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Effect of PWHT Temperature and Time on Hardness and Microstructure of 410NiMo Weld Metal

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Abstract

ASTM A743 CA6NM alloy is a martensitic stainless steel typically used in energy industry -runners and hydraulic turbine components- due to its superior toughness, yield and fatigue properties. In both the manufacturing, shielded metal arc welding is applied to join for this grade steels. However, weldability of the steels is limited due to formation of hard and brittle phases such as untempered martensite during welding and post weld heat treatment processes. The formation causes a reduction in toughness. In this study, influence of post-weld heat treatment procedure (single tempering and double tempering) and parameters on microstructure and hardness of AWS410NiMo all weld metal. Hardness tests were conducted from weld metal. Microstructures of the all weld metals subjected to different heat treatment process were characterized.

Key Words: 410NiMo, all weld metal, heat treatment, hardness, microstructure

1. Introduction

Low carbon 13%Cr-4%Ni (CA6NM) martensitic stainless steels such as Alloy 410 (410NiMo) are used at elevated temperature and corrosive environments such as hydroelectric turbine runners, chemical and power industries due to having good mechanical and corrosion properties [1, 2]. These steels have high flow stress and toughness, high resistance to cavitation and reasonable weldability. Martensitic steels with low carbon content are always quenched and tempered to have good mechanical properties [3]. A post-weld heat treatment (PWHT) is then required to temper the brittle martensite. The use of 410NiMo steel and weld metal without PWHT is not recommended due to high level of residual stresses, cold cracking and poor fatigue resistance [3-5]. Another beneficial effect of this PWHT is to lower the residual stresses induced by welding [6]. Tempering temperature and time have a great influence on microstructure [7]. Two different tempering types were prescribed for 410NiMo martensitic stainless steel according to NACE MR0175 standard to acquire maximum 265 HB hardness [8]. The aim of this study is to evaluate the influence of the applied PWHT type on microstructure and hardness of 410NiMo weld metal deposited by the shielded metal arc welding (SMAW) process.

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2. Experimental

In this study, effect of post weld heat treatment on the microstructure and hardness of 410NiMo weld metal was investigated. All weld metal was produced by shielded metal arc welding (SMAW) technique. A 25 mm thick weld metal was deposited on a 25 mm thick S355 JR substrate (250 mm × 350 mm) using GeKa Elox B 410NiMo stick electrodes. The electrodes were fabricated by Gedik Welding Co. in Turkey. Welding parameters were given in Tab.1

Table 1. Welding parameters of produced 410NiMo All Weld Metal.

Weld Pass Number	Preheat and Inter Pass Heating (°C)	Current (A)	Voltage (V)	Weld speed (mm/min)	Heat Input (kJ/mm)
25	**100-150**	**110**	**32**	**125**	**1.689**

Preheat and interpass temperatures were held at 100 °C and 150 °C respectively. The weld metals were subjected to post weld heat treatment (PWHT) process as seen in Figure 1.

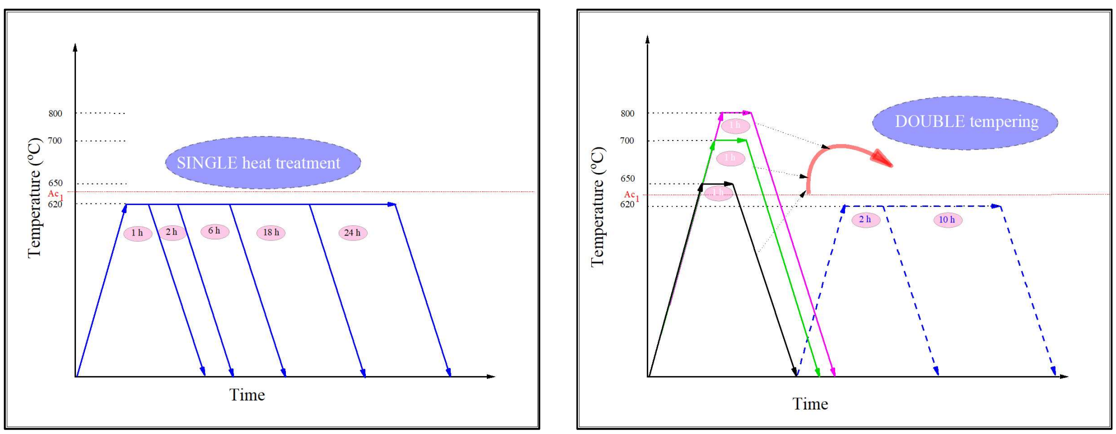

Figure 1. Systematic presentation of PWHT applied to weld metal.

Standart metallographic procedure was applied to PWHT'ed weld metal samples for microstructure characterization. Modified vilella's reagent (2.5 gr picric acid + 2.5ml HCI + 95ml Ethanol) [9] was prepared as etching solution. Nikon Eclipse MA100 inverted optical microscope was employed. RIGAKU ZSX Primus II X-Ray fluorescence device and LECO CS600 were used to determine chemical composition and carbon and sulfur content respectively. Chemical analysis of weld metal is shown in the Tab. 2. Hardness' of the weld metals were measured by Brinell hardness tester 187.5kgf-⌀2.5mm ball diameter.

Table 2. Chemical analysis of weld metal.

	C	Mn	Si	Ni	Mo	Cr	Cu	V	Fe
ELOX B 410 NiMo	0.03	0.58	0.21	5.29	0.52	11.23	0.04	0.037	Bal.

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3. Results and Discussion

3.1. Microstructure

Figure 2 shows the microstructure of welded condition and single PWHT processes. Microstructure of welded condition has martensitic and thicker and harder than single or double PWHT'ed samples due to fresh martensite. Delta ferrite phase did not detect optical microscopy investigation. Finer martensitic structure observed 620 ºC 18h and 24 h PWHT. In the microstructure white area may be fresh martensite/retained austenite. Increasing tempering time, the lath and white area are finer.

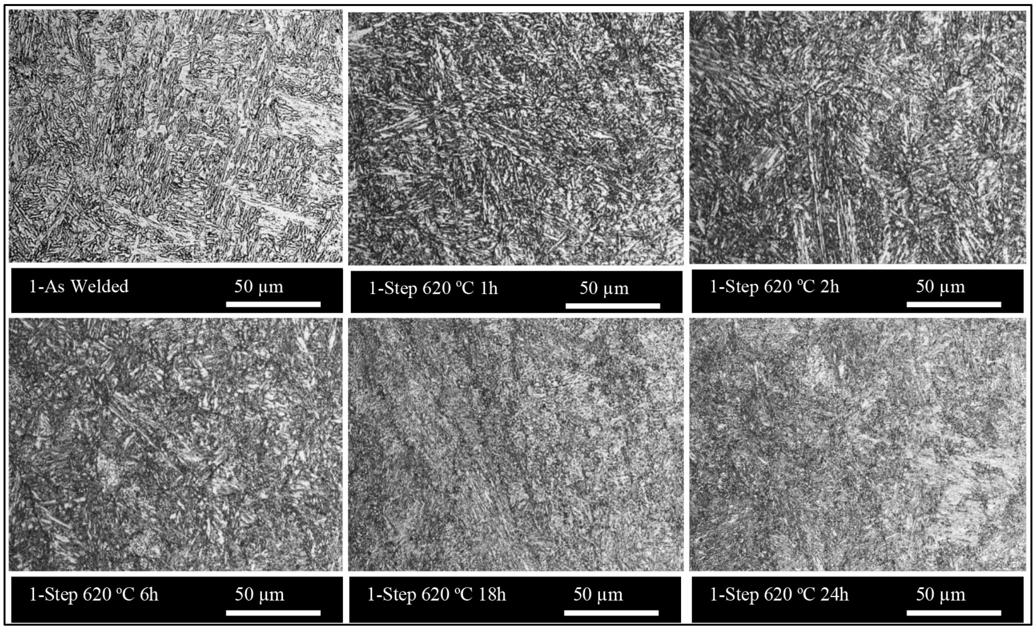

Figure 2. Microstructure of weld metal after single heat treatment processes.

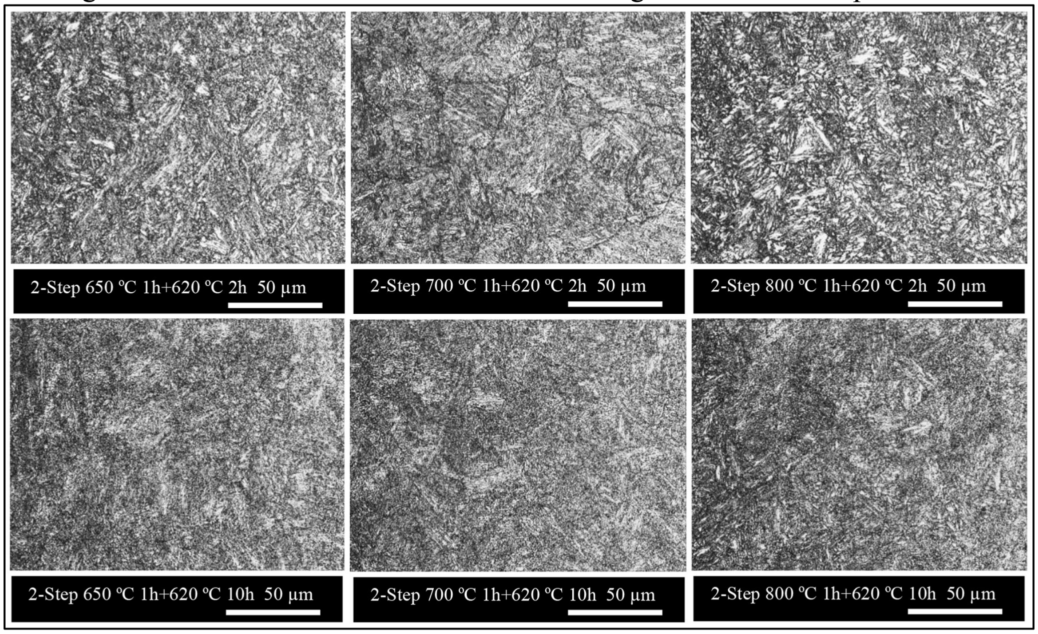

Figure 3. Microstructure of weld metal after double heat treatment processes.

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Figure 3. shows double tempered 410NiMo weld metal. First step 650 ºC, 700 ºC, 800 ºC applied and second step subjected to 620 ºC 2h and 10h. First step temperature subjected to above the A_{C1} transformation temperature, second step below the A_{C1} temperature inhibiting hard fresh martensite. Microstructure in double tempered microstructure first step 800 ºC have more blocky white area this probably retained austenite, because hardness results (Figure 4) advocating this result. Increasing tempering time from 2h to 10h finer microstructure observed. 410NiMo martensitic stainless steel starts to solidification as δ ferrite. δ ferrite transforms to γ austenite above 1200 ºC and fully transforms to γ austenite at 1200 ºC. Austenite will transform to martensite. Then martensitic microstructure occurs after cooling room temperature [5, 10]. The sequence of the transformation was presented by [5] as below:

$$L \rightarrow L+Fp \rightarrow Fp \rightarrow Fp+A \rightarrow A \rightarrow Martensite \quad (1)$$

During solidification, alloying elements segregation can form between dendrites. Therefore δ ferrite can remain in the microstructure at room temperature. Retained austenite can also may remain between martensite laths [10].

3.2. Hardness

Hardness results are shown in Figure 4 while hardness is 350HB as welded condition, the hardness decreased with increasing tempering time at 620 ºC in the single heat treatment process. In double tempering process, the samples tempered at 620 ºC for 10h have the lowest hardness. The results agree with literature [11, 12]. Furthermore, the hardness limit for UNS S41425 steel is 265 HB according to NACE 0175/ISO 15156. In this study, the limit was achieved in double tempering process. It can be concluded that double tempering causes considerable effect softening of martensite [12].

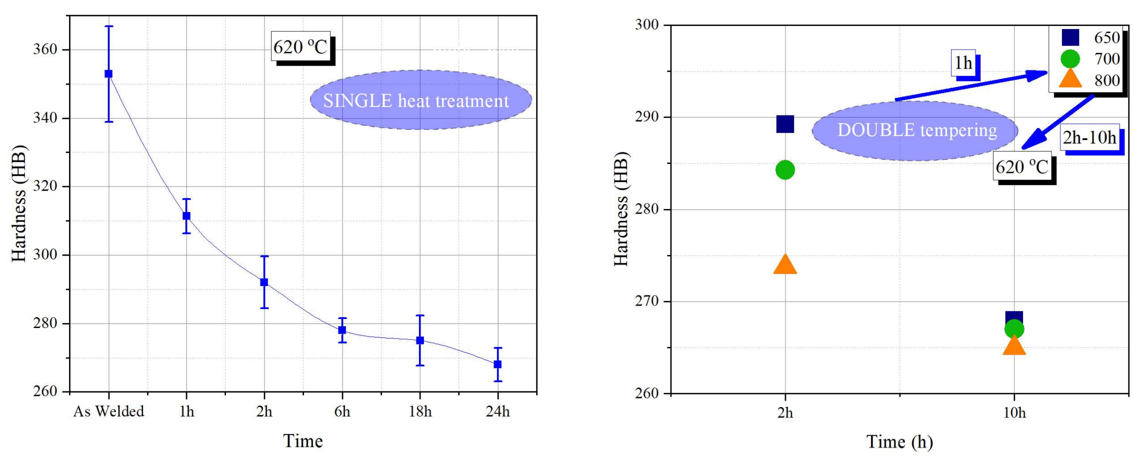

Figure 4. hardness results of 410NiMo weld metal after single and double heat treatment processes.

4. Conclusion

The effect of post-weld heat treatment temperatures on microstructure and hardness was investigated in the present study. Following conclusions could be drawn from this study;

1. Microstructure as welded condition has martensitic and did not detected delta ferrite phase by optical microscopy investigation.

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2. Microstructures of Single heat treatment 620 ºC 1h, 2h and 6h have martensitic and may be some retained austenite/fresh martensite and thicker than 620 ºC 18h and 24h.
3. Microstructures of double tempering finer structure detected 620 ºC 10h.
4. Increasing tempering time (620 ºC) reduced hardness.
5. First heat treatment temperature in DOUBLE tempering hardness effected by temperature, lower hardness determined higher first temperature.

Double tempering is vital for welded martensitic stainless steels due to hardness.

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7. References

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