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Development of High Performance ERW Pipe for Linepipe†

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Abstract:

To respond to customers' needs for higher grade and higher quality linepipe in recent years, in 2003, JFE Steel's Chita Works carried out a revamp of its 26" medium-diameter ERW pipe mill, in which the maximum wall thickness of API 5LX56 grade (API: American Petroleum Institute) was increased from the former 20.6 mm to 25.4 mm. At the same time, Chita also improved its measurement technology and developed an original quality assurance system, represented by a multiprobe weld seam ultrasonic test (UT) inspection device, with the aim of improving weld seam quality.

1. Introduction

In recent years, demand for linepipe has been strong. As petroleum and natural gas drilling and transportation environments have become increasingly severe, high quality requirements for pipe, including strength, toughness, and corrosion resistance, have become remarkable, particularly in environments where large-diameter pipe, as represented by UOE pipe, is applied[1)].

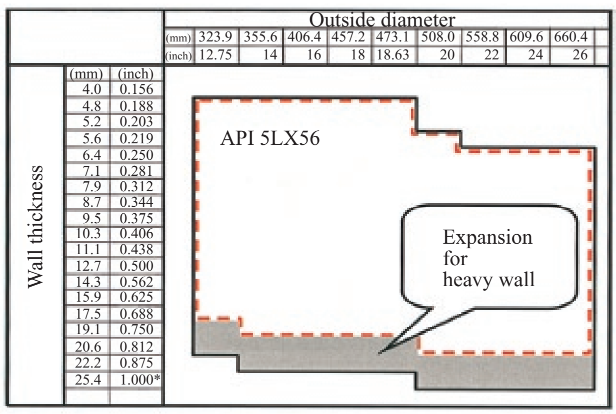
On the other hand, against a background in which priority is assigned to high productivity, there has been a continuing changeover from UOE and seamless steel pipe to electric resistance welded (ERW) pipe, supported by rapid progress in material and pipe manufacturing technologies for ERW pipe for linepipe.

The 26" medium-diameter ERW pipe mill at JFE Steel's Chita Works is the only mill in the world which is capable of manufacturing ERW pipe with outer diameters up to 26". Therefore, taking advantage of this feature, Chita Works revamped its manufacturing equipment to expand the maximum wall thickness, and simultaneously improved its technology and established a quality assurance system for enhanced welded seam quality with the aim of entering the market for UOE pipe. These equipment improvements and new technologies developed for ERW pipe for linepipe are described in this report.

2. Development of Manufacturing Technology for Heavy Wall Pipe

In April 2003, the 26" medium-diameter ERW pipe mill was revamped to expand the available wall thickness of API 5LX56 from 20.6 mm to 25.4 mm. The available size range is shown in **Fig. 1**.

The design specification of this mill was outer diameter: OD12"–26" and wall thickness: WT16 mm with



* ERW 1" wall thickness pipe: Only JFE Steel's 26" ERW mill can manufacture.

Fig. 1 Available size in 26" ERW mill

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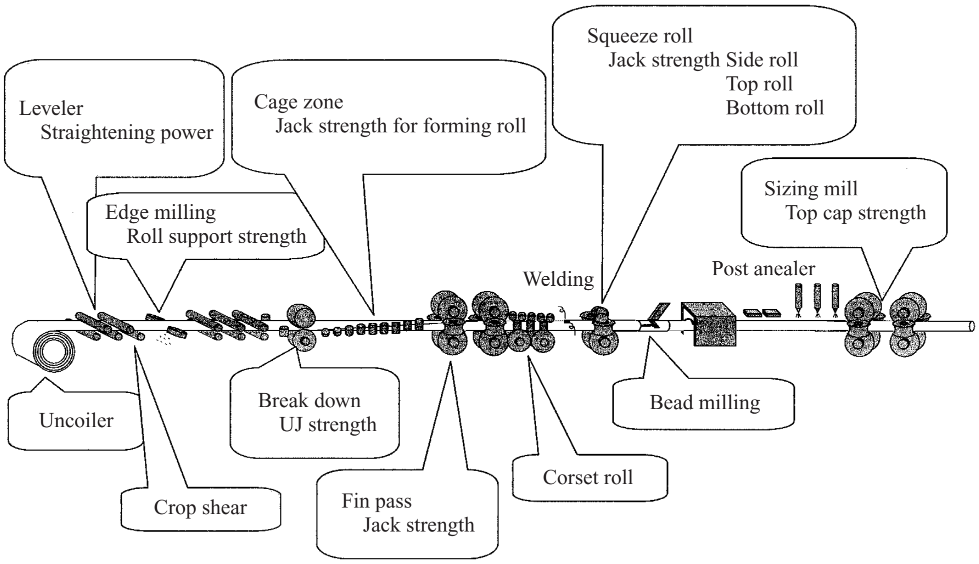


Fig. 2 Reinforcement for 1" wall thickness

X42. To date, however, the size range has been expanded by carrying out various improvements. Following the most recent revamp, the general strength index, which is expressed by (width) $\times$ (thickness)^2 $\times$ (strength), is approximately 3.3 times that when the mill was originally constructed. Therefore, strengthening of the mill by making full use of equipment design technology was studied with importance attached to investment efficiency. The main improvements in the mill are shown in **Fig. 2**. All work from development through design and construction was performed by the JFE Steel Group.

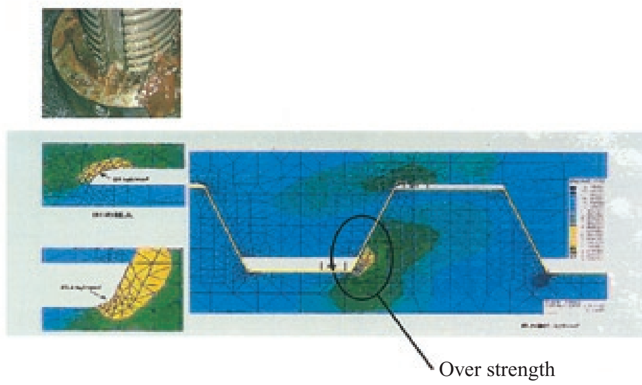


Fig. 3 FEM analysis result of finpass top roll jack

2.1 Strengthening of Mill Jack System

In studying strengthening of the mill jack system, first, the pipe forming load when manufacturing the 25.4 mm maximum wall thickness was predicted based on previous research in the JFE Steel Group, proven pipe forming load prediction equations, and measured values of the pipe forming load.

The jack displacements of various parts of the mill under pipe forming loads were estimated by FEM analysis, and the appropriateness of the results was verified by actually measuring displacement. In addition, the target allowable load was estimated from previously derived predictions of the pipe forming load and reflected in the strength design. **Figure 3** shows an example of finite element method (FEM) analysis of the stress applied to the screw part of the fin pass top roll jack. As a close correlation between the verification results and diagnostic results was obtained, the accuracy of the verification method could also be confirmed.

2.2 Strengthening of Mill Drive System

For the mill drive system, the direction of increasing torque by reducing the reduction gear ratio was adopted based on the fact that there was a margin in the speed design of the line. The specifications for strengthening the drive system were decided by measuring the load current of the main shaft drive motor, preparing a design which considered the motor heat capacity in addition to the predicted forming load, and verifying the results by continuous load predictions.

2.3 Strengthening of Conveying/Finishing Equipment

In strengthening the conveying and finishing equipment, it was necessary to cope with the increased unit weight of pipes. The main improvements were increases in the capacities of the stopper, kicker, and lifting equipment and strengthening of the shock-absorbing function for impact during material conveying.

With the hydrostatic test machine, the hydrostatic withstand pressure (in the following, pressing load) of the existing equipment was 6.9 MN, as shown in **Fig. 4**, and it was not possible to test large diameter, heavy wall pipes with high strength at 95% SMYS.

In this revamp, the maximum pressing load was

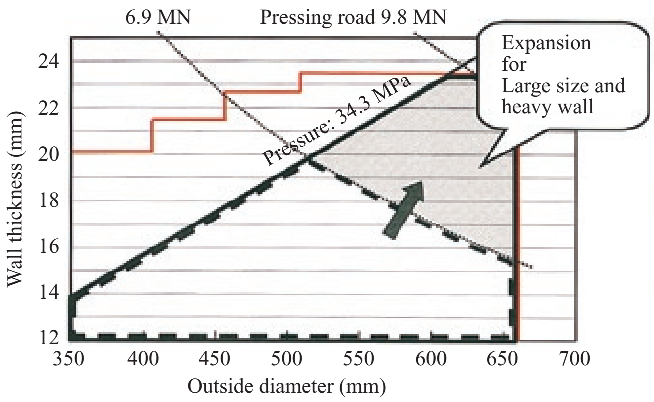


Fig. 4 Available size for hydrostatic test (X65 95%SMYS)

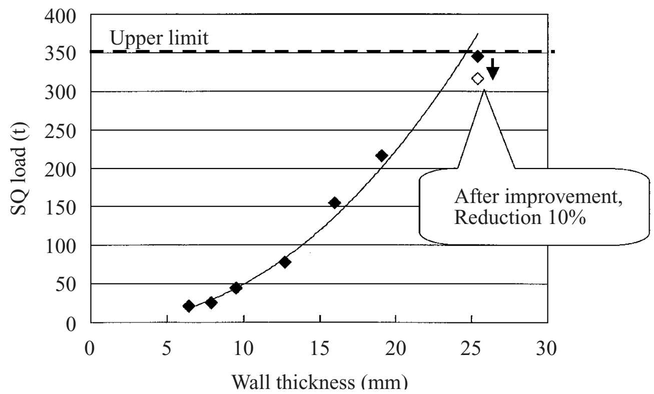


Fig. 5 Efficient of ERW pipe wall thickness on SQ load (X42–X56, Outside diameter: 26")

increased to 9.8 MN by strengthening the main cylinder and other pressing load mechanism parts of the hydrostatic test machine. As a result, the available size range for hydrostatic testing was expanded as shown in Fig. 4.

3. Technical Development for Stabilization of Weld Seam Quality in Heavy Wall Linepipe

3.1 Stabilization of Forming during Manufacture of Heavy Wall Pipe

Although the forming equipment was strengthened, as described in the previous chapter, the pipe forming load in the squeeze side roll when manufacturing OD26" × WT25.4 mm products approached the 350 t upper limit of the equipment specification. Thus, there were remaining problems for achieving stable weld seam quality, as it was not possible to select the optimum forming setting for the weld seam due to partial equipment restrictions.

Therefore, the load balance was improved by conducting a detailed review of the forming settings of each of the forming stands in order to minimize the forming load applied to designated equipment and distribute the load over the equipment as a whole.

Furthermore, in order to improve the forming stability of the coil edge, the shapes of the various kinds of forming guide rolls were optimized to increase the constraining force, successfully reducing deviations in forming immediately prior to welding.

As a result, as shown in **Fig. 5**, the forming load at the squeeze stand with WT25.4 mm was reduced by approximately 10%, even when a stable forming setting was adopted.

Where the squeeze stand forming load was concerned, systemization was carried out to enable full-time monitoring and storage of results in a database in order to control forming deviations, which are linked to weld deviations. This has also contributed to stabilizing product quality.

3.2 Toughness of Welds in Heavy Wall Products

Seam heat treatment is a process for improving the quality of the weld seam in ERW pipes. **Figure 6** shows an outline of the manufacturing process, including the heat treatment processes. The purpose of seam heat treatment is to improve the microstructure of the weld seam by heating the seam from the outer side of the pipe by induction heating, followed by tempering and other heat treatment procedures. However, when attempting to apply adequate tempering through the product to the inner side of heavy wall pipes, overheating of the outer side was a danger.

Figure 7 shows an example of the results of an evaluation by the CTOD test, which is the strictest test method for evaluating weld toughness. When the outer side of the pipe is overheated, it was found that the microstructure of the outer surface layer coarsens, resulting in a remarkable deterioration of weld toughness.

To prevent this overheating of the pipe outer side, the temperature control thermometer used in the annealer was changed from the conventional outside surface average temperature measurement method to a scanning-type thermometer (scanning-type peak temperature con-

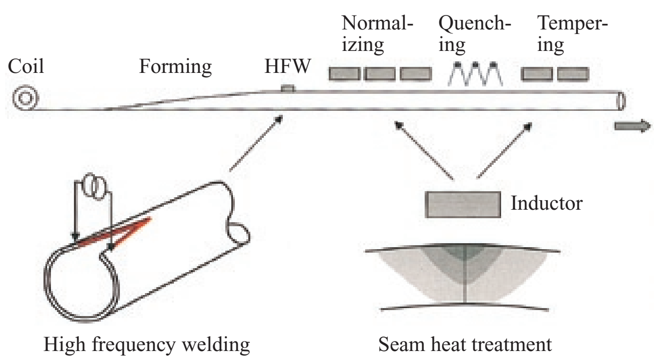


Fig. 6 Manufacturing process of ERW pipe

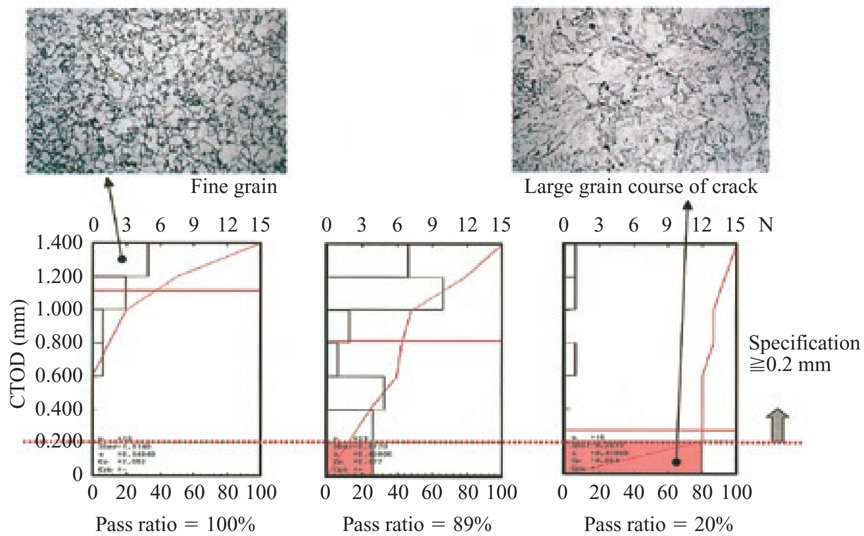


Fig. 7 Relation between CTOD value and grain size

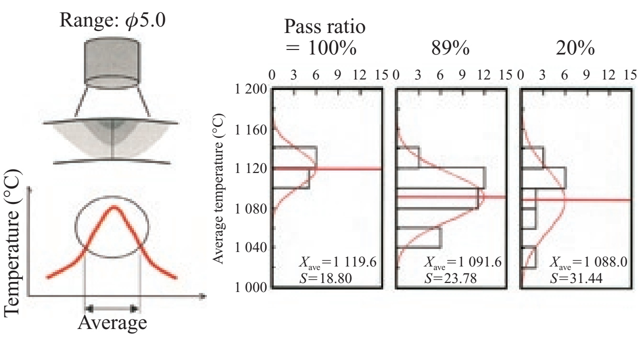


Fig. 8 CTOD results in conventional thermometer

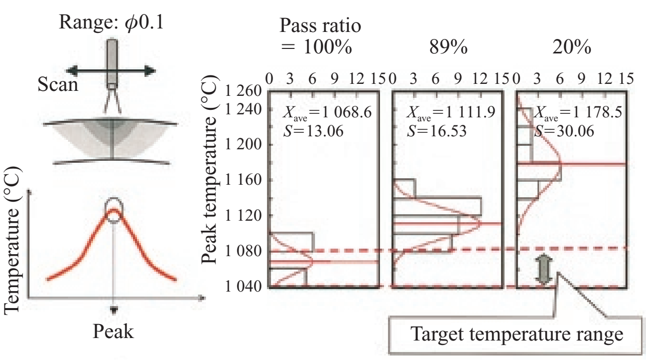


Fig. 9 CTOD results in scan-type thermometer

trol method). As shown in **Fig. 8**, when the conventional radiation thermometer was used, the correlation between the outside surface temperature and the CTOD values was unclear. In contrast to this, as shown in **Fig. 9**, the tendency of the CTOD values to deteriorate as the outside surface temperature increases could be clearly grasped by using the scanning-type thermometer.

Introduction of the scanning-type thermometer enabled optimum strict temperature control, resulting in a broad improvement in the CTOD value of the weld seam.

As a result of these improvements, Chita Works received orders for products (API 5LX65; OD24" × WT19.1 mm) with CTOD specifications for the weld seam, which is a world's first for ERW pipe, and began standard production.

4. Quality Properties of Heavy Wall Products

The revamp of the line and trial pipemaking were completed in April 2003, and standard production of WT25.4 mm products began in May.

The mechanical properties of products of the 25.4 mm wall thickness process are shown in **Figs. 10–12**. In both the weld and the body, the tensile test results, Charpy impact test results, and flattening test results satisfy all API specifications.

An optical microscope image of the ERW weld seam of API 5LX56, OD26" × WT25.4 mm is shown in **Photo 1**. A satisfactory weld seam microstructure was successfully obtained by normalizing heat treatment of the weld seam.

Approximately two years have passed since the start

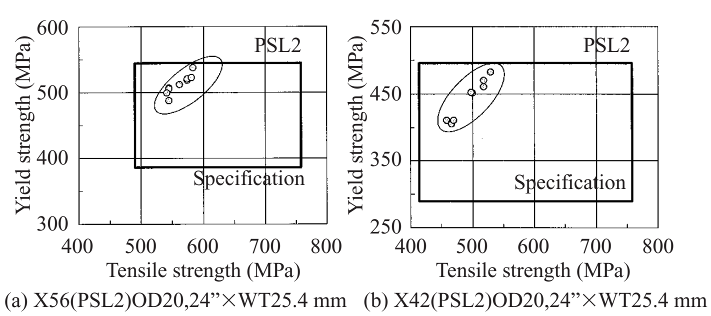
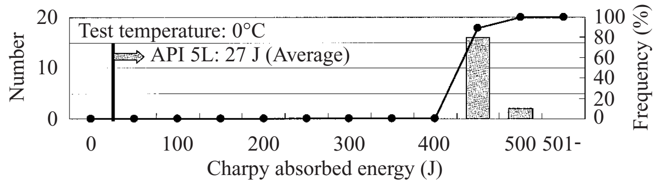


Fig. 10 Tensile test result



(a) X56(PSL2)OD24”×WT25.4 mm Body

(b) X56(PSL2)OD24”×WT25.4 mm Weld

Fig. 11 Charpy impact test results

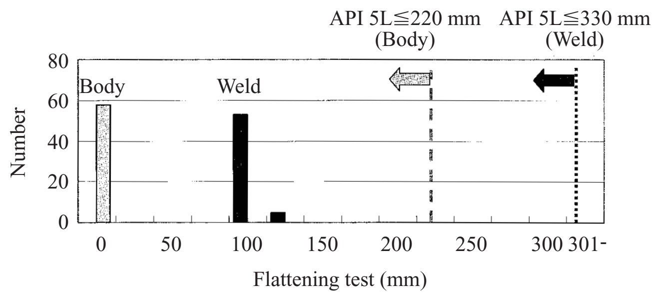


Fig. 12 Flattening test results (API 5LX56 OD26” × WT25.4 mm)

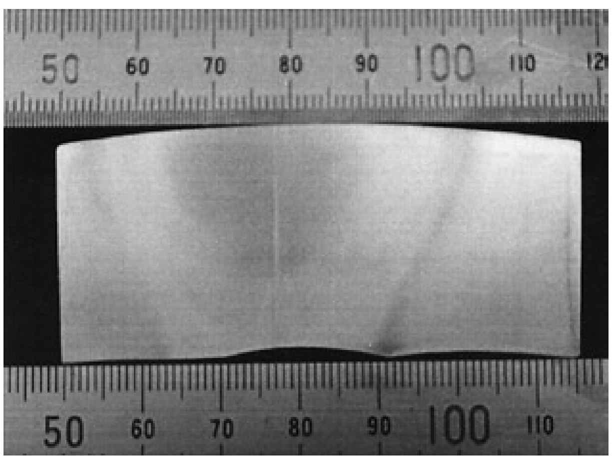


Photo 1 Cross section of ERW welded seam (API 5LX56 OD26” × WT25.4 mm)

of standard production, and product quality is extremely stable.

5. Development of UT Inspection/Assurance Technology for Weld Seam in Heavy Wall Pipes

Heavy wall linepipes, represented by UOE pipes, are mainly used in sea bottom linepipes, and service conditions are extremely severe. Therefore, reliable detection of flaws trapped in the material is necessary, not only in the body but also in the welds. In particular, in recent years, there have been strong movements, beginning with the major oil companies, to establish specifications which attach importance to the weld seam flaw detection capability in heavy wall products.

Anticipating this trend, JFE Steel developed and introduced a multiprobe ultrasonic inspection device for the weld seam[2]. As shown in **Fig. 13**, with the conventional one-side, 3-channel, 45° flaw detection angle probe arrangement, it is not possible to cover the full wall thickness in inspections of heavy wall pipes. Furthermore, the detection accuracy of reflected echoes from flaws trapped in the mid-wall area is low. For these reasons, operability was inevitably sacrificed in actual operation, for example, by using probes with different detection angles corresponding to the wall thickness and raising sensitivity to an extreme level in order to secure the necessary detection capability.

With JFE Steel’s newly-developed multiprobe UT inspection device, flaw detection is performed using a one-side, 8-channel continuous arrangement of probes with a 45° detection angle in the pipe circumferential direction. Therefore, as distinctive features, this system enables coverage of 100% of the wall thickness, even with heavy wall products, and can also detect all reflected signals. As a result, as shown in **Fig. 14**, even flaws in the mid-wall area can be detected without increasing detection sensitivity. The fact that this system shows an extremely stable detection capability with respect to deviations in the weld line during inspections has also been confirmed[2].

This is an original technology which was developed by JFE Steel and was introduced by the company before other companies. It has received a very favorable evaluation from the customers, and is making an important contribution to improving the reliability of ERW linepipe.

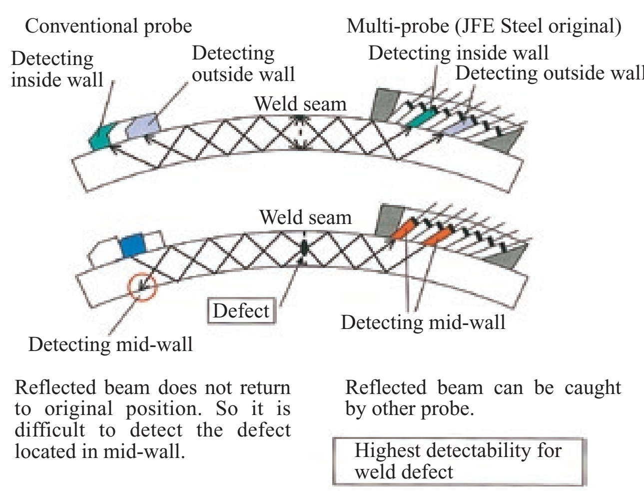


Fig. 13 Multi-probe ultrasonic inspection

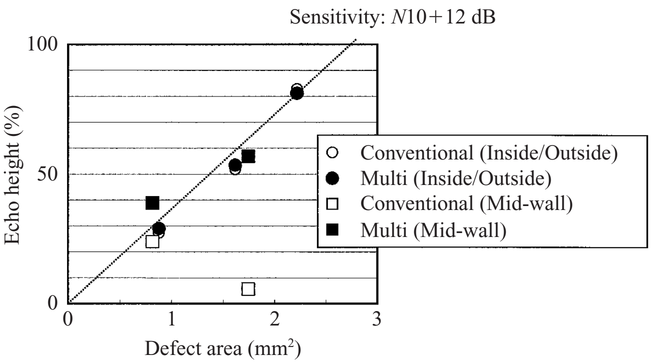


Fig. 14 Detection ability for weld defect

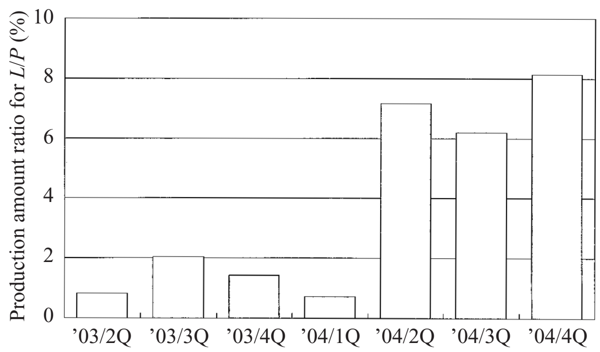


Fig. 15 Amount ratio of 1” wall thickness pipe in *L*/*P* products

As a result of the development of these technologies, JFE Steel’s ERW linepipe, which is produced as a substitute for UOE, has received an excellent evaluation from customers since the start of standard production in May 2003, and shipment tonnage has shown a strong trend, as can be seen in **Fig. 15**. Moreover, sales have achieved a pace far exceeding the original plan.

6. Conclusion

In order to manufacture ERW pipe as a substitute for UOE, JFE Steel’s Chita Works strengthened its 26” ERW mill to enable production of 25.4 mm wall thickness products and developed technologies to improve weld seam quality. The content is summarized as follows.

(1) The mill and finishing equipment were strengthened, making it possible to manufacture X56 ERW pipe with a wall thickness of 25.4 mm.

(2) Innovative improvements in the plant’s measurement technology enhanced annealer temperature control, making it possible to obtain stable weld quality properties through the full wall thickness.

(3) A multiprobe UT inspection system for the weld seam was developed and introduced, improving the flaw detection capacity and enhancing the quality assurance capability.

As described above, technical development and equipment improvements were carried out based on an accurate grasp of customers’ needs. As a result, it is no exaggeration to say that large diameter, heavy wall ERW pipe is continuing to grow as a central product line of the current 26” medium-diameter ERW mill. In the future, JFE Steel intends to develop Only One and Number One products which respond to new, stricter and more diverse market needs.

References

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