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A Qualitative Method for Determining the Quality of BGA Solder Joints in a Lead-Free Process

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Abstract

The introduction of lead-free soldering is inevitable for the electronics industry and its use poses a number of challenges. Manufacturing processes need to be re-evaluated and any reliability issue needs to be addressed. In this study the effect of lead free solder on a reflow soldering process is investigated. Experimental design techniques were used to examine a reflow soldering process using the process parameters as experimental factors. The factors included the conveyor belt speed of the reflow oven and the preheat, soak and reflow temperatures of the temperature profile. Micro Ball Grid Array (BGA) packages were used as the test components. No standard method exists to assess the quality of BGA solder joints. Solder joint quality is normally assessed using lengthy reliability tests that measure joint strength. It is highly advantageous if a qualitative assessment method was available that could determine the joint quality. This study presents a scoring method that can be used to evaluate this solder joint quality quickly and inexpensively. BGA solder joint quality was assessed using x-ray and micro section inspection techniques. This qualitative data was scored and weighted. The weighted solder joint quality scores were statistically analysed to check for effect significance. It was found that conveyor belt speed had a statistically significant effect on the weighted score. The statistical approach was verified using residual analysis. The results of the experiment demonstrate that the scoring method is a practical way of assessing BGA solder joint quality. This paper presents a unique scoring method for assessing the joint quality of BGA packages.

Introduction

The use of lead-free solders is rapidly increasing in the global electronics manufacturing industry. Until now tin-lead (SnPb) solders were the most popular alloy of choice due to their low melting point, high strength ductility, high fatigue resistance, high thermal cycling and joint integrity. SnPb solders have been used to create the electrical and mechanical connections between components and printed circuit boards (PCBs) for more than 50 years and have proved reliable. Recently, due to concerns over the environmental impact of lead, legislation has been introduced banning its use from electrical and electronic equipment. The EU directives 2002/95/EC (2003) and 2002/96/EC (2003) are two pieces of legislation that apply to EU member states and will come into effect on the 1st of July 2006. From this date electrical and electronic products sold in the EU must be lead-free. Currently there is no drop-in lead-free solder replacement for SnPb but there are many lead-free alternatives available as reported by Suraski and Seelig (2001) and Bath *et al* (2000). Since the introduction of lead-free solder is not a simple drop-in exercise, all related processes and reliability issues must be evaluated using the new solder alloys.

Ball Grid Arrays (BGAs) are electronic packages that have gained a large market-share in the electronics packaging industry. This is due to their compactness and large number of inputs and outputs that facilitates the trend toward smaller and lighter electronic products without the loss of equipment performance. Their attractive characteristics mean they have become integral to many electronic systems from military to consumer applications.

With the advent of lead-free solder, re-evaluation of processes and the solder joint quality of BGAs has become a major research area. This current study investigates the effects of a lead-free solder in a reflow soldering process by using experimental design techniques. Visual inspection of solder joint micro-sections through x-ray is the accepted industry method of inspecting BGA solder joints. No scoring method exists to rate the quality of the solder joints from visual inspection. An inexpensive qualitative method of assessing the solder joint quality after micro-sectioning and x-ray inspection was developed. The joints were evaluated and scored against quality characteristics taken from accepted industry standards, IPC standard 610 Rev. C. Each of the quality characteristics was weighted and the weighted scores were analysed using experimental design techniques to identify any significant process factors. Residual analysis was then used to verify the statistical approach. The results of the experiment show that this scoring system is a suitable method to use when assessing BGA solder joint quality.

Preparation of Test Assemblies

A 10 x 10 array micro BGA package with lead-free solder bumps was used as the test component. The test boards were eight-layer FR-4 printed circuit boards (PCBs) with 16 BGA component positions. An Organic Solderabilty Preservative (OSP) board finish was used for the lead-free components. The lead-free solder paste chosen for the experiment was a 95.5Sn 3.8Ag 0.7Cu alloy, which was the same material used in the BGA solder bumps. An example of a test assembly board with BGAs attached is shown in figure 1.

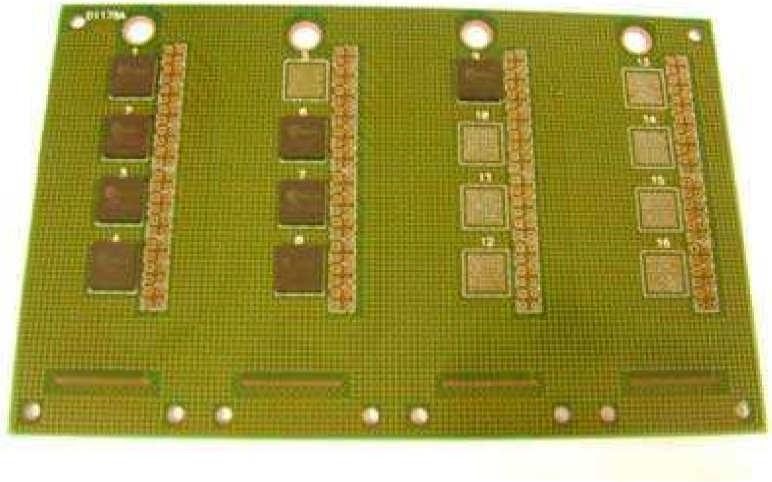

Figure 1: Test assembly board

A screen-printing process printed the solder paste on the PCBs after which eight BGA packages were placed using a BGA placement system. Each board was then reflowed at the chosen settings according to the experimental design matrix.

Experimental Design

Experimental design is a statistical technique used to help design new products and processes, optimise existing manufacturing processes and improve existing products. A 2_{IV}^{6-2} fractional factorial was used for the experimental design in the present study. This involved a total of sixteen experimental runs. One PCB containing eight BGAs was reflowed during each experimental run. The six factors in the experiment were the five temperature zones in the reflow oven and the speed of the oven conveyor belt. The factors and levels are detailed in Table 1. Factor levels were set to reflect the reflow profile recommended by the solder paste manufacturer.

	Factor	**-**	**+**
A	Conveyor Speed	12 inches/min	14 inches/min
B	Preheat temperature 1	170°C	180°C
C	Preheat temperature 2	210°C	220°C
D	Soak temperature	230°C	240°C
E	Reflow temperature 1	245°C	265°C
F	Reflow temperature 2	280°C	315°C

Table 1 Experimental Design Factors and Levels

The response of interest was the solder joint quality. There is no quantitative measure to evaluate solder joint quality so qualitative data was gathered through inspection of solder joint characteristics in accordance with IPC standard 610 Rev. C.

Method for Solder Joint Evaluation

There is no standard method used to assess the quality of BGA solder joints. Reliability tests such as accelerated temperature cycling, power cycling, or cyclic bending mechanical tests are typically used to measure solder joint strength. These are proven methods of testing but are costly and time consuming. A typical temperature cycling test carried out to assess solder joint strength could last anything up to four thousand hours as reported by Towashirapom *et al* (2002). It would be of great benefit if a fast and inexpensive method existed that could measure solder joint quality. By using visual evaluation of the solder joints and scoring of the resulting qualitative data such a method was devised in this study.

The techniques used to evaluate the solder joints were x-ray and cross section analysis. Figures 2 and 3 show examples of both.

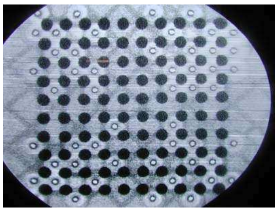

Figure 2 Solder Joint X-Ray

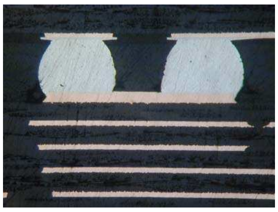

Figure 3 Solder Joint Cross Section

X-Ray was used to examine for defects such as bridging, open joints, and solderballs. Cross sectioning was used to examine the joints in detail for solder joint formation, wetting, voids, and alignment. One BGA was cross-sectioned from each PCB. Every cross section exposed a row of ten solder joints for inspection.

Each of the ten solder joints were evaluated under the following categories and scored out of ten:

- Defects
- Solder Joint Formation
- Wetting
- Void Area
- Void Frequency
- Alignment

These categories were carefully chosen based on the guideline the IPC standard provided and knowledge of the process. A score of ten represented a bad joint and zero represented a good one. Each category was assigned a weight according to its importance as shown in Table 2. For example an open joint is categorised as a defect that would cause failure of the component immediately, accordingly Defects was assigned a high weighting. Inspection of the solder joints revealed that there were no defects on any PCB. There is an important relationship between void area and void frequency. One large void occupying 50% of the solder joint was considered more serious than several smaller voids occupying the same area. Therefore, when void frequency (*Vf*) was greater than zero, the experimental run weighted score denoted *WS* was calculated as follows:

$$Ws = aD + \left(\frac{bJF + cW + \frac{xVa}{yVf} + zA}{n} \right)$$

When $Vf = 0$, *Ws* was calculated as:

$$Ws = aD + \left(\frac{bJF + cW + zA}{n} \right)$$

Where n= the number micro-sectioned solder balls.

Void frequency and void area were assigned a weighting of one to allow for this relationship within the equations.

Category	**Category Nomenclature**	**Weight**	**Weight Nomenclature**
Defects	D	0.90	a
Solder Joint Formation	JF	0.80	b
Wetting	W	0.70	c
Void Area	VS	1.0	x
Void Frequency	VF	1.0	y
Alignment	A	0.30	z

Table 2 Weighting Values

Results and Discussion

The experiment runs and weighted scores are included in the design matrix in Table 3. As this was an unreplicated experiment the analysis of the results involved using methods proposed by Daniel (1959). He suggests using probability plots to plot the effects making the assumption that the data comes from a normal distribution with a mean of zero and constant variance.

When plotted, nonsignificant effects should lie approximately on a straight line while significant ones tend to lie off the line.

Run Order	***Conveyor Speed***	***Preheat Temp. 1***	***Preheat Temp. 1***	***Soak Temp***	***Reflow Temp. 1***	***Reflow Temp. 1***	***Average Weighted Score***
1	12 in/sec	170°C	210°C	240°C	245°C	315°C	5.018
2	14 in/sec	170°C	210°C	240°C	265°C	315°C	4.81
3	14 in/sec	180°C	210°C	240°C	245°C	280°C	3.563
4	12 in/sec	170°C	220°C	230°C	265°C	315°C	5.235
5	14 in/sec	180°C	220°C	230°C	265°C	280°C	3.56
6	12 in/sec	180°C	220°C	230°C	245°C	280°C	4.866
7	14 in/sec	170°C	210°C	230°C	265°C	280°C	2.85
8	14 in/sec	170°C	220°C	230°C	245°C	315°C	2.04
9	12 in/sec	180°C	210°C	230°C	265°C	315°C	6.812
10	14 in/sec	180°C	210°C	230°C	245°C	315°C	3.27
11	12 in/sec	170°C	220°C	240°C	265°C	280°C	3.653
12	14 in/sec	170°C	220°C	240°C	245°C	280°C	3.105
13	12 in/sec	180°C	220°C	240°C	245°C	315°C	4.848
14	12 in/sec	170°C	210°C	230°C	245°C	280°C	8.583
15	12 in/sec	180°C	210°C	240°C	265°C	280°C	4.605
16	14 in/sec	180°C	220°C	240°C	265°C	315°C	4.788

Table 3 Experimental Design Matrix

The normal probability plot of the effects is shown in Figure 4. From the plot it may be seen that factor A (Conveyor Belt Speed) lies off the line and therefore may be considered significant. Daniels method rests on the principle of effects sparsity. This is the hypothesis that only a small proportion of the factors in an experiment have effects that are large.

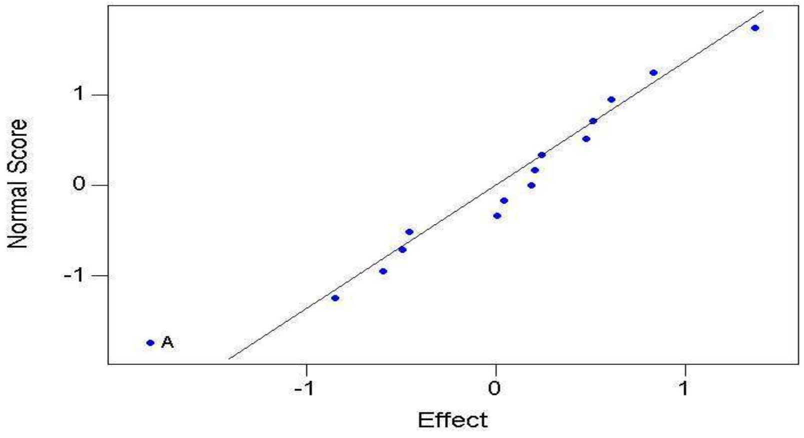

Figure 4 Normal Probability Plot of the Effects

The main effects plot for conveyor belt speed is shown in Figure 5. It may be seen that the best response, i.e. the lowest weighted score, is achieved at the higher conveyor speed of 14 inches per second.

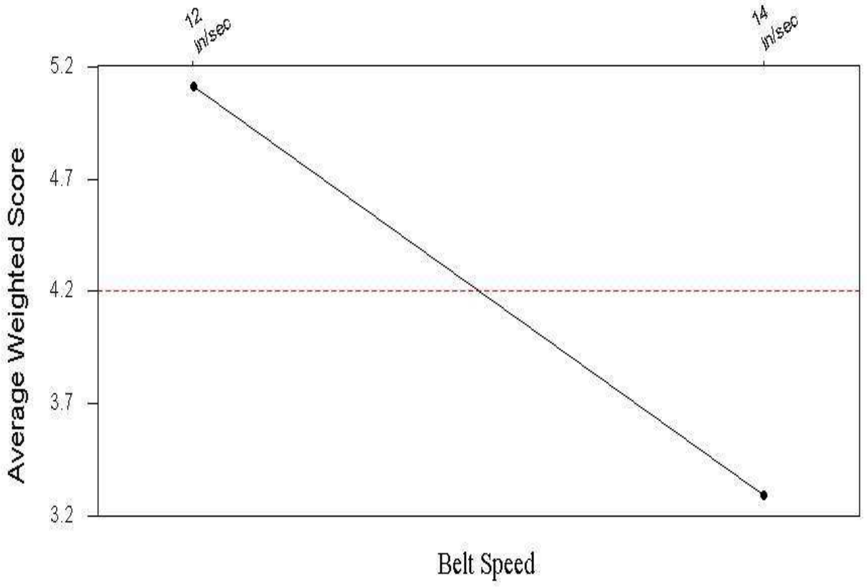

Figure 5 Main Effects Plot for Conveyor Belt Speed

ANOVA

The ANOVA table for the data is presented in Table 5. On examination of the p values factor A, conveyor belt speed is significant at the 5% level. All of the other terms were pooled to form the error.

Source	*DF*	*SS*	*MS*	*F*	*P*
Belt Speed	1	13.359	13.359	9.16	0.009
Error	14	20.414	1.458		
Total	15	33.773			

Table 5 ANOVA Table

The residuals were analysed to confirm the adequacy of the model and to ensure the ANOVA assumptions were not violated. Figure 6 and Figure 7 show the normal plot of the residuals and the residuals versus the predicted values respectively. From the plots it may be seen that there is no evidence of non-normality and the equality of variance assumption was not violated.

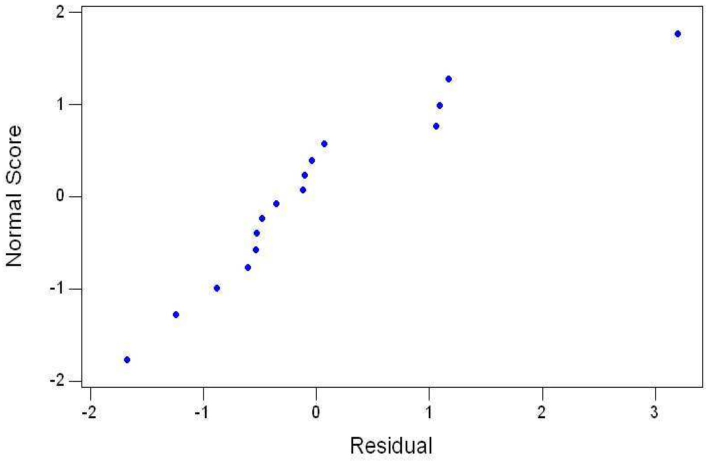

Figure 6 Normal Probability Plot of the Residuals

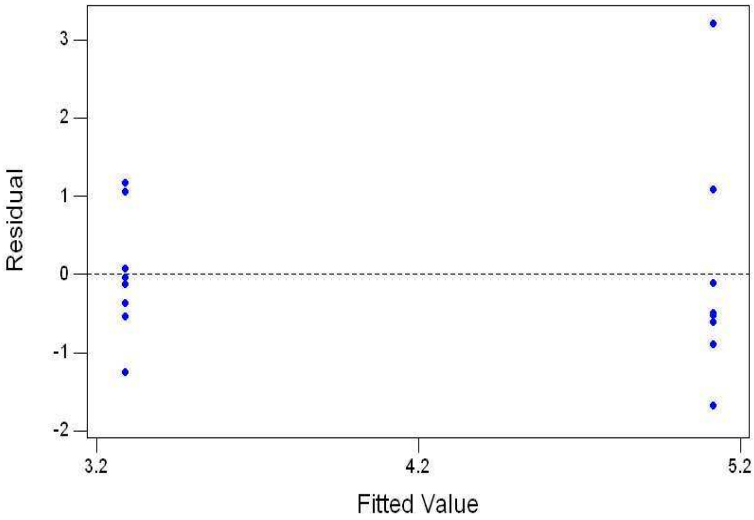

Figure 7 Predicted (Fitted) Values Versus the Residuals

Recommendation

The adequacy of the approach adopted in this study has been verified though analysis of residuals. To further validate the scoring technique presented in this paper, research into a test method designed to evaluate BGA solder joint strength must be conducted. The results presented in this paper and the results of the test to evaluate solder joint strength must then be examined for correlation.

Conclusion

The introduction of lead-free soldering in the electronics industry is coming and all related processes must be tested and evaluated. This study presents the investigation of the effects of a lead-free solder on a reflow soldering process. An experimental design was carried out on the process. Since no method of rating BGA solder joint quality exists, a scoring method was developed against accepted industry standards to assess the quality of the solder joints produced by the experiment. Statistical methods were used to evaluate the weighted score. Through experimental analysis it was shown that conveyor belt speed had an effect on the weighted score in the lead-free reflow soldering process. These results demonstrate that the scoring method is a practical way of assessing BGA solder joint quality in a confident and inexpensive manner.

Acknowledgements

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References

Bath, J., Handwerker, C. and Bradley, E., (2000), “Research Update: Lead-Free Solder Alternatives”, *Circuits Assembly*, May 2000, pp 31 – 40.

Daniel, C., (1959), “Use of Half-Normal Plots in Interpreting Factorial Two-Level Experiments”, *Technometrics*, vol. 1, no. 4, pp. 311 – 340.

Directive *2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (2003),* Official Journal of the European Union*, Vol. 37, pp. 19 - 23.*

Directive *2002/96/EC of the European Parliament and of the Council of 27 January 2003 on the Waste Electrical and Electronic Equipment (2003),* Official Journal of the European Union*, Vol. 37, pp. 24 – 38.*

IPC-A-610 Rev. C, pp 12-74 – 12-76, Available for purchase from IPC, orderipc@ipc.org

Suraski, D. and Seelig, K.,(2001), “The Current Status of Lead-Free Solder Alloys”,*IEEE Transactions on Electronics Packaging Manufacturing,* vol. 24, no. 4, pp 244 – 248.

Towashirapom, P., Subbarayan, G., McIlvanie, B., Hunter, B. C., Love, D., and Sullivan, B., (2002), “Predictive Reliability Models Through Validated Correlation Between Power Cycling and Thermal Cycling Accelerated Life Tests”, *Soldering and Surface Mount Technology,* vol. 14, no. 3, pp. 51 – 60.