JOINT SOLDER OF LEAD FREE SOLDER (Sn0.7Cu) AND PRINTED CIRCUIT BOARD WITH VARIOUS HEAT TREATMENT TEMPERATURES

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ABSTRACT

Soldering is used extensively in the electronic industry. It used to connect printed circuit board to join the circuit between electronic parts. The quality and reliability of electronic products strongly depend on those of solder joints. The quality reliability of solder joint as the title of this project is to study about joint solder of lead free solder (Sn0.7Cu) and printed circuit board with various heat treatments. The objectives of this project is to analyze the strength between solder and printed circuit board by various heat treatment temperature besides investigate whether the change of temperature treatment will affect the joint strength of solder and printed circuit board. Tensile test is used in this project to analyze the reliability of the solder joint. At the end of the project, the reliable and efficient temperature is determined, 120°C at 1 hour heat treatment while unreliable temperature is 120°C at 2 hours of heat treatment.

ABSTRAK

Pateri merupakan proses yang digunakan secara meluas di dalam industri elektronik. Pateri digunakan untuk menyambung produk elektronik ke papan litar. Kekuatan dan kualiti produk elektronik ini secara amnya bergantung kepada jenis sambungan pateri termasuk bahan dan peralatan yang digunakan. Oleh kerana itu, projek ini dicadangkan untuk mengkaji dan menganalisis sambungan pateri menggunakan fluks tanpa plumbum (Sn0.7Cu) dan papan litar dengan pemanasan pada jangka suhu yang berbeza. Objektif projek ini untuk menganalisis kekuatan sambungan pateri dengan menggunakan fluks tanpa plumbum pada papan litar dengan jangka suhu yang berbeza. Selain itu, projek ini juga mengkaji samada perubahan suhu melemahkan sambungan pateri di papan litar atau sebaliknya. Ujian ketegangan (tensile test) dijalankan untuk menganalisa kekuatan sambungan pateri tersebut. Di akhir projek, satu suhu yang efisyen dikenal pasti iaitu 120°C pada 1 jam pemanasan. Dan suhu yang kurang baik iaitu 120°C pada 2 jam pemanasan.

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LIST OF SYMBOLS AND ABBREVIATIONS

Sn	-	Stanum/tin
Cu	-	Copper
In	-	Indium
Bi	-	Bismuth
Pb	-	Plumbum/lead
Ga	-	Galium
Sb	-	Antimony
Ni	-	Nickel
Se	-	Selenium
Te	-	Tellurium
D,d	-	diameter
A	-	Area
L,l	-	Length
W,w	-	Width
mm	-	Millimeter
kN	-	Kilo Newton
V	-	Voltage
µm	-	Micrometer
°C	-	Celsius
PCB	-	Printed Circuit Board
PWB	-	Printed Wiring Board
PCA	-	Printed Circuit Assembly
IC	-	Integrated Circuit
IMC	-	Intermetallic Compound

CHAPTER 1

INTRODUCTION

1.1. Introduction

In the electronics industry, market demand and competency to make huge profit have been desired for every company. Under this circumstances research and development is needed. As a result of high technology system, machinery and material have been developed days by days. Meantime environmental friendly have become essential to technology and business competitiveness. This is a continuing challenge to the industry.

The overall of this study is to help the industry meet and exceed the challenge of designing future electronics with both performance and the environment in mind, meanwhile achieving manufacturing agility and efficiency for making today and future products. This study is focus on study of solder including the process, material and characteristic.

Soldering is used extensively in the electronic industry. In this case study printed circuit board is used widely as the base plate to join the circuit between electronic parts. Solders have played an indispensable role in electrical and mechanical joints between printed circuit board and electronic component. The quality and reliability of electronic products strongly depend on those of solder joints.

Lead-free solders are basically Sn-based alloys and soldered to Cu or Ni electrodes. During the soldering process inter metallic compounds form at an interface between Sn-based alloy/Cu or Sn-based alloy/Ni and printed circuit board to contribute to the wetting of solder to electrode and joining. Test methods for fundamental properties include the tensile test, bending test, hardness test and resonance test.

The tensile test is the most efficient method because it directly measures elastic modulus, fracture strength and Poisson's ratio without any conversion using special equations. This study investigates the change of treatment temperature to solder material can affect on joint strength of solder and printed circuit board. Tension test will be done on the joint to analyze the strength between solder and printed circuit board by various heat treatment conditions.

1.2. Project objective:

i. To analyze the strength between solder and printed circuit board by various heat treatment.

ii. To investigate whether the change of temperature treatment will affect the joint strength of solder and printed circuit board.

1.3 Project scope

i. Investigation on lead free solders Sn0.7Cu.

ii. Solder the voltage regulator to printed circuit board using lead free solder Sn0.7Cu.

iii. Conduct heat treatment to solder material (60°C to 120°C).

iv. Apply tension test at the joint and analyze the strength between solder and printed circuit board by various heat treatment.

1.4 Problem statement

In electronic products all the common base materials, coatings, metallization such as Cu, Ni, Ag, and Au, form inter metallic compounds with Sn, which is generally accepted to be the major element in lead free solder. Therefore, during soldering, chemical reactions occur between solders and printed circuit board.

This reaction produced inter metallic compound that have the tendency to generate structural defect. The greater thick of inter metallic compound occur at the joint the weaker joint solder will be. In this particular problem, inter metallic compound is proportional to the temperature that applied during the soldering process.

This paper presents a study of the effect on joint strength of solder and printed circuit board regarding the change of heat treatment. Tension test were conducted on the joint to analyze the strength between solder of integrated circuit and printed circuit board.

1.5. Flow chart

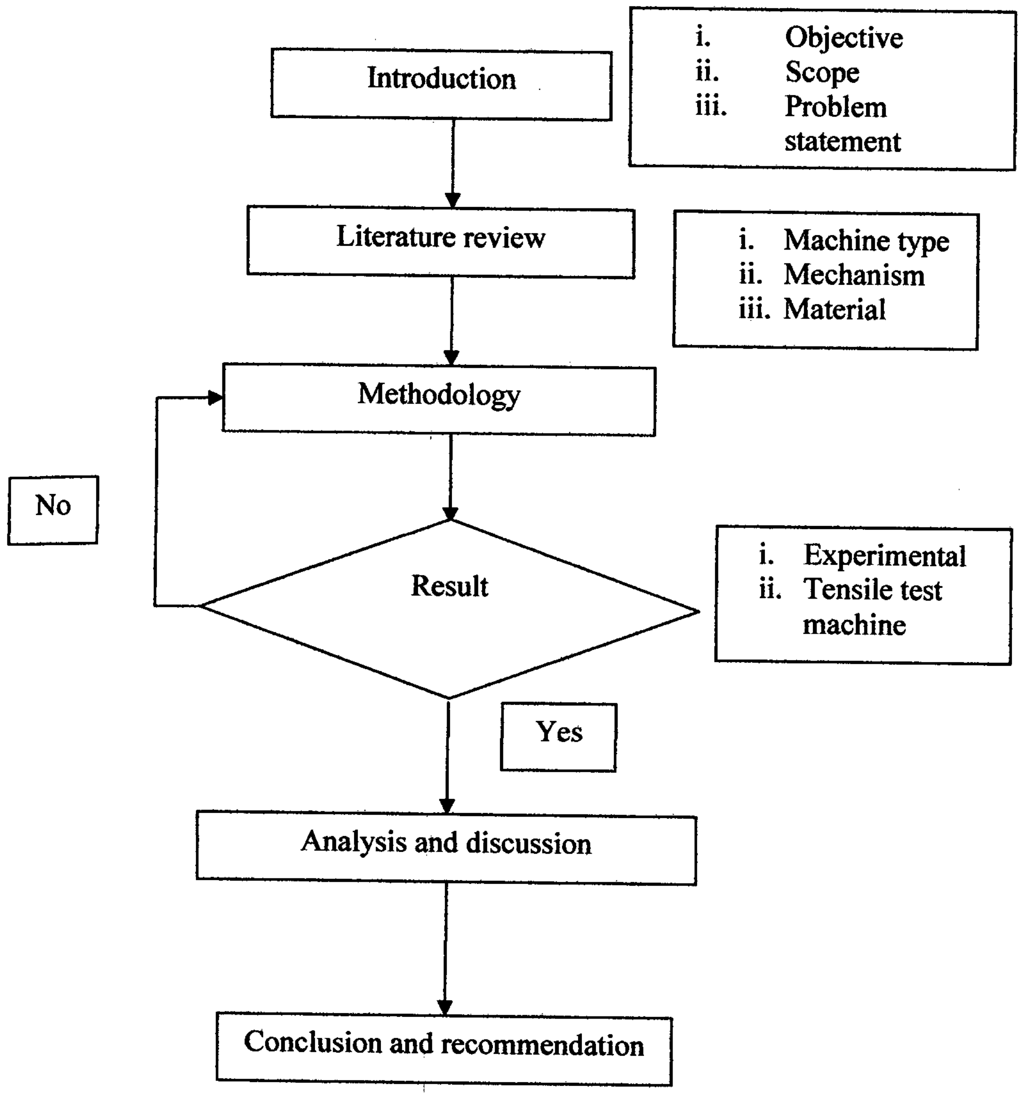

Figure 1.1: Project flow chart

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

Solder came from Latin word which mean to make solid, melt at a temperature that is the eutectic point of the solder joint. Soldering could be defined as joining method use filler metal known as solder. Conventionally the solder is made of a lead–tin eutectic alloy. Generally solder has a melting point lower than the metals to be joined and is carried out at temperatures usually less than 400°C [1]. In electronic industry solder play a major role due part assemblies. Traditionally tin lead eutectic alloy is used because of their of their low cost, good workability, ease of handling, adequate mechanical properties, low melting temperature, etc [2]. However, increased environmental and health concerns regarding the toxicity of lead have stimulated research and development of lead-free solders.

2.2 Material Selection

In microelectronic packaging processes, soldering is a well-known metallurgical interconnecting method. As the interconnecting materials of mechanical and electrical continuity, solder alloys are crucial parts in governing the reliability of high performance packaging of microelectronic devices. The trend of higher circuit board component densities results in the decrease of microelectronics packaging dimensions and solder bump sizes.

The importance of soldering in electronic packaging is increasing because the microelectronic industry has achieved rapid development in recent years. Some lead-free solder alloys have already come into use in microelectronic industry. As the interconnection materials, some Sn–Ag, Sn–Ag–Cu, and Sn–Cu solders have been used in packaging process of some microelectronic components. Sn–Cu binary alloy, as a
low cost substitute is one of most promising lead-free candidates, especially for iron, dip and wave soldering operation [3].

The Sn–Cu binary alloy has a eutectic temperature of 227 °C, which is a low-cost packaging material, but data that describes the property of this alloy hardly exists [4]. Sn 0.7Cu is used in this project and the properties data such as tensile property is investigated. Due the temperature factor, heat treatment will be conduct for each sample semiconductor and printed circuit board. Next the joint strength between the printed circuit board and integrated circuit will be determined. All this parameters will be explained later in this chapter.

2.2.1 Lead Free Solder

A viable lead free solder to replace SnPb eutectic composition providing adequate mechanical, electrical and thermal connections, must be Sn based system (i.e, containing a minimum of 60 wt.% tin). Based on the material principle, it thus comes as no surprise that local fatigue microcracking and global creep microcracking can occur in solder joints during their service life. It is reasonably well substantiated that common thermal failure in SnPb solder joints is linked with Pb rich phase [5].

This Pb rich phase cannot be effectively strengthened by Sn solute atoms, due to limited solubility and Sn precipitation. At room temperature, the limited solubility of Pb in an Sn matrix renders it incapable of improving plastic deformation slip. Under temperature cycling (thermomechanical fatigue) conditions, this Pb rich phase tends to coarsen and eventually leads to the solder crack.

It is therefore expected the absence of a Pb phase in a properly designed lead free, tin based solder may impart improved mechanical behavior, resulting in stronger solders. With growing requirements for increased interconnection integrity and reliability in electronic and microelectronic assemblies, a better solder should always find its useful place.

Overall, the keys areas of lead free technology to understand and practiced are as follows:

i. The Sn matrix
ii. Viable alloying mechanisms
iii. Doping elements
iv. Metallurgical interactions during alloying
v. Metallurgical changes in relation to temperature rise
vi. Microstructure evolution in relation to temperature rise and temperature cycling
vii. Known binary metallurgy extended to ternary systems
viii. Known ternary metallurgy extended to multiple element systems
ix. Establishing a correlation between the alloys performance and the amount of each of the constituent elements
x. Ultimate alloy composition, which demands a stunningly intricate balance among the elemental constituents

2.2.1.1 Alloy Strengthening Principle

From a material point of view, the crystalline alloys can deform via one or a combination of the following basic mechanisms:

i. Slip
ii. Dislocation climb
iii. Shear on grain boundary
iv. In grain vacancy or atomic diffusion

It is generally understood that fatigue failure or cracking of metals is often caused by dislocation slip and localization of plastic deformation. It is also generally understood that plastic deformation kinetics follows the power law dislocation climb controlling mechanism under high stress and low temperature conditions [5]. At the low stress region and high temperature grain boundary sliding becomes a rate controlling process. Therefore to strengthen the performances of conventional solders that are subject to stressful condition as a result of external temperature fluctuation and in circuit power dissipation and the powering on/off of electronic circuit boards, several approaches as listed below, can be considered.

2.2.1.2 Strengthen Approaches

Under the high temperature conditions (above room temperature) to which solder joints are normally exposed, the mobility of atoms increases and so do the dislocations. Other crystalline defects, such as vacancies also increase. Additional slip systems are introduced and metallurgical stability is unfavorably affected. In addition environmental effects (e.g, oxidation and corrosion) become more pronounced.

Approaches that can potentially hinder the above material phenomena are expected to enhance the performance of solders, which as a result will meet required performance levels for present and future applications. Such approaches include the following [5]:

i. Micro structural strengthening
ii. Alloy strengthening

iii. *Intermetallic strengthening*
iv. Macroscopic blend of selected fillers

These approaches involve both process and material factors. For example, solid solutioning where solute atoms normally reduce the stacking fault energy and favorably control the diffusion behavior is one of successfully adopted strengthening mechanism. In any of the approaches, the objective of the alloy design is to achieve the proper parameter for the following properties [5]:

i. Phase transition temperature (liquids and solid temperature) as close as practicable to those of Pb bearing counter parts
ii. Suitable physical properties especially electrical and thermal conductivity and thermal expansion coefficient
iii. Metallurgical properties that are compatible with the inter facial substrates of components and boards
iv. Adequate mechanical properties, including shear strength, creep resistance, isothermal fatigue resistance and thermo mechanical fatigue resistance
v. Improved micro structural stability
vi. Intrinsic wetting ability
vii. Environmental shelf stability
viii. Relatively low toxicity
ix. Reasonable cost
x. Overall favorable system cost

2.2.1.3 Alloy Design

As mentioned above, based on physical properties and metallurgy including melting temperature and metal wetting ability, the matrix of a lead free alloy must be Sn based. For a Sn matrix, candidates that can serve as viable alloying (intermetallic) elements are quite small in number, practically limited to Ag, Bi, Cu, In, Ni and Sb. However doping elements may extend to a larger group of elements and compounds such as Ga, Se and Te [10]. Metallurgical interactions and microstructure evolution in elation to temperature rise form the critical scientific basis for developing new lead free solders.

Binary phase diagrams provide the general information about the conditions and the extent of metallurgical interactions although complete phase diagrams beyond the binary system are scarce. Nonetheless, binary phase diagrams offer a useful starting point.

After years research, it has been found that the actual test result from multiple element alloy composition designs come very close to the anticipated properties and performance between a candidate element and the Sn matrix [6]. For example Se and Te in excessive amounts have been found to readily embrittle the Sn based alloys. Sb in an improper amount quickly jeopardizes the alloys wetting abilty. The distribution of In atoms in the Sn host lattice is sensitively reflected in fatigue performance. When Bi is in excess, the precipitation of a Bi second phase can occur. The formation of intermediate phases and intermetallic compounds between Sn and Cu, Ag, Ni or Sb remarkably affect the strength and the fatigue life of the alloy, which in turn depends on the concentration of each element as well as on relative concentration of each element as well as on the relative concentration of each element as well as on the relative concentration among the elements.

The general performance is as predictable as stated. However a high performance alloy composition demands a stunningly intricate balance of the elemental constituents. In each compositional system, the useful products are often a specific composition or at best a narrow range of compositions [6]. Table 2.1 lists the melting temperature of examples of lead free solder alloys among the viable lead free systems. Table 2.2 illustrates viable lead free compositions that offer superior mechanical properties in strength, creep resistance and fatigue resistance, as compared with 63Sn/37Pb [6].

New solder alloys must possess characteristic that are compatible with the practical manufacturing techniques and end use environment. The basic material properties (i.e. liquid/ solid temperature, electrical/ thermal conductivity, intrinsic wetting ability on commonly used surfaces, mechanical properties and environmental shelf stability) must be gauged. Under the current framework the alloys conductivity and shelf stability are not as sensitive to the makeup of a specific system as the intrinsic wetting ability, mechanical performance, and phase transition temperatures.

The ability to optimize these properties through in depth application of material science and metallurgical phenomena is the key.

During the last 15 years, many compositions have been developed and disclosed. More than 100 patents on lead free solder alloys have been issued world wide. Among them, most of the disclosed compositions cannot be readily utilized for commercial applications. Still, some lead free alloys can be put to practical use delivering a performance that exceeds that of their lead containing counterparts as shown under practical test condition.

Table 2.1 Ranking of viable alloy compositions by melting temperature

ALLOY	MELTING TEMPERATURE
88.5Sn/3.0Ag/0.5Cu/8.0In	195-199°C
93.3Sn/3.1Ag/3.1Bi/0.5Cu	209-212°C
91.5Sn/3.5Ag/1.0Bi/4.0In	208-213°C
96Sn/3.5Ag/0.5Cu	210-215°C
96.2Sn/2.5Ag/0.8Cu/0.5Sb	217-219°C
96.5Sn/3.5Ag	221°C
99.3Sn/0.7Cu	227°C
Reference 63Sn/37Pb	183°C

Table 2.2 Ranking of viable alloy compositions by fatigue resistance

ALLOY	*N_F
88.5Sn/3.0Ag/0.5Cu/8.0In	>19,000
91.5Sn/3.5Ag/1.0Bi/4.0In	10,000-12,000
92.8Sn/0.7Cu/0.5Ga/6.0In	10,000-12,000
93.3Sn/3.1Ag/3.1Bi/0.5Cu	6,000-9,000
96.2Sn/2.5Ag/0.8Cu/0.5Sb	6,000-9,000
96Sn/3.5Ag/0.5Cu	6,000-9,000
96.5Sn/3.5Ag	4,186
92Sn/3.3Ag/4.7Bi	3,850
99.3Sn/0.7Cu	1,125
Reference 63Sn/37Pb	3,650

*N_F denotes the fatigue life in number of cycles as measured in accordance with ASTM Standard E606-92 (Standard Practice for Strain- Controlled Fatigue Testing)

2.2.2 Lead Free Solders (Sn0.7Cu)

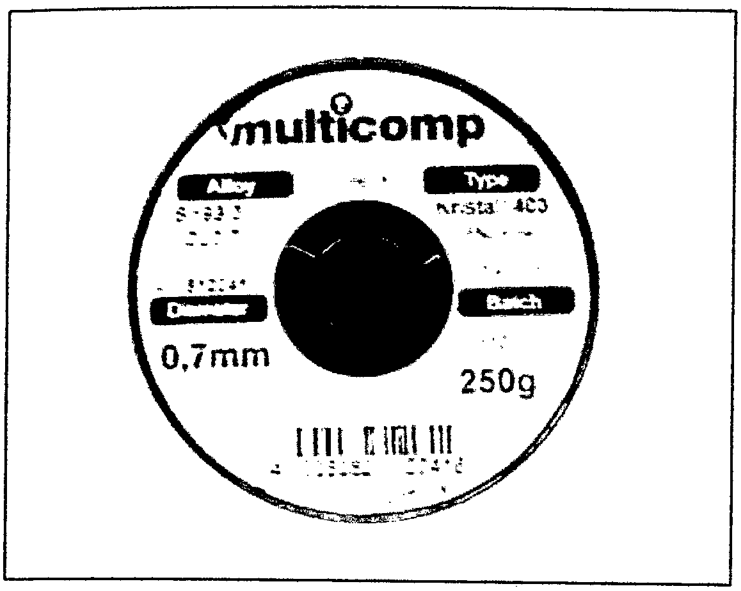

Figure 2.1 Lead free solder (Sn0.7Cu)

Figure 2.1 show solder wire of lead free solder (Sn0.7Cu) type 400 that been used in this project. This solder wire has a diameter 0.7mm, and weight 250 gram. Melting temperature range of this solder wire is 230°C-240°C (according data sheet that provide by Multicomp Company).

Sn 0.7Cu is used in this work. This solder was chosen because suitable for high temperature applications required by the automotive industry [5]. It is a candidate especially for companies looking for lead and silver free alloys. Preliminary testing conducted on this alloy has shown a significant improvement in creep and fatigue data over standard Sn-Pb alloys.

Table 2.3, 2.4 and 2.4 shows the relative wetting performance of Multicomp solders wire (Sn0.7Cu) type 400 compared to competitor A and B. the performance is evaluated based of flux content and oxidized copper and oxidized brass area of spread.

Table 2.3 Specification of Sn0.7Cu

Relative Wetting Performance of Multicomp Solder Wire and Halide Free Competitor Products*			
Product	Flux Content (%)	Area of Spread (mm^2)	
		Oxidised Copper	Oxidised Brass
Typ 400	2.2	222	209
Competitor A	3.5	191	140
Competitor B		202	

*Oxidised for 1 hour at 205°C.

Table 2.4 Specification of Sn0.7Cu

Relative Wetting Performance of Multicomp Solder Wire and Halide Free Competitor Products*				
Product	Flux Content (%)	Halide Content (%)	Area of Spread (mm^2)	
			Oxidised Copper	Oxidised Brass
Competitor E	2.0	0.4	200	150
Competitor F	2.4		190	180
Competitor G	3.5		150	120
Competitor H	2.7	0.5	230	150
Typ 505	3.0		220	240

*Oxidised for 1 hour at 205°C.

Table 2.5 Specification of Sn0.7Cu

Relative Wetting Performance of Multicomp Solder Wire and Halide Free Competitor Products*				
Product	Flux Content (%)	Halide Content (%)	Area of Spread (mm^2)	
			Oxidised Copper	Oxidised Brass
Typ 511	3.0	1.1	270	390
Competitor J	2.2	1.2	260	190
Competitor K	2.0	1.6	210	230

*Oxidised for 1 hour at 205°C.

**Source:* Multicomp Company