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Effect of Tempering Treatment on the Post-Weld Properties and Chemical Compositions of Arc-Welded Alloy Steels

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ABSTRACT
The effect of heat treatment on welded joints using the shielded metal arc welding (SMAW) on three different types of steel with different carbon ratios under constant conditions such as the welding current 120A, voltage 80V, Diameter 10 mm and angle 60 degree. Hardness tests chemical composition analysis were carried out and it was observed that, high carbon steel has the highest hardness of about 459 on maximum HV value, followed by the low carbon steel with the hardness of 316HV maximum and medium carbon experience the least value of 208HV. Hardness increases with low carbon content as shown in the experimental results which deduced that the low carbon steel used was confirmed to be the high-strength-low-alloy steel of grade 8620-HSLA-Nickel-Chromium-Molybdenum steel. The microstructure of the base metal was analysed before heating to support the results of chemical analysis. Nickel percentage of up to 0.147% and Chromium 0.083%. Molybdenum was just 0.030% which contributed in affecting the mechanical properties of the steel.
Keyword: Heat treatments, welded joints, Chemical compositions, microstructure, Micro hardness

1 INTRODUCTION

Alloy Steels as Engineering material become an essential class for diverse applications like construction of large ships, oil and gas transmission lines, offshore oil drilling platforms, pressure vessels, building construction, bridges, storage tanks [1]. With the technological development in advanced industries such as oil, automotive, aviation, piping networks, metallic bridges and other important industries, the need for a high-quality welding splice has increased [1][2][4]. Many studies have shown that the welding joints are fractured when subjected to dynamic loads that start in the transition zones from the weld line. Basic metal has been verified through several tests conducted in the field of fatigue tests [5]. The shape, dimension and reinforcement amount of the welded druse in welding line affect the extent of withstand of the different welding joints (whether these joints are spherical, perpendicular or otherwise) [6]. It is noticeable that whenever the values of transition angle increase between the welding line and the base metal, the values of extent withstand increases for spherical joints treated using this method. The mechanical methods varied to improve the sudden transition between the weld line and the base metal [7]. The grinding and rolling methods were used to make a smooth transition between the welding line and the base metal, and then reduce the concentration of the remaining stresses in this region [8].

The purpose of heat-treating carbon steel is to change the mechanical properties of steel, usually ductility, hardness, yield strength tensile strength and impact resistance. The electrical, corrosion and thermal conductivity are also slightly altered during heat treatment process [9]. The most common reasons that metals undergo heat treatment are to improve their strength, hardness, toughness, ductility, and corrosion resistance etc. Annealing is a form of heat treatment that brings a metal closer to its equilibrium state. It softens metal, making it more workable and providing for greater ductility.

The heat treatment develops hardness, softness, and improves the mechanical properties such as tensile strength, yield strength, ductility, corrosion resistance and creep rupture. These processes also help to improve machining effect and make them versatile. In the welding process, a high temperature is generated to melt the welding metal, the conditional interface between the welding metal and the welding zone is called fusion limits [9]. The temperature and cooling rate of the heat-affected area varies depending on the distance from the fusion line between the weld

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metal and the heat-affected area. As a result of this difference, the microstructure varies, although the chemical structure is not different [10]. Various mechanic and heat treatments are conducted on some metals that lead to reduce the stresses and distortions of the welded metals, these treatments include heating, pre-pressing, and heat treatment after the welding process [11]. These treatments reduce or remove the stresses and cracking, change the metallic properties of welded joints and to get the precise structure of the basic metal and metal fillers. The heat treatments affect (the temperature at which the metal is exposed, fixing period, the chemical composition of the metal, and cooling rate) [12].

Adjusting the carbon content is the simplest way to change the mechanical properties of steel. Additional changes are made possible by heat-treating, for instance, by accelerating the rate of cooling through the austenite-to-ferrite transformation point. The reason for this increasing hardness is the formation of a finer pearlite and ferrite microstructure that can be obtained during slow cooling in ambient air. In principle, when steel cools quickly, there is less time for carbon atoms to move through the lattices and form larger carbides. Cooling even faster, for instance, by quenching the steel at about 1,000°C per minute, results in a complete depression of carbide formation and forces the undercooled ferrite to hold a large amount of carbon atoms in solution for which it actually has no room. Tempering martensitic steel *i.e.,* raising its temperature to a point such as 400°C and holding it for a time decreases the hardness and brittleness and produces a strong and tough steel. Quench-and-temper heat treatments are applied at many different cooling rates, holding times, and temperatures; they constitute a very important means of controlling steel's properties.

Large number of researchers work on this area but consider the thickness of the alloy steel tested to be constant. In this work, we are to study the influence of heat treatments on the chemical compositions and hardness property on welded joints after welding process using arc welding, where three samples of steel were used with different carbon ratios in constant conditions of current and voltages with varying thickness of the metal.

2 EXPERIMENTAL WORKS

2.1 Sample Preparation

The three alloy steels of different carbon content were prepared by cleaning and grinding to remove the oil stains and other unwanted materials like dust and rust.

2.2 Welding Process

The parts to be welded were brushed with stainless steel brush and finished with sandpaper and observed that all the oxidation layer were removed. A heat source was used, to heat the base metal to at least 387°C. When hot enough, the flame was moved aside but was kept on the part to maintain the temperature, and then the welding rod was applied and melted on contact with the hot metal part. Test samples were prepared according to the standards to achieve an accurate result.

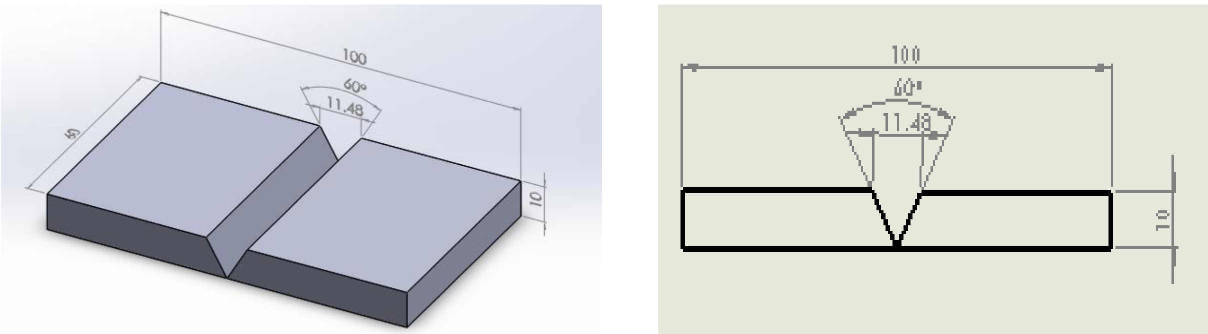

Figure 1: Dimensions of the sample used in welding process

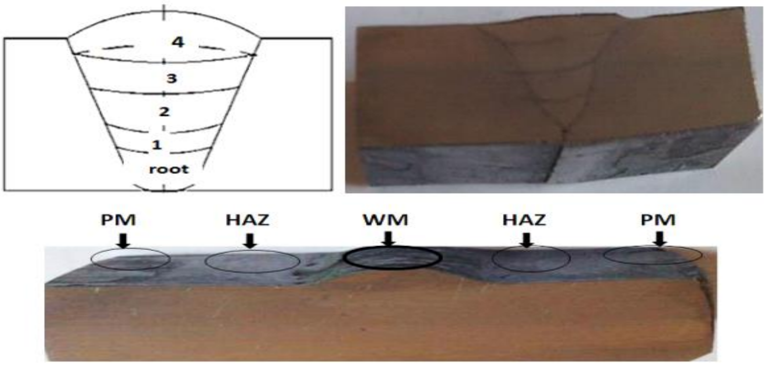

Figure 2: Sample of welded steel picture

3 EXPERIMENTAL RESULTS

Three different types of alloy steel were used in this work as low, medium and high carbon steel. The classification was based on the carbon content, but according to the level of main mechanical properties of practical importance as Low Carbon Steels having carbon up to 0.25%, Medium Carbon Steels having carbon between 0.25% to 0.55% and High Carbon Steels has carbon from 0.55% to ideally a maximum of 2.11% but commonly up to 1.5% max. in commercial steels. And this is the most commonly used commercial classification. Table 1, 2 and 3 present the results of chemical composition of the three selected carbon steel.

Table 1: Chemical composition of low carbon alloy steel

C %	Si %	Mn %	P %	S %	Cr %	Ni %	Mo %	Al %
0.095	0.235	0.90	0.011	0.013	0.0083	0.147	0.030	0.039
Cu %	Co %	Ti %	Nb %	V %	W %	Pb %	Mg %	B %
0.208	0.019	≤ 0.0010	≤ 0.0040	≤0.0010	≤0.010	≤0.0030	≤0.0010	0.0008
Sn %	Zn %	As %	Bi %	Ca %	Ce %	Zr %	La %	Fe %
0.012	≤0.0020	0.020	≤0.0020	0.00003	≤0.0030	≤0.0015	≤0.0010	98.2

Table 2: Chemical composition of medium carbon alloy steel

C %	Si %	Mn %	P %	S %	Cr %	Ni %	Mo %	Al %
0.272	0.108	0.449	0.00089	0.014	0.0027	0.029	≤ 0.0020	0.042
Cu %	Co %	Ti %	Nb %	V %	W %	Pb %	Mg %	B %
0.016	0.013	≤ 0.0010	≤ 0.0040	≤0.0010	≤0.010	≤0.0030	≤0.0010	≤0.0005
Sn %	Zn %	As %	Bi %	Ca %	Ce %	Zr %	La %	Fe %
≤0.010	≤0.0020	≤0.0010	0.0046	0.011	0.0051	≤0.0015	0.0017	99.0

Table 3: Chemical composition of high carbon alloy steel

C %	Si %	Mn %	P %	S %	Cr %	Ni %	Mo %	Al %
0.99	0.407	0.79	0.046	0.227	0.127	0.132	0.049	0.127
Cu %	Co %	Ti %	Nb %	V %	W %	Pb %	Mg %	B %
0.065	0.050	0.014	0.023	0.0023	0.414	0.132	0.175	0.028
Sn %	Zn %	As %	Bi %	Ca %	Ce %	Zr %	La %	Fe %
0.022	≥ 0.036	0.036	0.0048	≥ 0.015	0.180	≤ 0.0015	-0.261	≤ 94.6

Table 4: Chemical composition & mechanical properties of welding electrode

<table>
<tr><td>C %
≤ 0.12</td><td>Si %
≤ 0.35</td><td>Mn %
0.30-0.60</td><td>P %
≤ 0.040</td><td>S %
≤ 0.035</td><td>Cr %
0.127</td><td>V %
0.132</td><td>Mo %
0.049</td></tr>
<tr><td colspan="8">Mechanical Properties of Deposition Metal</td></tr>
<tr><td colspan="2">δ_b (MPa)
≥ 420</td><td colspan="2">δ_s (MPa)
≥330</td><td colspan="2">δ_5 (MPa)
≥17</td><td colspan="2">A kv (J) 0°C
≥ 47</td></tr>
</table>

3.1 Effects of Alloying Elements and Weldability

It was confirmed from the experimental results that, alloying elements can alter carbon steel in several ways. Alloying can affect micro-structures, heat-treatment conditions and mechanical properties. Today's technology with high-speed computers can foresee the properties and micro-structures of steel when it is cold-formed, heat treated, hot-rolled or alloyed. It was also proven that, improved properties such as high strength and weldability required in steel for certain engineering applications can only be achieved by adding other alloying elements as carbon steel alone will not serve the purpose because carbon's inherent brittleness will make the weld brittle which is desirable. The solution is to reduce carbon and add other elements such as manganese or nickel. This is one way of making high strength steel with required weldability. Fig. 3, 4 and 5 presents the metallography of high, medium and low carbon steel respectively.

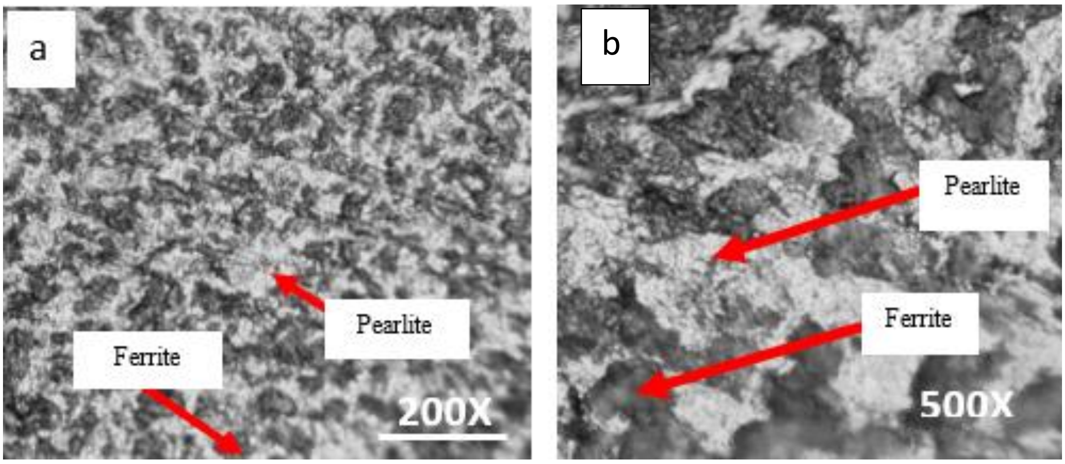

Figure 3: Optical micrograph of high carbon steel at (a) lower and (b) higher magnification for the base metal before tempering.

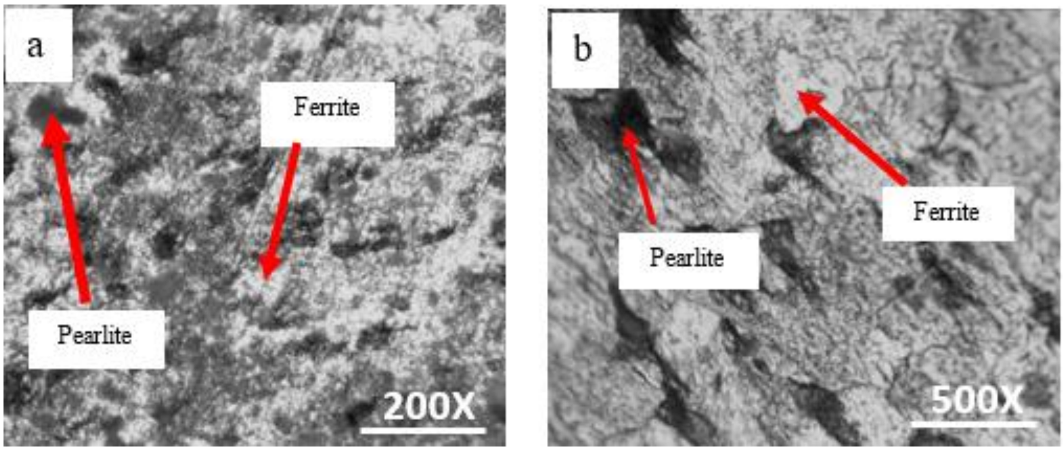

Figure 4: Optical micrograph of medium carbon steel at (a) lower and (b) higher magnification for the base metal before tempering.

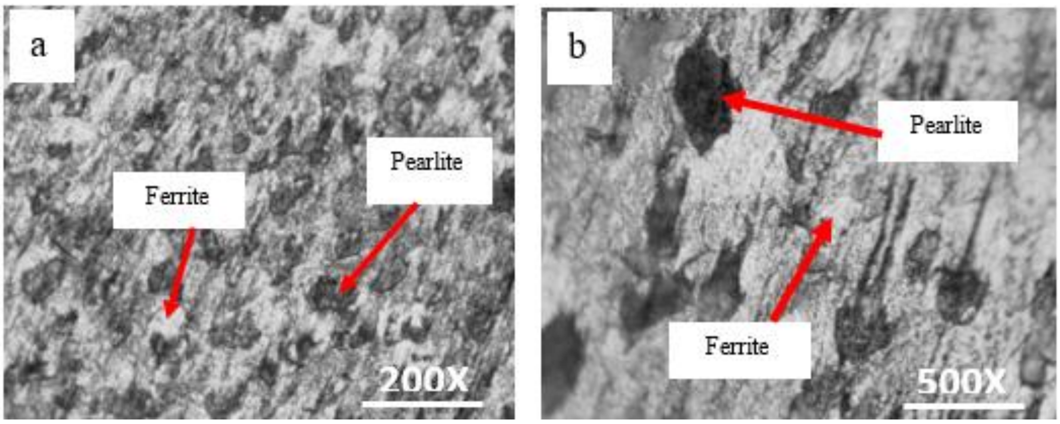

Figure 5: Optical micrograph of low carbon steel at (a) lower and (b) higher magnification for the base metal before tempering.

3.2 Hardness Test

Base metal was tested to serve as a reference point and it was observed that, high carbon steel has the highest hardness of about 459 and 226.6 on maximum and minimum HV value respectively, followed by the low carbon steel with the hardness of 316 and 290.8 maximum and minimum HV respectively. Medium carbon experience the least value of 208.1 and 183.1 maximum and minimum HV respectively. Hardness increases with low carbon content as shown in the used low carbon steel. This deduced that the low carbon steel used was confirmed to be the high-strength-low-alloy steel of grade 8620-HSLA-Nickel-Chromium-Molybdenum steel. This is as a result of having high percentage of Nickel of up to 0.147% and it has the ability to increase corrosion, oxidation resistance and strength of the steel. However, Chromium was found to be 0.083% in this particular steel and it has the capacity to affect the property of the steel by increasing its toughness, hardness and wear resistance. Molybdenum was just 0.030% which can also play an important role in affecting any of the mechanical properties of the steel.

In all the images of the microstructure, a fine pearlite structure was obtained for welded sample normalized at the selected temperature for all the steel grades. This leads to a consequential increase in hardness values. Heat affected zone, contains evolution of grains with typical martensitic and pearlite phase within the interface. Most area with HAZ contains lower hardness in the weld region with tendency of initial failure occurrence in service under the application of high load or severe stress.

Table 5: Hardness value of the samples at different zone

Steel sample	Process	Fusion zone WM HV(KN/mm^2)	Heat Affected zone HAZ HV(KN/mm^2)	Base metal BM HV(KN/mm^2)
Low carbon	Hardness before heat treatment	300	315	304
	Hardness after heat treatment at 550°C	310	324	290
Medium carbon	Hardness before heat treatment	190	200	196
	Hardness after heat treatment at 550°C	230	200	207
High carbon	Hardness before heat treatment	355	310	343
	Hardness after heat treatment at 550°C	370	345	330

3.3 Micro-Hardness Test

The welding samples were examined for accurate readings of the whole weld joint starting from the welding metal, the heat-affected area, then the base metal, and on both welding sides, at a distance of one mm between reading and another of the three welded joints (samples with performing heat treatments on which and samples without performing heat treatments). Figure 6 presents a Plot of Hardness values of welded joints in different zones under the same working conditions for the high, medium and low carbon steel respectively. As the microstructure of weldment (WM) and the base metal has undergoes considerable changes because of the heating and cooling cycle of the welding process and is expected to have greater value of hardness than in the heat affected zone when the percentage of carbon increases as shown in Table 3 and Fig. 6 [8]. The reason behind the high hardness in the welding area when using steel (Steel 321) is due to the union of chromium with carbon constituting chromium carbide ($Cr_{23}C_6$) which has property of high hardness in the hardening line due to the spread of carbon from the base metal to the welding metal.

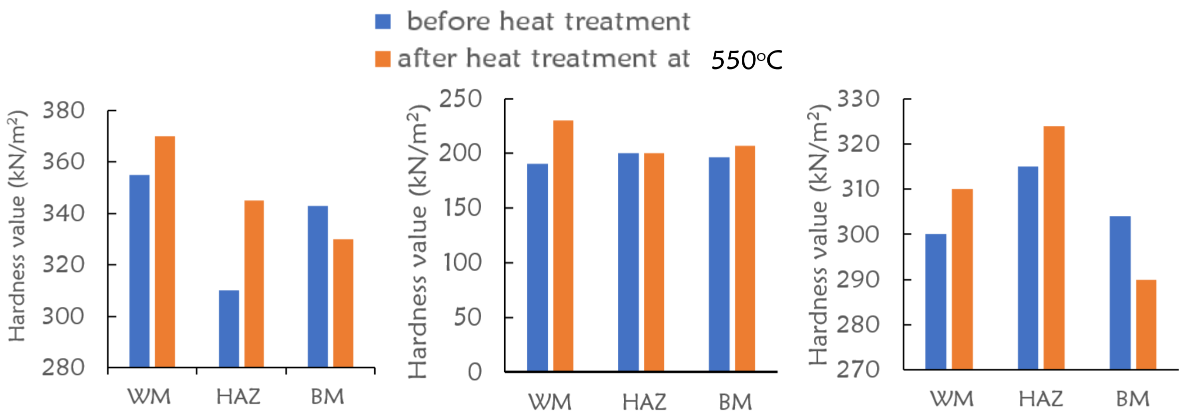

Figure 6: Plot of Hardness values of welded joints in different zones under the same working conditions for (a) high carbon steel, (b) medium carbon steel, and (c) low carbon steel.

It was observed from Fig. 6.0 that the variation in hardness value is because of the microstructural effect of carbon in terms of its volume fractions. Hardness increases with increase in carbon content which has been controlled to prevent the steel from been brittle in nature. The reason for this increase in hardness leads to the formation of a finer pearlite and ferrite microstructure that was obtained during controlled cooling.

4 CONCLUSIONS

It was concluded that, heat treatment has a clear and significant effect on the chemical and mechanical properties of steel. The highest hardness is achieved in the HAZ and the average value is in the Fusion zone for a welded joint of low-alloy steels. Whereas, in high-alloy steels, the highest hardness is achieved in the fusion zone and the average value in the HAZ. The highest hardness values can be obtained in the heat affect zone, then the hardness values start relatively decrease in the base metal in contrast to the steel (Steel 321), the highest hardness value is in the welding zone. Heating and cooling of the welding line zone is expected to change the crystalline volume of the metal and the formation of a Hard and fragile zone.

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