Research of heavy wall X65MOS submarine pipeline steel key process strategy

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Abstract. In recent years, there has been development of several significant pipeline projects for the transmission of oil and gas from deep water environments. The production of gas transmission pipelines for application demands heavy wall, high strength, good lower temperature fracture toughness, low yield ratio and good corrosion resistance. To overcome the difficulties of producing excellent performance in heavy wall X65MOS pipe Shougang Steel Research in cooperation with the Shougang Steel Qinhuangdao China (Shouqin) 4.3m heavy wide plate mill research was conducted. This paper describes the background, composition design, key process strategy to produce excellent performance in heavy wall X65MOS plate. The importance of recrystallized rolling process, the tensile property change during pipe making and the corrosion resistance change by "pre-stretching + bend" deformation simulate pipe making in the lab will be discussed. The results showed the per pass reductions during recrystallized rough rolling should be increased in a steady fashion, with special emphasis on the reduction of the final two roughing pass prior to the intermediate hold (transfer thickness for finishing) should be more than 20%. The tensile properties change rule and the reasonable pipe expansion process should be determine during pipe making. The crack length ratio(CLR) internal control criteria of the plate should be less than 6%, it helps to ensure the HIC performance of the pipe can meet the technical specification(CLR≤15%).

1. Introduction

With the development of economy and society, the demand for oil and natural gas are increasing progressively throughout the world[1, 2]. However, the reserves of oil and gas on the land have been reduced and the cost of oil and gas extraction has been gradually increasing, so the development of offshore oil and gas is a means to replace the reduction of reserves on land. Compared with pipeline projects on land, it was urgent to develop the submarine pipeline system to keep up with the offshore development effort. Because of the severe environment of submarine pipeline systems, the steel pipes used for the pipeline should be provided with other comprehensive properties, such as, heavy wall thickness (35–48mm), small diameter-thickness ratio (minimum 17.07), longitudinal tensile property, crack tip opening displacement (CTOD), corrosion resistance, crushing resistance to high pressure, and so on. For example, the water depth of the Middle East-India pipeline is 3500m. To prevent collapse of the pipeline at this depth from an ambient external pressure of about 350bars, the pipeline to be used has to meet severe requirements.
2. Alloy design

The submarine pipeline steel of heavy wall X65MOS was developed at Shougang Steel’s 4.3m heavy wide plate mill in Qinhuangdao China (Shouqin). For high grade and thick-walled pipeline plates, how to control the balance between the strength, the toughness and the weldability is very important.

According to the equipment characteristics of Shougang 4.3m heavy wide plate mill and the requirements of X65MOS pipe, an alloy composition design concept consisting of low C, moderate Mn, and moderate levels of Nb-Mo-Ni-Cr was developed. Steelmaking processing utilized clean steel melting technology in order to decrease the content of sulfur, phosphorus, nitrogen, oxygen, hydrogen. Table 1 shows the chemical composition used for X65MOS pipeline steel development.

In addition, clean steel practices along with slab casting soft reduction technology resulted in excellent internal inclusion cleanliness and centerline chemical segregation control. This helps to ensure good performance in production a fine grain, dislocation strength and phase transformation strength, etc [3,4].

Table 1. Chemical composition of heavy wall X65MOS pipeline steel (wt%)

|   | C    | Si   | Mn   | P     | S     | N     | Nb   | Mo   | Ni   | Cr   |
|---|------|------|------|-------|-------|-------|------|------|------|------|
|   | 0.04 | 0.20 | 1.35 | 0.008 | 0.002 | 0.004 |       |      |      |      |

3. Processing Strategy

Based on the final plate thickness, low temperature fracture toughness and good corrosion resistance requirements of the X65MOS plate, the Shouqin 4.3m heavy wide plate mill technical group elected to use slabs with 400 mm x 2400 mm (largest slab that can be produced at Shouqin) to minimize the broadside (width) ratio while optimizing the total metallurgical reduction ratio. In addition, the recrystallized rolling process of X65MOS plate was carefully controlled, the tensile properties change during pipe making and the corrosion resistance change by "pre-stretching + bend" deformation simulate pipe making in the lab will be discussed.

3.1. Recrystallized rolling process

The whole rolling passes consists of roughing passes and finish passes. To address potential issues in producing consistent low temperature toughness in heavy wall X65MOS plate, it should also be noted that the first few deformations passes in the rough rolling stage are mainly focused on creating proper final plate dimensions and hence only work the surface of plate. During the early roughing stage rolling the center region of the slab does not receive full mill force penetration to properly condition the cross sectional austenite grains, so the latter passes of the rough rolling stage must be of sufficient deformation achieve good conditioning of the austenite grain through the entire cross section of the plate [5,6]. Hence an optimal rolling deformation distribution strategy can be seen in Figure 1.

The optimal reduction schedule is shown in Figure 1, the per pass reduction of rough rolling schedule increased at a steady rate with the largest reductions of more than 20% occurring in the final two roughing passes with the absolute largest reduction in the final roughing pass.

![Figure 1. Optimal rolling deformation strategy](image-url)
3.2. Mechanical properties change during pipe making
Considering the round bar specimens of heavy wall submarine pipeline in transverse and longitudinal direction were taken from the pipe sample directly, that is to say, they do not need to be flattened, so that the yield strength should not decrease because of no Bauschinger effect, however the yield strength should be increase during the bending and expanding process of the pipe. Moreover, for the submarine pipeline with heavy wall and small diameter, the deformation hardening effect is very significant, so the yield strength of the round bar sample should be increased greatly. As mentioned above, it should be noted that there is an expected upward shift in yield ratio during pipe making, even exceeds the pipe technical specification. For this problem, a comparative analysis of the tensile properties during the industrial pipe making trial of 47.6mmX65MOS steel plates by JCOE processing was performed with the results shown in Figure 2. For the heavy wall X65MOS submarine pipeline, the best internal control range of tensile properties in transverse and longitudinal can be determined during subsequent mass production.

Figure 2 shows the tensile properties change of 47.6mm X65MOS during pipe making. For the transverse tensile properties, the yield strength upward shifts an average of 66MPa, the tensile strength no change, the yield ratio upward shifts an average of 0.10. In addition, For the longitudinal tensile properties, the yield strength upward shifts an average of 90MPa, the tensile strength also no change, the yield ratio upward shifts an average of 0.14.

3.3. The corrosion resistance change during simulate pipe making in the laboratory
In the laboratory, a "pre-stretching + bending" deformation was used to simulate the JCOE processing, which was helpful to research the effect of pipe deformation on the HIC performance, in order to master the changes of HIC performance during pipe making. Effectively determine the plate HIC performance indicators that ensure the HIC performance of the pipe can meet the technical specifications. More importantly, the stable production and quality risk can be guaranteed effectively.

Two transverse sample were taken from the heavy wall X65MOS plate at the same position, one sample was deformed by "pre-stretching + bending "deformation in laboratory, then two set of HIC samples were taken from the undeformed plate sample and the pipe sample with "pre-stretching + bending" deformation respectively. Moreover, according to the NACE TM0284-A solution specifications, the HIC performance tests were performed to obtain the hydrogen-induced crack length ratio (CLR) during pipe making. The corresponding relationship of HIC performance between the plate and pipe shown in Figure 3.

As can be seen in Figure 3, the crack length ratio(CLR) internal control criteria of the plate should be less than 6%, it helps to ensure the HIC performance of the pipe can meet the technical specification(CLR≤15%).
4. Conclusions
The Shougang Steel Qinhuangdao China (Shouqin) 4.3m heavy wide plate mill has successfully developed the heavy wall X65MOS plates for the deepwater pipeline with excellent performance. According to the research of 47.6mm X65MOS submarine pipeline key process strategy, the following conclusions can be drawn:

1) The per pass reductions during recrystallized rough rolling should be increased at a steady rate, with special emphasis on the reduction of the final roughing pass prior to the intermediate hold (transfer thickness for finishing). The final two roughing passes should have a per pass reduction of more than 20%.

2) The change of tensile properties during the industrial pipe making trial by JCOE processing was researched, the yield strength in transverse and longitudinal upward shift an average of 66MPa and 90MPa respectively. In addition, the yield ratio in transverse and longitudinal upward shift an average of 0.10 and 0.14 respectively.

3) The corresponding relationship of HIC between the plate and pipe was researched by "pre-stretching + bend" deformation simulate pipe making in the lab, when the crack length ratio (CLR) internal control criteria of the plate should be less than 6%, the HIC performance of pipe can meet the technical specification (CLR≤15%).

References
[1] Siciliano, F. (2008) Modern High Strength Steels for Oil and Gas Transmission Pipelines. In: 7th International Conference on Pipeline. Calgary. pp. 29-35.
[2] Petersen, C. (2004) Improving Long Distance Gas Transmission Economics. In: International Conference on Pipeline Technology. Ostend. pp. 47-51.
[3] Stalheim, D. Barnes, K. McCutcheon, D. (2006) Alloy Designs for High Strength Oil and Gas Transmission Linepipe Steels. In: CBMM-TMS International Symposium Microalloyed Steels for the Oil & Gas Industry. Araxa. pp. 83-89.
[4] Stalheim, D. (2011) Slab and Level 2 Automation Design Guidelines for Optimum Metallurgy and Productivity for Plate and Steckel Mills. In: Proc. of 6th International Conference on High Strength Low Alloy Steel Chinese Society for Metals. Beijing. pp. 126-133.
[5] Stalheim, D. (2011) Fundamentals of the Generation of Fine Grain As-rolled Structural Steels. In: Proc. AIST International Symposium on the Recent Developments in Plate Steels. Colorado. pp. 25-32.
[6] Ding, W.H. (2012) Research and Development into Low Temp Toughness of Heavy Wall X80 at Shougang. In: 9th International Conference on Pipeline. Calgary. pp. 117-121.