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An Outline of 26-inch Mill and Quality of Pipes

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Synopsis :
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The body can be viewed from the next page.

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1 Introduction

The 26-inch ERW pipe mill is the fifth pipe-producing machine set up at the Chita Works, following a 20-inch medium-diameter ERW pipe mill and three small diameter pipe mills. The 26-inch ERW pipe mill was put into operation in October 1978 to produce high quality, large-diameter line pipes with thick or thin walls, and has operated smoothly since then. The pipe-producing machine is a full-cage roll forming type supplied by Ishikawajima Harima Heavy Industries Co., Ltd.—Yorder Co., and is the largest of its kind in the world. It produces pipes with outside diameters of up to 660.4 mm and maximum wall thickness of 16 mm, with less than a 1.0% of t/D ratio (thickness/outside diameter). The primary production capacity of this equipment is 180 000 t/year (future production capacity is 480 000 t/year), which comes to a total of 610 000 t/year when added to the production capacities of the other mills, already established. The structure of the mills also allows production of pipes with outside diameters of from 21.7 mm to 660.4 mm, and wall thicknesses of from 1.0 mm to 16.0 mm. This report will give information concerning the outline of this 26-inch ERW pipe mill, as well as various operational conditions.

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**** London Office

2 Purpose of Construction

Until 1978, both line pipes and oil-well pipes had been manufactured at the 20-inch ERW pipe mill put into operation in 1964. With the recent oil shock as a turning point, world-wide active developments of energy resources had been causing a radical increase in demand for strong, high quality line pipes with large diameters and thin walls. The Chita Works quickly perceived this trend, and began construction of pipe-producing equipment employing a full-cage roll forming method, unprecedented in the history of equipment for producing large diameter pipes. This equipment was designed to steadily and efficiently produce high quality large diameter pipes.

3 Manufacturing Process

The pipe manufacturing process in the factory is shown in **Fig. 1**, the layout of the 26", ERW pipe mill in **Fig. 2**, and major specifications for each equipment in **Table 1**. Materials used are hot-rolled coils from the Chiba and Mizushima Works. The entry-side equipment, which deals with the receiving of materials to the side trimming of coils, automatically and efficiently feeds the mill with coils up to 45 t; therefore, the downtime in pipe manufacturing, caused by waiting for successive coils, is minimized. After the levelling, the central part of the strip is bent by the preforming roll and the break down roll, whereas the sides of the strip are bent into a desired shape by the edge-forming

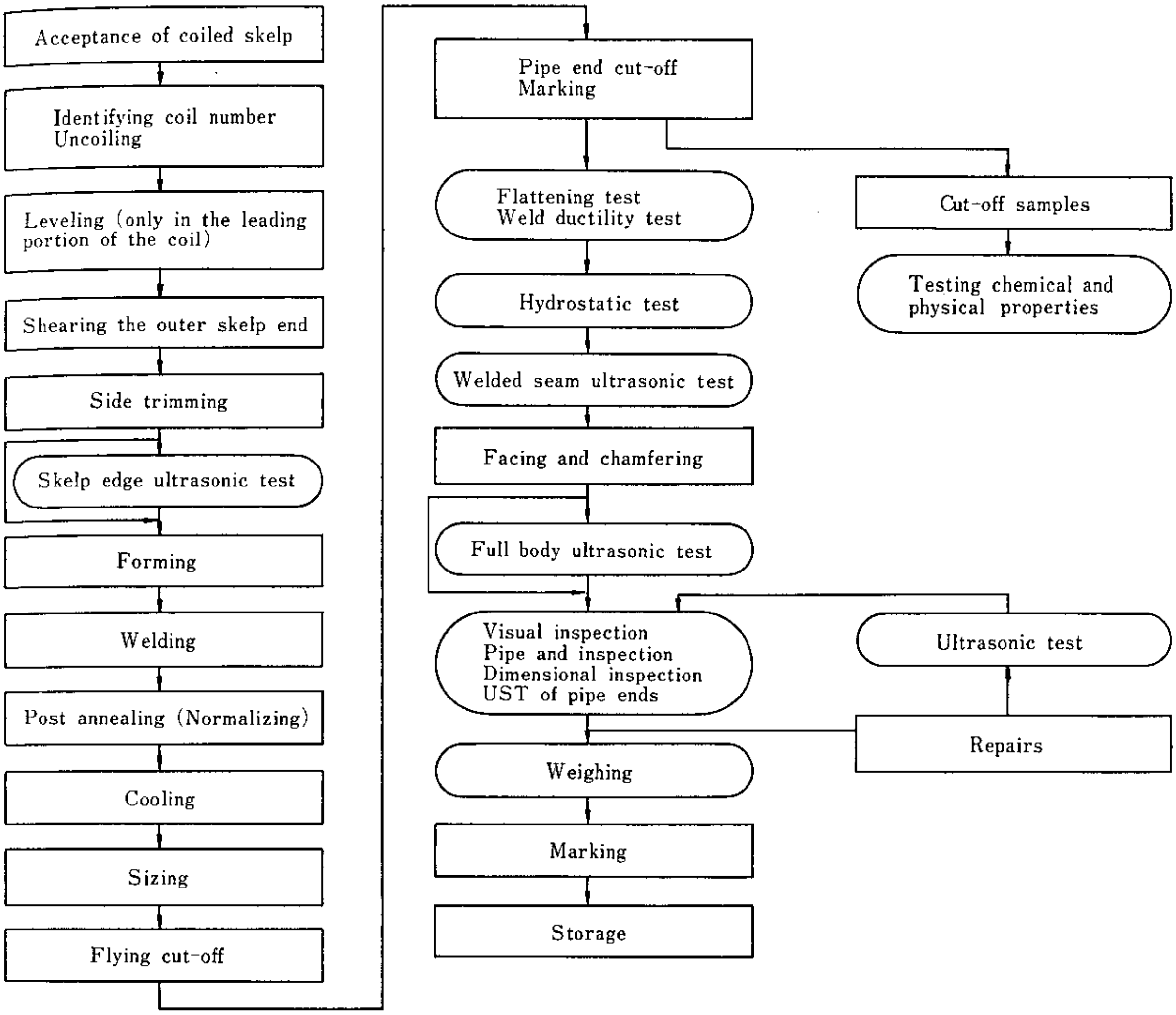


Fig. 1 Manufacturing and inspection processes of the line pipe

roll. Then, the cage forming stand bends the strip without causing any radical deformation in it, and the fin pass roll stands complete the pipe forming to get desired measurement. High frequency resistance welding is performed on the edges to be jointed together, and in order to improve the quality of the weld, the welded seam is annealed and then gradually air-cooled or water-cooled. Next, bends and orals in the pipes are corrected in the sizing stand, composed of four stands of the four-roll type and one turkeshead, and then they are cut into desired lengths with a flying cut-off machine.

Product quality is examined through the flattening test, the hydrostatic test, ultrasonic test of the welded seam, and the rotary ultrasonic test; and furthermore, the pipe ends are faced, and pipe surfaces are marked with specifications by electrified powder-ink. If requested, pipe surfaces will be greased before shipping.

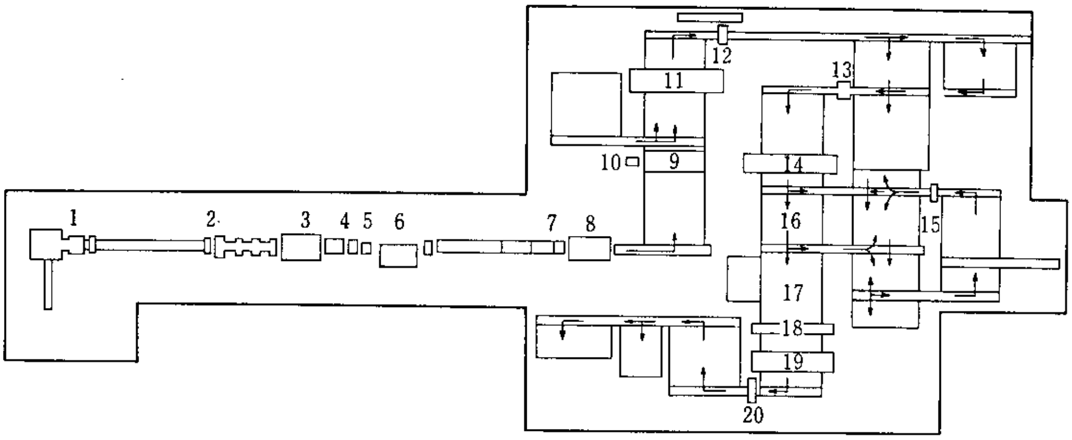
4 Available Size Range and Types of Products

The range of available outside diameters and wall thicknesses of 26-inch ERW pipes is indicated in **Fig. 3**. The mill can produce pipes from 5.5 m to 20 m in length.

Line pipes, structural pipes, and pipes for piles with high quality are the main products of the new 26-inch ERW pipe mill. In the area of line pipes, this mill has achieved excellent results in producing API 5LX X65, and tests for manufacturing pipes of higher strength are planned.

5 Characteristics of the Equipment

The 26-inch ERW pipe mill can stably and efficiently manufacture high quality large diameter pipes with thick or thin walls. Also, the equipment is designed to



1. Uncoiler
2. Side trimmer
3. Forming section
4. Welder
5. Squeeze roll
6. Seam annealer
7. Sizing section
8. Rotary cut-off machine
9. Pipe end cut-off machine
10. Flattening tester
11. Hydrostatic tester
12. Ultrasonic inspection of welded seam
13. Intermediate cut off
14. Facing and chamfering machine
15. Full body ultrasonic test
16. Dimensional and visual inspection
17. Customers inspection bench
18. Weighing machine
19. Marking machine
20. Anti rust coating machine

Fig. 2 Layout of 26″ ERW pipe mill

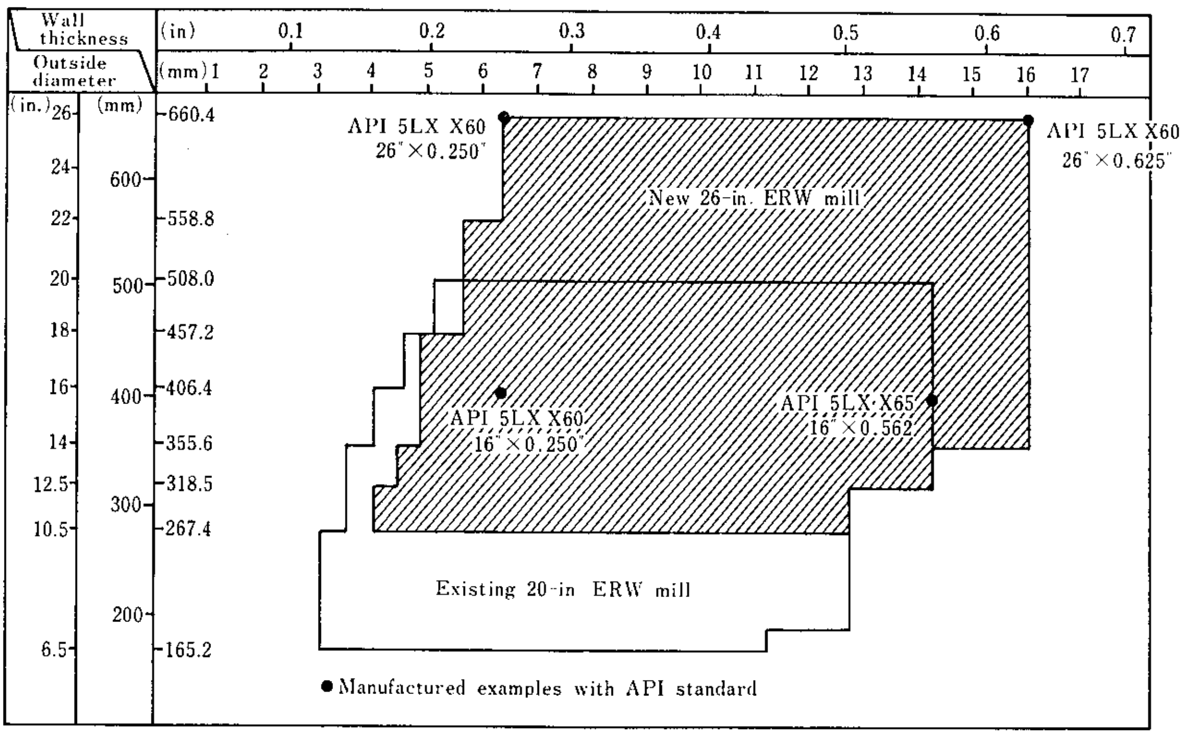


Fig. 3 Available size range

Table 1 Main equipment and their specifications

(1) Production equipment

Equipment	Main rolls		Main motor (kW)	Maker	Type
	Root dia. in (mm)	Length in (mm)			
Uncoiler			AC 15	Yoder-IHI	Double cone type Max. outside dia. 90.6" (2 300 mm) Max. width 86.6" (2 200 mm) Max. weight 45
Side trimmer			DC 90	ditto	Trimmer knife dia. 32.3" (820 mm)
Preforming roll			DC 22	ditto	1 top roll, 5 dish rolls
Break down roll	61.4 (1 559.6)	55.1 (1 399.5)	DC 150 DC 45×3	ditto	No.2 No.4 break down rolls are situated in the cage structure
Edge forming			Idle	ditto	
Cage forming			Idle	ditto	54×2=108 outside cage rolls 6×2=12 inside cage rolls
Fin Pass roll	25.9 (657.9)	23.6 (599.4)	DC 185×3	ditto	3 stands
Squeeze roll	26.7 (678.2)	23.6 (599.4)	DC 90	ditto	4 rolls type
Welder				Thermatool	VT 600 400 kHz 49.2~196.8 ft/min.(15~60 m/min.)
Seam annealer				Mitsubishi Electric Co.	1 000 Hz 400 kW×4 High frequency induction heating type
Sizer	25.9 (657.9)	23.6 (599.4)	DC 185×4	Yoder-IHI	4 stands
Rotary cut-off machine			DC 75	ditto	6 disk cutters
Pipe end and middle cut-off machine			AC 30	Sumitomo Heavy Ind.	3 heads cutter type 2 sets
Facing and chamfering machine			DC 55	Ikegai Iron Works Ltd.	Cutting tool rotating type Cutter: Carbide tool
Anti-rust coating machine				Asahi Okuma Ind.	1 set

(2) Inspection machines

Machine	Number	Maker	Type
Hydrostatic tester	1	Yamamoto Suiatsu Kogyosho Co., Ltd., Japan	Max. pressure 4 977 psi (350 kg/cm^2) Pipe dia. 10¾~26 in. (273.0~660.4 mm) Length: 18~80.4 ft (5.5~24.15 m)
Ultrasonic skelp-edge detector	1	Teitsu Denshi Kenkyusho Co., Ltd., Japan	Pulse transmission
Ultrasonic flaw detector	1	Tokyo Keiki Co., Ltd., Japan	Angle beam
Ultrasonic flaw detector	1	Mitsubishi Electric Corp. Japan	Rotary probe Angle beam and normal beam
Weighing machine	1	Kawatetsu Metetsuological Equipment & Vending Machine Co., Ltd., Japan	Max. 4 Torelance: 1/2 000 Measured results are processed by a process computer
Marking machine	1	Orizin Electric Co., Ltd., Japan	Electrostatic marking with automatic selection of words
Flattening tester	1	Otuka Iron Works	Open height: 35.4" (900 mm) Max. pressure: 200 t

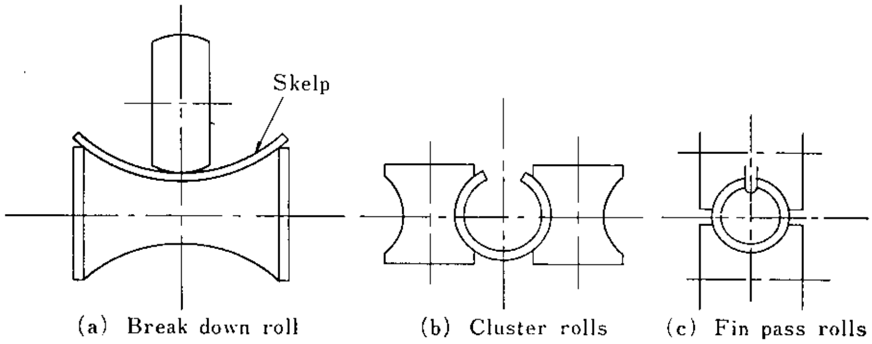


Fig. 4 Forming roll of conventional system

allow the introduction of automatically controlled forming systems in the future. The characteristics of this equipment are described in the following sections.

5.1 Full-cage Roll Forming Stand

Among the systems in which strips are slowly bent

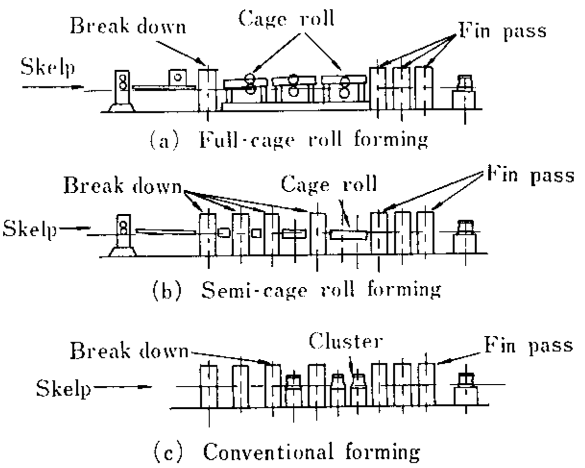


Fig. 5 Comparison of full-cage roll forming, semi-cage roll forming and conventional system

into pipes at room temperature, there is the conventional system, which is a combination of rolls as shown in **Fig. 4** (refer to **Fig. 5 (c)** for the roll arrangement), and there is the semi-cage roll forming system, which replaces the cluster roll with the cage rolls for improved forming (refer to **Fig. 5 (b)**). Then there is the full-cage roll forming system, which places the cage roll stand between the break down stand and the forming stand (fin pass stand). Formerly, manufacturing of large-diameter pipes was limited by the formability of both edges of the strip in the case of thick-wall pipes, and by the buckling of the edges in the case of thin wall pipes. The larger the pipe diameter and the smaller the ratio of t/D (thickness/outside diameter) are, the more obvious a tendency for the buckling becomes. In an attempt to solve these problems, the full-cage roll forming system was adopted for the very first time. A schematic comparison of the conventional system and the cage roll system is shown in **Fig. 6**. By adjusting the position of the numerous cage rolls placed in the forming direction, and by appropriate setting of the lower rolls, forming can be made without giving radical deformations in the strip. Thus, elastic and plastic deformation in each

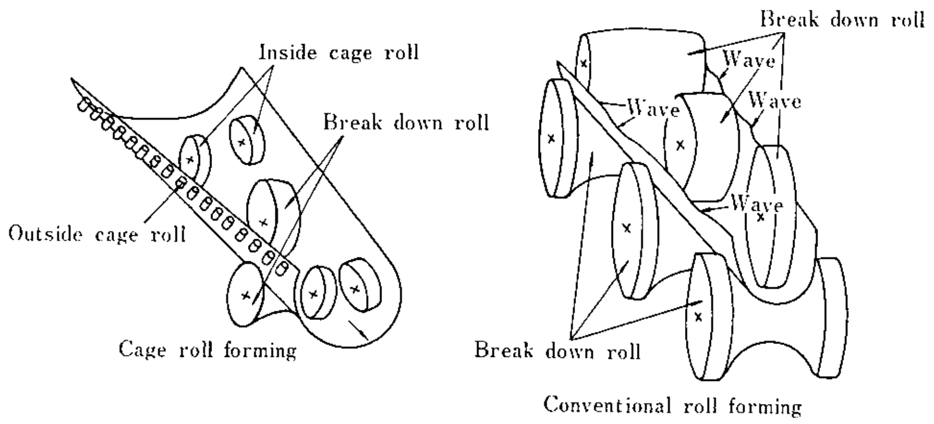


Fig. 6 Schematic comparison of two types of forming

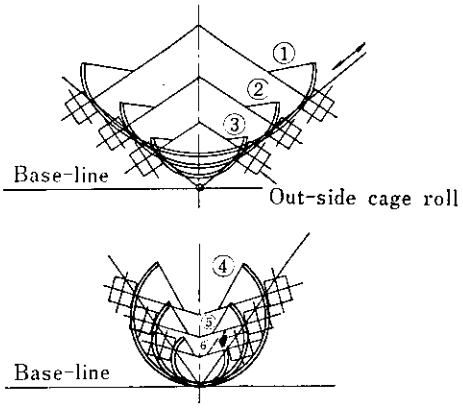


Fig. 7 Principle of new method for cage roll adjusting mechanism

location of the strip become uniform, and, especially, stretch in the edges becomes smaller, preventing the occurrence of edge buckling. This phenomenon made possible the manufacturing of large diameter pipes with thin walls (t/D: less than 1.0%). Moreover, in the case of the conventional system, numerous rolls had to be exchanged whenever there was a change in the size of pipes to be manufactured. With the cage system, the set angle of cage rolls can be quantitatively adjusted as shown in **Fig. 7** without changing rolls according to the pipe sizes manufactured .Therefore, the cage system can employ the same rolls for producing pipes of various sizes, permitting a large reduction in the number of rolls. Use of fewer rolls is very economical, for the 26-inch mill employs heavy, large diameter rolls for the production of pipes of various sizes. Also, the operating rate of the mill increased due to the decreased roll-changing, frequency.

5.2 Edge Forming Stand

The edge forming stand bends the desired widths of the strip edges into desired radius according to the pipe sizes manufactured. The outline of this equipment is shown in **Fig. 8**. The bending of edges heightens the rigidity of the material, and facilitates forming within the cage zone. Especially in the case of pipes with thin wall thickness, the edge can be inserted smoothly into the No. 1 fin pass roll, thereby preventing the occurrence of edge-buckling due to local deformation caused by rough forming. Thus, good results were achieved in manufacturing of low t/D ratio pipes with thin wall and large diameter. As for the thick wall pipe sizes, bending width of edges can be freely adjusted, and therefore the welded part can be fixed into the best condition, resulting in improvement of the quality of the welds. Further, by installing the edge forming stand, the No. 1 break down roll caliber was simplified; and number of rolls was reduced.

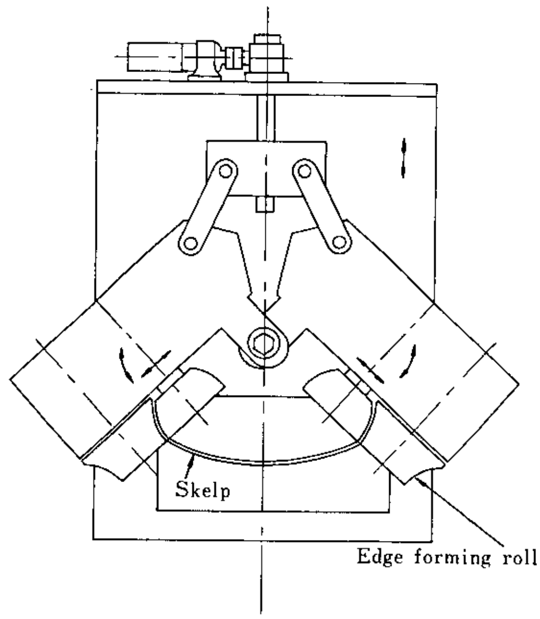


Fig. 8 Edge forming stand

5.3 Fully Automatic-Control Seam Annealer

The electric-resistance welded seam of pipe is subjected to post-weld heat treatment such as induction heating, etc. for quality improvement. Nevertheless, the welded seam sometimes meanders at some amplitude because of base metal or other manufacturing conditions. The annealer used to be adjusted by hand and with the eye to follow the welded seam. However, increases in the speed of pipe manufacturing, growing demand for better quality pipes, and enlargement of diameters of products, have made it necessary to have the annealer head follow up the seams at a fixed distance in order to further improve the quality of the seams. The newly developed distance-measuring system using laser reflection and high-performance scanning pyro-meter made it possible to detect and measure automatically the locations of seams, maximum temperature, and distance between the pipe and the annealer head; thus completed automatic control system for annealer with its head following the seam at a fixed distance.

5.4 Pipe End Cut-off Machine for Large Diameter Pipes

There are various methods for cutting pipes, but it was formerly believed to be impossible to cut pipes with outside diameters of more than 600 mm at high speed. The milling cutter system shown in **Fig. 9** was installed in the Chita Works to cut 26-inch (660.4 mm) pipes. The mechanism of the cutting machine is indi-

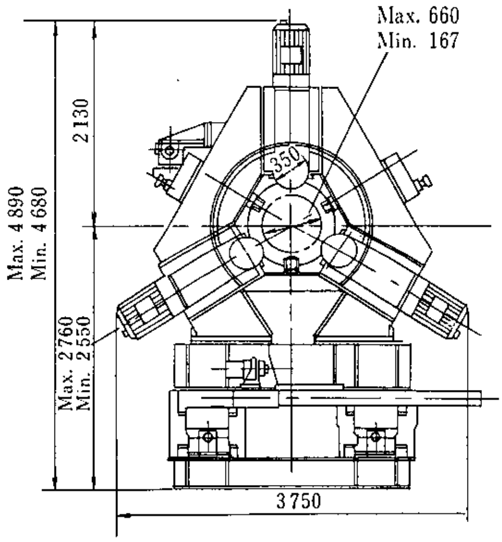


Fig. 9 Milling machine

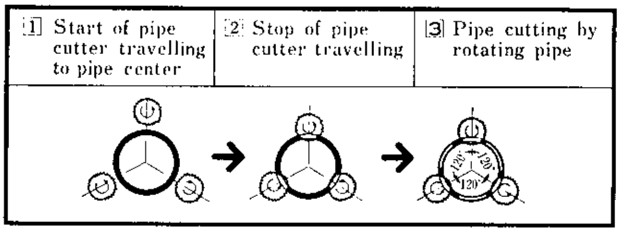


Fig. 10 Mechanism of milling machine

cated in **Fig. 10**. The pipe to be cut is stabilized, and three radially situated cutter heads cut towards the center of the pipe. After cutting in a little deeper than the wall thickness of the pipe, the cutter is stopped and the pipe is rotated 120 degrees to cut the rest of the pipe wall. The size of the cutter can be small, just enough to cut through the wall of the pipe. Therefore, the machine is lighter in weight, and changing blades is easier. The blades last longer than these in rotary cut-off machines, and heat caused by cutting scarcely increases, even when cutting speed is increased. Thus, speedy and accurate cutting of large pipes with outside diameters of up to 26 inches has become possible.

5.5 Electrostatic Marking Machine

Marks on pipes include items demanded by customer besides those determined by standard requirements, and their contents differ according to contracts. Especially those articles which require inspection by both parties before shipping, have complicated marking specifications, such as numerous typed letters, which sometimes include the length, weight, and series numbers of pipes. Therefore, the changing speed of mark-

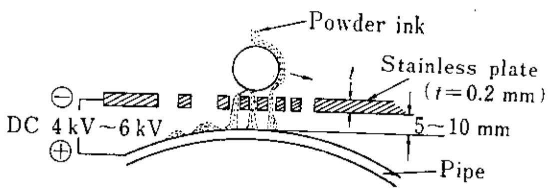


Fig. 11 Electrostatic marking mechanism

ing letters by usual printing methods does not always catch up the pipe manufacturing speed. For this reason, an electronic printing method, which can compile printing screens automatically, was adopted. The mechanism of this method is indicated in **Fig. 11.** This is an electronic printing machine which employs powder ink, and which constantly prints clearly, regardless of precision in the pipe surface because of no contact between them. Also, no coagulation occurs in the ink because it is in powder form. Further, working environments remain clean for there is no need to use such solvents as thinners. Word selecting methods includes an automatic one with various printing data for different pipes processed using computer, and a semi-automatic one with various printing items prepared in advance according to lots. Both methods select printing screens through control circuits.

5.6 Ultrasonic Flaw Detector for Weld

The ultrasonic flaw detector was installed in order to control and guarantee the quality of welded seam and its vicinity. As shown in **Fig. 12**, there are a total of six probes, three on each side, for the detection of flaws in welded seams. These probes are able to detect flaws in all areas of the seam with equal sensitivity. The equipment possesses additional special functions to ensure reliability of detection results. These functions are as follows:

(1) Acoustic coupling monitoring (ACM)
(2) Distance amplitude compensation
(3) Search unit monitoring

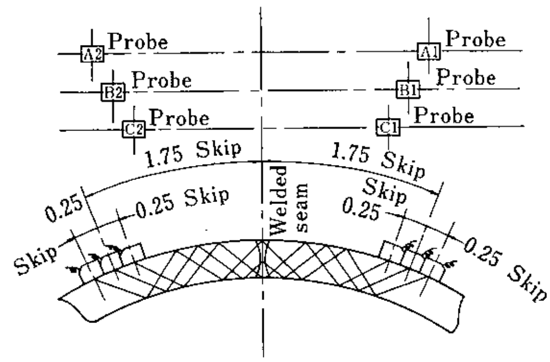


Fig. 12 Schematic illustration of the 6-probe ultra sonic test for the welded seam

(4) Follow-up of the seam

5.7 Full Body Ultrasonic Flaw Detector

The full body ultrasonic flaw detector is the largest rotary UST equipment in Japan, and can detect flaws in pipes with outside diameters of 168.3 mm to 660.4 mm. By combining the special characteristics of both the angle beam technique and the normal beam technique, the probes rotate over the entire circumference of the pipes to detect all flaws. The following functions were also added onto the equipment in order to ensure reliability:

(1) ACM
(2) Automatic calibration
(3) Automatic self-detection and indication of abnormal parts
(4) Data processing (four-quadrant marking using mini-computers, judgement of the lengths of flaws, etc.)

6 Cage Roll Forming Characteristics

Pipes are manufactured from steel sheets which undergo elastic deformation by the use of cold caliber rolls in the order indicated in **Fig. 13**. An important point in the pipe forming process is to minimize the occurrence of strain in the strip, especially between rolls. Concerning the deformation between rolls, the conventional system and the cage roll forming system were compared at the the edge and the center of a mild steel strip with 6.35 mm wall thickness and 660 mm outside diameter. With the conventional system, deformation of the strip tends to be concentrated at the restrained portion just before entering the next roll as shown in **Figs. 14** and **15**, and the repetition of this phenomenon frequently causes a strain due to a big bend just before the final forming. In the case of cage roll forming system as shown in **Figs. 16** and **17**, cage rolls can be placed along the line of forming direction connecting the start flower and the end flower, thus making the deformation pattern smoother, the length of the plastic deformation area longer, and resulting in reducing deformation concentration to one area. Moreover, strain in strip can be further reduced by adjusting the lower strip passing line (the down hill curve) based on the lower rolls height from the flat strip to pipes. The location of the lower rolls can be set at any height in the 26-inch mill, thereby optimum downhill curve can be fixed according to the various pipe sizes,minimizing the strain of strip. In addition, locus of the strip can be changed by adjusting the cage rolls, reducing the possibility of strain occurrence in all parts of the strip, including the edges. Strain in the

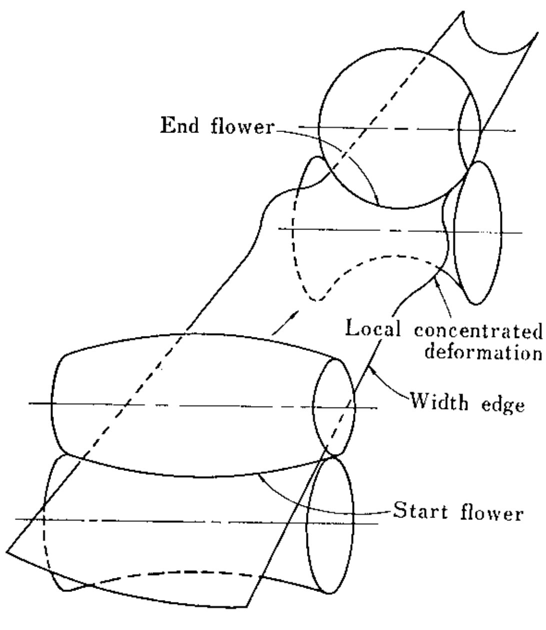


Fig. 14 Forming process through conventional roll forming

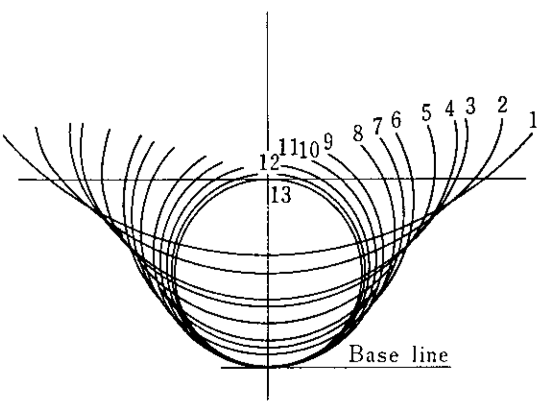


Fig. 13 Flower on full-cage roll forming mill

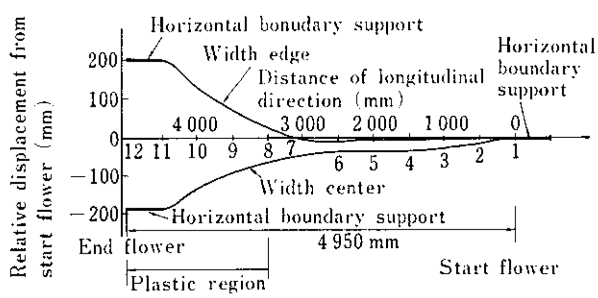


Fig. 15 Displacement trace of width center and width edge by conventional roll forming

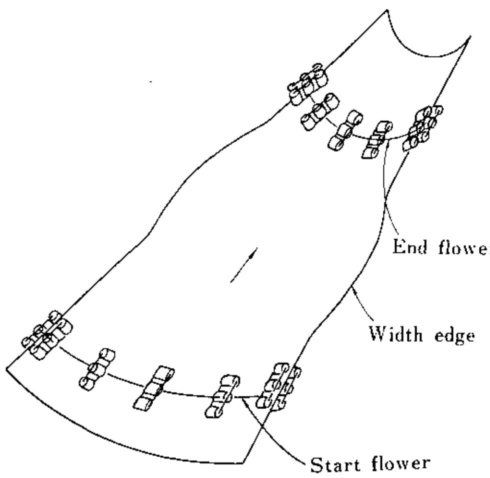


Fig. 16 Forming process through cage roll forming

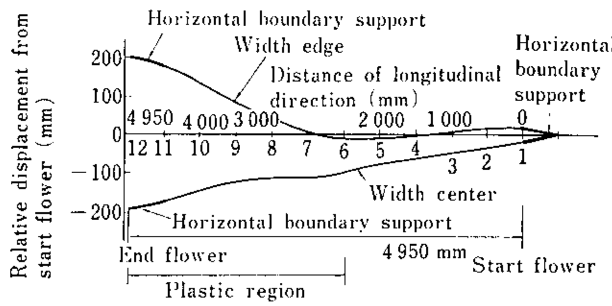


Fig. 17 Displacement trace of width center and width edge by cage roll forming

edges of steel sheets causes waves on the surface to be welded, which will later lead to unsatisfactory welding. **Fig. 18** shows the amount of strain in the edge, measured at the outlet of the final forming stand when producing pipes with outside diameter of 609.6 mm and wall thickness of 6.35 mm ($t/D = 1.04\%$). Vertical displacement of the edge is 0.5 mm, and it is almost at constant longitudinally.

Moreover, as the welded part is straightened by the seam guide roll at the back of the forming stand, the amount of edge buckling is further minimized, and stable welding conditions are obtained. As mentioned above, cage roll forming method, is effective in manufacturing pipes with large diameters and thin walls.

7 Examples of the Quality in Products

Since the mill went into operation in October, 1978, approximately 60 000 t of line pipes, from API 5LX X42 to X60 used for transportation of oil and natural gas, and approximately 50 000 t of pipes used as piling, have been shipped out.

The results of a performance test using API 5LX X52 line pipe with 22 inch outside diameter and 0.281 inch wall thickness are described in the following sections.

7.1 Chemical Composition

The main chemical composition of API 5LX is specified according to each grade. Because hook crack and inclusions, etc. in the up set zone cause defective welding, Kawasaki Steel Corporation reduces impure elements such as P, S, etc. to a minimum and uses Al-Si killed steel with Nb additives, the composition of which is indicated in **Table 2**.

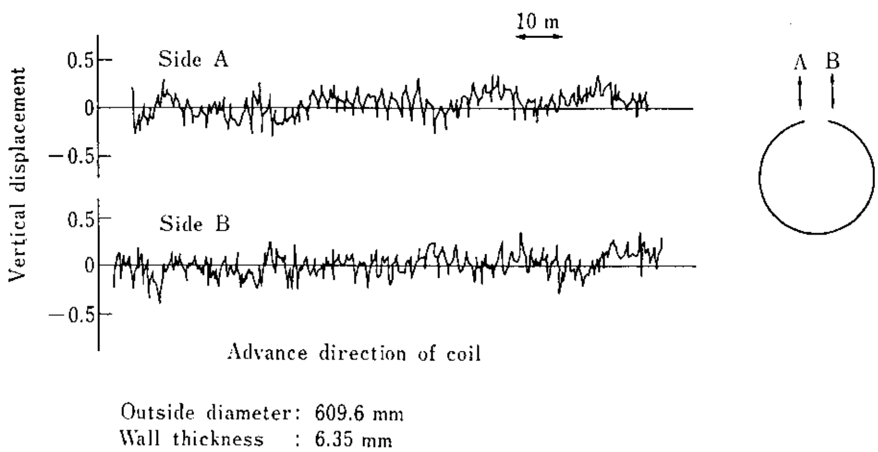


Fig. 18 An example of vertical displacement of width edge after fin pass rolling in cage roll forming

Table 2 Chemical composition of API 5LX X52 (558.8 mmϕ × 7.14 mm)

(wt %)

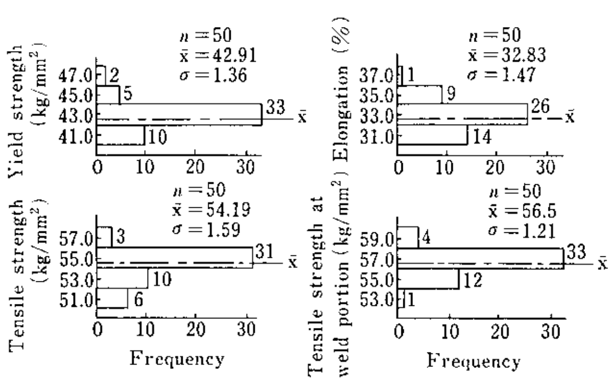
	C	Si	Mn	P	S	Nb	Al	C.E.
Heat	0.08	0.16	0.99	0.019	0.003	0.032	0.023	0.25
Product	0.08	0.16	1.02	0.020	0.005	0.033	0.025	0.25
API 5LX Spec.	Max. 0.30	—	Max. 1.35	Max. 0.04	Max. 0.05	—	—	—

$$C.E. = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15}$$

7.2 Mechanical Properties

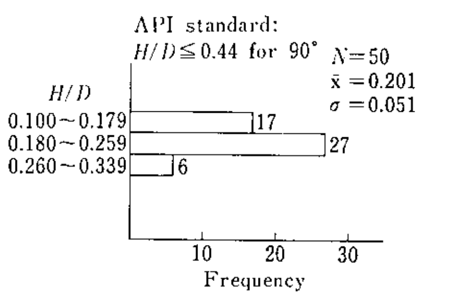
(1) Tensile properties

The results of a tensile test are shown in **Fig. 19**, all of which sufficiently satisfy API standards. Tensile strength of the weld portions is higher than that of the base metal.



Sample: API 5LX X52, 558.8 mmϕ×7.14 mm

Fig. 19 Tensile properties in the transverse direction



Sample: API 5LX X52, 558.8 mmϕ×7.14 mm
D: Outside diameter (22"; 558.8 mm)
H: Flattening height
Test Piece: The pipe of 4" or more in length shall be cut off for the test piece from an end of the pipe

Fig. 20 Flattening test results

(2) Flattening strength

API standards stipulate the flattening test, and the test results are shown in **Fig. 20**. The results indicate a satisfactory flattening ratio (H/D) of 0.2.

(3) Microscopic photographs

Welded seams have the rapidly heated and cooled structure because they are rapidly heated to the melting point, then rapidly cooled after welding. By normalizing the weld portion with a seam annealer, however, the structure becomes an unified, fine ferrite pearlite composite. **Photos. 1** and **2** show the macro- and microstructure of seam-normalized welded portions.

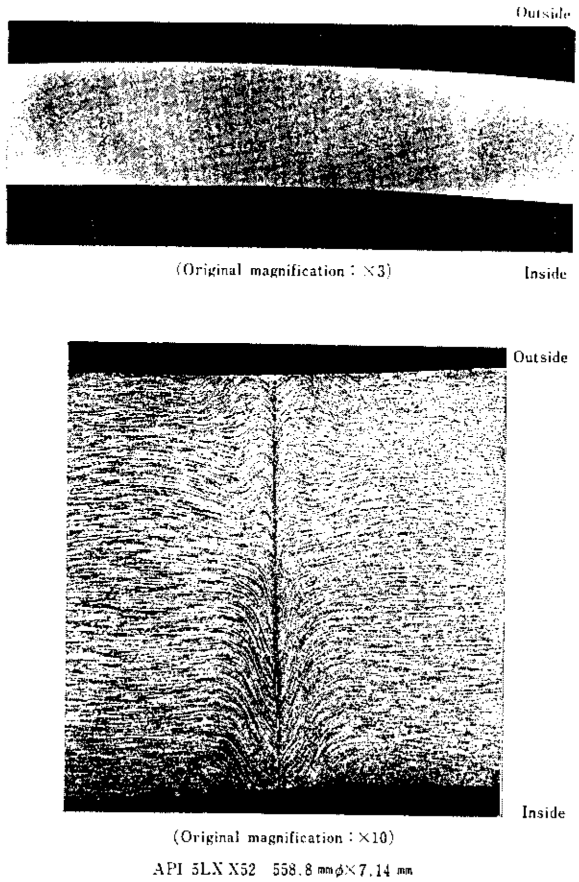


Photo. 1 Macrostructures at welded portion

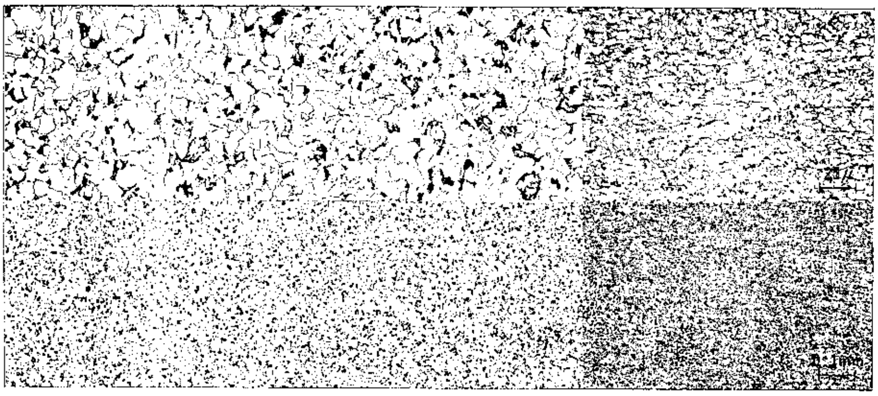


Photo. 2 Optical micrographs at the center of wall thickness with original magnifications of × 400 and 100

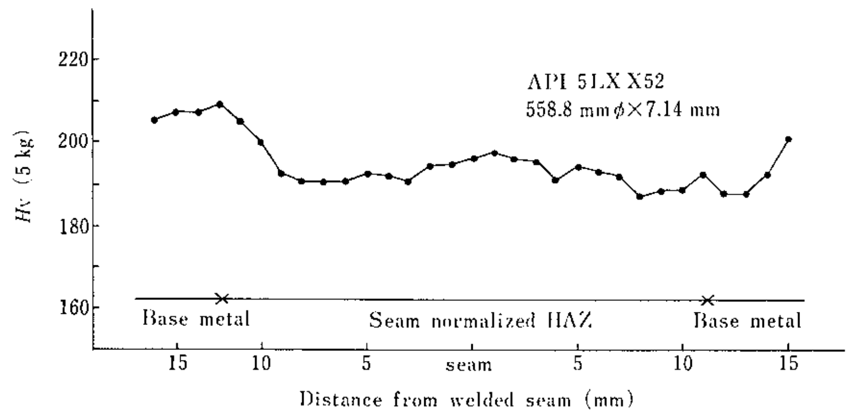


Fig. 21 Vickers hardness distribution of heat affected zone in transverse direction at the center of wall thickness after seam normalized

(4) Hardness distribution in welded portions

Fig. 21 illustretes Vickers hardness distribution, focused mainly on the welded portion. The welded portion (bond and HAZ) has been normalized, and there is scarcely any difference in hardness between the weld portion and the base metal.

(5) Impact properties of welded portions

Fig. 22 shows the results of the 2 mm V-notched Charpy test, comparing toughness of the welded seam and the base metal. These are the results of the tests using test pieces cut from the normalized bond line of a welded portion, from the heat affected zone 2 mm away from the bond line, and from the base metal in the direction towards their circumferences.

Impact energy of the welded portion is a little inferior to that of the base metal, but the levels of $_vT_{rs}$ are equal to that of the base metal.

7.3 Precision in Measurements

Pipelines are made by welding pipes together, so strict precision is required in the pipe end dimension. **Figs. 23**, **24** and **25** indicate little variations in outside diameter, outside roundness, and wall thickness on histograms. They sufficiently satisfy API standards.

8 Conclusion

The 26-inch ERW pipe mill is a new unit incorporating new technology, based on experience gained in producing over 1.5 million tons of pipes with existing pipe-manufacturing equipment. Kawasaki has already supplied customers with large diameter pipes used as linepipe (24 inch outside diameter, 0.25 inch wall thickness, t/D × 1.04%, API 5LX X60). In the future, every effort will be made to improve material quality, pipe manufacturing technology, welding technology, non-destructive test technique, and others including shipping systems. Kawasaki's endeavours will also be continued to efficiently and stably produce ERW pipes better in quality than seamless pipe, submerged-arc

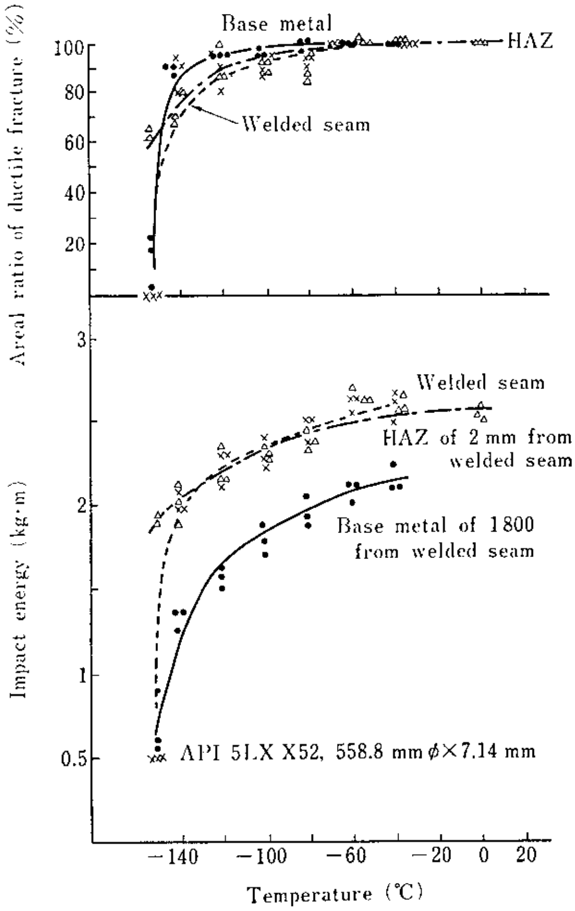
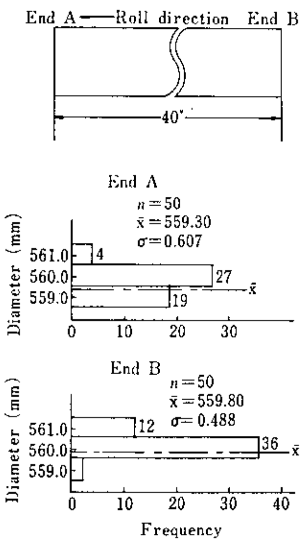
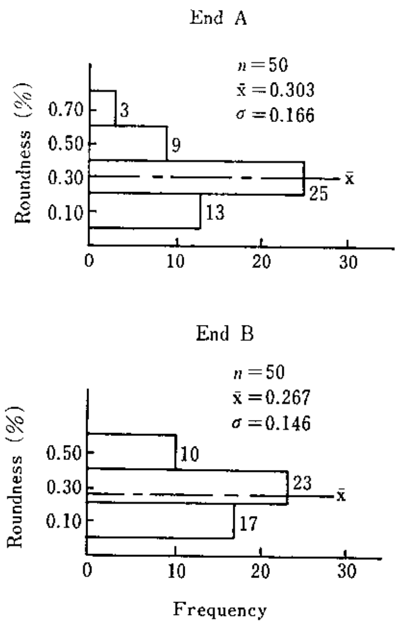


Fig. 22 2 mmV-notched Charpy impact properties in the transverse direction



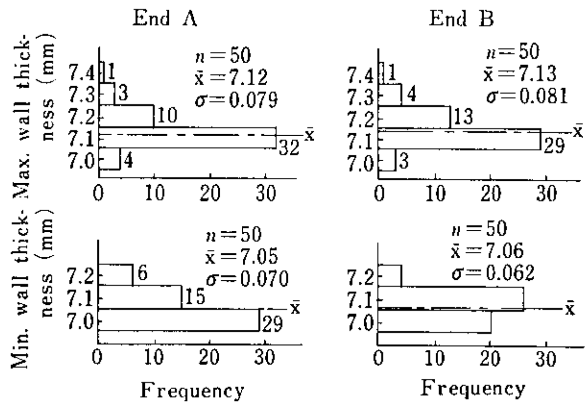
Sample: API 5LX X52, 558.8 mmφ×7.14 mm
Piameter tolerance at the end: 558.01~561.18

Fig. 23 Variation of outside diameter



Roundness: $\frac{D_{max}-D_{min}}{558.8}\times 100\%$
Sample: API 5LX X52; 558.8 mmφ×7.14 mm

Fig. 24 Variation of the outside roundness



Wall thickness tolerance: 6.78 mm~7.85 mm (−5%) (+10%)
Sample: API 5LX X52, 558.8 mmφ×7.14 mm

Fig. 25 Variation of the wall thickness of the pipes

welded large diameter pipe, and UOE pipe, in order to respond to increasing demand from the customers.

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