usually $n_{II} > n_I$ and nematics double refraction Δn is positive. The values of the such coefficients are equal about 1,5÷1,9 and 0,4, respectively.