The Effect of Electrode and Number of Passes on Hardness and Micro Structure of Shielded Metal Arc Welding

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Abstract. Shielded Metal Arc Welding (SMAW) process is widely used in the industrial world for metal welding processes. The use of SMAW with the types of electrodes and an incorrect number of passes will produce a geometric shape that has a low precision and high surface roughness in the process of making workpieces. The movement and types of welding electrodes can affect the welding characteristics. Wrong welding work can result in damage to the welding results in terms of both safety and economics. This research was conducted to determine the effect of electrodes and the number of passes on the hardness of the welding and microstructure results in the welding process of Shielded Metal Arc Welding. The plate used in this study was a rectangular plate with a thickness of 10 mm, a length of 30 mm and a width of 15 mm. The specimens were welded using E6013 and E7016 electrodes with the number of 3 pass 3 pass and the number of 3 pass 6 pass. In welding using E6013 electrode with the number of passes of 3 layers 6 pass gave effect on escalating violence in the HAZ area. This happens because if the layer increases, the heat input generated decreases. If the heat input is small, the hardness of the welded joint will be large. Therefore, the number of pass 3 and 6 had different hardness.

Keywords: Electrode, the number of passes, hardness test, microstructure, SMAW

1. Introduction
Over past decades, manufacturing processes have gained utmost significance in various industrial applications. Welding is one such manufacturing processes. Many industrial worlds use SMAW types than others because this welding is basic from all types of welding. The welding process is a very important process in production techniques, related to the construction of both machinery and buildings. Welding is one of the techniques for connecting metal by melting some of the base metals with filler metal with or without pressure and with an enhancer so as to produce a complete connection [1]. Steel is an alloy consisting of the main elements of iron (Fe) and carbon (C), as well as other elements such as Mn, Si, Ni, Cr and so on which are arranged in very small percentages. Besides, these elements will affect the quality of the steel [2].

Steel is an iron alloy with carbon content up to a maximum of about 1.5%. Iron alloy with carbon above 1.5% is called cast iron [3]. The use of steel is very dependent on the varying properties of steel obtained from the integration and application of heat treatment processes. The mechanical properties of steel depend on the microstructure. The low carbon steel has a carbon content < 0.3%. It also has...
relatively low hardness, softness, and high tenacity [4]. The low carbon steel is usually utilized in the form of plates, profiles, scrapes, threads, and bolts. The lower the C level, the easier the metal is to be welded.

SMAW uses webbed electrodes as the additional material; an electric arc that occurs between the ends of the electrode and the base material will melt the tip of the electrode and some of the base materials; the electrode membrane which is also burned will melt and produce a gas that protects the tip of the electrode, crater welding, electric arc, and welding area around the electric arc to the influence of outside air [5]. The types of electrodes are classified according to certain coding standards [6]. According to the American Welding Society (AWS), the type of SMAW electrode is stated with the E mark followed by 4 digit numbers, such as E 6013 and E 7016. Some types of electrodes are often used in the welding process of SMAW: E 6013, E7016. The welding process can be done in several positions [7]. The classification of welding positions can be based on AWS (American Welding Society). The special types of plate welding positions with plates according to AWS are classified into eight, namely: 1F, 2F, 3F, 4F, 1G, 2G, 3G, and 4G [8]. In the 1G welding process with V, there are 2 ways to carry out the welding process, namely 3 layer 3 pass and 3 layer 6 pass. In the welding process with 3 layers 3 pass, the electrode movement is swung while 3 layers 6 pass, the electrode movement is straight. The movement and type of welding electrodes can affect the welding characteristics. On the other hand, the types and shapes of electrode movements for welding are often the personal choices of the welder itself without regard to the strength of the weld. Wrong welding work can result in damage to the fatal welding results in terms of both safety and economics [9].

Hardness testing can be done by several methods, namely scratch hardness, rebound method, and indentation hardness. The basic principle used in the emphasis method as a measure of hardness is the resistance of the material to plastic deformation [10]. Rockwell hardness testing is suitable for all hard and soft materials; its use is simple. The microstructure is the smallest structure found in a material of which presence cannot be seen with the eye but must use microstructure observers such as light microscopy, electron microscopy, field ion microscopes, field emission microscopes, and x-ray microscopes. The benefits of microstructure observation are [11] being able to know the microstructure contained in the specimen and finding out and comparing changes in microstructure that occurs on the plate that has received the formation, observing changes in microstructure due to the process carried out and aimed at controlling the quality of the material, and estimating the properties of the material if the ratio is known.

The parameters in welding can affect the microstructure in the welded metal so that it can impact on the mechanical properties of the welding results. Looking at the various electrode types and the number of passes above, the background of this research was to determine the effect of the types of electrodes and the number of passes on the microstructure and metal hardness.

2. Methods
The material used was low carbon steel ST 42. The tools used in this study were plate cutting machines, milling machines, SMAW AC welding machines, metallographic microscopes, and hardness testing equipment. The steps taken from this research began with the preparation of equipment and materials, then proceeded with data collection. Retrieving the data was started from cutting material, forming specimens by welded, then testing the hardness and microstructure based on the type of electrode and the number of different passes. The plate used in this study was a rectangular plate. This plate specimen had a size in each specimen with a thickness of 10 mm, a length of 30 mm and a width of 15 mm. A total of all specimens that would be welded was 16 specimens with the same shape and size. The plate would be welded and the level of hardness would be analyzed due to the electrode attachment process and the number of passes. The first specimen observed was welded plate using E6013 electrode with a number of 3 layer 3 pass pass. The second specimen observed was welded plate using E6013 electrode with a number of 3 pass 6 pass pass. The third specimen observed was welded plate using E7016 electrode with a number of 3 layer 3 pass pass. The fourth specimen observed was welded plate using E7016 electrode with a number of 3 pass 6 pass pass. Each repetition was carried out three times. The
data obtained were then be analyzed. The data analysis technique used in this study was descriptive analysis, which was to find out the average of each trial of the process of welding the SMAW on the plate with various types of electrodes and the number of different passes.

3. Results and Discussion
The hardness testing used Brevetti AFFRI machines at three different points for each specimen. The test results were numbers. The mild steel hardness test results are shown in Table 1 on HRB (Hardness Brinell).

| The Electrode Types and the Number of Passes | Specimen | Average Hardness test (HRB) |
|---------------------------------------------|----------|-----------------------------|
| E6013 electrode with a 3 layer 3 pass       | 1        | 83.16                       |
| E6013 electrode with a 3 layer 6 pass       | 2        | 90.83                       |
| E7016 electrode with a 3 layer 3 pass       | 3        | 82.66                       |
| E7016 electrode with a 3 layer 6 pass       | 4        | 83.66                       |

Table 1 presents the results of hardness testing of Rockwell Hardness Tester that has the lowest hardness rate of 82.66 HRB and the highest hardness rate of 90.83 HRB. The average hardness for the specimens welded using E6013 electrodes with the number of 3 layer 3 pass was 83.16 HRB. The average hardness rate for the welded specimens using E6013 electrode with the number of 3 layer 6 pass showed the value of 90.83 HRB. The average hardness rate for the specimens welded using E7016 electrodes with the number of 3 layer 3 pass was 82.66 HRB. The average hardness rate for the specimens welded using E7016 electrodes with the number of 3 layer 6 pass was 83.66 HRB. Therefore, the average number for the hardness level of the four specimens on ST 42 steel after experiencing variations in SMAW welding process with the electrodes E6013 and E7016 with the number of 3 layer 3 pass and the number of 3 layer 6 pass pass on the HRB scale showed an average number of 85.07 HRB.

Based on the experimental analysis, it can be seen that the variables used were the types of electrodes and the number of passes having an influence on the value of hardness and microstructure. The welding using E6013 electrodes with a number of 3 layers 6 pass gave the increasing influence of violence in the HAZ area. This is in line with previous studies [12] that E6013 electrode had a high hardness. The highest hardness value with an average of 90.83 HRB was found in the E6013 electrode variable with the number of pass 3 layer 6 pass. This happened because if the layer increases, the heat input generated will decrease and if the heat input is small, the hardness of the welded joint will be large. Hence, the number of pass 3 and 6 had different hardness. The mechanical properties of weld metal deposited by the impermeable electrode were satisfactory when compared to the minimum required for the class E6013 electrodes; the energy absorbed in the impact tests were consistent with the microstructure of the weld metal [13].

Of all the specimens that had been tested, the results obtained for specimens that had the greatest hardness value were the specimens that were welded using E6013 electrodes with a number of 3 layers 6 pass. The observations made on the microstructure were carried out by taking pictures on the HAZ (Heat Affected Zone) area by using electrode differences namely E6013 and E7016 with the number of pass 3 and 6. Following the results of microstructure photo test of HAZ area test specimens with 500x magnification and digital etching 2%. The micro photos of ST 42 steel specimens are as follows:
Figure 1. HAZ area specimen from E6013 electrode, 3 Layer 3 pass

Figure 2. HAZ area specimen from E6013 electrode, 3 Layer 6 pass

Figure 3. HAZ area specimen from electrode E7016, 3 Layer 3 pass
Figure 4. HAZ area specimen from electrode E7016, 3 Layer 6 pass

The welds made with SMAW using different types of electrodes and the number of passes resulted in weld metal microstructure as fully perlite and ferrite, as shown in Fig.1-4. Fig.1 is specimen HAZ area from electrode E6013 with 3 layer 3 pass that has many perlites (dark mark) and ferrites (bright mark). Fig.2 is specimen HAZ area from electrode E6013 with 3 layer 6 pass that has many perlites and ferrites. Fig.3 is specimen HAZ area from electrode E7016 with 3 layer 3 pass which has many perlites and ferrites. Fig. 4 is specimen HAZ area from electrode E7016 with 3 layer 6 pass that has many perlites and ferrites. The more perlites are at fig.4 than fig.3 because the figure 4 is the darkest among the other. The weld microstructure had a maximum perlite structure shown in Fig.4. This specimen was welded using a specimen from the E7016 electrode; the microstructure that occurred in ferrite (bright), perlite (dark), when compared to the base metal, was finer with less amount than the other welds. The microstructure in the picture above is the HAZ area, the microstructure in the image is dominated by bright white ferrite grains, while the perlite phase is darker. The ferrite grains tend to be finer while perlite grains are more coarse; the perlite grains tend to be hard because they contain carbon, while the ferrite grains tend to be soft [14].

For the results of microstructure, it can be explained that the HAZ of the base metal during the welding process was under a thermal cycle. After heating the iron-gamma, the austenite process began to transform into iron-alpha or ferrite where the ferrite has very little carbon solubility to settle continuously along the austenite grain boundary. The austenite would transform to perlite and end at a temperature of around 500 °C. Under a temperature of 500 °C, the austenite would transform to bainite and end at a temperature of 300 °C, then at a temperature below 300 °C, the remaining austenite would become martensite. So, the estimated final structure formed was perlite ferrite. This structure had a fairly good hardness. With an increasing percentage of perlite than ferrite content due to the increasing number of layers, the hardness of a material would increase [15].

The results obtained in the mechanical tests, as well as micro analysis, showed that the types of electrodes and the number of passes significantly affected the mechanical properties and microstructure of the steel. This was shown with the increasing number of layer:, the microstructure that was formed had a lot of perlite contents, which means it was getting harder [16]. The structure that occurs in the welded joint is largely determined by the chemical composition, base metal, fill metal, welding method, and heat treatment carried out. The types of electrodes and the number of passes caused different microstructure in the HAZ region. The HAZ area for electrodes E6013 and E7016 both contained ferrite and perlite. However, the E6013 specimens with the number of pass 3 layer 6 pass had the most perlite, meaning this specimen tends to be harder because it contains carbon.
4. Conclusion
Based on the results of research and analysis carried out on the low carbon steel accompanied by a welding process with variations in electrodes and the number of passes, the following conclusions can be drawn namely the types of electrodes and the number of passes are very influential on hardness and microstructure of the welding results. The results of the hardness test indicated that by using E6013 electrode, the hardness value was higher than using E7016 electrode. The microstructure test results exhibited that the HAZ region for electrodes E6013 and E7016 both contained ferrite and perlite. However, the E6013 specimens with the number of pass 3 layer 6 pass had the most perlite, meaning this specimen tends to be harder because it contains more carbon.

References
[1] Daryanto, Proses Pengolahan Besi dan Baja. Bandung, 2010.
[2] Bintoto, G. Dasar-Dasar Pekerjaan Las. Kanisius, Yogyakarta, 1999.
[3] S. Ragu Nathan, V. Balasubramanian, S. Malarvizhi, and A. G. Rao, “Effect of welding processes on mechanical and microstructural characteristics of high strength low alloy naval grade steel joints,” Def. Technol., vol. 11, no. 3, pp. 308–317, 2015.
[4] Surdyia, tata. Saito, Sinroku, pengetahuan bahan teknik. Pradnya paramita. Jakarta: 2005.
[5] Widharto, S. Teknologi dan Proses Pengelasan. Balai Besar Bahan dan Barang Teknik, Bandung.
[6] H. Dai, X. Shen, and H. Wang, “Results in Physics Study on the arc pressure of TIG welding under the condition of Ar-Ar and Ar-He supply alternately,” Results Phys., vol. 10, no. June, pp. 917–922, 2018.
[7] The ABC’s Of Arc Welding And Inspection, 2015, kobestecel Ltd, Tokyo.
[8] Moshat, S. dkk. (2010). “Parametric Optimization of CNC End Milling using Entropy Measurement Technique Combined with Grey-Taguchi Methode,” International Journal of Engineering, Science and Technology, vol. 2, No. 2, pp 1-12.
[9] C. T. Vaz, A. Q. Bracarense, I. Felizardo, and E. C. Pereira Pessoa, “Impermeable low hydrogen covered electrodes: Weld metal, slag, and fumes evaluation,” J. Mater. Res. Technol., vol. 1, no. 2, pp. 64–70, 2012.
[10] C. T. Vaz, A. Q. Bracarense, I. Felizardo, and E. C. Pereira Pessoa, “Impermeable low hydrogen covered electrodes: Weld metal, slag, and fumes evaluation,” J. Mater. Res. Technol., vol. 1, no. 2, pp. 64–70, 2012.
[11] Jaenal Arifin, Helmy Purwanto, Imam Syafaat (2017), Pengaruh Jenis Elektroda terhadap Sifat Mekanik Hasil Pengelasan SMAW Baja ASTM A36, Momentum, Vol. 13, No 1.
[12] Naryono, Farid Rakhman (2014), Pengaruh Kecepatan Pengelasan Pada Penyambungan Plat Baja SA36 Menggunakan Elektroda E6013 dan E7016 Terhadap Kekerasan, Struktur Mikro dan Kekuatan Tariyka."Sintek, vol 5.
[13] A. Saxena, A. Kumaraswamy, G. Madhusudhan Reddy, and V. Madhu, “Influence of welding consumables on tensile and impact properties of multi-pass SMAW Armox 500T steel joints vis-a-vis base metal,” Def. Technol., vol. 14, no. 3, pp. 188–195, 2018.
[14] T.-J. Kim, B.-S. Jang, and S.-W. Kang, “Welding deformation analysis based on improved equivalent strain method considering the effect of temperature gradients,” Int. J. Nav. Archit. Ocean Eng., vol. 7, no. 1, pp. 157–173, 2015.
[15] Fong Yih, Tzeng dan Chen Fu-chen, (2003), “A simple approach for robust design of high-speed electrical- discharge machining technology,” International Journal of Machine Tools & Manufacture, Vol.43, pp. 217-227.
[16] L. De Jesus et al., “Mechanical properties and microstructure of SMAW welded and thermically treated HSLA-80,” Integr. Med. Res., no. x x, pp. 1–8, 2018.