FEASIBILITY ANALYSIS OF HALF BEAD TECHNIQUE TO REPLACE POST-WELD HEAT TREATMENT IN WELDING A335 GRADE P22 PIPES

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ABSTRACT: This work evaluates the feasibility of using the Temper Bead Welding (TBW) method with the Half Bead technique as an alternative to Post-Weld Heat Treatment (PWHT) for welding A335 Grade P22 pipes. Three treatment methods were compared: preheating, preheating with TBW, and preheating with PWHT. Hardness testing is carried out using the Vickers microhardness testing method. The only preheat method showed the highest hardness values in the HAZ (342 HV), fusion zone (357 HV), and weld metal (334 HV). TBW with the half bead technique had higher hardness only in the base metal (191 HV). PWHT provides the most uniform hardness distribution, effectively relieves residual stresses, and homogenizes the microstructure. TBW reduced HAZ size by 50% more than preheating. The microstructure observed in all methods was ferrite and pearlite, with differences mainly in grain size. Although TBW is a viable alternative for repair, this method is unsuitable for application in early fabrication processes.

KEY WORDS: TBW; Half Bead Technique; PWHT; Vickers hardness; microstructure.

1. INTRODUCTION

The mechanical components functioning under extreme temperature and stress conditions experience several degradation mechanisms that may result in material deterioration [1]. Creep is a term used to describe a material that deforms plastically as time goes on by changing its structures. Industrial design must be aware of the creep resistance of materials to prevent economic losses caused by component failure [2].

CrMo steels are commonly utilized in high-temperature structural applications, such as fossil fuel power plants and petrochemical industries, for boilers, pipes, and chemical reaction vessels [3-5]; the effectiveness of working under critical conditions is due to their excellent corrosion resistance, mechanical strength, and high temperability [6]. Steel structural components in power plants and oil refineries are frequently subjected to long-term loading at elevated temperatures. Microstructural degradation is the cause of mechanical properties such as tensile, creep strength, and toughness decreasing under elevated temperature and high pressure [3-5].

Temper and hydrogen embrittlement are the most common problems in steel used in power plants and petrochemical applications. Temper embrittlement occurs when the steel is exposed to temperatures between 340–565 °C. Impurities like phosphorus, sulfur, arsenic, tin, and antimony segregating at the grain boundary often lead to temper embrittlement in 2,25Cr-1Mo steel. The ductile-to-brittle transition temperature (DBTT) being shifted to higher temperatures is caused by temper embrittlement, which is a significant factor in the degradation of the toughness of ferritic steels. The embrittlement issue can be addressed by lowering phosphorus, sulfur, arsenic, tin, and antimony [7].

In power generation plants, components are exposed to creep due to operating temperatures around 600°C and constant stress conditions. Low alloy ferritic steels are commonly used for manufacturing boiler superheaters because of their low thermal expansion and high thermal conductivity. The material must maintain a stable microstructure to ensure proper equipment performance throughout its expected lifespan. While stability can typically be achieved for operating periods of around 100 hours, it becomes challenging when the service life extends beyond 200,000 hours, a standard duration in power plants[1].

2.25Cr-1Mo steels possess a stable microstructure with fine carbides that hinder dislocation movement. However, microstructural changes inevitably occur over extended service periods or under extreme conditions, reducing the material's resistance. These changes include carbide transformation, precipitation, decomposition of pearlite or bainite areas, alterations in carbide morphology, and variations in the matrix's chemical composition. The nature of these changes is primarily influenced by the steel's chemical composition, prior treatment, and operating conditions such as temperature and stress [1].

Appropriate heat treatments mitigate issues affecting 2.25Cr-1Mo steels at elevated temperatures. Key factors such as chemical composition and cooling rate are crucial in achieving an optimal microstructure, enhancing mechanical properties like tensile strength and hardness [6].

Welding is widely used in steel fabrication and repairing defective weld joints. It offers several advantages over other joining methods, such as permanently bonding complex shapes and welding thin materials. However, welding imperfections can occur in existing weldments due to various factors. According to the American Society of Mechanical Engineers (ASME), the causes of these imperfections are attributed to 41% poor process conditions, 32% operator errors, 12% incorrect techniques, 10% unsuitable consumables, and 5% improperly prepared weld grooves [8].

Residual stresses are internal stresses that remain within a material after manufacturing, processing, heat treatment, or welding, even without external forces or thermal gradients [9]. Understanding the magnitude and nature of these stresses is essential for assessing the structural integrity, as tensile residual stresses on surfaces are undesirable. Tensile residual stress can negatively impact the operational performance of engineering components [10]. Residual stresses can cause issues immediately or over a welded structure's lifespan and must be minimized or eliminated to prevent relaxation during service [11-12]. When tensile residual stresses surpass a material's yield strength, it deforms, leading to a distorted structure [11,13]. Moreover, residual stresses can be additive to operating stresses, contributing to crack initiation and enhancing the driving force for crack propagation, even without external stresses [14]. As a result, the steel requires a strict welding process and a thorough post-weld heat treatment (PWHT) procedure [15].

PWHT is a recovery heat treatment applied after welding, typically recommended right after welding to enhance the weldment's properties [8]. Its primary goal is to refine the microstructure and properties of the welded joint, soften the hardened areas, and improve toughness and long-term creep resistance [15]. PWHT can relieve or eliminate welding stresses, prevent the formation and spread of delayed cracks, and enhance the welded joint's service reliability and service life [15]. PWHT consists of reheating a weld to a temperature below the lower transformation point at a controlled rate, maintaining that temperature for a set duration, and then cooling it at a controlled rate [8]. Welded joints are typically subjected to PWHT, which is a tempering process to enhance the creep strength of the joint by postponing the formation of type IV cracks. [16-18]. Specifically, the tempering PWHT increases the number of particles in the fine-grained area of the heat-affected zone (HAZ) compared to the coarser regions [16-18].

Although PWHT is the standard method for relieving residual stresses, it is highly costly and time-consuming due to the typically long holding times at the PWHT temperature, the slow ramp-up and ramp-down rates required, and the significant downtime expenses [19]. Various alternative methods have been developed for repair without PWHT, ranging from traditional buttering to the half-bead technique and, later, the two-layer approach [20].

The temper bead welding technique is commonly employed to enhance weld properties, serving as an alternative to the PWHT process. It involves placing weld beads at specific points on the weld or weld surface to influence the metallurgical properties of the HAZ and the deposits of each preceding weld [21]. In the half-bead technique, as the name implies, half of the initial buttering layer is ground off before applying a second layer. It is done to ensure that the HAZ of the first layer is reheated by the second layer, with the goal of re-austenitizing and refining it or, at the very least, tempering any complex, brittle microstructures [20]. The disadvantages of this method include the challenge of controlling the grinding depth and the additional time the grinding process is added to the repair procedure [20].

This work aims to analyze the feasibility of the Half Bead Technique in replacing PWHT in welding A335 grade P22 pipes on the microstructure and their mechanical properties. The welding method is divided into three methods: Preheat, Preheat TBW, and Preheat PWHT, with the testing method carried out namely microstructure and hardness testing (microhardness Vickers). This is done to determine how much influence TBW has on replacing the PWHT method.

2. RESEARCH METHODS

This work falls under the category of experimental research. It follows a comprehensive process, beginning with preparation before the experiment and continuing through the analysis of the results, ensuring that the data gathered can support objective analysis. In this work, the variables used comply with relevant standards, ensuring that the results are reliable and can be justified.

Welding can be defined as the partial melting of two materials using heat to join them, whether or not filler metal is added during the welding process [22]. Welding joints require high welder skills, and the process refers to the WPS and PQR issued by the Welding Engineer to obtain quality joints.

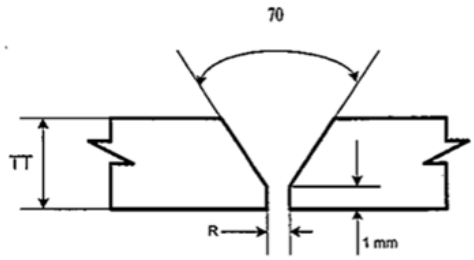
For the welding, A335 Gr. P22 schedule 120 seamless pipes were chosen. As a filler material, Filler metal TGS-2CM with a diameter of 2.4 mm and length of 100cm was used. Table 1 shows the chemical composition of the A335 Gr. P22 steel and electrodes. Furthermore, Table 2 shows the mechanical properties of the used materials.

Table 1: Chemical composition of used materials wt.%

Materials	C	Si	Mn	P	S	Cr	Mo	Ni
Pipe A335 Gr. P22	0.135	0.235	0.47	0.012	0.005	2.185	0.93	0.08
Filler Metal TGS-2CM (ER90S-G)	0.11	0.36	0.75	0.004	0.008	2.29	1.07	0.05

Table 2. Mechanical properties of used materials

Materials	Yield Strength (Mpa)	Tensile Strength (Mpa)	Elongation (%)
Pipe A335 Gr. P22	205	415	20
Filler Metal TGS-2CM (ER90S-G)	610	720	28



TT (mm)	4	6	More than 10
R (mm)	2.0	2.5	3.0

Fig. 1. Groove design

Preparation of materials (test coupon): In this study, the material used is seamless ferritic alloy steel pipe ASTM A335 Gr. P22, size 5 inch, and SCH 120. The pipe was cut into six pieces with a length of 125 mm and continued with the manufacture of a bevel using a lathe on one side of the pipe with an angle of 35° and a single V groove design.

The fitter tack-welded two pipes and checked the flatness between them, root opening, and root face dimension according to the welding parameters. In the preheating process, continuous heating is carried out so that the Ceramic Heater and Ceramic Fiber (Kaowool) are installed 10 cm from the welding area, continuously supplied with heat, and controlled using a temperature controller.

Fig. 2. Welding preparation

The welding procedure was executed utilizing the GTAW method. TGS-2CM filler metal (2.4 x 100 mm L) and 99.99% UHP pure argon gas are used in the GTAW welding procedure. The welding parameters in this work can be seen in the Table 3:

Table 3. Welding process parameters

	Joints	
1	Joint Design	Butt Joint
2	Type	Single V
3	Backing	No
4	Grooving Angle	70°
5	Gouging	NA
6	Back Weld	No
	Base Metal	
1	Plate Thickness	12,7mm
2	Type Grade	A335 Gr. P22
3	Plate Thickness Range	1,6 – 11,12mm
4	Preheat Temperature	200 - 350°C
5	Interpass Temperature	350°C max
6	PWHT	725°C
	Position	
1	Position	5G
	Filler Metal	
1	ASW Clasification	ER 90S-G
	Electrical Characteristic	
1	Type of Polarity	DCSP
2	Ampere Range	120-220 A
3	Voltage Range	10-13 V
4	Travel Speed Range	30-80 mm/min
	Shielding	
1	Gas	Argon UHP 99,99%

2.1. Preheat

No post-welding heat treatment is performed (only in preheat). Preheat temperature is in the range of 200-350°C. Interpass temperature is a maximum of 350°C. If the temperature measurement when stopping welding shows a temperature above 350°C (interpass), it will be left until it is below 350°C. Welding starts from the root pass, hot pass, and capping and then cools in the open air.

2.2. Preheat, PWHT

Post-welding heat treatment (PWHT) is performed. Preheat temperature is in the range of 200-350°C. Interpass temperature is a maximum of 350°C; if the temperature measurement when stopping welding shows a temperature above 350°C (interpass), it will be left until it is below 350°C. Welding starts from the root pass and hot pass to capping, then continues by wrapping the welded area using a ceramic heater and fiber. PWHT is carried out according to the chart listed in the WPS and PQR.

2.3. Preheat, TBW

No post-welding heat treatment is performed, but heat treatment is performed during welding (TBW). Preheat temperature is in the range of 200-350°C. Interpass temperature is a maximum of 350°C; if the temperature measurement when stopping welding shows a temperature above 350°C (interpass), it will be left until it is below 350°C. Welding starts from the root pass and hot pass as much as one layer. Continued with the TBW procedure by welding without shaking the welding rod; each welding layer is ground by as much as 50%. The last step is capping welding, which is cooled in the open air.

3. RESULT AND DISCUSSION

The welding process refers to WPS & PQR, which the welding engineer issues to obtain quality joints. The welder's skill also dramatically influences the welding process. Several tests are carried out to determine the mechanical properties and microstructure.

3.1. Welding Parameters

The welding process is carried out by a continuous heating method. During the welding process, ceramic fiber and ceramic heaters are installed and heated below the maximum limit of the interpass temperature but not lower than the minimum preheat temperature. Tables 4, 5, and 6 show the welding parameters used in each process.

Table 4. Preheat welding parameters

Weld Layer	Filler Metal	Current (Ampere)	Voltage (Volt)
Root pass	TGS-2CM	110	13,3
Hot pass:			
Layer 1	TGS-2CM	160	14,5
Layer 2	TGS-2CM	190	16,9
Layer 3	TGS-2CM	190	16,9
Capping	TGS-2CM	176	15,4

Table 5. Preheat, PWHT welding parameters

Weld Layer	Filler Metal	Current (Ampere)	Voltage (Volt)
Root pass	TGS-2CM	110	13,1
Hot pass:			
Layer 1	TGS-2CM	150	14,4
Layer 2	TGS-2CM	170	15,0
Layer 3	TGS-2CM	185	16,1
Capping	TGS-2CM	176	15,5

Table 6. Preheat, TBW welding parameters

Weld Layer	Filler Metal	Current (Ampere)	Voltage (Volt)
Root pass	TGS-2CM	110	13,3
Hot pass:			
Layer 1	TGS-2CM	160	14,5
Layer 2	TGS-2CM	190	16,9
Layer 3	TGS-2CM	190	16,9
Capping	TGS-2CM	176	16,6

3.2. Metallography

Metallography is a scientific subject that investigates the microstructural characteristics of metals, metal alloys, and other materials, which are closely related to the properties of these materials. Metallography is a technique used to prepare examination materials to assess quantitative and qualitative details, such as phases, grain structure, chemical composition, grain orientation, atomic distances, dislocations, and more [23]. Microetching metals and alloys for microscopic examination Fe + C and Fe + <1C + <4% additions can use Nital (nitric acid + alcohol) or picral (picric acid + alcohol) [24].

The initial solution is utilized with 1–5 mL HNO_3 and 100 mL ethanol (95%) or methanol (95%). An increased percentage of HNO3 increases the etching rate and decreases sensitivity. Immerse for a few seconds to a minute for etching. The etching time was 3 seconds. The metal surface will burn and char if the etching time is too long. The etching experiment was repeated several times until the right etching time was obtained.

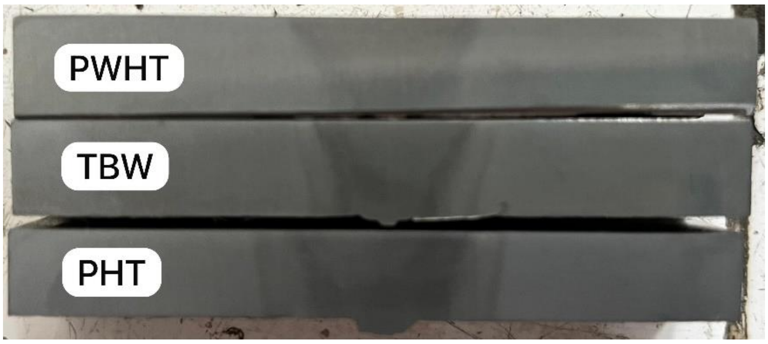


Fig. 3. Metallography and Vickers microhardness specimens

Refer to Figure 3, the test specimen is divided into several areas: weld metal, fusion zone, HAZ, and base metal. These areas have microstructures, grain sizes, and hardnesses that vary according to the amount of heat input into the metal.

1. The HAZ area for specimens that only used the preheating method is larger than for specimens that used the other two methods.
2. Specimens subjected to the preheat and temper bead welding methods (half bead technique) had a smaller HAZ area than those subjected to only preheat.
3. Stress was relieved in specimens subjected to the preheat and post-weld heat treatment methods, and there was no longer a HAZ area.

3.2.1. Microstructure of Base Material

Overall, the grain size in the base metal area of the three welding methods is uniform, which indicates that the hardness values in the three methods are relatively the same or close. The microstructure formed is a ferrite structure dominated by a pearlite structure. The grain boundaries are visible, and there are few carbides at the grain boundaries. Carbide formation at grain boundaries is a phenomenon that occurs when carbon is fused into the grain boundary area and interacts with certain metal elements to form complex carbide compounds. This phenomenon affects the material's mechanical properties, including hardness, wear resistance, and toughness, depending on the composition and condition of the material.

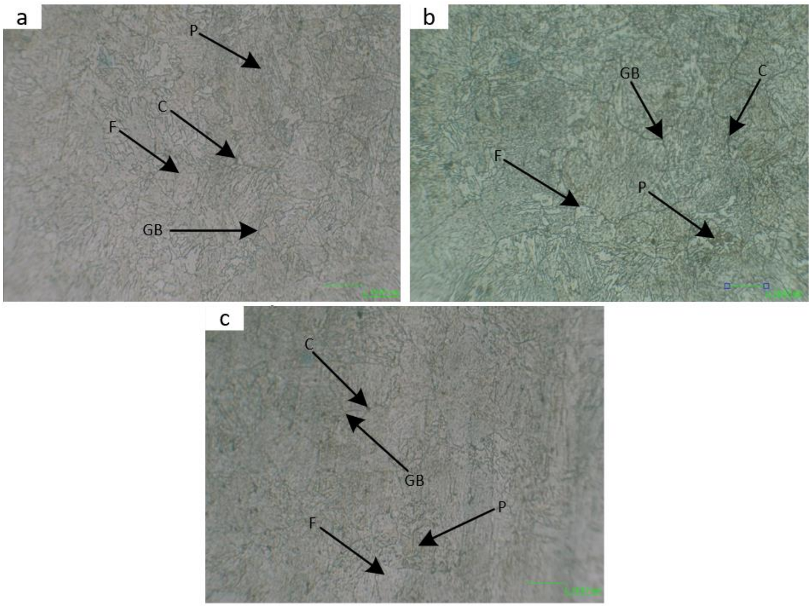


Fig. 4. Microstructure of the specimens with initial etching of base metal. (a) preheat, (b) preheat TBW, (c) preheat PWHT

3.2.2. Microstructure of HAZ

The grain size is relatively the same in the three welding methods, and the difference is in the preheat and preheat TBW welding methods; pearlite is more dominant than ferrite. However, in the preheat TBW method, the number of ferrite structures is slightly more than in the preheat method. Meanwhile, in the preheat PWHT welding method, ferrite is more dominant than pearlite. The HAZ area in the preheat PWHT welding method is no longer there because the stress in the HAZ area has been released by the PWHT method, but testing is carried out to see the microstructure formed in the area.

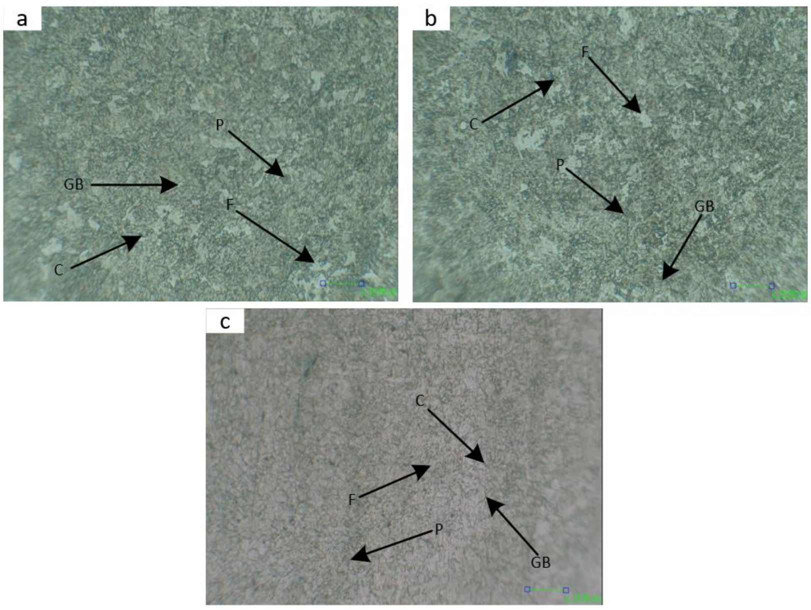


Fig 5. Microstructure of the specimens with initial etching of HAZ. (a) preheat, (b) preheat TBW, (c) preheat PWHT

3.2.3. Microstructure of Fusion Zone

In the three welding methods, the grain size in the preheating method is the most minor compared to other welding methods, and the pearlite structure is more dominant than the ferrite structure. Similar to the HAZ area, in the TBW preheat welding method, pearlite is more dominant than ferrite. However, the amount of ferrite structure is slightly more than that in the preheating method. In the PWHT preheat welding method, the dominant structure is the ferrite structure, but the distribution between ferrite and pearlite is uneven.

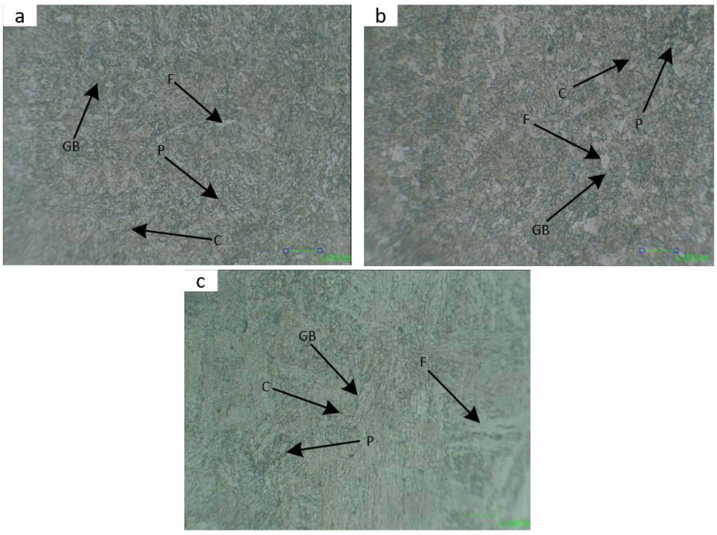


Fig. 6. Microstructure of the specimens with initial etching of fusion zone. (a) preheat, (b) preheat TBW, (c) preheat PWHT

3.2.4. Microstructure of Weld Material

The grain size in the preheating method is significant in the three welding methods, and both ferrite and pearlite structures are present. However, there is a cementite structure in the weld metal area. In TBW preheat welding, as in the HAZ and fusion zone areas, the pearlite structure is more dominant than the ferrite structure. In the PWHT preheat welding method, the dominant structure is the ferrite structure, and there is a little pearlite structure.

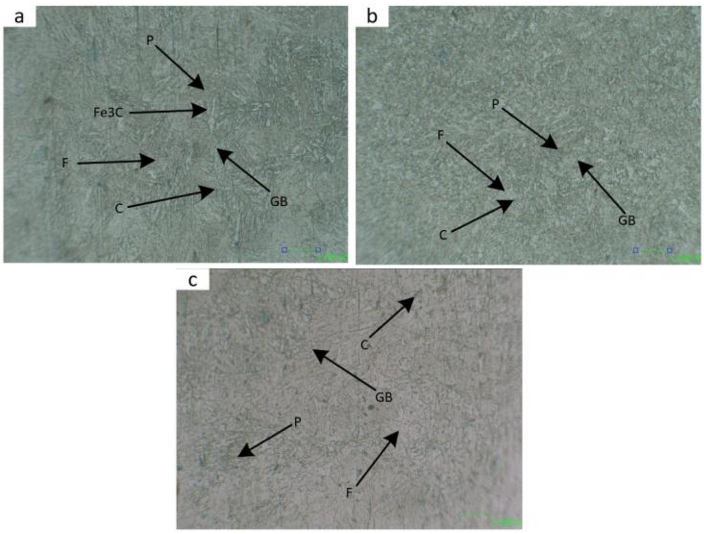


Fig. 7. Microstructure of the specimens with initial etching of weld metal. (a) preheat, (b) preheat TBW, (c) preheat PWHT

3.2.5. Vickers Microhardness

Vickers microhardness (Hv) is a standard test that uses a Vickers diamond indenter to measure the hardness of materials [23]. The basic principle of the microhardness test is applying a force via a diamond indenter that results in an indentation on the surface of the specimen. The indentation's force and area determine Hv [25].

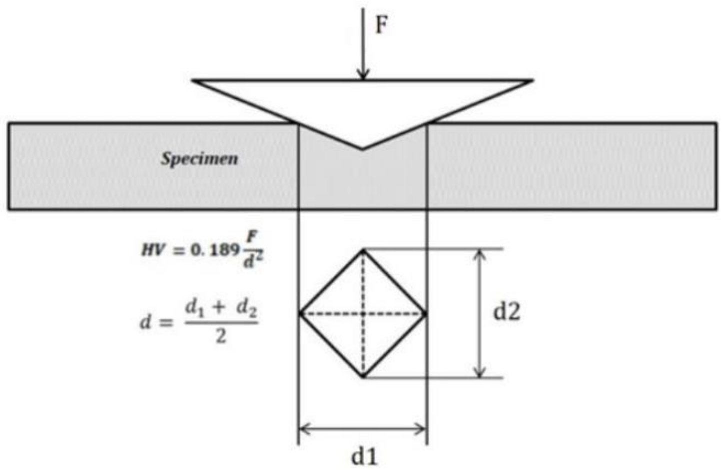


Fig. 8. Indentation and formula of Vickers microhardness (HV)

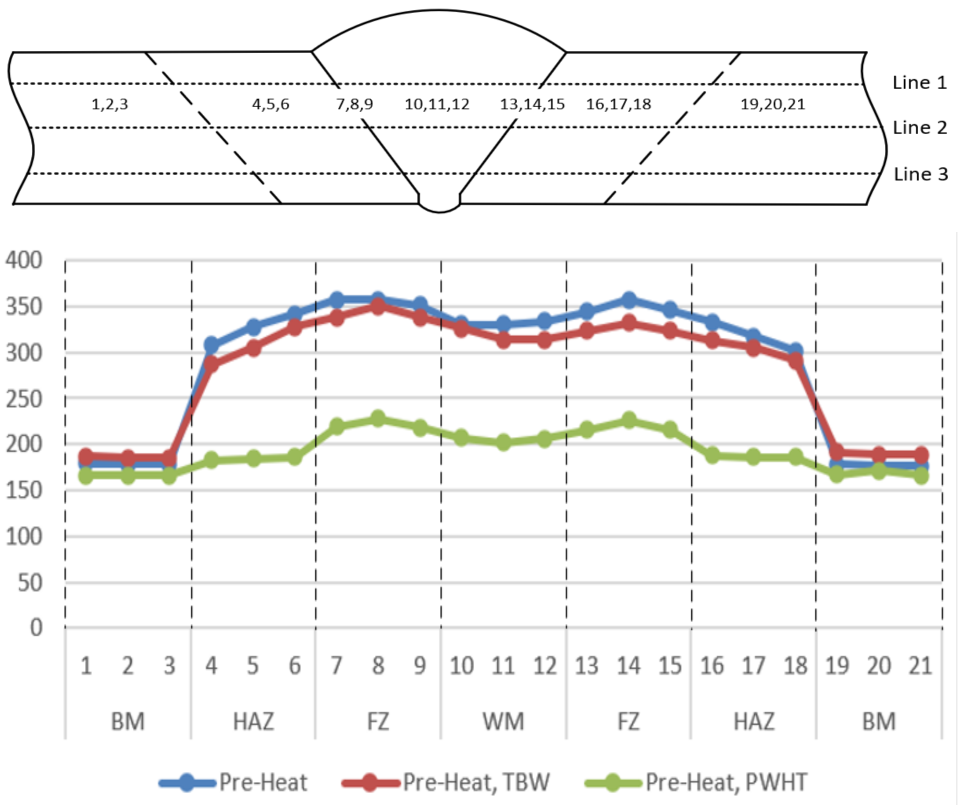


Fig. 9. Vickers microhardness average hardness number chart

Different welding methods produce varying hardness distributions across a wide area based on the average hardness value data obtained. The welding method that only uses preheating shows hardness values in the base metal (179 HV), HAZ (342 HV), fusion zone

(357 HV), and weld metal (334 HV). The welding method that uses preheating and TBW shows hardness values in the base metal (191 HV), HAZ (328 HV), fusion zone (350 HV), and weld metal (326 HV). The welding method that uses preheating and PWHT shows relatively stable hardness values starting from the base metal (171 HV), HAZ (188 HV), fusion zone (228 HV), and weld metal (207 HV). The welding method that only uses preheating has the highest hardness values in 3 areas: the HAZ at 342 HV, the fusion zone at 357 HV, and weld metal at 334 HV. It indicates significant thermal stress and microstructural changes due to rapid cooling after welding. In the method combining preheat and TBW with the half bead technique, the hardness value tends to be higher only in the base metal at 191 HV. Although the TBW method improves hardness distribution, it does not fully replace the effectiveness of post-weld heat treatment (PWHT).

Meanwhile, the method involving preheating followed by PWHT demonstrates a more uniform hardness distribution across all areas, including the base metal, HAZ, fusion zone, and weld metal. This proves PWHT's ability to relieve residual stresses and enhance microstructural uniformity. Overall, the TBW method is more suitable for weld repair processes, particularly for smaller thicknesses and limited welding areas, as the resulting HAZ size tends to be smaller.

4. CONCLUSION

The feasibility analysis of TBW (Half Bead Technique) as an alternative to PWHT in welding A335 Grade P22 pipe revealed significant findings related to mechanical properties, hardness, and microstructural evolution. While TBW shows promise as a repair method for thinner sections and localized weld areas, it cannot fully replicate the benefits of PWHT. Specifically, PWHT proved more effective in relieving residual stresses, homogenizing the microstructure, and ensuring uniform hardness distribution across the base metal, HAZ, fusion zone, and weld metal. TBW produced slightly lower hardness values and a 50% smaller HAZ area than preheat, making it a practical option for weld repair applications with specific conditions and repairs. However, its limitations in stress relief and microstructural refinement indicate that PWHT remains essential to ensure long-term performance and compliance of critical weld joints in high-temperature and high-pressure environments. Future research should focus on optimizing TBW parameters to improve its effectiveness and explore its potential in specific industrial applications.

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