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Development of New Heavy-Gauge Steel Plate Using Cladding Technology†

1. Introduction

Most heavy-gauge plates are currently produced from ingots. However, the time required for this process is long due to the complex process, which includes ingot casting, breakdown rolling, and hot rolling. Although heavy-gauge plates can be produced from continuous casting slabs (CC slabs), the thickness of heavy-gauge products is restricted with CC materials because the reduction ratio in hot rolling is limited by the maximum CC slab thickness and it is necessary to ensure the internal integrity of the material.

JFE Steel previously developed a low-speed, high-reduction rolling technique for the plate mill[1)], an evacuation method which protects the bonding interface from oxidation[2)], and surface control techniques which include securing suitable surface conditions for bonding and the selection of insert materials. The comprehensive development of these technologies has made it possible to produce high-performance clad steel plates with stainless steel and commercially-pure titanium as the cladding metal. Using these technologies, JFE Steel has produced approximately 150 000 t of clad steel plates during the past decade.

Recently, JFE Steel developed a production technology for a new heavy-gauge steel plate based on cladding technology. In the new technology, CC slabs are stacked and assembled into a multi-layer slab, and are then bonded by the above-mentioned cladding techniques, thereby expanding the thickness range of heavy-gauge plates produced from CC slabs. This report describes a new heavy-gauge plate with a thickness of 270 mm and performance equal to JIS SS400.

2. Features of New Heavy-Gauge Plate

2.1 Production Process and Size

Figure 1 is a schematic illustration of the production process for the new heavy-gauge plate. The surface of the CC slabs is conditioned to be suitable for bonding. A multi-layer slab is then made up and assembled by welding, and the CC slabs are hot rolled to produce a single plate. A low-speed, high-reduction rolling technique developed by JFE Steel is used to bond two slabs in the hot rolling process. Because this technique increases the stress in the mid-thickness portion of the multi-layer slab in comparison with the conventional rolling, it is advantageous for firm bonding, even with a relatively smaller total reduction ratio in the hot rolling process (**Fig. 2**).

JFE Steel successfully produced a new heavy-gauge plate with the thickness of 270 mm, the width of 1 800 mm, and the length of 5 000 mm using two stacked slabs with individual thicknesses of 250 mm. Except for the existence of the bonding interface, the properties of the product satisfy JIS SS400.

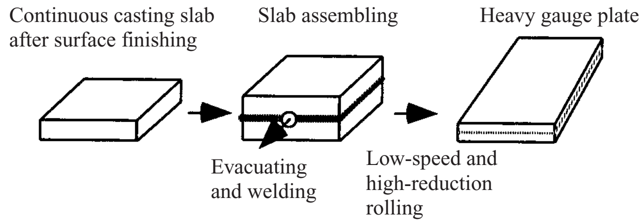

Fig. 1 Process outline of heavy gauge plate with cladding technology

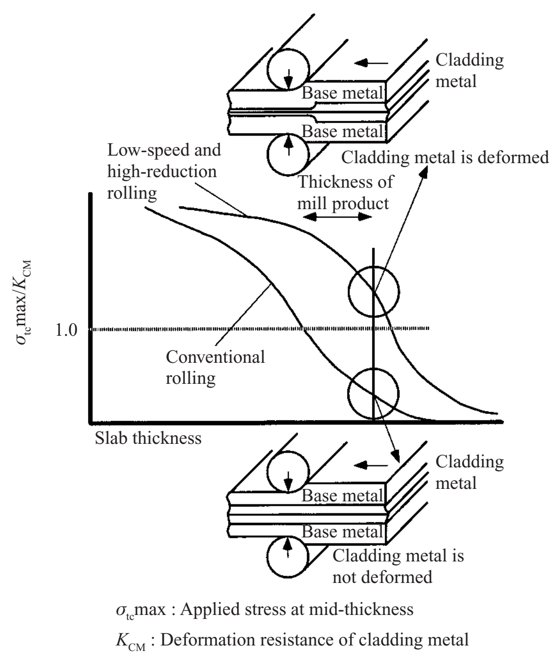

Fig. 2 Concept of low-speed and high-reduction rolling

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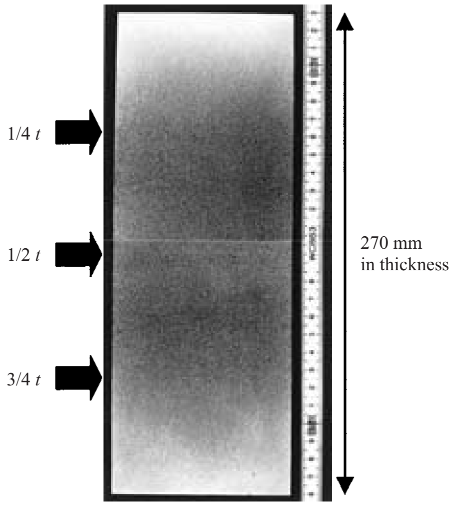

Photo 1 Macrostructure of 270 mm heavy gauge plate

Table 1 Tensile properties of 270 mm thick heavy gauge plate

Test position		Dir.	0.2%PS (MPa)	UTS (MPa)	El (%)	RA (%)
Top	1/4 *t*	L	273	471	29.4	66
	1/2 *t*		265	472	40.4	74
	3/4 *t*		255	464	30.8	60
1/4 *W*	1/4 *t*	T	265	470	30.8	65
	1/2 *t*		256	458	38.5	72
	3/4 *t*		259	463	31.6	66
JIS G 3101(over 40 mm *t*)			Min. 215	400–510	Min. 21	—

2.2 Properties of New Heavy-Gauge Plate

Photo 1 shows the macrostructure of a new heavy-gauge plate with the thickness of 270 mm. No distinct traces of bonding could be observed at the 1/2 thickness position, which corresponds to the bonding interface. Slight traces of segregation were observed at the 1/4 and 3/4 thickness positions, corresponding to center segregation in the 1/2 thickness portion of the two original CC slabs.

Table 1 shows the mechanical properties of the new heavy-gauge plate. No significant differences were observed in the tensile strength or ductility of specimens taken from the 1/4, 1/2, and 3/4 thickness positions, and the values fully satisfied JIS SS400[3].

2.3 Evaluation of Performance of Bonding Interface

The through-thickness tensile test was performed to evaluate the integrity of the bonding interface, with the results shown in **Table 2**. The bonding interface is located at the center of length in the gauge portion of tensile specimens taken from the 1/2 position of the product. The through-thickness tensile test showed that the tensile strength and reduction of area of the test specimens taken from the mid-thickness position were similar to those of the specimens from the 1/4 and 3/4 thickness positions.

The ultrasonic test (UT) and the mechanical test for the bonding property in clad materials[4] were performed to verify the integrity of the bonding interface. The UT was performed under the conditions of 6 dB more severe than in the JIS G 0801 test standard, which is applicable to pressure vessels. The UT results are given in **Table 3** and show no indication of defects. Furthermore, no cracks occurred in the side bend test at $R/t = 2$, where R is the radius of the tool tip (19 mm) and t is the specimen thickness (9.5 mm). Shear strength was approximately 280 MPa, or about 60% of tensile strength. This indicates that perfect bonding was basically achieved, as the shear strength of impeccable material is reportedly approximately 60% of tensile strength[5].

Figure 3 shows the relationship between tensile strength and fatigue strength in the through-thickness direction of the new heavy-gauge plate in comparison with the same properties in the normal direction (rolling direction (RD) or 90° to RD) for carbon steels[6]. The plot of this relationship for the new plate falls within the band of data for carbon steel, showing that the fatigue strength of the new plate, including the bond, is equal to that of impeccable material.

Table 2 Tensile properties in thickness direction of 270 mm thick heavy gauge plate

Test position			Tensile properties*	
Length	Width	Thickness	UTS (MPa)	RA (%)
Top	1/2*W*	1/4*t*	487	50
		1/2*t*	478	58
		3/4*t*	477	70
	Edge	1/4*t*	475	73
		1/2*t*	476	55
		3/4*t*	478	72
Bottom	1/2*W*	1/4*t*	479	63
		1/2*t*	480	74
		3/4*t*	480	55
	Edge	1/4*t*	495	64
		1/2*t*	475	56
		3/4*t*	491	40

* Tensile tests were performed in accordance with JIS G 3199.

Table 3 Properties of bonding boundary

Ultrasonic test (JIS G 0801*)	Side bend test (*R*/*t* = 2**)	Shear strength (MPa)	
	(JIS G 0601)		
No indication	No crack	L direction	286
		T direction	288

* More severe sensitivity by 6 dB compared with original.
** *R*: Radius of bend test tool, *t* : Thickness of test sample.

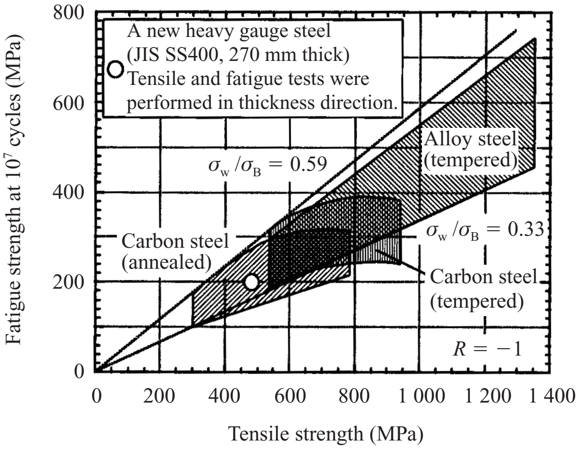

Fig. 3 Static tensile strength-fatigue strength relationship

The test results mentioned above are considered to verify the integrity of the bonding interface in the new heavy-gauge plate.

3. Conclusion

A new heavy-gauge steel plate with a thickness of 270 mm was produced by applying a cladding technology to multiple CC slabs. The tensile strength of the product satisfied the requirements of JIS SS400. The integrity of the bonding interface was verified by ultrasonic testing (UT) and various mechanical tests, including through-thickness tensile and fatigue tests and shear tests. The new heavy-gauge plate produced using cladding technology is expected to be applied to frames, surface tables, and housings. JFE Steel plans to expand the thickness range of heavy-gauge plates produced from CC slabs, which had been limited by the need to control material properties in the rolling process, and will apply this cladding technique to other steel materials.

References

1) Tsuyama, S. et al. Tetsu-to-Hagané. vol. 71, no. 6, 1985, p. 712.
2) Fukai, H. Materia Jpn. vol. 35, no. 9, 1996, p. 976.
3) JIS G 3101.
4) JIS G 0601.
5) MIL-HDBK-5.
6) Tekkou-Binran I Kiso (Iron and Steel Handbook, vol. I, Fundamentals). p. 543. (Japanese)