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Development of Laser Welder for Strip Processing Line

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Development of Laser Welder for Strip Processing Line*

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Kawasaki Steel Corp. (KSC) has developed CO_2 laser welders for the sheet steel production process. Four sets of CO_2 laser welders have already been installed on the production floor, since the first laser welder was installed for coil build-up line at Hanshin Works in 1981. The 5 kW CO_2 laser welders installed for pickling lines at Mizushima and Chiba Works in 1983 have unstable resonaters, and wire feeders. Those are the first industrial application of 5 kW CO_2 laser in Japan, which can weld all kinds of steel strips measuring up to 6 mm in thickness, and up to 1880 mm in width.

1 Introduction

In recent years, the need of continuous operation is keenly felt in the downstream processing of hot and cold rolled coils, and there is a growing trend toward making coils in continuation, in larger sizes, and in uniform quality. Against such background, various processing lines call for welders in an increasing number and variety, such as for seam welding, flash butt welding, TIG welding, MIG welding. Only thing is that these welding processes have the following drawbacks:

(1) In seam welding where two pieces of strip are overlapped, the thickness of welded zone tend to become greater than the strip thickness.
(2) Flash butt welding, TIG welding and MIG welding which all are butt welding are low in reliability at welded joints in the case of high-silicon steels, high-carbon steels, etc.

In order to solve these problems, attention was paid to the unique characteristics of laser welding which requires low heat inputs, and the research work was started some seven years ago[1].

The application of laser welding to actual production line was difficult because the very fine beam (0.3 to 0.5 mm in spot diameter) used for the laser welding required every component of the welder to be of far greater accuracy than in conventional welders.

This problem was finally solved, and the machine was applied to the welding of cold rolled strip as the first[2),3)], and then developed into a 5 kW laser welder for hot rolled strip before pickling. This report summarizes the above development.

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*** Mizushima Works
**** Research Laboratories

2 Background of Development of Laser Welder

2.1 KSC's Laser Welder

At Kawasaki Steel a prototype laser welder was developed in 1978, and subjected to various tests at No. 2 cold rolling plant at Chiba. As a result, a total of four laser welders are currently in operation: the first machine in the recoiling line at Hanshin Works, the second machine in the slitter line of the No. 2 cold rolling mill at Chiba Works, and the third and the fourth in the pickling lines at Mizushima and Chiba Works, respectively. The first machine, mainly for manual operation, is the company's first commercial laser welder and used for welding narrow and thin-gage cold-rolled silicon steel coils, including high-silicon steel. The second machine, a remodelling of the prototype installed in 1978, is an automatic laser welder for wide and thin-gage cold-rolled low carbon steel coils.

Both machines are provided with laser oscillators of 1.0 kW maximum and 1.5 kW maximum, respectively. The third and fourth machines are welders for wide and thick hot-rolled coils. They are equipped with laser oscillators of the Japan's first 5 kW class with unstable resonator and perform fully automatic welding. **Table 1** gives the specifications of the first and the second machines.

2.2 Needs for Laser Welders

(1) Hanshin Laser Welder (The First Machine)

Table 1 Specifications of laser welder for cold rolled strip

Item \ Welder	No. 1 (Hanshin Works)	No. 2 (Chiba Works)
Year installed	June 1981	Oct. 1981
Treated material	Cold rolled silicon steel	Cold rolled low carbon steel
Strip thickness (mm)	0.2 ~ 0.7	0.4 ~ 2.3
Strip width (mm)	50 ~ 500	508 ~ 1 270
Type of laser	CO_2 laser	CO_2 laser
Laser power (kW)	1.0 max.	1.5 max.
Torch speed (m/min)	10 max.	10 max.
Remarks	• The first laser welder for commercial production at KSC*	• The first automatic laser welder at KSC*

* Kawasaki Steel Corp.

Silicon steel coils have so far been welded by TIG welding. In this welding process, however, burn-through is apt to occur at weld ends and it has been difficult to completely obtain the weld quality required by users. Since power control is easy in laser welding, burn-through can be prevented and high weld quality is obtained.

(2) Chiba No. 2 Cold Strip Mill Laser Welder (The Second Machine)
In building up finished thin coils, it is necessary to make the thickness of the welded portion equal to that of the nonwelded portion to prevent coil breaks (transverse kinks) during coiling. In the conventional butt welding processes, weld beads have large amounts of excess metal as well as flash, and it was difficult to completely remove them. The adoption of laser welding was considered in view of the characteristic of this welding process that provides small excess weld metal which is therefore easy to remove.

2.3 Laser Welding Techniques

There are cutting, welding, heat treatment, etc. as techniques utilizing laser. Laser oscillators of relatively low power have already been put into practical use in the above-mentioned fields. However, high-power laser oscillators required at steelworks have scarcely been used and there was no example of practical application in steelworks at all in the world.

Laser welding itself requires a very high degree of mechanical accuracy and it was very difficult to achieve the straightness of the butted portion, laser beam travel accuracy, etc. However, Kawasaki Steel steadily improved the performance of laser welders starting with the first machine and completed a series of laser welders[4].

3 Laser Welders for Pickling Line

In pickling line, the flash butt welders have mainly been used so far in many existing lines. In this welding method, however, high welding heat input requirement limited the type of coils to be welded, and especially in materials such as high-silicon steels and high-carbon steels, high welding strength cannot be obtained, making cold-rolling of built-up steels. For this reason, a project was started off for developing laser welders mainly for use in pickling line for such alloy steels.

In developing laser welders for pickling line, it was necessary to solve the following problems:

(1) Coils to be welded are thick (6 mm maximum) and wide (1 880 mm maximum).
(2) Coils have high tensile strengths (120 kgf/mm^2 maximum).
(3) They are hot-rolled coils before pickling and their flatness is poor (flatness: 4% maximum).
(4) The environment of the locations is bad.

These problems were solved by developing a high-power oscillator, improving the machine accuracy and adopting filler wire. As a result, laser welders for pickling line were put into practical use for the first time in the world. Main features and operation results of the laser welders for pickling line are described in the following.

3.1 Line Layout

Figure 1 shows an example of pickling line layout (entry section). The laser is installed at the entry section of the pickling line and is composed of a laser oscillator, a welder and a grinder. **Figure 2** shows the basic composition of this equipment. **Table 2** gives the specifications of the two laser welders. **Figure 3** schematically shows the concept of laser welding.

3.2 Flow of Processing

Heat treatment and bead grinding are performed after laser welding. **Figure 4** shows the flow of processing.

3.3 Functions Required

(1) Welder Proper
The laser welder uses a very fine beam of which diameter is in the range of 0.3 to 0.5 mm. Therefore, it is necessary to keep the butt joint tolerances within certain tighter ranges (**Fig. 5**).

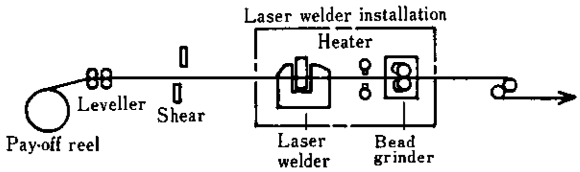


Fig. 1 Arrangement of pickling line (at entry section)

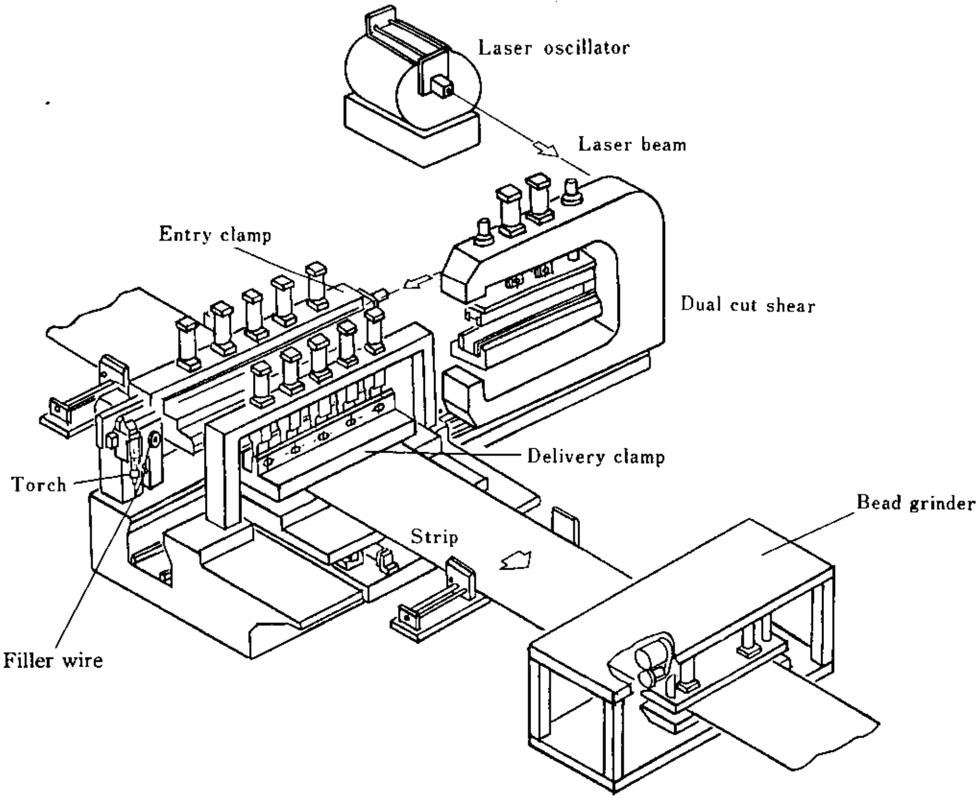


Fig. 2 Schematic diagram of laser welder and bead grinder

Table 2 Specifications of laser welder installation at pickling line

Item	Welder	No. 3(Mizushima Works)	No. 4(Chiba Works)
Treated material	Kinds of steels	Hot rolled silicon steel, high carbon steel	
	Thickness (mm)	1.6~6.0	1.2~4.5
	Width (mm)	600~1 650	610~1 880
	Tensile strength (kgf/mm^2)	Max. 80	Max. 120
Laser oscillator	Type	CO_2 laser (Unstable)	
	Output power (kW)	5	
	Head type	3-axes high gas pressure	2-axes low gas pressure
	Laser gas	(CO_2·CO·N_2·He)	(CO_2·N_2·He)
Laser welder	Shear type	Dual cut shear (shear rake 1°30′)	
	Torch speed (m/min)	Max. 10	
	Filler wire supplying device	Owned	
	Wire feed rate (m/min)	1.0~10	
	Focal distance of lens (mm)	254 (10″)	
	Material of lens	ZnSe	
	Shielding gas	Ar	
Bead grinder	Type	One-head stone grinder	Two-head stone grinder
	Grinding speed (m/min)	1.0~5	
Heat treatment device		Not owned	Owned

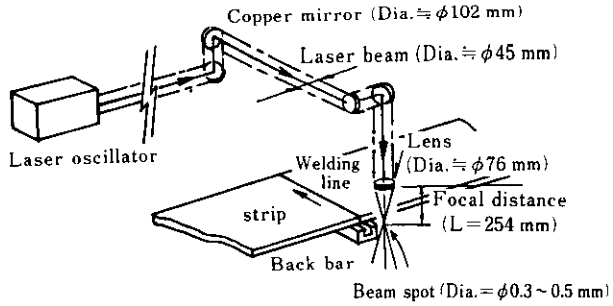


Fig. 3 Process of laser welding

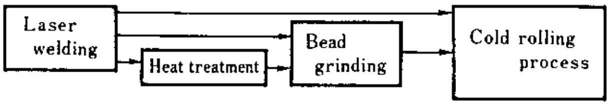


Fig. 4 Flow diagram of laser welded joint being treated for cold rolling

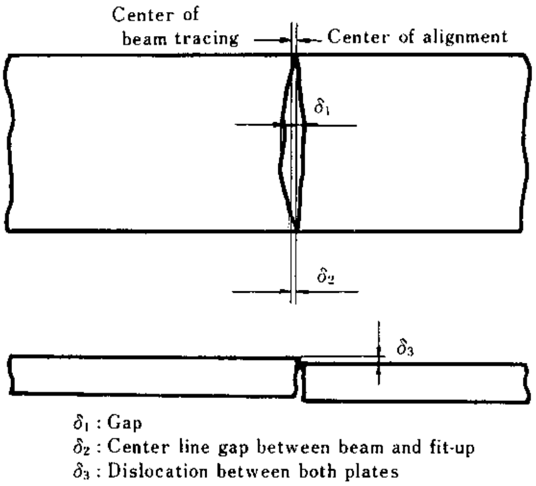


Fig. 5 Fit-up configuration

(2) Grinder
Weld beads are apt to have under-cut defects which readily cause rupture in high-silicon steels. Therefore, they are ground to be free from under-cut defects. The surface roughness and the width of grinding were also found to have a great effect on the weld strength.

3.4 Features

(1) High-Power Oscillator with Unstable Resonator
In the laser welding of steel coils with thickness up to 6 mm maximum, it was difficult to obtain a sufficient depth of penetration with conventional oscillators of power up to 1.5 kW. Furthermore, a sufficient weld strength could not be obtained unless the welding speed is raised and the welding heat input is

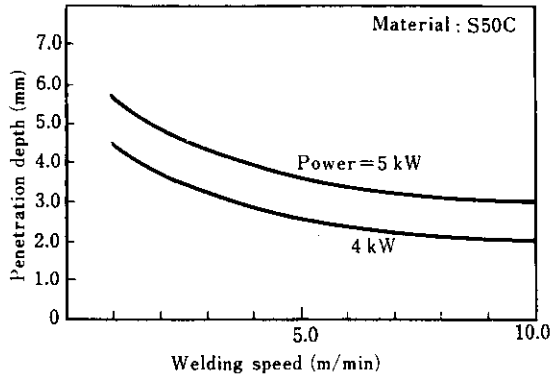


Fig. 6 Variation of penetration depth with laser power and welding speed

kept at a low level. Now high-speed welding of thick strip has been made possible since a laser oscillator of 5 kW with unstable resonator was developed. **Figure 6** shows the relationship between the output of oscillator, welding speed and penetration depth.

(2) High-Accuracy Shearing and Butting Mechanisms
Shears with dual blades of rake angle 1°30′ were adopted in order to get high straightness of cut line. The shears are composed of two top blades and two bottom blades and cut the leading and trailing ends of two coils at the same time. In this kind of shears, the droop of the cut portion and the strip deformation due to shearing lateral forces occur generally and the squareness of the shearing line tends to be low. To prevent this, the shearing accuracy was raised by minimizing the amount of the protrusion from the blade and the distance between the end of the clamp and the blade position. Incidentally, the amount of the protrusion from the shear blade was minimized by improving the accuracy of automatic strip stop. In addition, the shear is also provided with a mechanism for preventing the deformation of the shear frame during shearing and a mechanism for preventing variations in the shear clearance caused by lateral forces. High shearing accuracy was obtained by these means.

To joint two coils with high reproducibility, the equipment was designed to permit two butting methods. By one method, the delivery clamp is shifted toward the entry side and positioning is performed by using a stopper. Under the other method, two coils are pressed against each other end to end. In the former method, the fine adjustment of butting is performed by using the stopper. In the latter method, the delivery clamp itself is provided with a horizontal shift mechanism which reduces the gap between the butting faces. Furthermore, high-accuracy butting has been made possible by pressing with a back bar from under the butted portion in

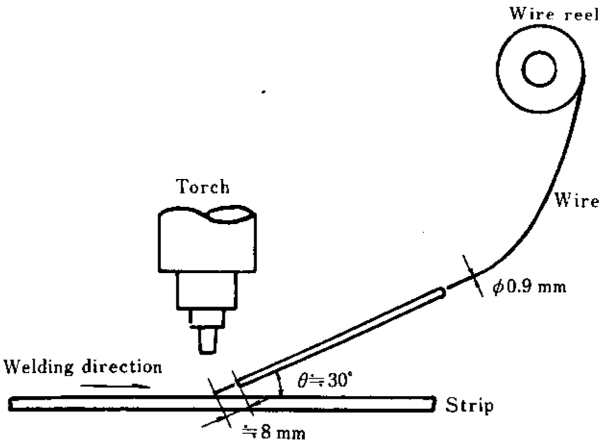


Fig. 7 Schematic diagram of filler wire supply

order to straighten the strip shape in this portion.

(3) Filler Wire Feeding Device
Filler wires are used mainly to prevent welding defects of high carbon steel. They are fed to the butted portion as shown in **Fig. 7**[5]. When the filler wires are not used, the gap between the two butting faces usually has to be held as close as possible to zero. However, when a wire is used, welding can be performed with a gap of about 0.1 to 0.5 mm which is adequate to make homogeneous deposit of weld metal.

Thus, filler wires are effective in keeping and improving the weld quality and reducing grinding load in welding of high carbon steels because of adjustment to weld metal composition.

(4) Torch Transfer Mechanism
When the thickness or type of steel coils to be welded is changed, it is necessary to adjust the position of focus by raising or lowering the condensing lens by remote control. When a filler wire is used, it is also necessary to move the torch in longitudinal direction so that the beam center can be aligned with the center of the gap in butt joint. The amount of adjustment and stop accuracy shown in **Fig. 8** are ensured in this device.

(5) Adoption of Grinding Method by Grindstone
In the conventional flash butt welding, the amount of excess weld metal is large and this excess weld metal is trimmed off with cutting tools moving in the direction of the strip width. In laser welding, the amount of excess weld metal is small, thereby saving on the trim-off allowance. Furthermore, the cutting tool method is not suitable for a certain type of steels whose weld quality is worsened significantly by the formation of scratches on the trimmed surface.

In addition, it was found as described above that the weld quality of high-silicon steels, etc. was greatly influenced by the strip surface roughness after grinding and the magnitude of ground width. In view of the foregoing, the grinding method by a grindstone was adopted this time. In this method, overgrinding is apt to take place especially at coil edges. For this reason, a mechanism for preventing overgrinding is provided.

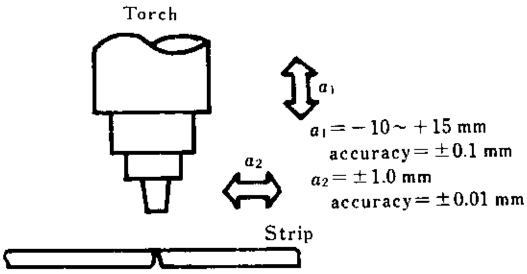


Fig. 8 Adjustable range of torch

3.5 Safety Measures

Laser beams are a heat source of very high energy density, although, unlike X-rays, they are safe except in the beam paths including the optical transmission path. Yet the following prudent safety measures were taken upon the installation of high power laser oscillator in a strip processing line.

(1) Optical Transmission Path
The whole optical transmission path from the oscillator to the welder is covered with a steel duct. A thermosensor for detecting deviations of beams from the set path is installed inside. Beams are shut off within the oscillator instantaneously when they deviate from the predetermined path.

(2) Welder Proper
The welder proper was surrounded with acrylic plates as far as possible so that reflected beams from the working point do not leak to production floor.

(3) Torch
To cope with abnormalities, the torch enclosing a focussing lens is equipped with a sensor which detects any possible external forces applied during welding.

4 Results of Operation

Table 3 gives steels unsuitable for flash butt welding, because cold rolling of these steels with weld portion included is beyond the capacity of flash butt welding since the conventional flash butt welding is totally impossible or unstable in the case of these steels.

The properties of welded joint and the operating condition of laser welding are described with respect to these representative steels.

(1) Silicon Steels

Table 3 Materials unsuitable for flash butt welding process

Material	Note
Silicon steel (More than 1.5% Si)	(1) SiO_2 film in welded joint (2) Coarse grains in HAZ
High carbon steel ($0.4\% \leqq C \leqq 1.5\%$)	(1) Unstable flashing (2) Hardened reinforcement
Medium carbon steel ($0.3\% \leqq C \leqq 0.4\%$)	Unstable flashing
Low alloy steel	Unstable flashing
High tensile steel	Unstable flashing

The following means are necessary for obtaining sufficient weld strength:

(a) The grain coarsening in the heat-affected zone is prevented by reducing the welding heat input.

(b) Uniform welded joints of small amount of excess weld metal are obtained by controlling the gap, position of focus, and filler wire feed rate (when a filler wire is used).

At present, silicon steels are welded at welding speeds of 4 to 5 m/min. **Photo 1** shows the cross section of a welded joint of a high-silicon steel (3% Si). The molten zone is narrow and the grain coarsening in heat affected zone is scarcely observed. The welding of high-silicon steels, which has so far been impossible, is performed by using laser beams, and built-up coils are successfully applied for cold rolling.

(2) High-Carbon Steels and Alloy Steels

The following measures are taken for these types of steel:

(a) Especially in steels of high carbon content, the carbon content of weld metal is properly lowered by using a filler wire to prevent the formation of blowholes. **Figure 9** shows the relationship between the carbon content of weld metal and the weld strength (represented by the number of repetitions of bending as a strength index).

(b) The gap, welding speed and filler wire feed rate are controlled to mix the base metal with the wire in an optimal manner. **Photo 2** shows the cross section of a welded joint of a 0.6% C steel. The same good weld quality as with the above-mentioned high-silicon steel is obtained.

(3) Medium-Carbon Steels and Other Steels

Unlike flash butt welding, the oxide formation and the slag inclusion do not occur at all. Therefore, stable laser weld strength is obtained. **Figure 10** shows a comparison of medium-carbon steel weld strength (represented by the number of repetitions of bending as a strength index) between laser welding and flash butt welding. As is apparent from this figure, the weld strength in laser welding is four to five times that obtained by flash butt welding.

As described above, laser welding permits welding of materials that cannot be flash butt welded, and a total of about 8 000 t of hot-rolled coils per month is currently processed at the Mizushima and Chiba Works combined. The laser welders have been operating with no great troubles and contribute to the improvement in the

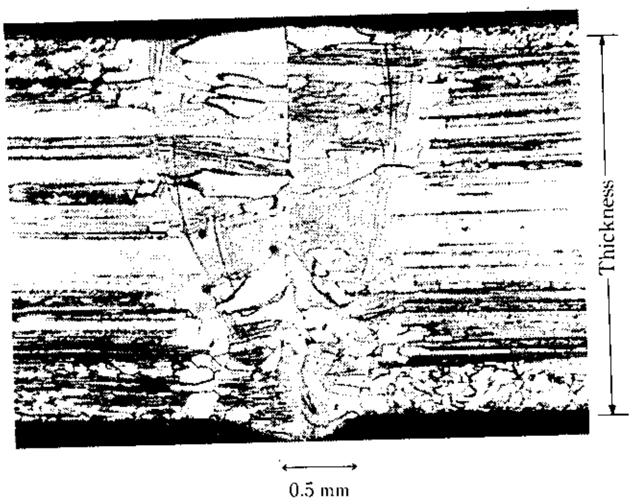


Photo 1 Cross section of welded joint (with filler wire)

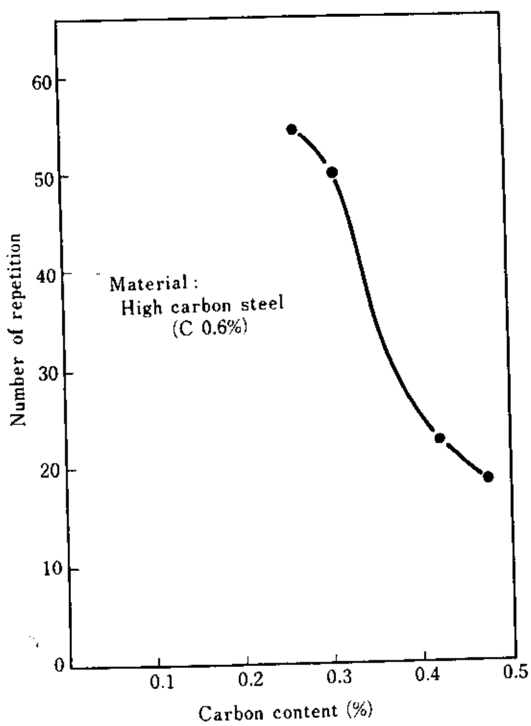


Fig. 9 Relation between number of repetition and carbon content of welded metal

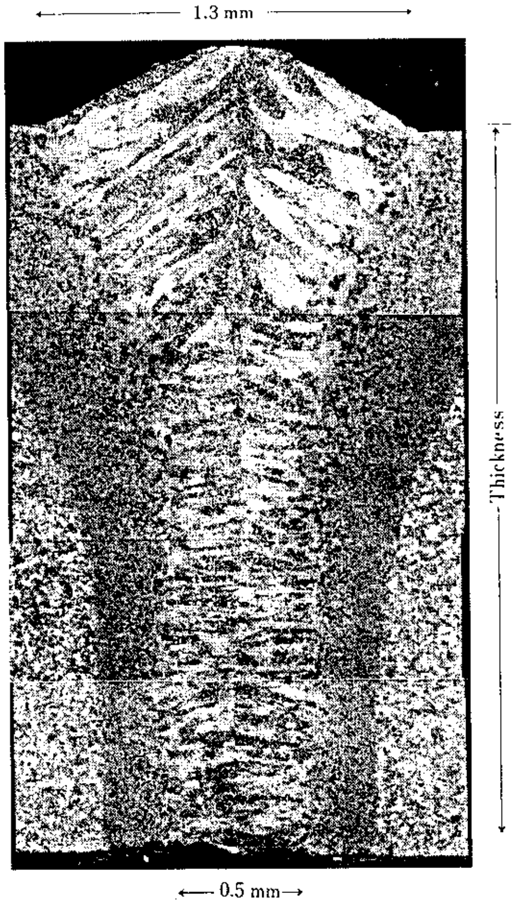


Photo 2 Cross section of welded joint (with filler wire)

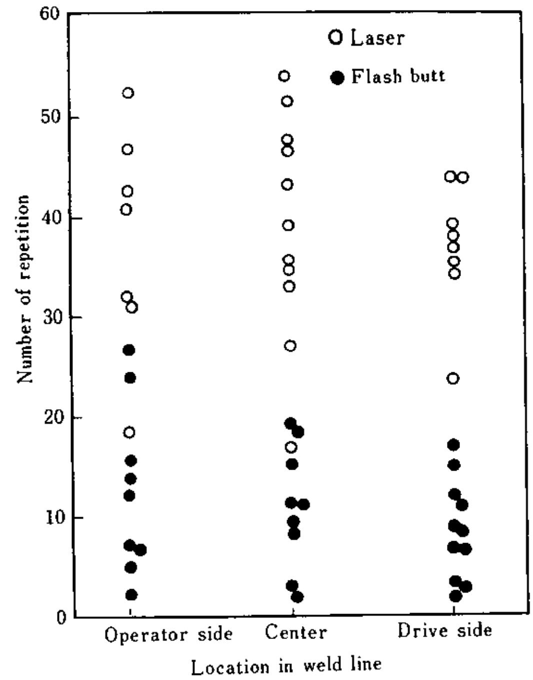


Fig. 10 Comparison of welded joint fatigue strength by reverse bend test (JIS Z 3126) in both laser and flash butt welding of a medium-carbon steel

ease of coil handling by build-up welding as well as in yield rate and unit consumption. With respect to the welding time, a cycle time of the same level as in flash butt welding can be expected also in laser welding. Furthermore, good weld quality has been obtained also in general low-carbon steels.

It was feared at first that the design performance of the optical transmission system (lens, mirror, etc.) from the laser oscillator to the welder might not be expected in the bad environment of the strip processing line. Judging from the results of operation so far obtained, however, there is no problem in this respect.

5 Comparison with Flash Butt Welder

Table 4 shows a comparison between a laser welder and a flash butt welder. The laser welder is equal or superior to the flash butt welder with the exception that the cycle time of the former is longer.

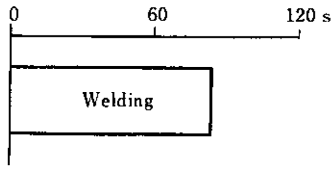
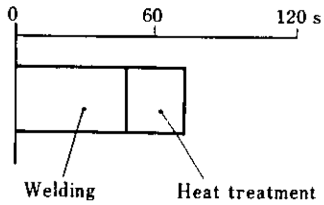
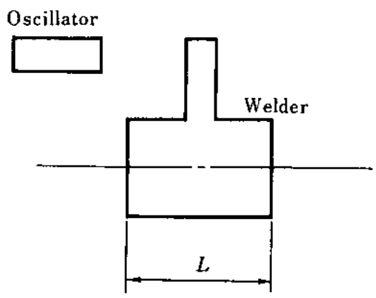
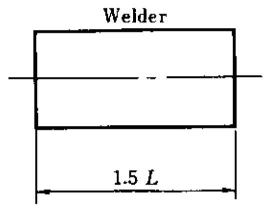
In flash butt welding, molten metal spatters around during welding, which is unavoidable from the character of this welding process. Therefore, it is necessary to take environmental control measures related to equipment. Although fumes are generated a little in laser welding, their amounts are negligible and hence it is unnecessary to take special means in equipment.

6 Summary

Kawasaki Steel put laser welders, which are being spotlighted as a new welding process, into practical use in steel processing lines. The four laser welders so far installed have achieved their purposes as expected. Especially the laser welders for pickling line are operating to weld a wide variety of steel grades with much better results than with conventional welders.

In laser welding, welding can be performed with low heat inputs because of a high power density at weld points and better weld quality than with conventional welding processes can be obtained. In addition, a good weld profile is one of the features of laser welding. Making full use of these advantages, the company intends to increase (a) applicable steel grades and (b) applicable lines and establish laser welders as multi-purpose welders.

Table 4 Comparison of laser welder with flash butt welder

Item \ Welder	Laser welder	Flash butt welder (The newest type)
Treated material	High silicon steel High carbon steel	Low carbon steel
Cycle time (Ex. mild steel)		
	(Time ratio ≒ 1.2 : 1)	
Initial cost	Laser oscillator Welder	Welder
	(Cost ratio ≒ 0.8 : 1)	
Maintenance (Parts periodically exchanged)	Lens Mirror Shear blade	Electrode Trimmer bite Shear blade
Space for welder		
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