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Research Article

The Lead-Free Solder Selection Method and Process Optimization Based on Design of Experiment

Wang Bing
Institute of Mechanical Engineering, Huaihai Institute of Technology, Lianyungang 222005, China

Abstract: In the study, through researching the characteristic of the lead-free solder, we introduce the method of QFD (Quality Function Deployment) to transform the demand of production properties and process into the technical demand of the lead-free solder, thus we could transform the demand concept of sampling into a concrete performance index. Finally we can obtain two parameters of the technological competitive power index and market competitive power index to evaluate performance of the lead-free solder through making a series of experiments. We utilize the design of experiment method to find out key parameter of process and the best collocation of parameter, which make the co planarity of tin ball descend to 149 from 178 and promote the process's ability up to 95.2 from 85%.

Keywords: Design of experiment, lead-free solder, quality function deployment, restriction of hazardous substances

INTRODUCTION

The definition of international lead-free solder: Sn as the base, add elements Ag, Cu, Zn, Bi, binary, or even three or four eutectic alloy instead of Sn37Pb solder and the W (Pb) should be less than 0.01%. Unanimously recognized the preferred on behalf of the tin-lead solder is mainly concentrated in the Sn-Ag-Cu system (Liu, 2010).

More backward our country in the lead-free soldering technology and materials research has been conducting research, but the basics are in the applied research stage of foreign materials and process technology, the planned development research is still very lacking. While the related materials, processes, standards, research has yet to be planning and organization of the government level. Therefore, the real strength suppliers of lead-free solder are almost foreign products dominate the world (Zhang *et al*., 2009).

SOCKET products are used in computer motherboards, the connectors used to connect the motherboard and CPU, the PCB connection is through the surface solder balls and PCB PAD welding a combination of solder ball alloy has been used before 63/37 Sn-Pb alloys. Now because of the ROHS directive, lead-free alloy must be used, is also facing the above problems (Chen, 2008).

There are many factors affecting the ability of the product process, such as the tray of the activity of the plating layer, the flux of activity, temperature conditions, the welding environment factors, if you want to improve process capability, using traditional analytical methods, only to find process of the key factors you need to do hundreds of experiments, we use the Taguchi method (Xiong, 2005), the best process parameters on the minimum number of experiments (Chen *et al*., 2005).

Global production socket manufacturers only a few and each choice of solder balls are not the same. Plus manufacturers and the confidentiality of their technology, resulting in delays effectively enhance Socket products lead-free process capability. There are many factors affecting Socket process capability, for example, the tray plating layer of activity, the activity of the flux, the furnace temperature conditions, welding environment factors, if you want to enhance the ability to process using traditional analysis methods alone to find a process the key factor may need to do hundreds of experiments, I hope to optimum conditions of process parameters on the minimum number of experiments using the Taguchi method.

TAGUCHI METHOD

In 1949, Taguchi Hyun (Genichi Taguchi) Dr. laboratory work in Japan Telecom, the traditional experimental design methods do not apply to the progressive development of the basic principles of "Quality Project" (Wang and Yang, 2004)

Taguchi method is a best optimization design method by test to process system parameter and has practical application. Taguchi method can deal with product and process engineers concerned with two major problems:

Table 1: The mechanical properties of solder balls table

	Alloy composition	Tensile strength (Kgf)	Ductility
1	Sn-37Pb	4.6	31
2	Sn-0.7Cu	2.3	45
3	Sn-3.5Ag	3.5	39
4	Sn-3Ag-0.5Cu	4.8	36.5
5	Sn-3Ag-0.5Cu-Bi	4.8	38

Table 2: Solder balls with different soldering strength on PCB test results

Alloy PCB	Sn-37Pb	Sn-0.7Cu	Sn-3.5Ag	Sn-3Ag-0.5Cu	Sn-3Ag-0.5Cu-Bi
OSP	-	2.09	2.82	2.70	2.75
NiAu	-	1.87	2.74	2.68	2.88
Ag	-	2.02	2.72	2.52	2.45
Sn-Pb	2.42	-	-	-	-

Table 3: Solder balls CT test value

Sn-Pb	20-25
Sn-Ag	25~35
Sn-Cu	25~35
Sn-Ag-Cu	35~45
Sn-Ag-Cu-Bi	35~45

Table 4: The table of welding strength of the solder balls and PCB after high temperature and humidity

	Sn-37Pb	Sn-0.7Cu	Sn-3.5Ag	Sn-3Ag-0.5Cu	Sn-3Ag-0.5Cu-Bi
OSP	-	1.59	2.29	2.26	1.92
NiAu	-	1.48	2.21	2.15	2.01
Ag	-	2.67	2.57	2.09	2.57
Sn-Pb	1.97	-	-	-	-

Fig. 1: Solder balls strength test equipment

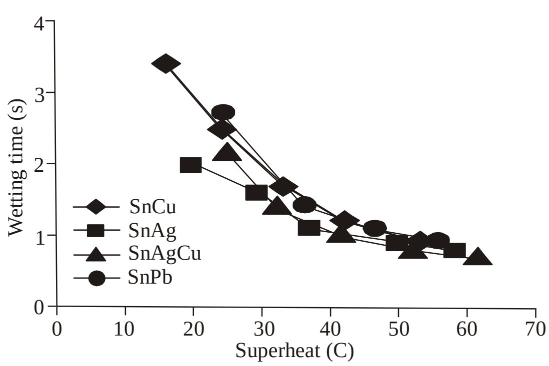

Fig. 2: Alloy wet ability map-without flux

- How to effectively reduce the function of products in consumer use of environmental variation.
- How to ensure that under the laboratory optimal conditions, the production and consumption environment is still the optimal conditions (Shao, 2004).

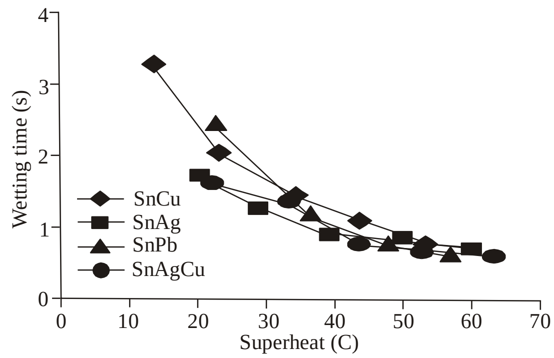

Fig. 3: Alloy wet ability map-add flux

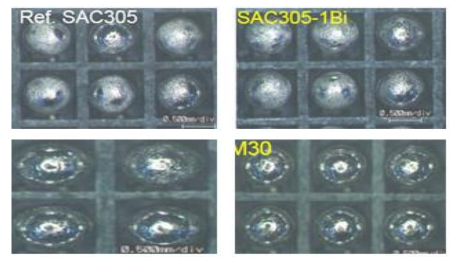

Fig. 4: Surface gloss after solder ball welding

Performance testing of the solder ball:

The mechanical properties of the test: The mechanical properties of solder balls-by testing the tensile strength and ductility to express different alloy mechanical properties of test data in Table 1.

Test of welding strength: Welding strength of the solder balls-solder balls with different PCB board welding and then test their binding capacity to assess, test equipment, plug the power machine (Fig. 1), the test results shown in Table 2.

Wetting performance test: Selection of the wetting balance method to evaluate the wetting properties of lead-free solder ball, the test results shown in Fig. 2 and 3.

Solder ball alloy oxidation resistance test: ICOS test equipment to evaluate the surface gloss and testing Reflow soldering of a variety of solder balls, solder ball surface quality (CT) is in Table 3 and surface gloss after solder ball welding is in Fig. 4.

Welding reliability testing: Retention after the welding of the test solder ball terminals tray to evaluate the growth characteristics of different solder ball IMC. Test conditions: high temperature and humidity (85°C, 85% RH, 96 h), temperature cycling (-40°C, 125°C each 30 min 100 cycles), random vibration 2.09 g/axis for an h, test the thrust, the test results shown in Table 4.

Establish an evaluation model of quality house on the solder ball performance: Demand projects

Table 5: S/N response table

	A	B	C	D	E	F	G	H
Level 1	-45.5132	-44.3849	-45.4506	-45.5718	-45.4187	-45.6621	-45.4616	-45.3316
Level 2	-45.1020	-45.4967	-45.0318	-45.2902	-45.4549	-45.1169	-45.2275	-45.3904
Level 3		-46.0410	-45.4403	-45.0607	-45.0492	-45.1436	-45.2336	-45.2007
Effect	0.4112	1.6561	0.4188	0.5111	0.4057	0.5452	0.2342	0.1897
Rank	5	1	4	3	6	2	7	8

Table 6: Contrast of experimental results

	Solder ball coplanarity	S/N calculated value	S/N predicted values
Original design combinations	178	-45.0084	-44.8195
Best design combinations	149	-43.4637	-43.4564

Table 7: Effect comparison

	Year	
Item	2010	Mar.-Oct.2011 (the new process conditions)
Production process yields	85%	95.2%
Customer complaint Times	8	1 (shell tilt)
The amount of compensation due to the poor quality	80000 USD	90 USD

according to customer demand project lead-free solder ball and the needs of the project into the technical characteristics and the technical characteristics of the different components of the solder balls through experiments were evaluated using the model of the House of quality comprehensive evaluation of different components of solder balls.

Through comparative analysis of the performance of the Sn-Ag-Cu alloy the nearest Sn-Pb, Sn-Ag alloy, followed by Sn-Cu worst. As Bi element is a derivative product of Pb mining, Sn-Ag-Cu-Bi alloy welding Bi crack recommended (Liu, 2004)

SOCKET SMT soldering process involved many of the parameters, therefore the Taguchi method to carry out data analysis, (Zheng and Han, 2000) by controlling the number of factors and their standards of select appropriate right angles to the table, with a minimum of experiments the number of calculating optimal product performance, at the same time fatherly confirm the strength of the process factors on the quality characteristics.

EXPERIMENTAL RESULTS

In accordance with 18 sets of S/N ratio to produce the various factors on the S/N ratio response table and response diagram, shown in Table 5.

Contrast on the best design to experiment with the original design results in the final stage:

The original design combination is A2 B2 C2 D2 E2 F2 G2 H2.

The best design combination is A2 B1 C2 D3 E3 F2 G3 H3.

The experimental result is shown in Table 6.

The results indicate that the optimal parameter design is better than the original design, good coplanarity of solder balls reduced to 149 from 178 of the original design.

Experimental validation: Selected the most suitable Sn-3Ag-0.5 Cu for lead-free solder from a number of lead-free solder SOCKET products and then utilize the Taguchi method to optimize the product lead-free process to identify the key factor affecting the ability of the product process and its level and find the best combinations through experiment, making key product features solder ball coplanarity be significantly reduced.

In order to verify the validity of the experimental results, the optimal process parameters obtained from the experiment is applied to the actual mass production, mass production and product after seven months of feedback from customers over the use, the product is found to process capability and quality in the client's improved significantly, Table 7 shows 2010 product of the year process yields and customer usage from March to October 2011 Table (Source company management review report).

Can be seen from the table, after the Taguchi method optimized process conditions in the actual production not only significantly enhance the process yield (the yield by 85% last year to 95.2%), but also because the solder ball coplanarity improvement, improve control level of manufacturing process, from the previous total face degree 200 specifications to improve to 170 now, this control quality in client performance out of the level also get the upgrade, by 2010 eight customer complaints to the 2011 1 pieces (and not welded), impairment charges fell from 80,000 to 90 USD visible welding quality has improved significantly.

CONCLUSION

In this study, SOCKET product carry on research to lead-free solder ball performance, combined with the quality function deployment, propose how to choose the evaluation of lead-free solder and use the Taguchi method through a limited experiment to find out the key factor impacting lead-free process as well as the best combination to enhance the process capability of lead-free soldering processes.

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