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Kawasaki Steel has been exploring technology for API 5L X80 by 26" φ ERW pipe mill at Chita Works. It is the most important to develop the high-strength, large-thickness hot rolled coil with excellent toughness and to improve the toughness of welded seam. By adoption of the new controlled-rolling method, edge miller machine and gas-shielded welding technology, Kawasaki Steel has made the development of API 5L X80 ERW line pipe 26"φ×0.574"t with excellent toughness, whose vTrs of the Charpy impact test is under -32℃. This paper describes the details of the pipe manufacturing process and the properties obtained.

The body can be viewed from the next page.

Manufacturing Techniques and Characteristics of High Grade ERW Line Pipe API 5L X80*

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Kawasaki Steel has been exploring technology for API 5L X80 by 26″ϕ ERW pipe mill at Chita Works. It is the most important to develop the high-strength, large-thickness hot rolled coil with excellent toughness and to improve the toughness of welded seam. By adoption of the new controlled-rolling method, edge miller machine and gas-shielded welding technology, Kawasaki Steel has made the development of API 5L X80 ERW line pipe 26″ϕ × 0.574″t with excellent toughness, whose $_vT_{rs}$ of the Charpy impact test is under −32°C. This paper describes the details of the pipe manufacturing process and the properties obtained.

1 Introduction

Recent years have seen a trend toward the use of increasingly high grades of line pipe for petroleum and natural gas transport. Both dimensional and material property requirements have become increasingly rigorous. Greater diameters and heavier gauges, as well as higher strength, have been needed to improve transport efficiency, and better toughness is required for arctic service. In line with these requirements, X80 was approved for standard API 5L use in May 1985.

Formerly, UOE pipe was used to meet these needs, but electric-resistance welded (ERW) steel pipe has been increasingly adopted by such users as major oil firms. Not only is ERW pipe lower in production cost than UOE, but improved hot-rolled coil quality and progress in welding techniques have also led to improved product reliability.

The development of a high-grade ERW line pipe meeting the API 5L X80 standard was carried out at the 26-in. ERW pipe mill at Kawasaki Steel's Chita Works.

This paper describes the manufacture of this pipe and the properties obtained.

2 Manufacturing Techniques

2.1 Techniques for Producing High-Strength, Heavy Gauge Hot-Rolled Coils with Excellent Toughness

The requirements for API 5L X80 are shown in **Table 1**. The requirements for X80, unlike those for X70 and lower grades, include Charpy impact properties as well as tensile properties. One problem in promoting the replacement of UOE steel pipe with ERW steel pipe, however, is to obtain appropriate material properties in a hot-rolled coil mother material of a thickness sufficient for line pipe applications. Thus, the development of techniques for producing hot-rolled coils suitable in both strength and thicknesses was crucial in developing

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Table 1 API 5L X80 requirement

Chemical requirement	C≦0.18% Mn≦1.80% P≦0.030% S≦0.018%
Tensile requirement	YS≧80 ksi (56.2 kgf/mm²) TS=90～120 ksi (63.3～84.4 kgf/mm²)
Toughness requirement at 32°F (0°C) (base metal)	Absorbed energy: All heat ave.≧50ft·lb (6.9 kg·m) Ave. from one heat≧20ft·lb (2.8 kg·m) Shear area: All heat ave.≧70% Ave. from one heat≧40%

an ERW steel pipe of X80 grade.

Techniques for thorough grain refining and precipitation hardening are necessary for producing high-strength, high-toughness hot-rolled coils. As already reported,[1] Kawasaki Steel has established a controlled rolling technique for optimizing chemical composition, slab reheating temperature, rolling temperature, reduction ratio, etc. in the production of X70 grade hot-rolled coils. However, when the thickness of the hot-rolled strip must be increased, it is difficult to secure reduction ratios in the unrecrystallized region of austenite, an important factor in increasing toughness. Furthermore, the higher the strength, the more toughness deteriorates. In producing heavy gauge X80 grade hot-rolled coils, therefore, it was necessary to establish a controlled rolling process that would prevent the loss of toughness as thickness and strength increased. This problem was solved by improving the conventional controlled rolled technique.

The new controlled rolling technique was developed by extending the already-established controlled rolling technique described above to include rough rolling.[2] The concept of the mill line where this new controlled rolling is conducted is shown in **Fig. 1**. The principal feature of the method is that an excellent fine grain structure is obtained by increasing the effect of controlled rolling. To this end, rolling at the No. 4 (R4) and No. 5 (R5) roughing mills is conducted in the unrecrystallized region of austenite. This is accomplished by controlling the entry temperature at the No. 4 roughing mill (R4ET), and thus extends the concept by which slab reheating temperature (SRT), finisher entry temperature (FET), finisher delivery temperature (FDT), and coiling temperature (CT) are controlled in the existing controlled rolling process.

The effectiveness of the new controlled rolling process in improving toughness was significant. For test purposes, an X65 steel, as shown in **Table 2**, was used as the starting material for 15.88-mm thick hot-rolled coils produced using the new and conventional rolling processes under the conditions shown in **Table 3**. A comparison of the toughness of the hot-rolled coils thus obtained is shown in **Figs. 2** and **3**, and a comparison of microstructures, in **Photo 1**. The Charpy V-notch transition temperature (${}_vT_{rs}$) improves by about 40°C, and the 85% FATT (fracture appearance transition temperature) improves by about 15°C in the drop-weight tear test (DWTT) when the new controlled rolling process is used. It may be considered that this is because the reduction ratio in the unrecrystallized region of austenite is high, at about 80%, in the new controlled rolling process, when compared with the approximate 66% maximum in the conventional process. As a result, as

Table 2 Chemical composition of API 5L X65

(wt %)

C	Si	Mn	P	S	Others
0.07	0.30	1.20	0.008	0.001	Al, Nb, V, Ti

Table 3 Hot rolling conditions of API 5L X65

CR Process	Thickness of hot strip (mm)	SRT (°C)	FDT (°C)	CT (°C)	Reduction in austenite non-recrystallization region (%)
New	15.88	1 200	740	510	79.6
Conventional	15.88	1 200	750	510	66.2

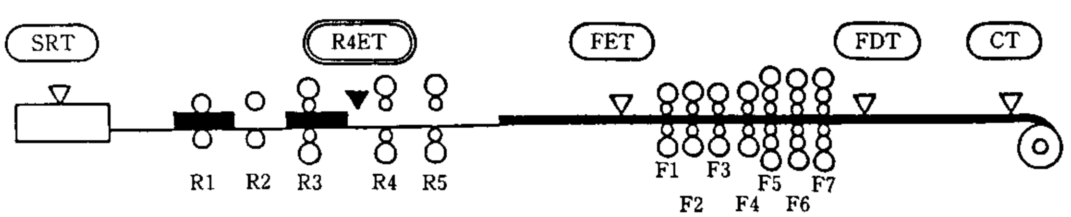


Fig. 1 Layout of hot strip mill (SRT, slab reheating temperature; R4ET, R4 entry temperature; FET, finisher entry temperature; FDT, finisher delivery temperature; CT, coiling temperature)

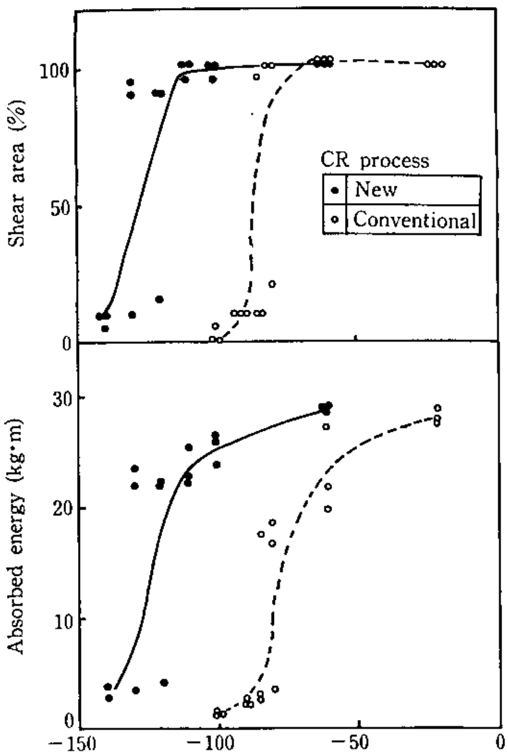


Fig. 2 Comparison of Charpy impact toughness of hot coils between the new and conventional CR processes (Test direction C, specimen size 10 mm × 10 mm)

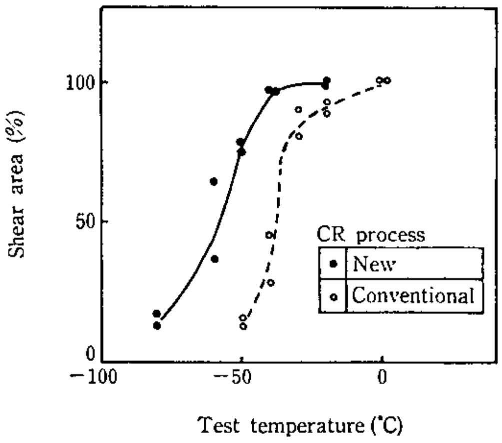


Fig. 3 Comparison of DWTT of hot coils between the new and conventional CR processes (Test direction C)

shown in Photo 1, the degree of grain refinement increases. Thus, the new controlled rolling process is very advantageous in obtaining favorable impact properties with heavy gauge hot-rolled coils.

2.2 Techniques for Manufacturing Pipe with Improved Weld Zone Toughness

At Kawasaki Steel's ERW pipe mills, automatic weld heat input control and spark detection have long been used as means of improving the integrity of weld zones.[3] The quality of weld zones has been further improved by the introduction of edge miller equipment[4], gas-shielded welding techniques for pipe manufacture[5], a positioning control system for the seam annealer[6], and related techniques.

Table 4 gives a comparison of the Charpy impact properties of welded seams when an edge miller is used for edge trimming and when a side trimmer is used. As shown in **Photo 2**, smooth-machined surfaces free from shear edge defects are obtained by edge trimming. Joining during welding is good and Charpy impact properties are thus improved. An outline of the pipe manufac-

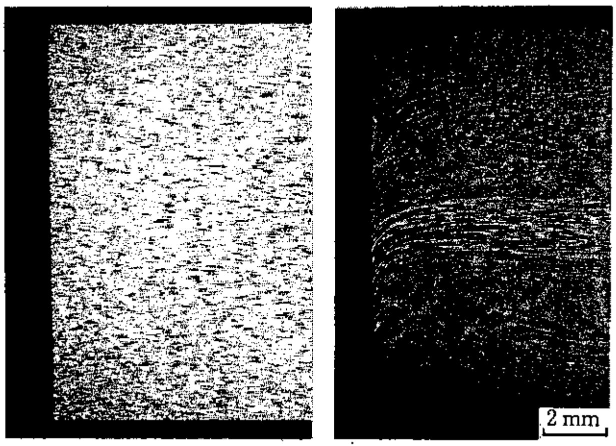
(a) New CR process (b) Conventional CR process

Photo 1 Comparison of microstructure of hot coils between the new and conventional CR processes (API 5L X65, t = 15.88 mm)

Table 4 Effect of edge trimming methods on Charpy absorbed energy of welded seams*[1]

Edge trimming method	Test piece number	Ave. absorbed energy (kg·m)	Standard deviation (kg·m)
Edge miller	30	9.7	4.66
Side trimmer	51	8.7	4.92

*[1] API 5L X65, 24″ϕ×0.375″t, test temperature −46°C, test direction C, specimen size 10 mm×7.5 mm



(a) Edge miller (b) Side trimmer

Photo 2 Metal-flow of trimmed edge of coil

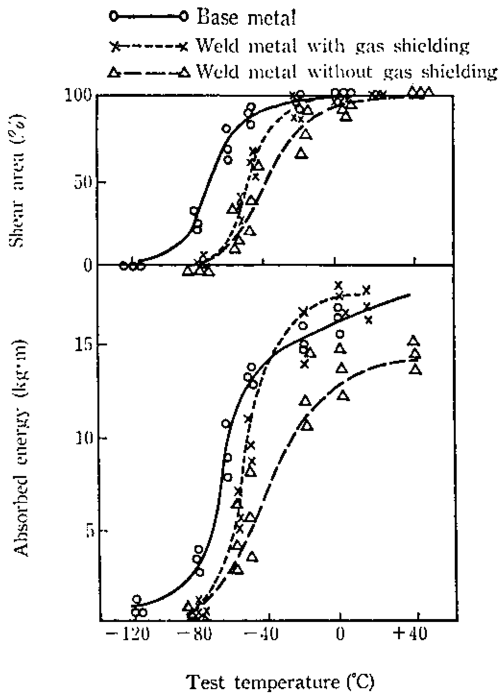


Fig. 5 Effect of gas shielded welding on Charpy impact toughness of seam (API 5L X65, 24″ϕ × 0.375″t, test direction C, specimen size 10 mm × 7.5 mm)

turing equipment using gas-shielded welding is shown schematically in **Fig. 4**. The formation of oxidation products can be prevented by conducting welding in a non-oxygen atmosphere. The Charpy impact toughness of welded seams thus obtained is good, as indicated in **Fig. 5**. As shown in **Fig. 6**, the seam annealer is composed of

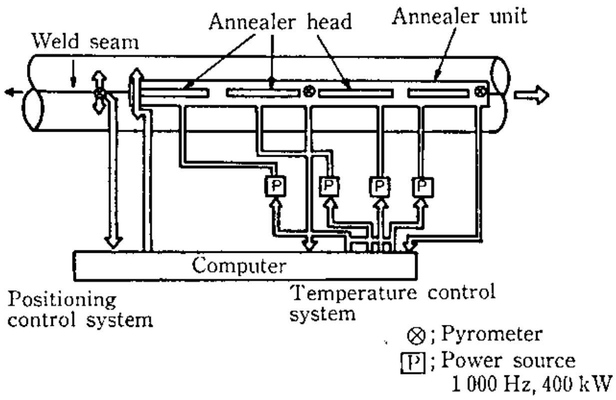


Fig. 6 Automatic control system of seam annealer

four induction heating coils and exercises temperature control, gap control, and positioning control of the welded seam to ensure accurate and stable heat treatment of welded seams.

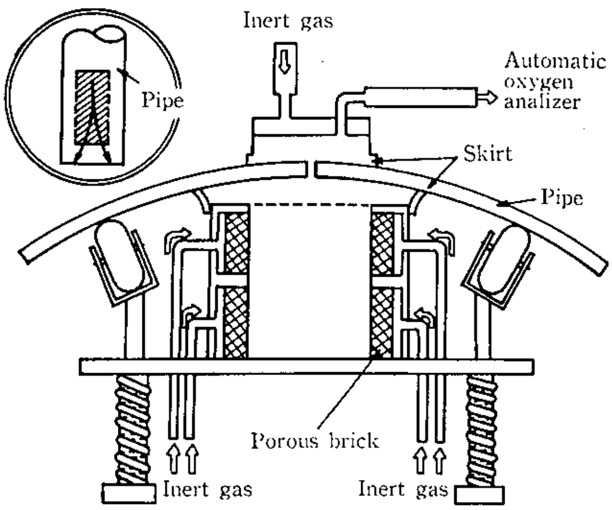


Fig. 4 Gas-shielded welding

3 Quality Characteristics of API 5L X80 ERW Steel Pipe

3.1 Manufacturing Conditions

Results of the manufacture of pipe 26 in. (660.4 mm) in diameter and 0.574 in. (14.57 mm) in wall thickness

Table 5 Dimensions and chemical compositions of API 5L X80

Dimensions		Chemical compositions (wt %)					
Hot coil	Pipe	C	Si	Mn	P	S	Others
14.57 mm × 2 077 mm	26″φ × 0.574″t (660.4 mmφ × 14.57 mmt)	0.07	0.34	1.50	0.017	0.001	Al, Nb, V, Ti

Table 6 Hot rolling conditions of API 5L X80 (14.57 mm × 2077 mm)

CR process	SRT (°C)	FDT (°C)	CT (°C)	Reduction in austenite non-recrystallization region (%)
New	1 260	720	500	79.2

Table 7 Pipe making conditions of API 5L X80 (26″φ × 0.574″t)

Velocity of pipe making (m/min)	16
Current of weld (A)	36.8
Voltage of weld (kV)	14.2
Upset (mm)	10.0
Forming condition (mm)	
Coil width after trimming	2 073
Circumference before No. 1 finpass roll	2 106
Circumference after No. 1 finpass roll	2 092
Circumference after No. 2 finpass roll	2 089
Circumference after No. 3 finpass roll	2 090
Circumference after squeeze roll	2 080

are described below as an example of the manufacture of API 5L X80 ERW steel pipe. As shown in **Table 5**, a 0.07%C-1.5%Mn-Nb-V-Ti steel was used as the material. The slab was rolled into a hot-rolled coil 14.57 mm in thickness and 2 077 mm in width under the hot rolling conditions shown in **Table 6**. The new controlled rolling process was adopted to improve the toughness of the hot-rolled coil. The coil was made into pipe on a 26-in. ERW pipe mill under the conditions shown in **Table 7**. To improve the toughness of the welded seams, trimming was conducted using an edge miller, and gas-shielded welding and seam anneal control were applied.

3.2 Product Quality

The tensile and Charpy impact properties of the base metal and welded seams are shown in **Figs. 7** and **8** respectively. The requirements for X80 were satisfactorily met for both properties. The Charpy impact properties, in particular, were excellent, as both the weld metal and welded seams not only met the value of energy absorbed, specified in the API Standard, $_vE_0 \geqq$ 50 ft · lb(6.9 kg · m), but also attained fracture transition

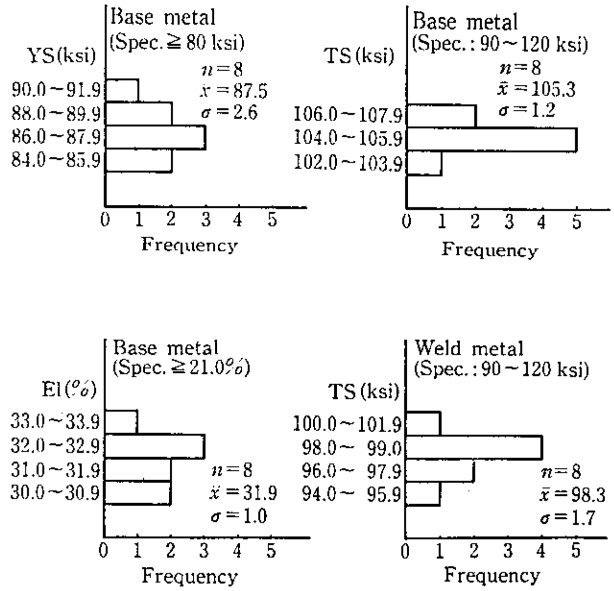


Fig. 7 Tensile properties of API 5L X80 (26″φ × 0.574″t)

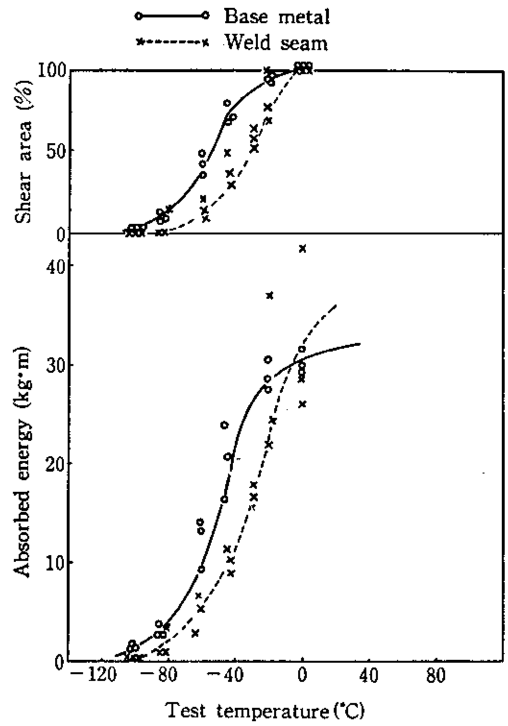


Fig. 8 Charpy impact toughness of API 5L X80 (26″φ × 0.574″t, test direction C, specimen size 10 mm × 10 mm)

temperatures of −32°C or less. Incidentally, the shear area in the DWTT at 0°C is specified as 40% or better for API 5L SR6 (Supplementary Specifications). The 85% FATT was −20°C in this example of pipe making, as shown in **Fig. 9**, sufficiently meeting this requirement. Results of comparisons of the toughness levels with the new and conventional manufacturing methods are shown in **Figs. 10** and **11**. The toughness of X80 pipe produced by the new method shows substantial inprovement.

As is apparent from **Fig. 12**, the hardness distribution of welded seams on the outer surface, at the midpoint, and on the inner surface is uniform, although the hardness of the welded seams is slightly lower than that of

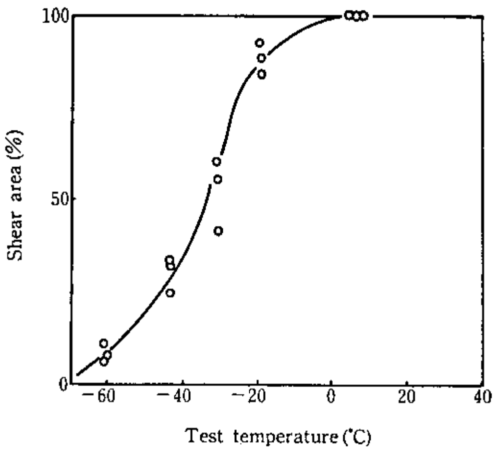


Fig. 9 Drop weight tear test of API 5L X80 (26″ϕ × 0.574″t, test direction C)

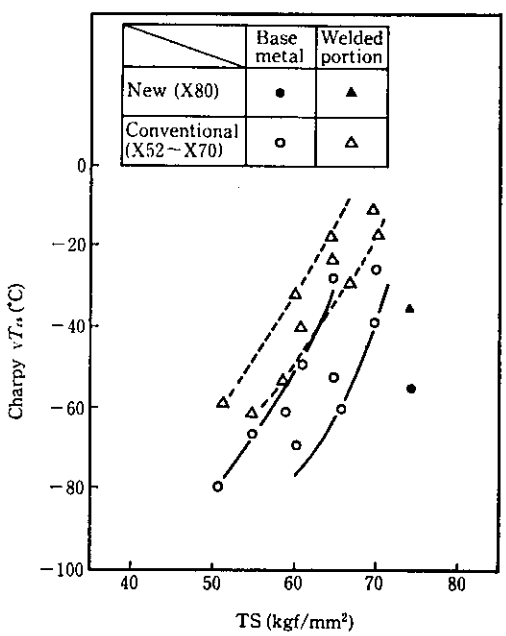


Fig. 10 Effect of new process on TS-$_{V}T_{rs}$ relation of pipes (API 5L X52∼X80, t = 0.500″∼0.625″, test direction C, specimen size 10 mm × 10 mm)

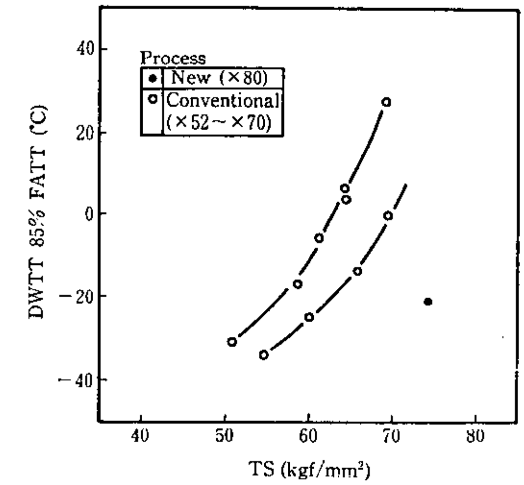


Fig. 11 Effect of new process on TS-85% FATT relation of pipes (API 5L X52∼X80, t = 0.500″∼0.625″, test direction C)

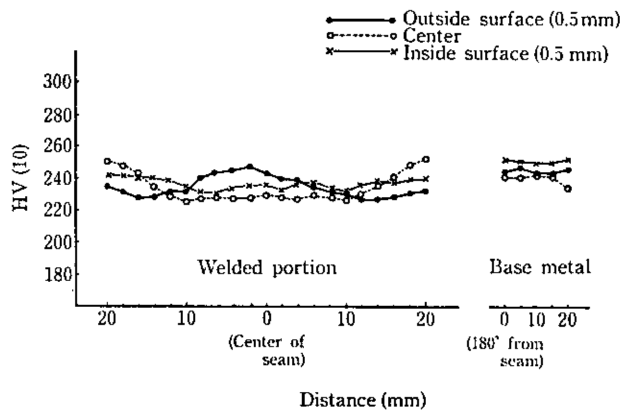


Fig. 12 Hardness properties of API 5L X80 (26″ϕ × 0.574″t)

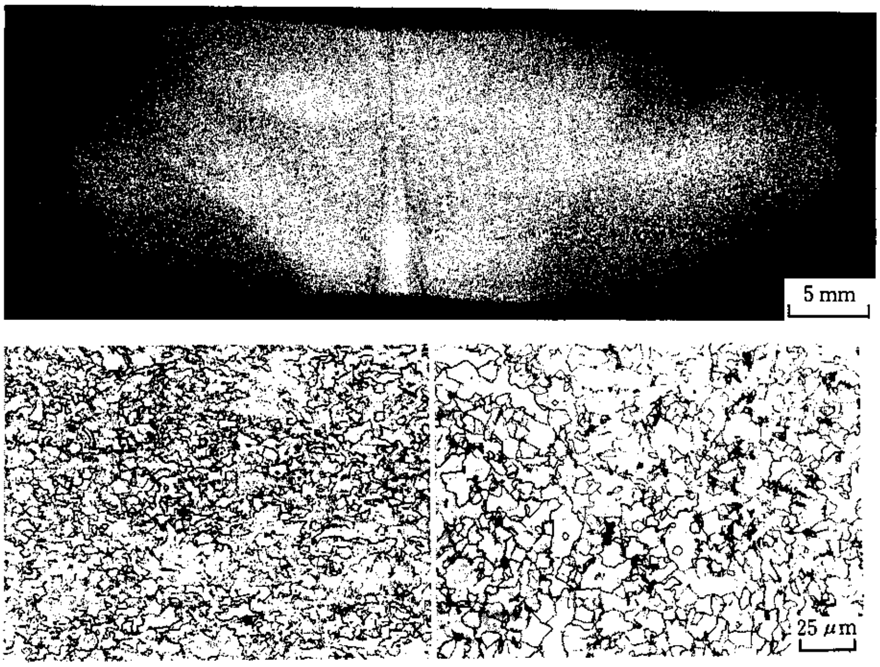
Table 8 Dimensions of API 5L X80 (26″ϕ × 0.574″t)

	Outside diameter of pipe end (in)	Outside diameter of pipe body (in)	Out of roundness*1 (%)	Wall thickness (in)
Test piece No.	12	6	12	12
Average	26.018	26.068	0.325	0.578
Standard deviation	0.012	0.009	0.130	0.004
Specification	25.969 −26.094	25.740 −26.260	—	0.528 −0.686

*1 (max. OD-min. OD)/nominal OD

Macrostructure of welded seam

Microstructure



(base metal) (welded seam)

Photo 3 Macro- and micro-structure of API 5L X80 (26″ϕ × 0.574″t)

the base metal because seam annealing was performed. The macro- and microstructures obtained are shown in **Photo 3**. Judging from the macrostructure of the seam, the cut bead and seam annealing on the outer and inner surfaces were good. Furthermore, an observation of the microstructures reveals that the ferrite grain size was fine at No. 11 or above.

As shown in **Table 8**, the median values of dimensional tolerances specified by the API were obtained with only slight variation.

4 Conclusions

The development of high-grade API 5L X80 ERW line pipe was carried out using a 26-in. ERW pipe mill, with the following results:

(1) A new controlled rolling technique including the rough rolling process was developed to produce heavy gauge hot-rolled coils with excellent toughness.

(2) A pipe making technique capable of obtaining toughness sufficiently meeting API 5L X80 was established by using an edge miller to improve edge shape and by applying automatic weld heat input control, spark detection, gas-shielded welding, and seam annealing control.

(3) ERW pipe 26 in. (660.4 mm) in diameter and 0.574 in. (14.57 mm) in wall thickness manufactured by the new process sufficiently met the API Standard for Charpy impact and tensile properties. Charpy impact transition temperatures of −32°C or less were achieved in both the base metal and welded seams, indicating excellent toughness.

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