CHAPTER IV

DATA COLLECTING AND PROCESSING

4.1 PT. XYZ

4.1.1 PT. XYZ in Brief

Because the data that used in this research is confidential, the company name and profile will not be published in this research, for easiness of identification the company name will be assumed as PT. XYZ.

4.1.2 Limited Over-Lap Seam Welding Machine

This welding machine is designed and manufactured to join the leading and travelling strip of coil 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*.

4.1.3 Welding Wheel Electrode

Welding electrode is an electrode that used to conduct current through a work piece to join two metal pieces together, in this case is strips of coil that processed in Continuous Galvanizing Line Machine. The welding electrode used is welding wheel electrode.

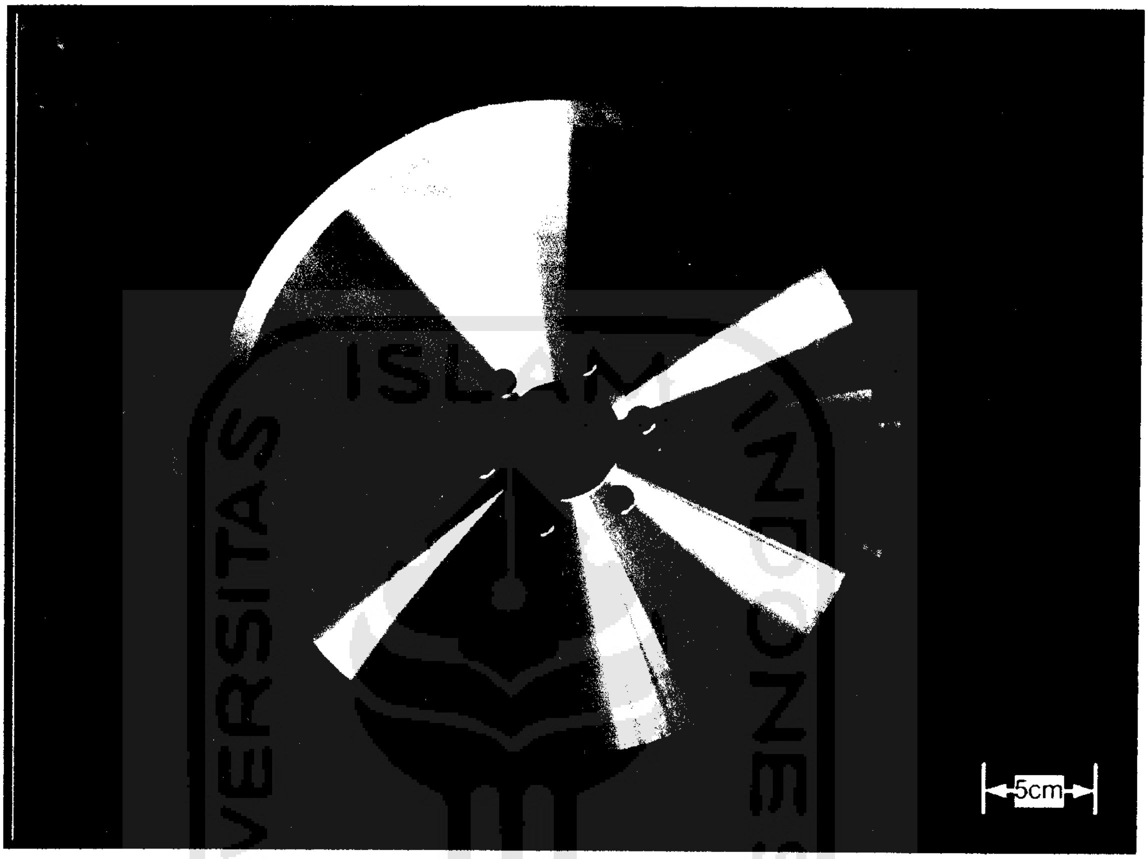

Figure 4.1 Import Welding Electrode

This chapter will explain about the method and analysis to develop a domestic welding wheel electrode to replace the original Japan made welding. After the domestic welding electrode being made, the domestic welding electrode will be perform some performance test to challenge the imported one to determine whether domestic welding electrode could be used to weld the strip of coil in Continuous Galvanizing Line Machine safely and fulfill the welding quality assessment.

4.2 Domestic Welding Electrode Development

4.2.1 Data Collecting

4.2.1.1 Properties of Import Welding Electrode

Researcher use metallographic techniques, study of the physical structure and components of metals to determine the properties of import welding electrode. The metallographic result shows that the import welding electrode metal properties consist of Cu (copper): 98.37%, Cr (chromium): 1.17% and the remaining substances are unknown and will be defined by researcher.

4.2.1.2 Microstructure Test of Import Electrode

Studying the microstructure of a material provides information about its composition, processing technique, properties and performance of the material. These microstructural features affect the properties of a material, and certain microstructural features are associated with superior properties. Through microstructural examination we can determine if a component made from specific material and whether the material receives certain processing treatments or not. Microstructural analysis used in research studies to determine microstructural characteristic of a material, the characteristic of a material resulted from some parameters such as composition and processing technique. Through this microstructural analysis, the structure, properties and elements relationships of the material are developed. Figure 4.2, 4.3, 4.4 and 4.5 shows the microstructures photos of import welding electrode in different magnification.

Figure 4.2 Import Welding Electrode Microstructure Photo with 50x Magnification

Figure 4.3 Import Welding Electrode Microstructure Photo with 100x Magnification

Figure 4.4 Import Welding Electrode Microstructure Photo with 200x Magnification

Figure 4.5 Import Welding Electrode Microstructure Photo with 400x Magnification

4.2.2 Data Processing

4.2.2.1 Developing Domestic Welding Electrode

Based on ASM Metals handbook of nonferrous alloys and pure metals, one of the best compositions to build seam welding wheels is 99% of Cu and 1% of Cr (ASM International , 1985). Because not all the composition of import welding electrode revealed in the metallography process, which 0.47% of its substances remaining unknown, based on the literature review and consultations with supervisor, the researcher decide to add Zirconium (Zr) to build domestic welding electrode. Zirconium chosen because it will complement the alloy with its own characteristic to increase the quality of domestic welding electrode that being made. The characteristic and analysis of Cu, Cr and Zr chemical element, also after it combined as alloy will be explained below.

Copper is a chemical element with the symbol **Cu** with atomic number 29 in periodic table. Copper considered as malleable ductile metal with very high thermal and electrical conductivity. Copper melting point is at 1084.62 °C and its electrical resistivity at 20 °C is 16.78 nΩ·m. Copper has the second highest electrical conductivity of any element, the number one is silver. Pure copper characteristic are rather soft, malleable and the surface color seems rather pinkish, reddish, orange, or even brownish. Copper has good corrosion resistance and usually used as thermal conductor, electrical conductor, a building material, and usually combine with other materials to produce various metal alloys. Copper usually used as alloy for industrial needs to get really good machinability characteristics because of its character. Copper is often too soft for its applications, so it is incorporated in numerous alloys.

Chromium is a chemical element which has the symbol **Cr** with atomic number 24 in periodic table. It is a steely-gray, lustrous, hard metal and has a high melting point at 1907 °C and its electrical resistivity at 20 °C is 125 nΩ·m. It is also odorless, tasteless, and malleable. Chromium known of its high corrosion resistance and hardness, the used of chromium in steel and alloy resulting in highly resistant to corrosion and discoloration of the steel and increase its hardness. The strengthening effect of forming stable metal and the strong increase in corrosion resistance made chromium an important alloying material for steel.

Zirconium is a chemical element which has the symbol **Zr** with atomic number 40 in periodic table. It is a lustrous, grey-white, soft, ductile, and malleable metal which is solid at room temperature, though it becomes hard and brittle at lower purities. Zirconium is used as an alloying agent for its strong resistance to corrosion and heat resistance. Zirconium's melting point is at 1855°C and its electrical resistivity at 20 °C is 421 nΩ·m.

The first step in the development of a new alloy was to first determine its basic elements. Consideration of the trade-off between high strength and high electrical conductivity was important at this stage. Yamamoto, Sasaki, Yamakawa, & Ota (2000) states that generally, strength and electrical conductivity act against each other, which means materials with high strength tend to have low electrical conductivity. Observation to a favorable combination of mechanical properties and electrical conductivity, alloys belonging to the Cu element are commonly applied for fabrication of electrodes for resistance spot and seam welding of low carbon steels. Copper and Cu-based alloys are certain candidates to build this welding electrode since copper has excellent thermal and electrical conductivities. But pure copper is too soft for many technical applications and different approaches to harden copper were done as there are adding other elements, work hardening, grain refinement, solid solution hardening and precipitation hardening.

According to Nikolaev, Borodai, & Pleshakov (2008), to increase the wear resistance and strength of metals and alloys, additions of niobium, vanadium, zirconium, and rare-earth elements, as well as of certain nonferrous metals, strontium, boron, and other elements or their compounds, are used. The positive effect of additions is seen upon their introduction into coatings and performance of welding electrodes in amounts of 0.1% or even 0.01%. The low application other elements in metallurgy in the production of welding materials will affect the structure and properties of the steel and metal of the seam welding electrode. A quantitative estimate of how much the additions of alloying components will affect the welding characteristics of seam metal will depend on the nature and concentration of the addition elements characteristic.

The most important factor determining weld metal properties is chemical composition (Gharavol, Sabzevar, & Haerian, 2009). Based on Batra (2007), Bockus (2006), Gharavol, Sabzevar, & Haerian (2009), Ma, Wang, Li, Gai, & Zhu (2009), Liu, Su, Dong, & Li (2005) and Wang, Dong, Zhang, & Xu (2009) study about chemical elements and their influence on metal alloys, the researcher decided to add Chromium (Cr) and Zirconium (Zr) substances to the Copper (Cu) electrode. The addition 1% of Cu and 0.1% of Zr will increase the metal properties and characteristic of domestic welding electrode that being made.

The study of Ghosh, Haldar, & Chattopadhyay (2009) revealed that pure Cu is too soft to be used as an electrode, it will need some addition of other element that will increase its hardness. Addition of Cr elements has obtained significant changes in morphology and microstructure of Cu, Cr elements also refines the columnar structure and decreases the surface roughness of Cu in electrode that already analyzed by Wang, Dong, Zhang, & Xu (2009). This statement also in line with Gharavol, Sabzevar, & Haerian (2009) analysis which explain that Cr addition to low alloy steel in the range of 0.05% - 0.91% will increase the hardness and tensile properties and also refinement of the microstructure of the alloy.

Besides Cr, Zr element also has a significant role in enhancing the properties of an alloy. According to Jovanović & Rajković (2009), a very small addition of Zr (less than 0.1%) improve hardness and electrical conductivity of alloy due to very low solubility of Zr in Cu matrix. The addition of Zr has significant influence on the morphology and mechanical property of composites too, the refinement mechanism of Zr was attributed to the combined effects of increase in nucleation rate at the constitutionally super cooled zone ahead of the solidification front and reduction in growth rate (Ma, Wang, Li, Gai, & Zhu, 2009). Batra (2007) revealed that the addition of Zr to the alloy strongly influenced the sequence of precipitation. Because of this, an improvement in the fatigue resistance of the alloy results due to a change in the nature of pure Cu to the alloy. If Zr is added, the Zr in the copper matrix could act to retard the softening of the alloy at high temperatures (Ellis, 2006). Because of the reason that explained above, Cr and Zr elements were added to form an alloy of CuCrZr welding electrode.

For the optimal application of these materials it is necessary to know changes in microstructure due to treatment via different external factors such as heat treatment, ageing, water quenching, etc. Slugen, Ballo, & Domonkos (2000) explained that precipitation hardened alloys reach an optimum strength after the thermo mechanical treatment involving a solution annealing at high temperature to dissolve the alloying elements, then a water quench to keep the alloying elements in supersaturated solid solution at room temperature and finally an ageing treatment at intermediate temperatures to decompose the supersaturated solid solution.

The strengthening effect in conventional solid solution aging is limited due to low solubility of Cr in Cu at the solid solution temperature, and grain structure. Rapid solidification can lead to an obvious extension of the solid solubility of Cr and Zr in Cu matrix and remarkable refinement of grain size. Upon aging, very fine dispersions of Cr and Zr are precipitated in the matrix. As a result the dispersion hardening effect is greatly intensified without degrading the electrical conductivity. Aging is a common heat treatment for many copper alloys, with the aim of raising their strength and hardness. The high hardness of Cu-Cr-Zr alloys is attributed to the precipitation and dispersion strengthening, and the excellent electrical conductivity to the very low solubility of Cr and Zr in Cu (Jovanović & Rajković, 2009). The strength and hardness increase with decreasing grain size, with a reduction in grain size, the barrier for dislocation increases and this account for the increase in strength and hardness (Liu, Su, Dong, & Li, 2005), this statement also in line with Hall Petch equation $\sigma_y = \sigma_o + kd^{-\frac{1}{2}}$ about grain size in alloy microstructures.

So the hardness of the alloy is obviously influenced by aging treatment meanwhile the hardness generally correlates with yield and ultimate strengths. The correlation of hardness and strength represent in figure 4.6.

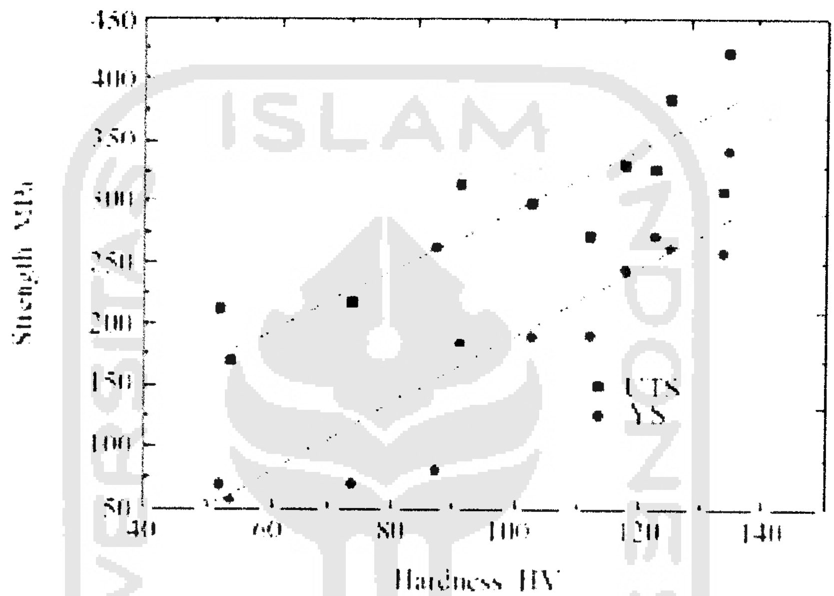

Figure 4.6 Correlation of Hardness with Strength of CuCrZr Alloy. Adapted From Danhua, Jihong, Pengfei, Desheng, & Jiming (2007)

It is known that the high hardness of CuCrZr alloy is due to the low solubility of Cr elements in Cu, Yamamoto, Sasaki, Yamakawa, & Ota (2000) studied this matter and conclude that the maximum Cr solubility in Cu is approximately 0.89% at 1077°C, whereas the solubility of Cu in Cr is negligible, the material that investigated is Cu alloy with 1% of Cr and 0.1% of Zr (CuCr1). The equilibrium phase diagram of Cu – Cr shown in figure 4.7.

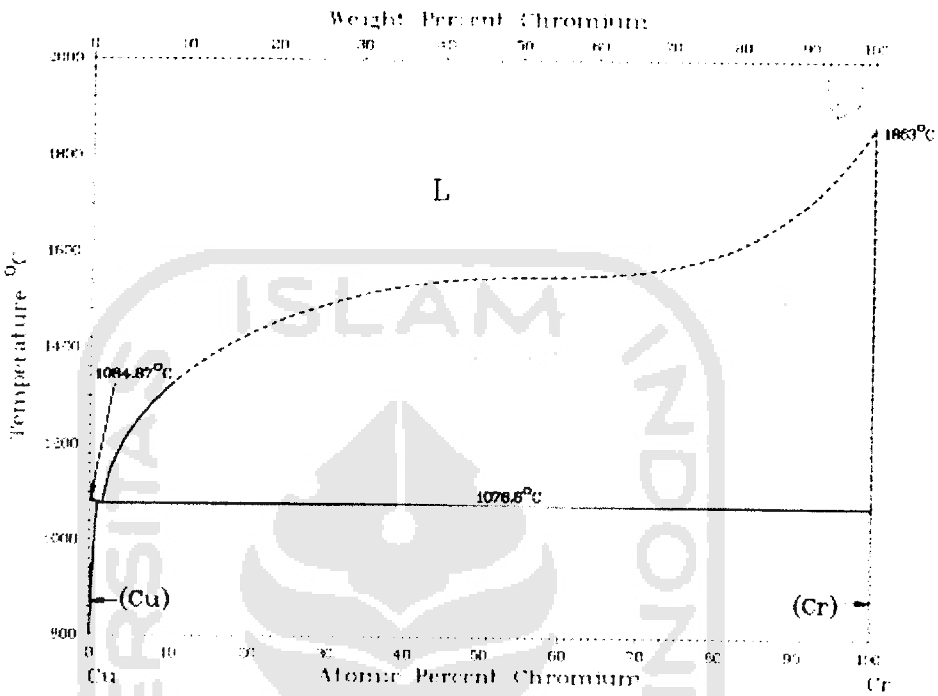

Figure 4.7 The Equilibrium Phase Diagram Of Cu – Cr. Adapted From Yamamoto, Sasaki, Yamakawa, & Ota (2000)

To increase the hardness, different thermal treatments with varying aging times and temperatures were conducted and the hardness of each condition was measured. This was done to find the best conditions to increase the hardness.

Table 4.1 Overview of Different Aging Parameters. Adapted From Jessner (2006)

Aging Temperature (°C)	Aging Time (min)	Micro Hardness (HV)
450	30	71 ± 1.3
	60	103 ± 2.2
	120	104 ± 2.7
	360	140 ± 3.0
475	30	112 ± 2.7
	120	136 ± 2.1
	240	134 ± 3.8
	360	135 ± 4.0
500	60	134 ± 4.2

As can be seen, the highest hardness was reached at a temperature of 450°C and an aging time of 6 hours with 140 ± 3 HV. At this temperature, the solubility of Cr in Cu is very low and the driving force to build precipitations is rather high. But the mobility of Cr is low; this is why it takes 6 hours to reach the maximum hardness. With increasing aging temperature the mobility increases but the driving force to precipitate Cr decreases because more Cr can be dissolved in the matrix (475°, 6 hours: 135 HV). At an aging temperature of 500 °C the solubility is even bigger and fewer precipitations can be build. The highest hardness reached at the lowest aging temperature can be explained by a higher driving force for precipitations, since the solubility of Cr in Cu is lower. At higher temperature more Cr can be dissolve and the driving force to build precipitations is lower.

4.2.2.2 Microstructure Analysis

From the microstructure photo at 200um, 100um, 50um and 25um it can be seen that the elements are dispersed in all the alloy structure. The microstructure and grain size of the elements are very uniform which account for the dispersed Cr and the unknown elements in Cu alloys. The dispersed Cr and unknown elements, also the heat treatment that applied counts for the high hardness and high electrical conductivity of import welding electrode.

For domestic welding electrode that contains 1% Cu and 0.1% Zr elements in Cu alloy, the effect would be different. Based on Ellis (2006) study about a cast of CuCrZr alloy with similar amount of elements percentage, it is assumed that the dark spot in the microstructure photo will be subjected to Cr elements that strengthen the alloy, the orange-brown color which is the major color in the alloy representing Cu elements, and the bright orange color representing Cu-Zr elements that counts for the high hardness of the alloy. To strengthen the analysis, Ellis (2006) observation of a cast Cu-6%Cr-5.4%Zr alloy will be presented. The samples of Cu-6%Cr-5.4%Zr were polished and examined in the scanning electron microscope (SEM). Back scattered electron (BSE) imaging was used to qualitatively determine the location of the elements and phases present in the casting. It was also possible to use the images to quantitatively determine the volume fraction of each phase. Energy dispersion spectroscopy (EDS) was used to semi quantitatively determine the composition of each phase observed. The image is shown in figure 4.8.

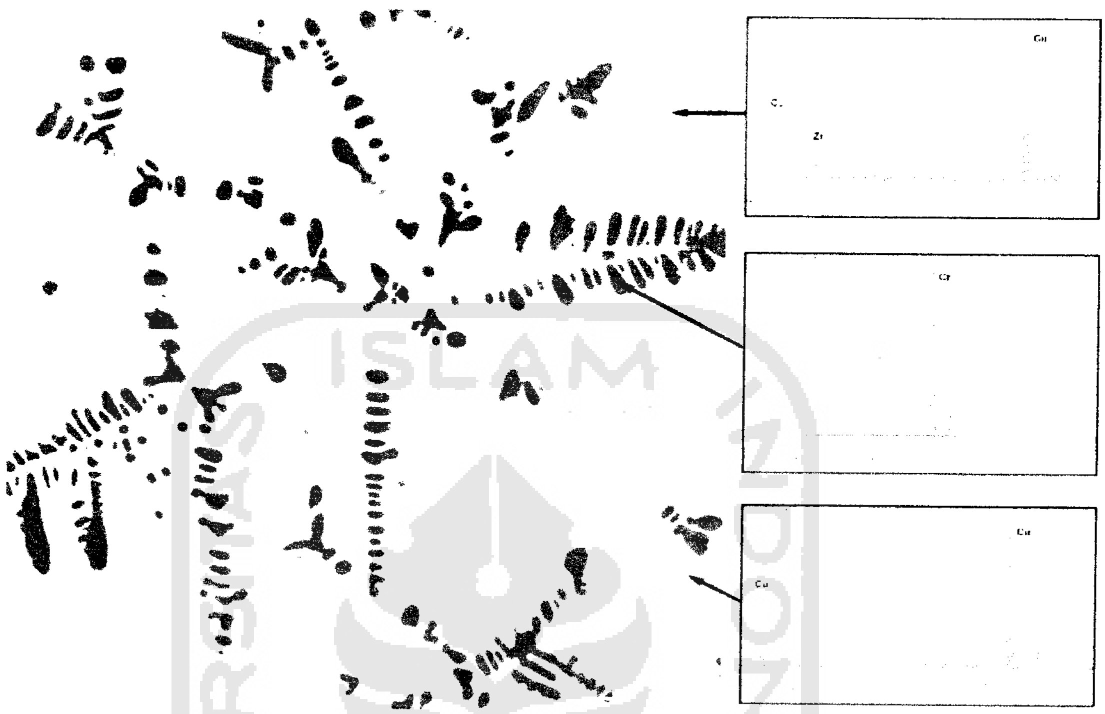

Figure 4.8 Detail of General Microstructure (BSE Image) with EDS Spectra. Adapted From Ellis (2006)

Using EDS and the information from the x-ray diffraction results, the observed regions were identified as elemental Cr dendrites, elemental Cu dendrites, and Cu-CuZr in the interdendritic spaces. The Cr and Cu have a larger, dendritic structure. Based upon this structure and the various melting points, it is surmised that the Cr solidified first followed by the Cu. The remaining Cu-Zr liquid solidified last. This study and image are in line with the import electrode microstructure photo.

4.3 Domestic Electrode Performance Test

4.3.1 Data Collecting

4.3.1.1 Visual and Physical Examination

Visual and physical examination conducted to identify and analyze the difference between import and domestic electrode. The image is in figure 4.9 below.

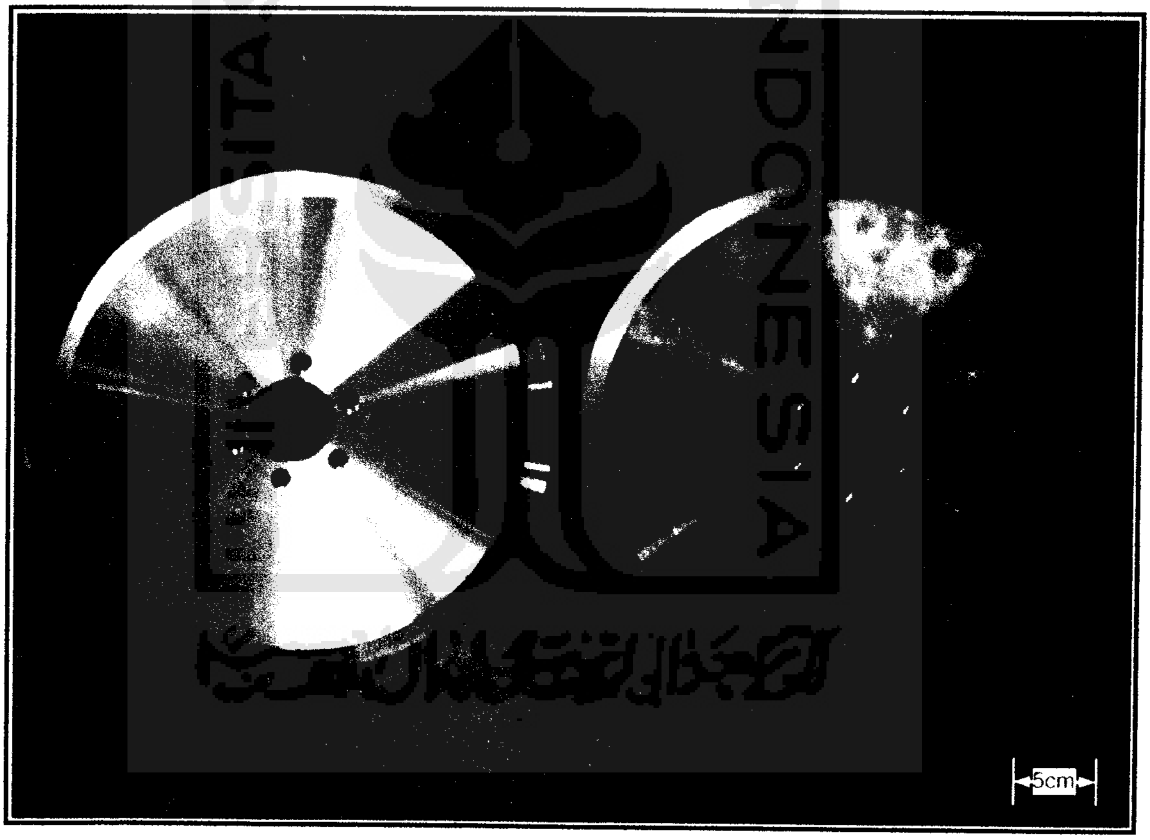

Figure 4.9 Import and Domestic Welding Electrode

4.3.1.2 Hardness Test

Hardness test conducted to compare the endurance and strength between import and domestic electrode. The data are in table 4.2 and 4.3.

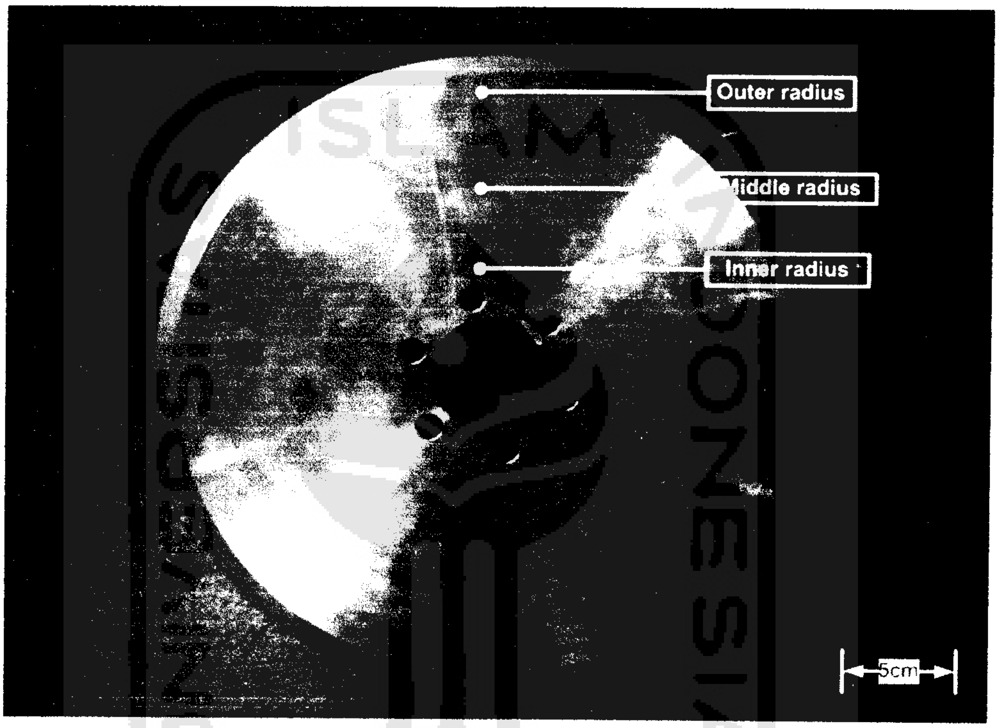

Figure 4.10 Electrode Radius Information

Table 4.2 Hardness of Import Electrode

No	Outer (HV)	Middle (HV)	Inner (HV)
1	124	128	122
2	128	122	126
3	116	110	112
average	122.7	120	120

Table 4.3 Hardness of Domestic Electrode

No	Outer (HV)	Middle (HV)	Inner (HV)
1	118	124	116
2	120	118	121
3	114	112	113
average	117.3	118	116.7

4.3.1.3 Welding Test

Welding test conducted to see the difference between import and domestic electrode when used to weld the strip of coil. The data are in table 4.4 and 4.5.

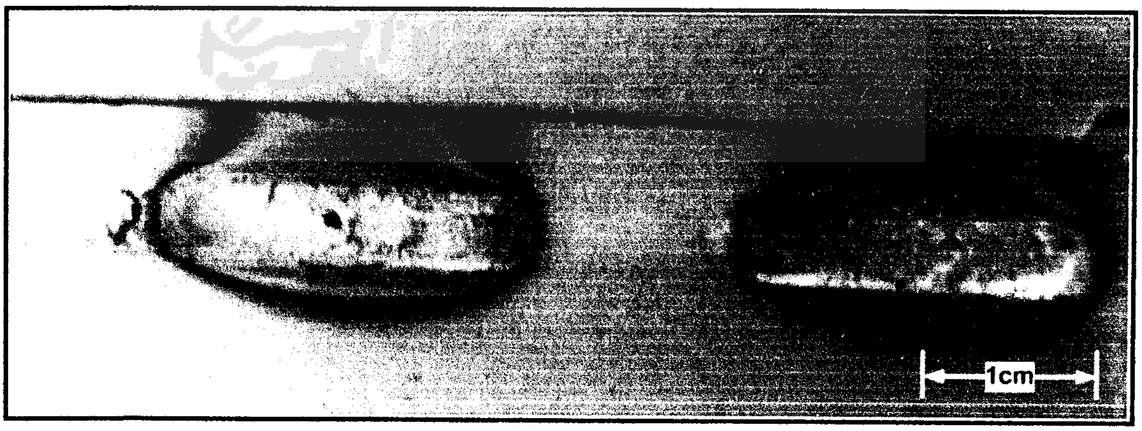

Figure 4.11 Weld Result

Table 4.4 Welding Test of Import Electrode

Thickness x width (mm)	weld thickness (mm)	weld width (cm)	HAZ width (cm)	weld length (cm)	HAZ length (cm)	weld interval (cm)	HAZ interval (cm)	spot
0.2 x 914	0.44	0.4	0.6	2	2.2	1.75	1.55	25
0.25 x 882	0.6	0.4	0.65	2	2.2	1.7	1.6	24
0.30 x 882	0.8	0.4	0.8	1.9	2.1	1.75	1.6	24
0.50 x 914	1.1	0.4	0.8	2	2.1	1.8	1.7	25
0.6 x 1219	1.38	0.45	0.9	2.1	2.25	1.8	1.6	33
0.7 x 1219	1.6	0.475	1	2.1	2.2	1.6	1.5	33
0.8 x 914	1.82	0.5	1.15	2.2	2.3	1.5	1.4	25
1.0 x 914	2.4	0.5	1.3	2.3	2.5	1.4	1.3	25
1.2 x 1219	2.6	0.5	1.3	2.3	2.4	1.4	1.3	33

Table 4.5 Welding Test of Domestic Electrode

Thickness x width (mm)	weld thickness (mm)	weld width (cm)	HAZ width (cm)	weld length (cm)	HAZ length (cm)	weld interval (cm)	HAZ interval (cm)	spot
0.2 x 914	0.45	0.4	0.5	1.5	1.6	2.2	2.1	25
0.25 x 882	0.6	0.4	0.6	1.6	1.75	2.1	2	24
0.30 x 882	0.73	0.45	0.6	1.8	1.9	2	1.8	24
0.50 x 914	1.1	0.45	0.8	1.9	2	1.8	1.7	25
0.6 x 1219	1.3	0.5	0.9	2	2.1	1.7	1.6	33
0.7 x 1219	1.52	0.5	1	2.1	2.2	1.6	1.5	33
0.8 x 914	1.8	0.5	1.1	2.2	2.3	1.5	1.4	25
1.0 x 914	2.2	0.52	1.1	2.3	2.4	1.4	1.3	25
1.2 x 1219	2.6	0.52	1.2	2.3	2.4	1.4	1.3	33

4.3.1.4 Weld Strength Test

The weld strength test conducted to identify whether the result of domestic electrode weld in the strip of coil is strong, save and fulfill the quality requirement to be processed in CGL machine. The test conducted by punching the strip of coil weld using a hammer and chisel. If the weld is broken, it means that the weld is not good, but if the strip of coil that broke rather than the weld means that the weld is good and fulfills the quality requirement. The images of weld strength test are shown in figure 4.12 until 4.20.

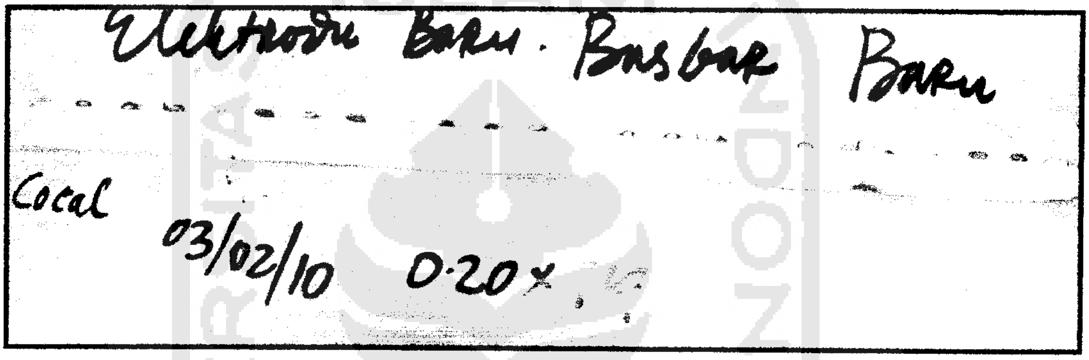

Figure 4.12 0.20mm x 914mm Strip of Coil Weld

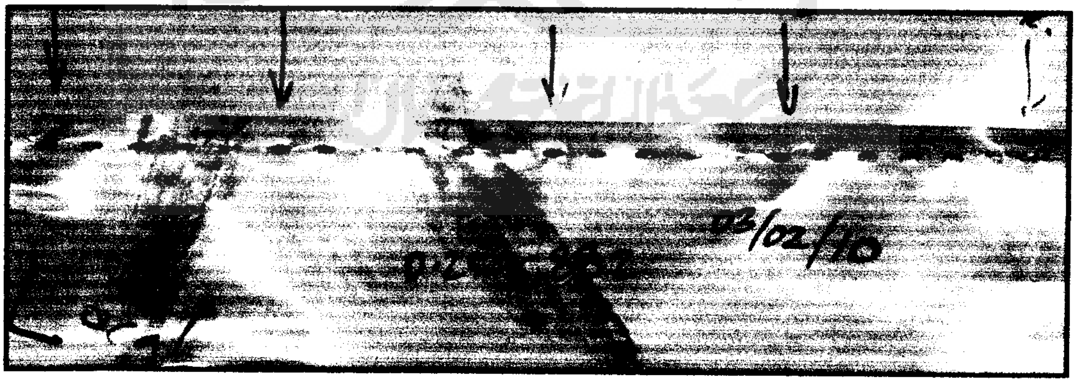

Figure 4.13 0.25mm x 882mm Strip of Coil Weld

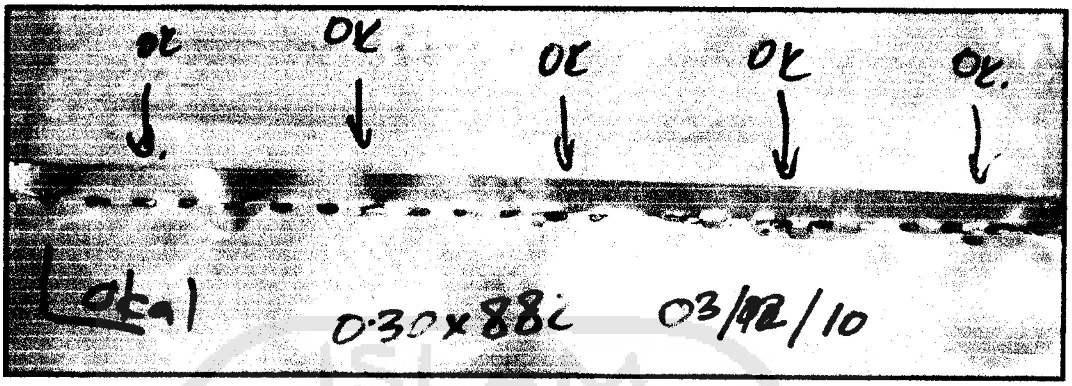

Figure 4.14 0.30mm x 882mm Strip of Coil Weld

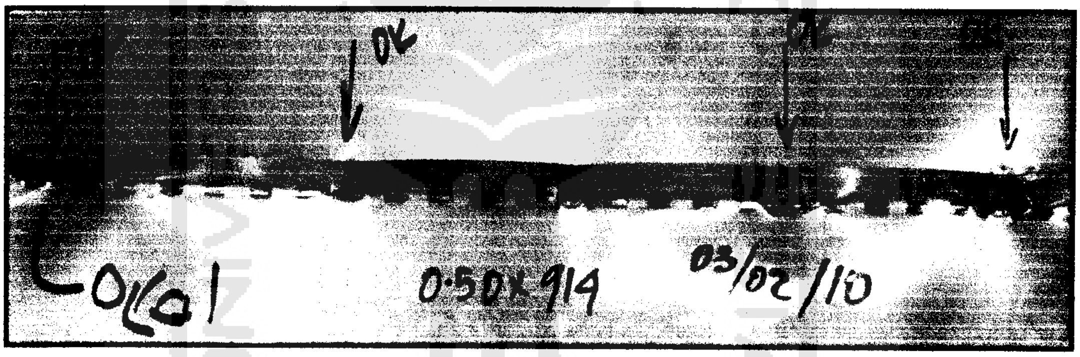

Figure 4.15 0.50mm x 914mm Strip of Coil Weld

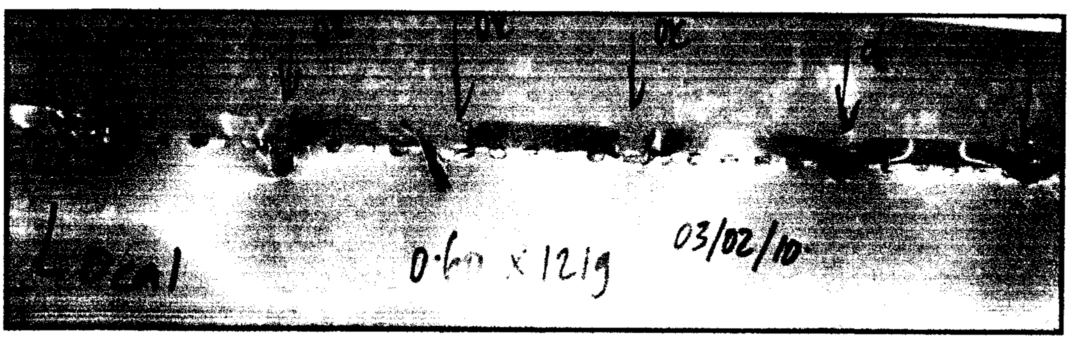

Figure 4.16 0.60mm x 1219mm Strip of Coil Weld

Figure 4.17 0.70mm x 1219mm Strip of Coil Weld

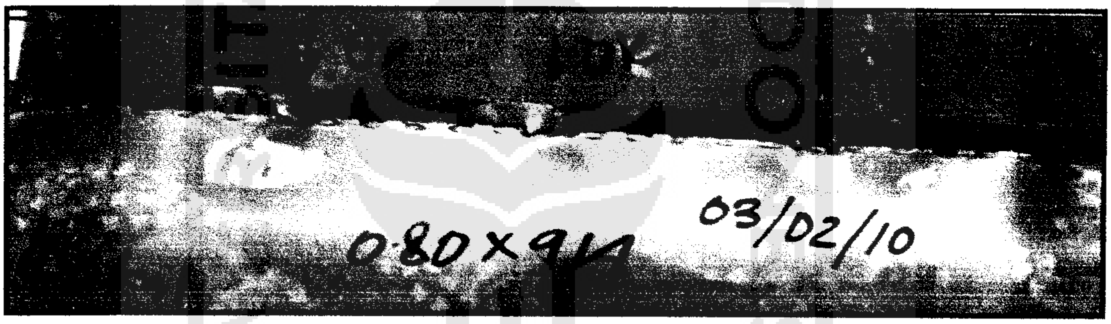

Figure 4.18 0.80mm x 914mm Strip of Coil Weld

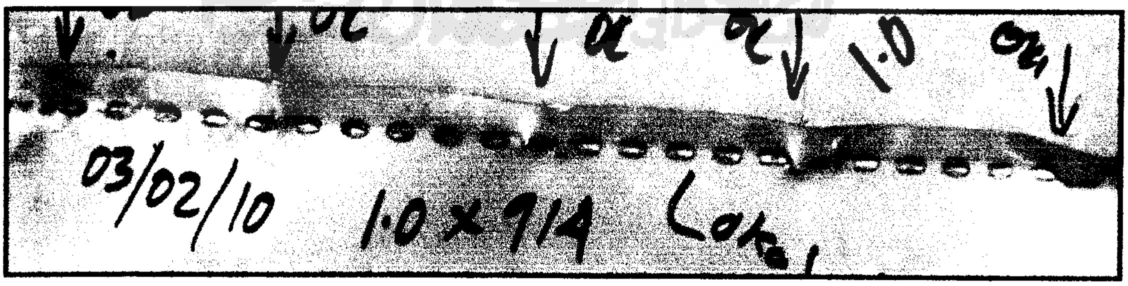

Figure 4.19 1.0mm x 914mm Strip of Coil Weld

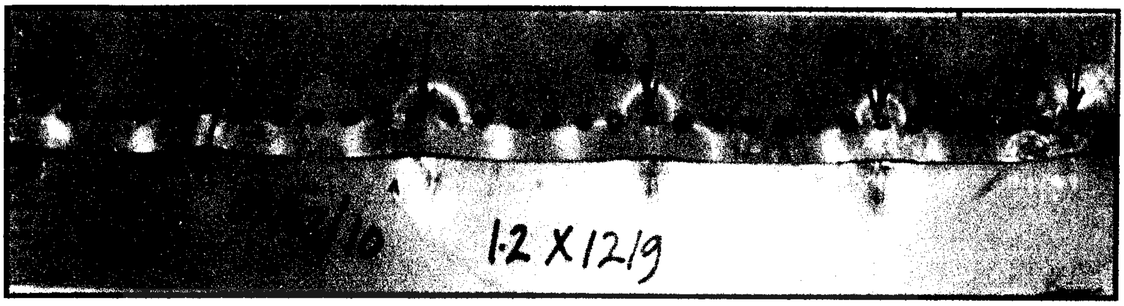

Figure 4.20 1.2mm x 1219mm Strip of Coil Weld

4.3.2 Data Processing

4.3.2.1 Visual and Physical Analysis

The visual observation of import and domestic electrode is very identical, but there is color difference between them. Import electrode color is very homogeneous orange compare to domestic electrode which is darker and the color is not homogeneous. This difference is caused by different technique in the making of the electrode, import electrode use die casting and heat treatment in the process whether domestic electrode use sand casting because its economical attributes that stated by Lost & Foundry TM (2010) with natural air in the solidification process and made without heat treatment. But the color difference is not a problem because the quality measure is according to the welding test itself.

4.3.2.2 Hardness Test Analysis

The comparison of hardness between import and domestic electrode will be shown in 4.21, 4.22 and 4.23.

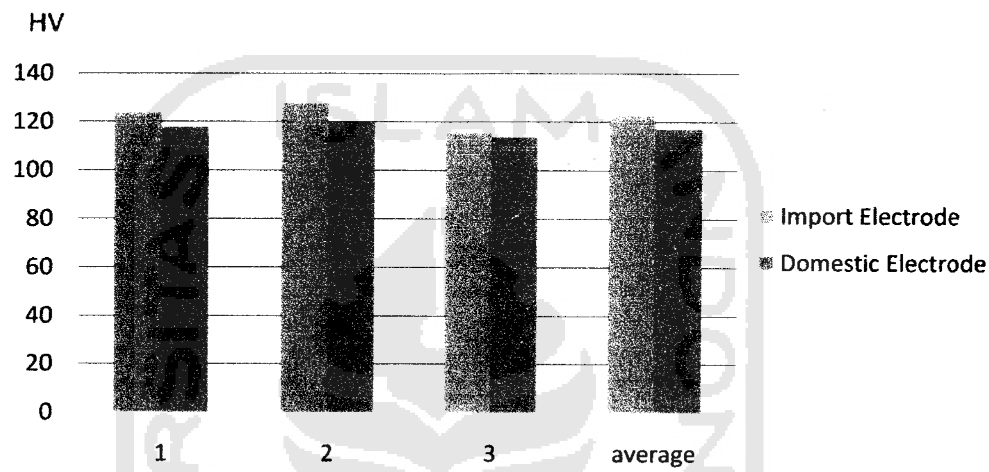

Figure 4.21 Hardness in Electrode Outer Radius

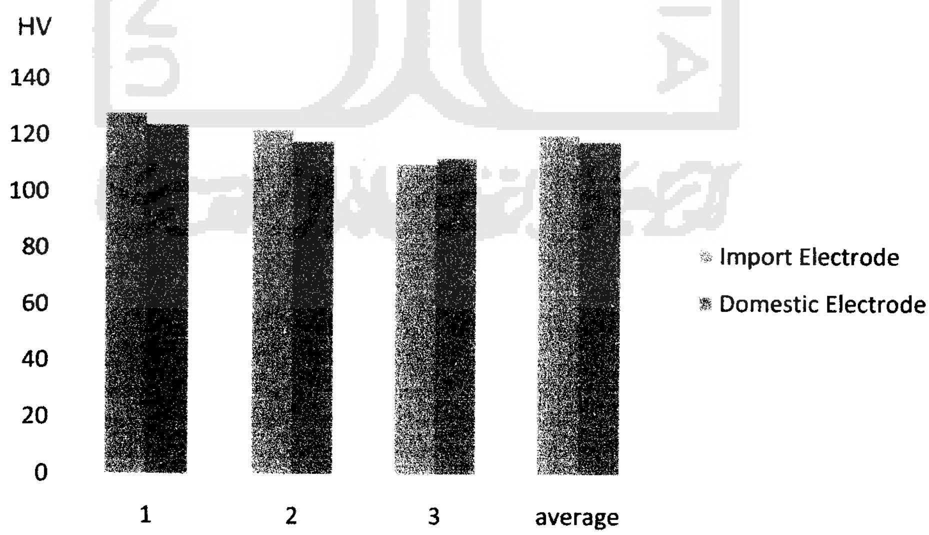

Figure 4.22 Hardness in Electrode Middle Radius

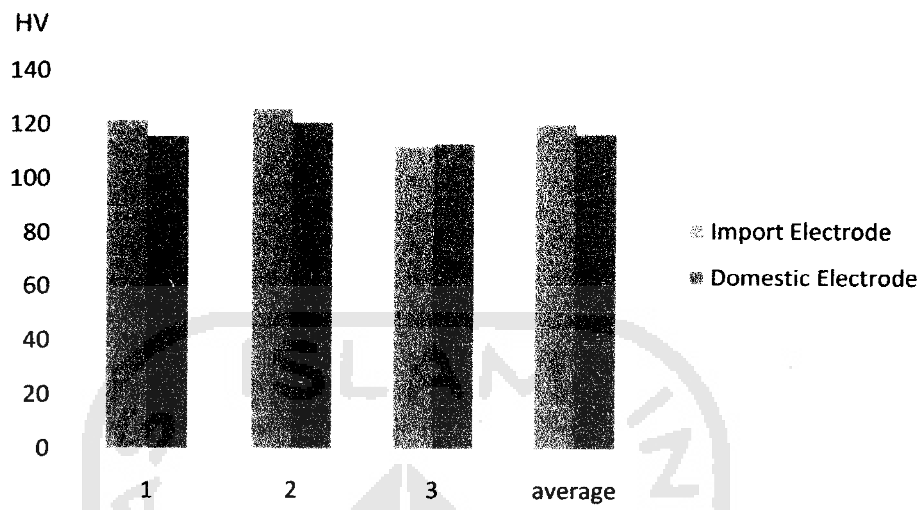

Figure 4.23 Hardness in Electrode Inner Radius

From the diagram above it can be seen that the hardness of domestic electrode is slightly lower than import electrode, but the difference is not high so the domestic electrode is appropriate to be used. It also can be seen that the hardness does not differ significantly over the radius, this indicates a homogenous microstructure over the whole specimen.

By statistical process using Independent Samples T Test where

Ho : The population of import and domestic electrode is same ($\mu 1 - \mu 2 = 0$)

H1 : The population of import and domestic electrode is not same ($\mu 1 - \mu 2 \neq 0$)

Since the hypothesis showing that the difference between domestic electrode and import electrode does not have to be equal to zero, hence it use 2-tailed probability where $\alpha = 0.01/2 = 0.005$, hence

If probability > 0.005 then do not reject Ho

If probability < 0.005 then reject Ho

Based on Independent Samples T Test result, the P-value of each variable in hardness are:

1. Variable : Outer

   P-value : 0.283

2. Variable : Middle

   P-value : 0.442

3. Variable : Inner

   P-value : 0. 308

From all the variable, the P-value is > 0.005, hence do not reject Ho, it is concluded that the population of domestic electrode and import electrode is not different significantly. This shows that the hardness between import electrode and domestic electrode did not differ significantly.

4.3.2.3 Welding Test Analysis

The comparison of welding result between import and domestic electrode will be shown in figure 4.24 until 4.31.

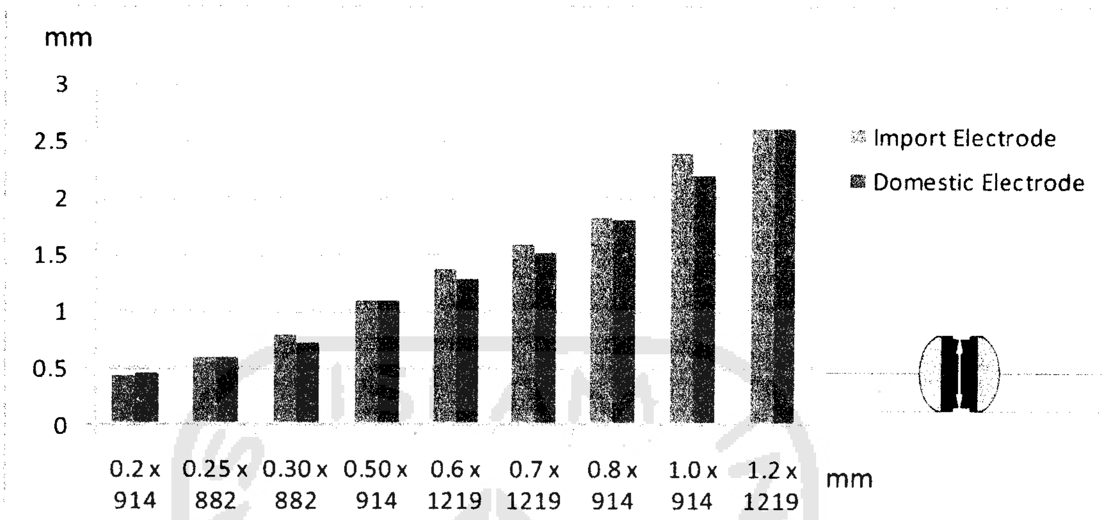

Figure 4.24 Weld Thickness Comparison

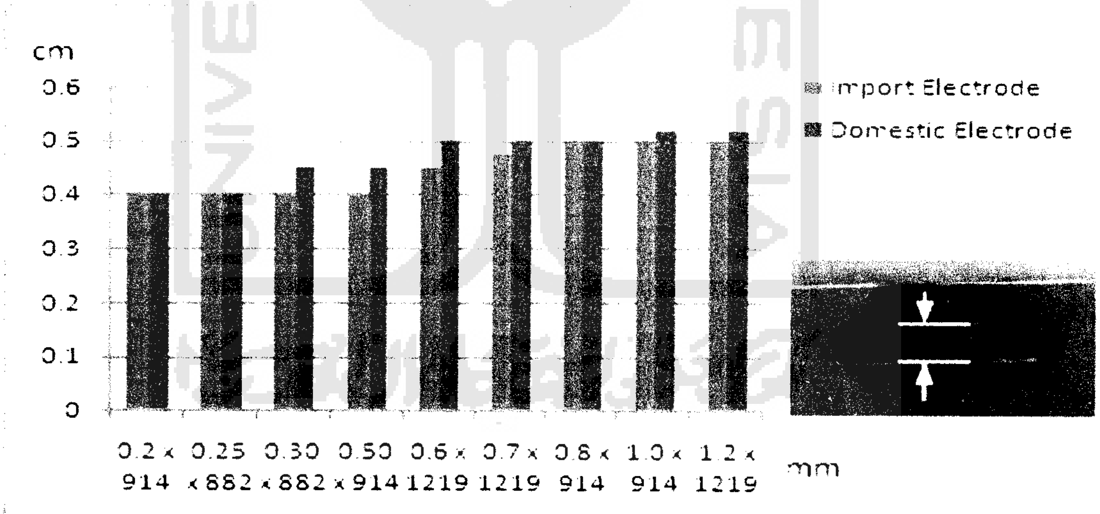

Figure 4.25 Weld Width Comparison

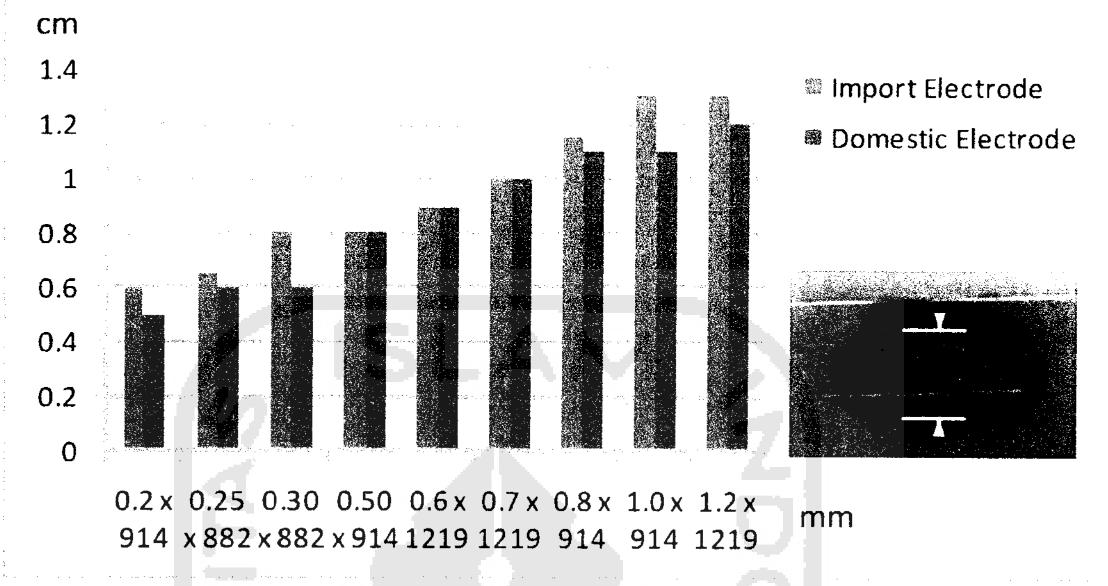

Figure 4.26 HAZ Width Comparison

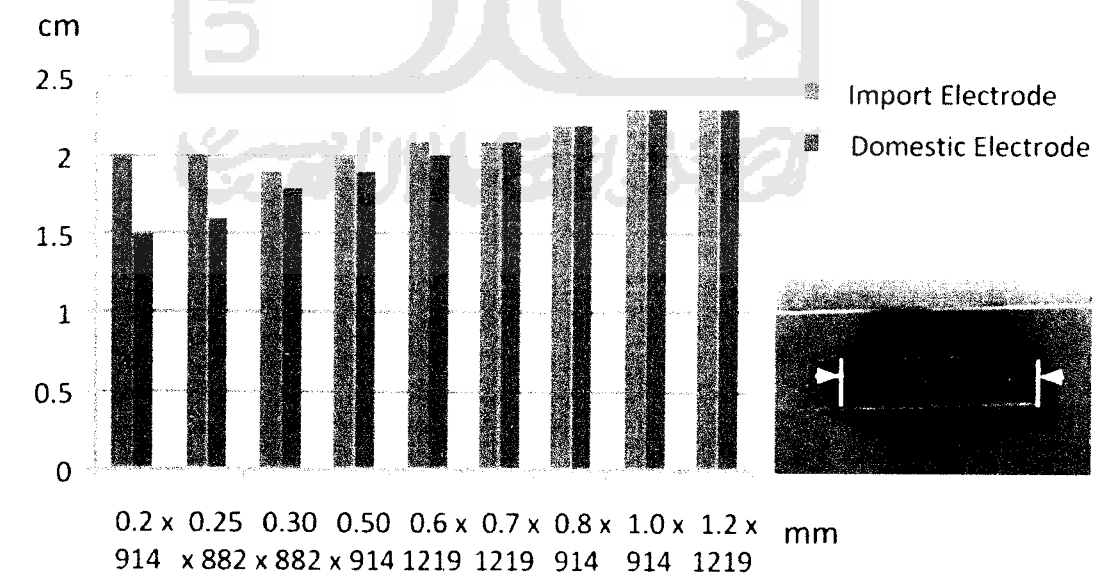

Figure 4.27 Weld Length Comparison

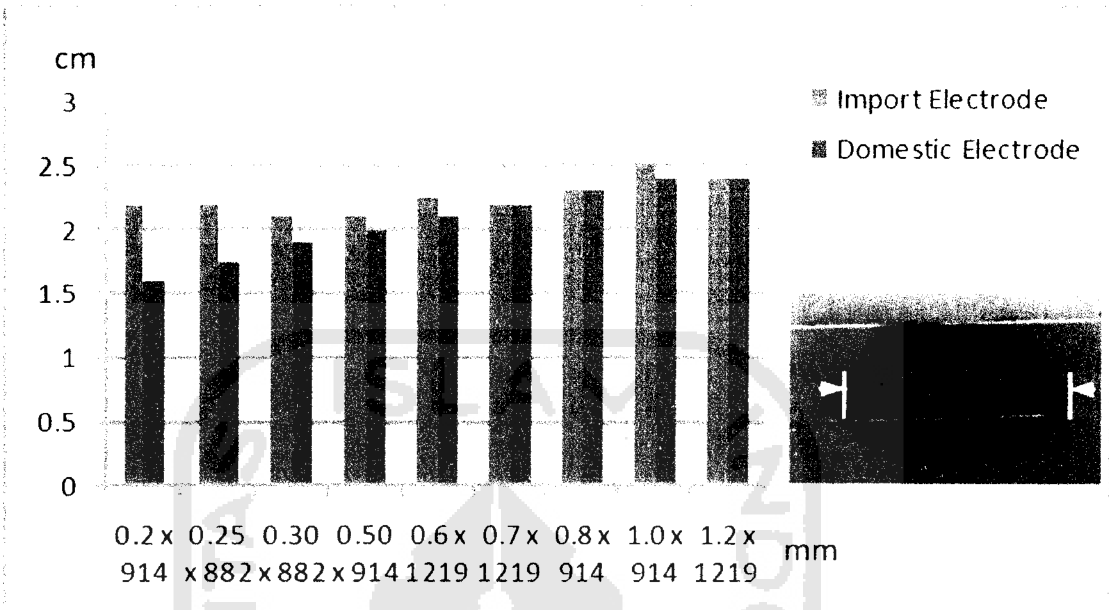

Figure 4.28 HAZ Length Comparison

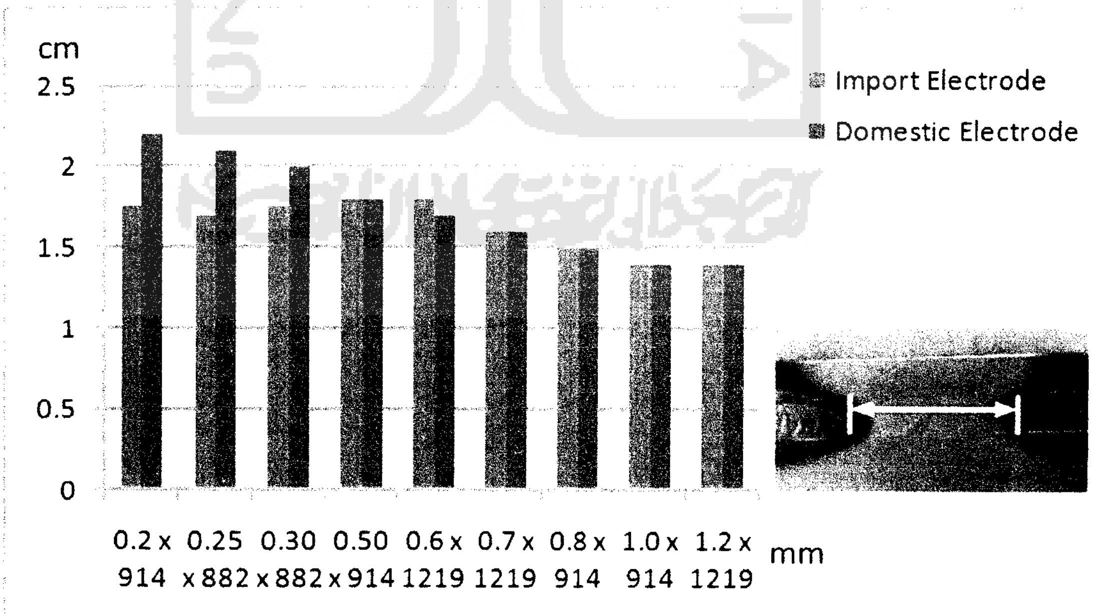

Figure 4.29 Weld Interval Comparison

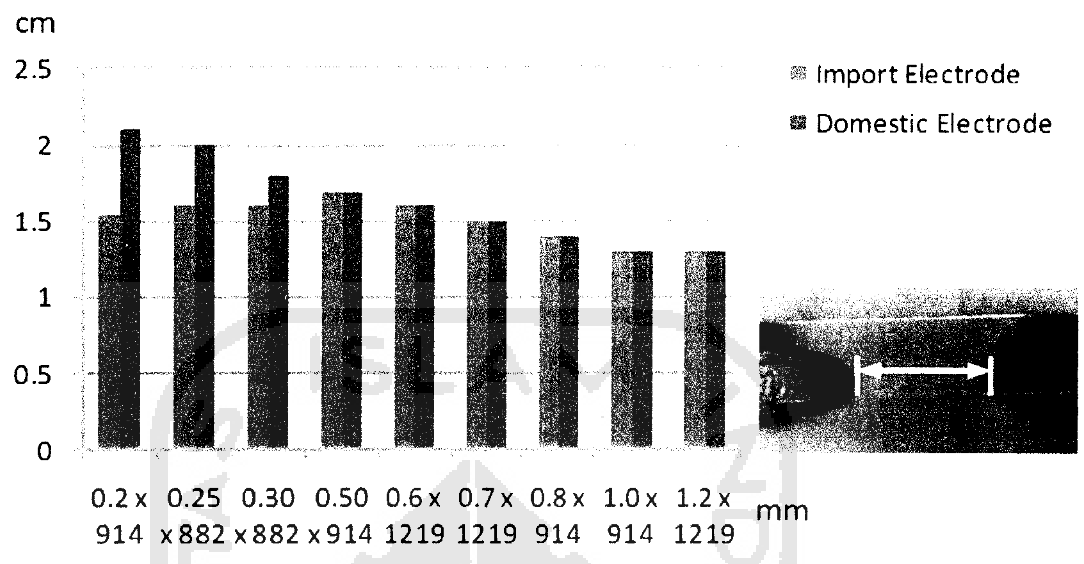

Figure 4.30 HAZ Interval Comparison

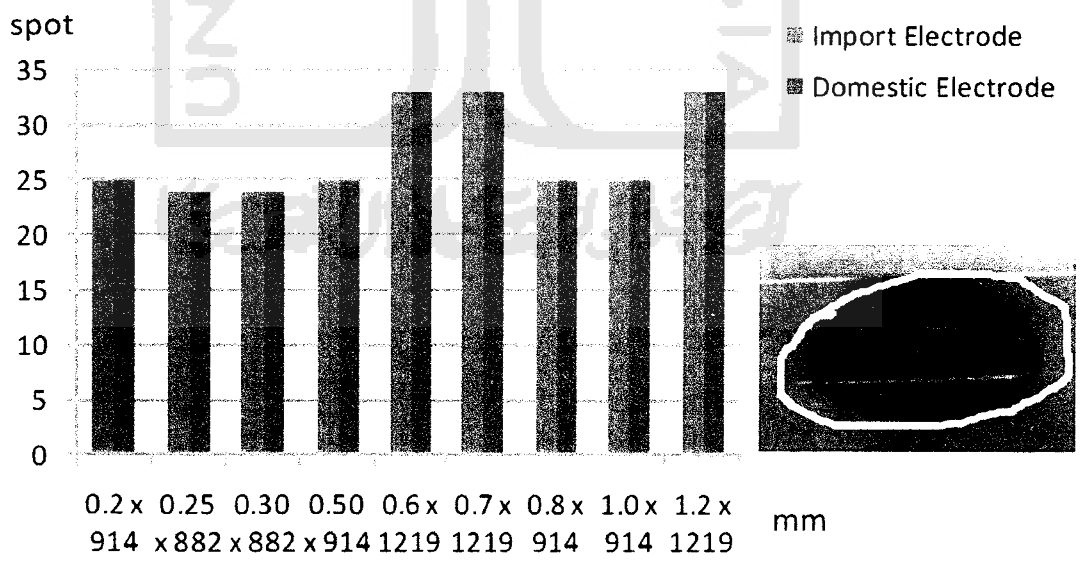

Figure 4.31 Weld Spot Comparison

Based on the diagrams above, it can be shown from the parameters of welding test comparison that domestic electrode welding quality is slightly lower than the import electrode one. Although domestic electrode welding quality is lower, the difference is very little compared to import electrode, so the domestic electrode welding quality considered good.

By statistical process using Independent Samples T Test where

Ho : The population of import and domestic electrode is same ($\mu 1 - \mu 2 = 0$)

H1 : The population of import and domestic electrode is not same ($\mu 1 - \mu 2 \neq 0$)

Since the hypothesis showing that the difference between domestic electrode and import electrode does not have to be equal to zero, hence it use 2-tailed probability where $\alpha = 0.01/2 = 0.005$, hence

If probability > 0.005 then do not reject Ho

If probability < 0.005 then reject Ho

Based on Independent Samples T Test result, the P-value of each variable in welding are:

1. Variable : weld thickness

   P-value : 0 .902

2. Variable : weld width

   P-value : 0.910

3. Variable : HAZ width

   P-value : 0.983

4. Variable : weld length

   P-value : 0.038

5. Variable : HAZ length

   P-value : 0.030

6. Variable : weld interval

   P-value : 0.055

7. Variable : HAZ_interval

   P-value : 0.042

8. Variable : spot

   P-value : 1.000

From all the variable, the P-value is > 0.005, hence do not reject Ho, it is concluded that the population of domestic electrode and import electrode is not different significantly. This shows that the welding test between import electrode and domestic electrode did not differ significantly.

4.3.1.4 Weld Strength Analysis

From all the punch test that conducted in many different thickness of strip of coil, none of them fails the punch test, which means that the weld are stronger than the strip of coil. Based on this test, it is concluded that the welding quality already fulfills the quality requirement, and the strip of coils are safe to be processed in CGL machine. Therefore the domestic electrode is safe to be use and can substitute the import electrode. More obvious image of the success in the punch tests are shown figure 4.32 and 4.33.

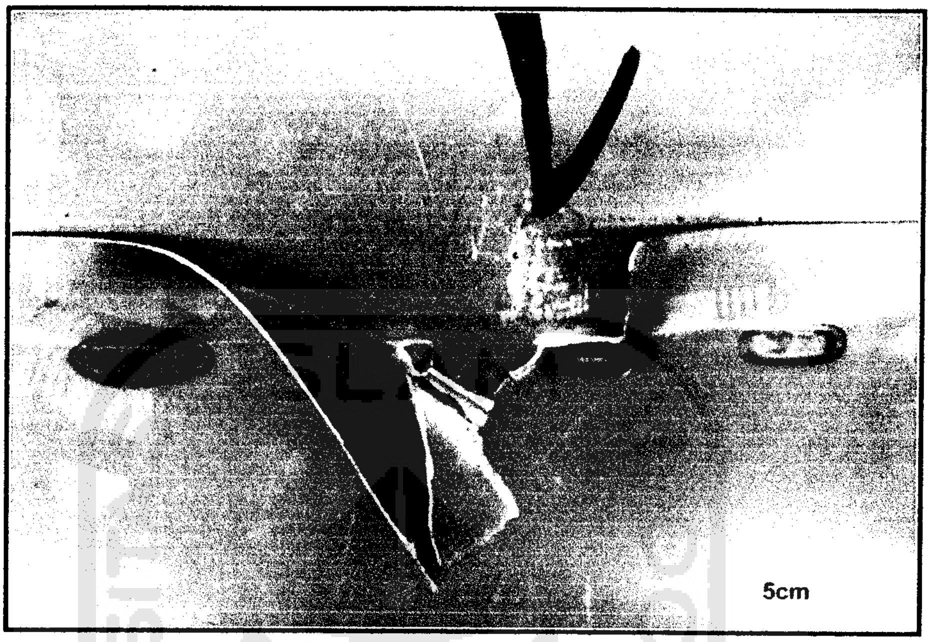

Figure 4.32 Strip of Coil Punch Test

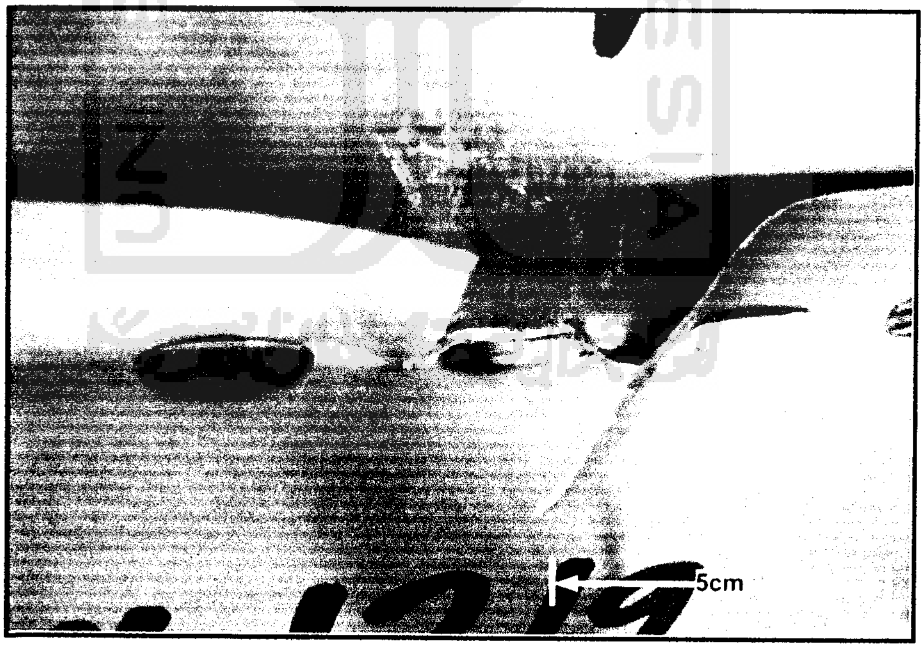

Figure 4.33 Strip of Coil Punch Test