FERRITE GRAIN SIZE AND MECHANICAL PROPERTIES IN THE WELD HAZ OF A HIGH-STRENGTH LOW-CARBON MICROALLOYED STEEL

Nuttaporn Bungmek and Ganwarich Pluphrach
Department of Mechanical Engineering, Faculty of Engineering, Srinakharinwirot University
63 M.7 Rangsit-Nakhonnayok Rd., Khong 16, Ongkharak, Nakhonnayok 26120, Thailand

ABSTRACT

The process of Shielded Metal Arc Welding (SMAW) was used to join High-Strength Low-Alloy (HSLA) with AWS E7016 electrodes. The ABS EH36 steel was a part of HSLA grade. The testing forms of weld ability use to predict mechanical properties and microstructure. An investigation was carried out to determine mechanical properties in a hardness test (Vickers hardness tester) and tensile test. Microstructure as chemical composition analysis with a spectrometer, EDS analysis on the SEM with a scanning electron microscope and predicts the strength as the optical microscope (OM) that used the figure to find the grain size number by the intercept method and applied to use the value to find the yield stress with the Hall-Petch relationship. The result has a higher strength than HAZ and base zone respectively.

KEYWORDS: Ferrite Grain Size, Mechanical Properties, Microstructure, High-Strength Low-Carbon Microalloyed Steel, Hall - Petch relationship

1. Introduction

High-Strength Low-Alloy (HSLA) or Micro alloyed Steel are widely used to provide many benefits over regular steel alloys [1]. In general, they are much stronger and tougher than ordinary plain carbon steels and used in shipbuilding, oil platform, cars and other structures that are designed to handle a lot of stress, often at very low temperatures. One typical benefit from micro alloyed steel is the grain refinement of ferrite due to the effect from fine micro alloy (Ti, Nb and V). When micro alloyed steels are fusion welded as Shielded Metal Arc Welding (SMAW), it is also of interest and significance to study the ferrite grain size and further phase transformation at HAZ. Accordingly, simulation of the welding process is to be more important for the welding industry. Therefore, it should be studied for strength from the manner and general use to be certain before applying them.

The ferrite grain size is an important fundamental physical property of steel. In particular, the strength of many steels such as micro alloyed steel [2, 3]. So that we can use the result in this paper to predict and analyze the ferrite grain size at the welding joint and HAZ.

The mechanical properties of materials have shown the microstructural dimensions. Based on Hall - Petch [2, 4], a relationship of yield strength was predicted between grain size and the mechanical properties of steel (HSLA) and formulated.

For HSLA [5],

$$\sigma_y = \sigma_0 + kd^{-1/2} \tag{1}$$

Where σ_y is the yield stress, σ_0 is the materials constant for the starting stress for dislocation movement and k is the materials constant for the strengthening coefficient, d is the average grain diameter. Normally the stress can be used or applied to the yield strength for division of plasticity and elasticity behavior. Hall – Petch [4], relationship was focused on the large variety of material properties more than the lower yield point and the stress of material such as hardness. Hall – Petch [4], relationship related to find or to measure the grain size for describe the microstructure. However the strength of different grain sizes was estimated by applying a weighting fact or equal to the volume of the grains [4] each area such HAZ. The grain size indicate the yield strength and can be explained by the grain boundary because they are also much more disordered than inside the grain. But several studies with the average grain diameter can be obtained from the experimental measurements.

In the calculation process the ASTM E112 standard was measured in accordance to the ferrite grain size in each material [5] and gives a value of grain size relationships computed for uniform, randomly oriented, equiaxed grains. It is validated for microstructure and the recommended measurement procedure for linear intercept length method coupled with used other measurement method such as optical microscope for comparing the results of the calculation. The ASTM commonly used included “Comparison method”, “Planimetric method or Jeffries method” and “Intercept method”.

1.1. Comparison method

Normally imaging microstructure or photomicrographs that extends at 100X. Then compare the grain size with standard microscopic structure and called “ASTM grain size number” This method is suitable for equiaxed grain [5]. The ASTM grain size number can be calculated by counting the number of grains in one square inch at the surface area which extends at 100X. Thus, calculated according to the equation as follow.

$$N = 2^{n-1} \tag{2}$$

Where the quantity of grains are N in per square inch and n is the ASTM grain size number.

1.2. Planimetric method or Jeffries method

In the “Planimetric method or Jeffries method” created a circle or rectangle on the area on the photomicrographs (usually $500mm^2$ to simplify the calculations) and the quantity of grains no less than 50 grains. Equation of Planimetric method or Jeffries method as follow

$$N_A = f(N_{inside} + \frac{N_{int ercept}}{2}) \tag{3}$$

Where N is the number of grains per square millimeter at 1X, f is the Jeffries’ multiplier [5], N_{inside} is the number of grains completely inside the test circle and $N_{int ercept}$ is the number of grains that intercept the test circle

The ASTM Grain Size, G in unit N_A in mm^{-2}, using the following equations [5]

$$G = (3.321928loq_{10}\overline{N}_A) - 2.954 \quad mm^{-2} \tag{4}$$

1.3. Intercept method

“Intercept method”, is more convenient to use than the planimetric such as the Heyn lineal intercept procedure [5], or Circular intercept procedure. There is no direct mathematical relationship between the ASTM grain size number and the mean lineal intercept as follow

$$\ell = \sqrt{\frac{\pi}{4}\overline{A}} \quad (5)$$

Where ℓ is the mean lineal intercept, $\overline{A}$ is exact for circles. Therefore, the relationship between the ASTM grain size number and the mean lineal intercept has been defined. ASTM No.0 has a mean intercept size of precisely 32.00 mm for the macroscopically determined grain size scale and of 32.00 mm at 100X on a field of view magnification for the microscopically determined grain size scale.

$$G = 2\log_2 \frac{\ell_0}{\overline{\ell}} \quad (6)$$

Where ℓ_0 is 32 mm and $\overline{\ell}$ and $\overline{N}_L$ [5], are in millimetres at 1X or number of intercepts per mm for the macroscopically determined grain size numbers and in millimetres or number per mm on a field at 100X for the microscopically determined grain size numbers.

1.3.1 Heyn lineal intercept procedure

In the Heyn lineal intercept procedure, that use a several cross line through on a photomicrograph and count the number of grains which intercept the line to calculate the arithmetic average or mark a line on the surface of spacemen to measure grain size with a length of 0.005 inches and 3.75 inches at 750X. If number of grains about 8-12 grains it means rough grain but if the number of grains is about 8-12 grains it's called a fine grain and if more than 15 grains it's called very fine grain

1.3.2 Circular intercept procedure

In the circular intercept procedure, that use drawing of three circle on the photomicrograph to find the grain size and except that circles of known circumference are used instead of lines. Three circles with a diameter at 26.53 mm, 53.05 mm, and 79.58 mm respectively [5]. The circumference length of the three circles combined are 500 mm. Then count the amount of grain that was cut through the line. Every grain that was intercepted on the three circles is equivalent to 1, while the line of the circles that intercept through three grain equivalent 1.5 and number of grain boundary intersections per unit length of test line as follows

$$\bar{\ell} = \frac{1}{N_i} = \frac{1}{P_i} \tag{7}$$

Where $\overline{N}_L$ and $\overline{P}_L$ [5], are number of grain boundary intersections per unit length of the test line, $\bar{\ell}$ is the mean lineal intercept value for each field, L is the total test line length (500 mm) and M is the magnification. Therefore, they are used to calculate in (6), (7) and (8) or determine the microscopically measured ASTM grain [5].

2. Experimental Procedure

The scope of this research aims to study the strength at welding joint (Base zone, Heat affect zone (HAZ) and Weld zone) and the detail as follows:

a) HSLA Steel (ABS EH36) in 4 mm thickness of steel plate.
b) Welding process by Shielded Metal Arc Welding (SMAW).
c) Welding electrodes standards AWS-A 5.1 E7016
d) Mechanical properties in Vickers hardness test and tensile test
e) Microstructure as chemical composition analysis, EDS analysis on the SEM, the strength as the optical microscope (OM) that used the figure to find the grain size number by the intercept method

The development and use of high strength low alloy (HSLA) steels has been driven by the need to reduce costs. The microstructure as chemical composition analysis with a spectrometer. ABS EH36 is a part of HSLA and the chemical composition of specimen and standard property details as shown at [6, 7]. Nowadays, the economic impact of the welding-related processes to use and the steel industries remain to solve the problems of welding. One of them is ABS EH36 steel and it is popular less than other steel grade such as SCM440 etc. It is difficult find to buy in local and the best price (cheap).

Often materials are calculated for stress, so when they are used and performing the test on the materials for strength such as mechanical properties (tensile test or harness test) and microstructures (OM, SEM and EDS) as a function of applied load, time, temperature and other conditions or standards which are published by the ASTM. Thus, these processes are used for this experiment. Therefore the process is approximately as follows:

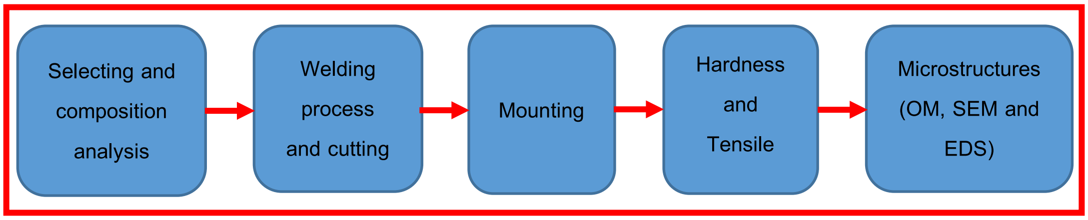


Figure 1 Metallography examination process

2.1 SMAW and Specimen

In SMAW Process or any process of welding, the important parameters for influence input an influence on the joint mechanical properties. By varying the input process parameters the combination of output would be different welded joints with significant variation in their mechanical properties. Accordingly, welding is usually done with the aim of getting a welded joint with excellent mechanical properties. To determine these welding combinations that would lead to excellent mechanical properties. Different methods and approaches have been used to achieve this aim. The following is a review of some articles that utilized these techniques for the purpose of optimizing the welding process in order to achieve the desired mechanical properties of the welded joint. This method used welding DC+ at 26.4 volt, 85 Amp and the speed is 120 mm/min. Welding electrodes AWS-A 5.1 E7016 2.4 mm was using for weld butt joint of two specimens shape V (In certificate of specimen (ABS EH36), the yield stress is 451 Mpa)

Welding electrodes AWS E7016 is a kind of electrode with low-hydrogen potassium type coating AC / DC. All position welding [8]. It has excellent welding performance, stable arc, fewer spatters and good slag detachability.

After the weld process, prepare the specimen for the test 2 kind method. They consist of the specimen for hardness and tensile test method and another one by cutting at the welding joint and nearby surface for microstructures the test method such as Optical Microscope (OM), Scanning Electron Microscope (SEM) and Energy Dispersive spectroscopy (EDS).

2.2 Hardness test

The specimen was then sectioned for a micro-hardness measurement. Micro-hardness was measured using ANTON PAAR model MHT-10 with diamond pyramid angle of 136^{o} indenter and conditions Force 100 g. Pressing time 10 sec, Magnification 500x. A total of 11 points were measured to establish the hardness profile of the specimen by press throughout the axial of surface at left to right under ASTM E92-82 (Reapproved 1997) [9].

2.3 Tensile test

The tensile test use to study the relationship between stress and strain of specimen derived from the pull test and using a universal testing machine INSTRON MODEL 8801. [10]

2.4 Microstructures (OM, SEM and EDS)

The microstructures were examined for the small scale structure of the specimen using an optical microscope (OM) by OLYMPUS LEXT OLS4000 LASER SCANNING CONFOCAL MICROSCOPES. The structure of the grain size can use the optical microscope to analyze and apply to find grain size number such as the intercept method. Then scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS) is used to study the morphology and surface characteristics of a specimen and analyzed using SEM and EDS techniques. They are employed were HITACHI: S-3400N Energy Dispersive Spectroscopy microanalysis system. The modes of analysis used consist of point analysis, line scanning, and elemental mapping.

In all of the test methods, there will be testing at the three surfaces consisting of the base zone, heat affect zone (HAZ) and weld zone.

3. Result

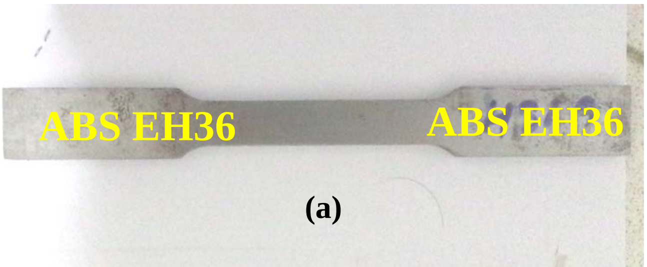
Chemical composition of the ABS EH36 was analyzed using a spectrophotometer test machine (ARL 3640). ABS EH36 was made from low-alloyed steels. The average values of the chemical composition are shown in Table 1.

Table 1 Chemical composition of ABS EH36

C	Si	Mn	P	S	Cr	Mo	Ni	V	Al	Cu	Ti	Nb	Fe
0.0704	0.322	1.4834	0.0102	0.0025	0.0247	0.0129	0.0569	0.0033	0.0333	0.0772	0.0107	0.0174	Balance

3.1 SMAW and Specimen

The specimen of ABS EH36 had been welded by SMAW process and begins with the rough cutting of material to length on a saw or more refined cutting, closer to size and prepare for the test 2 kind method. After cutting is completed they are consist of the first specimen for tensile test method (figure 2 (a)) by the milling machine and another one by cutting at the welding joint and nearby surface and prepare by polishing etching mounting for hardness test method and microstructures the test method (figure 2 (b)).



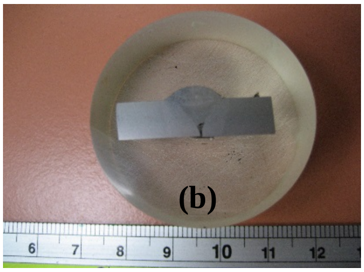


Figure 2 Specimen of ABS EH36 (a) for tensile test method (b) for hardness test method, OM, SEM and EDS

3.2 Hardness test

The hardness test used a press throughout the axial of surface at the left to right of the specimen was measured using a Vickers hardness tester force 100 g, pressing time 10 sec and magnification 500X. The results are shown Figure 3. The maximum hardness of approximately 192.61 HV occurred near the surface of weld zone and minimum hardness diminish with distance at about 150.06 HV of the base zone.

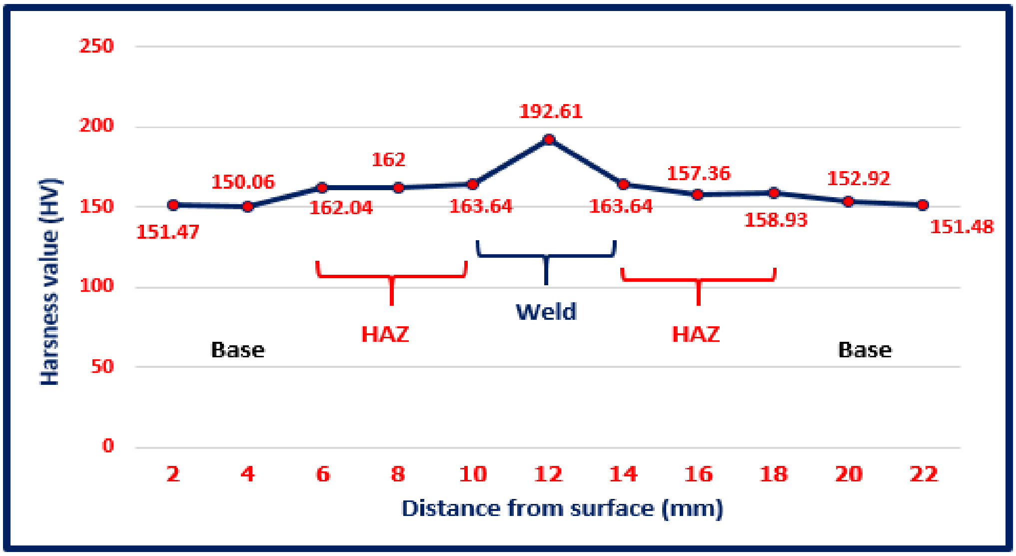


Figure 3 The hardness test used a press throughout the axial of surface at the left to right of the specimen.

3.3 Tensile test

The results in Table 2 from this testing was shown in the fracture point that nearby between the base zone and HAZ and they are indicated to be known that to reference from the standard [6, 7] with similar values.

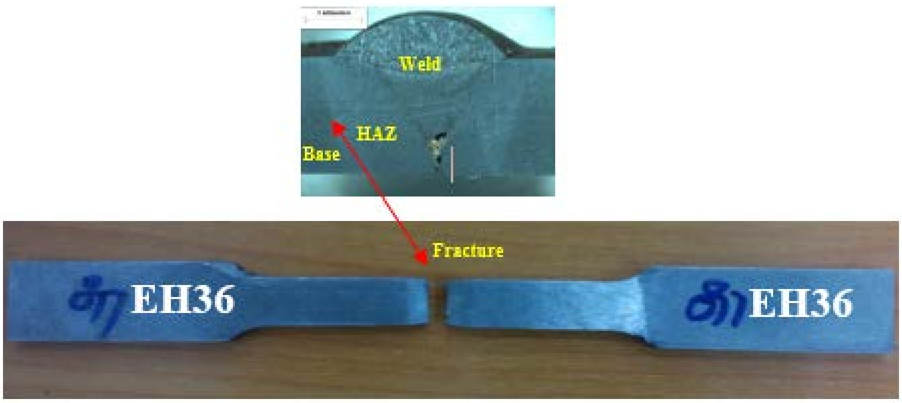


Figure 4 The tensile test was shown in the fracture point that nearby between the base zone and HAZ

Table 2 The result of tensile test

Max. Load (kN)	Yield (MPa)	Tensile strength (MPa)	Modulus (Automatic Young's) (MPa)	Tensile strain at Break (%)
33.18	474.04	511.71	101,919.12	9.93

3.4 Microstructure

3.4.1 OM (Optical Microscope)

Figure 5 illustrates the microstructures (OM) results shown original grain size boundary of EH36 at the base zone which consist of ferrite and pearlite. Therefore apply this figure to find the grain size number with the intercept method. The grain size number $(G) = 11.41$ and compared to the table from ASTM E112 [5] (Table 3) can know that the average grain diameter $(d) = 0.006916mm$. Considering the Hall-Petch relationship from equation (1) to determine the yield stress $(\sigma_y) = 371Mpa$

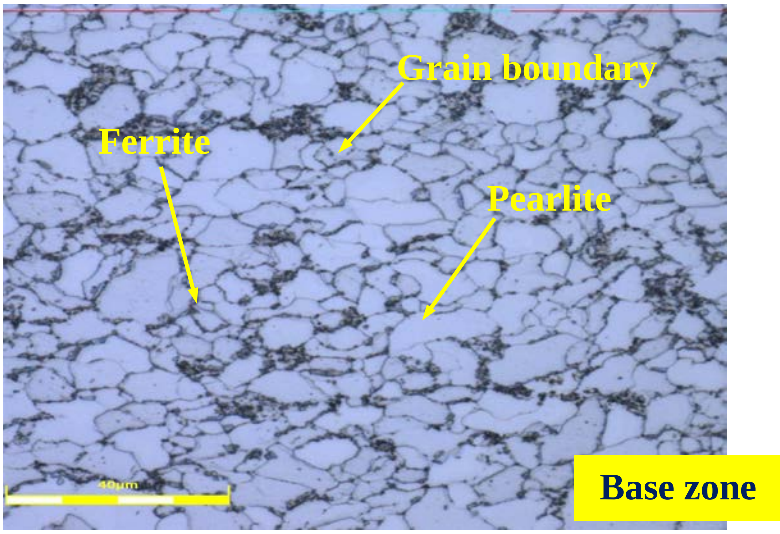


Figure 5 Varity of grain sizes at base zone and apply this figure to find the grain size number.

Figure 6 illustrates the microstructures (OM) results show the grain size boundary of EH36 at HAZ. They consist of ferrite and pearlite which are similar to the base zone. But the differences of the both in the figure is the size of grain. Grain size at HAZ began to change the shape to smaller .Therefore apply this figure to find the grain size number with the intercept method. The grain size number $(G)=12.10$ and compared to the table from ASTM E112 [5] (Table 3) can know that the average grain diameter $(d)=0.00542mm$. Considering the Hall-Petch relationship from equation (1) to determine the yield stress $(\sigma_y)=414Mpa$

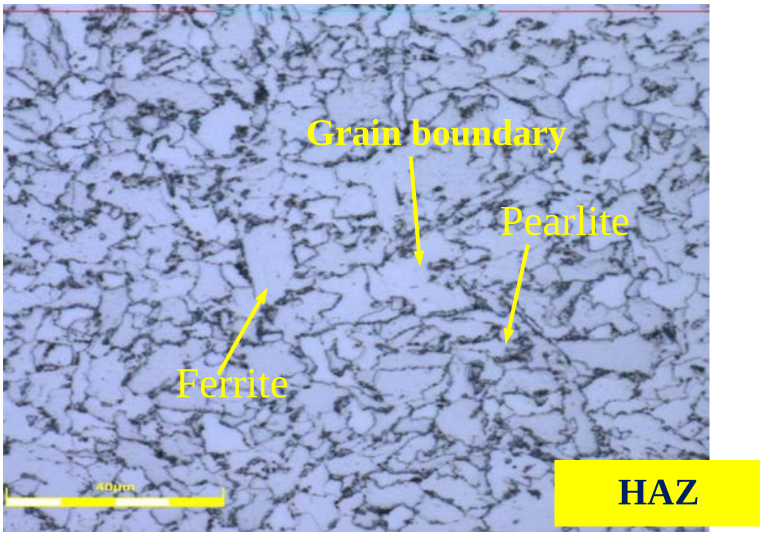


Figure 6 Varity of grain sizes at HAZ zone and apply this figure to find the grain size number.

Figure 7 illustrates the microstructures (OM) results shown the grain size boundary of EH36 at the weld zone. Ferrite grain size are smaller than in the base zone and HAZ and the shape being sharpened also known as acicular ferrite. In the case of acicular ferrite, they are very small and a barrier to count the grain size. They affect to find the grain size number and cannot calculated the yield stress.

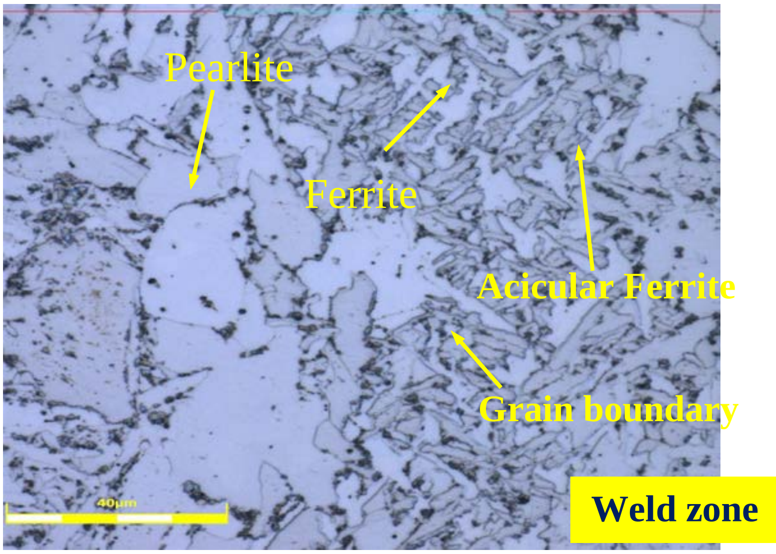


Figure 7 Varity of grain sizes at weld zone and apply this figure to find the grain size number.

Table 3 The result of OM (Optical Microscope)

Area / Results	**The grain size number,** (G)	**The average grain size number,** $d(mm)$	**the yield stress** $\sigma_y(Mpa)$
Base zone	11.4	0.006916	371
Heat effect zone	12.1	0.00542	414
Weld zone	-	-	-

3.4.2 SEM and EDS (Scanning Electron Microscope and Energy Dispersive Spectroscopy or Energy Dispersive X-ray)

Usually, initial EDS analysis involves the generation of an X-ray spectrum from the scan area of the SEM or also call this method the EDS analysis on the SEM. They consist of the Y-axis witch shows the result of counts (number of X-rays received and processed by the detector) and the X-axis shows the energy level of those counts. Figure 8 illustrates the microstructures and EDS results of the base zone. The results show enriched amounts of Mn, Fe, C, and Si. At HAZ and the weld zone, the thermal from welding resulting in a number of element found that changes in the base area and the results in Figure 9 and Figure 10 were shown C, Si, P, S, Mn, and Fe. However, another reason for the increased amounts of elements possibly from mixing between the welding electrode and base metal such as HAZ and the weld zone. They found similar element but the differences in them are the value of the element (Wt%) and the percentage of Fe decreases respectively from base zone to weld zone.

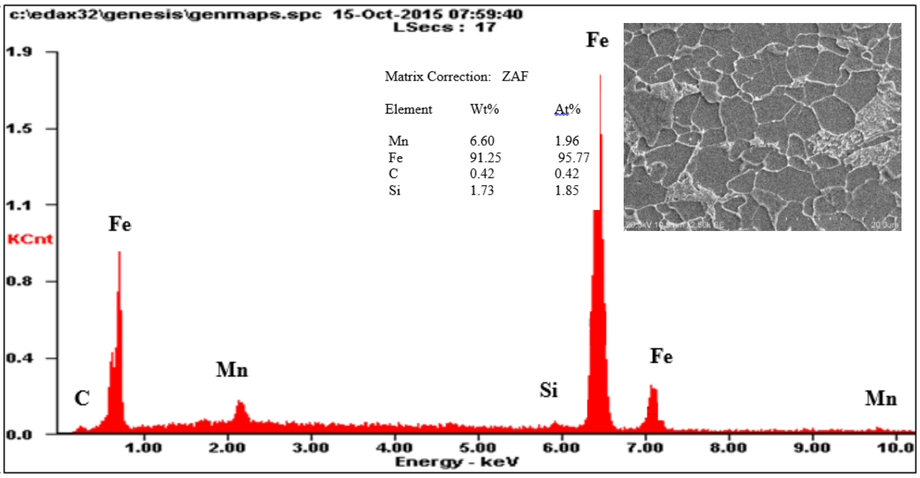


Figure 8 The result of EDS (analysis on the SEM) spectrum analysis at base zone.

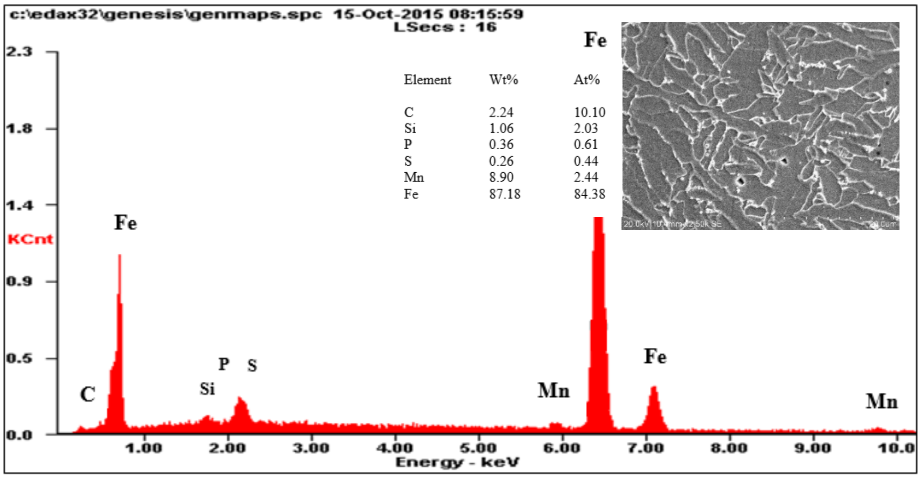


Figure 9 The result of EDS (analysis on the SEM) spectrum analysis at HAZ

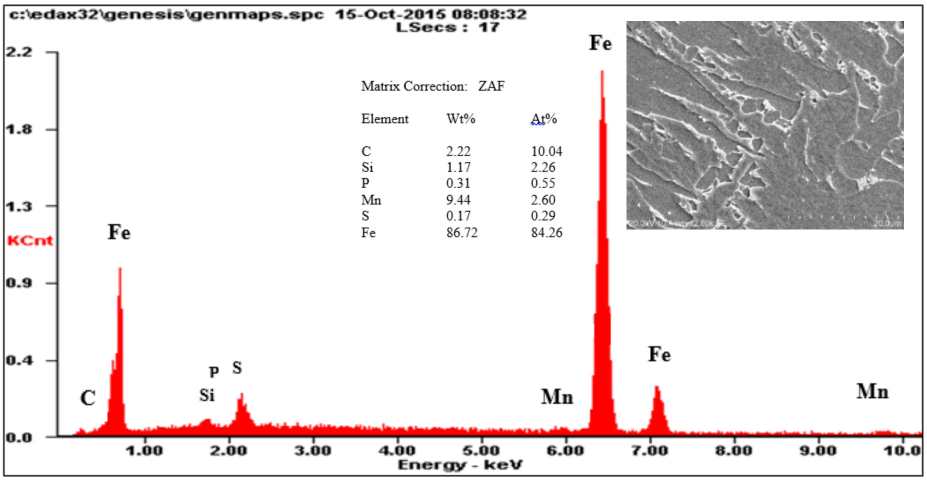


Figure 10 The result of EDS (analysis on the SEM) spectrum analysis at weld zone

4. Discussions

In mechanical properties, the strength of ABS EH36 was shown in the result. The SHAW process used for the experimental procedure and the result of them consisted of a hardness test and tensile test. The minimum value of the hardness test is 150.06 HV at the base zone and maximum value is 192.61 HV at the weld zone. It was assumed that the synchronization of material (ABS EH36 and welding electrodes AWS-A 5.1 E7016) and the thermal influence the surface of the weld zone hardness greater than the surface of the base zone, respectively. However, in tensile test, the fracture point is nearby between base zone and HAZ and it indicates the strength of the weld zone. The yield point is 474.04 Mpa and tensile strength is 511.71 Mpa and which is approximate to the standard (at the base zone).

In the microstructure, the result of EDS analysis on SEM found that elements at base zone consisted of Mn, Fe, C and Si. At HAZ and weld zone They found similar element which consisted of C, Si, P, S, Mn and Fe but the differences of them are the value of element (Wt%) and the percentage of Fe decreases respectively from base zone to weld zone. The reason for the increased amounts of elements possibly from mixing between ABS EH36 and welding electrodes AWS-A 5.1 E7016. Another microstructure, the optical microscope (OM) used the figure to find the grain size number with the intercept method and applied to use the value to find the yield stress with the Hall-Petch relationship. The result at the base zone is 371 Mpa, HAZ is 414 Mpa and the weld zone cannot calculated the yield stress because the shape of ferrite grain size being sharpened also known as acicular ferrite and affect to find the grain size number. They are very small and a barrier to count the grain size. The many acicular ferrite can found at the weld zone more than HAZ. The reason for the yield stress could be described as it could possibly be from the thermal and cooling rate from the welding process changed the structure of ferrite grain size.

5. Conclusions

The following conclusions were drawn from the result in this paper which probative involved about ferrite grain size and mechanical properties

5.1 Weld zone has a maximum value of hardness test. It was the hardest zone and greater than HAZ and the base zone respectively.

5.2 In the tensile test, the result has similar values with the standard and certificate of ABS EH36. The weakness point (the fracture point) is the central area between base zone and HAZ

5.3 The element found by EDS analysis on SEM have similar values with the composition and standard. They are the result from element of ABS EH36 and welding electrodes AWS-A 5.1 E7016

5.4 The yield stress at the weld zone is a maximum value more than HAZ and the base zone.

5.5 Considering the result from those methods can know that at the weld zone has a higher strength than HAZ and base zone respectively and from the reasons mentioned above can prove assumption about the strength at welding joint (ABS EH36 and welding electrodes AWS-A 5.1 E7016) and used to predict the strength of the material for use before the starting process.

Acknowledgment

I would like to express sincere thanks to my advisor, Assoc. Prof. Dr .Ganwarich Phulphrach and Prof. Dr. Hadi Sutanto, for their valuable suggestions, attentive interest. I would like to express sincere thanks to Asst. Prof. Charnont Moolwan kind recommendations in my present study and I would like to express sincere thanks to Mr. Anuprong Pronpijit, Mr. Nirut Bunchoo, National metal and materials technology center

(M-Tech), for their help and guidance during my study and another recommendations. Lastly, I would like to thank my family for always helping me to remember what is important in life, their always supporting me in my good and bad times and for giving right suggestions to me, encouragement, endless love and understanding throughout my study program.

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Author's Profile

Nuttaporn Bungmek Maintenance Supervisor at Ayutthaya Industrial Gases Co., Ltd. Mobile: +66 (81) 8532690 / E-Mail: nuttaporn.aig @gmail.com

Ganwarich Phulphrach Assoc. Prof. Dr. at Department of Mechanical Engineering, Faculty of Engineering, Srinakharinwirot University. Mobile: +66 (89) 1411135 / E-Mail: pganwarich@yahoo.com