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# Effect of PWHT on Mechanical Properties of High Temperature and Pressure Resistant Nuclear Power Plant Steel Welded with SMAW and GTAW Methods

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***Abstract***

This research aims at effect of Post Welding Heat Treatment (PWHT) on mechanical properties of 2.25Cr1Mo (P22) high temperature and pressure resistant nuclear power plant steel welded with GTAW (gas tungsten arc welding) and SMAW (shielded metal arc welding). Pre-heating was applied to the materials to be welded at 200°C before welding processes. Welding processes of materials were performed at room temperature. After welding processes, post weld heat treatment (PWHT) was applied at 750ºC for 2 hours. Before and after the PWHT, welded materials were prepared in accordance with EN standards for tensile, bending, impact, hardness tests and macrostructure examinations for the investigation of mechanical properties.

***Keywords:*** PWHT, Preheating, 2.25 Cr1Mo Steel, GTAW, SMAW.

# SMAW ve GTAW Metotları ile Kaynaklanmış Yüksek Sıcaklık ve Basınç Dirençli Nükleer Enerji Santrali Çeliğinin Mekanik Özelliklerine Kaynak Sonrası Isıl İşleminin Etkisi

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***Öz***

Bu çalışma, GTAW (gaz tungsten ark kaynağı) ve SMAW (elektrik ark kaynağı) ile kaynaklanmış 2.25Cr1Mo (P22) yüksek sıcaklık ve basınca dayanıklı nükleer santral çeliğinin mekanik özellikleri üzerine Kaynak Sonrası Isıl İşleminin (PWHT) etkisini araştırmayı amaçlamaktadır. Kaynak işlemlerinden önce kaynak yapılacak malzemelere 200 °C' de ön ısıtma uygulanmıştır. Malzemelerin kaynak işlemleri oda sıcaklığında gerçekleştirilmiştir. Kaynak işlemlerinden sonra kaynak sonrası ısıl işlem (PWHT) 2 saat süreyle 750 °C' de uygulanmıştır. PWHT'den önce ve sonra, EN standartlarına göre hazırlanan kaynaklı malzemelerin, mekanik özelliklerin incelenmesi için, çekme, eğme, darbe, sertlik testleri ve makro yapı testleri uygulanmıştır.

***Anahtar Kelimeler:*** PWHT, Ön ısıtma, 2.25 Cr1Mo Çeliği, GTAW, SMAW.

## 1. INTRODUCTION

High temperature, pressure, creep and corrosion resistant 2.25Cr1Mo steel can be used for a long time at construction of thermal and nuclear generation, chemical and petroleum plants [1].

The original microstructure of typical 2.25Cr1Mo consist of ferrite and small amounts of pearlite and martensite. This microstructure is located at Figure 1. On the other hand, it can have different microstructure due to different heat

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treatments [2]. (For example: preheat or postheat welding heat treatments).

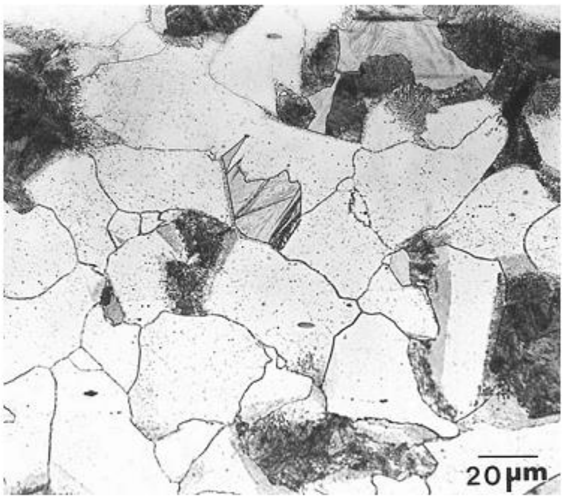



**Figure 1.** Original Microstructure of 2.25Cr1Mo [2]

Preheating operation is very important prior to welding for this type steels. This process provides thermal energy to the regions surrounding the weld resulting in slower conduction of welding heat away from the weldment. Preheat also provides practical benefits such as decreasing the amount of atmospheric water vapour condensation on a work piece before welding. Moreover, if it is carried out over the ambient temperature over a long period of time, it also results in more hydrogen effusion from the weldment with a corresponding decrease in hydrogen-cracking sensitivity [3].

In this study, two types of welding methods are applied on 2.25Cr1Mo steel plates. One of these method is SMAW. This method is a common method used in the welding of 2.25Cr1Mo steel. SMAW uses heat produced by an electric arc to melt a covered electrode and the welding joint at the base metal. During operation, the rod core both conduct electric current to produce the arc and provides filler metal for the joint. The core of the covered electrode consists of either a solid metal rod of drawn or cast material or a solid metal rod fabricated by encasing metal powders in a metallic sheath [4]. Schematic SMAW process shown in Figure 2.

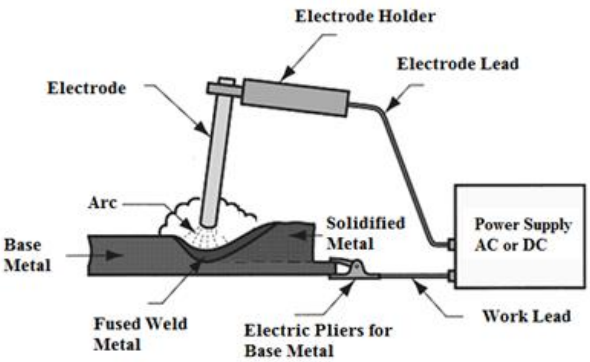



**Figure 2.** Schematic SMAW Process [5]

The other welding method is GTAW. This method involves striking an arc between a non-consumable tungsten electrode and the work piece. The weld pool and the electrode are protected by an inert gas, usually argon, supplied through a gas cup at the end of the welding torch, in which the electrode is centrally poisoned. GTAW is used for applications such as joining pipes and welding of tubes in to the end plates of heat exchangers [6]. Schematic GTAW process shown in Figure 3.

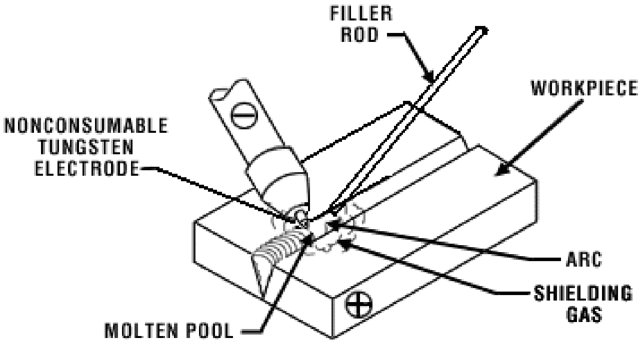



**Figure 3.** Schematic GTAW Process [7]

The ASME Boiler and Pressure Vessel Code requires a post weld heat treatment (PWHT) for welded P22 steel. Residual stresses that occur during welding adversely affect the performance of welded joints. The remaining stresses can be reduced by post-weld heat treatment (PWHT) [8]. Post weld heat treatment (PWHT) is a technique for improving the properties of weldments by subjecting them to a homogenizing heat treatment [3]. The most important feature of post weld heat treatment is to prevent brittle fracture of welded joint. Post-weld heat treatment softens the hardened areas and facilitates machining of the welded material. Where dimensional stability is important, residual stresses must be eliminated. Heat treatment can be applied by stress relieving annealing or solution annealing processes depending on the requirements [9].

## 2. MATERIAL AND METHOD

In this study, two different welding methods were applied for joining 2.25Cr1Mo steel. The chemical analysis results obtained by optical emission spectrometry are shown in Table 1.

**Table 1.** Chemical composition of 2.25Cr1Mo steel

| | | | | |
|---|---|---|---|---|
| **2.25Cr1Mo (P22)** | **% C** | **% Si** | **% Mn** | **% P** |
| | 0,09 | 0,38 | 0,34 | 0,02 |
| | **% S** | **% Cu** | **% Cr** | **% Mo** |
| | 0,02 | 0,01 | 2,31 | 0,99 |

According to the results of the chemical analysis, after understanding that this material is P22 (normalized: 970°C for 30 min. then tempered:700°C for 32 min. and cooled in air), 4 plates were cut from this steel in size 275 mm x 225 mm x 16 mm, for use in welding operations. “V” type welding groove was prepared to materials for both welding methods. Schematic welding mouth shown in Figure 4.

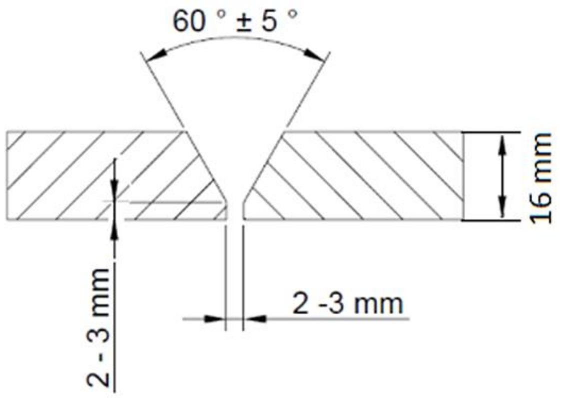
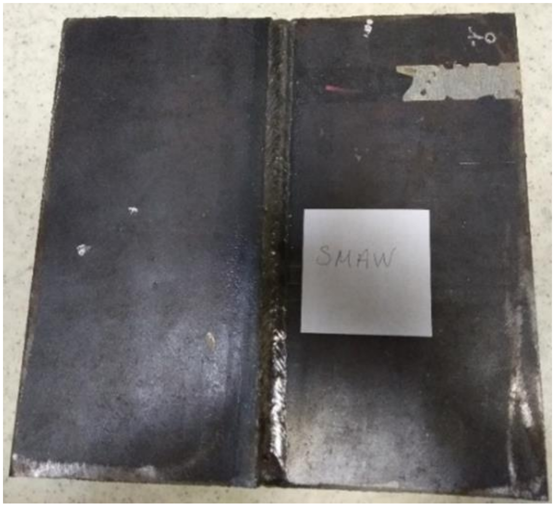



**Figure 4.** Schematic welding mouth

All of the welding processes were carried out by EN 9606-1 certified welders and specimens were preheated at 200 ºC with gaseous fuel before welding considering carbon equivalent ($C_{eq}$) value. 16 mm thick plates were used for welding processes. This plates are shown in Figure 5.



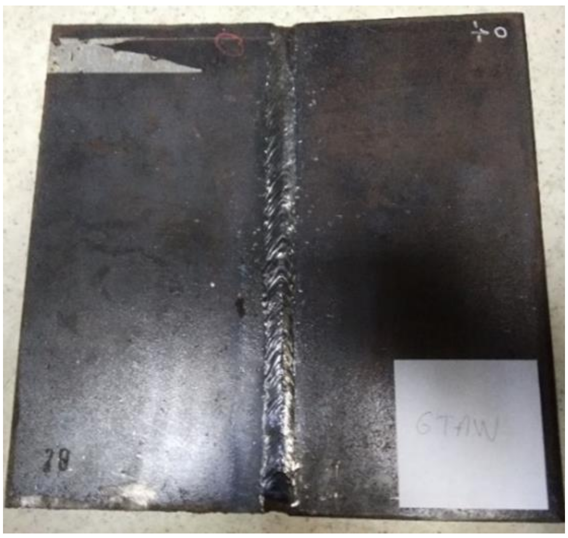




**Figure 5.** Welded plates with SMAW and GTAW

The parameters used in performing welding operations are shown in Table 2.

**Table 2.** Welding Parameters

| 2.25Cr1Mo (P22) | GTAW | SMAW |
|---|---|---|
| **Voltage (V)** | 15 | 15 |
| **Current (A)** | 120 | 120 |
| **Travel speed (mm/min.)** | 80 | 100 |
| **Polarity** | DC Straigth | DC Straigth |
| **Heat input (kj/mm)** | 1,35 | 1,08 |

The heat input, a relative measure of energy, is calculated according to the unit length of the weld seam [10]. For calculating the heat input which is one of these parameters, the following formula is used.

$$H = \frac{60xExI}{1000xS} \quad (1)$$

H = heat input (kJ/mm), E = arc voltage (V), I = current (A), S = travel speed (mm/min)

For GTAW process, "Phoenix SH Chromo 2 KS" covered electrode and for SMAW process, "Union I CrMo 910" filler rod was used. Their chemical analysis is shown in Table 3 and Table 4.

**Table 3.** Chemical Analysis of Covered Electrode for SMAW Process

| Phoenix SH Chromo 2 KS (EN ISO 3580-A) | | | | |
|---|---|---|---|---|
| **% C** | **% Si** | **% Mn** | **% P** | **% Cr** |
| 0,07 | 0,25 | 0,70 | ≤0,012 | 2,20 |
| **% Mo** | **% As** | **% Sb** | **% Sn** | **% S** |
| 0,90 | ≤0,010 | ≤0,005 | ≤0,005 | ≤0,010 |

**Table 4.** Chemical Analysis of Filler Rod for GTAW Process

| Union I CrMo 910 (EN ISO 21952-A) | | | | |
|---|---|---|---|---|
| **% C** | **% Si** | **% Mn** | **% Cr** | **% Mo** |
| 0.07 | 0.25 | 0.70 | 2.20 | 0.90 |

After welding processes, the welded plates are divided into two equal parts perpendicular to the weld seam. One of these pieces was later used for PWHT. The PWHT process was carried out at 750 °C for 2 hours to welded plates. After this process, the welded samples were allowed to cool at room temperature. Mechanical test specimens were then prepared from welded plates to identify differences before and after PWHT. All samples were prepared in accordance with EN standards for tensile (EN 4136) [11], bending (EN 5173) [12], impact (EN 9016) [13], hardness (EN 9015-1) [14] and macrostructure (EN 17639) [15] examinations. All the experiments in this study were performed at room temperature.

After the welding operations, the samples were prepared for macroscopic etude according to EN 17639. Samples cut in parallel with the bottom surface and the upper surface were etched with Nital 10 (10% HNO3 + 90% ethyl alcohol) after the sanding and polishing operations were completed. In this way, the structure of the weld seam has been uncovered and made ready for hardness testing and visual inspection. Macroscopic structures of welded samples are shown in Figure 6 and 7.

**Figure 6.** Macro photo of welded sample with SMAW

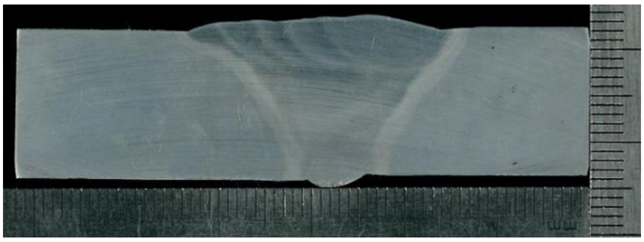


**Figure 7.** Macro photo of welded sample with GTAW

Tensile tests were carried out according to EN 4136 standard and the schematic drawing of tensile test specimen is given in Figure 8. below.

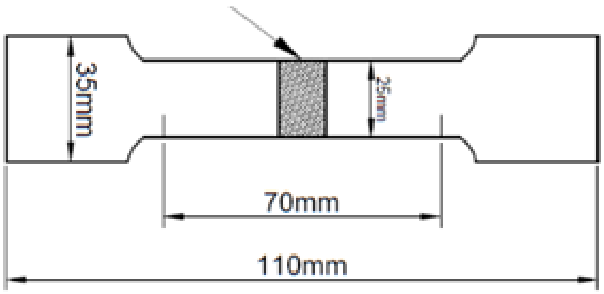



**Figure 8.** Schematic Tensile test specimen according to EN 4136 standard [16]

The deformation rate values which should be used for tensile test are explained by different methods and the underlying formula is used [17].

Cross head speed/Gauge Length of the Specimen = Strain Rate (2)

According to the formula; When 1 mm / min speed and 70 mm test specimen were used, the rate of deformation was calculated as 0,014.

It was found that the tensile strengths of steels both GTAW and SMAW welded, decreased after PWHT. Also, for all the samples, the rupture occurred from the base material. Tensile test results are shown in Table 5 and test specimens after tensile tests shown in Figure 9.

**Figure 9.** Test specimens after tensile tests

**Table 5.** Tensile test results of samples

| **Welding Method** | **Before PWHT** | | |
|---|---|---|---|
| | **Tensile Str. ($N/mm^2$)** | **Elongation (%)** | **Rupture Zone** |
| **GTAW** | 750 | 15 | Base Metal |
| **SMAW** | 680 | 16 | Base Metal |
| | **After PWHT** | | |
| **GTAW** | 632 | 17 | Base Metal |
| **SMAW** | 597 | 20 | Base Metal |

According to EN 5173 standard, if the welding wall thickness is more than 12 mm, side bending test should be applied to the sample. Therefore, side bending test was applied to the welded samples. For each welding method, two samples were tested before and after PWHT. In both welding methods, no samples were damaged in the side bending tests. Test specimens after bending tests shown in Figure10.

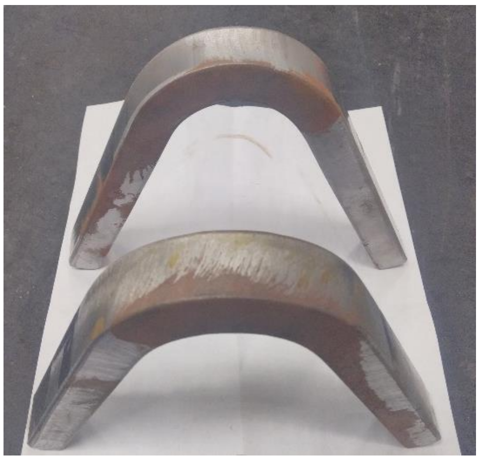


**Figure 10.** Test specimens after bending tests

The hardness tests were measured by the Vickers method using a load of 30 kg. Three measurements in two rows were made from each of the base metal, HAZ and weld metal. Then, the averages of each are calculated. A schematic illustration showing how the hardness measurement is performed according to the EN 9015-1 standard is shown in Figure 11. also hardness test results are shown in Figure 12.

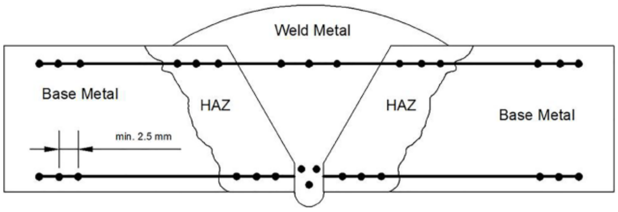



**Figure 11.** Schematic hardness measurement of welded material according to EN 9015-1 standard [16]

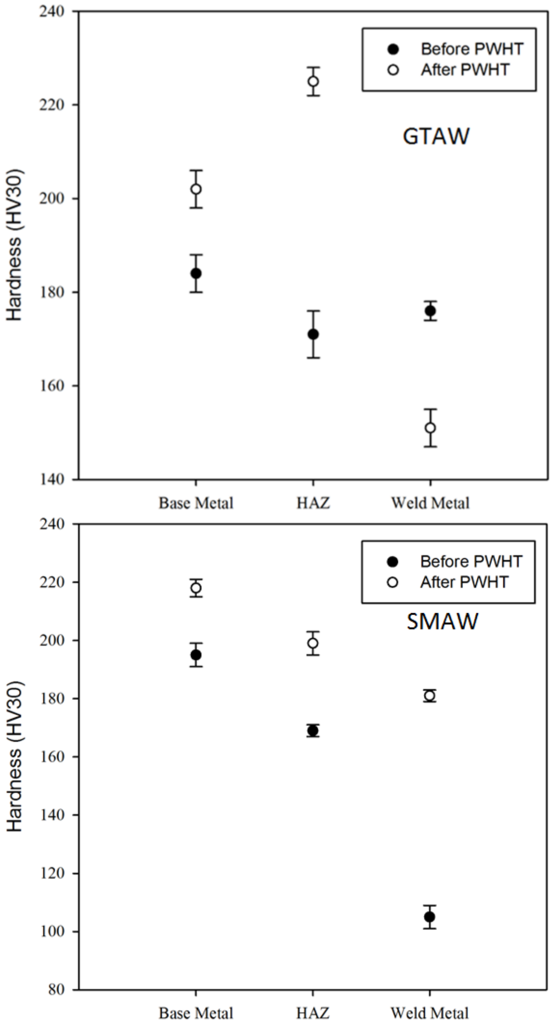



**Figure 12.** Hardness test results of welded samples with GTAW and SMAW

A Charpy Impact Test was applied to detect fracture energies of the samples. As in the hardness tests, 3 tests were performed for each region and the averages between them were calculated. A schematic illustration showing how the samples taken from the welded plates for Charphy Impact Test according to the EN 9016 standard is shown in Figure 13, also Charphy Impact Test results are shown in Figure 15.

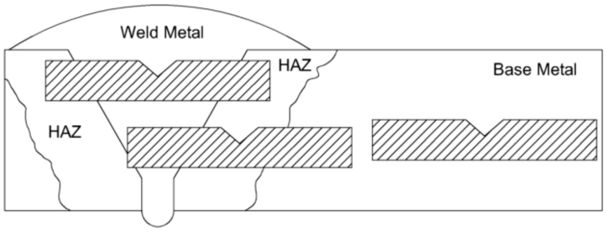



**Figure 13.** Notch locations according to EN 9016 standard

As a result of the Charpy Impact Tests, it was observed that the samples were fractured brittle. This situation shown in Figure 14.

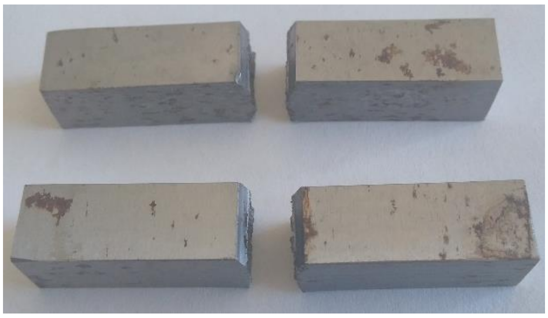


**Figure 14.** Test specimens after impact tests

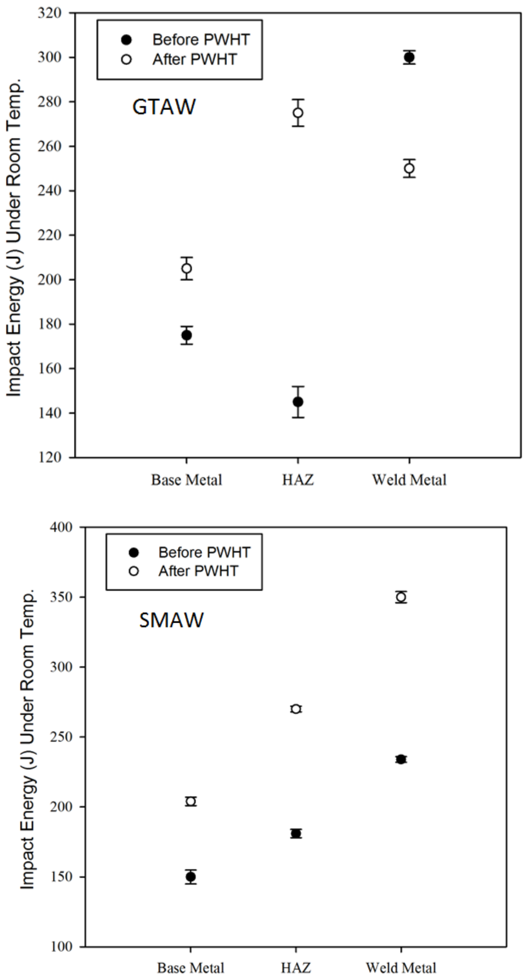



**Figure 15.** Impact energies of welded samples with GTAW and SMAW

## 3. RESULTS

The effects on the mechanical properties of the PWHT process applied to the welded materials are listed in the bottom.

Tensile strengths of steels both GTAW and SMAW welded, decreased after PWHT. It is stated in the literature that, 2.25Cr1Mo steel of 16 mm or thicker should have a tensile strength value of 480 to 630 N/mm$^2$ and a minimum elongation of 20%.

- Accordingly, it was revealed that the sample bearing both properties was the SMAW welded sample.

- In both welding methods, bend tests performed before and after the PWHT, no sample was damaged.

- When the hardness test results were examined; it was found that the hardness of the sample welded with GTAW, welded region and the base material region increased and the HAZ region decreased after the PWHT. On the other hand, in the case of the sample welded with SMAW, the hardness of all three regions decreased.

- When the Charphy Impact Test results were examined; it was found that the impact energy of the sample welded with GTAW, welded region decreased, base material region and HAZ region increased after the PWHT. On the other hand, in the case of the sample welded with SMAW, the impact energy of all three regions increased.

- After PWHT, the mechanical properties of the materials combined with both welding methods have changed positively. However, the mechanical properties of the welded materials before PWHT have also changed positively. For this reason, the implementation of the PWHT has not seemed to be necessary.

## 4. CONCLUSION

After PWHT process, tensile strengths of both steels welded with GTAW and SMAW, were decreased. In terms of tensile strength and minimum elongation, it was seen that the most compatible results with the literature were obtained from welded samples with SMAW. Looking at the results of the bend tests, no sample was damaged performed before and after the PWHT. According to the hardness values of welded samples measured before and after PWHT; After the PWHT, the hardness values of SMAW welded sample, HAZ, welded region and base region were observed to decrease. On the other hand, after PWHT, the hardness increase in the welded region and the base region of the GTAW welded sample and the hardness decrease in HAZ were detected. According to the Charpy impact tests performed before and after PWHT, in all samples, inversely proportional results were obtained with hardness values. This is also an expected result.

It is certain that the PWHT process improves the mechanical properties of both GTAW and SMAW welded 2.25Cr1Mo (P22) steel, but these positive values have only pulled up the positive values obtained after welding operations. So, it is not necessary to apply the PWHT process, as it can lead to waste of money and time.

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