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Tensile Behavior of SM520B-1G Plate by SMAW Joint Applied for Elevated Highway Road Construction

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Abstrak.

Tujuan utama dari proyek ini adalah untuk mempelajari karakteristik mekanik dan kimia pelat las SM520B yang digunakan pada pembangunan Tol Layang Jakarta-Cikampek. Pembangunan tersebut diperlukan untuk mengurangi tingginya volume kendaraan yang melintas di jalan raya tersebut setiap harinya. Pelat logam SM520B digunakan sebagai material pada kotak girder karena kekuatan dan ketangguhannya yang tinggi serta kemampuan las yang baik. Terdapat beberapa pengujian yang dilakukan di laboratorium PT Biro Klasifikasi Indonesia (Persero) yaitu uji percikan OES, uji tarik, uji lentur, uji impak Charpy, uji kekerasan makro, dan uji etsa makro. Hasil pengujian Spark OES menunjukkan bahwa SM520B merupakan baja paduan rendah dengan kandungan karbon 0,165%. Hasil uji tarik SM520B menunjukkan bahwa kekuatan luluh rata-rata yaitu 503,45 N/mm² dan kekuatan tarik rata-rata yaitu 608,87 N/mm² pelat baja SM520B telah memenuhi persyaratan sesuai standar ASTM DS67B. Hasil uji lentur menunjukkan tidak ditemukan retak pada area pengelasan. Hasil uji impak Charpy pelat Las SM520B menunjukkan bahwa energi impak yang tinggi terjadi pada daerah pengelasan dengan nilai tertinggi yaitu 214,24 J dan berkurang secara perlahan ketika mendekati garis fusi yaitu 186,08 J. Nilai Kekerasan Vickers yang lebih tinggi terjadi pada luas HAZ SM520B pada kekerasan Vickers yaitu 235,8 J dan hasil uji makro etsa pada pelat las menunjukkan tidak ditemukan adanya retakan, porositas, dan inklusi terak yang signifikan pada pengelasan.

Kata kunci: *SM520B, sambungan SMAW, perilaku tarik, jalan raya layang, konstruksi jalan*

Abstract.

The main objective of this project is to study the mechanical and chemical characteristics of the SM520B welding plate used in the Jakarta-Cikampek Elevated Highway construction. The construction is needed to decrease the high volume of vehicles passing the highway every day. SM520B metal plate is used as the material in the girder box due to high strength and toughness and also good weldability. There are several tests conducted in the lab of PT Biro Klasifikasi Indonesia (Persero), i.e., spark OES test, tensile test, bending test, Charpy impact test, macro hardness test, and macro etch test. Spark OES test result shows that SM520B is low alloy steel with 0.165% carbon content. The SM520B tensile test result determines that the average yield strength, i.e., 503.45 N/mm², and the average tensile strength, i.e., 608.87 N/mm² of SM520B steel plate has met the requirement according to ASTM DS67B standard. The bending test result shows that no crack was found in the welding area. The Charpy impact test results of SM520B Welding plate indicates that high impact energy occurs in the welding area with the highest value of 214,24 J and slowly reduces when approaching close to the fusion line, i.e., 186.08 J. Higher Hardness Vickers value occurs in the HAZ area of SM520B during Vickers hardness, i.e., 235.8 J and the macro etch test result on the welding plate indicate there is no significant crack, porosity, and slag inclusion found in the welding.

Keywords: *SM520B, SMAW joint, tensile behavior, elevated highway, road construction*

Introduction

Jakarta-Cikampek Toll Road has long been one of the busiest highways in Indonesia. It has been operated by PT. Jasa Marga (Persero) Tbk since 1988. as the link between the north coastline of Java and Jakarta. Jakarta-Cikampek nowadays has gone through many construction changes. Most of the Jakarta-Cikampek Toll Road sections currently have 4 x 2 lanes. This marked the heavy traffic passing through this toll road [1]. To prevent the Jakarta-Cikampek toll road from being overburdened by the ever-increasing volume of vehicles each year, in 2017 PT Jasa Marga (Persero) Tbk has constructed a new highway called Jakarta-Cikampek Elevated Toll Road 2.

The Elevated Toll runs from west to east along the Jakarta-Cikampek Toll Road for 38 kilometers, beginning at KM9+500 Cikunir interchanges and ending at KM 47+500 West Karawang. The drill pole-type foundation supports the Elevated Toll, which has four lanes with two lanes each and is 3.5x2 square meters in size. In addition to the foundation, the technology used to construct the overpass is the Sosrobahu system. The technology developed by the Indonesian engineer is thought to be capable of reducing traffic to a bare minimum due to the construction of road foundation pillars [2].

One of the materials used by Jakarta-Cikampek Elevated Toll 2 is SM520B – 1 G Welding Plate. This material is a part of the construction using steel box girder applications to make the construction time more efficient. The steel material used has 12 times higher weight and strength ratio compared to concrete, is more flexible, and can be recycled [3]. Therefore, this study aims to identify the characterize of SM520B – 1 G Welding Plate by using Tension Test, Bending Test, Impact Test, Hardness Test, Macro Etch, and Chemical Composition Test. The research objectives are to analyze the construction of the SM520B – 1 G Welding plate, which includes the Welding Process using SMAW and the chemical composition of the steel material, and to determine whether the SM520B steel plate mechanical and chemical tests met the ASTM standard requirements.

Experimental Methodology

Shield metal arc welding (SMAW) uses consumable electrodes, in which the electrodes will be consumed as it melts with the material during the welding process. Bohler Fox S 2.5 Ni – E80 will be the type of electrode used in this study. The materials used as objects for tensile testing in this study were two SM520B welding plates with thicknesses of 22 mm. For the weld metal tensile test, the test specimen should be completely removed from the weld metal. Normally, the material will break in the weakest part of the welding, which is frequently in the HAZ area [6]. For tensile testing, Schenck Trebel 100 Ton and United SHFM – 600 kN were used by PT Biro Klasifikasi Indonesia (Persero). Based on the position of the specimens collected, bending tests can be divided into transversal and longitudinal bending [7]. In this study, specimens were collected using transversal bending. Specimens were collected from the test plate according to AWS rules [8]. All specimens had similar thickness and width dimensions of 10 mm x 22 mm. the mandrel diameter for each test was 4.t in mm, and the bending angle was 180°.

The Vickers hardness test area is calculated from microscopic measurements of the diagonal length of the trace [9]. The range of test loads used in Vickers hardness testing ranges from 1 kgf to 120 kgf, and the commonly used test loads are 5, 10, 30, and 50 kgf. Meanwhile, the standard dwell time is usually carried out for 10 - 15 seconds. Charpy impact test was used in this study as a means to determine the strength of the material. The amount of energy transferred to the material can be calculated by comparing the height of the hammer before and after the fracture (energy absorbed by the fracture event) [10]. The normal Charpy-V notched specimen in cross section is 55 mm long and 10 mm square, 2 mm deep, with 45° angle and 0.25 mm radius along the base. Samples of 10 mm by 7.5 or 5 mm are also allowed, with the criteria for effect toughness depending on the size of the specimen. Sub-sized Charpy specimens need to be tested at a reduced temperature compared to normal specimen [11]. There were two types of specimens used in this test, SM520B welding plate, and SM520B metal plate. The dimension of both specimens were 10 mm x 10 mm, thickness at the base of the notch is 8 mm. Meanwhile, the test temperature were conducted at -20°C for the welding plate and -23°C for the metal plate.

Grinding was done by rubbing the specimens on a hand grinding machine. The grinding paper used were grit size 40-, moving up to 60-, 120-, 220-, 320-, 400-, and 600-grit sequentially. Meanwhile polishing was carried out by rubbing the specimen on a polishing machine equipped with a wool cloth coated with alumina powder with a fineness of 1-0.05 microns. The addition of alumina powder aimed to further smoothen the surface of the specimen, making the test easier to perform [12]. The final polishing resulted in a layer that covered the surface of the metal structure. In order for a microstructure to be clearly visible under a microscope, the layer must be dissolved by etching. The solution used for macro etching was Nital, a composition of 20% nitric acid in water [13]. The testing machine used in this test was HIROX KH – 1300 and the test was conducted in PT Biro Klasifikasi Indonesia (Persero) according to EN 1321 for the test method. The specimen was collected from the SM520B – 1 G SMAW Welding Plate with a thickness of 22 mm.

To determine the chemical composition of steel from a specimen, it is necessary to do a chemical composition test. In emission spectroscopy, the energy obtained from atoms emitting electromagnetic radiation is collected and analyzed by a spectrometer. Thus, the elements contained in the specimen can be known both qualitatively and quantitatively [14].

Experimental Result

The test was conducted using test method ASTM E 415 with the test temperature of 23.6°C. Table 1 shows that there are 10 types of elements detected in the specimen. These elements include: Fe, C, Si, Mn, P, S, Cr, Mo, Ni, and Al. Each element has different percentages as well as special characteristics on steel metals. The specimen has a high percentage of manganese composition, namely 1.50%. In carbon steels, the manganese element is often added in order to increase the depth of hardening and improve strength and toughness. The small amount of Nickel and Phosphorus, namely 0.0122% and 0.0102% respectively can increase the resistance against corrosion and solid–solution hardening.

Table 1. Chemical composition of SM520B Steel Plate Thickness 22 mm

Description	Chemical Composition (%)									
	C	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**	**Al**	**Fe**
Spark 1	0.166	0.334	1.51	0.0091	0.0057	0.0231	0.0046	0.0125	0.0480	97.9
Spark 2	0.163	0.330	1.50	0.0113	0.0063	0.0226	0.0047	0.0119	0.0471	97.9
Average	0.165	0.332	1.50	0.0102	0.0060	0.0229	0.0047	0.0122	0.0475	97.9

The Weld Plate test was conducted using 2 specimens of SM520B SMAW – 1G welding plate. The test method complies with ISO 4136: 2001, and AWS D1.5: 2015 Standard. The specimens T-1 and T-2 were tested using the Tensile Test machine Trebel 100 Ton. It should be noted that the yield strength, elongation, and reduction area cannot be determined in the tensile test of welding plate due to at least three different areas with dissimilar mechanical properties (base metal, weld metal, and HAZ), which could result in such measurements being inaccurate and unreliable [10]. The location of the fracture in the welding plate can be determined on the specimens themselves. The type of fracture is a ductile fracture. Ductile fractures are a form of fracture that is characterized by comprehensive plastic deformation or "necking" before the real fracture happens. The word "ductile rupture" relates to extremely ductile material failure. In such instances, instead of cracking, materials fall apart. The Base Plate test on the other hand was conducted using 2 specimens of SM520B Base metal plate. The test method complies with EN 10002-1: 2001 and JIS Z 2201 Standard. The specimens T-1 and T-2 are tested using the Tensile Test machine Trebel 100 Ton.

The stress-strain curve diagram of specimens T-1 and T-2 is shown in Fig. 1. Yield strength occurs when the load on the material continues to increase through the linear elastic limit and the material begins to form a plastic deformation or yield. It can be determined in Fig. 1 that the yield strength of specimen T-1 is 494.54 N/mm² and occurs when the strain or elongation is on 4,6%. During this phase, the SM520B T-1 begins to form a plastic deformation, which means the length of the material cannot return to the normal length. The strain hardening phase of the material begins when the stress increases from 505.4 N/mm2 to 603.6 N/mm2. While the material is still deformed at this stage, it can still receive more tensile stress without becoming weaker. The ultimate strength occurs when the stress and strain are on 603.6 N/mm² and 43.48%. This is the point where the material is no longer capable of handling increased tensile stress. Fig. 1 also shows SM520B T-2s curve has a slightly different number than the T-1s. The yield strength of T-2 is 512,37 N/mm² and occurs when the strain or elongation is on 4.7%. The strain hardening phase begins at 522.5 N/mm² with the ultimate strength being on 614.1 N/mm² when the strain is on 41.8%. The result in Fig. 1 shows the stress-strain curve from the testing of specimen and the ASTM standard. Based on the ASTM standard, SM520B has the minimum yield strength of 355 N/mm² and the minimum tensile strength of 520 N/mm². The test results of T-1 and T-2 indicate that the yield and tensile strength of both specimens are higher than the standard value. Therefore, specimen T-1 and T-2 have met the requirement according to ASTM standard.

The Metal Bohler Fox S 2.5 Ni – E80 test was conducted at PT Biro Klasifikasi Indonesia (Persero) using 1 specimen of all welding plates. The test method complies with ISO 4136: 2001, AWS D1.5:2015 Standard. The specimen W1 is tested using the Tensile Test machine United SHFM – 600 KN. The specimen indicates a ductile fracture caused by the shear stress. The fracture angle forms a 45° angle with respect to the specimen's normal axis. Maximum shear stress causes such fractures, and tensile loads play a role in causing this stress. Test data are then presented in stress-strain curve diagram as shown in Fig. 1. Plastic deformation begins as the yield strength of W-1 is 481.01 N/mm² and the strain or elongation is on 4.19%. The strain hardening phase begins at 488.2 N/mm² with the ultimate strength is on 552.9 N/mm² when the strain is on 31.22%. Fig. 1 indicates that electrode S 2.5 Ni – E80 has a quite similar tensile and yield strength properties with SM520B, which is in the range of 400 – 600 MPa. It means the test result of base metal and all weld metal has exceeded the minimum number of the ASTM standard. Therefore, the electrode can be used as the filler metal for the SM520B.

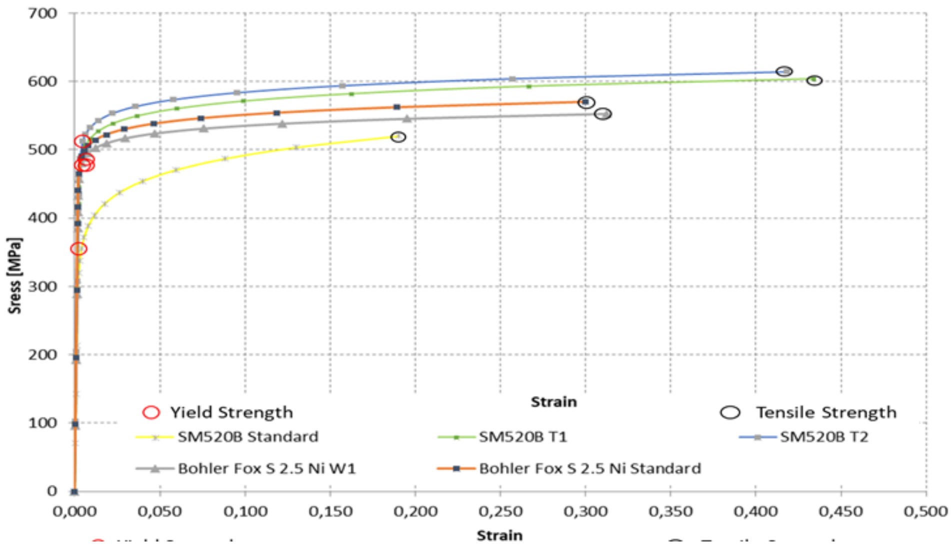

Fig. 1. Stress – strain curve comparison of SM520B and S 2.5 Ni – E80

Bending test is conducted using 4 samples. The samples used in this test are SM520B SMAW – 1G welding plates with a thickness of 22 mm. The test method complies with ISO 4136: 2001 and

AWS D1.5: 2015 Standard. The purpose of the test is to determine the ability of steel to bend up to an angle of 180° without cracking. The test result indicates that no defects were found in the specimen. Therefore, it passed the requirement and complies with the AWS standard, as shown in Table 2.

Table 2. Bending test result SM520B SMAW – 1G Thickness 22 mm

Sample Code	Bending test result SM520B SMAW – 1G Thickness 22 mm			
	Side Bend 1	**Side Bend 2**	**Side Bend 3**	**Side Bend 4**
Dimension w x t (mm)	10 x 22	10 x 22	10 x 22	10 x 22
Mandrel Diameter (mm)	4 x T	4 x T	4 x T	4 x T
Bending Angle	180°	180°	180°	180°
Weld Defect	No Discontinuity	No Discontinuity	No Discontinuity	No Discontinuity
Test Result	No Defect	No Defect	No Defect	No Defect

Specimens were tested using TINIUS OLSEN impact test machine. 7 specimens were collected in the SM520B SMAW – 1 G Welding plate according to AWS D1.5 Standard. These specimens were divided into fusion line, f + 2 mm, and weld metal. The test method complies with ISO 148 – 1:2006 and all test were conducted at the temperature of –20° C.

Table 3. indicates that the highest impact energy of 214.24 J occurs in the center line of weld metal due to the use of Ni-based electrode. Nickel improves the mechanical properties of the weld metal by increasing the strength and crack resistance. The specimen closest to the fusion line had the tendency of low impact energy due to the microstructure grain growth from fine to coarse. The impact energy in Fusion was 186.08 J due to the change of microstructure into a coarse grain. The coarse-grained HAZ was a result of the excessive heat input during the welding process and the grain structure minimizes the toughness of the weld metal. The specimen F+2 located in the fine-grained HAZ has a better impact energy of 202.89 J than fusion. According to the mechanical properties from Bohler Welding, the impact work value of Bohler Fox 2.5 Ni at –80° C and 20° C is 110 J and 180 J [15]. The average impact energy of the welding area based on the Charpy impact test result at –20° C is 168.78 J. To determine whether a material is brittle or ductile, the impact transition curve of Fig. 2 can be used, along with the impact energy from the test results.

Table 3. Charpy impact test of SM520B Welding plate temperature -20°C

Sample Code	Charpy impact test result of SM520B SMAW – 1 G Welding plate						
	Fusion line	**Fusion line + 2 mm**	**Welding**	**Welding**	**Welding**	**Welding**	**Welding**
Dimension (w×t) (mm)	10 x 10	10 x 10	10 x 10	10 x 10	10 x 10	10 x 10	10 x 10
Thickness at base Notch (mm)	8.00	8.00	8.00	8.00	8.00	8.00	8.00
V Notch/ U Notch	V	V	V	V	V	V	V
Impact Energy (J)	186.08	202.89	135.29	147.62	214.24	203.54	143.19
Average Energy (J)	194.49		168.78				
Impact Toughness (J/mm²)	1.9449		1.6878				

From the impact transition curve diagram, it is described that the specification of Bohler Fox 2.5 Ni requires minimum impact energy of 47 J at –80° C. The diagram shows that the electrode has exceeded the acceptance requirement (47 J at –80° C) and it also shows the type of fracture which is ductile with the value of 110 J at the temperature of -80° C and increasing. The result concluded that the electrode had a high impact energy or good toughness at very low temperatures. For the base metal, 3 specimens were collected from each 2 positions, transverse and longitudinal. The test method was conducted according to ISO 9016:2001 and JIS Z2202 standard with the test temperature of – 23° C. The Microstructure of SM520B base steel consists of mostly fine ferrite grain in Body Centered Cubic (BCC) crystal structure. It has greater fatigue resistance, toughness, and shock resistance [11]. In the longitudinal position, the impact force extends through the grain of the test specimen. Because the fracture of the specimen is harder, more energy is required to fracture the steel through the grain. Table 4. Determines that the impact energy of the longitudinal position is 183.83 Joule The impact force runs parallel to the grain of the specimen is called a transverse test direction. Therefore, the transverse impact energy needed to break the steel through the notch will be less than the longitudinal [16]. The average impact energy from this test is 89.94 Joule. It can be concluded from the result that the longitudinal impact force has a higher number than the transverse due to the higher notch toughness. It is obviously more difficult to create longitudinal impact toughness because the steel's grain direction provides natural fracture resistance.

Table 4. Charpy impact test of SM520B plate transverse and longitudinal position

Sample Code	Charpy impact test of SM520B plate transverse position			Charpy impact test of SM520B plate longitudinal position		
	T 1	**T 2**	**T 3**	**L 1**	**L 2**	**L 3**
Dimension (mm)	10 x 10	10 x 10	10 x 10	10 x 10	10 x 10	10 x 10
V Notch/ U Notch	V	V	V	V	V	V
Impact Energy (Joule)	91.220	91.310	87.275	182.09	170.56	198.83
Average Energy (Joule)	89.94			183.83		
Impact Toughness (J/cm²)	89.94			183.83		

The purpose of this test is to determine the hardness of the SM520B SMAW–1G Welding Plate. The test is conducted using ISO 6507–1:2000 standard test methods. From the test result, the HAZ area in line 1 and 2 has a higher hardness number than the base metal and weld. The hardness of HAZ 1, 2, 3 in line 1 are 240.6 HV, 235 HV, and 235.8 HV. In line 2, the hardness of HAZ 1, 2, 3 are 245.2 HV, 241.3 HV, and 232.5 HV. In comparison to the weld and base metal areas, the HAZ area is the most critical because it is prone to the formation of very hard and easily cracked phases. This results in decreased mechanical properties, such as low toughness and increased hardness in the upper HAZ area and lower HAZ area, resulting in an increasingly brittle material. Hard phases formed in the HAZ area are also very sensitive to hydrogen embrittlement. Corrosion occurs easily in the HAZ area due to the inhomogeneity of the crystal structure grains.

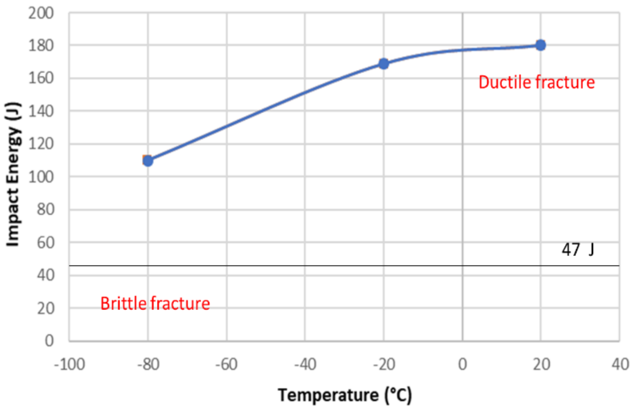

Fig. 2. Impact transition curve diagram

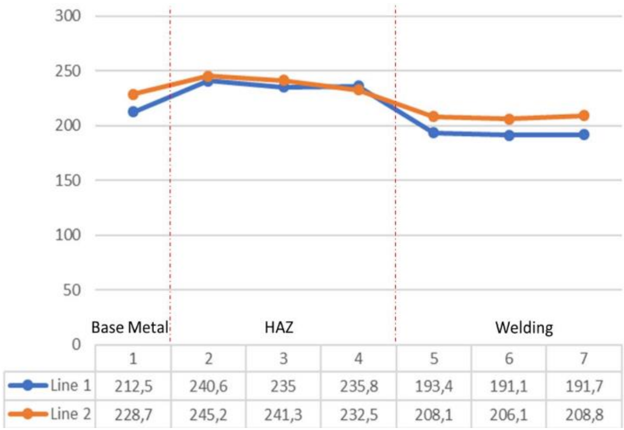

Fig. 3. Graphic of Vickers Hardness Test in base, HAZ, and weld

The purpose of this test is to examine cracks and holes in the surface of SM520B SMAW – 1G Welding Plate thickness with the test method according to EN 1321 and the test temperature of 23° C. Fig. 4 shows the test result of macro etch. Good penetration in Fig. 4 means that the heat input is properly used during welding, where the weld metal does not melt past the thickness of base metal. The fusion between filler and base metal is also good, which means that the heat input is suitable, the workpiece is clean, and the welding technique is right. Crack is also not found in the welding area.

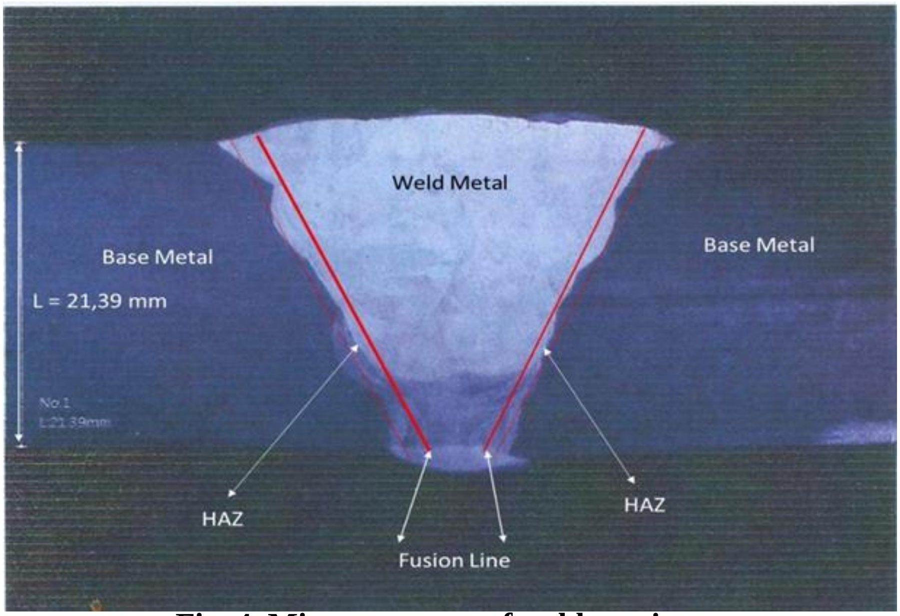

Fig. 4. Microstructure of weld specimen.

Conclusion

The following are several points that can be drawn to answer the test objectives: SM520B steel has a low carbon content of 0.165 % with other elements, such as manganese, nickel, and aluminum, added to improve the steel properties. Low-carbon steel has a carbon content of 0.05% – 0.3%. Therefore, SM520B is classified as low-carbon steel. Because SM520B steel has a ductile fracture during the tensile test testing, it can be concluded that SM520B is a ductile material. The cooling process of SM520B steel occurs in the temperature of 650°C. According to the Iron Carbon phase diagram, the microstructure of SM520B specimens consists of ferrite grain with the addition of pearlite.

Based on the test result, Bohler Fox S 2.5 Ni – E80 electrode has a yield strength of 481.01 N/mm² and tensile strength of 552.90 N/mm². According to AWS standard, the tensile strength value of E 8018 – C1H4R is 570 N/mm² with a yield strength value of 490 N/mm². Therefore, the electrode used for SM520B welding has met the requirement according to AWS standards. Based on the test result, the average yield strength is 503.45 N/mm², and the average tensile strength, i.e., 608.87 N/mm² of SM520B steel plate, has met the requirement according to ASTM DS67B standard. The bending test result of the SM520B Welding Plate indicates no crack was found.

The Charpy impact test results of SM520B Welding plate indicates high impact energy occurs in the welding area with the highest value of 214.24 J and slowly reduces when approaching near the fusion line with a value of 186.08 J. The impact energy of 183.83 J occurs in the longitudinal position. It is higher than the impact energy that occurs in the transverse position with the value of 89.94 J. The difference in impact energy happens due to the different impact force that runs to the grain of the specimen.

Vickers Hardness values of 235.8 J in line 1 and 241.3 J in line 2 occur in the HAZ area during Vickers hardness testing. These highest Hardness Vickers number happens because the HAZ area is prone to form phases that are very hard and easily cracked. As a result, brittle material forms in the HAZ area. The macro-etch test result on the welding plate shows that there are no significant cracks, porosities, or slag inclusions in the welding.

Therefore, the mechanical and chemical properties of the SM520B steel plate met the standard required for the construction of the Jakarta-Cikampek Elevated Highway.

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