

EFFECT OF CORROSION ON PRINTED CIRCUIT BOARD

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DEGREE OF MECHANICAL ENGINEERING

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EFFECT OF CORROSION ON PRINTED CIRCUIT BOARD

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I hereby declare that the work in this report is my own, except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any other Degree and is not concurrently submitted for award of other degree.

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Date :

Special dedication to my parents and family members that always inspire, love and stand beside me, my supervisor, my beloved friends, my fellow colleagues, and all faculty lecturers and members. For your love, care, support, and believe in me. Thank you so much.

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ABSTRACT

Corrosion of electronic systems has been a significant issue in electronic industry nowadays. One of the most common corrosion type is the atmospheric corrosion. Therefore, even a small environmental impact can cause huge damages if the components are not well protected. When the device is in use, the large voltage gradients between points on a printed circuit board (PCBs) will accelerate the corrosion problems dramatically. The complexity of the atmosphere, as corrosion environment, results from atmosphere composition and from presence of some factors as pollutants, temperature, humidity, wind speed and direction. So, the objective of the study is to identify the effect of corrosion on solder joint and copper substrate in 0.5M Sulphuric acid (H_2SO_4) in order to determine the corrosion rate of the substrate in duration time by using weight loss measurement method. Lead-free solder bump were used to form solder joint between lead-free solder Sn-3Ag-0.5Cu (SAC 305) solders with the plated copper substrate. The copper substrate surface finish was deposited by the electroless nickel. The result of study shows the corrosion on the substrate after immersed in 0.5M Sulphuric acid at 168 hours, 336 hours, and 504 hours. The effect of corrosion was increased with the time duration increased. The weight loss data indicated that the thickness of the substrate decreased with the time duration. The structure of the solder joint was analyze using scanning electron microscopy (SEM).

ABSTRAK

Kakisan sistem elektronik telah menjadi isu yang penting. Salah satu jenis yang paling kerap mengalami kakisan adalah kakisan atmosfera. Oleh itu, walaupun kesan yang kecil alam sekitar boleh menyebabkan kerosakan yang besar jika komponen-komponen tidak dilindungi dengan baik. Apabila peranti yang digunakan, kecerunan voltan yang besar antara titik pada PCB akan mempercepatkan masalah hakisan secara mendadak. Kerumitan atmosfera, persekitaran kakisan, hasil daripada komposisi atmosfera dan dari kehadiran beberapa faktor seperti pencemaran, suhu, kelembapan, kelajuan angin dan arah. Oleh itu, objektif kajian ini adalah untuk mengenal pasti kesan hakisan pada sendi pateri dan kepingan tembaga dalam asid sulfurik 0.5M (H_2SO_4) untuk menentukan kadar kakisan kepingan tembaga dalam tempoh masa yang ditetapkan dengan menggunakan kaedah pengukuran berat kepingan tembaga yang hilang. Bebola pateri plumbum telah digunakan untuk membentuk sendi pateri antara tembaga Sn-3Ag-0.5Cu (SAC 305) dengan kepingan tembaga bersalut. Kemasan permukaan kepingan tembaga telah disalut oleh nikel tanpa elektrik. Hasil kajian menunjukkan hakisan pada kepingan tembaga selepas di rendam dalam 0.5M asid sulfurik pada tempoh 168 jam, 336 jam dan 504 jam. Kesan hakisan meningkat dengan peningkatan tempoh masa. Data berat kepingan tembaga menunjukkan penurunan ketebalan kepingan tembaga dalam tempoh masa dan menganalisis struktur sendi pateri dengan menggunakan mikroskop imbasan elektron (SEM).

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW OF THE PROJECT

In recent years, corrosion of electronic systems has been a significant issue in electronic industry nowadays. Multiplicity of materials used is one reason of limiting the corrosion reliability. The reduced spacing between components on a printed circuit board (PCB) due to miniaturization of device is another factor that has made easy for interaction of components in corrosive environments. Presently the knowledge on corrosion issues of electronics is very limited. Simultaneously, increased use of electronics has also increased the demand for reliability. The demand for miniaturization, multiplicity of materials used, effect of process residues together with unpredictable user environment has opened up serious corrosion problems. Therefore, even a small environmental impact can cause huge damages if the components are not well protected. When the device is in use, the large voltage gradients between points on a PCB will accelerate the corrosion problems dramatically. However, the impact of voltage gradient on PCB corrosion is often overlooked with respect to damage in electronic circuits. The atmospheric conditions for corrosion are very complex and the corrosion rates vary in function of geographic zone, of season and daily time. The complexity of the atmosphere, as corrosion environment, results from atmosphere composition and from presence of some factors as pollutants, temperature, humidity, wind speed and direction, etc.

1.2 PROBLEM STATEMENT

The purposed of this research is to identify the effect of corrosion between the solder joint and the copper board with electroless nickel surface finish in 0.5M Sulphuric acid by using weight loss measurement with scanning electron microscopy (SEM). By using this method, the formation of structure in the joining can be analyzed and can identify the life time of the material and joining used in the electronic device especially PCB that very popular in electronic gadgets especially smart phones among the consumers. Unfortunately the electronic device such as phones will not last longer and the life of these gadgets also became questioned when exposed to different kind of environment such as sea water and sulfur environment. They have several type of corrosion that happened in electronic system (PCB). Several materials are used in electronic industry and new materials are emerging all the time. However, the materials combinations together with demand for miniaturization and large spread in user environment have introduced significant corrosion problems.

1.3 OBJECTIVES OF RESEARCH

Basically, the main purposes in accomplishing this study are shown below :

- (i) To investigate the effect of corrosion at the joining of the lead-free solder Sn-3Ag-0.5Cu (SAC 305) and electroless nickel surface finish of the copper board.
- (ii) To study the suitable method for the experiment and to calculate the corrosion rate for each specimen by using formula.

1.4 SCOPE OF RESEARCH

Scopes of this research, lead-free solder bump were used to form solder joint between lead-free solder Sn-3Ag-0.5Cu (SAC 305) with the surface finish of copper substrate. The copper substrate surface finish was deposited by the electroless

nickel. The work focuses on the formation of the microstructure after the corrosion test. On the other hand, this research involves the investigation of corrosion effect on the joining of the solder ball and the surface finish of copper substrate. The different corrosion test duration were applied. In this research also some characterization tools were used including image analyzer and scanning electron microscope (SEM) in order to determine the structure of the joining of solder ball formation.

1.5 STRUCTURE OF THESIS

This thesis consists of five chapters. Chapter one is an introduction in which problem statement, objectives of the research and scope of work are presented. The second chapter covers the literature review which includes printed circuit board, surface finishes, solder bump process and soldering technique. In addition, it also includes topics on the intermetallic compound formation at the interface of the solder joint and the environmental corrosion behavior that usually happened in electronic industry. In chapter three, the detailed experimental methodology followed in this research in order to achieve the objectives of the projects is described. In chapter four, result and discussion, all experimental results obtained are presented with the supportive explanation. Finally, in chapter five, a set of conclusions are drawn based on the findings throughout the research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this literature review is to establish a theoretical framework regarding the effect of corrosion on printed circuit board. This literature review is also an evidence to support the research topic to make easier to understand and to complete the project later on. The journals, conference papers, technical report and other useful resources will be including by summarize in this literature review section.

2.2 PRINTED CIRCUIT BOARD (PCB)

PCB form the electrical and mechanical connection between electrical components in the complex circuit of modern electronic designs. PCB not only interconnect with components through conductor routed through the board with traces and vias, but it also provide effective electrical insulation between conductors of different potentials and in different circuit nodes (Daren, 2004). In PCB, there are traces that electrically connect the various connectors and components to each other. Solder is the metal that makes the electrical connections between the surface of the PCB and the electronic components. Being metal, solder also serves as a strong mechanical adhesive.

Before the advent of the PCB circuits were constructed through a laborious process of point-to-point wiring. This led to frequent failures at wire junctions and

short circuits when wire insulation began to age and crack. There are three major types of PCB construction: single-sided, double-sided, and multi-layered. Single-sided boards have the components on one side of the substrate. When the number of components becomes too much for a single-sided board, a double-sided board may be used.

2.2.1 Manufacturing Process PCB

PCB processing and assembly are done in an extremely clean environment where the air and components can be kept free of contamination. Most electronic manufacturers have their own proprietary processes, but the following steps might typically be used to make a two-sided printed circuit board (Pritchard, 1979)

- (i) Generated from the design files and create an exact film representation of the design. Then, create one film per layer.
- (ii) Shear raw material. Industry standard 0.059" thick, copper clad, two sides. Panels will be sheared to accommodate many boards.
- (iii) Drill holes by using NC machines and carbide drills.
- (iv) Apply thin copper deposit in holes barrels.
- (v) Apply image. Apply photo sensitive dry film (plate resist) to panel. Use light source and film to expose panel. Develop selected areas from panel.
- (vi) Electrochemical process to build copper in the holes and on the trace area. Apply tin to surface.
- (vii) Remove dry film, and then etch exposed copper. The tin protects the copper circuitry from being etched.

- (viii) Apply solder mask area to entire board with the exception of solder pads.
- (ix) Apply solder to pads by immersing into tank of solder. Hot air knives level the solder when removed from the tank.
- (x) Apply white letter marking using screen printing process.
- (xi) Route the perimeter of the board using NC equipment.

2.3 SURFACE FINISH

Most of the PCB have surface finishes on their surface due to its improved electrical performance. However, if they are left unprotected, the copper will oxidize and deteriorate. It quickly forms a robust, chemically stable and electrically insulative oxide that creates a connection challenge once it exposed to air. Therefore, surface finish technologies have been developed and are applied to PCB to prevent oxidation of exposed copper on the board, thus ensuring a solderable surface when components are added at a later processing stage. The ideal surface finish would exhibit characteristics that listed below (Jose, 2002):

- (i) The surface finish should be flat and uniform (planar) to allow for good lead connection and uniform component placement.
- (ii) The surface finish should be environmentally friendly. It should not contaminate the environment during mining, manufacturing, assembly and post product life disposal.
- (iii) The finish is compatible with standard assembly process that are proven and well used on today's various assembly lines.

- (iv) The surface finish should have an extended shelf life and should not require special storage control to keep from oxidizing or contaminating the finish.
- (v) The surface finish should promote good solderability. It should process during assembly just as HASL and have good solder reliability.
- (vi) The finish process should generate the highest yield. It should not introduce the PCB to excessive and volatile process, handling or thermal excursions.

However, the ideal surface finish does not exist. Every finish has reliability concerns or fabrication problems. So the goal is to pick out the most important aspects of the surface finish and choose the alternative that best meets the assembly requirements. The following are the most common process variables of concern at assembly (Grainger, 1989):

- (i) Component type and placement method
- (ii) Solder paste type and application (if applicable)
- (iii) Fusing method
- (iv) Possible exposure of each board type to a variety of assembly processes
- (v) Multiple thermal exposures
- (vi) Post cleaning (if applicable)

Less common considerations include the elimination of CFCs and the possible exclusion of leaded solders, solder paste, and flux at assembly. There are

various technologies used for surface finishing nowadays. The predominant PCB surface finishes include:

- (i) Hot Air Solder Level (HASL)
- (ii) Electroless Nickel/Electroless Palladium/Immersion Gold (ENEPIG)
- (iii) Organic Solderability Preservative (OSP)
- (iv) Immersion Silver (ImAg)
- (v) Electroless Nickel/Immersion gold (ENIG)
- (vi) Immersion Tin (ImSn)

2.3.1 Hot Air Solder Leveling (HASL)

In Figure 2.1, HASL is the standard surface finish available in the electronic industry. Basically, a thin coating of solder is applied on the exposed copper by immersing the panel into a molten solder bath. After that, the panel surface passes through the hot air. However, as the miniaturization of electronic packages further continued, the HASL surface finish is not flat or coplanar enough for fine pitch pads. Figure 2.1 is the cross section of the HASL surface finish (Clyde, 2001). The excess solder is then blown from the board by an air knife, leaving a thin, protective layer of solder on the exposed circuitry. The HASL process differs from the other alternatives in that it does not rely on a chemical process to apply the final surface finish. However, this process has been increasingly under scrutiny due to environmental and safety issues (hazardous waste, lead exposure etc), technological limitations (fine-pitch device assembly) and equipment maintenance cost.

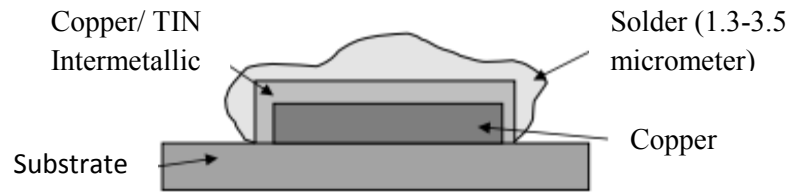


Figure 2.1: Schematic of HASL Surface Finishing

Source : Clyde 2001

2.3.2 Electroless Nickel/Electroless Palladium/Immersion Gold (ENEPIG)

ENEPIG is the universal surface finish where it has the similar function with ENIG. In this surface finish, an electroless nickel layer is deposited on the copper surface. Then a palladium layer is coated on top of the nickel layer. Lastly, immersion gold is topped as a final layer. The function of the palladium is to prevent corrosion during immersion reaction. The palladium and gold will dissolve in the solder during soldering and forms a nickel/ tin inter metallic. However, the limitation of this surface finish is additional cost which leads to higher packaging fabrication cost (Clyde, 2001). The ENEPIG surface finish is illustrated in Figure 2.2.



Figure 2.2: Schematic of Ni/Pd/Au Surface Finish

Source: Clyde 2001

2.3.3 Organic Solderability Preservative (OSP)

By referring the Figure 2.3, OSP is a thin organic compound coats the copper surface. This organic coating preserves the copper surface from oxidation until it is soldered. Benzotriazoles and imidazoles are most widely used preservatives and both are nitrogen-bearing organic compounds. Both compounds have the ability to complex with the exposed copper surface and it does not adsorb to the laminate or solder mask. The organic solderability preservative (OSP) is illustrated.

Benzotriazoles form a thin monomolecular layer to protect the copper until it is exposed to a single thermal excursion at assembly. Where else, Imidazoles form a thicker coating and survive multiple thermal excursions at assembly. Nevertheless, the transparent and colorless coating has caused some inspection difficulties after processing. It also requires thicker coating for electrical testing purpose due to its non-conductive characteristic. Besides that, OSP material especially Imidazoles need more aggressive flux after first and second thermal excursions (Clyde, 2001).

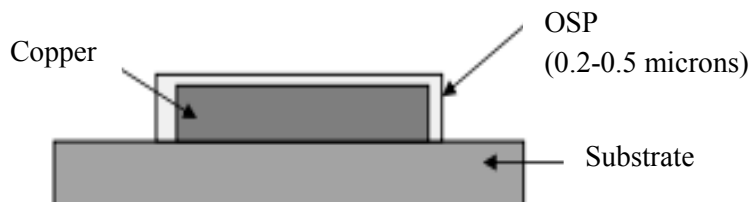


Figure 2.3: Schematic of OSP Surface Finish

Source: Clyde 2001

2.3.4 Immersion Silver (ImAg)

ImAg is an ideal surface finish for soldering where it provides a thin (0.1 to 0.65 μ m), solid silver deposit incorporating an organic and the organic seals the surface to allow for extended shelf life. During assembly the silver will dissolve

into the solder and form copper/ tin intermetallic solder joint which similar to HASL and OSP. Silver offers good coplanarity and solderable surface compare to HASL and it is easy for inspection since its appearance is visible.

It is a potential replacement for HASL due to its lead free coating where it fulfills the 'greener' environmental requirement. However, silver migration in electronic environments is a concern due to its property to form wafer soluble salts when exposed to moisture and electrical bias (Clyde, 2001). The ImAg surface finish is illustrated in Figure 2.4.

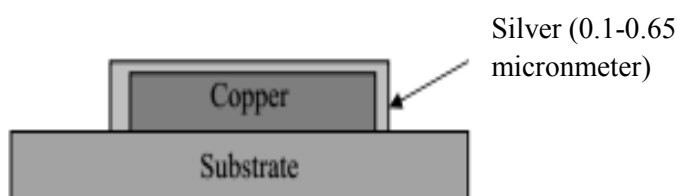


Figure 2.4: Schematic of Immersion Silver

Source: Clyde 2001

2.3.5 Electroless Nickel/Immersion Gold (ENIG)

ENIG is a surface finish that consists of a thick layer of electroless nickel on the top of copper surface and a thin layer of gold on top of nickel surface as shown in Figure 2.5. Characteristic of nickel such as hardness, wear resistance, solderability and uniformly make the PWB more durable while gold prevents oxidation of the nickel which is highly active. ENIG finishes can typically withstand as many as six or more thermal excursions (heating cycles) during assembly without losing solderability. Palladium salt in an acidic solution had been used as the catalyst for ENIG. Palladium ions are deposited onto the surface of the PWB in displacement reaction. The present of this palladium makes the reducing agent to provide electrons to the positivity charged nickel ions during electroless nickel process and

causing the reduction of the nickel and the deposition of element nickel onto the exposed palladium catalyst (Parquet and Spence, 1996).

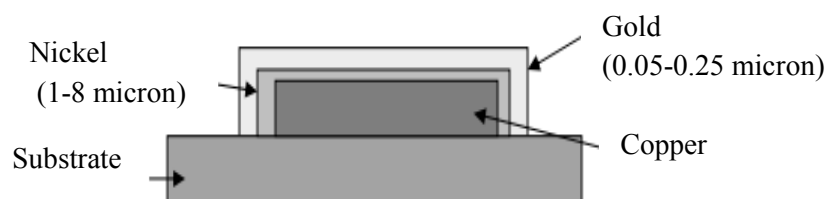


Figure 2.5: Schematic of ENIG Surface Finish

Source: Parquet and Spence 1996

2.3.6 Immersion Tin (ImSn)

ImSn is a good solderable surface where it is deposited directly on the copper surface by chemical displacement reaction. It provides a dense uniform tin with organic coating and forms a standard copper/ tin intermetallic solder joint. Good coplanarity and lead free characteristic allow it to become one of the option as HASL replacement especially for backplane panel application which assembled by pin insertion.

Nevertheless, there are few concerns which limit the growth of this surface finish. One of the main concerns is tin whiskers where it is hairline and mono-crystals that develop and grow as a result of internal stress (mechanical, thermal, and other forms) increase the possibility of electrical short. The growth of copper/ tin intermetallic also limiting the shelf life of the surface and it can further reduce as the reaction accelerates under excessive temperature and humidity condition (Clyde, 2001). ImSn surface finish is illustrated in Figure 2.6.

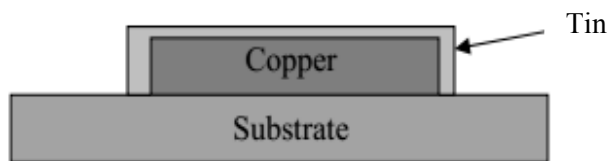


Figure 2.6: Schematic of ImSn Surface Finish

Source: Clyde 2001

2.3.7 Electroless Plating

Electroless plating is the chemical deposition of a metal coating onto an object using chemical reactions rather than electricity. The basic ingredients in an electroless plating solution are a source metal (usually a salt), a reducer, a complexing agent to hold the metal in solution, and various buffers and other chemicals designed to maintain bath stability and increase bath life. Copper and nickel electroless plating commonly are used for printed circuit boards (Mallory and Hadju, 1990).

2.3.8 Immersion Plating

Immersion plating is a similar process in that it uses a chemical reaction to apply the coating. However, the difference is that the reaction is caused by the metal substrate rather than by mixing two chemicals into the plating bath. This process produces a thin metal deposit by chemical displacement, commonly zinc or silver. Immersion plating baths are usually formulations of metal salts, alkalis, and complexing agents (e.g., lactic, glycolic, or malic acids salts). Electroless plating and immersion plating commonly generate more waste than other plating techniques, but individual facilities vary significantly in efficiency (Mallory and Hadju, 1990).

2.3.9 Electroplating

Electroplating is achieved by passing an electric current through a solution containing dissolved metal ions and the metal object to be plated. The metal object serves as the cathode in an electrochemical cell, attracting ions from the solution. Ferrous and non-ferrous metal objects are plated with a variety of metals including aluminum, brass, bronze, cadmium, copper, chromium, gold, iron, lead, nickel, platinum, silver, tin, and zinc. The process is regulated by controlling a variety of parameters including voltage and amperage, temperature, residence times, and purity of bath solutions.

Plating baths are almost always aqueous solutions, therefore, only those metals that can be reduced in aqueous solutions of their salts can be electrodeposited. Plating operations are typically batch operations in which metal objects are dipped into a series of baths containing various reagents for achieving the required surface characteristics. A typical plating sequence involves various phases of cleaning, rinsing, stripping, and plating. Electroless plating uses similar steps but involves the deposition of metal on metallic or non-metallic surfaces without the use of external electrical energy (Mallory and Hadju, 1990).

2.4 SOLDERING PROCESS

Soldering is defined as a process that is used to bond similar or dissimilar materials by melting a filler metal or alloy that is placed between the components being joined. The filler metal, or rather called the solders, must have a much lower melting point compare with the materials being joined. During the process, the molten solders wet the materials in contact with in, forming metallurgical bond by diffusion, dissolving, or alloying with the basis metal (Clyde, 2001). The base metals being joined are usually aluminium or copper. Meanwhile, there are various types of solders being used in the industry in Table 2.1.

Table 2.1: Common Solder Material

| Solder | Characteristic | Application |
|----------------|---|---|
| Tin-Silver | Non-toxic but expensive. Good high temperature properties. | Used for soldering medical or high precision instruments. High temperature applications |
| Tin-Lead | Good process characteristics and the best understood solders | General purpose and the most widely used solders |
| Tin-Antimony | Non-toxic. Good high temperature properties. Better electrical conductivity and strength than tin-lead solders. Good wetting. | High temperature and food industry applications |
| Indium | Deforms easily | Low temperature soldering, wets glass |
| Bismuth | Deforms easily. Needs Aggressive fluxes | Low temperature soldering |
| Cadmium-Silver | Toxic. Good tensile strength | High temperature applications |
| Lead-Silver | Good high temperature properties, good fatigue strength. Medium or low flow properties | High temperature applications |
| Cadmium-Zinc | Toxic | Soldering aluminum |

Source : eFunda (2005)

Therefore, choosing the right solders become the primary concern in the electronic industry. The decision to use a particular material is largely based on its properties such as: ductility, heat conductivity, thermal expansion, electrical resistance, tensile strength, toxic, wettability, and most importantly, the cost.

2.4.1 Solder Material

2.4.1.1 Lead-Free Solder

Due to the inherent toxicity of lead (Pb) to human body, the elimination of Pb usage in the electronic industry has been urged in recent years, most notably in Europe and Japan. The complete ban of lead in electronics in near future has been the driving force to search for suitable lead-free solders. Unfortunately, there is a general lack of the fundamental knowledge on the application, behavior and reliability of these lead-free solders.

In choosing a new solder to completely replace the current eutectic tin-lead solder, two issues which are manufacturing and performance of the solders have become the main concerns. Manufacturing issues are related to the cost, availability, and wetting characteristics of the alloy. More importantly, the melting point of the alloy, as it will have a direct impact on the other polymeric materials used in microelectronic assembly and encapsulation.

On the other hand, the performance issues are related to the mechanical and physical properties of the alloys. These properties include mechanical strength, fatigue resistance, coefficient of thermal expansion and intermetallic compound formation (Abtey and Selvaduray, 2000).

There are approximately seventy types of lead – free solders proposed thus far. Most of these new alloys are ternaries and quaternaries, rather than binaries. And a very large number among them are based on tin (Sn) as the primary constituent. Other alloying elements are zinc (Zn), copper (Cu), bismuth (Bi), silver (Ag) and indium (In). The descriptions of some lead-free binary systems have been summarized in Table 2.2.

Table 2.2: Descriptions on Some Lead-Free Binary Systems

| Solder Alloys | Descriptions |
|----------------------|--|
| Sn – Zn | 91Sn9Zn is the eutectic composition for the Sn – Zn system. It appears to be an attractive alternative due to its melting temperature of 198°C, which is relatively close to eutectic tin-lead. However, both Sn and Zn interact with Cu to form intermetallic phases. |
| Sn – Cu | The eutectic composition of this system is 99.3Sn0.7Cu and it has the eutectic temperature of 227°C. Due to the high concentration of tin in this alloy, it may be prone to whisker growth or the transformation to gray tin may occur. |
| Sn – Bi | The eutectic composition is 42Sn58Bi. It has relatively low eutectic temperature of 139°C. The expansion results in embrittlement, which may be due to strain hardening caused by deformation that occurs to accommodate the expansion. |
| Sn – Ag | The eutectic composition for the Sn – Ag binary system occurs at 96.5Sn3.5Ag. The eutectic temperature is 221°C. Similar to the Sn0.07Cu alloy, this solder may be prone to whisker growth due to its high tin composition. |
| Sn – In | In this binary system, the eutectic composition is 49.1Sn50.9In, and the eutectic temperature is 117°C. |

Source: Abtew and Selvaduray 2000

2.4.1.2 Tin-Lead Solder

Tin-lead alloys are the most widely used solders due to their low melting temperatures and wide availability. This combination has been used as soldering materials for more than 50 years, therefore, they are well studied and this makes

them a very important soldering material until today. Various compositions of tin – lead solders are used for different purposes. The non-eutectic solders will undergo a pasty phase when they are cooled from liquid state (Figure 2.7). This pasty phase is sort of half way between solid and liquid states, which will make the soldering work harder. Therefore, eutectic tin – lead solder (63Sn37Pb) is widely used in electronic applications, as it will solidify directly from liquid state once the temperature drops below the single melting temperature, 183°C. This allows for predictable soldering and fast cycle times.

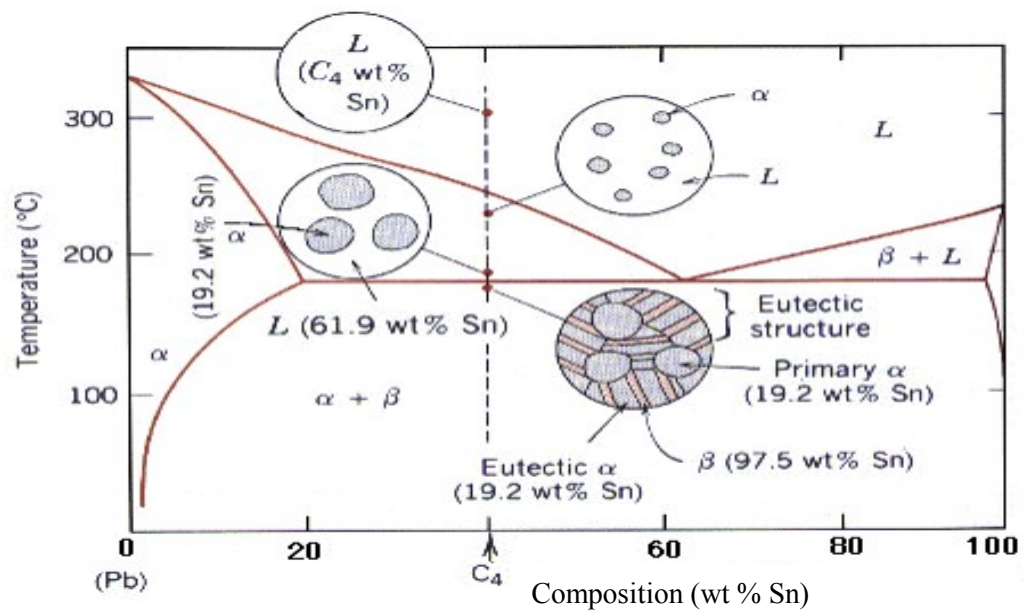


Figure 2.7: Phase Diagram for Tin–Lead Alloy

Source: Hinch 1988

2.4.2 Fluxing

Fluxing is an essential cleaning process to ensure the good solderability of the substrate surface. Basically, the main function of fluxing is to remove tarnish. Tarnish is the reaction products of metal in air which include oxides, sulphides, and others. And the tarnish composition depends on the impurities in the atmosphere. Besides that, a small amount of contaminations such as smoke, dust, lint, combustion

emissions and process fumes that collect on the bonded surfaces can be removed during the fluxing process.

Applying fluxes may also temporarily prevent further formation of oxide films on the surfaces. Another function of fluxing is to lower the surface tension of the molten solder to promote wetting. The residue fluxes need to be removed after the soldering process as they are corrosive. If they are not properly cleaned, they will eventually corrode the metals being joined, leading to product failures. Therefore, flux selection should be done with great care so that the flux selected can suit the surfaces which it is supposed to protect.

2.4.3 Flux Types

Generally, there are three categories of flux used in soldering process:

2.4.3.1 No-Clean (NC) Flux

This type of flux has mild action and the residue can be left at boards without adverse effect and does not require cleaning. The absent of the cleaning process lead to lower operating cost and capital expenditure. However, using this type of flux may limit the component from high frequency application.

2.4.3.2 Water Soluble (WS) Flux

This type of fluxes consists of organic acid, thus the residues must be completely removed after soldering because they are corrosive. It is designed so that it can be removed by using pure water or a water medium with the addition of a saponifier or an additive. Relatively higher operation cost due to water and energy consumption during cleaning process. They are widely used in wave soldering. Lack of tackiness limits its usage as solder paste in reflow soldering.

2.4.3.3 Rosin-Based (RA or RMA) Flux

Rosin is a solid extracted from the sap of pine trees. This type of flux is based on natural or modified gum rosin with the addition of organic acids and organic halides as activator. Thinner is added to liquefy the flux. The cleaning of these fluxes may be done in solvent or water/ saponifer solution. Rosin is inactive at room temperature but becomes active when it is heated to the soldering temperature. The melting point of rosin (172 – 175°C) is slightly lower than the melting point of solder (183°C). This desirable property makes them a good choice in both wave and reflow soldering.

2.4.4 Important Factors in Soldering

There are four factors that are equally important in the process of completing reliably soldered assemblies (Bernier, 1986):

- (i) Solderability
- (ii) Flux
- (iii) Solder
- (iv) Heat

Solderability is a measure of something's ability to be soldered; the more surface can be wetted by solder, the higher its solderability. Wetting can be defined as the process in which the solder comes in into direct contact with the metal surfaces to be soldered, while soldering can be described as the thermal joining process based on the fusion of a low melting alloy and its reaction with the substrate.

For successful joining, a clean metal substrate surface is essential. If not, direct metallic contact cannot occur, leading to dry joints where all or part of the metal surface is devoid of solder.

Copper is ideally suited to soldering, once its surface has been cleaned and etched to give an active surface. In this state, however, oxide layers are prone to form on its surface, reducing the solderability (Bernier, 1986). Metals such as copper must therefore be coated with a material resistant to oxidization, to maintain solderability. In order to solder a given metal or alloy, the substrate itself must also be solderable in its uncoated state.

A substrate which is insufficiently active to be soldered in its uncoated state will not perform well, even after deposition of tin or tin-lead. The reaction between solder and substrate will produce a layer on the interface between the solid substrate and the molten solder called intermetallic compounds comprising hard and brittle crystals but only the tin in the tin-lead solder alloy takes part in it.

This diffusion zone has a profound effect on the mechanical properties of the soldered joint and on its behavior during its service life. Any non-metallic surface layer on the substrate, such as oxide and sulfide however thin will prevent this reaction thus preventing soldering. Unless the contamination is removed, the reaction cannot occur. The soldering flux has to remove this layer, and must prevent it from forming again during soldering. It is important to understand that the flux only has to enable the reaction between substrate and molten solder to take place.

It does not take part in the reaction once it has arranged the encounter between the two reaction partners. The primary tasks which soldering flux must perform rapidly are:

- (i) Remove oxidation or tarnish
- (ii) Prevent oxidation during heating

(iii) Lower interfacial surface tensions

Figure 2.8 shows schematically how solder will wet and spread on a clean metal after flux has done its job of preparing the surface by removing oxides and tarnish. A surface is wetted when the solder flows well, forming a continuous, unbroken film, free of pinholes and depressions. Without flux the solder would pull back from the dirty surface into an elliptical shape, much as water balls up on a waxed surface (Bernier, 1986).

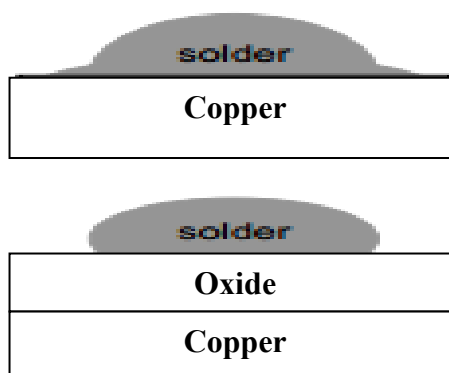


Figure 2.8: Effect of Flux on Wetting

Source: Bernier 1986

Though there are hundreds of solder alloys made from many different metals, the most common solders consists of a mixture of tin and lead. For electronics soldering only the alloys near the eutectic composition of 63% tin and 37% lead have the required properties.

The one parameter of soldering that receives the least attention is heat. Heat is defined as a temperature for a time. The objective to obtaining high quality soldering is to have the molten solder contact the metal surface for 1-2 seconds. If the metal surfaces have been properly cleaned and coated with flux and heated to the correct temperature, nearly every solder alloy will bond to the metal.

A longer amount of time may result in excessively thick intermetallic formation and solder joint embrittlement. To get the proper amount of heat with hand soldering irons, the mass of the tip must be balanced with the mass of the solder joint so that rapid heat transfer can take place. The soldering iron tip temperature should be selected so that each connection can be completed in 1-2 seconds.

2.4.5 Soldering Method

2.4.5.1 Reflow Soldering

Reflow soldering is the most common means to attach a surface mounted component to a circuit board, and typically consists of applying solder paste, positioning the devices, and reflowed the solder in a conveyORIZED oven. The purpose of the reflow process is to melt the powder particles in the solder paste, wet the surfaces being joined together, and solidify the solder to create a strong metallurgical bond.

Reflow soldering possesses several advantages over wave soldering where the solder is applied only at where it is needed. Another benefit is that the temperature profile can be accurately controlled. Thermal shocks of electronic components are eliminated with reflow soldering. There are usually four process zone in conventional reflow process, consisting of preheat, thermal soak, reflow and cooling.

The solvents will evaporate from the solder paste during the preheat phase before entering the soak phase. During the soak phase the temperature rises slowly. The purpose is to activate the flux and to equalize the temperatures on the PCB. Most fluxes activate at around 145°C. If this temperature is not reached during the soak period only partial cleaning of the solder spots are performed and wetting problems can occur. After that, while in reflow phase the temperature is risen to melt the solder paste alloy and then form the solder joints.

To avoid a too thick intermetallic layer, the ideal solder temperature is 30°C-40°C above the solder paste melting point (Bentzen, 2000). The final step is the cooling phase. The purpose of this step is for the solder joint to perform a strong bonding between the solder pad and the component terminal. For this, the cooling should be as fast as possible. There are many types of reflow soldering widely used in surface mount technology such as:

(i) Laser Soldering:

The Laser Soldering process utilizes a precisely controlled laser beam to transfer energy to a soldering location where it is absorbed and used for soldering. The laser energy is absorbed by the substrate, the solder, or the flux. The absorbed energy heats the solder until it reaches its melting point. This precisely controlled process leads to a fast joining of the involved components. Very short heating and cooling cycle results in a fine intermetallic structure, and accurate and non-contact process guarantees a high quality solder joint.

(ii) Infrared Reflow Soldering:

This method consists in heating the SMD with the heat generated from an infrared panel heater and soldering it onto the PWB. The advantages of IR reflow solder are low running cost with excellent maintainability and shorter soldering time.

(iii) Conduction Reflow Soldering:

Conduction reflow soldering machine that uses moving hot air or inert gas (nitrogen) to envelope the entire printed circuit assembly.

(iv) Condensation /Vapor Phase Reflow Soldering:

This process uses a condensation method where a saturated vapor is used to transfer heat. Saturated vapor is much more uniform and able to transfer its heat to all surfaces of the product evenly. It insures that all surfaces of the product, including shadowed or densely populated areas, are heated in a uniform fashion.

Vapor phase has always been a better reflow choice when it came to expensive boards, high mass and complex assemblies, because the assemblies get even heat quickly without the possibility of overheating.

2.4.5.2 Wave Soldering

Wave soldering is widely used in the thru-hole printed circuit board assemblies. Basically there is a tank which heated at high temperature to hold the molten solder. The components are inserted to the PCB and the loaded PCB is placed on a motorized, edge hold conveyor where it is fluxed, preheated and skimmed over the crest of the solder wave. As the PCB continues past the wave, it cools and solder solidifies and complete solder joint formation (Clyde, 2001).

Basically, there is three stages in this process which is fluxing zone, preheat zone and soldering zone. In fluxing zone, the fluxed applied flux underside of the PCB. This is a key sub-process where uniform and sufficient quantity of flux application requires for a good solderability. The two common fluxing methods used are spray fluxing and foam fluxing. In the preheating zone, the heaters function is to heat up the PCB to increase its temperature.

The purpose of this zone is to prevent thermal shock on the PCB which sudden high temperature expose will potential cause failure on board reliability and it is also essential for flux to reach enough temperature for its activation, reaction and disruption of oxides and tarnishes on the metals of the materials to be soldered (Clyde, 2001). In soldering zone, the solder waves contact the bottom of the PCB and attach to the solder pads and component leads via surface tension. The control

of solder wave height is important to ensure the solder does not splash to unnecessary areas.

This process requires nitrogen atmosphere to promote the quality of the solder joints. The presence of N₂ is essential to reduce oxidization which is known as solder dross where is a metallurgical term used to describe non-metallic waste products like oxides and sulfides that form on the melt. There are few parameters which influence the solder joints formation such as dwell time, conveyor speed, temperature and soldering direction.

All these parameters control is essential to produce a reliable solder joint. Nevertheless, surface mount technology has replaced the thru-hole assemblies which lead to the application of reflow soldering technique. The wave soldering is shown in Figure 2.9.

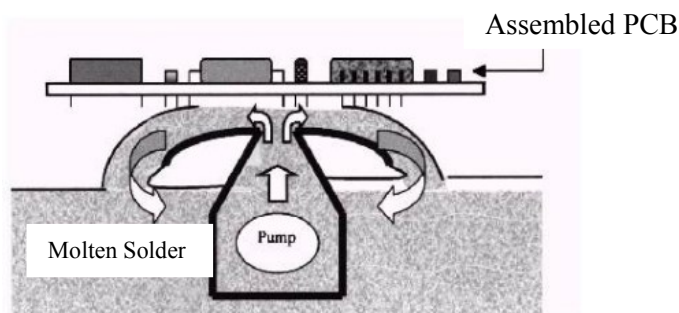


Figure 2.9: Schematic Wave Soldering

Source: Clyde 2001

2.4.5.3 Hand Soldering

Hand soldering remains a key part of many assemblies processes and demands a high level of operator skill allied with a careful choice of materials and equipment. Every production facility in the electronics industry performs hand soldering with a soldering iron, or bit, which is the oldest and most familiar heating

device used to solder. A soldering iron is selected on the basis of the power and tip size needed to maintain a constant tip temperature for the particular connection type to be made. To ensure maximal heat transfer to the part to be soldered, the tip must be applied at the best angle for the situation (Bilotta, 1985).

The soldering operation itself is intrinsically simple. To create a solder joint of high integrity the tip of a pre-tinned soldering iron should be applied simultaneously to the two surfaces to be joined as shown in Figure 2.10. The surfaces need to be sufficiently hot so that when molten solder is applied it does not instantly solidify, but instead remains liquid long enough to spread across the area of the joint and wet the surfaces to be joined (Hawkins, 2001).

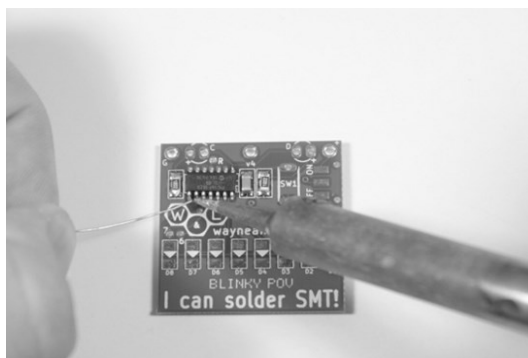


Figure 2.10: Hand Soldering

Source: Hawkins 2001

Solder itself is applied to the joint area as the iron is held against the joint. This causes the solder to melt, and at the same time the elevated temperature activates the flux content which cleans the surfaces promoting good wetting. Once sufficient solder has been added to form a strong joint, the heat is removed and the solder, the metal coating of the pad and component combine and solidify into an intimate mass forming a strong and conductive bond. To achieve good manual soldering some requirements must be met.

To begin with, a quality standard is required as a basis for both production build and quality control inspection. In order to meet these standards, correct soldering irons, tips, solders, fluxes, and fixturing must be supplied.

2.4.6 Solderability

Solderability can be defined as the ability of achieve a clean metallic surface on substrates to be joined during a dynamic heating process so that a good wetting molten solder on the surface of the substrates can be formed (Charles, 2005). Solderability is an important property in electronic assembly to ensure the formation of a uniform and continuous solder coating on the surface of solders pads. Thus wetting is crucial for soldering process. In general, wettability is a measurement of how well the molten solder diffuses into the solid surface of the metal to be soldered.

Any contamination on surface such as greases, oxide film will cause non-wetting or de-wetting between solder and metal surface. Solderability is much depends on the fluxing efficiency provided by fluxes and quality of the substrate surface (Charles, 2005). The fluxing efficiency can be measured by the effectiveness of the chemical cleaning on metal surface and solder bump to removing surface oxide on both components and promotes the formation of intermetallic bonding.

2.5 INTERMETALLIC COMPOUND (IMC)

IMC is defined as a mixture in specific proportions of two metallic elements that form a periodic crystalline structure different from those of the original elements. Unlike conventional metal alloys, the particular structure of intermetallic compounds is caused because of the respectively larger strength of bounding between the respective unlike atoms than between like atoms. This particular structure of intermetallic compounds gives them some mechanical properties such as high melting points and great strength (particularly at high temperatures), but poor ductility (Sandström, 2002).

The particular structure of intermetallic compounds is caused because of the respectively larger strength of bonding between the respective unlike atoms than between like atoms. This has resulted in ordered atom distributions where atoms are preferentially surrounded by unlike atoms. Since the crystal structure of an intermetallic compound is determined by the strength and character of bonding, thus it changes with the electronic configuration of the basic elements.

IMCs are commonly found at two places: the solder/ substrate interface and within the bulk of the solder joints as shown in Figure 2.11. This layer which contains one or more IMCs formed at the moment the joint is made, and is responsible to form a strong bond. However, thick IMCs layer would make the solder joint brittle and thus bring failure to the joint. Furthermore, IMC layers do not stop once they are formed, but they may grow and thicken after ageing or during service.



Figure 2.11: Intermetallic Compound Layer Formed between Solder/Base Metal

Source: Sandström 2002

Excessive growth of IMCs is unwanted. Despite of their hard and brittle natures which may cause crack around the interfacial area when stress is applied, the extreme dissolution of base metal into the solder may also cause de-wetting effect as

the substrate metal is depleted. Moreover, depletion of the substrate metal may expose the base material to oxidation. At the same time, dissolution of the solder material elements may also affect the solder joint properties adversely.

The formation of intermetallic compounds at the solder/ substrate interface is briefly due to these factors as listed below:

- (i) Metallurgical reactivity between the solder and the surface metal elements
- (ii) Soldering peak temperature
- (iii) Time of exposure at peak temperature
- (iv) Surface condition of substrate
- (v) Post-soldering storage and service conditions

2.5.1 Types of IMCs Formation in Solder Joint

Formation of IMC at the solder interface is primarily governed by the material of the solder, surface finish and substrate metal pad. As discussed previously, the most commonly found IMCs are from copper-tin frame, where the copper is the base material and the tin comes from solders. The growth of the total intermetallic layer is influenced by the synergy in formation and growth between $\eta(\text{Cu}_6\text{Sn}_5)$ and $\epsilon(\text{Cu}_3\text{Sn})$ phases. Both the η -phase and ϵ -phase are formed due to the reaction between Sn and Cu, although the η -phase forms first and at lower temperatures ($< 170^\circ\text{C}$).

The ϵ -phase has been shown to grow at the expense of the η -phase, and has higher activation energy of formation, so growth of ϵ is more predominant at higher temperatures. The mechanisms for intermetallic formation are also greatly influenced by the interdiffusion characteristics of tin and copper. This brittle

intermetallic compound not only reduces the strength of the solder joint but also functions as stress concentration regions. Due to the issue of solder joint reliability originating from formation of intermetallic compounds, surface finish and solder material compatibility becomes very critical. Figure 2.12 shows the dissolution rates of some metals in tin.

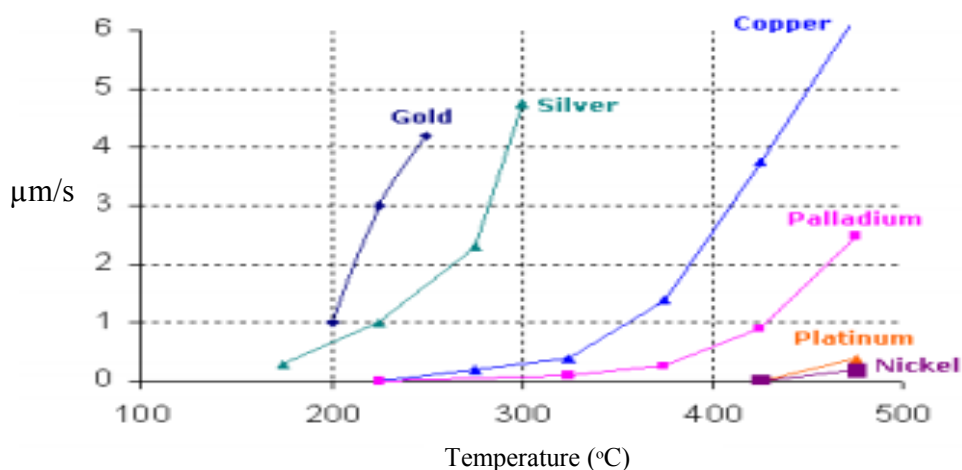


Figure 2.12: Dissolution Rate of a few Typical Base Metals in Tin

Source: Cullen 1998

The dissolution rates of base metals greatly affect the thickness of the IMC formed, and the thickening of intermetallic becomes brittle and susceptible to cracking, thus affecting the integrity of the solder joint. Since the nickel has one of the lowest dissolution rates in tin, the Ni-based UBMs have been widely used as a diffusion barrier due to the rapid reaction of Sn with the Cu conductor and the spalling problem associated with Cu–Sn intermetallic composition.

Figure 2.13 shows the layer of Copper-Tin adjacent to the solder material while the Cu_3Sn layer grows underneath the Copper-Tin layer adjacent to the copper pad.

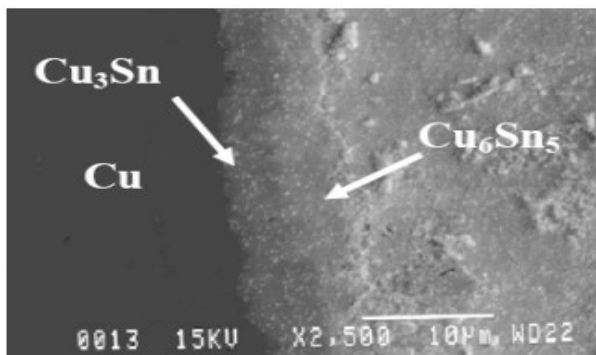


Figure 2.13: SEM Image of Copper Tin Interface

Source: Madeni, 2003

2.6 CORROSION

Corrosion is the gradual chemical or electrochemical attack on a metal by its surroundings such as that the metal is converted into an oxide, salt or some other compound which results to loss strength, hardness, toughness and other desirable mechanical properties which metal possess (Evan's, 1963). Corrosion also highlighted that corrosion can simply be defined as the destruction of a material (metallic or non-metallic) because of reaction with its environment (Fontana, 1967). Corrosion literally consumes the material reducing load carrying capability and causing stress concentration. It is often a major part of maintenance cost and corrosion prevention is importance in many designs.

The corrosion process is usually electrochemical in nature, having the essential features of a battery. It is nature process that commonly occurs because of unstable material such as refined metals want to return to a more stable compound. It involved two chemical process which is oxidation process and reduction process. Oxidation is the process of stripping electrons from an atom and reduction occurs when an electron is added to an atom. The oxidation process takes place at an area known as anode which is it positively charged atoms leave the solid surface and enter

into an electrolyte as ions and at the cathode, the corresponding reduction reaction takes place and consume the free electron.

2.6.1 Types of Corrosion

Corrosion is commonly classified based on the appearance of the corroded material. The classifications of the corrosion used vary slightly from reference to reference but there is generally considered to be different forms of corrosion. Corrosion can be categorized in some common types such as:

2.6.1.1 Uniform Corrosion

Uniform corrosion can be defined as the metal loss from the surface. It can be considered the form of corrosion that can be tolerated in marine structures and equipment. It easily to control measure and allowed for any corrosion which does occur. All corrosion phenomena can be also divided into two types: uniform (general) and non-uniform (localized) corrosion. Uniform corrosion is a process when all of a metal surface corrodes, or dissolves. Non-uniform corrosion is a process when only some definite part of a metal surface corrodes (Groisman, 2010).

2.6.1.2 Pitting Corrosion

Pitting corrosion form of extremely localized a corrosion that leads to the creation of a small hole on the surface of metal. Pitting corrosion is a dangerous process causing deep localized attack in metal surfaces, including perforations of thin-walled structures. Attending to this type of pitting only, two other types of attack also resulting in pitting are disregarded: One is pitting of iron after prolonged exposure to acid solutions containing an adsorption inhibitor. The other is pitting of Gs , which is interesting, as apparently a space charge layer in the semiconductor surface is now in the role of the oxide film on passive metals (Kaesche, 2003).

2.6.1.3 Galvanic Corrosion

Galvanic corrosion is an electrochemical process in which one metal corrodes preferentially to another when both metals are in electrical contact and immersed in an electrolyte.

2.6.1.4 Crevice Corrosion

Crevice corrosion is localized corrosion that occurred within narrow clearances or under shielded metal surface. Crevice corrosion initiates due to the operation of a differential oxygen cell. Oxygen reduction occurs both on the metal surface which is exposed to the bulk electrolyte and also on the portion of the metal surface which is contained within the crevice (McCafferty, 2010).

2.6.1.5 Concentration Cell Corrosion

Concentration cell corrosion occurs in soils when a metal is exposed to an environment containing varying levels of electrolytes either of different substances or of the same substance in different amounts.

2.6.1.6 Graphitic Corrosion

Graphitic corrosion is corrosion of gray cast iron in which the metallic iron constituent is converted into corrosion products which cement together the residual graphite.

2.6.1.7 Creep Corrosion

Creep corrosion is formed when unprotected copper reacts with another metal in an acidic medium such as moisture containing sulfur. The corrosion product creeps onto the solder mask surface and causes short circuits between the adjacent

pads and traces. Creep corrosion of electronic assemblies is a growing problem. Commonly seen in harsh environment, the failures result from the formation of copper sulfide films on Printed Circuit Board (PCB) assemblies in short period of time (Haley Fu, 2012)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The main purpose of this research study is to determine the effect of corrosion on the joining between the solder ball and the copper substrate with electroless nickel surface finish by immersed copper substrate in 0.5M of Sulphuric acid and characterize the solder joint that forms between Cu-Ni/Pd/Au metallization and the Sn-3Ag-0.5Cu lead-free solders. The research methodology started with copper substrate preparation followed by surface finish deposition. Following this, the eutectic lead-free Sn-3Ag-0.5Cu solder balls in various sizes were prepared and positioned onto the copper substrate.

After the reflow soldering, solder joints were formed. Then the experiment was followed by corrosion test of these soldered substrates with different corrosion durations. Several types of characterization techniques and analysis are conducted to examine the microstructure of the joining between lead free solders and surface finish after reflow soldering and corrosion test. Top surface of samples is observed by using optical microscopy and scanning electron microscopy (SEM).

3.2 SUBSTRATE MATERIAL

In this research, surface finish was deposited onto the copper-polymer sandwiched substrates. It was cut into the dimension of 45 x 5 x 1 mm (width x length x thickness), as shown in Figure 3.1. Prior to the electroless nickel plating process, the copper substrates were first subjected to a series of pretreatment

procedures to remove dust, grease and oxides. The copper surface was also activated during the pretreatment. Then the plated substrates were pretreated with palladium solution before the electroless palladium plating was initiated.

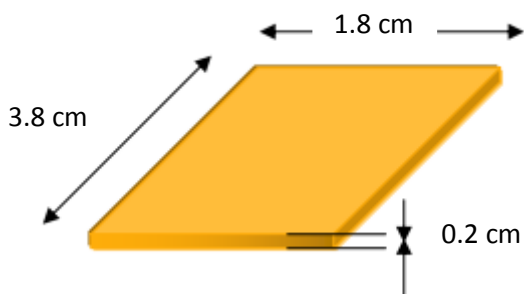


Figure 3.1: Copper Substrate Dimension

3.3 SURFACE FINISH DEPOSITION

3.3.1 Surface Preparation of Copper Substrate (Pretreatment)

The copper substrate needs to be clean in order to remove surface oxide and to activate the copper surface. The pre-treatment procedures include:

- i. Medium alkalinity soaks clean at 70°C-90 °C for 5 minutes to remove dust.
- ii. Rinse with distilled water.
- iii. Alkanity cleans with 10% NaOH at 60 °C for 3 minutes to degrease.
- iv. Rinsed with distilled water.
- v. Acidic clean with 10% H₂SO₄ for 1 minute for deoxidation of the surface.
- vi. Rinse with distilled water.
- vii. Dip into palladium chloride + HCl solution for 3 minutes to activate upper surface.

viii. Rinsed with distilled water.

A flow chart depicting the sequential process of surface pretreatment is shown in Figure 3.2.

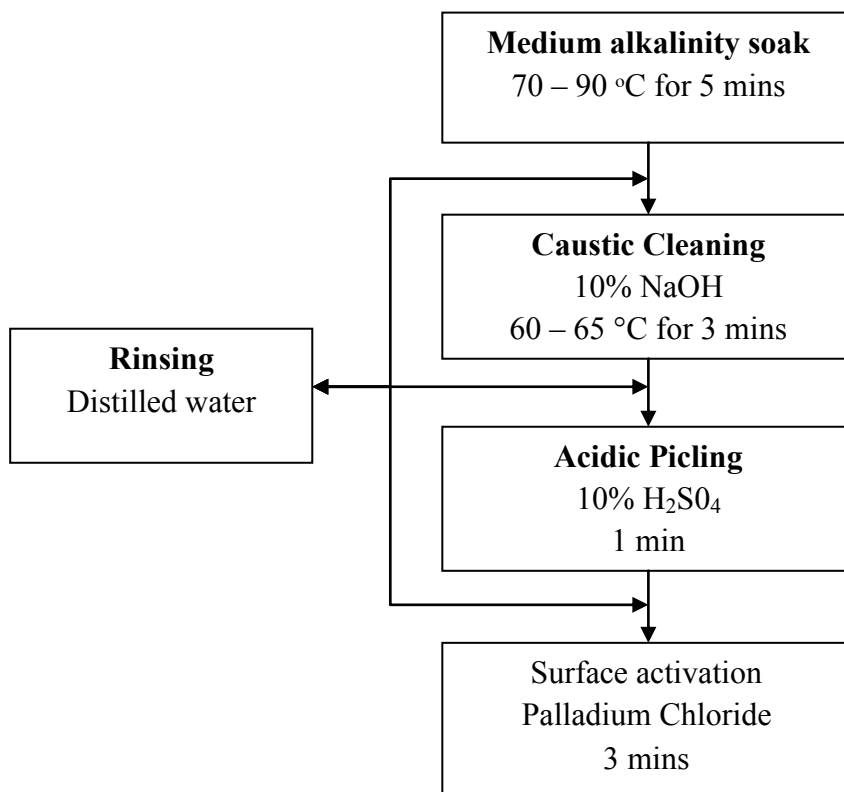


Figure 3.2 : Flow of Copper Substrate Pretreatment

3.3.2 Electroless Nickel Plating

The experimental setup for nickel plating and subsequent palladium/ gold plating comprised of a plating bath system equipped with a stainless steel heating coil to maintain constant temperature within the bath environment. The bath tank has a 10 liter water capacity which was filled with normal tap water.

Table 3.1: Electroless Nickel Plating Bath Chemical Composition and Parameter Detail

| Parameter | Chemical reagent | Quantity |
|----------------------|-------------------------|------------------|
| Metal salt | Nickel Sulfate | 28 g/L |
| Reducing agent | Sodium hypophosphite | 24 g/L |
| Complexing agent | Sodium Aerate | 17 g/L |
| Stabilizer (PH) | Ammonium Chloride | 50 g/L |
| Stabilizer | Thiourea | 0.3 mg |
| PH | - | 2.4-4.6 |
| Temperature | - | 82°C – 88°C |
| Duration (thickness) | - | 60 min (1.507µm) |

In Table 3.1 shows the variations in the solution pH are corrected using either sodium hydroxide or acid hydrochloric depending on excessive acidity or alkalinity respectively. Thiourea is added as a stabilizer to prevent the decomposition of the bath. The temperature for the bath is critical in obtaining a uniform and consistent thickness of nickel layer. A tolerance of $\pm 5^{\circ}\text{C}$ is usually accepted to obtain a good plating layer.

3.3.3 Electroless Palladium Plating

Electroless palladium plating for half the samples was carried out post nickel layer deposition. The additional palladium layer will provide additional protection to the nickel by preventing diffusion of nickel into the porous gold microstructure. Nickel plated copper substrates are rinsed with running water post nickel bath plating. Rinsed samples were then subjected to pretreatment of palladium chloride and hydrochloric acid solution for three minutes to begin surface activation. Upon completion of pretreatment, the samples were then placed into the palladium solution bath using the same plating bath setup as before.

3.4 REFLOW SOLDERING

The purpose of reflow soldering is done to form solder bumps on the surface finish. Generally, reflow soldering consists of three steps which are:

- (i) Flux application
- (ii) Solder balls placement
- (iii) Reflow

3.4.1 Flux Application

No-clean flux was used in this research due to its non-corrosive nature. Thus, no cleaning is required. Flux is applied on the surface finish using a paintbrush. The flux is applied evenly throughout the surface. The surface of flux is to ensure the solderability of the surface finish by removing oxide and tarnish from the surface as shown in Figure 3.3.

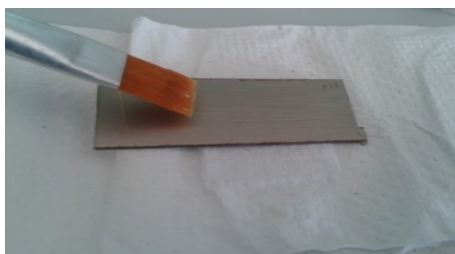


Figure 3.3 : Flux Application

3.4.2 Solder Balls Placement

In this research, we are using lead free solder which is Sn-3Ag-0.5Cu (SAC 305), where the melting temperature is 220°C. Before solder balls placement, a thin layer of no-clean flux is applied on the substrate. The primary function of applying flux prior to reflow soldering is to remove the oxide film and tarnish from the surface of solder balls and substrate surface finish. Besides that, it also improves wetting of

the molten solder during reflow soldering. After that, solder balls are manually placed and arranged in an array of 6 x 11 on each substrate as Figure 3.4.

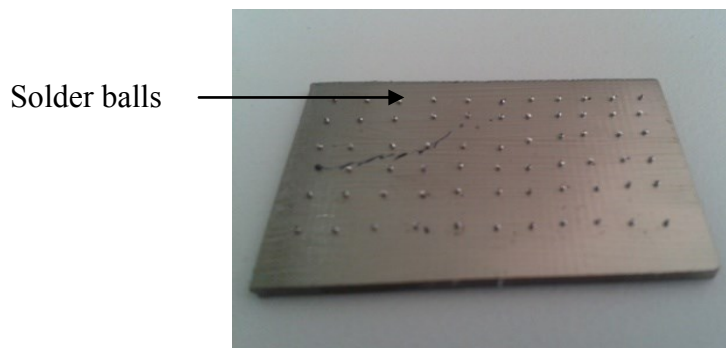


Figure 3.4 : Solder Balls Placement

3.4.3 Reflow

The substrate was subjected to reflow soldering in the resistance furnace with peak reflow temperature of 240°C to form solder joints and metallurgical bonding. Once the reflow peak temperature is achieved, the furnace is opened and substrates taken out and allowed to cool at room temperature. The excessive flux residue is removed by means of a tissue soaked with acetone. Figure 3.5 shows the reflow profile used in this study and Figure 3.6 shows the resistance furnace for reflow soldering.

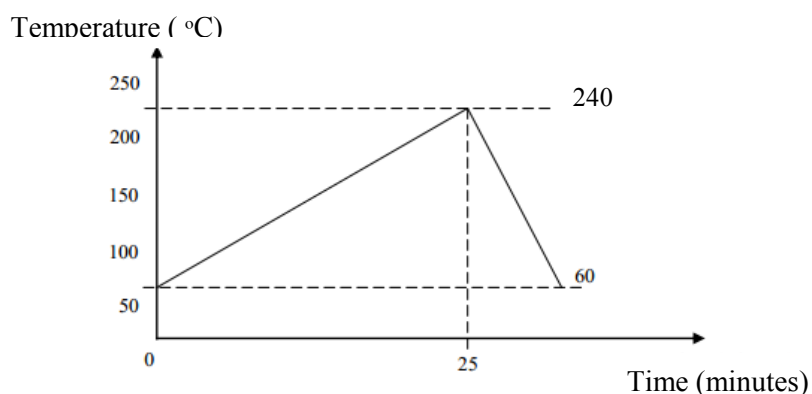


Figure 3.5 : Reflow Profile for Sn-3Ag-0.5Cu Solder



Figure 3.6 : Resistance Furnace for Reflow Soldering (Machine Model: Motion S-MT-JEQF)

3.5 CORROSION TEST

The weight loss experiments were carried out using rectangular copper substrate (99.999%) having dimensions of length 4.8 cm, width 1.8 cm, and thickness 0.20 cm with an exposed total area of 8.64 cm². Before start the corrosion test, all the six samples are cleaning by the alcohol and acetone to remove the excessive flux on the copper substrate. Then the substrate is weighted by using electronic balance and all the weight data is taken. After that, the substrate is fully immersed in 0.5M of sulphuric acid (H₂SO₄) solution at the atmospheric temperature. Figure 3.7 shows the immersion of copper substrate in 0.5M of H₂SO₄ and Table 3.2 shows the duration of all the substrate that carried out in this experiment.

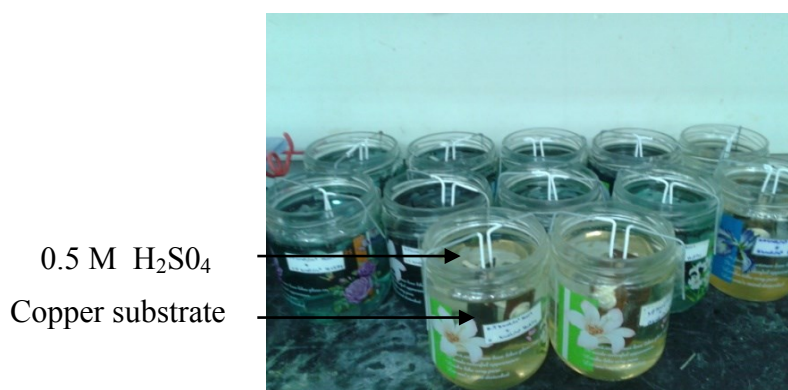


Figure 3.7 : Copper substrate with 0.5M H₂SO₄ solution

Table 3.2 : All substrate with Three Different Exposure Time

| Specimen | Time Duration |
|---------------------------------|---------------|
| Copper without lead-free solder | 168 hours |
| Copper with lead-free solder | |
| Copper without lead-free solder | 336 hours |
| Copper with lead-free solder | |
| Copper without lead-free solder | 504 hours |
| Copper with lead-free solder | |

After all the samples end of the duration, it will be weighted. The weight loss was determined at different immersion times at atmospheric temperature by weighing the cleaned samples before and after hanging the samples into the corrosive solution, namely 0.5M sulphuric acid.

3.6 CHARACTERIZATION ON TOP SURFACE MICROSTRUCTURE

In order to determine the characteristic of the top surface of microstructure formed within the solder joint, several material characterization techniques were applied for analysis and measurement. Characterization is performed on the samples to observe and identify the microstructure of the samples from top surface view. Tool such as Scanning Electron Microscope (SEM) was used in characterization works as Figure 3.8.

**Figure 3.8** : SEM Machine

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter will discuss the results obtained from the experiment of corrosion between copper board with solder ball and copper board without solder ball (as a reference) after immersed into a solution test which is 0.5M sulphuric acid, (H_2SO_4) solution. From this results, the weight loss and the corrosion rate of the specimen was calculated by using general formula then the microstructure formation of the samples was observed from the top surface finish of copper substrate substrate.

4.2 WEIGHT LOSS MEASUREMENT

The weight loss method is the simplest of all corrosion monitoring techniques by taking an initial weight and final weight of the specimen, then calculate the weight loss by using Equation 1. After reflow process, the specimen was cleaned with alcohol and acetone solution to ensure the specimen is clean. Then the weight for each specimens is measured before immersed in 0.5M of Sulphuric acid within the duration time. After immersed, the specimen was removed and reweighed to get the final weight. In this experiment, the corrosion rate formula used is shown in Equation 2. It was used to calculate the corrosion rate for each samples and the result for weight loss as well as corrosion rate for each samples from week 1 until week 3 as shown in Table 4.1, Table 4.2 and Table 4.3.

$$\text{Weight Loss, } w = \text{Final Weight, (g)} - \text{Initial Weight, (g)} \quad (1)$$

$$\text{Corrosion rate} = (K \times W) / (D \times A \times T) \quad (2)$$

Where:

K – Constant value

W – Weight loss (g)

D – Density of copper (g/cm³)

A – Area (cm²)

T – Time (hours)

Source : H.E Townsend (2002)

Table 4.1: Result for Weight Loss and Corrosion Rate for Week One of a specimens

| Week | Specimen | Initial weight (g) | Final weight (g) | Weight loss (g) W | Exposure time days (hrs) | Corrosion rate cm/hrs |
|------|---------------------------------|--------------------|------------------|----------------------|-----------------------------|--------------------------|
| 1 | Copper without solder | 3.774 | 3.728 | 0.046 | 168 | 0.00031 |
| 1 | Copper with SAC305 solder | 3.631 | 3.580 | 0.051 | 168 | 0.00034 |

Table 4.2 : Result for Weight Loss and Corrosion Rate for Week Two of a Specimens

| Week | Specimen | Initial weight (g) | Final weight (g) | Weight loss (g) W | Exposure time days (hrs) | Corrosion rate cm/hrs |
|------|---------------------------|--------------------|------------------|----------------------|-----------------------------|--------------------------|
| 2 | Copper without solder | 3.819 | 3.696 | 0.123 | 336 | 0.00042 |
| 2 | Copper with SAC305 solder | 3.768 | 3.632 | 0.137 | 336 | 0.00046 |

Table 4.3 : Result for Weight Loss and Corrosion Rate for Week Three of a Specimens

| Week | Specimen | Initial weight (g) | Final weight (g) | Weight loss (g) W | Exposure time days (hrs) | Corrosion rate cm/hrs |
|------|---------------------------|--------------------|------------------|----------------------|-----------------------------|--------------------------|
| 3 | Copper without solder | 3.782 | 3.554 | 0.228 | 504 | 0.00051 |
| 3 | Copper with SAC305 solder | 3.666 | 3.379 | 0.287 | 504 | 0.00065 |

4.3 CORROSION RATE

Table 4.1, Table 4.2 and Table 4.3 shows that the value of the weight loss and the corrosion rate that was calculated using general formula given. The corrosion is usually expressed in terms of loss of thickness per unit time. The corrosion rate showed that the loss of thickness of the specimen oxidized in 0.5M sulphuric acid, (H₂SO₄) solution. When the corrosion occurred on the specimen surface, the corrosion rate will be increased by the time. It is because the specimen will be easily oxidized when the pH value of the corrosive environment is low. The lower the pH

values of solution, the easier the specimen to corrode and oxidize. The acidity of the solution test is high and the corrosion rate will be increase and the material that easily to corrode first is Nickel, (Ni) because it has stronger reducing agent to compare to Copper (Cu) and Tin (Sn). The surface finish of electroless nickel will be the first to corrode in sulphuric acid and the thickness of the nickel layer will be decrease by time duration.

Weight Loss of copper board

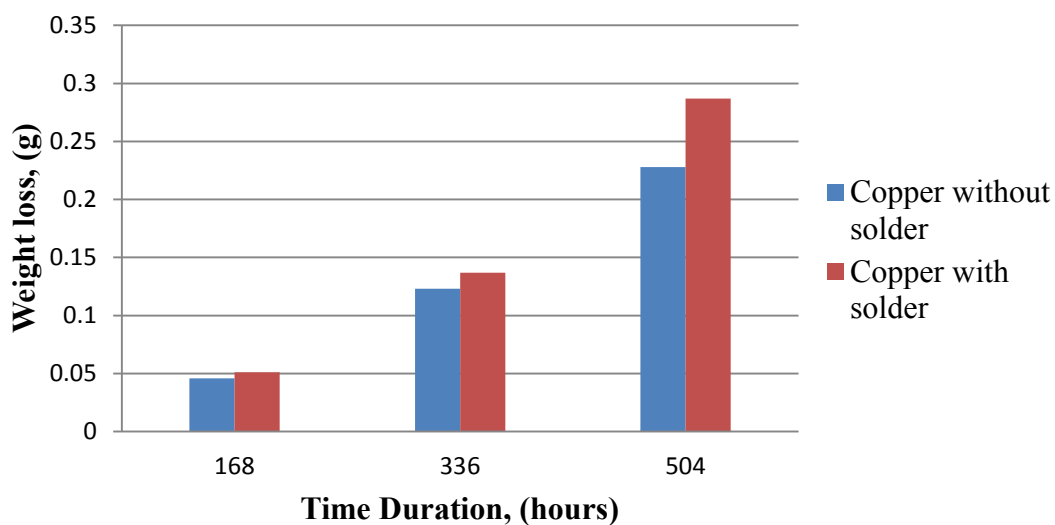


Figure 4.1 : Effect of Corrosion by Weight Loss of Copper with and without Lead-Free Solder

Figure 4.1 shows the effect of corrosion by weight loss of the specimen with and without lead-free solder in 0.5M of (H_2SO_4) solution. The weight loss of each specimen was calculated by difference the initial weight and final weight for each specimen.. From the bar chart at 168 hours, the specimen start to oxidize and the weight slowly loss by exposure time The weight loss reduced at the 168 hours is 0.046 g for the copper without lead solder and the weight loss for copper with solder is 0.051 g. The oxidation of the specimen will increase the weight loss when exposed in corrosive solution at the time duration. Oxidation is a process of stripping an electron from an atom that will affect the weight loss of that material. Therefore, the material of the specimen will be loss time by time. At 504 hours, the weight loss of specimen becomes increase at 0.228 g for copper without lead solder

and 0.287 g for copper with solder. The copper board with solder will be corroded at the joining of the solder as well as the electroless nickel surface finish of the copper board because the porosity at the joining will be increase the corrosion. When the corrosion occurred at the joining, the lead-free solder and the surface finish of electroless nickel is more easily to damage and oxidize in corrosive solution. The layer of nickel will be corrode faster when they have porosity and failure at the surface finish and the joining. The copper board without lead-free solder will corrode slowly in corrosive solution because the porosity at the surface finish is less. The porosity actually will caused the failure of the material. The corrosion at the solder joint will affected the realibility at the joining between copper board and lead-free solder and the weight of the specimen. Figure 4.2(a) and Figure 4.2(b) shows the schematics of the copper with lead-free solder and copper without solder and two of the is coating with nickel.

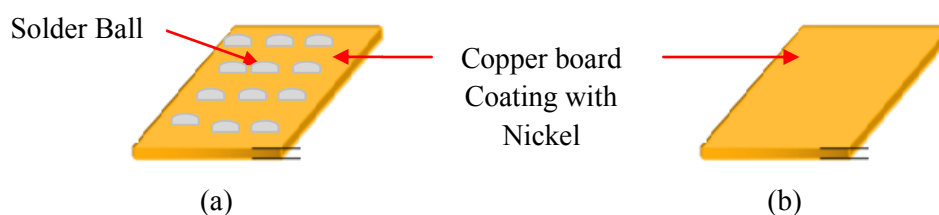


Figure 4.2 : Copper Board Coating with Nickel ; (a) with lead-free solder, and (b) without Lead-free solder

Figure 4.3 shows the bar chart of the corrosion rate of copper board with and without the lead-free solder. The corrosion rate is the speed which a metal deteriorates in a specific environment. It is dependent upon environmental conditions as well as the type and condition of the metal. It also known as the loss of thickness at the material exposure in corrosive environment. The environment that we applied in this study is sulphur. We applied Sulphuric acid as a corrosive solution. The corrosion rate at three different time as shown in Figure 4.3 is increasing uniformly which is at 168 hours, corrosion rate is 0.00031 cm/hr for copper without lead-free solder and the copper with solder is 0.00034 cm/hrs and at the 504 hours, corrosion rate is 0.00051 cm/hrs for copper without lead-free solder and copper with solder is 0.00065 cm/hrs. When the weight loss increases, the

corrosion rate will also increase specimen without solder because the corrosion occur more at the solder joint.

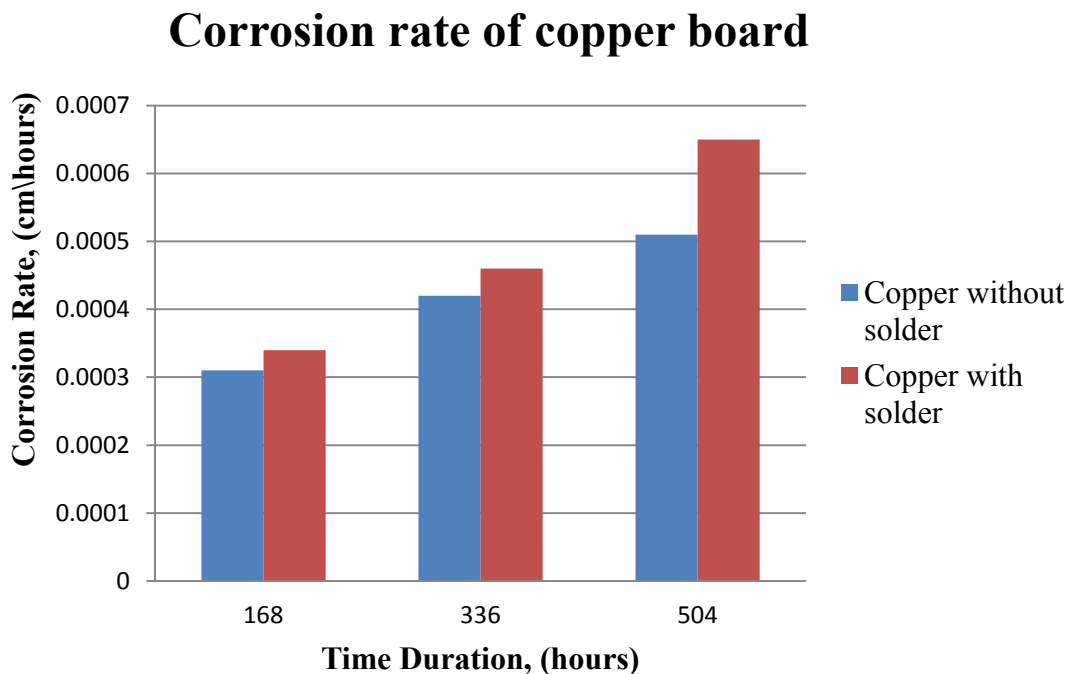


Figure 4.3 : Effect of Corrosion Rate by Time Duration

4.4 MICROSTRUCTURE OF SPECIMEN

After the time duration for all specimen is over, the followed process is analyze the microstructure for every specimen from the top surface of the nickel by using SEM. The SEM is a microscope that uses electrons instead of light to form an image. The SEM has a large depth of field, which allows more of a specimen to be in focus at one time. The SEM also has much higher resolution, so closely spaced specimens can be magnified at much higher levels. The SEM uses electromagnets rather than lenses, so must has much more control in the degree of magnification. All of these advantages, as well as the actual strikingly clear images, make the scanning electron microscope one of the most useful instruments to examine the microstructure for all these specimen (copper board with and without lead-free solder from week 1 until week 3 as shown in Figure 4.4(a), Figure 4.4(b), Figure 4.5, Figure 4.6(a), Figure 4.6(b) and Figure 4.6(c).

4.4.1 Microstructure of Copper Board without Sn-3Ag-0.5Cu Solder (SAC 305)

Figure 4.4(a), Figure 4.4(b), and Figure 4.5 shows the effect of corrosion on the surface finish of copper board after immersed in 0.5M of sulphuric acid, (H_2SO_4) solution at the different time duration which is 168 hours, 336 hours and 504 hours. The structure of the specimens was observed by using scanning electron microscopy, (SEM). All the figure below shows the failure of the nickel surface after exposed in Sulphuric acid. A 0.5M sulphuric acid, (H_2SO_4) solution is the corrosive solution that have low pH value. The pH value for 0.5M of sulphuric acid is approximately 1. It means the acid is quite strong and the tendency of the acid to corrode the material is high. As low pH value (acidity increasing), the corrosion rate is increasing. This is because low pH solution accelerate corrosion by providing hydrogen ions. Hydrogen attack and damages the nickel surface and increase the weight loss. Figure 4.4(a), Figure 4.4(b), and Figure 4.5 shows the crack development on the surface finish of the copper board. From 168 hours until 504 hours, the cracking increasing on the nickel surface and will form a hole if the specimen continue immersed in H_2SO_4 .

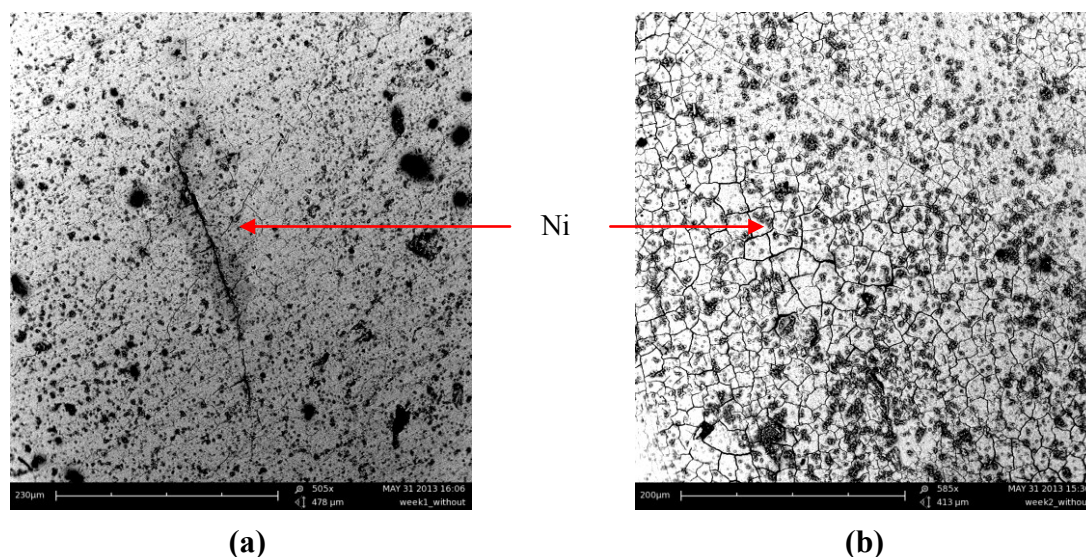
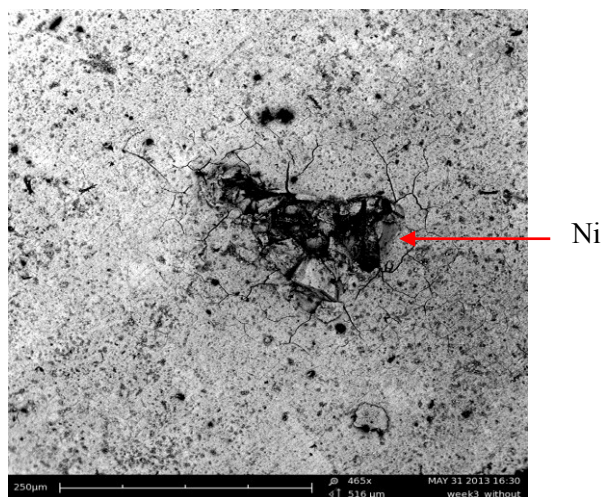


Figure 4.4 : Nickel Surface of Copper Board without Lead-free solder ;
(a) 168 hours, and (b) 336 hours



(c)

Figure 4.5 : Nickel Surface of Copper Board without Lead-free solder at 504 hours

4.4.2 Microstructure of Copper Board with Sn-3Ag-0.5Cu Solder (SAC 305)

Figure 4.6(a), Figure 4.6(b) and Figure 4.6(c) shows that the nickel surface at the solder joint of the lead-free solders (SAC305) at different exposure time. The surface of the nickel was cracking and forms a hole on nickel surface. The cracking becomes bigger when the specimen immersed at 504 hours. The nickel surface damaged and the thickness of nickel layer becomes loss. The material that easily to oxidize and to loss the thickness in corrosive solution is nickel because of nickel is strong reducing agent in reduction potential and it have tendency to loss electron and oxidize in corrosive solution.

Nickel surface finishes have ability to loss the thickness. The cracking on the nickel surface shows that the electroless nickel surface finish was not strong enough to withstand longer time in corrosive solution because the Sulphuric acid is a strong acid that attacked the material and the oxidation process occurred. The copper substrate will possible to corrode after the nickel surface finish loss. The porosity at the joining of the lead-free solder and the surface finish caused the corrosion at the solder joint.

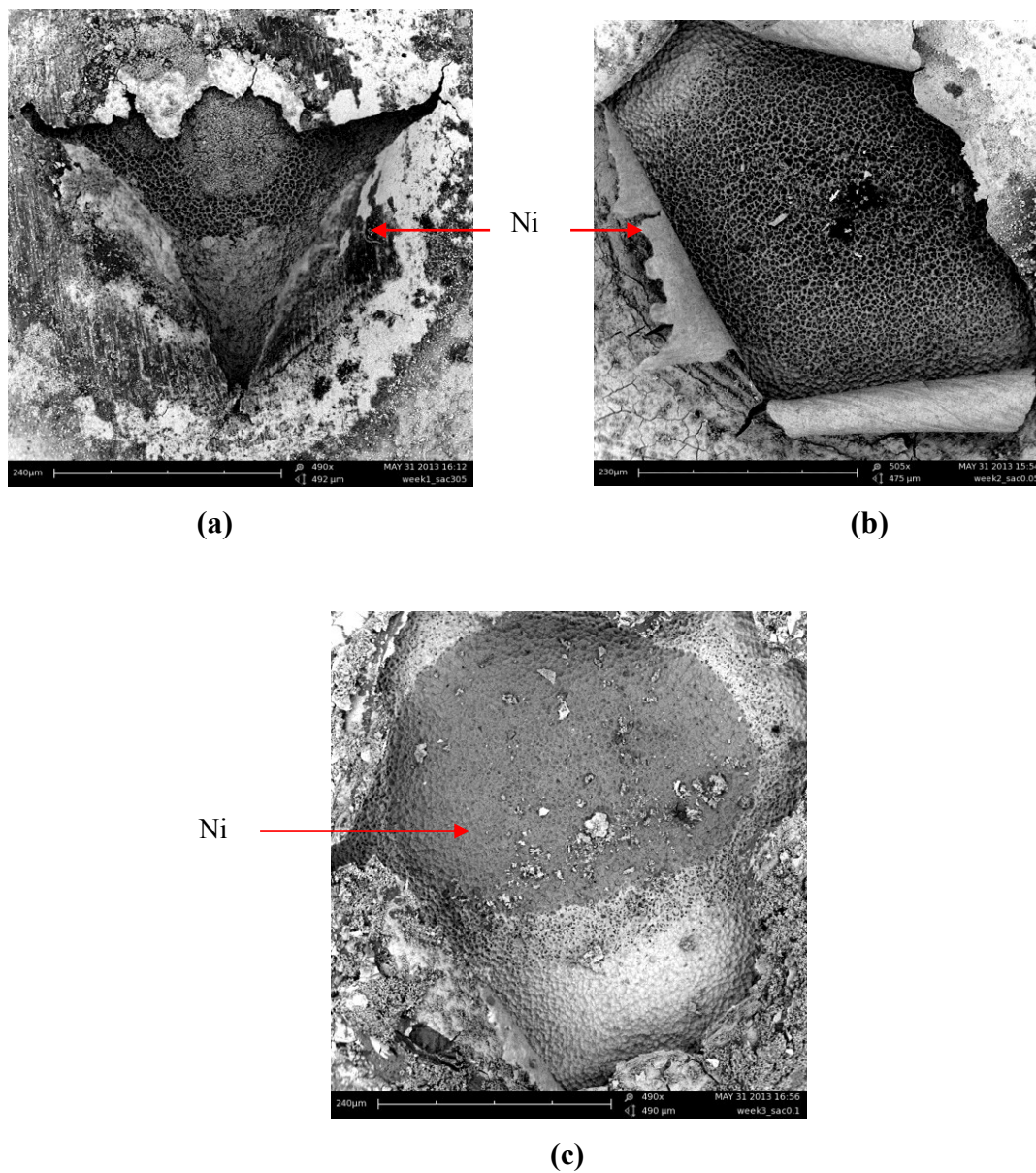


Figure 4.6 : Nickel Surface of Copper Board with Lead-free solder ; (a) 168 hours, (b) 336 hours, and (c) 504 hours

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The purposed of this research is to identify the effect of the corrosion of the joining between the lead-free solder and the copper plated nickel by observing the microstructure from the top surface that it has some failure at the joining. The effect of the corrosion increased the corrosion rate and the weight loss as shown in results. From the failure of the corrosion, the surface finish decreased the strength of the joining between the copper board and lead-free solder as we can see the microstructure in chapter 4. It is because the corrosion caused porosity at the joining. The porosity will reduce the ability of the joining of the material.

Besides that, the failure of the copper board will be affected by the electricity on the PCB and the functionality of the PCB in electronic device will problems. The PCB will not last longer when it expose in the corrosive environment. In this study, sulphuric acid was used as a solution to simulate the sulphur environment such as off shore area, fertilizer industry and oil and gas. In order to measure the corrosion rate, weight loss method was used because it is the simply method and it applicable to all environments and weight loss can be readily determined and corrosion rate easily calculated.

5.2 FUTURE RECOMMENDATION

For the recommendation for the future, the method of the experiment for the future should use electrochemical measurement method which is potentiodynamic polarization because that method can calculate the corrosion rate easily and fast by using potentiostat machine. The method no need much time for the analysis.

Other than that, the tools to observe the microstructure not only using scanning electron microscopy to adding tool such as Energy- dispersive X-ray spectroscopy (EDX) because this machine is an analytical technique used for the elemental analysis or chemical characterization of a sample. It also can observe more clearly to the sample specimen.

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