China Steel Technical Report, No. 23, pp. 78－82, (2010)

Development of Hot-Rolled Extra Thick Steel Coil for Pipe Piles

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China Steel Corporation (CSC) finished the equipment revamping of laminar cooling ability and heavy duty down coiling of #1HSM in 2004 to develop hot rolled coil products of extra thick steels. When the techniques of low carbon equivalent design, heavy duty down coiling, precise laminar cooling, optimum cooling pattern, heavy reduction in the finishing mill, and low temperature rolling were applied to meet the quality requirements, hot rolled extra thick steel coils with good weldability, good coil shape, suitable tensile properties, uniform microstructure throughout the thickness direction, and good impact properties attributed to fine grain microstructure have been produced. In 2009, CSC successfully commercialized high strength structural steels with 16-25mm thickness, which were manufactured into spiral pipes used for projects of public construction, such as pipe piles for boardwalks and expressways under the sea.

1. INTRODUCTION

With the strong demand for extra thick steel coil in south east Asian countries since the fourth quarter of 2008, CSC finally commercialized high strength structural steels with 16-25mm thickness.

The major qualities to fulfill the specification of public construction are good weldability, good coil shape, suitable tensile properties, and good impact properties.

1.1 Good weldability

For good weldability, low carbon equivalent design is beneficial.

1.2 Good coil shape

For good coil shape, the defects of protruding wraps and loosely wrapped coil need to be avoided.

1.3 Suitable tensile properties

Uniform tensile properties along thickness, transverse, and longitudinal directions are important for good spiral forming, so we must adjust optimum cooling pattern, side spraying system, and coiling temperature (CT) to get a uniform microstructure and the desired tensile properties. To control the CT along the longitudinal direction is not easy, so the speed of strip should be almost constant during the laminar cooling. Tensile properties and impact properties greatly rely on CT, so a suitable CT is needed to get the optimum combination of mechanical properties.

1.4 Good impact properties

The most difficult issue is to obtain good impact properties because it is not easy to minimize the microstructure of extra thick steels in the HSM (Hot Strip Mill). The TMCP (Thermo Mechanical Control Process) process is the major way to minimize the microstructure. The process includes adding micro-alloying elements like Nb to elevate the recrystallization temperature [1,3], low temperature rolling [4,5], large thickness reduction [5-7], and accelerated cooling [8] after rolling. Usually the HSM is designed to be a compact processing line, and seldom deals with transfer bars thicker than 50mm, so to greatly lower temperatures between the furnace and the finishing rolling processes becomes a serious problem. Forcible cooling or low temperature rolling will result in a rolling problem of a weak roughing mill and an irregular shape of the transfer bar. Unlike the plate mill, there is not sufficient time to wait until a specified low temperature is achieved for the subsequent thermo controlled rolling (TCR) to get good toughness unless the process is slowed down which would greatly reduce the production. However these difficulties must be overcome to get good impact properties. And the accelerated cooling (ACC), of which #1HSM is capable, will also be discussed.

2. EXPERIMENTAL PROCEDURES

2.1 Chemical Compositions

The experimental steels were made by the BOF-LF process and continuously cast into slabs of 250-270mm thickness. The chemical compositions of BS EN10025-2 S355J0/R steels are shown in Table 1. Nb was added for fine grain strengthening, so that the content of C and Mn could be lowered, which should result in lower CEV (Carbon Equivalent) for good weldability and good impact properties. The content of P and S were also lowered to achieve good mechanical properties.

2.2 Hot Rolling Processes

The slabs were heated and soaked at 1160°C-1290°C, and then hot rolled in CSC #1HSM. The details of the hot rolling processes are shown in Fig. 1. Reheated slabs were rolled to 40-65mm thickness transfer bars by the roughing mill, and then rolled to 16-25mm thickness strips by the finishing mill. The finishing exit temperature was within 810-920°C. After finishing rolling, the strip was cooled on ROT (Run Out Table). CT (Coiling Temperature) was between 570-710°C.

2.3 Tensile Test and Impact Test

Test pieces were taken at the quarter position of width JIS #1A tensile test specimens with gauge length size 40mm W * 200mm L were used. Full-sized charpy v-notched specimens were subjected to impact test to measure toughness.

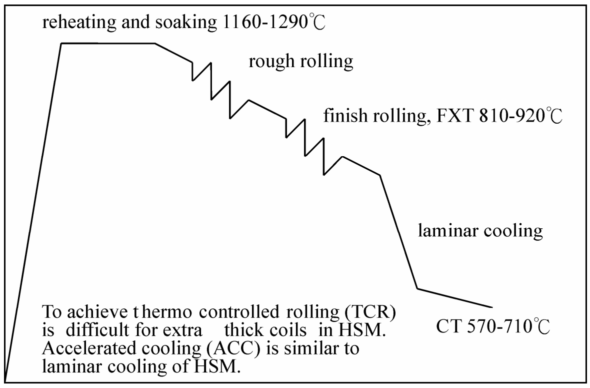

Fig. 1. Details of the hot rolling process.

2.4 Microstructure Observation

Test pieces were taken at the quarter position of width. Specimens were processed according to standard metallographic procedures. The microstructure characteristics were observed using optical microscope.

3. RESULTS AND DISCUSSION

3.1 Accomplishment of Shape of Steel Coils

The common defects of extra thick steel coils are protruding wraps as shown in Fig. 2a and loosely wrapped coil as shown in Figure 2b. With proper down coiling process parameters, such as pinch roll force and wrapper roll force, and improved guiding and straightening abilities for the unwrapped strip, the protrusion of wraps can be controlled to within 70mm. Loosely wrapped coils resulting from the expansion of coil itself could be improved by a strong braking system being applied when the coil tail end comes into the down coiler. The correct accomplishment of the coil shape is shown in Fig. 2c.

Table 1 Chemical compositions of BS EN10025-2 S355J0/R (wt%)

	C	Mn	P	S	Si	Nb	CEV
Spec.	0.23 max	1.70 max	0.040 max	0.040 max	0.60 max	-	0.45max
Aiming	0.09	1.10	0.025 max	0.005 max	0.06 max	0.025	0.27

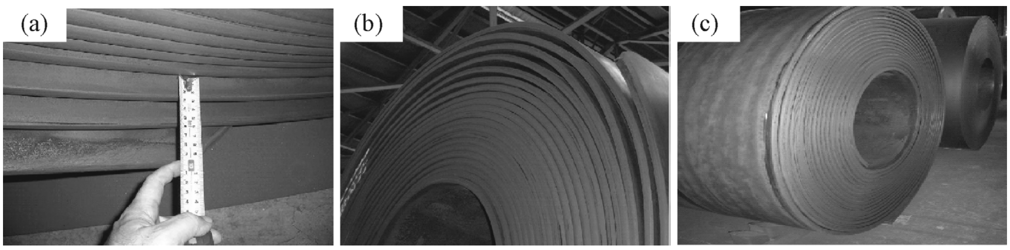

Fig. 2. (a) Protruding wraps. (b) Loosely wrapped coils. (c) Good coil shape of 25mm gauge product.

3.2 Effect of Cooling Pattern on Microstructure and Mechanical Properties

Firstly we tested the ratio of 1:1 for the top and bottom water spray of the laminar cooling process, and found variations in the microstructure throughout the thickness direction, as shown in Fig. 3(a, b, c). Figure 3a shows a benite structure for the top quarter thickness position, while Fig. 3c shows a pearlite structure for the bottom quarter thickness position. The steel showed a non-symmetric and abnormal fracture contour after the tensile test as shown in Fig. 4a. We then modified the ratio of 1:2 for the top and bottom water spray and got a uniform microstructure throughout the thickness direction, as shown in Fig. 3(d, e, f), with the fracture contour also being good, as shown in Fig. 4(b, c).

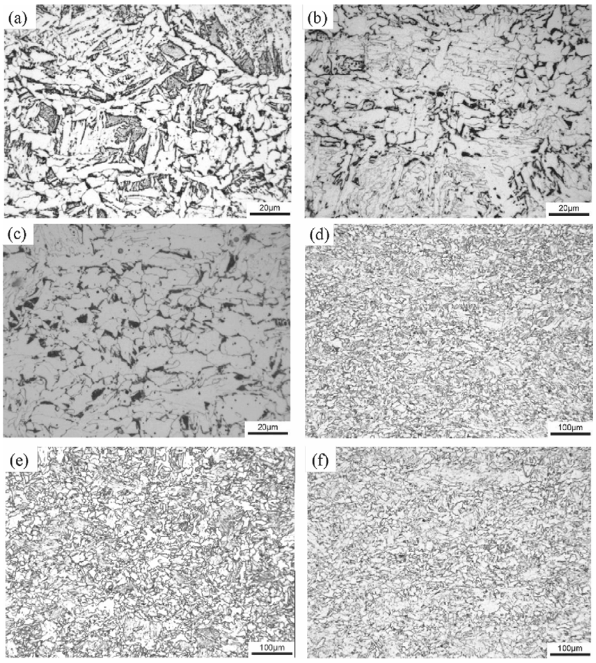

Fig. 3. (a)-(c) Microstructure by the ratio of 1:1 for the top and bottom water spray. (a) Benite structure for top quarter thickness position. (b) Central thickness position. (c) Pearlite structure for bottom quarter thickness position. (d)-(f) The microstructure by the ratio of 1:2 for the top and bottom water spray. (d)-(f) are all uniform benite structure through thickness direction.

3.3 Effect of CT on Microstructure and Mechanical Properties

Higher CT results in coarser microstructure (Figure 5a; sample B), lower strength, higher elongation, and poor toughness as shown in Table 2. Lower CT results in finer microstructure (Figure 5(b, c, d); samples A, C), high strength, lower elongation, and good toughness as shown in Table 2. Due to the engineering safety, we were concerned not only with the tensile properties but also with the impact properties although the lower toughness still can comply with the requirement of the specification, so there should be an optimal CT to get suitable tensile properties and not to deteriorate impact properties.

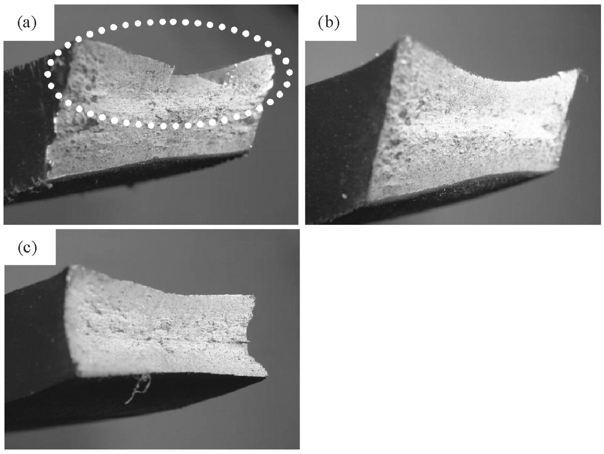

Fig. 4. (a) Non symmetric and abnormal fracture contour after tensile test by the ratio of 1:1 for the top and bottom water spray. (b)-(c) Symmetric and abnormal fracture contour after tensile test by the ratio of 1:2 for the top and bottom water spray.

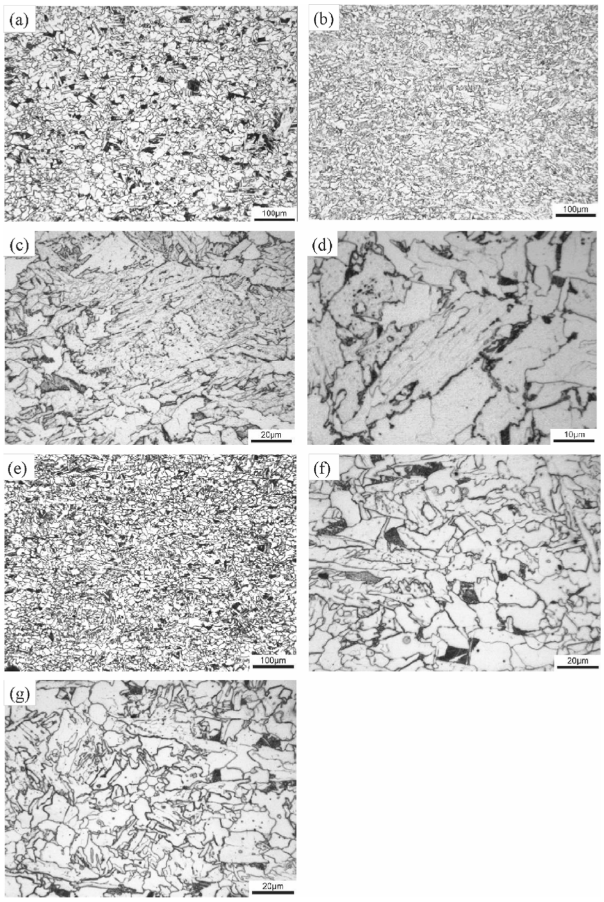

Fig. 5. (a) Higher CT results in coarser microstructure. (b)-(d) Lower CT results in finer microstructure. (e)-(f) Higher reduction ratio results in fine microstructure. (g) Higher reduction ratio and lower furnace temperature results in finer microstructure.

Table 2 The process parameters and mechanical properties

Item/ Sample	Spec.	Thickness	Bar Thick-ness	Reduction ratio	SRT	FT	CT	Tensile properties			Impact properties			Micro-structure	
											20°C	0°C			
								YS (MPa)	TS (MPa)	EL (%)	A.E. (J)	A.E. (J)	S.A. (%)	Phase	ASTM #
		mm	mm		°C	°C	°C	345 min	470~ 630	19.2 min	27 min	27 min	---	---	---
A	S355J0	25	41	1.6	1269	894	597	435	530	20.1	----	251	66	B	12
B		25	40	1.6	1235	882	677	393	486	23.2		86	11	F+P+B	11
C		25	41	1.6	1265	889	601	436	523	18.1		245	69	B	12
D		25	41	1.6	1198	838	650	416	507	21.9		62	10	F+P+B	11
E		25	64	2.6	1245	861	680	375	488	25.8		139	67	F+P	11.5
F		25	65	2.6	1219	849	658	412	511	23.1		160	71	F+P	12
G		25	65	2.6	1195	835	646	418	515	21.9		171	---	F+P	12
H	S355JR	22	50	2.3	1256	850	664	412	510	21.9	170	165	---	F+P	12
I		22	49	2.2	1262	886	626	411	514	21		67	---	F+B+P	11.5
J		22	50	2.3	1256	878	647	427	519	21		110	---	F+P	12
K		22	49	2.2	1259	858	652	425	520	21.9		120	---	F+P	12
L		16	40	2.5	1270	880	659	437	527	19.1	220	204	73	F+B+P	12
M		16	40	2.5	1255	885	666	429	517	20.1		190	74	F+B+P	12

Note: A.E. is absorbed energy. S.A. is shear area.

3.4 Effect of Finishing Mill Thickness Reduction Ratio and Furnace Temperature on Microstructure and Mechanical Properties

In order to get a finer microstructure, different finishing mill thickness reduction ratios and furnace temperatures were tested. Firstly, a higher reduction ratio results in a fine microstructure (Figure 5(e, f), samples E, F) and good toughness, as shown in Table 2. Secondly, a higher reduction ratio and lower furnace temperature results in a finer microstructure (Figure 5(g), sample G) than in Figure 5(e, f) and gets even better toughness, as shown in Table 2.

With a lower furnace temperature, the subsequent process temperatures, such as finishing exit temperature, will also be lower, known as low temperature rolling. Sample D was processed with a low furnace temperature but low reduction ratio and got poor toughness. So, a higher finishing mill thickness reduction ratio with low temperature rolling is useful to enhance toughness. And the effectiveness to enhance toughness ranked as follows:

High finishing mill thickness reduction ratio＞Low temperature rolling (5).

3.5 Best Process to Fulfill all the Requirements of BS EN 10025-2 S355J0/R

Under same processes, the absorbed energy deteriorates when thickness increases. So, maintaining a good toughness of extra heavy gauge products becomes a very important issue. The effectiveness to enhance toughness ranks as follows:

Low CT＞High finishing mill thickness reduction ratio＞Low temperature rolling

Because lower CT will greatly deteriorate elongation property, we use moderate CT and put great effort into elevating toughness by the processes of the higher finishing mill thickness reduction ratio and low temperature rolling. The best combination of the aimed processes for 25mm thickness is of lower SRT:1190°C, lower FXT:840°C, moderate CT:650°C, and finishing mill thickness reduction ratio 2.5 minimum.

4. CONCLUSIONS

Good coil shape was accomplished. The effects of hot rolling parameters and cooling parameters on the mechanical properties and microstructures of hot rolled high strength steels of extra thickness were investigated. Main results for BS EN-10025-2 S355J0/R are as follows:

(1) With heavy duty down coiling, proper process parameters such as pinch roll force and wrapper roll force, and improved guiding and straightening abilities of unwrapped strip, the protrusion of wraps can be controlled to within 70mm.

(2) The ratio of 1:2 for the top and bottom water spray of the laminar cooling process results in uniform microstructure and mechanical properties throughout the thickness direction.

(3) The absorbed energy deteriorates when the thickness increases. Finer microstructure is helpful to enhance toughness. The effectiveness to enhance toughness ranks as follows:

Low CT＞High finishing mill thickness reduction ratio＞Low temperature rolling

(4) Low CT will greatly deteriorate the elongation property. The processes of higher finishing mill thickness reduction ratio and low temperature rolling are the best ways to enhance toughness.
(5) With moderate CT and the processes of higher finishing mill thickness reduction ratio and low temperature rolling, the best combination of tensile and impact properties is achieved.

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