Effect of Normalizing Temperature and Time on Microstructures and Mechanical Properties of Hot Rolled Steel Strip for Gas Cylinder Production

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Abstract

Normalizing heat treatment was applied to the hot rolled steel strip used for gas cylinder production with various temperatures, 860-960°C, and time, 10-40 minutes. It was observed that with increasing temperature and time, the strength decreased. The ferrite decarburization at the surface of the strip occurred at a temperature of 860°C due to the fact that the steel was soaked at this temperature at which the microstructure of the steel develops into ferrite and austenite duplex phase. The carbon depletion was confirmed by micro hardness profile and EPMA mapping analysis. Ferrite and pearlite structure can be observed at 900°C while acicular ferrite occurred at a higher temperature. Oxide scale thickness and phase determination were also observed.

Key words: Hot rolled steel, Gas cylinder, Normalizing

Introduction

Hot rolled steel strip is one of the important raw materials for petroleum pressure vessels production, especially for liquid petroleum gas (LPG) for household usage. Normalizing heat treatment is carried out to produce uniform, fine ferrite/pearlite microstructures in the steel(1) and reduce compositional segregation thus improving the properties of HAZ and weldment.(2) Since normalizing is conducted, weldment and HAZ are improved, however, the properties of base steel are changed from the original hot rolled steel strip properties. Hot rolled steel strip properties are required to be controlled both before and after normalizing in order to control the mechanical properties of base steel to remain unchanged or only small deviation from the original properties and finally meet the customer specification. Therefore, suitable hot rolling temperature and normalizing condition is necessary to be carried out.

There are some reports about the effect of normalizing heat treatment on the mechanical properties and microstructure of the steel.(3-4) However, an investigation of the mechanical properties and microstructure of low carbon steel strip for gas cylinder production is a specific case and is necessary to be studied. Therefore, this study focused on the effect of normalizing heat treatment on the base steel properties and microstructures of base steel to acquire the steel properties suitable for gas cylinder production.

Materials and Experimental Procedures

The steel 245NB with average composition shown in Table 1 was used in this investigation and minimum requirement of mechanical properties are shown in Table 2. Steel with this composition was hot rolled to be a strip with 2.65mm thickness. Finishing and coiling temperature was 870°C and 540°C, respectively. In addition, coiling temperature 650°C was applied on hot rolled strip to determine the effect of coiling temperature on the mechanical properties of normalized steel samples.

Table 1. Chemical composition of steel.(wt%)

<table>
<thead>
<tr>
<th></th>
<th>%C</th>
<th>%Mn</th>
<th>%Si</th>
<th>%P</th>
<th>%S</th>
<th>%Al</th>
<th>%Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>0.13</td>
<td>0.76</td>
<td>0.019</td>
<td>0.011</td>
<td>0.005</td>
<td>0.042</td>
<td>bal</td>
</tr>
</tbody>
</table>

Table 2. Mechanical properties requirement of P245NB as per EN10120.

<table>
<thead>
<tr>
<th></th>
<th>Yield Strength (MPa)</th>
<th>Tensile Strength (MPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>245</td>
<td>360-450</td>
<td>26</td>
</tr>
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In order to investigate the mechanical properties and microstructure of steel strip, samples were then normalized using heating furnace in air atmosphere. Steel samples were preheated to 650°C for 30 minutes and then heated to 860, 900, 940 and 960°C with various soaking time which were 10, 20, 30 and 40 minutes in each temperature and then cooled in air (Figure 1).

Figure 1. Heat cycle of normalizing of steel strip.

After these treatments, tensile tests were carried out by a universal testing machine using EN10002-1 specimens to investigate the mechanical properties. Metallographic samples were prepared and etched in 2% nital to reveal the microstructure. In addition, hardness profile in through-thickness direction was carried out by using micro-Vickers hardness 10g load and 10 seconds dwell time.

Electron probe micro analysis was used to observe the carbon and other elements distribution along through-thickness direction. Moreover, phase determination of scale on the surface of the steel strip was carried out and oxide scale layer thickness was also measured.

Results and Discussion

Effect of Normalizing Temperature and Time on Microstructure of Hot Rolled Strip Sample

The microstructure of normalized steel at various temperature and time is presented in Figure 2. It is found that the ferrite decarburization occurs at the surface of the strip at the normalizing temperature 860°C (Figure 2(a)). The decarburizing depth was in range between 15-40 micrometers. At 900°C, polygonal ferrite and pearlite microstructure is found (Figure 2(b)). At higher normalizing temperature, 940 and 960°C, acicular ferrite can be observed among the polygonal ferrite and pearlite structure both at the surface and center of the strip (Figures 2(c), 2(d) and 3).

Figure 2. Microstructure at the strip surface, normalized at (a) 860°C (b) 900°C (c) 940°C (d) 960 °C at various soaking time
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It can be explained that ferrite decarburization occurred at the surface of the strip due to the steel was soaking at the temperature at which the microstructure of the steel becomes ferrite and austenite duplex phase.\(^{(3)}\) This is confirmed by the calculation of A\(_3\) of this steel using the equation \(^{(5)}\)

\[
A_3 = 910 - 203 \cdot \sqrt{\% C} - 15.2 \cdot \% N + 44.7 \cdot \% Si + 104 \cdot \% P + 31.5 \cdot \% Mo + 13.1 \cdot \% W
\]

Where \(%X\) means concentration of X element in mass %

Moreover, Vickers hardness profile (Figure 4) and EPMA investigation result confirm that carbon depletion occurs at the surface of the strip (Figure 5). EPMA mapping analysis shows that at the surface of the strip, less carbon content appears than the inner part. In addition, Vickers hardness profile gives the same trends of carbon depletion at the surface of the strip which is less hardness value than inner part of strip.

**Figure 3.** Acicular ferrite in mixture with polygonal ferrite and pearlite, normalized at (a) 960°C, 10 minutes soaking time (b) 960°C, 40 minutes soaking time.

**Figure 4.** Micro-Vickers hardness profile of steel sample, 10 minutes soaking time at various temperatures.

**Figure 5.** EPMA mapping analysis of normalized steel sample, 860 °C, 10 minutes soaking time.

In addition, microstructure of steel surface reveals that oxide scale which formed on the outer surface of the specimens becomes thicker with increasing temperature from 860°C to 940°C (Figure 6(a)). It is also observed that oxide scale thickness increases considerably when normalizing temperature is reached 960°C. In the meantime, oxide scale thickness increases a little when increasing soaking time (Figure 6(b)).

**Figure 6.** Oxide scale thickness at various normalizing temperatures.
Besides the microstructure of normalized steel samples, cross sectional samples analysis was carried out to determine the phase of oxide scale and scale layer thickness. Electron micrograph shows that mixture of Magnetite (Fe₃O₄) and Hematite (Fe₂O₃) are observed (Figure 7). This oxide scale characteristic is quite similar to those occurs in hot rolled steel strip, which temperature is below 500 °C.(6)

**Effect of Normalizing Temperature and Time on Tensile Properties of Hot Rolled Steel Strip Samples**

Tensile and yield strength of steel strip decrease when increasing normalizing temperature. This is also similar when holding time is increased, tensile and yield strength tends to decrease (Figures 8 and 9). All of these mechanical properties value are still conformed to the product specification. However, a slightly increasing of tensile and yield strength when holding time is 40 minutes at 960°C can be observed. This can be affected from the high amount of acicular ferrite occurred in the steel both in the surface and inner part of strip (Figures 2(d) and 3).

**Effect of Strip Coiling Temperature on Tensile Properties of Normalized Steel Strip**

The tensile strength of steel strip, which was hot rolled and coiled at 650°C, slightly decreases when coiling temperature is increased as normalized at 900°C. However, at 960°C, tensile strength is quite not changed when increasing coiling temperature (Figure 10). In the meantime, yield strength tends to decrease when increasing coiling temperature (Figure 11).

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**Figure 6.** Scale layer thickness (a) 10 minutes at various temperatures (b) 900°C at various soaking time.

**Figure 7.** Electron micrograph of oxide scale layer, normalized at 960°C and 40 minutes soaking time.

**Figure 8.** Tensile strength of hot rolled steel sample normalized at 860-960°C, soaking time 10-40 minutes.

**Figure 9.** Yield strength of hot rolled steel sample normalized at 860-960°C, soaking time 10-40 minutes.
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Figure 10. Tensile strength of hot rolled steel sample with different coiling temperature (540 and 650°C).

Figure 11. Yield strength of hot rolled steel sample with different coiling temperature (540 and 650°C).

Conclusions

1) Ferrite decarburization occurred at the surface of the strip at the normalizing temperature 860°C which decarburizing depth was in range between 15-40 micrometers. Ferrite decarburization occurred at the surface of the strip due to the steel was soaking at the temperature at which the microstructure of the steel became ferrite and austenite duplex phase. At 900°C, polygonal ferrite and pearlite microstructure was observed while at 940 and 960°C, acicular ferrite occurred in mixture with polygonal ferrite and pearlite.

2) Tensile and yield strength of steel strip decreased when increasing normalizing temperature and time. However, a slightly increasing of tensile and yield strength when holding time is 40 minutes at 960°C can be observed. This can be affected from the high amount of acicular ferrite occurred in the steel both in the surface and inner part of strip.

3) The tensile strength of steel strip, which was hot rolled and coiled at 650°C, slightly decreases when cooling temperature is increased as normalized at 900°C. However, at 960°C, tensile strength is quite not changed when increasing cooling temperature. Yield strength tends to decrease when increasing cooling temperature.

4) Oxide scale formed on the outer surface of the specimens became thicker with increasing temperature. Remarkable increase of oxide scale layer thickness was observed at temperature 960°C. In the meantime, oxide scale thickness increased a little when increasing soaking time.

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References


