METHOD FOR PRODUCING LINE PIPE

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ABSTRACT

A method for producing steel line pipe having low yield strength to tensile strength ratio in order to improve the capability of steel line pipe to undergo reeling into coil form and unreeling therefrom. The method includes (a) providing a steel pipe having a composition consisting essentially of in weight percent: C 0.01 to 0.40, Mn 0.25 to 2.0, P residual to less than 0.5, S residual to less than 0.020, Si residual to 2.0, Cu residual to 1.0, Ni residual to 1.0, Cr residual to 2.0, Mo residual to 1.0, Al 0.010 minimum to less than 1.0, N residual to 0.030, V residual to less than 0.5, B residual to less than 0.02, Ti residual to less than 0.3, and Nb residual to less than 0.3, balance iron and incidental impurities. The pipe is heated to a temperature within the intercritical A_{15} to A_{33} temperature range, cooled to a temperature below the M_{s} (martensite start) temperature in order to obtain martensite, reheated to a temperature below the A_{33} temperature for a time sufficient to obtain the desired yield strength, tensile strength and yield strength to tensile strength ratio, and then air cooled.
Fig. 1

Tempering Temperature (°F)

0.5% EUL Yield Strength (ksi)

- 1450°F
- 1475°F
- 1500°F

Fig. 1
Fig. 2

The diagram shows the relationship between tempering temperature (°F) and ultimate tensile strength (ksi) for different tempering temperatures: 1450°F, 1475°F, and 1500°F. The tensile strength decreases as the tempering temperature increases.
Typical YT Ratio of Commercially Produced Pipe

Yield/Tensile Ratio

Tempering Temperature (°F)

Fig. 3
Fig. 4

The graph shows the CVN energy absorbed at 32°F (ft-lb) as a function of tempering temperature (°F) for different tempering temperatures: 1450°F, 1475°F, and 1500°F. The graph indicates the relationship between tempering temperature and CVN energy absorbed for these temperatures.
Fig. 5

CVN Energy Absorbed @ -40°F (ft-lb)

Tempering Temperature (°F)

- 1450°F
- 1475°F
- 1500°F
METHOD FOR PRODUCING LINE PIPE
FIELD OF THE INVENTION

[0001] The present invention relates to a method for producing steel line pipe having low yield strength to tensile strength ratio, and particularly to a method for producing steel line pipe by intercritical annealing, quenching and tempering. The invention includes a method for improving the capability of steel line pipe to undergo reeling into coil form and unreeleing therefrom which includes reeling steel line pipe into coil form which has been produced by intercritical annealing, quenching and tempering.

BACKGROUND OF THE INVENTION

[0002] Customers for steel line pipe are interested in acquiring pipe having relatively low yield strength to ultimate tensile strength ratios. The low yield to tensile strength ratio is thought to aid coiling of the pipe for transport. Typically it is desired that the pipe have a yield strength of less than 85 percent of the tensile strength. This requirement is specified so as to accommodate the pipe reeling and unreeleing operations. Normally in prior art commercial production, steel line pipe is heat treated by annealing at a temperature above the A3 temperature to fully austenitize the steel, water quenching and then reheating to a temperature below the A1 temperature to temper the steel. Most current line pipe steels are produced with microalloyed high strength low alloy compositions and frequently result in yield to tensile ratios approaching, and in some cases exceeding, the 0.85 yield to tensile ratio requirement.

[0003] U.S. Pat. No. 3,655,465 discloses steel pipe for oil country goods applications, such as tubing and casing, that has over 90 ksi yield strength and which is rendered less susceptible to sulfide corrosion cracking in sour oil wells through an intercritical heating and tempering treatment. The steel is heated to a temperature within the intercritical A1 to A3 temperature range. Then it is cooled to below the M1 (martensite start) temperature and preferably below the M2 (martensite finish) temperature, reheated to a tempering temperature below the A1 temperature and finally cooled to room temperature. Cooling can be conducted by air, oil quenching, water quenching, etc. Steels containing Ni were found to actually increase in strength after the tempering treatment, more particularly those which also contain at least one temper resistant element, such as up to Mo up to 3%, Cr up to 4%, Si up to 3%, V up to 3%, and W. Tests conducted on C75, AISI 4140 and 4340 steels, as well as 3.5% Ni and 9% Ni alloys, showed a significant increase in sulfide stress corrosion cracking resistance after the intercritical heating and tempering treatment described above.

[0004] U.S. Pat. No. 4,354,882 discloses a process for improving sulfide stress cracking resistance of steel pipe comprising extruding a steel tube of AISI 4130 composition, intercritically annealing the steel tube, cooling, cold sizing and surfacing grinding, intercritically annealing again, and then reheating to fully austenitize, quench and temper the steel tube.

[0005] U.S. Pat. No. 4,938,266 discloses a method of producing steel plate having a low yield ratio, high strength and a dual-phase mixed microstructure of ferrite and second-phase carbide. The method includes heating a slab of low carbon steel or low carbon low alloy steel to a temperature of 950 to 1250°C, hot rolling the slab to plate, rapid cooling the plate to a temperature not exceeding 250°C, reheating to a temperature of A1+20°C to A1+80°C, water cooling and then tempering at a temperature in the range of 200 to 600°C. The reference requires rapid cooling after hot rolling to a temperature not exceeding 250°C prior to reheating to the intercritical temperature range.

[0006] Various line pipe steel compositions are disclosed in U.S. Pat. Nos. 3,692,514 and 3,955,971. Various methods for producing line pipe steels with low yield ratio are disclosed in Abstracts of JP 63-014815, JP 63-250418, JP 63-227715, JP 3-097809, JP 5-088350 and JP 8-337816. JP63-014815 discloses heating steel line pipe to the A3 temperature or above, rapid cooling, stopping cooling when the average temperature in the pipe wall in the thickness direction is between 350 C. to 550 C., and then air cooling. The pipe has low maximum hardness, good sour resistance and low yield ratio. JP63-250418 discloses subjecting seamless pipe after finish hot rolling to water cooling from less than or equal to 600 C. to room temperature at 5-30 C/sec. A yield ratio less than or equal to 85% can be obtained. JP63-227715 discloses production of hot rolled sheet for line pipe. A slab is heated to 1180-1300 C, rough rolled at 950-1050 C. and finish rolled at 760-800 C. The hot rolled sheet is air cooled at 5-20 C/sec to 670 C. and cooled. A yield ratio of less than or equal to 85% is obtained. JP3-097809 discloses seamless pipe after finish hot rolling at a temperature between Ar3 and 900 C. is allowed to cool, and then cooled rapidly from a temperature between just under the Ar1 point and 400 C. down to room temperature. Or finished pipe may be cooled to room temperature, reheated to the austenitizing temperature, allowed to cool, and then cooled rapidly from a temperature between the Ar1 point and 400 C. JP5-088350 discloses subjecting pipe in the final stage of hot piercing continuous rolling to working at 900-700 C. with 3-15% reduction of area. The pipe has a temperature between Ar3–100 C. and Ar3+50 C. after this operation. The pipe is reheated to 900 to 1000 C and subjected to hot finish rolling with an Ar3+50 C. finishing temperature. The resulting pipe is subjected to air cooling from greater than or equal to the Ar3 temperature, or is subjected, after air cooling to heating up to less than or equal to Ar3 and air cooled to undergo a tempering treatment. JP 8-337816 discloses production of low yield ratio steel sheet for line pipe. A steel slab is heated and hot rolled with a finishing temperature of Ar3+30 C. to Ar3, cooled at a mild cooling rate of less than or equal to 10 C/sec for 5 to 10 seconds. The hot rolled sheet is subsequently cooled at a cooling rate of greater than or equal to 15 C/sec and cooled at 400 to 500 C.

DISCLOSURE OF THE INVENTION

[0007] According to the present invention a method for the production of steel line pipe includes providing a steel pipe having a composition consisting essentially of in weight percent: C 0.01 to 0.40, Mn 0.25 to 2.0, P residual to less than 0.5, S residual to less than 0.020, Si residual to 2.0, Cu residual to 1.0, Ni residual to 1.0, Cr residual to 2.0, Mo residual to 1.0, Al 0.010 minimum to less than 1.0, N residual to 0.030, V residual to less than 0.5, B residual to less than 0.02, Ti residual to less than 0.3, and Nb residual to less than 0.3, balance iron and incidental impurities. The pipe is heated to a temperature within the intercritical A1 to A3 temperature range to obtain ferrite and austenite in the microstructure. Preferably the pipe is heated to a tempera-
ture within the intercritical range that is sufficient to obtain between 5 to 90 percent austenite in the microstructure.

Most preferably the pipe is heated to a temperature within the range of 1346 to 1562°F (730 to 850°C) for a time at temperature within the range of 5 to 120 minutes. The pipe is water quenched to a temperature below the Ms (martensite start) temperature at a cooling rate sufficient to cause the austenite present to transform to martensite. Depending on the alloy content of the steel, appropriate cooling rates may range from 1°C/second to 200°C/second. After cooling from the intercritical annealing temperature, the pipe is reheated to a temperature below the A3 temperature for a time sufficient to obtain the desired yield strength, tensile strength and yield strength to tensile strength ratio. The pipe is then air cooled to room temperature. The advantages provided by treating pipe according to the method of the invention are: creation of microstructures capable of achieving yield/tensile ratios of 0.40 to 0.85, while employing commonly available heat treatment facilities.

[0008] In one embodiment the steps of heating to a temperature within the intercritical temperature range, water quenching and reheating to a tempering temperature are performed in-line on a seamless pipe mill. However, the method of the invention may be performed off-line. The method may also be performed on line pipe manufactured by other pipe manufacturing processes.

[0009] The invention also includes a method for improving the capability of steel line pipe to undergo reeling into coil form and unreeing therefrom which includes reeling steel line pipe into coil form which has been produced by intercritical annealing, quenching and tempering.

DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 is a graph of yield strength, as defined by the 0.5% Extension Under Load (EUL) method, vs. tempering temperature for the Example 1 steel after intercritical annealing at three different temperatures, followed by water quenching to room temperature and then tempering at the various tempering temperatures indicated.

[0011] FIG. 2 is a graph of ultimate tensile strength vs. tempering temperature for the Example 1 steel after intercritical annealing, quenching and tempering as referred to with respect to FIG. 1.

[0012] FIG. 3 is a graph of the 0.5% EUL yield strength to ultimate tensile strength ratio vs. tempering temperature for the Example 1 steel after intercritical annealing followed by tempering as referred to with respect to FIG. 1.

[0013] FIG. 4 is a graph of the CVN energy absorbed at 32°F (0°C) in foot-pounds vs. tempering temperature for the Example 1 steel after intercritical annealing followed by tempering as referred to with respect to FIG. 1.

[0014] FIG. 5 is a graph of the CVN energy absorbed at -40°F (-40°C) in foot-pounds vs. tempering temperature for the Example 1 steel after intercritical annealing followed by tempering as referred to with respect to FIG. 1.

[0015] According to the present invention a method for the manufacture of steel line pipe includes providing a steel pipe having a composition consisting essentially of in weight percent: C 0.01 to 0.40, Mn 0.25 to 2.0, P residual to less than 0.5, S residual to less than 0.020, Si residual to 2.0, Cu residual to 1.0, Ni residual to 1.0, Cr residual to 2.0, Mo residual to 1.0, Al 0.010 minimum to less than 1.0, N residual to 0.030, V residual to less than 0.5, B residual to less than 0.02, Ti residual to less than 0.3, and Nb residual to less than 0.3, balance iron and incidental impurities. The pipe may be made by a seamless process or various other pipe manufacturing processes. The process for manufacturing the pipe is not in and of itself critical. Also, the pipe may have been subjected to various prior heat treatments.

[0016] The pipe is heated to a temperature within the intercritical A3 to A3 temperature range to obtain ferrite and austenite in the microstructure. Preferably the pipe is heated to a temperature within the intercritical range that is sufficient to obtain between 5 to 90 percent austenite in the microstructure. Most preferably the pipe is heated to a temperature within the range of 1346 to 1562°F (730 to 850°C) for a time at temperature within the range of 5 to 120 minutes. It is desirable to have austenite within the above range in order to achieve the low yield/tensile ratio, while maintaining yield and tensile strength requirements dictated in common line pipe specifications. With austenite contents outside this specified range, the effect of martensite in reduction of the yield/tensile ratio will not be reliably achieved. Generally, a range of austenite between 5 to 50 percent is satisfactory.

[0017] After cooling from the intercritical anneal temperature, the pipe is reheated to a temperature below the A3 temperature for a time sufficient to obtain the desired yield strength, tensile strength and yield strength to tensile strength ratio. Preferably the pipe is reheated to a temperature within the range of 572 to 1292°F (300 to 700°C). The pipe is then air cooled to room temperature.

[0018] An example of the composition in weight percent of a steel treated in the laboratory according to the invention is set forth in Table 1 below:

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Al</th>
<th>N</th>
<th>V</th>
<th>B</th>
<th>Ti</th>
<th>Nb</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.14</td>
<td>0.98</td>
<td>0.01</td>
<td>0.002</td>
<td>0.24</td>
<td>0.013</td>
<td>0.01</td>
<td>0.06</td>
<td>0.1</td>
<td>0.022</td>
<td>0.004</td>
<td>0.047</td>
<td>0.0001</td>
<td>0.002</td>
<td>0.001</td>
</tr>
</tbody>
</table>

[0019] This steel was commercially produced by the basic oxygen process and ladle refinement. It was continuously cast as round billets, and subsequently rolled to seamless pipe product.

[0020] Samples of the pipe were heat treated in the laboratory in accordance with the invention described herein. Samples were exposed to three intercritical soaking temperatures, 1450°F (788°C), 1475°F (802°C) and 1500°F (815°C).
F. (816°C), and subsequently water-quenched to room temperature. After quenching the samples were sectioned for examination in the as-quenched condition or for tempering. Several tempering temperatures were employed to determine the material response to this process.

FIGS. 1-5 illustrate the performance of the example 1 steel as related to the thermal treatments employed. FIGS. 1 and 2 show that yield strength and tensile strength decline with increasing tempering temperature. FIG. 3 shows that the yield-tensile ratio increases with increasing temperature. However, in all cases the example 1 steel treated in accordance with the invention demonstrated yield-tensile ratio substantially below that of the typical range in prior art commercial production of the alloy employed in this study. The tempering procedure was found to be necessary to achieve acceptable impact toughness performance, as shown in the graph of Charpy V-notch energy absorbed at a 32° F. (0° C.) test temperature. Many customers require 50 foot-pounds energy absorbed, or more, for line pipe products. For the composition of steel employed in this study, tempering temperatures in the range of 1050 to 1150°F. (565 to 620°C) provided the best combination of strength and toughness, while maintaining a yield-tensile ratio substantially less than commonly available with the examined steel chemistry.

What is claimed is:

1. A method for the production of steel line pipe, comprising:

(a) providing a steel pipe having a composition consisting essentially of in weight percent: C 0.01 to 0.40, Mn 0.25 to 2.0, P residual to less than 0.5, S residual to less than 0.020, Si residual to 2.0, Cu residual to 1.0, Ni residual to 1.0, Cr residual to 2.0, Mo residual to 1.0, Al 0.010 minimum to less than 1.0, N residual to 0.030, V residual to less than 0.5, B residual to less than 0.02, Ti residual to less than 0.3, and Nb residual to less than 0.3, balance iron and incidental impurities;

(b) heating the pipe to a temperature within the intercritical $A_s$ to $A_c$ temperature range to obtain ferrite and austenite in the microstructure;

(c) cooling the heated pipe to a temperature below the $M_s$ (martensite start) temperature at a cooling rate sufficient to cause the austenite present to transform to martensite;

(d) after cooling from the intercritical annealing temperature, reheating the pipe to a temperature below the $A_s$ temperature for a time sufficient to obtain the desired yield strength, tensile strength and yield strength to tensile strength ratio; and

(e) then cooling the pipe to room temperature.

2. The method of claim 1, wherein the heating step comprises heating the pipe to a temperature within the intercritical range that is sufficient to obtain between 5 to 90 percent austenite in the microstructure.

3. The method of claim 1, wherein said heating step comprises heating the pipe to a temperature within the range of 1346 to 1562°F. (730 to 850°C) for a time at temperature within the range of 5 to 120 minutes.

4. The method of claim 1, wherein said cooling step (c) comprises cooling the pipe at a rate within the range of $1^\circ$ C./second to 200°C./second.

5. The method of claim 4, wherein said cooling step comprises water quenching the pipe.

6. The method of claim 1, wherein said reheating step (c) comprises reheating the pipe to a temperature within the range of 572 to 1292°F. (300 to 700°C).

7. The method of claim 1, wherein said cooling step (d) comprises air cooling the pipe to room temperature.

8. The method of claim 1, wherein said pipe has a yield/tensile ratio of 0.40 to 0.85 after cooling step (d).

9. The method of claim 1, wherein steps (b), (c) and (d) are performed in-line on a seamless pipe mill.

10. The method of claim 1, wherein steps (b), (c) and (d) are not performed in-line on a pipe mill.

11. The method of claim 1 which further comprises reeling said steel line pipe into coil form.

12. The method of claim 1 wherein said steel line pipe is in coil form, said method further comprising unreeeling said steel line pipe.

13. A method for the production of steel line pipe, comprising:

(a) providing a steel pipe having a composition consisting essentially of in weight percent: C 0.01 to 0.40, Mn 0.25 to 2.0, P residual to less than 0.5, S residual to less than 0.020, Si residual to 2.0, Cu residual to 1.0, Ni residual to 1.0, Cr residual to 2.0, Mo residual to 1.0, Al 0.010 minimum to less than 1.0, N residual to 0.030, V residual to less than 0.5, B residual to less than 0.02, Ti residual to less than 0.3, and Nb residual to less than 0.3, balance iron and incidental impurities;

(b) heating the pipe to a temperature within the temperature range of 1346 to 1562°F. (730 to 850°C) for a time at temperature within the range of 5 to 120 minutes in order to obtain ferrite and austenite in the microstructure;

(c) cooling the heated pipe to a temperature below the $M_s$ (martensite start) temperature at a cooling rate sufficient to cause the austenite present to transform to martensite;

(d) after cooling from the intercritical annealing temperature, reheating the pipe to a temperature below the $A_s$ temperature for a time sufficient to obtain the desired yield strength, tensile strength and yield strength to tensile strength ratio; and

(e) then air cooling the pipe to room temperature.

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