#### Technology

# Introduction of New Type Laser Welding Technology (Installation of New Coil Build-up Line)

Shinichi OBARA\* Shigeru TOMITA Takayuki YAMASAKI Kenji HYOHDOH Yuusuke TAKAFUJI

### Abstract

The cold rolling mill at the Hikari Area Yamaguchi Works, Nippon Steel Stainless Steel Corporation manufactures stainless steel using two batch-type reversing mills and three aging coil build-up (CB) lines. Making the equipment layout more efficient and introducing laser welding technology has made it possible to more than double the productivity of CB. We abandoned the existing three CB lines and integrated them into one light new coil buildup (LCB) line. With the capacity for large coil unit weight, LCB also increased the productivity of a batch line and boosted the production yield. By interlocking the previous process of LCB, the process time has been shortened leading to enhancement of competitiveness in delivery date management. Accordingly, the new LCB line has enhanced the consistent manufacturing capability.

#### 1. Introduction

The cold rolling mill at the Hikari Area Yamaguchi Works of Nippon Steel Stainless Steel Corporation manufactures stainless steel sheet products using two batch-type reversing mills. In a reverse mill, since the end portion of the coil loaded onto the entry side reel is wound around the delivery side reel, and then rolled with a tension applied, the end portions of a sheet coil with a length equivalent to the distance between the mill and the reel result in them being off-gauge. Therefore, to eliminate the off-gauge, a dummy material with a length equivalent to the above mentioned offgauge length is welded to the front and tail ends of the coil respectively in the accompanying process of the coil build-up (CB) line before rolling.

**Table 1** shows the major specifications of the CB lines. Since the 1CB line and the 2CB line that started operation in 1960–1970 can process coils with a unit weight of less than 14.5 tons, the productivity of the two reversing roll mills with capability of rolling 27 ton unit weight coils was deteriorated.

Then, in 1989, to enhance the productivity of the reversing mills, a double coil line (WCL) was built, in which the unit coil weight was doubled by welding two coils with a unit weight of less than 13 tons (13 ton coils  $\times 2$  coils=26 tons). However, the materials pro-

cessed by the 1CB and the 2CB continued to remain a productivitydeteriorating factor of the reversing mills.

In addition, the 1CB and the WCL required large-scale replacement of the electrical components of the master control system and the driving system due to deterioration by aging.

Thus, since the CB line is a crucial accompanying process for the reversing mills to fully exploit their features of being able to

Table 1 Spec of main equipments in CB line

Item		1CB	2CB	WCL	
Operation start		Jan-1964	Apr-1970	Aug-1989	
Strip spec	Thickness	Max 6.0 mm	Max 6.0 mm	Max 6.0 mm	
	Width	Max 1320 mm	Max 1320 mm	Max 1600 mm	
	Weight	Max 13.5 t	Max 14.5 t	Max 27 t	
	Waldar	Dlagma	TIG, MIG	SAW	
Line	welder	Flasilla	SAW	SAW	
spec	Trimmer	With	With	Without	
	Line speed	Max 49 mpm	Max 65 mpm	Max 130 mpm	

TIG: Tungsten Inert Gas welding MIG: Metal Inert Gas welding SAW: Submerged Arc Welding

<sup>\*</sup> Senior Manager, Cold Strip Technical Dept., Cold Rolling Mill, Hikari Area Yamaguchi Works, Production Division, Nippon Steel Stainless Steel Corporation 3434 Ooaza-shimata, Hikari City, Yamaguchi Pref. 743-8550

comply with small-lot and varied size production with high productivity, at the timing when the abovementioned replacement of the electrical components of the two lines became necessary, the deteriorated three CB lines were abolished, and their functions were integrated into a newly constructed high-efficiency light new coil buildup (LCB) line specified for large unit weight coils. Thus the enhancement of the productivity of the integrated production process from the CB process to the reversing mills and streamlining of the accompanying logistics flow were promoted.

The LCB, reusing and modifying for reuse in part the mechanical equipment of the former equipment, is designed to significantly enhance the CB line productivity by streamlining the layout and the introduction of new type laser welding technology (disk laser). Because schedule-free processing is made possible, by connecting the production scheduling to the previous production schedule (implementation of production of the LCB pursuant to the production schedule of the previous process), strengthening of the integrated delivery scheduling competitiveness of sheet products has been promoted.

This article reports the function and the effect on improvement of the LCB.

#### 2. Direction of LCB Designing (Features of LCB)

To integrate to one line, design of high-efficiency LCB was pursued for the realization of the following viewpoints.

- 1) Optimization of the basic equipment specification and streamlining of equipment layout
- A line capable of handling large unit weight coils including double coils
- High-speed processing (to be equal to or higher than that of the WCL)
- Streamlined equipment layout that allows for the preparation of dummy materials in parallel with coil processing to shorten the preparation time thereof and for schedule-free processing
- 2) High-function welding by the introduction of laser welding technology
- Enhancement of welding efficiency and stabilization of weld quality by employing high-speed and automated welding
- · Schedule free-welding of various steel grades
- Thinning of dummy materials (reduction of dummy material cost) by widening the range of possible different thickness welding of a coil sheet and a dummy material
- Introduction of maintenance-free disk laser welding machine for the first time in the world
- · Stabilization of equipment operation and weld quality

## 3. Equipment Specification and Outline of Equipment

#### 3.1 Equipment specification

The main specification of the LCB is shown in **Table 2**. The maximum specified unit coil weight is 27 tons that allows for double coils. The dummy material for the LCB is a disqualified-quality, cold-rolled steel sheet with a minimum thickness of 1 mm so as to suppress off-gauge in salvage-rolling when the cold-rolled sheet is rolled to a thickness of 0.6 mm for salvaging purposes.

For welding, the new type disk laser welding machine was employed for the first time in the world (capacity: 6.6 kW, welding performance equal to that of 8 kW CO, laser).

The line speed and the tension are equal to those of the then-existing equipment. As with the reuse of the 2CB trimmer, reusable equipment of the three lines has been reutilized and equipment cost reduction was promoted.

#### 3.2 Streamlining of equipment layout

In the LCB, the welding operation for a dummy material is conducted in the following flow: (1) pass a dummy material for the coil front end in the line, (2) pass a hot coil sheet, (3) weld the dummy material to the front end of the coil, (4) wind around the tension reel, operate the line until the coil bottom end leaves the payoff reel, (5) pass a dummy material for the coil bottom end, (6) weld the dummy material to the bottom end of the coil and (7) wind around the tension reel and discharge from the line. As the above flow shows, to process a coil, since two times the arrangement of a dummy material and two times the welding are conducted, shortening of the coil/dummy material arrangement time and the welding time is a crucial factor.

**Figure 1** shows the equipment layout of the LCB. The major constituent equipment is: pay-off reel (POR), laser welding machine, trimmer, tension unit and tension reel (TR).

As for the supply of dummy materials, in parallel with the processing in the abovementioned line, the preparation of dummy ma-

Table 2 Spec of main equipments in LCB

It	em	Spec	
	Thickness	1.0–6.0 mm	
Strip spec	Width	635–1600 mm	
	Weight	Max 27 t	
	Waldan	Disk laser	
	weider	Max power: 6.6 kW, max speed: 10 mpm	
Line spec	Line speed	Max 140 mpm	
	Tension	Max 15 t	
	Trimmer	Thickness: 2.0–6.0 mm	



terials has been facilitated.

With the streamlining of preparatory works and the laser welding machine function, schedule-free processing of the LCB has been enabled.

The coil and dummy material preparation works have been automated, and the parallel work is conducted in a stable manner.

The tension unit at the entry side of the TR provides coils with bending deformation with five upper rolls and four lower rolls, and provides tension when the TR winds the coil. By securing sufficient winding tension when the coil tail end leaves POR, the occurrence of surface slipping scars in the subsequent process of reversing mill due to retightening of coils by the difference in tension is prevented. **3.3 High-function welding by introduction of laser welding technology** 

**Figure 2** shows the welding flows of the MIG welding machine and the SAW welding machine used in the 2CB and the WCL, and the laser welding machine applied to the LCB. In the 2CB line welding operation, after the front ends of a coil and a dummy material are shear-cut simultaneously and the shear-cut section surfaces are butted, the MIG welding machine is automatically operated. After the start of welding, an operator, wearing a face shield, adjusts the welding current through visual observation of the state of welding, and a certain weld joint quality level is maintained thereby.

Since the welds of the MIG welding machine are of convex shape, the welds were smoothed by confirming the bead shape and grinding the bead with a manually operated grinding machine installed at a position about 4 m away from the delivery side of the welding machine. Furthermore, for ferritic stainless steel, the weld quality was secured by annealing using a gas burner located a further 3 m away.

Thus, in the welding operation prior to the countermeasure, the welding part had to be moved manually to the welding machine position, bead grinding machine position and the gas burner position as necessary, and since the welding, bead grinding and the annealing operation were manually conducted, the operation efficiency was low and a high operator skill was required.

Figure 3 shows the diagram of the laser welding machine. In the laser welding machine, the end of a coil and a dummy material are shear-cut simultaneously with high accuracy by an up and down type shearing machine with high rigidity, and the cut section is automatically butted.



Fig. 2 Installation effect of laser welder

Subsequently, while the welding machine is traveling in the sheet width direction, the following operations are conducted: (1) smoothing the shear-cut part by the front pressure rollers, (2) welding by laser radiation (if required, a filler wire is used to enhance the weld quality), (3) smoothing the welds by the back pressure roller and (4) annealing by the induction heater (for ferritic stainless steel and so forth). One cycle of welding and the accompanying operations are automated with high efficiency. The most optimized welding conditions such as those of welding speed and of filler wire feeding speed are predetermined according to material specification (steel grade to be butted, combination of sheet thickness), and are automatically set.

With the laser welding machine to which a high energy density laser is applied, high-speed welding is possible, and since such accompanying operations as surface smoothing and annealing after welding are possible in parallel during high-speed welding, significant enhancement of efficiency is realized as compared with the conventional welding methods shown in Fig. 2.

Additionally, since automatic welding is possible by changing the welding conditions for various steel grades (changes of such conditions as filler wire feeding speed and annealing condition), schedule-free processing and operation that doesn't rely on operator skill have been realized.

**Figure 4** shows cross section diagrams of the welds of plasma welding and laser welding. In the laser welding wherein welding is conducted with high-energy density, the widths of the weld deposit (DEPO) and the heat-affected-zone (HAZ) are much narrower than those of the conventional welding methods, and the weld quality is higher.

Furthermore, in the laser welding machine, since the positions of the materials are adjusted so as to align the centerlines of both for butting, and then welding is conducted, as compared with the welding by the conventional welding machines wherein the thickness bottom lines are matched, the weld bending strength at the reversing mill deflector roll is also improved (see Fig. 2).

By effectively taking advantage of the high weld quality, the ranges of possible different thickness welding (widening of the difference between the coil thickness and the dummy material thick-



Fig. 3 Diagram of laser welder (welding unit)



Fig. 4 Cross-section diagram of plasma welder and laser welder



Photo 1 Overall view of LCB

ness) and different width welding (i.e. application to the welding of the 1 240 mm width coil and 1 020 mm width dummy material) have been expanded, and the dummy material cost was reduced.

An overall view of the LCB, the equipment outline of which was explained above, is shown in **Photo 1**.

#### 4. Maintenance-free Realized by Introduction of Disk Laser Welding Machine

The CO<sub>2</sub> laser capable of emitting high power output equivalent to 8-16 kW is applied to the laser welding of sheets. For a low power output laser of less than 2 kW, a yittrium aluminum garnet (YAG) laser is widely used because of its flexibility in transmission by using fiber cables and maintenance-free operation.

**Figure 5** shows a comparison of the disk laser capable of emitting power output as high as 16 kW and the YAG rod laser.

In the conventional YAG laser, since the laser is oscillated by the excitation applied through the side of the rod, and the rod is cooled on the side, the temperature at the center section of the rod becomes high, and a parabolic temperature distribution appears. Therefore, high power output is not achieved due to the influences of heat lens effect and so forth.

In the disk laser, the laser is oscillated by exciting the surfaces of YAG crystals forming a thin disk, and the disk is cooled from the back side, uniform temperature distribution with a nearly equal temperature rise gradient within the crystals is obtained, and the high power output is enabled.

**Table 3** shows a comparison of the performance of the  $CO_2$  laser and the disk laser, and the disk laser is superior to the  $CO_2$  laser in the following aspects.

- Penetration property is higher by 1.3 times. (The 6 kW disk laser has a welding penetration property nearly equal to that of the 8 kW CO<sub>2</sub> laser.)
- Less susceptible to the moisture on the sheet surface, and stabilized welding is realized.
- The welding cost such as that for electric power and welding gas is less than one third.
- (Costly He gas to suppress the influence of plasma is not required.)
- 4) The oscillator is maintenance-free.
- 5) The laser path and the welding head are mostly maintenance-free.



Fig. 5 Comparison of YAG-rod laser and disk laser

Item		CO <sub>2</sub> Laser	Disk Laser	
Wave length		10.6 µm	1.03 µm	
Spec	Absorptivity	5% (at normal	40% (at normal	
		temperature)	temperature)	
		(100% at after melting)	(100% at after melting)	
		Standard	1.3x weld penetration	
	Spatter	Standard	Large	
	Moisture	Affected	Not affected	
	Cost	Sandard	Less than 1/3	
		(necessary He gas)	(unnecessary He gas)	
	Oscillator	Mirror, vacuum tube:	Maintanana fira	
		periodic maintenance		
		Adjust the optical axsis	Maintenance-free	
		after replacing a mirror		
Mainte-		Mirror: periodic		
nance	Laser path	maintenance	Maintenance-free	
		Adjust the optical axsis		
		after replacing a mirror		
	Head	Mirror: periodic	Guard glass: periodic	
		maintenance	maintenance	

Table 3 Performance comparison of CO, laser and disk laser

Since the transmission of the CO<sub>2</sub> laser with a wavelength of 10.6  $\mu$ m through a fiber cable is impossible, the transmission via reflection by bend mirrors and straight path in a tube purged with nitrogen gas is required. The laser focusing mechanism of the welding head employs a parabolic mirror. Therefore, for both of the laser path and the welding head, high level maintenance skill is required for cleaning and/or exchange of the mirrors and for the adjustment of the optical axis.

Flexible transmission of the disk laser with a wavelength of 1.03  $\mu$ m through cable fibers is possible. (Transmission through bent fiber cables is possible.)

Since the laser focusing mechanism of the welding head uses a focusing lens, maintenance-free operation is possible except for the cleaning and/or the exchange of the protective glass that is from the welding head system. (Refer to Table 3 and **Fig. 6**.)

Thus the disk laser has excellent performance. However, in the application to actual operation, there were problems of spattering

during welding that required solutions to suppress such activity and a lack of actual application cases of the welding machine to the iron and steel industry.

Figure 7 shows the relationship between the laser wave length and the absorption rate. The laser absorptivity of steel at an ordinary temperature is about 40% with the disk laser and about 5% with the  $CO_2$  laser, and the effect of this difference influences the extent of spattering.

To solve this problem, with Toshiba Mitsubishi-Electric Industrial Systems Corporation and Tada Electric Co., Ltd., we conducted a spattering suppression test in which the welding conditions such as laser radiation and Ar gas flow rate and direction were changed by using a welding machine in which the welding head protective glass was less susceptible to spatter adhesion due to the employment of a long focal lens.

Figure 8 shows the states of spattering during welding by the  $CO_2$  laser and by disk laser before and after taking the countermeasure, and due to the optimization of the welding condition, spattering has been significantly reduced, and weld quality equivalent to



Fig. 6 Focusing mechanism of laser beam



Fig. 7 Relation between laser wave length and absorption rate



Fig. 8 Welding spatter

that of CO<sub>2</sub> laser welding has been obtained.

Furthermore, the reliability of the disk laser oscillator was examined with respect to the strength of the resonator, influence of the reflected laser light and the installation state of the equipment self-diagnosis function, and as the reliability was judged as high based on the sufficient strength and the satisfactory equipment self-diagnosis system covering from the oscillator proper to the welding head, the application to practical operation was implemented.

#### 5. Effect of LCB on Improvement

- Significant productivity enhancement to a level higher than that of the previous production capacity by two times or more has been achieved by increasing the maximum unit coil weight to 27 tons (productivity enhancement by increasing the unit coil weight by double coils and by employing large unit weight hot coils), streamlining of equipment layout (enhancement of hot coil and dummy material preparation work efficiency), introduction of laser welding technology (employment of high performance automatic welding) and so forth, and the deteriorated three lines were abolished and the production thereof was integrated with highly productive LCB.
- Due to the employment of fully automatic welding, stabilized weld quality has been obtained without reliance on operator skill.
- 3) By introducing a new type of disk laser welding machine, due to the maintenance-free oscillator, laser path and the welding head, stabilized operation of the welding machine and improvement in weld quality have been obtained.
- 4) By the introduction of the laser welding machine, significant reduction of dummy material cost has been achieved by expanding the range of the possible different width welding to the extent possible wherein the welded part is not broken by the inward bending in coiling in addition to the widening of the possible different thickness welding range.

**Figure 9** shows the ratios of possible smallest dummy material cross-sectional area vs. coil cross-sectional area before and after taking the measure in the cases of welding a dummy material to a coil 4 ft in width, 3 mm and 6 mm in thickness.

In the case of the 3 mm thick coil, the dummy cross-sectional area ratio was reduced from 100% (a dummy material of identical thickness and width is welded) to about 55%.

5) The bottleneck of the production of the large unit weight coils in the integrated sheet production was the CB process, and by the construction of the LCB specified for large unit weight coils, the production of the sheet mill based on large unit weight coils was promoted. By the expansion thereof, the en-





Fig. 10 Logistics flow of hot rolled coil from acceptance to LCB

hancement of the productivity of such batch-type lines as reversing mills and the integrated product yield have been achieved.

6) By utilizing the former 2CB line site as the hot coil receiving and storage yard, the logistics efficiency has been enhanced.

Hot coils are transported by ship from other steel works and unloaded at the Hikari wharf. **Figure 10** shows the logistics flow from the reception of the coils in the sheet mill to the LCB operation.

By utilizing the former 2CB line site as the hot coil receiving and storage yard, hot coils are directly transported to the sheet mill from the wharf by exclusive carriers. Until then, hot coils were temporarily stored in an open-air yard and transported to the sheet mill by lift cars. Such work was eliminated.

7) By utilizing the function of the LCB capable of schedule-free processing, by connecting the LCB production schedule with that of the previous process, the integrated delivery management competitiveness of sheet products has been strengthened (operation by connecting the work schedules of (3)→(4)→(5)

 $\rightarrow$  6 in Fig. 10, the production period has been shortened.).

#### 6. Conclusion

Due to the LCB, the newly constructed accompanying line with high productivity and high functionality for rolling mills, enhancement of the productivity and the cost reduction of the CB process have been promoted, and the enhancement of the integrated productivity of the batch line including rolling mills, enhancement of integrated product yield, shortening of the processing period from the reception of hot coils to the LCB processing and streamlining of logistics have been realized.

Through the measures taken this time, the competitiveness of a batch-type mill capable of producing with high efficiency small and varied size lots of special steels, special sizes (thick sheets, ultrathin sheets, wide width sheets and so forth) have been strengthened.

Hereafter as well, we are determined to continue to tackle further competitiveness strengthening measures, bearing in mind the challenging spirit with which we have introduced the new laser welding technology for the first time in the world.



Shinichi OBARA

Senior Manager Cold Strip Technical Dept., Cold Rolling Mill Hikari Area Yamaguchi Works, Production Division Nippon Steel Stainless Steel Corporation 3434 Ooaza-shimata, Hikari City, Yamaguchi Pref. 743-8550



Kenji HYOHDOH General Manager Technical Control Division Nippon Steel Stainless Steel Corporation



Shigeru TOMITA General Manager Equipment Control & Maintenance Div. Hikari Area Yamaguchi Works, Production Division Nippon Steel Stainless Steel Corporation



Yuusuke TAKAFUJI Group Manager Process Engineering Dept. Equipment Technical Control Div. Production Division Nippon Steel Stainless Steel Corporation



Takayuki YAMASAKI Manager Control Technical Dept. Equipment Technical Control Div. Production Division Nippon Steel Stainless Steel Corporation