

Effect of Ultra Fast Cooling Coiling Temperature on Microstructures and Properties of X80 Pipeline Steel

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Abstract: Effect of ultra fast cooling coiling temperature on microstructures and properties of X80 pipeline steel was studied adopting the detection means of energy dispersive spectrometer, scanning and transmission electron microscopy. Result shows that the toughness increases with the increasing of ultra fast cooling coiling temperature. The yield strength decreases firstly and then increases with the increasing of ultra fast cooling coiling temperature. The yield strength reaches the minimum value at the temperature of around 350 °C.

1. Introduction

There is a great demand on pipeline steel for oil and gas transmission, especially in P.R.China [1-3] due to its high strength and good toughness[4]. At the present, thermo-mechanical controlled processing (TMCP) is the main manufacturing technology to obtain better performance of X80 pipeline steel with refining grains [5-14]. The basic mean to controlled rolling is that the big pressure rate rolling at low temperature which may beyond the equipment capability.

The core concept in ultra fast cooling which is also called NG-TMCP (new generation thermo-mechanical controlled processing) includes [15]: 1) achieving the strain accumulation in austenite during the continuous rolling at relatively high rolling temperatures; 2) ultra fast cooling after rolling to keep the work hardening of austenite; 3) stop cooling temperature near dynamic phase transition temperature; 4) cooling route control according to the requirements for microstructure and properties of the steel. The present work aims to utilize ultra fast cooling process to produce the X80 pipeline steel and investigate its microstructure characteristics and mechanical properties.

2. Experimental Procedures

The specimens were 17.5 mm-thick plates. The chemical compositions are listed in Table 1. The technical parameters of TMCP for pipeline steel are shown in Table 2. Specimens for tensile tests were taken from the rolled plates in the transverse direction. Tensile tests were conducted at room temperature at a crosshead speed of 5 mm/min on a SHT4106-1000KN servo-hydraulic machine. Drop weight tear test (DWTT) specimens were machined into the dimensions of 75 mm× 17.5mm× 305 mm (T-L). The DWTT test was performed at -15°C using a JL-40000 impact machine. Full size Charpy impact specimens were machined from the rolled plates in the transverse direction with their notch parallel to the rolling direction (T-L), and impact tests were done at temperatures from 20°C to -100 using a ZBC-300C impact machine. Specimens for SEM observations were mechanically polished and etched by a 4 vol% nital solution or a Lepera solution. They were observed by a scanning electron microscope (Quanta 600 SEM). Specimens for transmission electron microscope (TEM, JEM – 2100F) analysis were



mechanically ground to about 50 μm in thickness. Then, these specimens were twin-jet electropolished at a voltage of 40 V. The electrolyte consisted of 10 vol% perchloric acid and 90 vol% glacial acetic acid.

Table 1. Chemical composition of the X80 pipeline steel (wt%)

| C | Si | Mn | Nb | Mo +Cr+ Ti | P | N |
|-----------|---------|---------|-----------|------------|-------------|--------|
| 0.04~0.06 | 0.2~0.3 | 1.7~1.9 | 0.06~0.10 | 0.60~0.70 | ≤ 0.02 | 0.0073 |

Table 2. The rolling process parameters for X80 pipeline steel

| Code | Recrystallization zone rolling stage | Non recrystallization zone rolling stage | | Ultra fast cooling stage | | Laminar cooling stage | |
|------|---|--|---|-------------------------------------|---|--|---|
| | Start blooming rolling temperature $^{\circ}\text{C}$ | Start finishing rolling temperature $^{\circ}\text{C}$ | Finishing exit temperature $^{\circ}\text{C}$ | Exit Temperature $^{\circ}\text{C}$ | Cooling rate, $^{\circ}\text{C}/\text{s}$ | Coiling temperature $^{\circ}\text{C}$ | Cooling rate, $^{\circ}\text{C}/\text{s}$ |
| 1# | 1050 | 940 | 840 | 650 | 40 | 450 | 8 |
| 2# | 1050 | 940 | 840 | 650 | 40 | 400 | 8 |
| 3# | 1050 | 940 | 840 | 650 | 40 | 350 | 8 |
| 4# | 1050 | 940 | 840 | 650 | 40 | 320 | 8 |

3. Results

3.1. Mechanical Properties

Mechanical properties are shown in Table 3. It is seen that the mechanical properties of all specimens meet the requirements of X80 pipeline steel standard. The yield ratio of Specimen 3# is the lowest. Result of drop weight tear test are shown in Table 4. It can be seen that all specimens' DWTT datum meet the requirements of X80 standard. Tear area of Specimen 4 # is relatively small. Full size Charpy impact test results are shown in Table 5. It is concluded that all specimens' mechanical properties meet the requirements of X80 standard.

Table 3. Tensile properties of X80 pipeline steel

| code | $R_{t0.5}$, MPa | R_m , MPa | A_{50} , % | $R_{t0.5}/R_m$ |
|------|------------------|-------------|--------------|----------------|
| 1# | 652 | 720 | 38 | 0.91 |
| 2# | 645 | 735 | 38 | 0.88 |
| 3# | 635 | 745 | 37 | 0.85 |
| 4# | 660 | 760 | 37 | 0.87 |

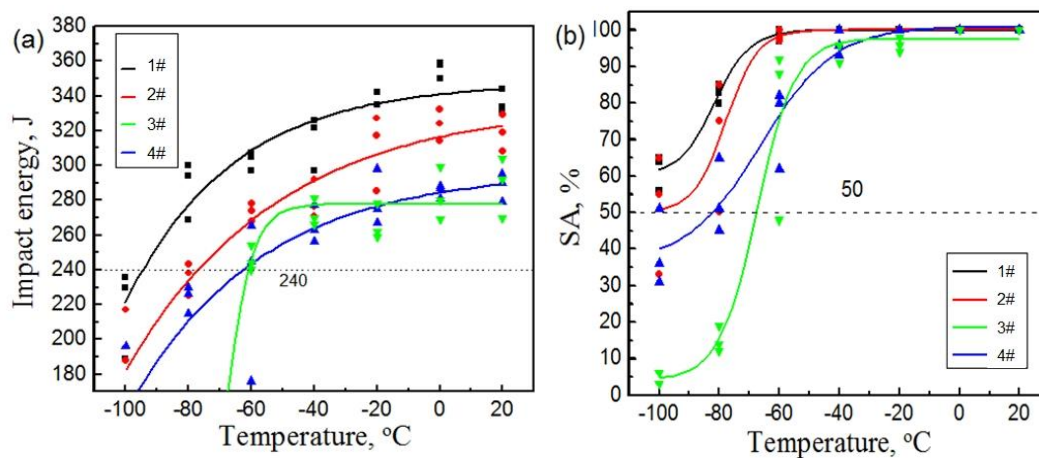
Table 4. DWTT of X80 pipeline steel

| Code | SA/% |
|------|------|
| 1# | 95 |
| 2# | 92 |
| 3# | 90 |
| 4# | 88 |

Table 5. CVN of X80 pipeline steel

| temperature code | | 1# | 2# | 3# | 4# |
|------------------|-------|-----|-----|-----|-----|
| 20°C | CVN/J | 336 | 288 | 288 | 289 |
| | SA /% | 100 | 100 | 100 | 100 |
| 0°C | CVN/J | 356 | 285 | 287 | 283 |
| | SA /% | 100 | 100 | 100 | 100 |
| -20°C | CVN/J | 337 | 280 | 267 | 259 |
| | SA /% | 100 | 100 | 100 | 94 |
| -40°C | CVN/J | 315 | 265 | 256 | 252 |
| | SA /% | 100 | 93 | 93 | 94 |
| -60°C | CVN/J | 303 | 229 | 245 | 254 |
| | FA /% | 97 | 80 | 80 | 92 |
| -80°C | CVN/J | 288 | 224 | 215 | 21 |
| | SA /% | 83 | 51 | 51 | 9 |
| -100°C | CVN/J | 227 | 155 | 196 | 13 |
| | SA /% | 65 | 51 | 51 | 4 |

From Figure1, it is observed that the impact energy of the 4# specimens under -60 °C that can satisfy the requirements of technical conditions.

**Figure 1.** X80 pipeline steel impact toughness

3.2. Microstructure Characteristics

Figure2 shows SEM micrographs of the X80 pipeline steel. It can be seen microstructure of Specimen1 # is relatively bulky, There is a small amount of polygonal ferrite(PF) and M/A islands in the microstructure, Specimen 2 # mainly acicular ferrite tiny evenly, Most of M/A islands are small and evenly distributed, microstructures of Specimens 3 # and 4 # are fine, acicular ferrite matrix grain boundary in the mutual crisscross.

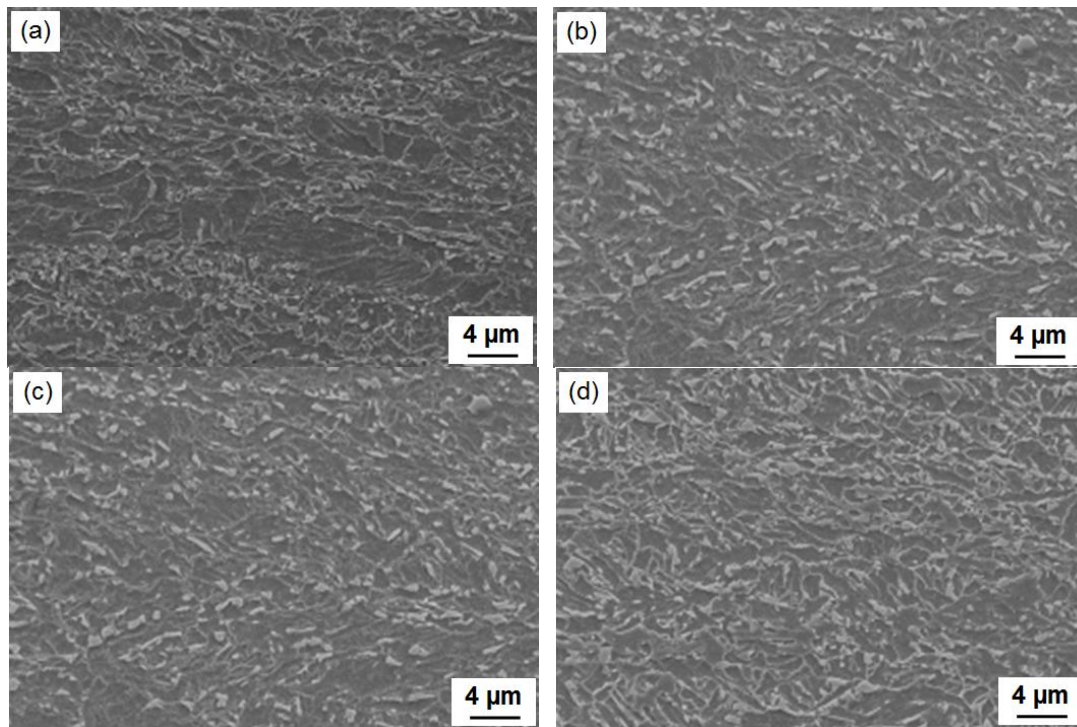


Figure 2. X80 pipeline steel impact toughness

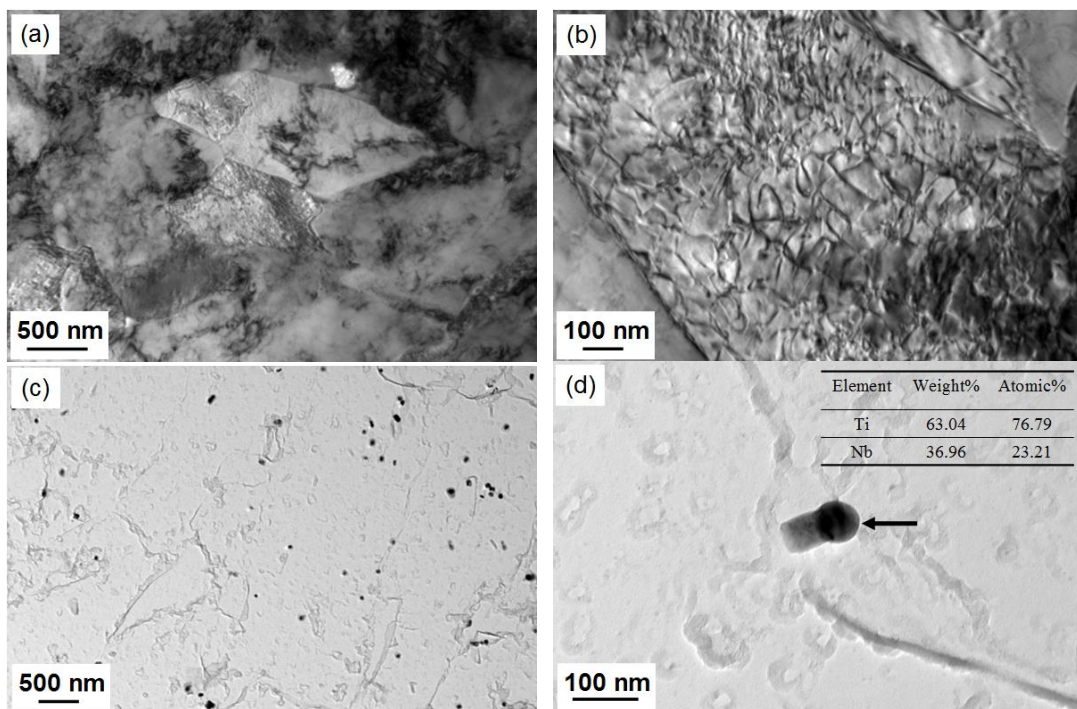


Figure 3. Specimen 2 # TEM observations

Figure 3 gives the microstructure morphology of Specimens2# and 4# for X80 pipeline steel using TEM observation.

It is seen that Specimen 2 # dislocation is developed, while precipitation is less. The size precipitation is relatively fine and uneven distributed. The types of precipitation is Ti, Nb carbonitride precipitation.

It can be known that Ti content is higher in rectangular particle, Nb content is higher in round particles. Nb/Ti ratio is 0.3.

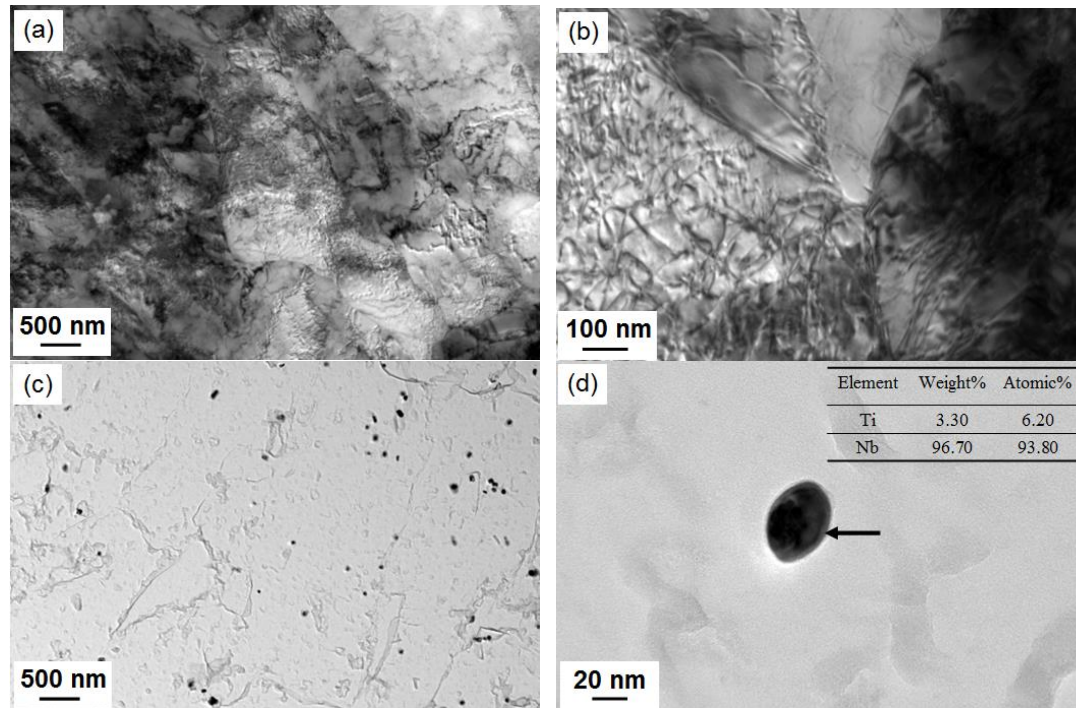


Figure 4. Specimen 4 # TEM observations

The grain boundary of Specimen 4 # has plenty of dislocation which is widely distributed in the range of observation. Figure 4(c) shows that most precipitation particle size is small (around 30nm), and Figure 4 (d) shows a single round particle whose types of precipitation are Ti, Nb carbonitride precipitation composite. Most precipitation particle size is smaller, most typical particles as shown in the picture on the right around 30 nm. A single round particles can be observed, types of precipitation mostly Ti, Nb carbonitride precipitation composite. Through the EDS analysis It can be known that Nb content is high in circular particle Ti content is low and Nb/Ti ratio of 15.1.

4. Discussion

4.1. Relationship between X80 Pipeline Steel Coiling Temperature and Mechanical Properties

The coiling temperature of the samples are shown in table 2. It is seen toughness increases with the increase of coiling temperature, and the yield strength decreases firstly and then increases for X80 pipeline steel. Moreover, at about 350 °C, the lowest yield strength presents, yield ratio firstly decreases and then increases with the rising of coiling temperature. Comprehensive analysis shows that coiling temperature at about 400 °C can deliver better comprehensive mechanical properties.

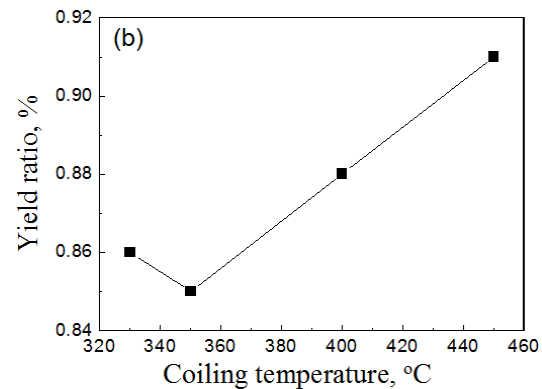
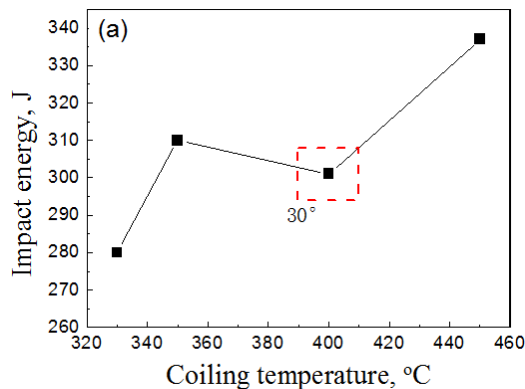


Figure 5. impact toughness to the coiling temperature **Figure 6.** yield ratio to the coiling temperature

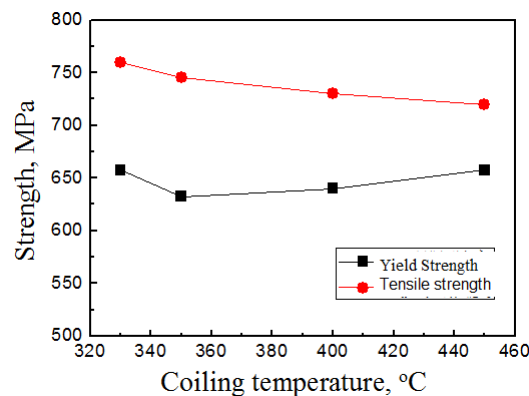


Figure 7. yield strength, tensile strength to the coiling temperature

4.2. Relationship between X80 Pipeline Steel Cooling Rate and Mechanical Properties

The cooling speed is greater than 30 degrees per second to ensure the passing through in austenite region in a tiny period of time, which results in work hardened austenite before transformation, which can lay a solid foundation for the control of phase transformation in work hardened state. The faster the cooling rate, the finer the microstructure can be obtained. Microstructure 1 # relatively is bulky.

As compared with the microstructure observation, it is seen that the M/A island near dislocation plug and launch dislocation phenomenon, dislocation in grain boundary caused the grain of work hardening and grain boundary of stress concentration. In addition, precipitation particle counterpoint dislocation pinning effect is significant. And with the increase of coiling temperature, precipitation particles get more and more, and also gradually become evenly distributed. But with the increase of coiling temperature, precipitation particle size increases gradually.

5. Conclusions

The relation between microstructure characteristics and mechanical properties of X80 pipeline steel by ultra fast cooling process was researched, and the following conclusions are drawn.

a) As the coiling temperature increases, so does the impact toughness of X80. Its yield strength decreases first and then decreases, the lowest point presents at around 350 °C, and yield ratio first decreases and then increases with the rising of coiling temperature. Comprehensive analysis shows that, at coiling temperature of about 400 °C, better comprehensive mechanical properties can be achieved.

b) Cooling speed is greater than 30°C/s to ensure the passing through in austenite region in a tiny period of time, resulting in work hardened austenite before transformation, which can lay a solid foundation for the control of phase transformation in work hardened state. The faster cooling rate, the finer microstructure.

c) Types of precipitation are mostly Ti, Nb carbonitride precipitation composite. The EDS analysis shows that Ti content is higher in rectangular particle, Nb content is higher in round particles.

d) With the increasing of coiling temperature, precipitation particles get more and more, and also gradually become evenly distributed. But with the increase of coiling temperature, precipitation particle size increases gradually.

6. Acknowledgments

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