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Recent Progress in Pipemaking Technology Developed at Kawasaki Steel Corporation

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1 Introduction

Since entering the field of pipemaking in 1952, Kawasaki Steel has devoted great effort to the creation of a production system which will ensure the stable supply of high quality steel pipe. This period has seen the aggressive development of a variety of processes intended to "build into" the product a consistently high level of quality, as well as the development of new products with expanded applications. The company has won an outstanding reputation for these efforts, as evidenced by the award of Okochi Memorial Prize (Grand Production Prize) in 1982 and the Aida Prize (JSTP Prize) for Technology in 1985, and has established a system which is capable of meeting a wide range of customer requirements. This paper will present a brief outline of steel pipe production technology and new product development at Kawasaki Steel.

2 Trends in Steel Pipe Output

The history of Kawasaki Steel's pipemaking activities is summarized in **Fig. 1**. Since it began the production of ERW pipe at its Nishinomiya Works (present Hanshin Works) in 1952, the company has continued to upgrade and expand its pipe manufacturing facilities with the aim of supplying a comprehensive line of tubu-

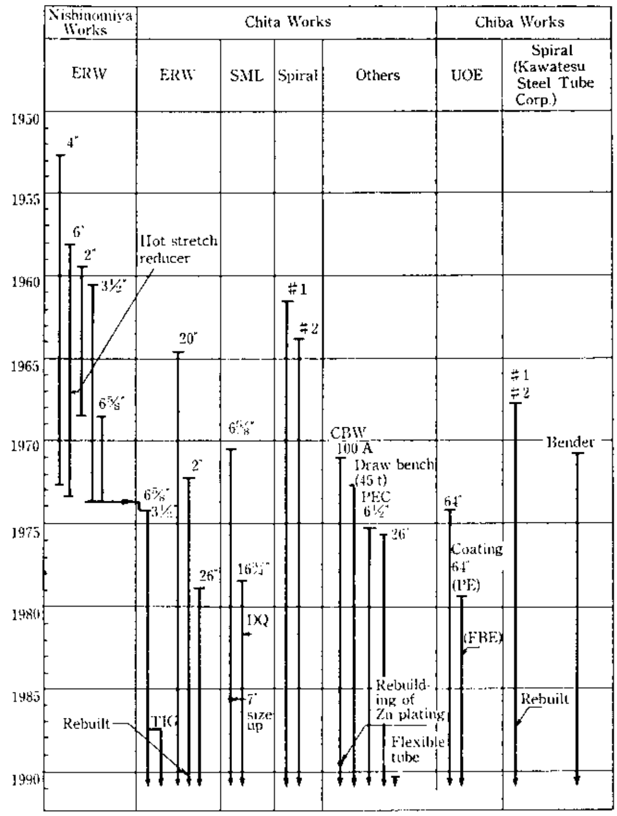

Fig. 1 History of tubular products manufacturing facilities at Kawasaki Steel

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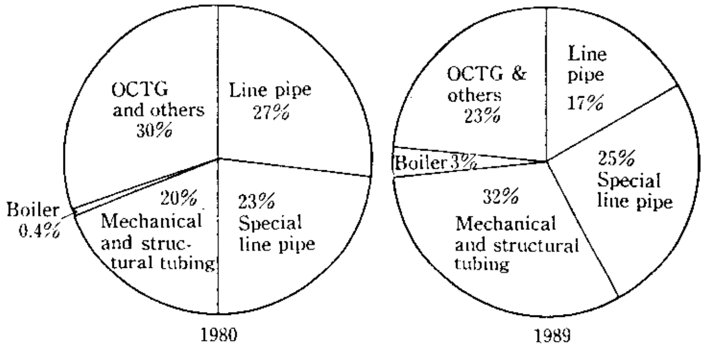

Fig. 3 Comparison of mix ratio of tubular products

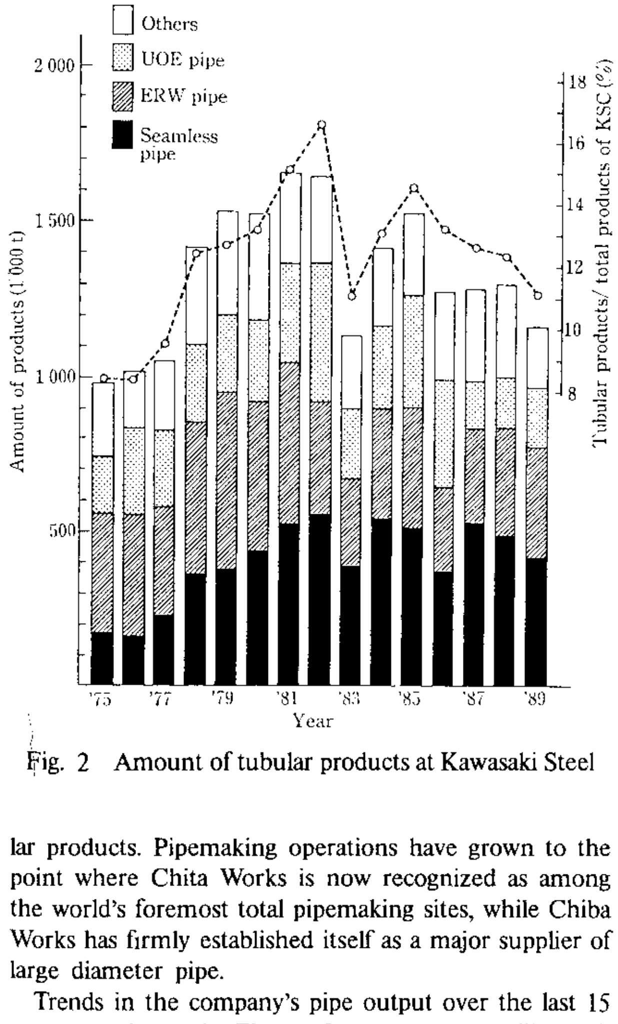

Fig. 2 Amount of tubular products at Kawasaki Steel

lar products. Pipemaking operations have grown to the point where Chita Works is now recognized as among the world's foremost total pipemaking sites, while Chiba Works has firmly established itself as a major supplier of large diameter pipe.

Trends in the company's pipe output over the last 15 years are shown in **Fig. 2**. Output grew steadily until 1981, when tubular products held a share of over 16% of the company's overall production. More recently, this share has fallen to 11-13%, reflecting changes in the economic environment, not the least of which was the collapse of oil prices in the mid-1980s. Major changes also occurred in the mix of tubular products during this period, as shown in **Fig. 3**, with line pipe and OCTG (oil country tubular goods) holding a decreasing share and mechanical and structural tubing assuming greater importance.

3 Process Development

The pipe manufacturing processes used by Kawasaki Steel are illustrated in **Fig. 4**. Because the goal in all these processes is to achieve a high level of product quality with the greatest possible consistency, extensive work has been put into (1) development of various types of sensors, (2) upgrading of control techniques, and (3) development and improvement of pipemaking equipment. Typical examples of technology development in each of the main pipemaking processes are discussed in the following sections.

3.1 Manufacturing Process for Seamless Pipe

The Mannesmann process is introduced in the manufacture of small and medium diameter seamless pipe. On-line techniques, automation, and computerization have been actively introduced to achieve better dimensional accuracy, product quality, and productivity.

3.1.1 Development of high accuracy sensors

Because precise monitoring of the configuration of the product during the rolling process is essential in improving control accuracy, Kawasaki Steel has placed great importance on the development of various types of sensors, including the on-line wall thickness gauge and the bulge (width) meter. Kawasaki Steel's gamma-ray on-line wall thickness gauge was the first of its type in the world. The three-beam method[1] used with medium diameter seamless pipe production is particularly noteworthy because it makes possible not only measurement of the wall thickness, but also the detection of wall thickness variation. The parallel-beam method[2] used with small diameter seamless pipe production may fairly be termed revolutionary, since it is capable of measuring changes in wall thickness at the top and bottom ends in real time. The bulge meter[3]

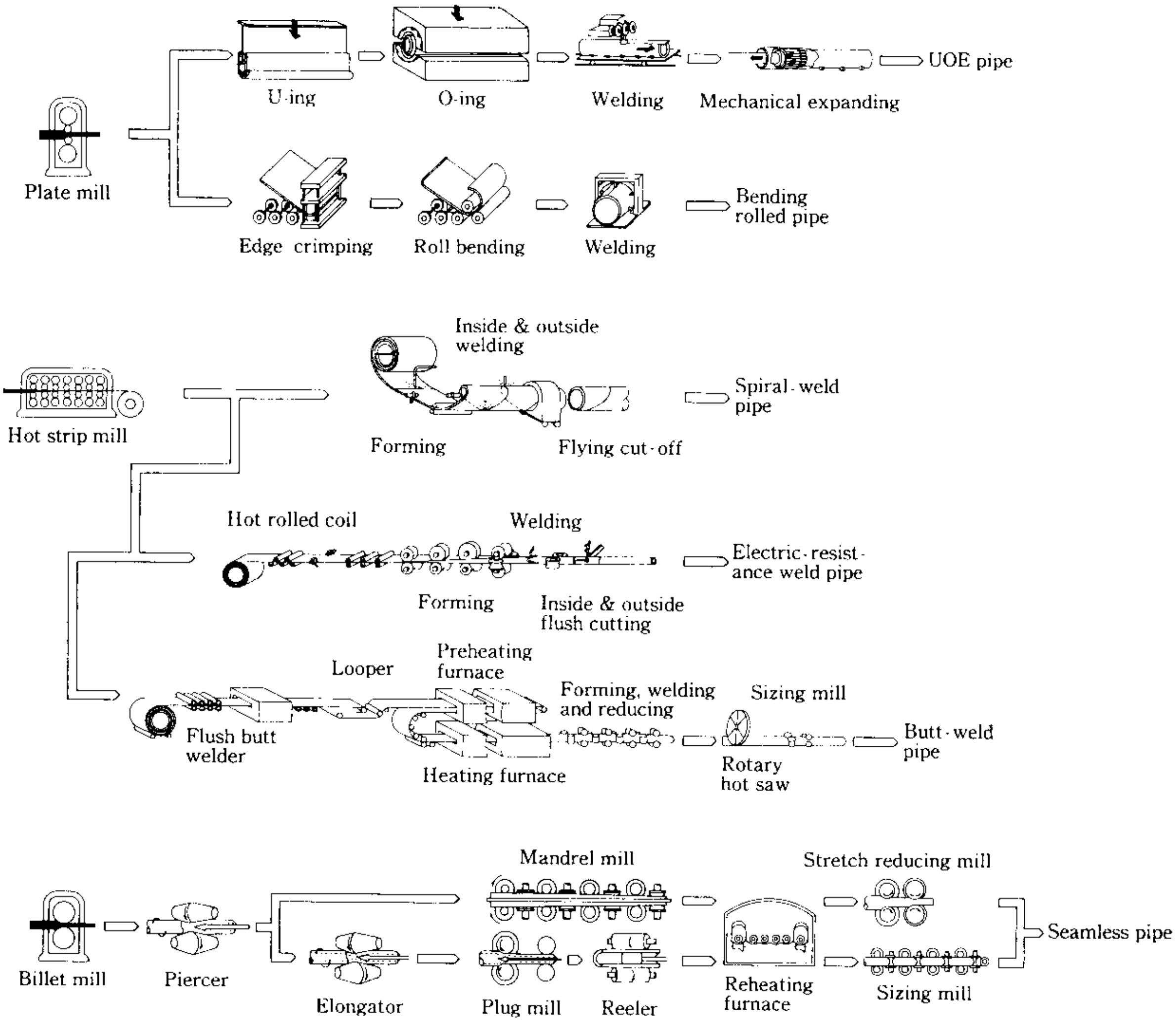

Fig. 4 Manufacturing processes of tubular products at Kawasaki Steel

developed to monitor the behavior of material during mandrel mill rolling has also proved effective in maintaining optimum rolling conditions.

3.1.2 Development of rolling control model

A control model was developed for automatic setup of all mills from the piercing step through reducing or sizing.[4] In addition, basic features were studied using a five-stand model mill,[5] resulting in the creation of an optimal designing for mandrel mill rolling called MAP, shown in **Fig. 5**, which has made possible a broad expansion in the range of sizes and grades which can be rolled. The value of these techniques can be judged from overseas sales of the technology. The work on which these techniques are based, entitled "Development of Numerical Control Rolling Method for Seam-

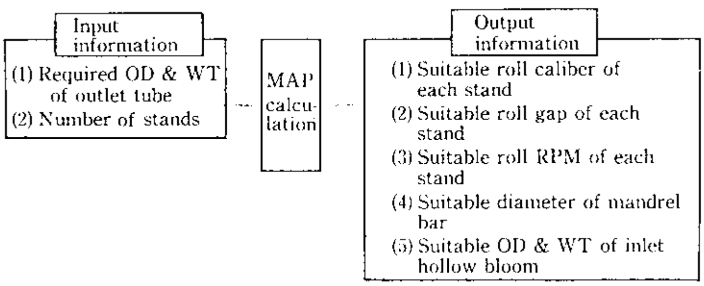

Fig. 5 Outline of MAP system

less Steel Pipe," was honored with the Okochi Memorial Prize (Grand Production Prize) in 1982.[6)]

3.1.3 Development of production techniques for high-grade products

A direct quenching (DQ) furnace[7)] and the drive roller shoe (DRS)[8)] were developed to support the production of high-grade tubulars. The DQ furnace was developed as an energy-saving system for the effective use of the sensible heat of pipes during the rolling stage, but at the same time the company developed a unique method characterized by internal and external axial flow in a closed system to ensure uniform quenching over the entire length of the product. The DRS, as shown in **Fig. 6**, uses rollers in place of the conventional fixed guide shoes, markedly lessening the sliding friction, thereby reducing the occurrence of guide shoe marks on products. These techniques have made it possible to roll high alloy steel tubulars by the Mannesmann method, contributing to a steady increase in production volume. **Table 1** presents an example of the technical problems connected with the production of stainless steel pipe.

On the other hand, some improvements in finishing line equipments were carried out. In particular, multipurpose non-destructive inspection equipment has been installed for high-grade products such as boiler tubes, high-Cr alloy steels, and stainless steel tubes which require a combination of pickling, cold drawing, and heat treatment. The NDI process combines a magnetic leakage flux tester and ultrasonic tester, and is also capable of measuring wall thickness. State-of-the-art coating and packing facilities are newly installed, and will substantially complete a production system designed to cope with customers' requirements.

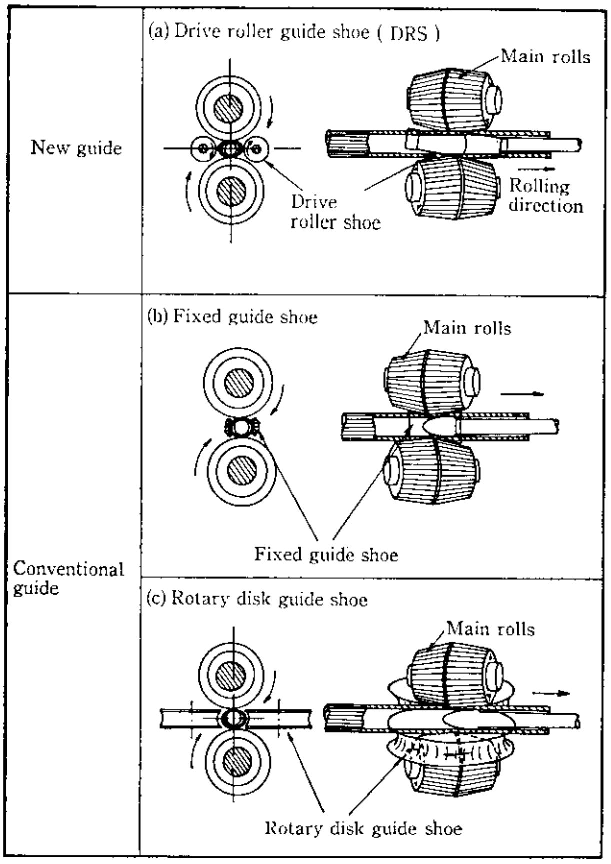

Fig. 6 Schematic diagrams of new roller guide shoes and conventional guides in cross helical rolling mill

Table 1 Technical problem & applicable technology on stainless steel tubular goods

Class	Technical problem	13 Cr	22 Cr	SUS 304	Applicable technology
Raw material defects	Shortness of hot workability	●	●	●	Low S, low P steelmaking
			●		Ca/S control
Internal surface defects	Scab by high temperature embrittlement	●		●	Temperature control of billet mill & heating furnace
	Scab by plug dissolvement		●		Improvement of material & shape of piercer plug
	Wrinkle			●	Development of rolling schedule at reducing mill
External surface defects	Piercer shoe mark	●	●	●	Installation of disk shoe & drive roller shoe Development of shoe lubricant
	Roll edge mark		●	●	Development of roll lubrication system
	Defect by intergranular oxidation			●	O_2 potential control of heating furnace
Dimensional problem	Deviation in wall thickness	●	●	●	Improvement of rolling schedule at mandrel mill
Toughness	Embrittlement by σ phase precipitation		●		Temperature control of reheating furnace

3.2 Manufacturing Process for Welded and Forged Pipe

3.2.1 ERW Pipe

Kawasaki Steel operates four ERW pipe manufacturing facilities and produces goods in sizes ranging from small to very large diameters (21.7 mm-660.7 mm). Customers' requirements are diverse, including high strength, high toughness, and high corrosion resistance. The entire production process, covering material production techniques (steelmaking and hot coil rolling technology) and pipemaking techniques, including both forming and welding, has been refined and improved so as to meet all performance specifications. The main techniques developed in the areas of forming and welding are discussed below.

(1) Forming

With introduction of the 26″ cage roll forming method, coil edge wave problems have been reduced, and it has now become possible to produce thin wall tubulars down to t/D ratios of less than 1%.[9] A simulated example of the deformation behavior of material undergoing roll forming is shown in **Fig.** 7. Another important development was a technique for the common use of a single set of rolls for products with a wide range of outer diameters.[10] Based on an expanded deformation analysis, a method of chance free bulge roll forming (CBR forming method)[11,12] has also been developed and is now used at the 2″ mill. The 2″ mill also uses a preset adjustment method and a quick-change process by carriages in order to meet the requirements of small lot production under tight delivery schedules.

(2) Welding

Stabilized welding performance has been obtained by the use of Kawasaki Steel's proprietary automatic heat control system (which features feed-forward of welding sheet thickness changes in the coil length direction and welding speed, and feedback of welding temperature information)[13] and a gas shielded welding method. Upgrading of seam annealing equipment has made it possible to satisfy product quality requirements for high toughness, and the development of the inside bead monitor shown in **Fig. 8** permits complete monitoring of the weld bead shape.

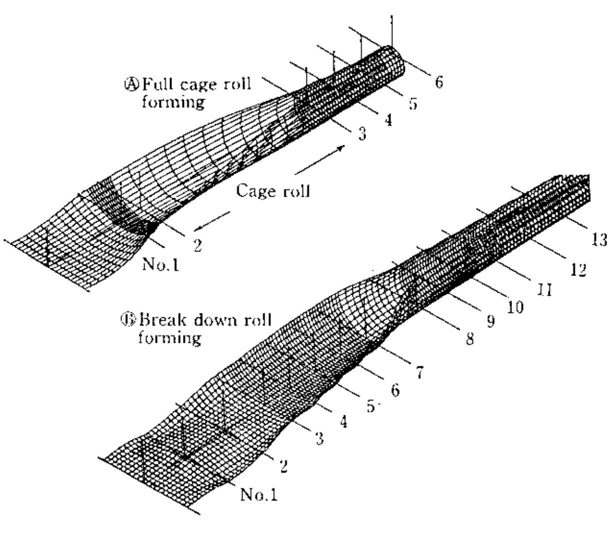

Fig. 7 Schematic view of forming

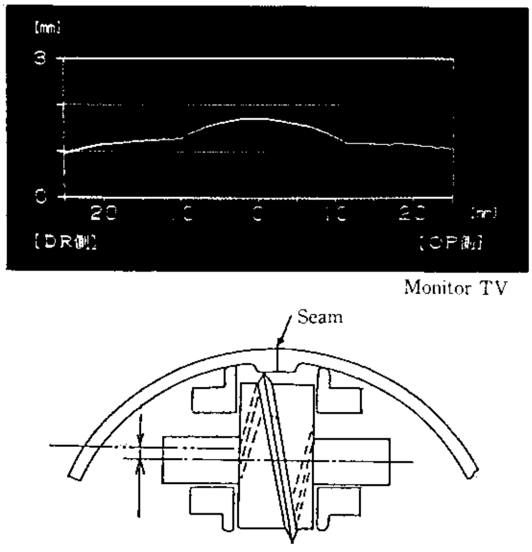

Fig. 8 Measurement of inside bead shape

3.2.2 UOE pipe

The company's UOE mill, located at Chiba Works, produces pipe in outer diameters of up to 64″, which is the world's largest. The main application of UOE pipe is pipelines for the transportation of crude oil and natural gas. Quality standards for these products have become increasingly high, as have the requirements applied to the quality assurance system. The main techniques and the control system for coping with quality requirements are described below.

(1) Welding

Four electrodes are used for both inside and also outside welding.[14] A more satisfactory weld bead can be consistently obtained by this method, which also contributes to improved productivity. Sound product quality is ensured in the pipe ends of thin wall pipes, which are susceptible to cracking at the weld seam, by securing this area with a clamp.

(2) Dimensional Measurement

In the inspection process, the outer diameter, thickness, length, and roundess of the product are verified by the automatic measuring device for pipe dimensions shown in **Fig. 9**. The device functions in combination with a computer to output production

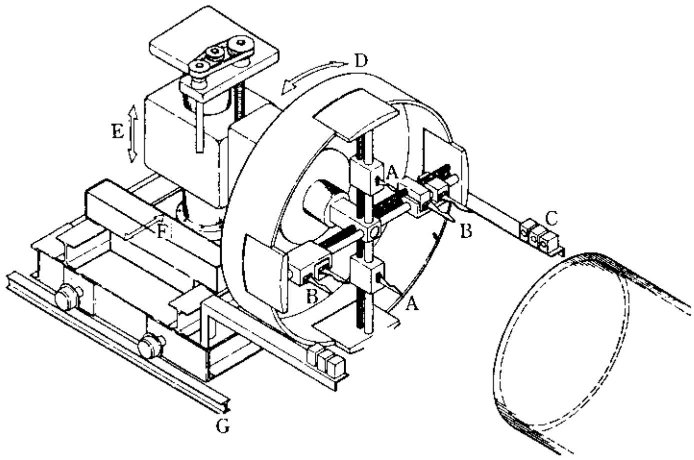

Fig. 9 Automatic measuring device for pipe dimension

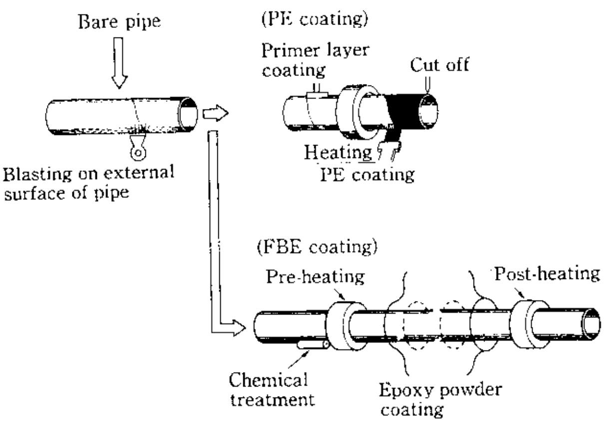

Fig. 10 Schematic illustration of coating equipment for UOE pipe

records of the measured values. The quick supply of precise data has had an important effect on product quality control.

(3) Marking of Pipe Body
Specified identification items are automatically printed on the inner and outer surfaces of the pipe by a dot spray process. The content of these markings is controlled by the pipe tracking system and can be varied automatically on a pipe-to-pipe basis as required.[15)]

(4) Coating Equipment
Polyethylene coated pipe is manufactured by the T-die process. In addition, the transport line, induction coil heaters, and coating equipment have been upgraded for the production of fusion bonded epoxy coated line pipe (shown in **Fig. 10**).[16,17)]

3.2.3 Spiral pipe

Kawasaki Steel operates two spiral mills, one at Chita Works and a second at its subsidiary Kawasaki Steel Tube Co., Ltd. in Chiba. The main applications of spiral pipe are water distribution, where large diameter water service pipe is used, and civil and architectural construction, where pipe piles and pipe sheet piles are required, particularly in harbor work. The recent tendency in structural pipe has been toward thicker walled and larger diameter products, in line with the upsizing of structures and construction projects. To meet these changes in demand, new forming and welding technologies were incorporated in the mill during a refurbishment carried out in 1988.[18)] These improvements gave the mill the greatest capability in Japan, and made it possible to produce large-diameter, thick-wall pipe with outer diameters of up to 2650 mm and thicknesses of 30 mm, and super-thin wall products 2308 mm in outer diameter and 3.2 mm in thickness. Thick wall pipe is generally used in water service pipe and piles, while thin wall pipe is mainly used in steel-cement composite pipe piles and silo bodies. Requirements for even greater diameters and thicknesses can be met by the roll bending method. Very long products over 80 m in length can be produced by in-factory circumferential welding.

3.2.4 CBW pipe

For the particular CBW pipes used for gas and water piping, the conventional batch method of Zn galvanizing has been replaced with a continuous method, which provides better product quality and stability.

4 System Development

Customers' requirements are becoming more diverse each year, and it is essential that information in this regard be reflected both quickly and accurately in the pipemaker's sales, production, and distribution divisions.

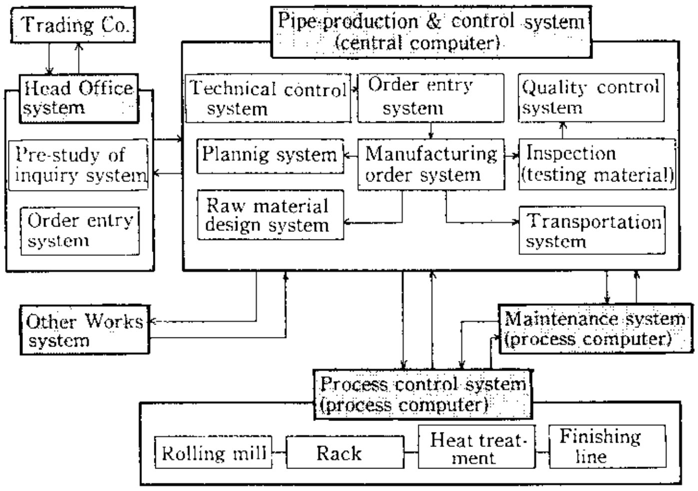

Fig. 11 Pipe-production control system flow

Based on information of inquiries from customers, Kawasaki Steel has created a sales and production management system to meet this need. The corresponding system in the factory is the pipe production control system. In particular, the following are handled at the plant level:

(1) Administrative
- Customers' amendments to specifications
- Plans and manufacturing instructions in regard to details of rolling and finishing
- Material requisitions etc.[19]

(2) Pipemaking
- Setup of operational conditions for manufacturing and collection of related information[20]
- Monitoring of each item of equipment

(3) Distribution
- Deliver and inventory control following completion of manufacture
- Shipping plans

In addition, a maintenance and parts control system has been instituted as a support system for the manufacturing operation, and a factory wide on-line information processing system has been established. A flow chart of the pipe production control system at Kawasaki Steel is shown in **Fig. 11**.

5 Product Development

5.1 Line Pipe

With the increasing severity of pipelaying environments and service conditions for line pipe, this product is expected to meet ever higher performance standards. Examples include thickner walls and higher strength for increased service pressures, low temperature toughness features for pipelines in frigid climes, and high corrosion resistance for the transport of sour oil and gas. In illustration of this point, **Fig. 12** shows the trend in the

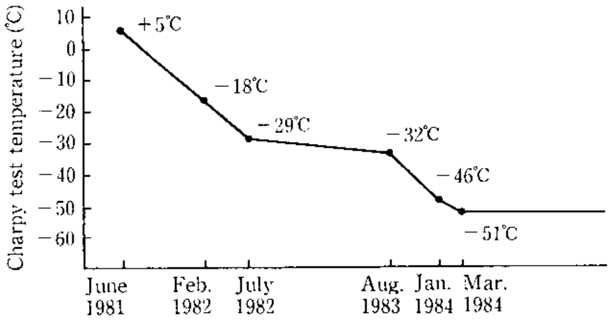

Fig. 12 More severe Charpy test temperature with year

Charpy test temperature required to the company's ERW pipe. Development efforts related to linepipe material and products have included the production of ultra-clean, ultra low-S, P, and N steels with improved corrosion resistance, and steelmaking techniques for the shape control of non-metallic inclusions. As thermomechanical methods of obtaining improved low temperature toughness, controlled rolling and the MACS (multi-purpose accelerating cooling system) method are used in plate rolling, and controlled rolling is used in hot strip rolling.[21] Welding materials have been developed to achieve improved weld toughness in UOE pipe, and the seam annealer used in ERW shops has been upgraded.

5.2 OCTG

With recent trends toward deeper wells, exploitation of arctic fields, increased off-shore activity, and the recovery of sour oil and gas containing H_2S and CO_2, the conditions applied to the development of OCTG have become increasingly difficult. As a result, these product must provide an unprecedented level of both performance and product quality. Various grades devel-

Table 2 List of Kawasaki Steel's special casing and tubing "KO-series"

SMYS level (ksi (MPa))	Deep well service V	High collapse service T, TT	Sour service General S	Sour service Special SS	Sour service High collapse TS	Arctic service L	Wet CO_2 service
55 (379)		KO-80 TT*				KO-55 L*	
75 (517)							KO-13 Cr 75 KO- 9 Cr 75
80 (552)		KO-80 T KO-80 T*	KO-80 S		KO-80 TS	KO-80 L	KO-13 Cr 80 KO- 9 Cr 80
85 (586)			KO-85 S	KO-85 SS			
90 (620)			KO-90 S	KO-90 SS			
95 (655)		KO-95 T KO-95 T* KO-95 TCYS KO-95 TCYS*	KO-95 S	KO-95 SS	KO-95 TS	KO-95 L	KO-13 Cr 95
105 (724)						KO-105 L	
110 (758)		KO-110 T	KO-110 S	KO-110 SS		KO-110 L	
125 (862)	KO-125 V					KO-125 L	
140 (965)	KO-140 V						
150 (1034)	KO-150 V						

* ERW process

oped by Kawasaki Steel to incorporate unique performance features are available in the product series shown in **Table 2**. Technical data for use in the selection of the optimum material for the service environment has also been compiled, contributing to the prevention of oil well accidents and the more economical extraction of petroleum resources.[22] Seamless pipe is mainly used for OCTG, but as a recent trend, ERW pipe has also found increasing application where conditions allow. Significant developments in oil field products are discussed below.

5.2.1 Sour service tubulars

In recent years, demand for tubes resistant to H_2S and CO_2 corrosion has shown a further increase. With excellent resistance to stress corrosion cracking (SCC) and the high strength required by deep wells, KO 110 S (shown in **Fig. 13**)[23,24] is being supplied in increasing quantity to major oil companies. In CO_2 gas wells, a serious problem is pitting corrosion, a different type of corrosion from that caused by H_2S, and the use of 13% Cr steel as a CO_2 corrosion resistant high Cr specialty steel is increasing.[25,26]

5.2.2 Premium joints

A unique premium joint called the FOX joint[27] was developed in conjunction with England's Hunting Oilfield Serive Ltd. to solve the problem of inadequate sealability in API joints. The FOX joint, shown in **Fig. 14**, uses the concept of thread pitch changing, resulted in reduced stress concentration of tooth load, to achieve a new level of performance for high stress and corrosive environments. The design was created using finite element analysis (FEA). Commercialization of this high-reliability product followed extensive evaluative testing at the company's state-of-the-art Tube and Pipe Testing Center.[28~30]

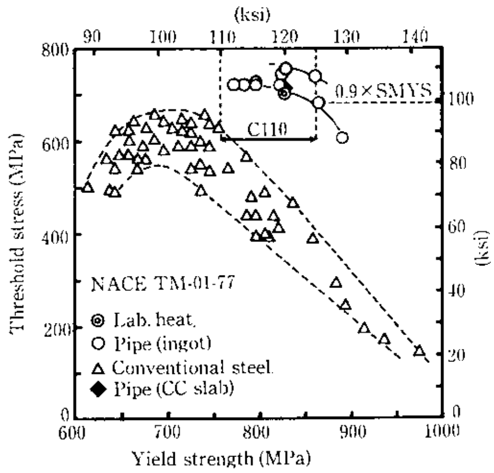

Fig. 13 Comparison of threshold stress of the newly developed 110 ksi yield strength grade steel with conventional Cr-Mo steels

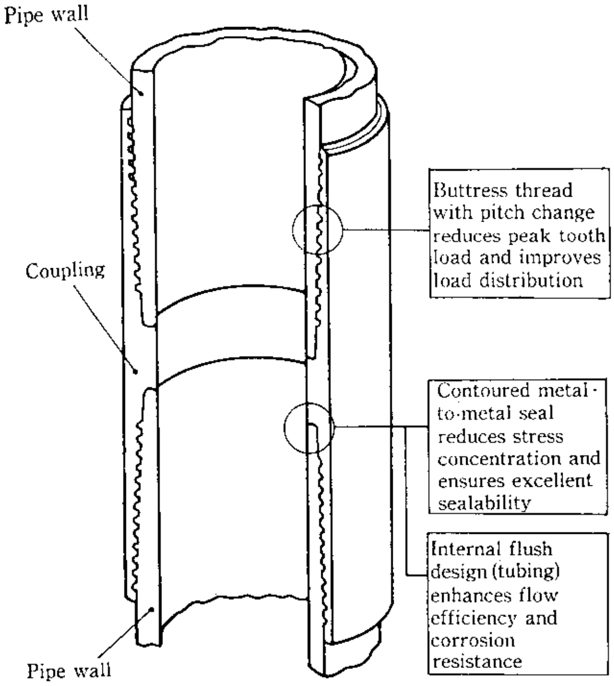

Fig. 14 Basic design of Fox joint

5.2.3 Other oil-related products

The drilling of well requires a variety of tubular hardware, including drill pipe, drill collars, pup joints, and cross-overs. One notable special-application product is heat-insulated double-wall tube. Kawasaki Steel's American subsidiary Kawasaki Thermal Systems Inc. (KTS) manufactures this type of insulated tubular, which features excellent thermal insulation characteristics, for the production of high viscosity oil and steam injection for EOR.[31,32] Insulated tubulars are not only contributing to the efficient production of high viscosity oil in countries such as Canada and mainland China, but are also drawing attention for use in polar regions and other frigid environments.

5.3 Tubes for Boiler and Chemical Plant Applications

The goal of energy saving requires the achievement of higher levels of efficiency in electric power generation through the use of higher temperatures and higher operating pressures. A variety of alloy steels have been developed for this purpose, among the most important the Super 9 Cr steel tube developed by the Oak Ridge National Laboratory (ORNL) in the United States. In ferritic alloy steel tubes of up to 12% Cr, Super 9 Cr provides maximum allowable stress values equivalent to those of SUS 304 austenitic stainless steel while offering the additional feature of good weldability.

Although Super 9 Cr and SUS 321 H are typically produced by the hot extrusion process, Kawasaki Steel succeeded in manufacturing both products by the Mannesmann process, following a thorough study of the chemical composition of materials and pipemaking techniques. These products are now widely used in super heaters and reheaters. A type of ferritic boiler tube superior in creep rupture strength to Super 9 Cr is now the object of research and development efforts.

In addition, customers have recently begun to study the use of hot finished products in super heaters and other applications where cold finished products have generally been used. In line with this trend, Kawasaki Steel has developed and begun shipping hot-finished boiler tubes with dimensional accuracy and surface quality features equivalent to those of cold finished tubes, an accomplishment made possible by the company's outstanding quality control system.

5.4 Mechanical and Structural Tubing

5.4.1 Ultra-thin walled products for high pressure gas cylinders

Two measures are used to reduce the weight of seamless high pressure gas cylinders: (1) higher strength of materials, made possible by a shift from normalizing type C–Mn steels to quench and temper type C–Mn, and at present to quench and temper type Cr–Mo or Cr–Mo–Ni, and (2) reduction in wall thicknesses.

To meet the strict requirements placed on steel pipe makers for ultra-thin wall products, Kawasaki Steel applied the MAP system at its small diameter mandrel mill and has achieved wall-to-diameter ratios as low as 2.3%.

5.4.2 Cold drawn tubes

In the field of seamless pipes, KM and KMA series, as mother tubes for cold drawing, have long enjoyed an excellent reputation for dimensional accuracy and superb surface quality. Improved pipemaking techniques have further made possible the production of small diameter, thin-wall, higher t/D ratio, and improved inner shape, all contributing to a reduction in the number of drawing pass at customers' plants.

On the other hand, increasingly strict standards are now applied to inner surface roughness and inner and outer surface defects in ERW pipe (STN and SAE series), and in some cases there is demand for DOM (drawn over mandrel) products in which as-cold drawn goods are used directly in cylinders.

5.4.3 High tensile strength steel tubes for tower structural purposes

High tensile strength steel tubes for tower structural purposes, JIS G 3474 STKT 55 and STKT 60, were incorporated into the JIS (Japanese Industrial Standards) in 1988. Under these specifications, Kawasaki Steel uses Zr-added material to produce high toughness tubes with good weldability ($C_{eq} \leq 0.40$) and resistance to fused zinc embrittlement (CEZ $\leq$ 0.28, $R_{\sigma, \text{ft}=400} \leq 40\%$).[33]

5.4.4 Square steel pipe (K Column R)

Demand for square steel pipe has grown markedly during the recent building boom. Using material supplied by the medium diameter ERW mill at Chita Works, Kawasaki Steel has been producing square pipe with a maximum size of 550 mm x 22 mm t since November 1990 using a roll forming method.

5.5 Anti-corrosion Steel Pipe

A summary of Kawasaki Steel's anti-corrosion steel pipe products is shown in **Table 3**. Some representative examples are discussed below.

5.5.1 Plastic resin coated steel pipe

In the development of polyethylene-coated pipe for underground service in gas and water lines and polyurethane coated pipe for offshore structures, deterioration tests of the coating material and a study of coating/steel surface boundary characteristics were conducted in consideration of durability requirements. The coating materials adopted offer excellent adhesion, shock resistance, and resistance to sea water and weathering.

5.5.2 Grooving resistant ERW pipe

When ERW pipe is used to handle industrial water and cooling water, or in other water transport applications, the ERW weld area is subject to a type of preferential corrosion which produces "grooving" and rarely results in leaks. Following an investigation into the causes of grooving and a study of preventive measures, the company succeeded in developing an ERW product known as River GR which offers remarkably improved resistance to grooving corrosion. This result was obtained by adjusting the chemical composition to lower S values and adding Cu and Ni.[34] An example of grooving resistance test results is shown in **Fig. 15**.

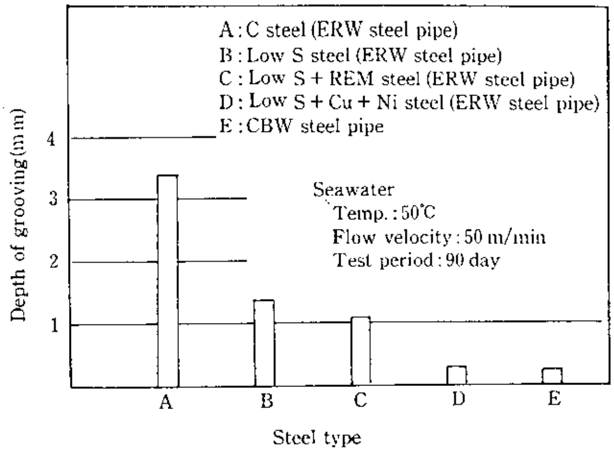

Fig. 15 Effect of alloying elements on grooving corrosion

5.5.3 Flexible corrugated stainless steel tubing

Kawasaki Steel's flexible corrugated stainless steel tubing,[35] which offers outstanding formability, is manufactured with the greatest importance placed on the quality of welds. The entire process from forming througn inspection is conducted under near clean-room conditions to eliminate dust from outside sources.

Table 3 Kawasaki Steel's corrosion resistance pipe

Environments	Corrosion resistance pipe	Use
Underground services	① Polyethylene-coated pipe (KPP) ② Polyethylene powder-lined pipe (KFP SGP-PD) ③ Polyvinyl chloride-lined pipe (KLP SGP-VD) ④ External fusion-bonded epoxy-coated pipe	· Gas · Oil · Water · Drainage · Protecter of cables · Plant services
Ground services	① Polyethylene powder-lined pipe (KFP SGP-PA, PB) ② Polyvinyl chloride-lined pipe (KLP-VA, VB, VC) ③ Galvanized steel pipe ④ Flexible corrugated stainless steel pipe ⑤ Grooving corrosion resistance ERW pipe (River GR)	· Gas · Oil · Water · Drainage · Plant services · Air conditioner
Offshore structure services	① Polyethylene-coated pipe (KPP) ② Polyurethane-coated pipe	· Protective wall services · Breakwater services · Shore-protection services

6 Conclusions

This paper has presented a brief outline of the manufacturing techniques for the various steel pipe products produced by Kawasaki Steel, and has also discussed the current level of technology. The company has established the following three tasks as essential to its continuing success in pipemaking and will make full scale efforts to improve its performance in each of these areas.

(1) Improvement of Manufacturing System
The company will establish a flexible manufacturing system which will allow it to cope successfully with the growing trend toward small lot, multi-kind production and the need for shorter delivery times.

(2) Higher Value-added Product Mix
In response to customers' requirements, the company will produce a full line of steel pipe products, with emphasis on high-alloy products.

(3) New Areas of Business
Areas where the company has not previously been involved will be actively cultivated, responding to the diversification of the marketplace.

In the future, as in the past, the company will strive to achieve a higher level of pipe and tube making activities based on the motto "Learn from the customer, and offer top quality, performance, and service."

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