CHAPTER II

LITERATURE REVIEW

2.1 Hot Dip Galvanizing

Hot dip galvanizing is a form of galvanization. It is the process of coating iron, steel, or aluminum with a thin zinc layer by passing the metal through a molten bath of zinc at a temperature of around 860 °F (460 °C) (Wikipedia, 2010). It forms fairly strong material and stops further corrosion by protecting the steel below from corrosive elements. Zinc coatings prevent corrosion of the protected metal by forming a physical barrier coating, it provides a tough, metallurgically-bonded zinc coating that completely covers the steel surface and seals the steel from the environment's corrosive action. Additionally, zinc's sacrificial action (cathodic) protects the steel even where damage or a minor discontinuity occurs in the coating. Because zinc is anodic to steel, the galvanized coating provides cathodic protection to the exposed steel. When zinc and steel are connected in the presence of an electrolyte or corrosive material, the zinc is slowly consumed while the steel is protected. Zinc's sacrificial action offers protection even where small areas of steel are exposed, such as cut edges, drill-holes, scratches, or as the result of severe surface abrasion. Cathodic protection of the steel from corrosion continues until all the zinc in the immediate area is consumed, the equation for this phenomenon is: $Zn + Fe^{2+} \rightarrow Fe + Zn^{2+}$

Galvanizing forms a metallurgical bond between the zinc and the underlying steel or iron, creating a barrier that is part of the metal itself (American Galvanizers Association, 2000). During galvanizing, the molten zinc reacts with the iron in the steel to form a series of zinc/iron alloy layers. Figure 2.1 is a photomicrograph of a galvanized steel coating's and shows a typical coating microstructure consisting of three alloy layers and a layer of pure metallic zinc. The gamma, delta and zeta alloy are actually harder than the base metal itself. The temperature at bonding activity between base steel and zinc must be at least 800 °F (427 °C) or the bonding cannot occur.

Figure 2.1 Photomicrograph of Galvanized Coatings. Adapted From American Galvanizers Association (2004)

Electrons will naturally gravitate towards zinc and consume it. The thicker the layers, the longer it will take to corrode. The base steel is covered with four different levels of hot dip galvanization. The hardest, strongest level starts out at the bottom, closest to the steel. The thickness of the galvanized coating is the primary factor in determining the service life of the product (American Galvanizers Association, 2004). The thicker the coating, provide higher corrosion protection. Although galvanizing will prevent corrosion in the base steel, corrosion will be inevitable, especially if the environment is acidic or contain salt material. For example, sea environments also lower the lifetime of galvanized iron roofs and similar products, because the high electrical conductivity of sea water encourages and increases the rate of corrosion. Galvanized steel products can last longer if further protected by a paint layer.

2.2 Continues Galvanizing Line Machine

Continues galvanizing line (CGL) machine is a machine that produces galvanized iron (GI) by immersing strip of coil into zinc alloy liquid in the process. The galvanizing process of CGL machine in PT XYZ use *continuous* hot dip galvanizing as the coating process, it convert cold roll coil into galvanized iron coil. As the name implies, continuous hot-dip coating involves the application of a molten coating onto the surface of strip of coil in a *non-stop process* (GalvInfo Center, 2007). The strip of coil is passed as a continuous ribbon through a bath of molten metal at speeds up to 183mpm, in the molten metal bath, the steel strip reacts (alloys) with the molten metal to bond the coating onto the strip surface. As the strip emerges from the molten bath, it drags out excess liquid metal (zinc). Using a gas-wiping process, a controlled thickness of coating, usually expressed as weight (mass) of coating per unit area, is allowed to remain on the strip surface.

The material that processed in Continuous Galvanizing Line machine called Cold Rolled Coil (CRC), which is an unannealed, low carbon steel without coating. The specifications of the CRC that processed in CGL machine are:

- -Thickness = 0.20 – 1.20 mm
- -Width = 762 – 1,219 mm
- -Weight = max 20 ton
- -Inner diameter = min 508mm
- -Outer diameter = min 1000mm – max 2000mm

Based on the technology of the production system, hot dip galvanizing in PT. XYZ is categorized as modern continuous hot dip galvanizing (coil to coil) that use NOF system for its furnace (Rachmat, 2006). Because the production system is coil to coil and must run continuously, a welding machine is installed to join the strip of the coil to make it run continuously. The illustration of CGL machine shown in figure 2.2.

CGL

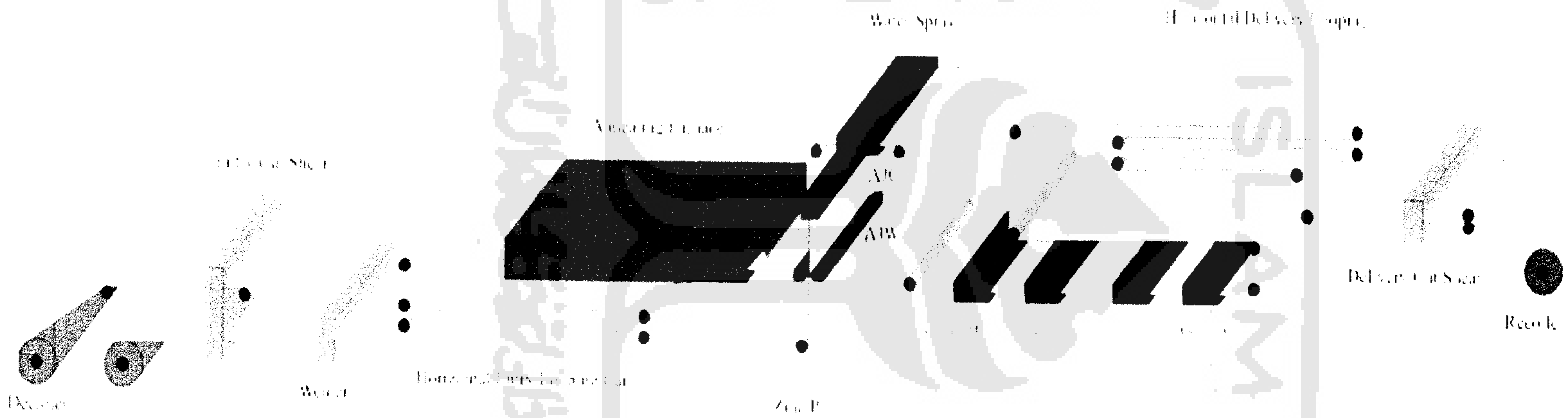

Figure 2.2 Continuous Galvanizing Line Machine

The CGL machine itself consists of 8 sections, which are:

1. Entry section

Material coil transferred from the entry coil yard is placed on the entry coil skid by the overhead travelling crane. The transferred coil is then transferred by the entry coil car and inserted into the pay off reel after height and width are aligned manually. The top end of the coil on the pay off reel is led to the pinch roll by manual and threaded to the double cut shear. The double cut shear cuts the top and tail end (off gauge and defect) of the strip for welding and then the scraps are removed by manual. The top end of the succeeding is transferred to the welder and welded to the preceding tail end of the strip. Double pass system is applied from the pay off reel to the welder to feed the material coils continuously.

2. Entry looper section

A horizontal type looper is installed to store the required length of the strip due to the continuous furnace operation when the entry section is stopped for welding.

3. Annealing Furnace section

The annealing furnace is off horizontal type, consist of Pre-heater, Non Oxidizing Furnace, Radiant Tube Furnace, Slow Cooling Section, Jet Cooling Section and Turn Down Section. (each of which is referred to as PH, NOF, RTF, SC, JC, TD). Strip first enters into PH & NOF which heat the strip up to proper temperature and remove rolling oil by means of direct firing up to 650° C. PH is located prior to NOF to recover the heat of waste gas from NOF. NOF is conducted by direct burning using fuel gas under atmospheric gas without Oxygen (O_2). The O_2 is purged by N_2 and H_2 gas from before the process start and in the process of burning for better corrosion resistant.

The strip next enters into RTF which heat the strip up to final annealing temperature up to 1,200° C depend on the GI coil specification expected by means of indirect radiational heating utilizing fuel gas fired radiant tube. Another function of RTF is to reduce the strip surface which is weakly oxidized in previous direct fire section, the microstructure formation of the strip is change in the reductive atmosphere of this section. And next, the strip is slow cooled in SC section to avoid the deterioration of the strip shape and also to complete the reduction of the strip surface. For this purpose, radiational cooling utilizing cooling tube and additional electrical heating is adopted. Finally, the strip is rapid cooled in JC section down to appropriate temperature for successive coating by means of circulation gas jet cooling. After JC section, the strip goes to coating pot through TD section, in which the strip pass is turned down to sink roll in the pot, and furnace atmosphere is sealed by snout which covers the strip into molten zinc.

The temperature for each zone in annealing furnace section is different, the temperature will also be different in different product type. The temperature cycles will be explained in figure 2.3.

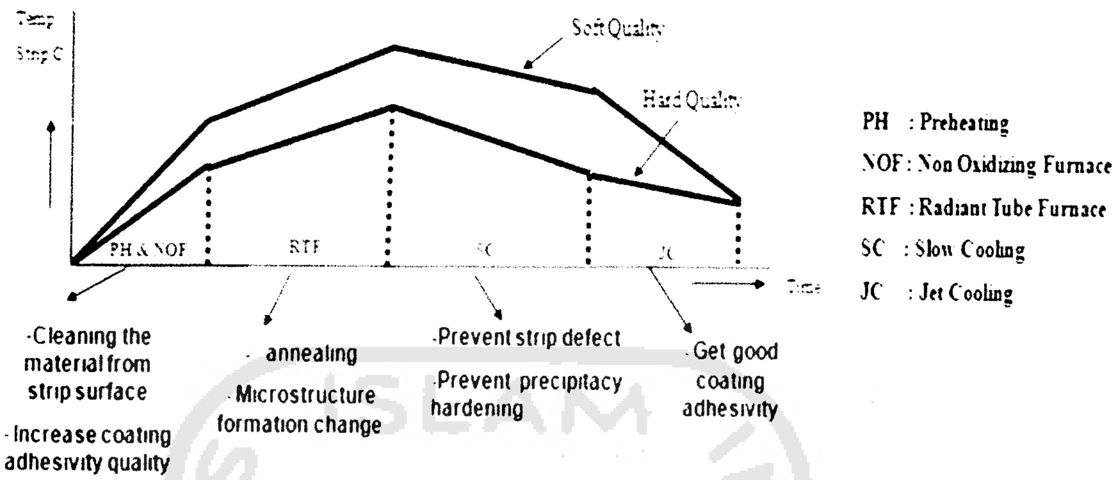

Figure 2.3 Temperature Cycles in Annealing Furnace. Adapted From Rachmat (2006)

4. Coating section

The strip is led into a molten zinc iron pot through the furnace snout, and galvanized while strip passes in it through. The temperature of zinc bath in iron pot is controlled to about 460'C by electric resistance heater. Molten zinc deposited on the strip while it passes the zinc bath is wiped off to the specified coating weight by air jet wiping (AJW) device. A few roll units is arranged to deflect the strip run from the furnace through the zinc pot to the vertical pass line at coating equipment. Motor driven support roll is arranged in zinc bath to prevent the vibration of the strip to make uniform coating possible.

5. Cooling equipment with air jet cooler (AJC) and water spray cooler

The strip passes over a cooling tower to cool the coatings which is flowering fine spangle in the strip. Cooling tower consist of an air jet cooler which blow pressured air and a water spray cooler to cool down the zinc.

6. Post treatment section

After cooling, the strip is passed through Skin Pass Mill (SPM), to press the strip under rough surfaced roll to make the surface smoother. After SPM the strip is corrected in shape by Tension Leveler (TLV), the purpose is to improve product flatness by stretching all of the longitudinal structures in the metal strip to equal length. After the tension leveler, Chromate equipment is installed to improve resistance against the white rust corrosion and the coatability of galvanized strip of galvanized steel. The dryer system is installed just after the spraying tank to dry the strip surfaces with hot air.

7. Delivery looper section

A horizontal type looper is installed to store the required length of the strip due to the continuous furnace operation when the delivery section is stopped for the coil dividing.

8. Delivery section

The coil went out of the delivery loop car is divided and cut off the portion of the welded area by the delivery shear. The product coil wound by the tension reel is carried off by the delivery coil car. The head of the succeeding coil is fed and wrap by the belt wrapper to the tension reel mandrel. The edge coil can be wound uniformly by an edge position control system. The product coil is transferred to next process by the overhead crane.

2.3 Limited Over-Lap Seam Welding Machine

2.3.1 General

This welding machine is designed and manufactured to join the leading and travelling coil strip by seam welding in Continuous Galvanizing Line machine. The operations are to overlap two strips, clamp together and seam-weld them by a pair of *wheel electrodes*.

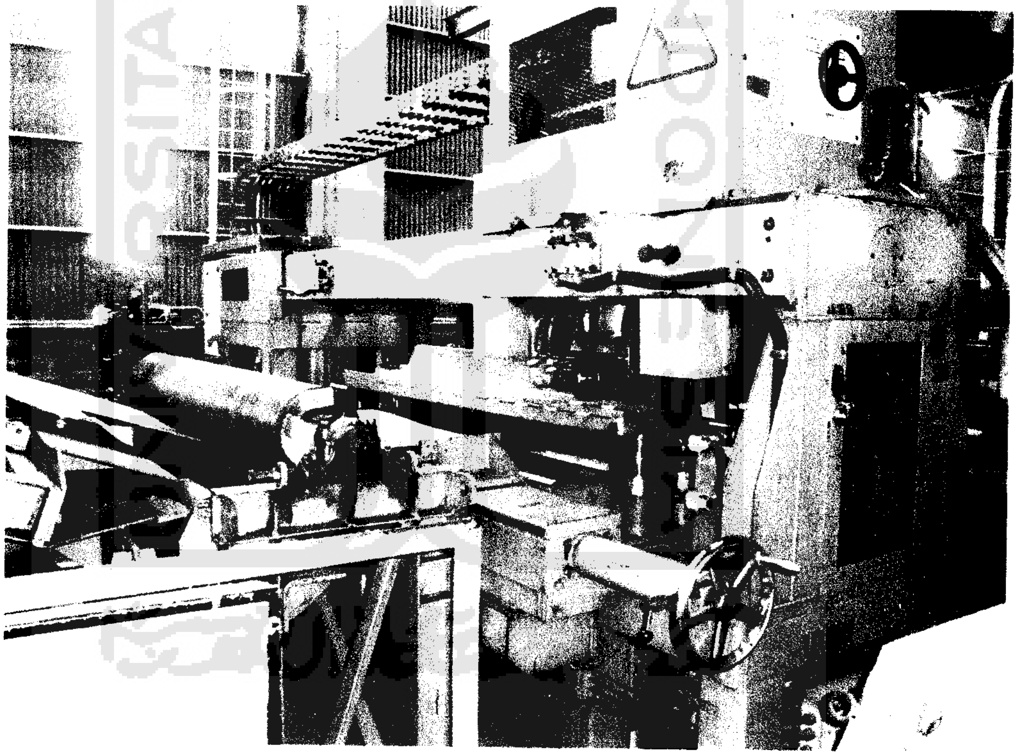

Figure 2.4 Limited Over-Lap Seam Welding Machine

2.3.2 Welding Capacity

Material to be weld	: cold rolled, non-annealed, low carbon steel JIS G 3141 SPCC, SPHC
Yield point	: min 20.0 kgf/mm^2 max. 38.5 kgf/mm^2
Tensile stress strength	: min. 28.0 kgf/mm2 max. 55.0 kgf/mm2
Thickness	: 0.18 – 1.2 mm
Width	: 615 – 1219 mm
Thickness of welded zone	: two times
Value of lapping	: approximately 22mm
Cycle time	: 40 seconds

2.3.3 Utilities

Welding power supply	: single phase AC 380V±5% 50Hz
Motor power supply	: three phase AC 380V±5% 50Hz
Control power supply	: three phase AC 380V±5% 50Hz
Compressed air supply	: 0.69 – 0.49Mpa
Cooling water supply	: 0.29 – 0.15Mpa 13liter/min lower than 30'C
Hydraulic supply	: 11 – 14Mpa 60liter/min. from line

2.3.4 Main Unit

1. Main Frame

   The main frame is fabricated by welded construction, and on this frame main carriage unit, back-bar, two sided guide units, punch unit and others are assembled

2. Carriage unit

   On this unit, welding head assemblies and welding transformer are mounted, this unit is driven by motor on V-guide rails

3. Welding unit

Welding transformer	: model RS-T
Rated capacity	: 120kVA
Rated primarily voltage	: 380V
Rated frequency	: 50Hz
Max. Welding Capacity	: 300kVA
Max. Welding current	: 26000A
Rated duty cycle	: 8%
Max Welding pressure	: 8800N
Welding electrode size	*: Ø300mm x 12t*
Contact electrode size	*: Ø220mm x 12t*
Space between electrodes	: 118mm
Direction of welding	: from operator side to drive side
Start and finishing of welding	: by photo sensor

4. Clamp unit

Entry clamp pressure : 500 kgf x 2

Exit clamp pressure : 500 kgf x 2

5. Side guide unit

Side guide unit are attached at entry and exit side of the welding machine. Leading and trailing strip are centered by these units manually

6. Punch unit

Punch unit is mounted on the exit side of the welding machine. Two Ø15mm holes are punched on the trailing strip by hydraulic cylinder.

The illustration of welding machine component and process shown in figure 2.5 and 2.6 below:

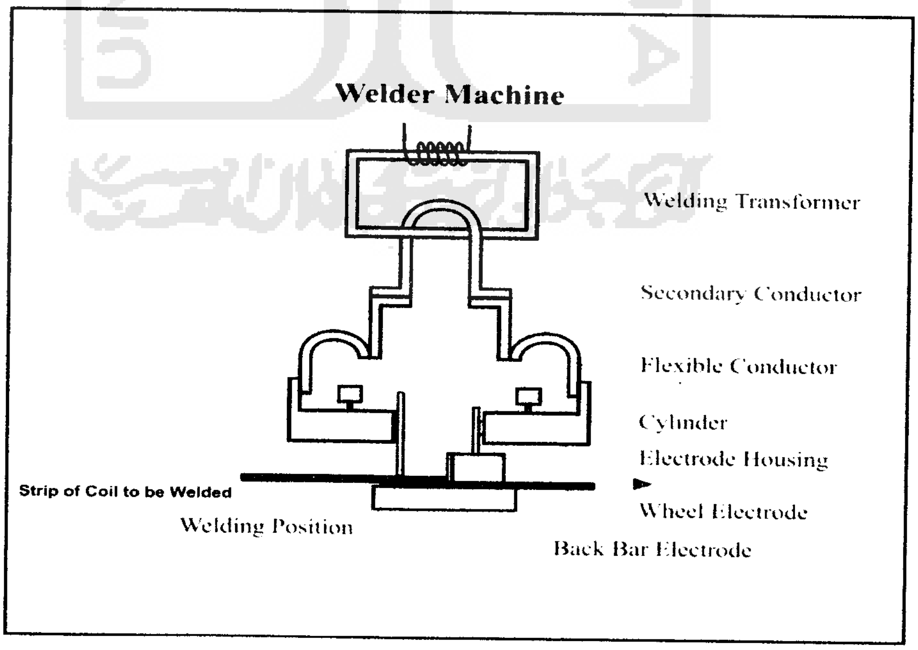

Figure 2.5 Welding Machine Component

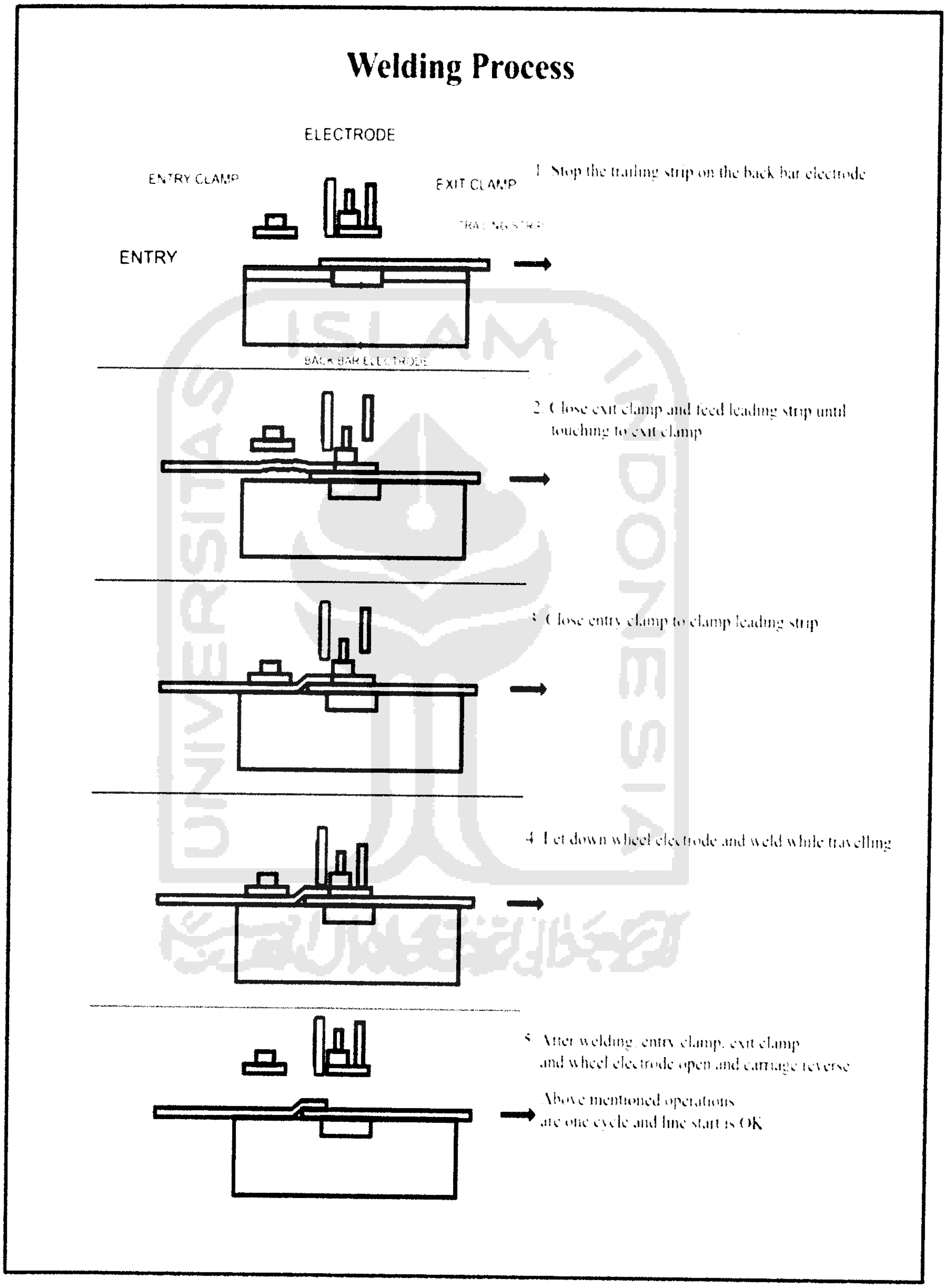

Figure 2.6 Welding Process

2.4 Welding

Welding is a metal joining process in which coalescence is obtained by heat and pressure. In welding, the metallurgical bond is accomplished by the attracting forces between atoms, but before these atom can bond, absorbed vapors and oxides must be eliminates from contacting surfaces (Oswald & Munoz, 1996). Some factors influencing welding result are the proportions of the work pieces, the electrode materials, electrode geometry, electrode pressing force, weld current, weld time and the base metal itself. It necessary to control or adjust welding current, welding time and electrode pressure according to the material, thickness and others to be welded. Welding process involving thermal energy to melt the base metal, this phenomenon expressed in this equation $E = I^2 R t$ where E is energy (joule), I is current (ampere), R is resistance (ohm) and t is time (second).

Seam welding is a resistance welding method used to join two to four overlapping metal sheets which are up to 3 mm thick each. Two copper electrodes are simultaneously used to clamp the metal sheets together and to pass current through the strip of coil, it relies on two electrodes to apply pressure and current to join metal sheets. Resistance Seam Welding/Roll Welding is a resistance welding process that produces a weld at the surfaces of overlapped parts along a length of a joint. Instead of using two cylindrical electrodes as in case of spot welding, here two circular disks are used as electrodes. The work piece, in this case is strip of coils is passed through the space between the two discs, and under pressure applied by the discs and current flowing through them, a continuous weld is formed. With seam welding the material passes between two rotating wheels or welding rollers.

Generally a welding activity will form 3 different zones, which are:

- Base metal : metals that not affected by the welding activity
- Heat Affected Zone (HAZ) : zone within the base metal that experience structural changes but does not melt during the welding.
- Fusion Zone : the welded area of the metals

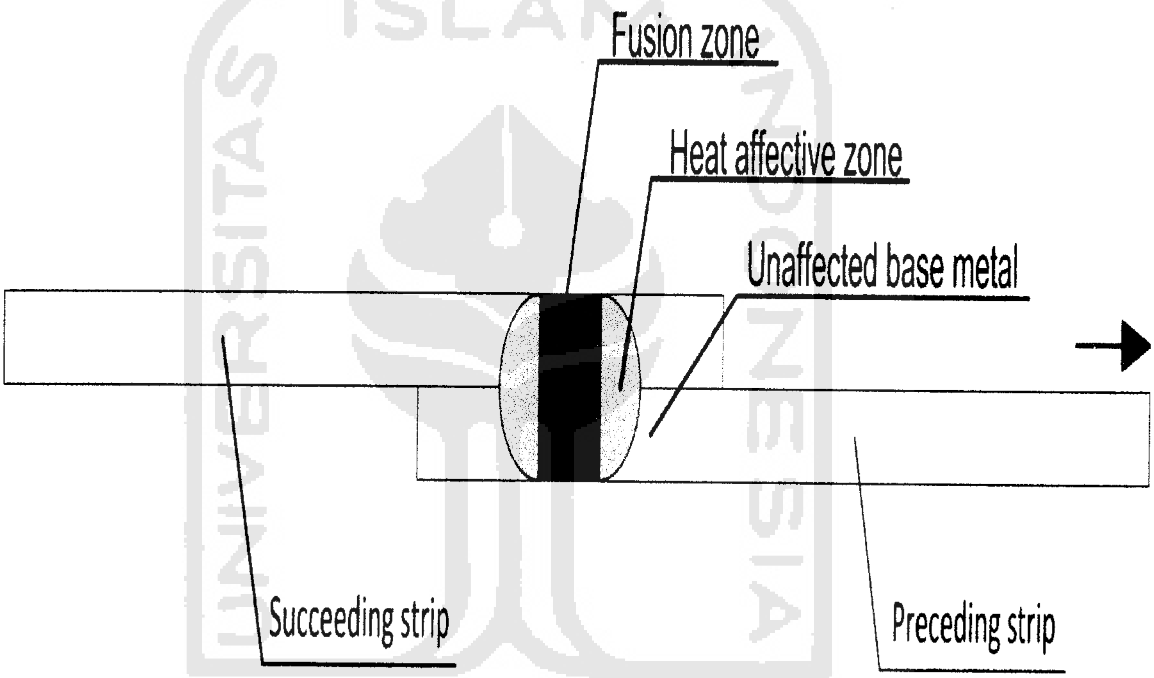

Figure 2.7 Welded Area In Strip Of Coil

Based on David, Babu, & Vitek (2003) explanation that during welding, where the molten pool is moved through the material (FZ), the growth rate and temperature gradient vary considerably across the weld pool. Geometrical analyses have been developed that relate welding speed to the actual growth rates of the solid at various locations in the weld pool. An important aspect of weld solidification is the dynamics of weld pool development and its steady state geometry. Weld pool shape is important in the development of grain structure and dendrite growth selection process. Thermal conditions in and near the weld pool and the nature of the fluid flow have been found to influence the size and shape of the weld pool. Where in steels sheet joint the shape and size of the weld pool arranged so that the overlapping strip of coil joint are stronger than the strip of coil itself.

2.5 Electrode

Electrode is a terminal through which electric current passes between metallic and nonmetallic parts of an electric circuit (Columbia Electronic Encyclopedia, 6th Edition, 2009). Generally, circuit's current is carried by metallic conductors, but in some circuits the current passes for some distance through a nonmetallic conductor. An electrode is usually in the form of a wire, rod, or plate. It may be made of a metal, e.g., copper, lead, platinum, silver, or zinc, or of a nonmetal, e.g., electrolyte, gas, or carbon. The electrode through which current passes from the metallic to the nonmetallic conductor is called anode and that through which current passes from the nonmetallic to the metallic conductor, the cathode. (Electron flow is in a direction opposite that of conventionally defined current.) In most familiar electric devices, current flows from the terminal at higher electric potential (the positive electrode) to the terminal at lower electric potential (the negative electrode); therefore, the anode is usually the positive electrode and the cathode the negative electrode. In some electric devices, e.g., an electric battery, nonelectric energy is converted to electric energy, causing current to flow within the device from the negative electrode to the positive electrode, so that the anode is the negative electrode and the cathode is the positive electrode.

Welding electrode is an electrode that used to conduct current through a work piece to join two pieces together. Depending upon the process, the electrode is either consumable, in the case of gas metal arc welding or shielded metal arc welding, or non-consumable, such as in gas tungsten arc welding. The electrodes used for welding have many shape, depend on how they will be used and their specification such as stick and circle.

2.6 Metallurgy Aspects

Metallurgy is a part of materials science that studies the physical and chemical behavior of alloying elements, their compounds, and their mixtures, which called alloys (Wikipedia, 2010). Metallurgy studies the microscopic and macroscopic properties using metallography, study of the physical structure and components of metals. In metallography, a sample that being analyze flattened and polished, the sample then etched to reveal the microstructure and macrostructure of the metal, after that the sample examined in an optical or electron microscope, and the image contrast provides details about the composition, mechanical properties, and processing history. Using only metallographic techniques, a skilled technician can identify alloys and predict material properties.

Microstructure is defined as the structure of a prepared surface or thin foil of material as revealed by a microscope above 25× magnification (ASM Metals Handbook vol. 9, 1985). The microstructure of a material can strongly influence physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behavior, wear resistance, and so on, that will determine the application of these materials. The microstructure is very critical because the microstructure reveals the grains of an alloy, which then from the grain the properties and characteristic of an alloy could be determined.

The grain size of an alloy highly affects the strength of an alloy, the fine grain size is often desired for high strength, large additions of solute atoms are added to increase strength and bring out new phase of relationships, fine particles may be added to increase strength and phase transformations may be utilized to increase strength. The boundary between grains is regions of disturbed lattice only a few atomic diameters wide, the crystallographic orientation changes abruptly in passing from one grain to the next across the grain boundary. The ordinary high angle grain boundary represents a region of random misfit between the adjoining grains. As the difference in orientation between the grains decreases, the state of order in the boundary increases (Dieter, 1976).

Mechanical strengthening of grain boundaries is provided by experiments on bicrystals in which the orientation difference between longitudinal grain boundaries varied in a systematic manner. The yield stress of the bicrystals increased linearly with increasing misorientation across the grain boundary. These results imply that a simple grain boundary has little inherent strength and that the strengthening due to grain boundaries results from mutual interference to slip within the grains. The role of grain boundaries in causing non homogeneous deformation and in introducing multiple slip empirically established by Hall and Petch that the tensile yield strength was related to grain size by $\sigma_y = \sigma_o + kd^{-\frac{1}{2}}$

Where: σ_y = the yield strength

σ_o = friction stress opposing motion of dislocations

k = 'unpinning constant' measuring the extent to which dislocations are piled up at barriers

d = the grain diameter

The Hall-Petch equation has been found to express the grain size dependence of the flow stress at any plastic strain out to ductile fracture. Also to express the variation of brittle fractures stress with grain size and the dependence of fatigue strength on grain size.

2.7 Copper Based Alloy

Copper and copper alloys (Cu and Cu alloy) are among the most commercially important metals because of their excellent properties, ease of manufacture and numerous applications. They are widely used because of their excellent electrical and thermal conductivity, resistance to corrosion and ease of fabrication. Low alloyed Cu are used extensively for cables and wires, electrode, reactor wall, electrical contacts and a wide variety of other parts that are required to pass electrical current. The development of electronics industry has led to a number of new applications for Cu alloys including lead frames, connectors and other electronic components. These applications require alloys with unique combinations of strength, conductivity and thermal stability.

Many types of high electrical conductivity alloys have been developed by researchers around the world. A number of commercial alloys have been developed and these are used for a variety of applications requiring combinations of high-strength, high-conductivity and resistance to softening. A small amount of certain element additions are required to achieve optimum properties in these alloys. The electrical-resistance welding process reached full development in the production of strip of coil, aviation assemblies, car chassis and bodies, metallic furniture, and other applications. This welding process uses copper and Cu based alloys as the electrode material. Electrical resistance welding involves passing a high current at a low voltage through a circuit closed by the pieces that to be welded, these pieces are maintained in close contact with the two electrodes with an applied pressure. The heat generated by the electrode is enough to produce local fusion of the pieces under pressure, leading to a forged union to join the steels. Therefore electrode materials must exhibit high electrical and thermal conductivities, combined with high strength, at elevated temperatures.