Optimization Of Cooling Media In Post-Weld Heat Treatment For Improved Durability Of Low Carbon Steel Components

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Abstract- This study investigates the influence of post-weld heat treatment (PWHT) in various cooling media on the mechanical properties and microstructure of low carbon steel used in fabrication industries. Low carbon steel samples, sourced locally in Ado-Ekiti and complying with ASME specifications, were subjected to welding and subsequent heat treatment processes at temperatures between 900°C and 920°C. Post-weld heat treatment involved quenching in different media, including water, groundnut oil, palm oil, engine oil, and quartz 5000, with the aim of assessing their impact on hardness, microstructure, impact strength, and fatigue behavior. Microstructural analysis revealed notable differences across media: quenched samples in engine oil and groundnut oil exhibited finer grain structures and more uniformly distributed ferrite-pearlite phases, whereas untreated samples showed coarser, less homogeneous microstructures. Hardness testing using Brinnell scale indicated that engine oil-quenching yielded the highest hardness of 133.735 BHN in the heat-affected zone (HAZ) and 106.855 BHN in the welded zone, surpassing the untreated sample's hardness of approximately 100.77 BHN and 100.97 BHN, respectively. Impact strength measurements demonstrated the lowest values in samples quenched in water (35.8 J) but improved significantly in oil-quench media, with engine oil achieving 39.1 J and groundnut oil 37.75 J, approaching the untreated value of 41.55 J. Fatigue tests indicated that oil-quenched specimens possessed higher endurance limits compared to water-quenched ones, signifying enhanced durability. The results substantiate that choice of cooling medium during PWHT critically affects the microstructure and mechanical performance of low carbon steel. Engine oil emerged as the most effective media for attaining higher hardness, impact resistance, and fatigue life, thereby justifying its recommendation for industrial applications requiring strong, durable welded steel structures. The findings underscore the importance of controlled cooling in optimizing the microstructural and mechanical qualities of low carbon steel, facilitating safer and more reliable fabrication practices.

Index Terms : post-weld heat treatment (PWHT), low carbon steel, cooling media, microstructure, mechanical properties.

I. INTRODUCTION

Thermal treatment methods for low carbon steel have been studied, and it has been stated that TTP has significant economic consequences for Nigeria's industrial growth. Parts of these papers were looked at as a starting point for this investigation. The Effect of Post-weld Heat-Treatment on the Torsional Behavior of Low Carbon Steel is a research project. TTP procedures were discovered to increase the mechanical properties of butt-welded low carbon steel considerably [1, 2]. Further research into the effect of post-weld heat-treatment on mechanical properties and residual stresses mapping in welded structural steel discovered that microhardness, tensile strength, and impact tests on the welded joint under two conditions, as-welded and as-heat-treated, were used to assess this effect. The results reveal that thermal treatment enhances toughness by about 15% without affecting tensile strength or hardness, and also has a considerable effect on lowering residual stresses by nearly 70% [2, 3]. Other authors studied the microstructure and mechanical characteristics of grade 91 steel after welding and post-weld heat treatment. It was discovered that TTP is required to enhance the microstructure and mechanical characteristics of P91 steel. This resulted in a more homogenous microstructure in welded metal and HAZ, as well as lower susceptibility to cracking [4 5]. Research also showed the effect of post-weld heat treatment on the impact strength, toughness, and microstructural properties of P-91 steel weld melt and also revealed that only after a TTP can acceptable mechanical characteristics such as impact strength, toughness, ductility, and hardness, be attained [3, 4]. However, because the number of welded joint failures is increasing at an alarming pace, further research into the influence of thermal treatment techniques on the microstructure and strength of low carbon steel is needed to enhance the mechanical characteristics of low carbon steel structures [5]. In comparison to carbon and alloy steel, the chemical composition and microstructure of the alloy govern the mechanical qualities. The microstructure has a greater effect than chemical composition, which can only be influenced by the thermal treatment used [10,11]. Carbon increases hardness, nickel increases toughness, while a combination of chromium, molybdenum, vanadium, and tungsten combinations improves temperature resistance strength [6,7]. Thermal treatment is a word used to describe the process of heating a material to a specific temperature, maintaining it at that temperature, and then, cooling it to ambient temperature. The changes are diffusion-controlled, and as a result, the majority of the material attributes are altered. Hardness, strength, ductility, toughness, and grain size are examples of mechanical qualities. It is well known that the heat treatment procedure has an impact on the grain structure and mechanical characteristics of low carbon steel. In thermal treatment, however, the pace of cooling is the deciding element [6,8]. Rapid cooling over the critical range results in hard structures, but extremely slow cooling, especially in commercial steel, has the reverse effect. Preheating and post-heating are two types of thermal treatment [7, 9].

The term "thermal treatment" refers to a series of heating and cooling steps used to achieve the desired combination of characteristics in steel. The phase transformations and structural changes that occur during the heat treatment are responsible for these changes in steel characteristics [5, 8]. The fundamentals of thermal treatment are the mechanisms that govern and control these structural changes. The following are the thermal treatment principles that must be followed and during the heating process, a phase transition occurs. The impact of cooling media and pace on structural changes during cooling, as well as the impact of carbon content [9, 10]. Yield strength and tensile strength are reduced marginally, with the impact strength diminishing over time while the ductility is increased. Toughness is moderately diminished over a short period, but the effect can be considerable over a prolonged period [9, 12] when compared to the as-welded condition, these are the results of thermal treatment.

II. MATERIALS

This article looked at the mechanical characteristics of low carbon steel bars with a typical thickness of 14mm. The low carbon steel flat bar served as the study's foundation. Other materials utilized in the experiment include Arc welding equipment, heat treatment furnace, quenched media; Water, Palm oil, Spent Engine oil, and Ground Nut oil, all maintained at room temperature in the quenching tank.

Table 1: Chemical composition of Low carbon steel (NST 44-2).

C	Si	Mn	P	S	Cr	Ni	N
0.135 – 0.33	0.18 – 0.28	0.40 – 0.60	0.0 - 0.05	0.0 - 0.03	17.50 - 19.50	8.00 - 10.50	0.0 - 0.11
0.165	0.19	0.50	0.02	0.02	17.34	9.45	0.09

III. EXPERIMENTAL PROCEDURE

Low carbon steel bars with a thickness of 14mm were used in this study. They were cut in pairs to dimensions 100mm by 50mm from a thickness of 14mm and ten samples of these Low carbon steel bars were examined. The weld junction was designed using a double V-butt weld joint. The achievement of the specified static strength is a critical consideration in joint design choices. To finish the assembly, currents of 100 amps and a constant voltage of 24 volts were employed at a welding rate of 3.56 mm/s. In this junction, the movement of the two parallel sides of the welded line was restricted.

Plate 1: Experimental procedure shows an array of the specimen after SMAW welding operation.

IV. THERMAL TREATMENT PROCESSES

A pair of two standard specimens were heated to 920ºC and homogenized for 20 minutes at that temperature and this was done four times. After 20 minutes in the furnace, the specimens were removed and quenched in a variety of media: water-cooled, SHP; palm oil-cooled, SHP; Quartz 5000 Total Engine oil, SHE; and groundnut oil, SHG; all of which were kept at room temperature in separate quenching tanks. After thirty minutes, the specimens were removed from the quenching tanks and thoroughly cleansed [20, 22]. The control specimens were the remaining two as-weld specimens. Plate 2 shows some of the specimens before and after the thermal treatment techniques were carried out.

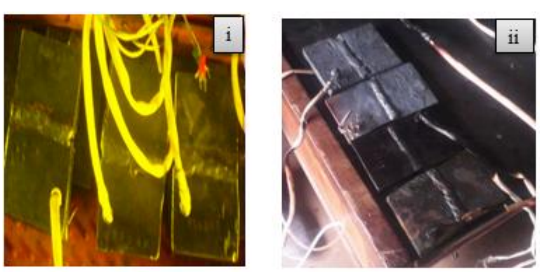

Plate 2: Welded specimens before thermal treatment (i) and after quenched in different media(ii)

IV. RESULTS AND DISCUSSION

Tensile behaviour of thermal treatment specimens

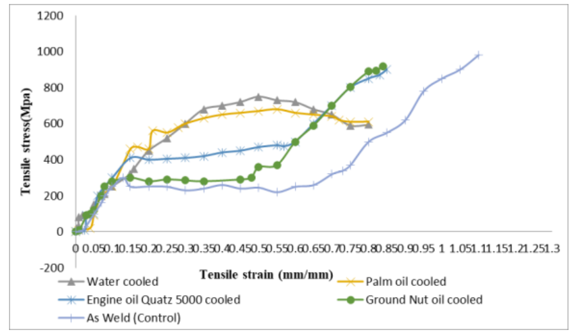

Figure 1: Tensile Stress against Tensile Strain for thermal treatment.

Figure 1 depicts the fluctuation of Tensile Stress (MPa) vs Tensile Strain (mm/mm) for the various cooling medium. When examining a material's capacity to withstand mechanical forces and loads, all of the mechanical characteristics of low carbon steel are important however, the tensile strength or yield stress is the most important parameter in the selection and inspection of low carbon steel. As predicted, martensite (hardened) specimens (quenched in various fluids) show different elongation (extension) at break than untreated coupons [14, 17]. Untreated specimens are harder than heat-treated specimens (hardened quenched in various media). The material's hardness was improved by the chosen thermal treatment procedures. When compared with the welded specimen, the thermal treatment of the welded junction altered mechanical properties such as hardness, strength, residual stresses, and fracture mechanism [19, 20].

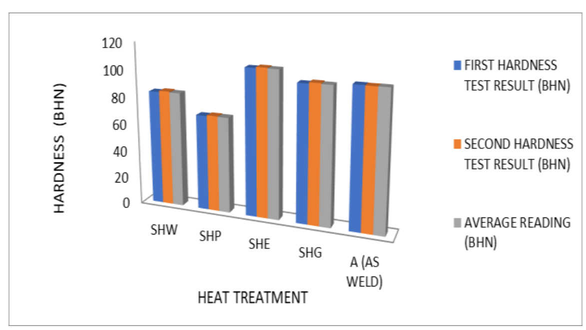

Figure 2: Brinell hardness Test Result for Welded pool.

Figure 2 shows changes in hardness values for welded specimens in the welded pool and heat-affected zone (HAZ). The hardened specimens (martensite) have average hardness values of (133.73 BHN, 125.64 BHN, 88.13 BHN, and 123.99 BHN) (Rockwell C) at heat affected zone quenched in Quartz 5000 Engine oil, Groundnut oil, Palm oil, and Water media, respectively, compared to the untreated as-weld specimen's average hardness value of 100.97BHN at heat affected zone. Except for the one quenched in palm oil, this means quench hardening enhances the strength of low carbon steel by increasing the hardness value in the heat-affected zone. The hardened specimens (martensite) have average hardness values of (100.77 BHN, 99.26 BHN, 84.06 BHN, and 69.83BHN) at welded pool hardened in (Quartz 5000 Engine oil, Groundnut oil, Water, and Palm oil) media, respectively, compared to the untreated as-weld specimen's average hardness value of 106.855BHN. This means that quench hardening in a welded pool hasn't increased the strength of low carbon steel by lowering the hardness value.

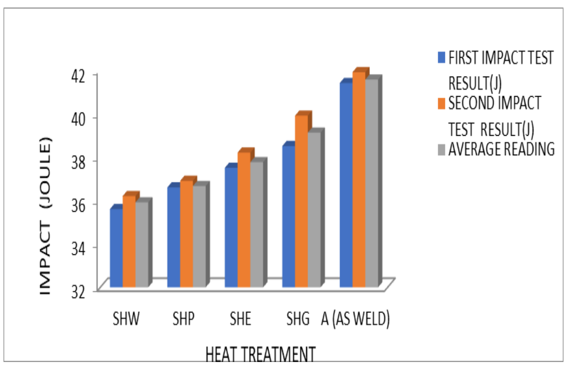

Figure 3: Impact Test Result of Heat Affected Zone (HAZ)

Variations in impact values in the heat-affected zone (HAZ) for welded specimens are illustrated in Figure 3. The impact values for the heat-affected zone (HAZ) for all specimens quenched in different media are 35.8, 36.65, 37.75, and 39.1J at heat affected zone quenched in Quartz 5000 Engine oil, Groundnut oil, Palm oil, and Water media, respectively, compared to the untreated as-weld specimen's average value of 41.55J.

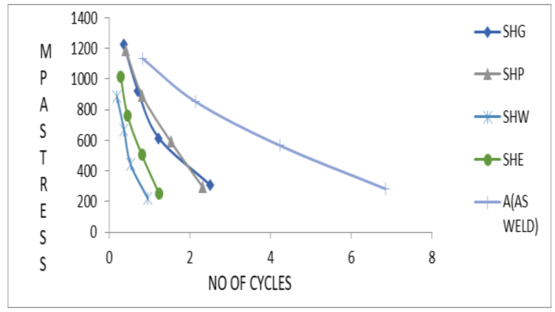

Figure 4: Graph of Stress against several Cycles for TTP Low Carbon Steel Specimens

Figure 4 showed the fatigue strength values for each specimen's heat-affected zone (HAZ). Lowest-cycle fatigue is achieved using hardened specimens (quenched in various media). TTP of material improves endurance limit and endurance strength at a specific number of cycles to failure for this material.

Plate 3: Microstructural analysis of LCS HAZ hardened in Water.

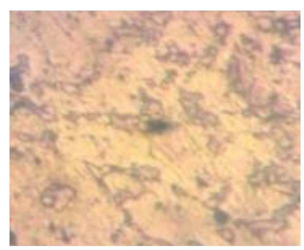

Plate 4: Microstructural analysis of LCS HAZ hardened in Palm oil.

Plate 5: Microstructural analysis of LCS HAZ hardened in Engine oil Quenched.

Plate 6: Microstructural analysis of LCS HAZ hardened in Groundnut oil Quenched steel.

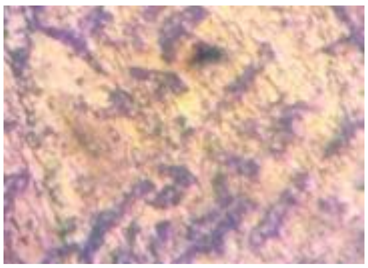

Plate 7: Microstructural analysis of LCS HAZ untreated.

Plates 3–7 show the microstructures of low carbon steel (LCS) before and after various heat treatment techniques at constant temperature (9200C for 6 hours). The as weld low carbon steel sample's microstructure revealed ferrite in the grain boundaries of the acicular pearlite grains. As a result, the weld low carbon steel microstructure may be defined as having a ferrite-austenite duplex phase (Plate 7). This was attributable to oxidation at the metal surface, the quick cooling rate because it cooled in the medium and the lack of equilibrium structure. The presence of scales more widely distributed on the metal surface and highly scattered ferrite was shown by the quench-hardening heat treatment in media (Water, Palm oil, Engine oil quartz 5000, and Groundnut oil) (Plate 3 to Plate 6).

CONCLUSIONS

The following findings are drawn from the research:

i. The study demonstrates that the choice of cooling medium during post-weld heat treatment significantly affects the microstructure and mechanical properties of low carbon steel. Quenching in engine oils such as engine oil and groundnut oil resulted in higher hardness and improved resistance to impact and fatigue. Therefore, selecting an appropriate cooling medium can enhance the performance and durability of welded steel components in industrial applications.

ii. The findings reveal that post-weld heat treatment (PWHT) employing various cooling media effectively increases the hardness and microstructural uniformity of low carbon steel, thereby improving its mechanical properties. Among the tested media, engine oils provided the most favorable results, suggesting that controlled cooling in suitable media is critical for optimizing steel performance.

iii. This research confirms that the application of PWHT with specific cooling media positively influences the microstructural characteristics, hardness, and impact strength of low carbon steel. The results advocate for the adoption of particular quenching media, such as engine oils, to attain desired mechanical properties, which can contribute to safer and more reliable steel structures in manufacturing industries.

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