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ANALYSING EFFECT OF ALUMINIUM ON WETABILITY OF LEAD FREE SOLDER ALLOYS USING TAGUCHI METHOD

Engineering

KEYWORDS: wettability, wettability area, hardness, resistivity, strength.

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ABSTRACT

The area of study that this paper focuses on is primarily the effects of hardness, resistivity and strength of two alloys under consideration (namely Sn-Zn and Sn-Zn-Al alloys).The results were optimized in an experimental study while using Design of Experiment with full factorial design. The ANOVA analysis was used to obtain optimum wettability area, based on which it was concluded that the Sn-Zn-Al alloy provides us with better wettability areas, thus stating that the addition of Al provides a better solder. Basically this paper explains why Sn-Zn-Al alloy shall be preferred in case of soldering based upon the wettability area responses.

I. INTRODUCTION

Tin/Lead solders (soft solders) with tin concentrations between 5-70% are commercially available. 60/40 Sn/Pb (Tin/Lead) which melts at 370F and 63/67 Sn/Pb, a eutectic alloy with a melting point of 361.4F – the lowest of all the Sn/Pb alloys, are generally used for electrical work. The addition of tin (more expensive than lead) to lead (which otherwise has poor wetting qualities) improves wetting properties of the alloy. Lead Tin solders have the ability to readily dissolve gold plating and form brittle intermetallics. Lead, and to some degree Tin, contain radioisotopic properties which may cause soft errors.

Addition of lead to electronics was prohibited by the European Union Waste Electrical and Electronic Equipment Directive (WEEE) and Restriction of Hazardous Substances Directive (RoHS) because it is poisonous and retards growth of tin whiskers and lowers. Commercially lead free solders may contain tin, copper, silver, bismuth, indium, zinc, antimony, etc. So, the alloy primarily considered here is lead free i.e. Sn-Zn. Properties of Sn-Zn-Al Alloys Used were - Composition – Sn 91%, Low Oxidation, Higher wettability, Better Joint Reliability, Shear Strength Evaluation, and Resistivity of Joint.

ROLES OF ALLOYING ELEMENTS	
Antimony	Increases strength without affecting wettability.
Bismuth	Lowers melting point and improves wettability.
Copper	Lowers melting point, increases resistance to thermal fatigue and increases wettability.
Nickel	Inhibits dissolution of thin film under bump metallization in the form of a supersaturated solution.
Indium	Lowers the melting point and enhances ductility.
Lead	Inexpensive but does not have good wetting properties and is toxic and retards growth of tin whiskers.
Silver	Enhances mechanical strength but does not have ductility as good as lead.
Tin	Good strengthening and wetting properties.
Zinc	Cheap and lowers melting point and it is susceptible to corrosion and oxidation in air.
Germanium	Influences formation of oxides.

ROLES OF IMPURITY ELEMENTS	
Aluminum	Little solubility.
Antimony	Since it improves wettability it is added deliberately in little quantities.
Arsenic	Adversely affects mechanical properties.
Cadmium	Solder tarnishes when it is added.
Copper	While being the most common contaminant it forms needle shaped intermetallics.
Gold	Easily dissolves and forms brittle intermetallics
Iron	Forms intermetallics and causes grittiness.
Nickel	Causes grittiness.
Silver	Forms intermetallics, causes grittiness and forms pimples.
Sulfur	Forms lead and tin sulfides and causes dewetting.
Zinc	Forms excessive dross.

Wettability: The capacity of a strong surface to diminish the surface pressure of a fluid in contact with it such that it spreads over the surface and wets it. Wetting is imperative in the holding or adherence of two materials. The contact edge ( ) is the angle at the point at which the liquid–vapor interface meets the solid–liquid interface. A contact edge under 90° (low contact point) typically shows that wetting of the surface is exceptionally positive, and the liquid will spread more than an extensive range of the surface. Contact points more prominent than 90° (high contact edge) by and large implies that wetting of the surface is unfavorable, so the liquid will minimize contact with the surface and structure a minimal fluid droplet. Larger the wettability characteristic of an alloy, larger is the wettability area which in turn assures larger contact between particles resulting in higher strength of the solder joint.

II. OBJECTIVE

As per Taguchi, the product should be so designed that it remains unaffected by uncontrollable environmental factors. The signal (product quality) to noise (uncontrollable factors) ratio should be high. This project basically studies the wettability in solders in order to achieve maximum strength. Following are the purposes of writing this project:

(a) To study about the influence of wettability on strength of the alloy.

(b) To design experimentation series using Design of Experiments (DOE) layout, thus to study the wettability of solders.

(c) To study about the best combination of solution in order to maintain maximum possible hardness while maintaining maximum possible resistivity to achieve maximum possible wettability and thus maximum possible strength.

III. EXPERIMENTATION

This paper investigates the effects and parametric optimization of process parameters for the wettability of Sn-Zn and Sn-Zn-Al alloys. Following was the experimentation procedure:-

Sn-Zn Alloy Preparation	After setting a furnace temperature of 240C, 23.5g Zn was added when 227.5g Sn melted. Then the furnace was held for 30 min for homogenization of alloy at a temperature of 350C.
Sn-Zn-Al Alloy Preparation	The same procedure was followed for this alloy except for the fact that 0.2g of Al was added along with Sn and Zn.
Sample Preparation	Sample prepared for micro structural examination and was polished against 100-400 grit size emery paper and then against a velvet paper. After this it was etched using a 2% natal solution and examined under a microscope magnification of 100X and 200X.
Wire Drawing	The prepared alloy will now be ready to be used as solder once it has been drawn into wires. The wire drawn is a square cross-sectioned with area 1mm x 1mm.
Joint preparation	Solder joints were prepared using copper wires as base wires, a soldering iron and soldering wires. Red Wire was soldered using Sn-Zn-Al joint and blue wire was soldered using Sn-Zn joint
Testing	Tests listed below were performed in order to examine the samples :- Hardness Test Resistivity Test Shear Strength Test

Next analysis was carried out using minitab17. The process parameters viz. hardness, resistivity and strength are considered and experiments are conducted based on L9 orthogonal array (OA).Process response wettability area of the soldered joint are measured for every experimental runs. For maximum wettability area, the process parameters are optimized based on Taguchi method. Analysis of variation (ANOVA) is performed to get the contribution of each process parameter on the performance characteristics and it observed that all the three factors are significant process parameter that affect the response i.e. wettability area.

IV. RESULTS & OBSERVATIONS

Following experimental design strategy, using Taguchi orthogonal arrays concept as used. The following L-9 orthogonal array was applied for Sn-Zn alloy.

Table 1.1 L-9 orthogonal array was applied for Sn-Zn alloy

L-9 Orthogonal array for Sn-Zn Alloy				
Run	**Hardness**	**Resisti-vity**	**Strength**	**Wettability area**
1	11	11.02	4.487	28.275
2	11	11.04	5.02	38.485
3	11	10.9	4.697	33.185
4	11.7	11.02	5.02	29.725
5	11.7	11.04	4.697	37.285
6	11.7	10.9	4.487	33.025
7	11.2	11.02	4.697	28.875
8	11.2	11.04	4.487	37.925
9	11.2	10.9	5.02	32.275

Observations in Taguchi Analysis: Wettability versus hardness, resistivity and strength of Sn-Zn Alloy

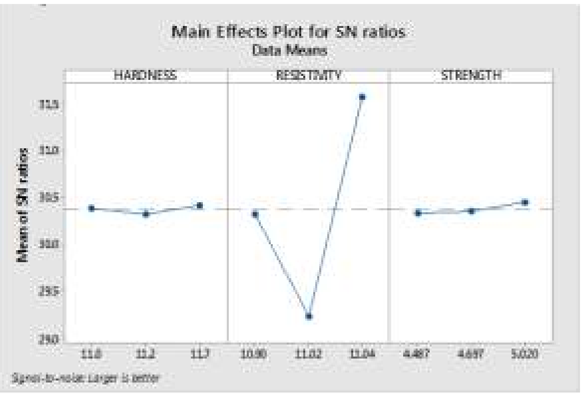

Figure 1.1 Main effects plot for S/N Ratio (Wettability Area)

The above SN ratio graph was made using 3 variables i.e. hardness, resistivity and strength. As observed from graph, it is clear that at 11.7 units of hardness, 11.04 micro ohm.cm resistivity and 5.020 kN strength gives the best output in order to maximize wettability.

ANOVA Test results for Wettability Area of Sn-Zn Alloy

Table 1.2 General linear Model (ANOVA) for Wettability Area for Sn-Zn Alloy

Source	DF	Adj SS	Adj MS	F	P	Contribution %
Hard ness	2	0.187	0.0937	0.11	0.903	0.15
Resistivity	2	120.60	60.302	69.11	0.014	98.16
Strength	2	0.322	0.1612	0.18	0.844	0.26
Residual Error	2	1.745	0.8725			
Total	8	122.86				

For the above ANOVA model, the calculations are done at 95% confidence level. In an analysis of variance table, the P value determines the most significant factor. The factor whose P value is less than 0.05 will be most effective factor. The ANOVA table clearly indicates that the resistivity parameter is the most significant parameter for defining the Wettability Area that means that these terms influence the model to a great extent.

General Regression equation for Wettability versus hardness, resistivity and strength of Sn-Zn Alloy

WETABILITY AREA = -108 + 0.16 HARDNESS + 12.3 RESISTIVITY + 0.82 STRENGTH

OPTIMIZED PARAMETERS COMBINATION for Sn-Zn Alloy

As Wettability Area is the "Larger is better" type quality type characteristic, from the figure1.1 it can be seen that the third level of hardness, third level of resistivity and third level of strength results in maximum value of wettability area.

Table 1.3 Optimal value of Wettability Area for Sn-Zn Alloy

Hardness	Resistivity	Strength	Wettability area
11.7	11.04	5.020	33.78

The following L-9 orthogonal array was applied for Sn-Zn-Al alloy:

Table 1.4 L-9 Orthogonal array with actual values for Sn-Zn-Al alloy

L-9 Orthogonal array for Sn-Zn-Al Alloy				
Run no.	**Hardness**	**Resistivity**	**Strength**	**Wettability area**
1	12.3	10.45	5.011	50.265
2	12.3	10.42	5.595	46.178
3	12.3	10.46	4.858	56.745
4	12.5	10.45	5.595	51.925
5	12.5	10.42	4.858	45.284
6	12.5	10.46	5.011	56.015
7	11.9	10.45	4.858	50.975
8	11.9	10.42	5.011	45.245
9	11.9	10.46	5.595	55.025

Observations in Taguchi Analysis: Wettability versus hardness, resistivity and strength of Sn-Zn-Al Alloy

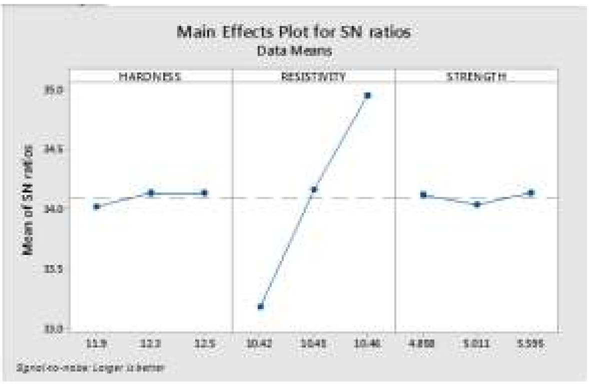

Figure 1.2 Main effects plot for S/N Ratio (Wettability Area)

The above SN ratio graph was made using 3 variables i.e. hardness, resistivity and strength. As observed from graph, it is clear that at 12.5 units of hardness, 10.45 micro ohm.cm resistivity and 5.595 kN strength gives the best output in order to maximize wettability.

ANOVA Test results for Wettability Area of Sn-Zn-Al Alloy

Table 1.5 General linear Model (ANOVA) for Wettability Area for Sn-Zn-Al Alloy

Source	DF	Adj SS	Adj MS	F	P	Contribution %
Hard ness	2	0.855	0.4274	0.42	0.706	0.52
Resistivity	2	161.161	80.5807	78.62	0.013	97.91
Strength	2	0.530	0.2651	0.26	0.794	0.32
Residual error	2	2.050	1.0250			
Total	8	164.596				

From the ANOVA model for the above experimentation, the calculations are done at 95% confidence level. In an analysis of variance table, the P value determines the most significant factor. The factor whose P value is less than 0.05 will be most effective factor. The ANOVA table clearly indicates that the resistivity parameter is the most significant parameter for defining the Wettability Area that means that these terms influence the model to a great extent.

General Regression equation for Wettability versus hardness, resistivity and strength of Sn-Zn-Al Alloy

WETABILITY AREA = -2486 + 1.17 HARDNESS + 241.4 RESISTIVITY + 0.29 STRENGTH

OPTIMIZED PARAMETERS COMBINATION for Sn-Zn-Al Alloy

As Wettability Area is the "Larger is better" type quality type characteristic, from the figure1.2 it can be seen that the third level of hardness, third level of resistivity and third level of strength results in maximum value of wettability area.

Table 1.6 Optimal value of Wettability Area for Sn-Zn-Al Alloy

Hardness	Resistivity	Strength	Wettability area
12.5	10.46	5.595	55.29

V. CONCLUSION

This paper presents the application of the Taguchi method in order to optimize the wettability of Sn-Zn and Sn-Zn-Al alloy and in turn decide which of the two would produce a better and stronger solder joint. It has been shown that wettability area can be significantly enhanced using the optimum level of parameters. From experimental analysis done on the two stated alloys, it was concluded that:

(1) Wettability greatly depends upon resistivity whereas the other parameters viz. hardness and strength are less effective.

(2) Greater wettability area is achieved in Sn-Zn-Al alloy i.e. 55.29 mm2 than in case of Sn-Zn alloy i.e. 33.78 mm^2 This clearly indicated that Sn-Zn-Al alloy will provide a better and stronger solder joint.

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