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Analysis of mechanical properties on API 5CT pipe casing welded using GTAW- SMAW process

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Abstract

The drilling process commonly employs API 5CT pipes, one type of which is API 5CT Casing Pipe Grade L80 Type-1. Long casing pipes are generally connected using the Threaded and Coupled (male-female) method. In certain conditions, welding is used for joining, and the combination welding process GTAW-SMAW is commonly employed in the field. The electrodes used are generally ER-70S-G (GTAW) and E7010-P1 (SMAW). The E7010-P1 electrode is difficult to obtain in the field. It is not only expensive but also scarce. Therefore, in some cases, construction contractors often substitute the E7010-P1 electrode with E7016, which is more readily available. This substitution is based on the consideration that both electrodes have similar tensile strength values (70ksi). This study aims to determine the mechanical properties of the joint process of API 5CT Casing Pipe Grade L80 Type-1 using E7016 electrodes and to evaluate the feasibility of substituting it for the E7010-P1 electrode. NDT testing was performed using a penetrant test, while DT testing was carried out using Vickers Hardness testing. The hardness test results showed that the highest average hardness value was found in the material using the E7016 electrode, which was 304 HVN, specifically in the weld metal area. Based on these results, E7016 can be recommended as a substitute for the E7010-P1 electrode.

1. Introduction

The combination welding process, particularly Gas Tungsten Arc Welding (GTAW), is often combined with the Shielded Metal Arc Welding (SMAW) process. The application areas include oil drilling, pipelines, pressure vessel fabrication, piping systems, heat exchangers, boilers, and shipbuilding industries. Almost all construction projects use metals, especially carbon steel, and welding techniques are recognized as one of the most efficient technologies for joining metals in their molten state [1][2].

In drilling processes, API 5CT pipes with various types are used [3], including the API 5CT Grade L80 Type-1, which is a carbon steel pipe with standard technical specifications for casing pipes used in drilling wells in the oil and gas industry. Long casing pipes are needed, which are connected by joining one pipe to another, typically using a threaded and coupled (male-female) system. However, in certain conditions, welding is required [4].

In the field, casing pipe welding is commonly performed using GTAW and SMAW processes with E7010-P1 electrodes [5]. These electrodes are difficult to obtain due to their high cost and limited availability in the market, so in some cases, construction contractors often substitute E7010-P1 with E7018 or E7016 electrodes, which are more readily available. This substitution is based on the consideration that these electrodes have relatively similar tensile strengths (70 ksi).

Based on the above issues, experimental research is necessary to investigate the mechanical properties of API 5CT Grade L80 Type-1 casing pipe welds using E7016 electrodes. Several studies have been conducted on the combination welding of SMAW and GTAW for material joining [6][1][7]. In his research, Weiwei Yu studied the welding of two main coolant pipes joined by multi-lap, narrow gap edge welding using GTAW and SMAW separately, and then tested their microhardness to differentiate base metal (BM), heat-affected zone (HAZ), fusion zone (FZ), and weld metal (WM). Afterward, uniaxial tensile testing was performed using a 3D DIC system to study strain changes in each area of the GTAW and SMAW welds and compare their tensile properties. Fracture toughness was tested at four different locations on the SMAW and GTAW welds. The offset line method (0.2 mm) and strain zone width method were applied to calculate the initial critical fracture toughness (Ji). The results showed that the fusion zone (FZ) had the lowest fracture toughness compared to other areas in both types of welds. Moreover, the GTAW welds exhibited better overall performance compared to the SMAW welds [8].

MTZ Butt, et al., in their study on the use of two different welding techniques (SMAW, GTAW) applied to mild steel with ASTM SA 516 Gr. 70 standards, commonly used in boilers and pressure vessels, conducted welding according to standard industrial procedures under controlled welding conditions. Each welding technique was tested on three areas—base metal, heat-affected zone (HAZ), and weld zone—using optical microscopy. Mechanical properties were tested using a universal tensile testing machine, while hardness testing was conducted with a Vickers hardness tester. Bend tests were performed to assess the strength of the weld joints using a universal bend testing machine. The aim of metallographic and destructive testing was to determine the effects of different welding techniques (GTAW and SMAW) on the microstructure and mechanical properties of SA 516 Gr. 70 steel used in boilers and pressure vessels. The results showed that to take advantage of GTAW, the root pass should be made with this technique, while hot pass and face pass can be done with SMAW to achieve the best combination of strength and cost efficiency [9].

The purpose of this study is to investigate the mechanical properties of API 5CT Grade L80 Type-1 casing pipe joints welded using E7016 electrodes and to consider the substitution of these electrodes in practice.

2. Research Methods

The materials used are API 5CT Grade L80 Type-1 Casing Pipe Ø 7” with a length of 247.6 mm, thickness of 11 mm, and filler rods ER70S-G with trade name Kobelco TGS-50 Ø 2.4 × 350 mm, and E7016 with trade name Kobelco LB-52 Ø 3.2.

The method begins with the preparation of the API 5CT Grade L80 Type-1 Ø 7” casing pipe, which is cut into three 120˚ sections. Each section is then divided into three parts to create six joints. The combination GTAW-SMAW welding process is then carried out using the parameters shown in Table 1.

Table 1. Combination GTAW-SMAW Welding Parameters.

Welding Process	GTAW	GTAW	SMAW	SMAW
Layer Number	1	2	3	4
Welding Pass	*Root pass*	*Hotpass*	*Filler*	*Capping*
***Travel Speed* (mm/s)**	1,18	1,14	0,6	0,83
***Ampere* (A)**	90	100	100	100
DC *Polarity*	DC - EN	DC - EN	DC - EP	DC - EP
***Voltage* (V)**	11 - 13	12 - 13	21 - 27	21 - 27
***Elektrode* (mm)**	-	3,2	3,2	3,2
***Filler Wire* (mm)**	Ø 2,4	-	-	-

The welding process used is a combination welding process, namely GTAW and SMAW. Gas Tungsten Arc Welding (GTAW) is a welding process where the heat source comes from the electric arc between an electrode made of tungsten. This type of welding uses a shielding gas, without applying pressure, and can be used with or without filler metal [10]. Shielded Metal Arc Welding (SMAW), also known as Manual Metal Arc Welding (MMAW), is a welding process that joins two or more pieces of metal into a permanent joint, using the heat source from an electric arc and adding a filler material in the form of a coated electrode [11].

The GTAW welding process consists of two welding layers: the root pass with a current of 90 amps and the hot pass with a current of 100 amps. For the root metal, with a current of 90 amps, the welding uses ER70S-G filler rod and EWTH-2 tungsten, which is suitable for carbon steel welding. In the root welding, DCEN polarity is used to ensure that more heat is concentrated on the workpiece, making it easier for root pass penetration, as 2/3 of the heat is at the positive pole and 1/3 at the negative pole.

After the GTAW welding is completed, the root pass is cleaned and smoothed with a grinder to remove any flux residue from the GTAW process. Then, the current, polarity, and the E7016 LB-52 electrode with a diameter of Ø 3.2 mm are set for the filler and capping passes. The welding current for the filler and capping is varied, typically 100 amps, as seen in the welding parameters in Table 1.

The coupon test for welding, which will be studied in this research, is shown in Fig. 1.

Fig. 1. E7016 electrode test coupon

Next, a coupon test is performed by carrying out the welding process and forming the test specimen. Welding was performed on the pipe using a combination of two welding methods: Gas Tungsten Arc Welding (GTAW) and Shielded Metal Arc Welding (SMAW). The GTAW process was used for the initial welding, producing precise and clean joints as the welding arc utilizes a non-consumable tungsten electrode. Subsequently, the SMAW process was employed to continue the welding, particularly for thicker sections or to expedite the work, as this method provides good penetration and high efficiency. The combination of these two methods aims to achieve high-quality welding results in terms of joint strength, time efficiency, and cost-effectiveness. Welding is carried out with the parameters determined in the previous explanation.

The welding results were subjected to hardness testing with the aim of evaluating the mechanical properties of the welded joint. This test helps determine the hardness distribution across the weld metal, heat-affected zone (HAZ), and base metal, ensuring that the joint meets the required strength and durability standards. Additionally, the hardness test is intended to identify any potential weaknesses or inconsistencies in the weld, such as zones that may be prone to failure under operational loads. The results provide critical data for assessing the quality and reliability of the welding process [12].

3. Results and Discussion

A macro etching test is required to observe the HAZ (Heat-Affected Zone) and Weld Metal areas before performing hardness testing on these areas. This test also aims to identify any welding defects after welding on each specimen. The hardness test points are shown in Fig. 2.

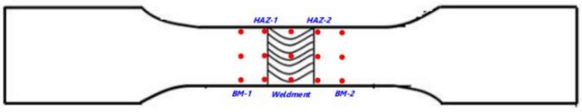

Fig. 2. Hardness testing points [12]

The results of the hardness test can also be presented in graphs, as shown in Fig.s 3 and 4. Fig. 3. shown the hardness graph for specimen 2-1 E7016. It is known that the highest hardness value, due to the influence of using the E7016 SMAW electrode in the welding process on the API 5CT Grade L80 Type-1 Casing Pipe material, is found in the Base Metal-2 area at test point-1, with a value of 252.7 HV. The lowest hardness value is found in the BM-1 area at 224.1 HV, while the highest hardness value in the weld metal area is 241.4 HV. This indicates that the hardness of the weld metal area is slightly below the hardness value of BM-2 but higher than the hardness value of BM-1.

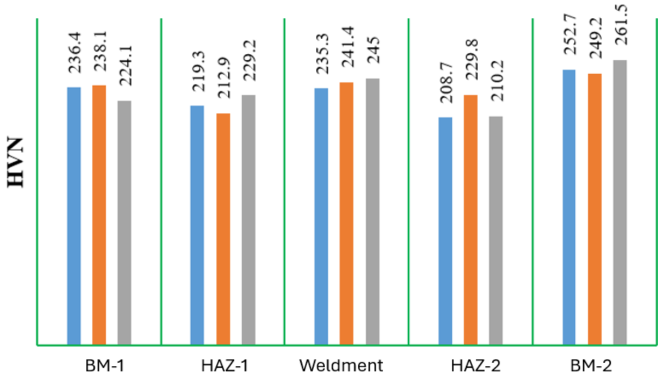

Fig. 3. Comparison of hardness values for Sc 2-1 E7016.

Fig. 3 shown too the difference in hardness values in the Heat Affected Zone (HAZ) is also visible. The highest hardness in HAZ-1 is 229.2 HV, while the lowest is 212.9 HV. The highest hardness value in HAZ-2 is 229.8 HV, with the lowest value in HAZ-2 being 208.7 HV.

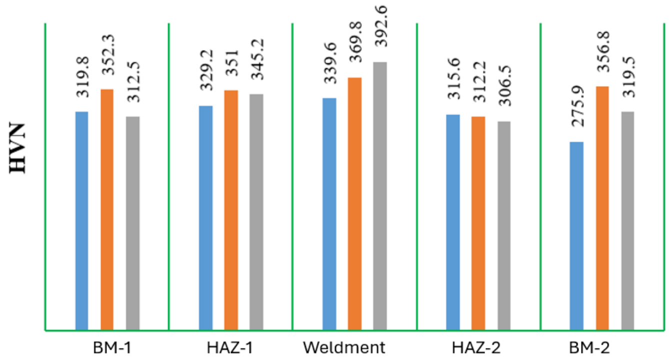

Fig. 4. Comparison of hardness values for Sc 2-2 E7016.

Fig. 4 shown the highest hardness value is found in the weld metal area at test point-3, with a value of 392.6 HV. Test point-2 has a hardness of 362.9 HV, and test point-1 has a value of 339.6 HV. The highest hardness in the Base Metal (BM) is found in BM-2, at 356.8 HV, while the lowest hardness in BM is also in BM-2 at 275.9 HV. The highest hardness in the HAZ area is found in HAZ-1 at 351 HV, while the lowest is found in HAZ-2 at 306.5 HV.

The cause of the hardness variation in the weld results can be explained by the influence of several factors related to the welding process and the material properties. First, the difference in hardness between the Base Metal (BM), Heat Affected Zone (HAZ), and weld metal (WM) can be attributed to the changes in microstructure that occur during the heating and cooling processes in each area. In the BM, hardness variations occur due to differences in chemical composition and microstructure conditions, which can be influenced by the presence of compounds such as carbon and other alloying elements in the material.

In the HAZ, the lower hardness near the BM (HAZ-2) is due to slower cooling, which allows microstructural transformations such as the formation of martensite or pearlite, which have lower hardness than the areas closer to the weld metal (HAZ-1), which cool faster and can form harder structures such as bainite.

In the weld metal, high hardness can occur due to rapid cooling and differences in chemical composition between the filler metal and base metal. The use of the E7016 electrode with a specific composition also plays a role in determining the hardness of the weld metal, as the effect of alloying elements in the filler material differs from that of the BM.

Overall, the highest hardness in BM-2 and the weld metal can be caused by microstructural changes during cooling and differences in cooling rates between the BM and weld metal. These hardness variations reflect the different mechanical properties in each welded zone, influenced by the heating, cooling rates, and the different material compositions .

4 Conclusion

The conclusion drawn from this study is that the hardness test results show a hardness value of 304 HVN for the E7016 electrode, specifically in the weld metal area, while the average hardness value for the raw material of the API 5CT Grade L80 Type-1 Casing Pipe is 290 HVN. Based on the test results of specimens welded with the E7016 electrode, it can be recommended as a substitute for the E7010-P1 electrode in SMAW welding of the API 5CT Grade L80 Type-1 Casing Pipe material in terms of hardness value.

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