Experimental Study of the Effect of Preheating Process on Welded Joints of ASTM A36 Material on Mechanical Characteristics: Evaluation of Tensile, Bending, and Macrostructure

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Abstract

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In the oil and gas industry, welding errors frequently necessitate replating. Preheating is a heat treatment method used to minimize temperature gradients between the weld area and its surroundings, thereby reducing the risk of weld defects. This study employs an experimental approach to evaluate the effect of preheating during rewelding and to assess the resulting mechanical properties of the weld metal. The experiment involved two rewelding cycles with preheating. The minimum preheating temperature was set at 50 ℃, and the minimum interpass temperature at 240 ℃. Shielded Metal Arc Welding (SMAW) was used to weld ASTM A36 carbon steel. The experimental procedures included tensile testing, bending testing, and macrostructural analysis. Welding was performed on A36 steel using E7016 and E7018 filler materials, with a current of 94.1 A and a groove configuration featuring a 30° bevel angle. The findings of this research can inform the development or revision of procedure qualification records (PQR) to meet industry quality and safety standards.

1. Introduction

In the manufacturing industry and industry in general, the welding process is crucial to ensure that welded joints meet the expected strength and toughness standards[1]. Therefore, selecting high-quality materials is a priority in any industry. One material commonly used in industrial welding processes is ASTM A36 steel plate. This steel plate is a low-carbon steel with good mechanical strength. Furthermore, this type of steel is easily formed[2].

Electric arc welding, particularly Shielded Metal Arc Welding (SMAW), is the predominant method in industrial settings. SMAW employs electrical energy to join metal components by generating an electric arc that melts both the workpiece and the electrode, which gradually diminishes until consumed[3]. SMAW machines are categorized by current type: direct current (DC), alternating current (AC), and dual current. DC welding machines operate with either straight or reverse polarity. Straight polarity (DCEN) is suitable for parent materials with high melting points and large capacities, connecting the electrode holder to the negative pole and the parent metal to the positive pole[4]. Despite the importance of preheating, it is sometimes omitted, even though different metals require specific preheat temperatures. Preheating is essential to prevent defects and ensure optimal weld quality.

During the welding process, residual stresses often arise unnoticed in the welded structure. Excessive residual stresses can cause permanent deformation and even lead to cracking of the weld joint. This condition generally occurs because the welding process is carried out without going through the initial heating stage (preheating) first. Preheat, according to the American Welding Society (AWS), is defined as the process of applying heat to the metal to be welded with the aim of achieving and maintaining the preheat temperature. Preheat temperature is the temperature of the base metal around the area to be welded before the welding process begins[5].

Preheating must be done without damaging the metal surface in the area to be welded. There are several reasons for using preheating, namely: slowing the cooling rate of the weld metal and parent metal, producing a more ductile metallurgical structure, and increasing resistance to cracking. The slow cooling rate allows time for hydrogen to diffuse out of the metal without damaging it, thus reducing the possibility of weld defects[6]. Therefore, the purpose of this research is to determine the effect of the preheat process and ambient temperature on the mechanical characteristics of welded joints on ASTM A36 material, through testing Tensile strength, bending resistance, and observation of the macro structure of the welding results. This research focused solely on ASTM A36 material, measuring 300 x 140 x 25 (4 EA).

The first study, conducted by M. Reza Nugraha, examined the effect of 500°C preheat on dissimilar welding between ASTM A36 and A6 steel using the SMAW method. Test results showed that preheating strengthened the weld structure by forming martensite, increasing the hardness to 202 BHN in the weld zone, and reducing defects such as undercuts. However, the lowest hardness value was found in the ASTM A36 base metal region without preheat (145 BHN). Bending tests showed that A36 material demonstrated the highest strength compared to the dissimilar weld zone, indicating greater ductility in the base metal[7].

The second study, conducted by Achmad Rifaldi, used ASTM A36 with a preheat temperature ranging from 0°C to 300°C. The test results showed that the highest tensile strength was achieved at a temperature of 200°C (458 N/mm^2), while the maximum hardness occurred at 300°C with a value of 147 VHN (base metal), 178 VHN (HAZ), and 185 VHN (weld metal). This indicates that the preheat temperature affects the mechanical properties differently, where optimal tensile strength occurs at moderate temperatures, while hardness increases with increasing temperature[8].

Sudirman investigated API 2W Grade 50 material welded in a 3G position with preheating temperatures ranging from 40°C to 90°C. The study found that increasing the preheat temperature raised the tensile strength from 494 MPa to 653.72 MPa. The highest hardness was observed in the heat-affected zone (HAZ) at 90°C. The authors highlighted that slow post-weld cooling is essential to prevent cracking and to enhance the strength of the fusion zone. These findings have direct implications for welding offshore structures, particularly platform topsides[9].

Nuraliansyah conducted a study using AISI 1045 steel and gas metal arc welding (GMAW), demonstrating that a preheat temperature of 320°C combined with a postheat of 650°C resulted in the highest hardness value of 209 HV in the HAZ. The weld zone microstructure comprised ferrite and pearlite phases. The ferrite grain size was larger in the weld metal than in the HAZ and base metal, suggesting that cooling rates regulated by preheat and post-heat temperatures significantly affect microstructural size and distribution[10].

Irfansyah investigated the effects of preheat temperatures of 0°C, 100°C, and 200°C on welding ASTM A36 steel above the water surface using the shielded metal arc welding (SMAW) method. The findings indicated that preheating increased the yield strength from 305 MPa without preheat to 453 MPa at 200°C. Although ultimate tensile strength (UTS) also increased, the change was not statistically significant. Additionally, hardness in the HAZ and weld metal decreased as preheat temperature rose, reflecting a transition to a softer and more ductile metal structure[11].

2. Methods

This study employs quantitative experimental methods by applying preheat treatment to A36 welding joints and subsequently evaluating changes in mechanical properties and macrostructure. The flow diagram of the research is presented in Figure 1.

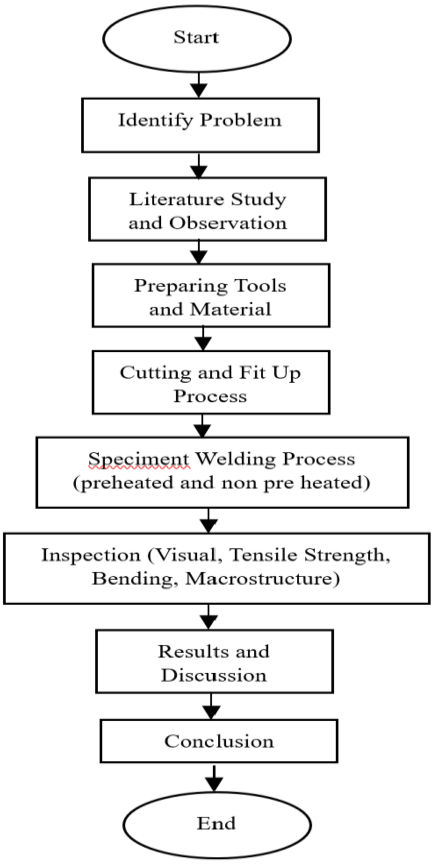

Figure 1. Research flowchart

The research references ASME Section IX standards, utilizes the Shielded Metal Arc

Welding (SMAW) process at the 1G welding position, and uses ASTM A36 base metal specimens measuring 300 x 140 x 25 mm. The investigation focuses on the effects of ambient temperature and a preheat temperature of 50 ºC[12].

2.1 Problem

The problem formulation aims to assess whether variations between preheat and ambient temperatures significantly influence the mechanical properties of the material and the occurrence of weld defects following the welding process.

The research problems are how does preheating affect the tensile strength of welded joints in ASTM A36 material, how does preheating affect the bending ability of welded joints, and what is the effect of preheating on the macrostructure of welded joints in ASTM A36 material.

2.2 Literature Study and Observation

Literature study was conducted to study and understand the importance of the influence of a material on preheat behavior in order to avoid susceptibility to welding defects and failure in a weld. shows that optimal preheat can increase the tensile strength and elongation of welded joints in A36 material. References for carrying out this research were obtained from books, scientific journals, papers, and previous final assignments that are still relevant.

2.3 Preparation of Tools and Materials

The ASTM A36 steel was selected as the material for this research. Chemical composition for ASTM A36 can be seen on Table 1. The steel plate, with a thickness of 25 mm, was cut to dimensions of 300 x 140 x 25 mm. Prior to welding, the material was prepared for the welded joint using the Shielded Metal Arc Welding (SMAW) method. Following cutting, the edges of the material were beveled with a grinder at a 60º angle.

During the welding stage, a Shielded Metal Arc Welding (SMAW) machine is employed. This equipment operates within a welding current range of 60 to 200 Amperes. A welding wire is a wire-shaped tool used to join two metal components during the welding process. It is typically composed of various metals and is melted by a heat source from the welding equipment to fill the joint gap, thereby creating a strong metallurgical bond. In this study, welding wires E7016-1 (2.6 mm, Kobelco, LB 52U) and E7018 (3.2 mm, Kobelco, LB 7018-1) were utilized. Both wires conform to the ASME Specification SFA-5.1 standard. A burn torch is a tool that produces a flame for cutting, heating, or welding metal by combusting gas fuels such as acetylene, propane, or butane mixed with oxygen. Working pressure for the oxygen burn torch which is 90 bar or 1400 psi.

Table 1. Chemical composition of ASTM A36

Product	Plates > 380mm
Thickness [mm]	Over 20 to 40 mm
Carbon, max %	0.25
Manganese, %	0.80 – 1.20
Phosphorus, max %	0.030
Sulfur, max %	0.030
Silicon, %	0.40 max
Copper, min % when cop per steel is specified	0.20

A thermocouple is a sensor designed to monitor or record temperature data reliably. Thermocouples operate according to the Seebeck Effect. When two dissimilar metals are joined at two junctions and exposed to a temperature gradient, an electrical voltage (measured in millivolts) is produced that is proportional to the temperature difference. Figure 2 presents the temperature of Material 1 without preheat treatment, which is 35.2ºC. Figure 3 shows Material 2 without preheat treatment at 35.4ºC. Figure 4 displays the temperature of Material 1 after preheating, recorded at 51.9ºC. Figure 5 illustrates Material 2 after preheating, with a temperature of 5.ºC.

Figure 2. Non preheat treatment of material 1

Figure 3. Non preheat treatment of material 2

Figure 4. Preheat treatment of material 1

Figure 5. Preheat treatment of material 2

Cutting and fit-up constitute the initial stage of specimen preparation prior to welding. This study utilizes low-carbon steel type A36. Following cutting, the fit-up process involves aligning two A36 plates in a butt joint configuration using a jig or clamping tool to achieve precise alignment[13] The root gap and weld angle are set according to the welding procedure specification (WPS), with careful attention to root gap, joint surface, and perpendicularity of the angle to ensure optimal weld penetration and to prevent defects such as lack of fusion or undercut. Prior to welding, the material must be preheated. Preheating is performed using an oxy-acetylene torch positioned 50 to 75 mm from the bevel angle as in Figure 6 and 7. The process uses a reference ambient temperature of 30ºC and a preheat temperature of 50ºC. Heat is applied evenly to the weld area, and the temperature is monitored using a thermocouple[14]. Welding is conducted on ASTM A36 steel specimens using the Shielded Metal Arc Welding (SMAW) method. Before welding, the joint surface is cleaned of dirt and rust to ensure optimal results.

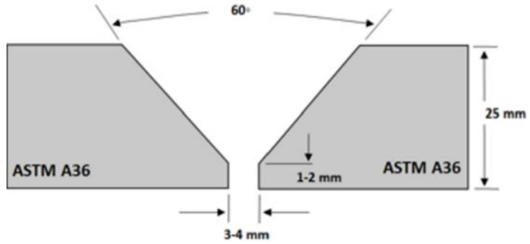

Figure 6. Root weld, fil and cap distance

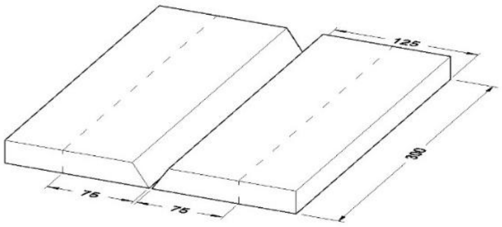

Figure 7. Base metal preheat distance

3. Results and Discussion

This study aims to interpret and evaluate the test results of A36 weld joints subjected to preheat treatment. The following section systematically analyzes test data, including tensile strength, bending strength, and macrostructure, to provide a comprehensive understanding of the weld joint performance.

3.1 Welding Parameters

In this study, several parameters influence welding results as in Figure 2. The material used is ASTM A36 with a thickness of 25 mm. The filler metal or welding wire follows Classification E7016 and E7018, with a diameter of 3.2 mm. Welding is performed in the 1G position using alternating current (AC) polarity. The choice of polarity significantly affects heat input, penetration, and the overall quality of the welded joint. These parameters are determined in accordance with the standards presented in Table 3.

Table 2. Material and electrode

Name	Description
Material Specification	ASTM A36
Thickness	25 mm
ASME Classification	E7016 & E7018
Filler Diameter	3.2 mm
Welding Position	1G
Polarity	AC, DCEP

Table 3. Welding parameter data

Process	Non Preheat	Preheat 50 ºC
Ampere (A)	91,4 – 95,1	91,4 – 95,1
Voltage (V)	21,8 – 27,1	21,8 – 27,1
Travel Speed (mm/s)	55,5	76,3
Heat Input	1,72	1,76

3.2 Tensile Test

Tensile strength is a key material property that characterizes a material's response to applied loads. Ultimate tensile strength (UTS) refers to the maximum stress a material can endure under tension before failure. Tensile test specimens were tested according to test method ASTM E8/E8M:2021. Higher tensile strength indicates greater material robustness. Several factors influence tensile strength, including preheat treatment prior to welding. According to the data in Table 4, specimens subjected to a preheat temperature of 50 ºC exhibited a tensile strength of 550 MPa, whereas those without preheat treatment showed a tensile strength of 548 MPa. These results suggest that preheat treatment can alter the mechanical properties of the material.

Table 4. Ultimate tensile test data

Treatment	Thickness (mm)	Width (mm)	UTS (MPa)
Ambient	24.82	19.19	548
Temperature	24.77	19.07	547
Preheat 50º C	24.60	19.70	550
Preheat 50º C		19.80	551

3.3 Bending Test

Bending tests were performed to evaluate the capacity of A36 welded joints to undergo plastic deformation without incurring damage such as cracks or fractures. Bending test specimens were tested according to the AWS D1.1/D1.1M:2020 standard test method. Specimens were bent to specified angles according to established standards to facilitate observation of the welded joints. Testing was carried out on 4 test pieces with 4 pieces each.

The results presented in Table 5 demonstrate a clear difference in performance between specimens subjected to preheat treatment and those welded without preheating. Preheated specimens exhibited superior bending performance, as evidenced by smoother bent surfaces and a reduced incidence of defects such as cracks or delamination. These findings suggest that preheating effectively reduces residual stress and enhances ductility in welded joints.

In contrast, non-preheated specimens frequently displayed cracking in the weld area during bending and exhibited irregular bent surfaces. This outcome suggests that rapid cooling after welding leads to increased residual stress and diminished joint performance. Overall, the preheat process positively influences the bending behavior of A36 welded joints by stabilizing the interface between the weld metal and the base metal, thereby improving the mechanical properties of the joint. These results are consistent with the theoretical understanding that preheating reduces thermal stress.

Table 5. Bending test data

Speciment	Results	Description
S1	Found Defect 4.8 mm	Material Non Preheat 1
S2	No Defect Found	
S3	Found Defect 3 mm	
S4	No Defect Found	
S1	Found Defect 4.91 mm, 4.8 mm	Material Non Preheat 2
S2	No Defect Found	
S3	Found Defect 1.98 mm	
S4	No Defect Found	
S1	No Defect Found	Material Preheat 1
S2	No Defect Found	
S3	No Defect Found	
S4	No Defect Found	
S1	No Defect Found	Material Preheat 2
S2	No Defect Found	
S3	No Defect Found	
S4	No Defect Found	

3.4 Macrostructure

Macrostructure examination assesses the physical condition and characteristics of welded joints in A36 material after welding, comparing preheated and non-preheated specimens. This technique is essential for evaluating joint features such as weld metal penetration shape and depth, and the interface between weld and parent metal. Macrostructure observations reveal significant differences between preheated and non-preheated specimens, as illustrated in Figure 8 and Figure 9, respectively. Preheated specimens exhibit a more uniform weld area, improved penetration, and fewer macro defects such as cracks. Pre-welding heat treatment reduces extreme temperature gradients during welding, thereby decreasing the likelihood of defect formation[15]. In contrast, non-preheated specimens display more cracks, less uniform weld penetration, and a rougher, larger appearance, indicating high thermal stress from rapid post-weld cooling. Overall, preheating significantly enhances the quality of welded joints in A36 material by minimizing macroscopic defects and increasing structural uniformity. These macrostructural improvements correlate with enhanced mechanical properties, as supported by tensile and bending test results.

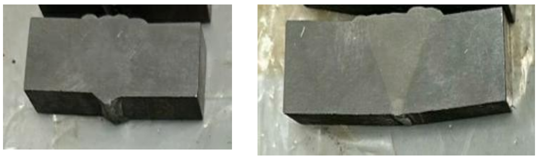

Figure 8. Macromaterial using preheated

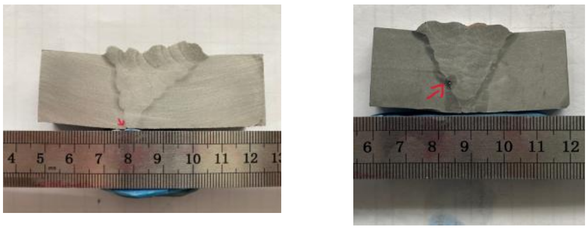

Figure 9. Macromaterial using non preheated

4. Conclusion

Experimental results comparing preheating at 50^{0}C and ambient temperature on A36 steel using shielded metal arc welding (SMAW) were evaluated through tensile, bend, and macrostructure tests. The tensile strength of specimens preheated to 50^{0}C was 550 MPa for material 1 and 551 MPa for material 2. In contrast, non-preheated specimens exhibited tensile strengths of 548 MPa and 547 MPa, respectively. Bend tests indicated that preheated specimens achieved larger bending angles without cracking, whereas non-preheated specimens developed small cracks or fractures before reaching the target angle. Macrostructure analysis revealed that preheated specimens had more uniform weld areas, while non-preheated specimens displayed defects such as porosity and uneven weld penetration. These results suggest that preheating low-carbon materials is an effective way to minimize weld defects and can inform best practices in welding processes.

References

[1] Setiyo Kuncoro, P., Anggono, I. A. D., & Aklis, I. N., 2025. *Tegangan sisa pada komponen las baja berkekuatan tinggi (HSS) dengan kombinasi pemanasan awal (preheating) dan perlakuan panas pasca pengelasan (PWHT)*. Universitas Muhammadiyah Surakarta.

[2] Ardi, A., Asri, M. H., & Mardin, M., 2024. *Analisis pengaruh variasi bentuk sambungan terhadap karakteristik mekanis baja karbon rendah hasil pengelasan SMAW dan GTAW.* Innovative: Journal Of Social Science Research, Vol. 4, No. 1, pp. 12201-12219.

[3] Muthia, H. M., Nugraha, I. G., & Hanafi, D. R., 2023. *Pengaruh jenis elektroda las SMAW terhadap sifat mekanik dan struktur mikro.* J. Pendidik. Tek. Mesin Undiksha, Vol. 11, No. 1, pp. 93-110.

[4] 岡戸順一, 艾斌, 巴山玉蓮, 櫻井尚子, 藤原佳典, & 星旦二, 2003. *主観的健康感を中心とした在宅高齢者における健康関連指標に関する共分散構造分析.* 総合都市研究, Vol. 81, pp. 19-30.

[5] Rifaldi, A., Ryadin, A. U., & Hakim, A. R., 2021. *Pengaruh suhu preheating terhadap kekuatan tarik dan kekerasan pelat baja ASTM A36 pada pengelasan shielded metal arc welding (SMAW).* Sigma Teknika, Vol. 4, No. 1, pp. 81-90.

[6] Koesgi, D. P.& Wicaksono, D., 2021. *Pengaruh pemanasan awal terhadap sifat mekanik sambungan spot friction stir welding dalam pemasangan rivet alumunium 2024.* Teknika STTKD: Jurnal Teknik, Elektronik, Engine, Vol. 7, No. 1, pp. 140-153.

[7] LAS SMAW, T. M.& NUGRAHA, M. R. *Pengaruh pre-heat pada pengelasan dissimilar antara baja karbon rendah dan.*

[8] Firmansyah, A. A., 2023. *Pengaruh variasi temperature pre-heat terhadap kekerasan rockwel dan struktur mikro pada pengelasan SMAW baja SS400.*

[9] Sudirman, S., 2023. *Pengaruh preheat terhadap kekuatan tarik, kekerasan dan NDT pada pengelasan SMAW posisi 3G*

menggunakan material API 2W grade 50 untuk pembuatan topside platform. Institut Teknologi Sepuluh Nopember.

[10] Nuraliansyah, E., 2022. *Pengaruh proses preheat dan postheat pada pengelasan gas metal arc welding (GMAW) baja AISI 1045.* Gorontalo Journal of Infrastructure and Science Engineering, Vol. 5, No. 2, pp. 59-72.

[11] Irfansyah, R. A., 2022. *Analisis pengaruh variasi preheating temperature pada hasil pengelasan baja ASTM A36 di atas permukaan air dengan proses SMAW terhadap weld defect, kekerasan, dan kekuatan tarik*. Institut Teknologi Sepuluh Nopember.

[12] Siregar, J. F., Ariyanto, N. P., & Irawan, B. H., 2023. *Destructive test material SA516 70n untuk kualifikasi pengelasan standar ASME bpvc sec. Ix-2021.* Jurnal Teknik Mesin, Vol. 16, No. 2, pp. 133-138.

[13] Rahman, G. F., Ariyanto, N. P., & Irawan, B. H., 2024. *Pengujian rusak untuk procedure qualification record sambungan kombinasi las SMAW-FCAW pada material BS en 10025 S355J2 berdasarkan standar AWS d1. 1/d1. 1m: 2020.* Jurnal Teknik Mesin, Vol. 17, No. 2, pp. 106-111.

[14] Irawan, B. H., Saputra, I., & Ardiyansyah, M., 2024. *Dampak nilai hardness berdasarkan parameter heat input pada proses pengelasan GTAW untuk material superduplex stainless steel S32750.* Jurnal Teknik Mesin, Vol. 17, No. 2, pp. 133-138.

[15] Irawan, B. H., Syahidah, B. B., & Gemala, M., 2025. *Heat input calculation in GTAW welding to obtain values according to PWPS.* Journal of Welding Technology, Vol. 7, No. 1.