# The Effect of Welding Electrode Variation on the Mechanical Properties and Microstructure of API 5L Shielded Metal Arc Welds

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Keywords: Electrodes, Weld Metal, Mechanical Properties, Micro Structure.

Abstract: Welding is a metallurgical bond on metal alloy joints that is performed while the metal alloy is melted or liquid. The purpose of this research is to determine the effect of the electrode types E 6010 and E 7016 on the mechanical properties and microstructure of API 5L low carbon steel during SMAW welding. The welding electrodes are E 6010 and E7016, and the welding current is 110A. The welding seam used is a v-groove with a 60o angle. Welding samples were cut and machined into standard configurations for tensile strength, impact, and hardness tests, as well as SEM for microstructure analysis. The results show that the type of electrode has a significant effect on mechanical properties such as tensile strength, impact, and hardness of the welding metal. Welding electrodes of various types are used as the welding variable. The E 7016 electrode has the highest tensile strength with a tensile strength value of 617 MPa, while the E 6010 electrode has a tensile strength of 554 MPa, and the E 7016 electrode has the highest toughness with a toughness value of 1.856 Joules / mm2. The E 7016 weld metal area had the highest average hardness of186.9 VHN. SEM microstructure analysis reveals several phases, including Acicular Ferrite (AF), Grain Boundary Ferrite (GBF), and Bainite.

## 1 INTRODUCTION

Welding is a metallurgical bond on metal or metal alloy joints which is carried out in a melted or liquid state. In other words, welding is a local joint of several metal rods using heat energy. Today, a variety of different welding processes are available, such that welding is extensively used as a fabrication process for joining materials in a wide range of compositions, part shapes and sizes. Welding is an important joining process because of high joint efficiency, simple set up, flexibility and low fabrication costs (Armentani, 2007). Welded joints are finding applications in critical components where failures are catastrophe. Hence, inspection methods and adherence to acceptable standards are increasing. These acceptance standards represent the minimum weld quality which is based upon test of welded specimen containing some discontinuities. Welding involves a wide range of variables such as time, temperature, electrode, pulse frequency, power input and welding speed that influence the eventual properties of the weld metal (Jariyaboon et al., 2007; Karadeniz et al., 2007; Lothongkum et al 2001; Lothonhkum., 1999; Mirzaei et al 2013; Sakthivel et al., 2009; Razal et al., 2012; afolabi 2008). Welding of steel is not always easy. There is the need to properly select welding parameters for a given task to provide a good weld quality. Welding is an efficient, dependable and economical process. The electrodes used in SMAW welding have different compositions of the membrane and core wire. The chemical composition and the magnitude of the current can affect the mechanical properties welded material joints which have an impact on the strength and toughness of the welded joints. Selection of the right electrode will produce good and perfect welding results, therefore choosing the type of electrode is very important before carrying out the welding process.

## 2 METHODS

The welding process uses SMAW (Submerged Arc Welding) using a current of 110 A and the type of electrode E 6010 and E 7016. The type of groove used is v-groove with angles 600. The material used in this study is API 5L Grade X 52 pipe with a diameter of 6 inches and a thickness of 8 mm which is welded with



Susilowati, S. and Sumardiyanto, D.
The Effect of Welding Electrode Variation on the Mechanical Properties and Microstructure of API 5L Shielded Metal Arc Welds.
DOI: 10.5220/0011980500003582
In *Proceedings of the 3rd International Seminar and Call for Paper (ISCP) UTA âĂŹ45 Jakarta (ISCP UTA'45 Jakarta 2022)*, pages 312-316
ISBN: 978-989-758-654-5; ISSN: 2828-853X

E 6010 and E 7016 electrodes using 3 stages, namely root, filler, capping . API 5L pipe material is a low carbon steel pipe material with a carbon content of 0.25% and wear-resistant properties. The chemical composition of API 5L pipe material is C (0,20%), Mn (1.35%), P (0,025% max), S (0.01% max), and Fe. The standard referred to is ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code Section IX, one of many used in the oil and gas industry(Asme spec,2010). The experiment was designed with the different types of welding electrode as variables. The mechanical properties of the weld zone, including tensile strength, impact toughness, hardness, and the microstructure with SEM, were observed.

# 3 RESULT AND DISCUSSIONS

## 3.1 Tensile Properties

Tensile testing is performed using a servopulser machine at a scale of 10 tons and at room temperature. The tensile test is used to determine the tensile strength of low alloy steel produced by SMAW welding with various electrodes. The effects of different types of welding electrodes at a specific current of 110A on the tensile strength of the weld metal were studied. Each condition was run three times, for a total of six sets. The result was summarized in Table 1 and Figure 1.The different electrode usage produce significantly different tensile strength values. The tensile strength value of the E 6010 type of electrode has a value of 554 MPa and for the E 7016 type of electrode is 617 MPa. There is a difference in the valueof tensile strength by 11,5% of the two electrodes, where the E7016 electrode has a greater value than E 6010. The main variables in the SMAW process can be described as weld electrode, flux and welding parameters (Kanjilal et al., 2006). The welding parameters of SMAW are current, polarity, voltage, weld groove, travel speed, distance between electrodes, electrode extension, angle and diameter [Candel et al., 1997; Kolhe et al., 2008].

Table 1: Test Results for Tensile Strength in the Weld Metal.

| Electrode | Welding Current(A) | Tensile Strength, MPa | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | Average |
| E 6010 | 110A | 563 | 545 | 554 | 554 |
| E 7016 | 110A | 627 | 609 | 614 | 617 |

Figure 1 shows that the E 6010 welding electrode produces a lower tensile strength value than the E7016 welding electrode both in tests 1, 2 and 3. The average tensile strength of the E 6010 welding electrode is 554 MPa, while for the E 7016 electrode it is 617 MPa . The significant difference is 11.5%. These results are similar to studies conducted by several other investigators [14-16]. The E 6010 electrode material is composed of C (0.08%), Mn (0.5%), Cr (0.06%), and Si (0.3), whereas the E7016 electrode is composed of C (0.1%), Mn (0.9%), and Cr (0.14%), Si (0.3). (0.7). The results show that the welding electrode E 6010 has a lower tensile strength than E 7016 because its composition of C, Mn, and Cr is lower [17]. This study demonstrated that increasing Mn, C, or Cr individually can increase tensile strength and hardness values of welded joints [18].

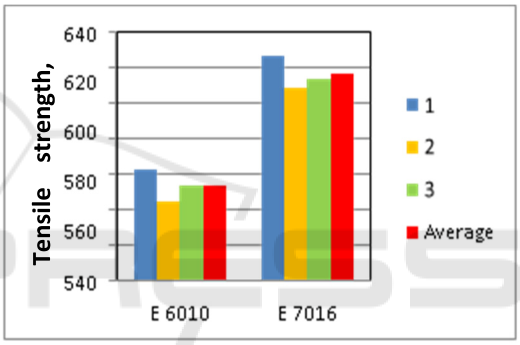



Figure 1: Tensile Strength of Weld Metal.

## 3.2 Hardness

Hardness testing was performed at several points in each specimen. The point is parent material/base metal, HAZ and weld (fussion zone). Vickers hardness testing area identification scheme with electrodes E7016, and E 6010 is shown in Figure 2. The Vickers HVN hardness test results of each electrode type in the welding area ,HAZ, and parent material are shown in Table 2and Figure 3. The Vickers hardness value of the E7016 electrode welded metal area is 186.9 VHN, higher than the E6010 electrode type of 178.4 VHN. This result is similar to research conducted by several other researchers [Bracarense et al., 1994; Sarian et al., 1999; Talabi et al.,2014; Tahir et al., 2018]. During the welding process, a thermal cycle occurs in the weld metal area and the HAZ includes heating to a certain temperature. This affects the microstructure and mechanical properties of the weld metal and HAZ, so that the weld metal will undergo a phase transformation. The thermal cycle is thawing then freezing. This condition causes changes in the microstructure of the metal concerned, while changes in grain size and structure formed in the microstructure results in different mechanical properties values. The hardness value of the HAZ region for each electrode is lower than that of the weld metal region. This is due to the fact thatin the HAZ area there is an increase in the size of ferrite grains compared to the weld metal, so it can affectthe nature of hardness in the HAZ area. In the HAZ area, there is an enlargement of the ferrite grain size compared to the weld metal, so that it affects the hardness properties in the HAZ area. Since thegrain size becomes coarse when welding current increase, the mechanical properties such as hardness value, impact and tensile strength value reduce (Bodude et al., 2015 & Gharibshahiyan et al., 2011). As the heat energy input was increased, the mechanical properties for tensile strength, impact and hardness decrease due to microstructure of coarse pearlite in ferrite matrix become coarse as the grain size increase(Asibeluo et al., 2015).

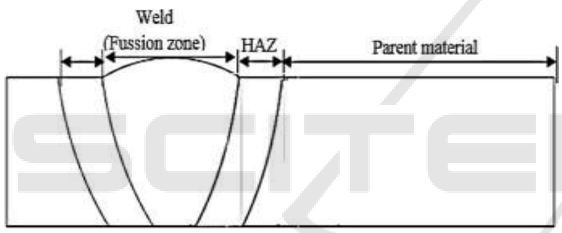



Figure 2: Hardness testing point.

Table 2: The Result of Vickers Hardness Test

| Area | Electrode | Vickers Hardness Test (VH) | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | Average |
| **Weld** | E 6010 | 173,9 | 187,4 | 173,9 | 178,4 |
| | E 7016 | 189,2 | 185,7 | 185,7 | 186,9 |
| **HAZ** | E 6010 | 170,7 | 175,9 | 170,7 | 172,4 |
| | E 7016 | 170,5 | 183,6 | 183,6 | 179,2 |
| **Base Metal** | E 6010 | 165,9 | 163,8 | 165,9 | 165,2 |
| | E 7016 | 152,5 | 159,5 | 152,5 | 154,8 |

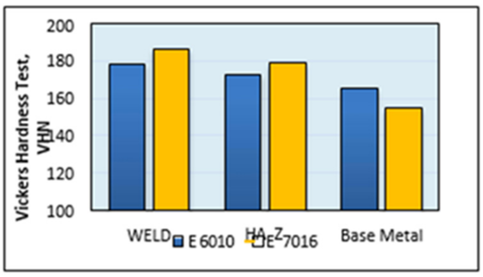



Figure 3: The Vickers Hardness Test.

## 3.3 Impact Toughness

Toughness is the ability of a material to absorb energy before it breaks or toughness is the ability of a weld to permanently deform while absorbing energy before fracturing, specifically when stress is applied rapidly—typically, in under one second. Impact test was conducted to know the mechanical properties of low carbon steel material as a test material in this research. In general, materials with a body center cubic (bcc) crystal structure such as low carbon steel and alloy steel show brittle properties at low temperatures.The result of the impact test is generally the toughness parameter (notch blow value). Table 3 and Figure 4 summarize the effects of electrode types on weld metal impact toughness. Each condition was replicated three times. The figure depicts a profile that is similar to that of the hardness properties.

Table 3: The result of The Impact Toughness Test.

| Electrode | Welding Current (A) | Impact J/mm$^2$ | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | Average |
| E 6010 | 110A | 0,9432 | 0,9844 | 0,9592 | 0,96 |
| E 7016 | 110A | 1,9544 | 1,8478 | 1,7670 | 1,85 |

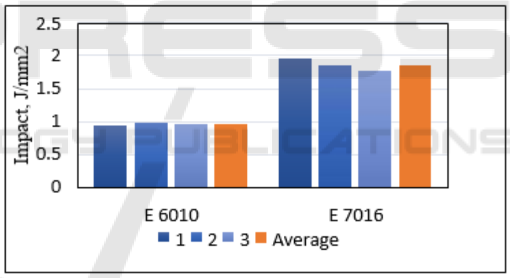
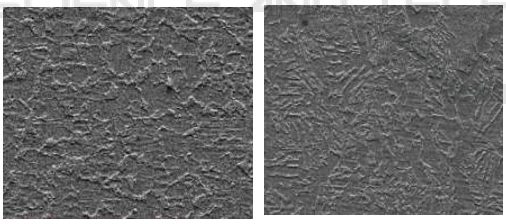



Figure 4: The Impact Toughness Test.

Figure 4 shows that the electrode E 6010 has the lowest average impact toughness value of 0.96 J/mm2. However, E7016 has the highest average impact toughness value, which is approximately 1.85 J/mm2 because contains large Mn elements, 0.9% and silicon (Si) content of 0.7%, higher thanthe content of the E6010 electrode, namely Mn elements by 0.5% and Si by 0.3%. The function of the Mnelement is to bind carbon (C) to form manganese carbide (Mn3C) which can increase the strength, toughness of steel and increase hardness. The function of the elemental content of silicon is to form a verystrong ferrite and also to strengthen steel.

## 3.4 Weld Metal Microstructure

The passage of a welding arc produces three zones in the welding process: (1) the weld metal, or fusion zone, (2) the heat-affected zone, and (3) the unaffected zone, or base metal. The weld metal is the part of the joint that has been melted during the welding process. The heat-affected zone is a region adjacent to theweld metal that has not been welded but has changed in microstructure or mechanical properties as a resultof welding heat. The unaffected material is one that was not sufficiently heated to change its properties. In welded metals, the microstructure typically consists of two or more phases, namely grain boundary ferrite, ferrite widmanstatten, acicular ferrite, bainit, and martensite. The acicular ferrite has a random direction orientation and is intragranular in size. Typically, acicular ferrite microstructures are formed around 650°C and have the highest toughness compared to other microstructures(Abson et al., 2013). Figure 5a depicts theweld metal microstructure with an E 6010 electrode. There is a significant amount of fine bainit and someacicular ferrite (AF). Figure 5b depicts the microstructure of weld metal with E7016 electrode, which contains a significant amount of fine acicular and some minor grain boundary ferrite (GBF). Acicular ferrite is a microstructural constituent that is commonly formed in low alloy steel weld metal deposits and has a direct impact on mechanical properties, particularly toughness and hardness (Sumardiyanto et al., 2018; Maksuti).



a b

Figure 5: Microstructure Weld Metal: a.With E 6010 Electrode and b. E 7016 Electrode.

# 4 CONCLUSIONS

Welding parameters (electrode type and heat input / welding current) have a significant effect on the tensile strength, hardness, and impact of the welded metal on API 5L low carbon steel via SMAW welding. The optimum tensile strength for welding metal is produced by the welding electrode E7016 at 110A with 617 MPa, while the lowest value is 554 MPa (decline of 11.4%) for E6010 at 110A, the optimum hardness is produced by E7016 at welding current of 110A with 186.9 VHN, while the lowest is 178,4 VH (decline of 4.8%) for E6010 at 110A, and impact toughness is 1.85Joules/mm2 by E7016 at 110A while the lowest 0.96 J/mm2. SEM microstructure analysis reveals several phases, including Acicular Ferrite ( (AF), Grain Boundary Ferrite (GBF) and Bainite.

# REFERENCES

Armentani, E., Esposito, R., Sepe, R. (2007). The effect of thermal properties and weld efficiency on residual stresses in welding, Journal of Achievements in Materials and Manufacturing Engineering, Vol. 20, No. 1-2, 319-322.

Jariyaboon, M., Davenport, A.J., Ambat, R., Connolly, B.J.,Williams, S.W., Price, D.A. (2007). The effect of welding parameters on the corrosion behaviour of friction stir welded. AA2024-T351, Corrosion Science, Vol. 49, No. 2, 877-909, doi: 10.1016/ j.corsci.2006.05.038.

Karadeniz, E., Ozsarac, U., Yildiz, C. (2007). The effect of process parameters on penetration in gas metal arc welding processes, Materials & Design, Vol. 28, No. 2, 649- 656, doi:10.1016/j.matdes. 2005.07.014.

Lothongkum, G., Viyanit, E., Bhandhubanyong, P. (2001). Study on the effects of pulsed TIG welding parameters on delta-ferrite content, shape factor and bead quality in orbital welding of AISI 316L stainless steel plate, Journal of Materials Processing Technology, Vol. 110, No. 2, 233-238, doi: 10.1016/S0924-0136(00)00875-X.

Lothongkum, G., Chaumbai, P., Bhandhubanyong, P. (1999). TIG pulse welding of 304L austenitic stainless steel in flat, vertical and overhead positions, Journal of Materials Processing Technology, Vol. 89-90, 410-414, doi: 10.1016/S0924-0136 (99)00046-1.

Mirzaei, M., Arabi Jeshvaghani, R., Yazdipour, A., Zangeneh-Madar, K. (2013). Study of welding velocity and pulse frequency on microstructure and mechanical properties of pulsed gas metal arc welded high strength low alloy steel, Materials & Design, Vol. 51, 709-713, doi: 10.1016/j.matdes.2013.04.077.

Sakthivel, T., Sengar, G.S., Mukhopadhyay, J. (2009). Effect of welding speed on microstructure and mechanical properties of friction-stir-welded aluminum, The Internation al Journal of Advanced Manufacturing Technology, Vol. 43, No. 5-6, 468- 473, doi: 10.1007/s00170-008-1727-7.

Razal Rose, A., Manisekar, K., Balasubramanian, V. (2012). Influences of welding speed on tensile properties of friction stir welded AZ61A magnesium alloy, Journal of Materials Engineering and Performance, Vol. 21, No. 2, 257-265, doi:10.1007 /s11665- 011-9889-0.

Afolabi, A.S. (2008). Effect of electric arc welding parameters on corrosion behaviour of austenitic stainless steel in chloride medium, AU Journal of Technology, Vol. 11, No. 3, 171-180.

ASME Boiler and Pressure Vessel Code Section IX – Welding and Brazing Qualification, 2010.

Kanjilal P, Pal TK, Majumdar SK (2006) Combined effect of flux and welding parameters on chemical composition and mechanical properties of submerged arc weld metal. J Mater Process Technol 171: 223–231.

Chandel RS, Seow HP, Cheong FL (1997) Effect of increasing deposition rate on the bead geometry of submerged arc welds. J Mater Process Technol 72:124–128.

Kolhe KP, Datta CK (2008) Prediction of microstructure and mechanical properties of multipass SAW. J Mater Process Technol 197:241–249.

Bracarense, A. Q., and S. Liu. "Control of covered electrode heating by flux ingredients substitution" Welding and Metal Fabrication 62.5 (1994).

Sarian, S. A., and L. A. De Vadia. "All Weld Metal Design For AWS E10018M, E11018M And E12018M Type Electrode." Welding Research Supplement (1999): 217- 219.

Talabi, SIa, et al. "Effect of welding variables on mechanical properties of low carbon steel welded joint." Advances in Production Engineering & Management 9.4 (2014): 181-186.

Tahir, Abdullah Mohd, Noor Ajian Mohd Lair, and Foo Jun Wei. "Investigation on mechanical properties of welded material under different types of welding filler (shielded metal arc welding)." AIP Conference Proceedings. Vol. 1958. No. 1. AIP Publishing, 2018.

Bodude, M. A., and I. Momohjimoh. "Studies on Effects of Welding Parameters on the Mechanical Properties of Welded Low-Carbon Steel." Journal of Minerals and Materials Characterization and Engineering 3.03 (2015): 142.

Gharibshahiyan, E., Raouf, A.H., Parvin, N., Rahimian, M. (2011). The effect of microstructure on hardness and toughness of low carbon welded steel using inert gas welding, Materials & Design, Vol. 32, No. 4, 2042-2048, doi 10.1016/j.matdes.2010.11.056.

Asibeluo, I. S., and E. Emifoniye. "Effect of Arc welding current on the mechanical properties of A36 carbon steel weld joints." SSRG International Journal of Mechanical Engineering (SSRGIJME)–volume 2 (2015). American Journal of Materials Science 2019, 9(1): 15-21

Abson, D. J., & Pargeter, R. J. (2013). Factors influencing as-deposited strength, microstructure, and toughness of manual metal arc welds suitable for C-Mn steel fabrications. International Metals Reviews, 31(1), 141-196.

Sumardiyanto, D., Susilowati, S. E., & Cahyo, A. (2018). Effect of Cutting Parameter on Surface Roughness Carbon Steel S45C. Journal of Mechanical Engineering and Automation, 8(1), 1-6.

Maksuti, R. Impact Of The Acicular Ferrite On The Charpy V-Notch