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Synopsis :
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Outline of 4 400 t Press and Manufacture of Large Forged Steel Shell Rings*

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A unique 4 400 t hydraulic press has been installed in Mizushima Works in order to provide larger shell rings and wider forged plates. The new press based on Kawasaki Steel's original idea forges the shell rings with the outside diameter up to 8.5 m. By using new equipments and large hollow ingot up to 320 t, forged shell rings have been made available for the reactor pressure vessels of nuclear power plants and oil refinery plants. Experimentally manufactured shell rings showed a uniform distribution of chemical composition and mechanical properties, thus suggesting their suitable application for pressure vessels.

1 Introduction

Large forged steels are in increasing application recently following the trend toward larger-size equipment for higher production efficiency and the growing need for higher product quality motivated by reliability engineering concept. In fact, in such end-uses as pressure vessels in light-water type power reactors, desulfurizing reactors which are typical equipment in petrochemical plants as well as in pressure vessels in liquefaction and gasification of coal, forged steel are steadily replacing the conventional steel plates. Since these pressure vessels are of 4.5 to 7.5 m in diameter and 150 to 400 mm[1] in wall thickness for improved efficiency, the suppliers of steels must have well-established manufacturing equipment and techniques that will satisfy these requirements. Kawasaki Steel Corporation has used as main equipment a 6 000 t free forging press manufactured by Hydraulic, of West Germany[2,3].

Further, a technique established in 1976 for making hollow ingots made it possible to produce up to 320 t of large-sized hollow ingots. In addition, the company installed a 4 400 t finish forging press as well as the related reheating furnace and heat treating furnace, etc. for large-sized shell rings and wide plates beyond the capacity of the 6 000 t press. This press is an original development of Kawasaki Steel, based on a unique design. The report outlines the features of these new equipment and trial production of shell rings.

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** Mizushima Works

2 Characteristics of New Equipment

The 4 400 t press was installed exclusively for finish forging of large-sized shell rings and wide plates to be used for 1 100 MWe boiling water reactors and reactors in chemical plants. Added further as auxiliary facilities were a large-sized reheating furnace, remodeled heat treating furnace and quenching bath, and enlarged machining equipment. **Fig. 1** shows the size of forged shell rings made available after this enhancement of equipment. The features of the main equipment are as follows.

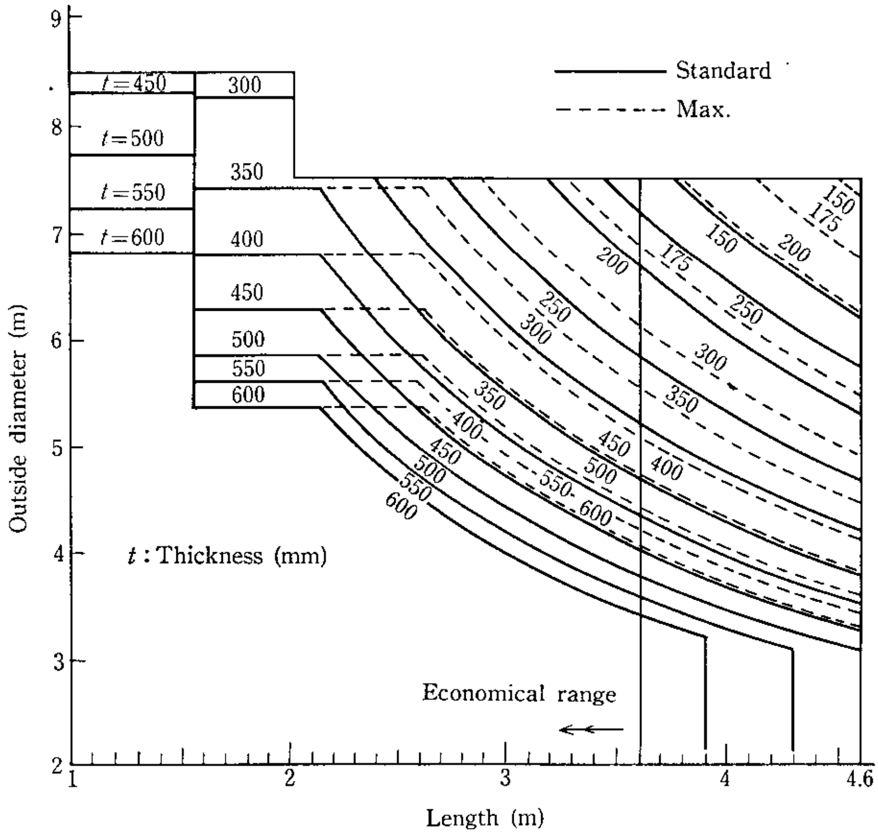
2.1 4 400 t Press

This is a new type press, which is roughly divided into the side housing, the bed and the slide beam which is equivalent to the cross head. This allows to finish forging of large-sized shell rings and wide plates which have been roughly forged by the 6 000 t press.

2.1.1. Structure and function

Fig. 2 shows finish forging of a shell ring and a wide plate by the 4 400 t press, and **Photo 1**, forging of a shell ring. This press has the following construction and functions.

A pair of side housings at both ends of the bed houses the reduction cylinder and guides the slide beam. The slide beam can move longitudinally, thus allowing it to go in and out of ring-shaped material. The slide beam set at a predetermined position joins the reduction ram and lifting ram. The reduction and lifting rams are hydraulically driven and have reducing capacity of 2 200 t on each side (4 400 t on both sides). The slide beam can be kept horizontal in detecting



Note: Finished dimension
In case of length,
dimension includes
test piece.

Fig. 1 Available size of forged shell

positions of the reduction rams on both sides. Anvils are provided on the lower face of slide beam and on the upper face of the bed, respectively. Through the combined operation of valves of reduction and lifting rams, the slide beam is guided into the housing to move vertically, thereby allowing the material to be forged between upper and lower anvils.

One of the features of this press is that unlike the conventional free forging press, the outside diameter of ring to be pressed is not restricted by the upper platen.

2.1.2 Main specifications

(1) Capacity: Main ram 2 200 t × 2

(2) Hydraulic pressure used: 315 kgf/cm²

(3) Auxiliary facilities: Descaling equipment, thickness controller.

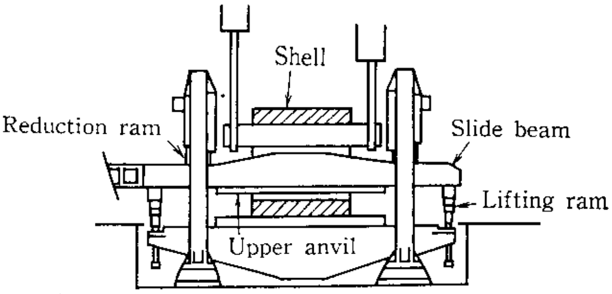
2.2 Reheating Furnace

A large-scale reheating furnace has been newly built taking into consideration the forging method of shell ring, and the reheating of large-diameter flanges and large plates.

2.2.1 Characteristics

This has been designed to be of buggy type car for common use by reheating furnace and heat treating furnace. In consideration of its control characteristics when used as a heat treating furnace as well as the in-furnace temperature distribution, two systems of combustion air pipings and a recirculation system of in-furnace exhaust gas by recirculation fan are adopted. **Fig. 3** shows a plan view of the reheating furnace.

Moreover, the lining of this furnace is made entirely



Finish forging of shell shape

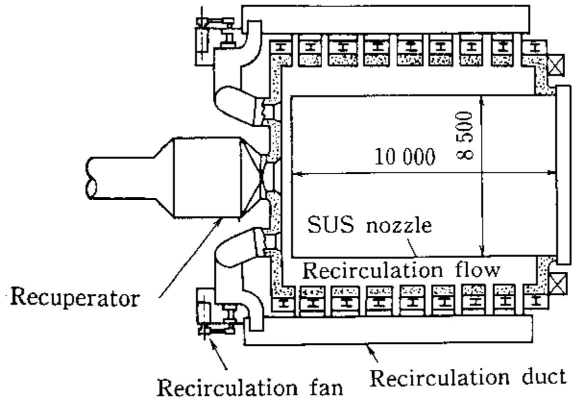
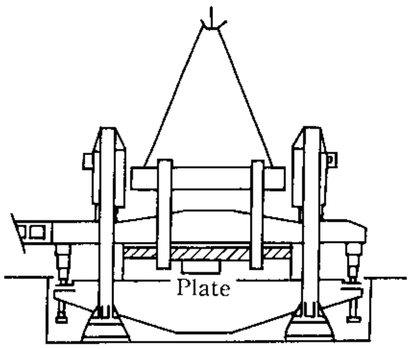


Fig. 3 Plan view of reheating furnace



Finish forging of plate shape

Fig. 2 Finish forging of shell ring and plate shape by 4 400 t press

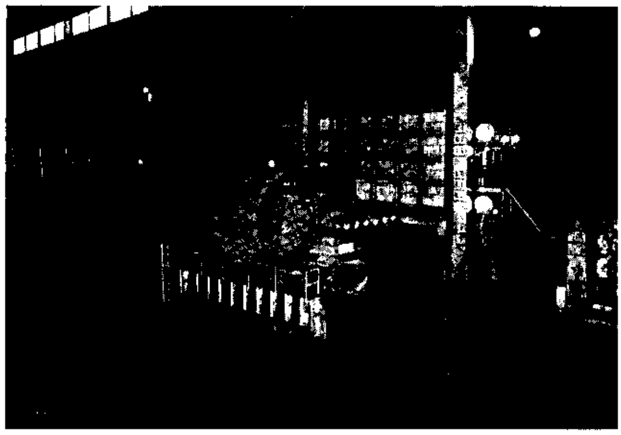


Photo 2 Extraction from reheating furnace

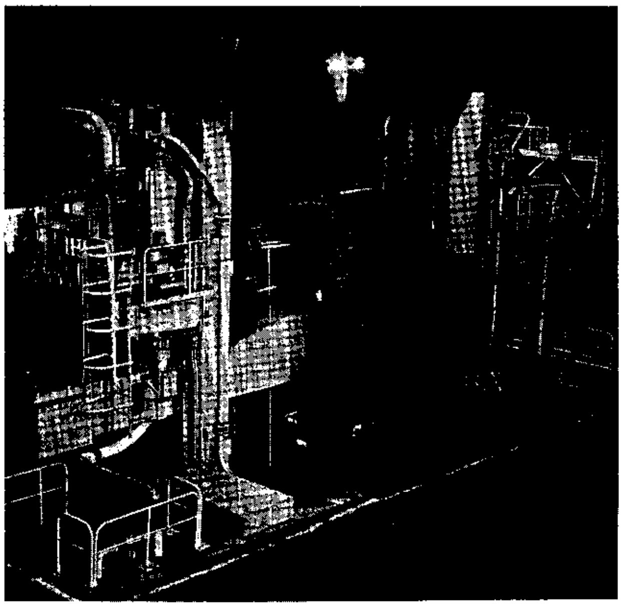


Photo 1 Forging of shell ring by 4 400 t press

of ceramic to save energy for about 35% fuel cost reduction. **Photo 2** represents extraction of shell ring from reheating furnace.

2.2.2 Main specifications

(1) Type: Buggy type furnace for common use: gas combustion heating and heat treating.

(2) Effective furnace inner volume: 7 500 *w* × 8 500 *h* × 10 000 mm *l*

(3) Charging capacity of buggy: 400 t

(4) Auxiliary facilities: In-furnance exhaust gas recirculating equipment. Recuperator for combustion air heating.

2.3 Heat Treating Furnace

The ceiling height of the existing buggy type heat treating furnace, was increased 1 000 mm with quenching of large-sized shell ring taken into account. On the

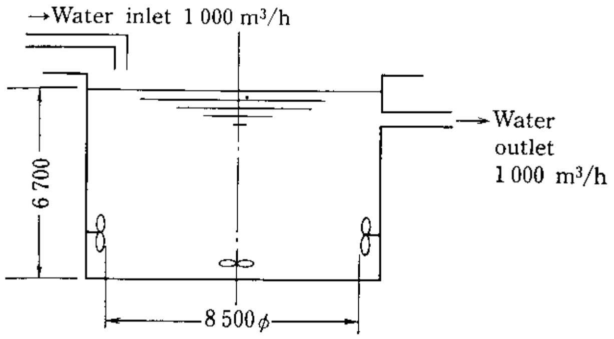


Fig. 4 Schema of quenching bath

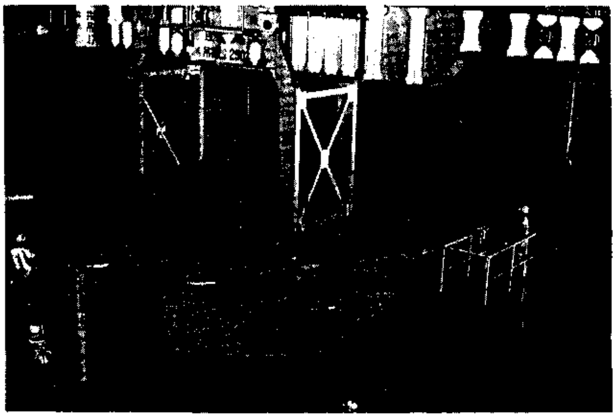


Photo 3 Quenching of shell ring

extended part and the ceiling, ceramic fiber instead of conventional castable refractory is used to save energy and to improve uniformity of temperature distribution. By these improvements, infurnace temperature accuracy is within ±10°C compared with target temperature.

2.4 Quenching Bath

Quenching bath is 8.5 m in diameter and 6.7 m in depth (both effective dimensions). It performs forced agitation by propellers installed on the outer periphery and at the center. Since it is provided with a refrigerator as well as a reserve tank, it can reduce water temperature rise while quenching (inlet and outlet capacity: 1 000 m^3/h). **Fig. 4** is a schematic drawing of quenching bath, and **Photo 3** shows quenching of shell rings.

2.5 Machining Equipment

To the existing 13 m vertical lathe, a two-dimentional copying equipment was attached, and further an 8 m vertical lathe was newly installed, thus increasing machining capacity for shell rings.

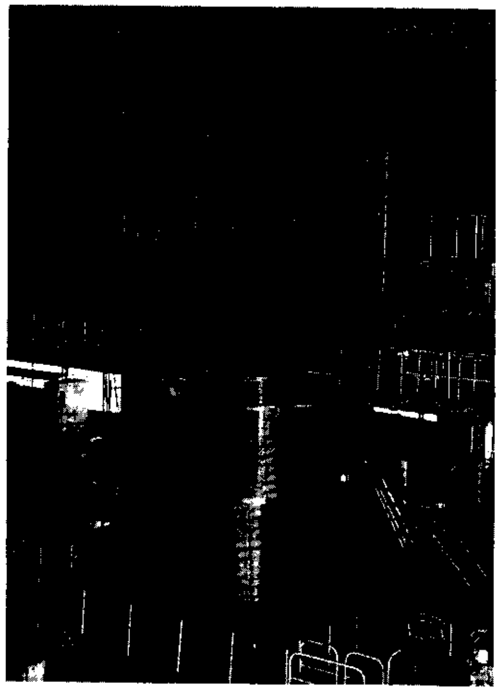


Photo 4 Machining of shell ring by vertical lath

2.5.1 8 m vertical lathe

This is a double housing type vertical lathe with two tool bars on a cross rail. It is also equipped with an electronic copying device. **Photo 4** shows machining of shell ring by 8 m vertical lathe.

2.5.2 13 m vertical lathe

Two-dimensional electronic copying equipment has been added to the existing lathe. Gage position is detected from the stylus of copying equipment separately installed, and instructions are sent to servomotors attached to the cross rail end (X axis) and upper part of tool bar (Z axis). Simultaneous functioning of these X and Z axes allow two-dimensional machining.

3 Production Technique for Large-sized Hollow Ingots

A production technique was already established at Kawasaki Steel for high-quality, large-sized ingots through melting by BOF of low phosphorous, low sulfur steel; deoxidizing through increased circulation by RH degassing; development of a technique to improve dehydrogenability and that of bottom pouring with argon seal[4]. This technique has been combined with the hollow ingot production technique to establish the large-sized hollow ingot making technique[5].

Fig. 5 shows the manufacturing method of hollow ingots. One of the most important points in making

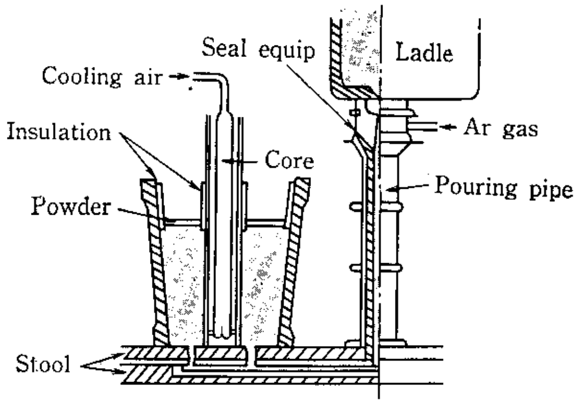


Fig. 5 Making of hollow ingots

Table 1 Comparison of solidification time between conventional and hollow ingot

Ingot weight (t)	Solidification time	
	Conventional ingot	Hollow ingot
15	7	3
35	10	3.5
50	12	6
70	14	8
110	23	10
140	30	17
200	37	23

hollow ingots is the structure of the core, which is a triple structure of pipe–refractory–pipe. Inner part of its core is forcibly air-cooled. This means shorter solidification time and, therefore, less segregation than conventional ingot, and at the same time an initial solidification layer with sound solidification structure on the inner face.

Table 1 shows a comparison of solidification time between conventional and hollow ingots. Another feature is the reduction of porosity produced. **Fig. 6** shows the decrease in liquid region at the last stage of solidification. In case of hollow ingot, 30 minutes before completion of solidification, the width of the liquid region is smaller than that of the conventional ingot, and further this small region gradually disappears. Thus replenishment of molten steel which compensates for solidification shrinkage can be sufficiently made to restrict production of porosity.

4 Production of Large-sized Shell Rings

The production system for large-sized shell rings had already been placed on a firm basis through

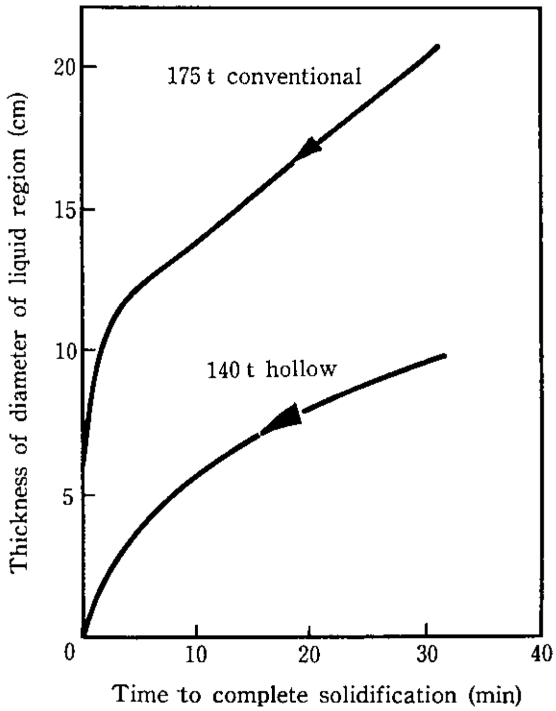


Fig. 6 Decrease in liquid region at the last stage of solidification

establishment of manufacturing techniques for large-sized hollow ingots and consolidation of production facilities. Therefore, the trial production of shell rings was made for 1 300 MWe class pressurized water reactor, (hereinafter referred to as "Mn-Ni-Mo steel shell ring") on the one hand and 2¼ Cr–1 Mo steel shell rings for chemical plants (hereinafter referred to as "Cr-Mo steel shell ring"), on the other. **Fig. 7** represents manufacturing process of trial forgings, and **Fig. 8**, dimensions of trial forgings before quenching.

4.1 Steelmaking

Both Mn-Ni-Mo steel shell rings and Cr-Mo steel shell rings were made by the BOF-RH degassing process, with molten steel cast into 200 t hollow ingots through bottom pouring with Ar seal.

Table 2 shows chemical composition of respective molten steel. For greater toughness, reduction of P and S contents for each ingot has been taken into consideration. Besides, use of BOF steel with high molten steel proportion greatly reduces the impurity content.

4.2 Forging

Fig. 9 shows the outline of the forging process. **Photo 5** shows forging of shell ring by 6 000 t press.

Manufacturing process	Manufacturing condition
Desulfurizing	· Desulfurization of molten pig iron
BOF retining	· High hot ratio · Low P.S
R.H degassing	· Degassing · Adjustment of chemical composition · Adjustment of steel temperature
Pouring	· Bottom pouring · 200 t hollow ingot
Reheating	
Forging	· Discard · 6 000 t, 4 400 t free forging press
Annealing	· De-hydrogen treatment (Normalizing-tempering)
Machining	· 13 m vertical lathe
Inspection	· UT, MT
Heat treatment	· Quenching-tempering
Mechanical test	· SR (P.W.H.T.)

Fig. 7 Trial forging manufacture process

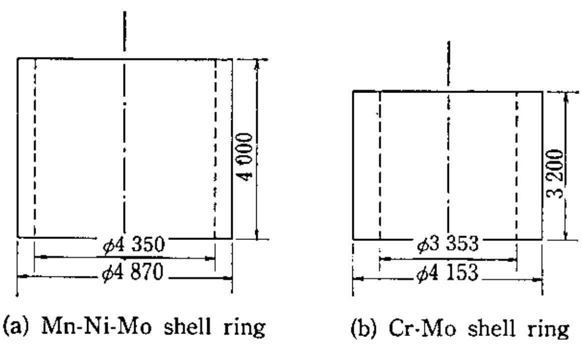


Fig. 8 Dimension of trial forgings before quenching

4.3 Heat Treatment

Quenching was performed to assure strength and toughness in the conditions shown in **Table 3**. Further, the temperature distribution and variation was measured, attaching thermocouples at various positions to confirm uniformity of temperature and cooling speed which are one of the most important control items of quenching. **Table 4** indicates, as a representative example, average cooling rate of Mn-Ni-Mo steel shell ring when quenched. It is clear from this table that a sufficient cooling speed is ensured even at the central part of wall thickness and that the top and bottom are both uniformly cooled down.

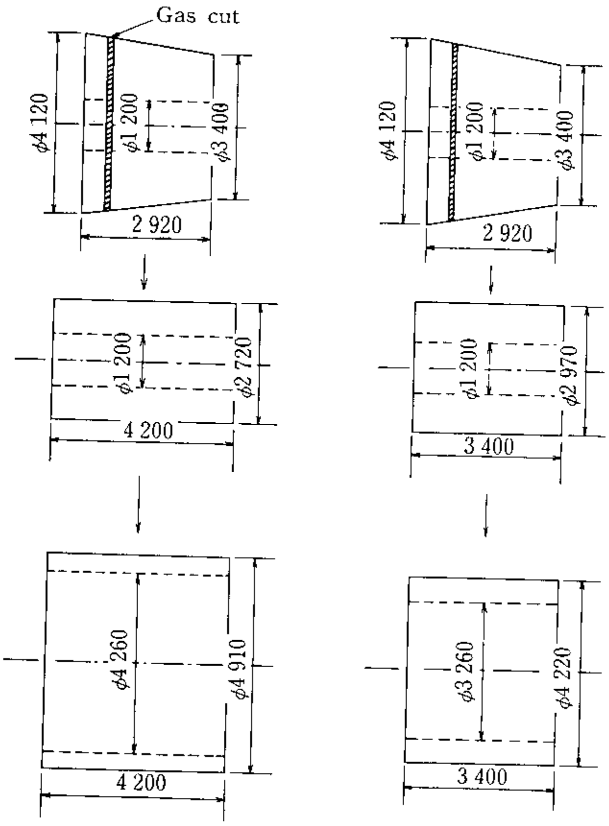
4.4 Inspection

As a result of dimensional and appearance inspection as well as ultrasonic testing and magnetic particle examination, Mn-Ni-Mo steel shell ring and Cr-Mo steel shell ring have turned out free of defects.

Table 2 Chemical composition of trial forgings

	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	U	Al
JIS SFVV3 Spec.	0.15 -0.25	0.15 -0.35	1.20 -1.50	Max. 0.025	Max. 0.025	—	0.40 -0.80	—	0.45 -0.60	Max. 0.05	—
Results	0.18	0.25	1.44	0.004	0.002	0.01	0.70	0.14	0.51	0.003	0.025
SA336 F22 Spec.	Max. 0.15	Max. 0.50	0.30 -0.60	Max. 0.030	Max. 0.030	—	—	2.00 -2.50	0.90 -1.10	—	—
Results	0.14	0.10	0.53	0.004	0.003	0.16	0.16	2.45	1.03	0.011	0.020

	N	As	Sn	Sb	B	Nb	Co
JIS SFVV3 Spec.	—	—	—	—	—	—	—
Results	0.010	0.001	0.001	0.000 4	<0.000 1	0.001	0.004
SA336 F22 Spec.	—	—	—	—	—	—	—
Results	0.008 9	0.002	<0.001	0.000 5	0.000 1	0.001	0.005



(a) Mn-Ni-Mo shell ring (b) Cr-Mo shell ring

Fig. 9 Trial forging process

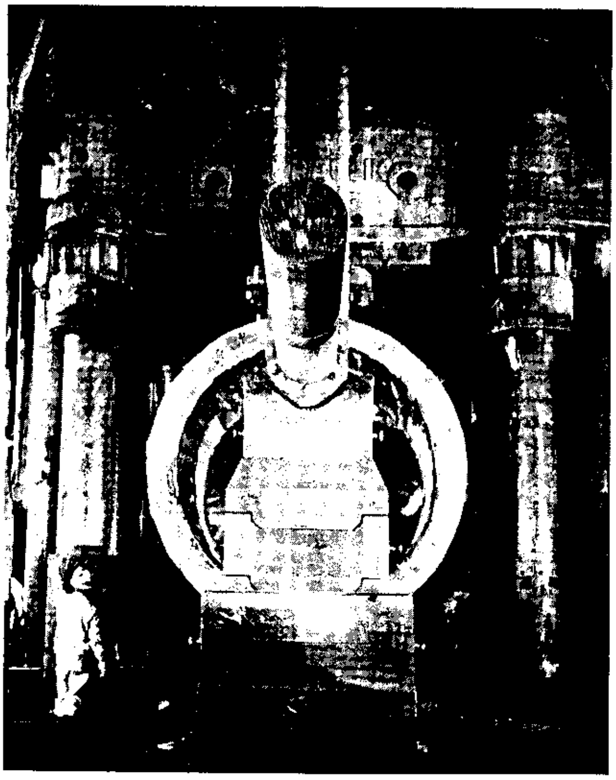


Photo 5 Forging of shell ring by 6 000 t press

Table 3 Quenching condition of trial forgings

		Mn-Ni-Mo shell ring	Cr-Mo shell ring
Quenching	Holding temp. (℃)	880	1 070
	Holding time (h)	8	17
Tempering	Holding temp. (℃)	655	650
	Holding time (h)	*5.5	*8

* Holding time of 1/2 position

Table 4 Average cooling rate from 800 to 400°C (Mn-Ni-Mo shell ring)

Position	Top C.R. (℃/min)	Bottom C.R. (℃/min)
40 mm from inner surface	32.0	36.3
20 mm from inner surface	61.5	72.7
3/4 t	21.6	22.2
1/2 t	20.0	20.5
1/4 t	24.2	23.5
20 mm from outer surface	100.0	114.2
40 mm from outer surface	53.3	44.4

5 Characteristics of Large-sized Shell Ring

Basic test, fracture toughness test, fatigue test and welded joint test were made on the base material. A part of this basic test is reported in the following.

5.1 Segregation

Figs. 10 and **11** shows the distribution of chemical composition (C, Mn, P, S). Segregation at each position is very minor, and uniform, which coincides with the chemical composition of trial forgings given in **Table 2**.

5.2 Internal Characteristics

In order to evaluate internal characteristics of forging steel in large-sized ingot, cleanliness, austenite grain size and microstructure were tested. **Tables 5** and **6** show a part of the results of the cleanliness test executed according to JIS G 0555. Only minor inclusions are evident for A and B types. **Photos 6** and **7** show representative austenite grain structure and typical microstructure, respectively. These structures are both fine tempered bainite structures. Thus in each of the tests carried out, excellent internal characteristics

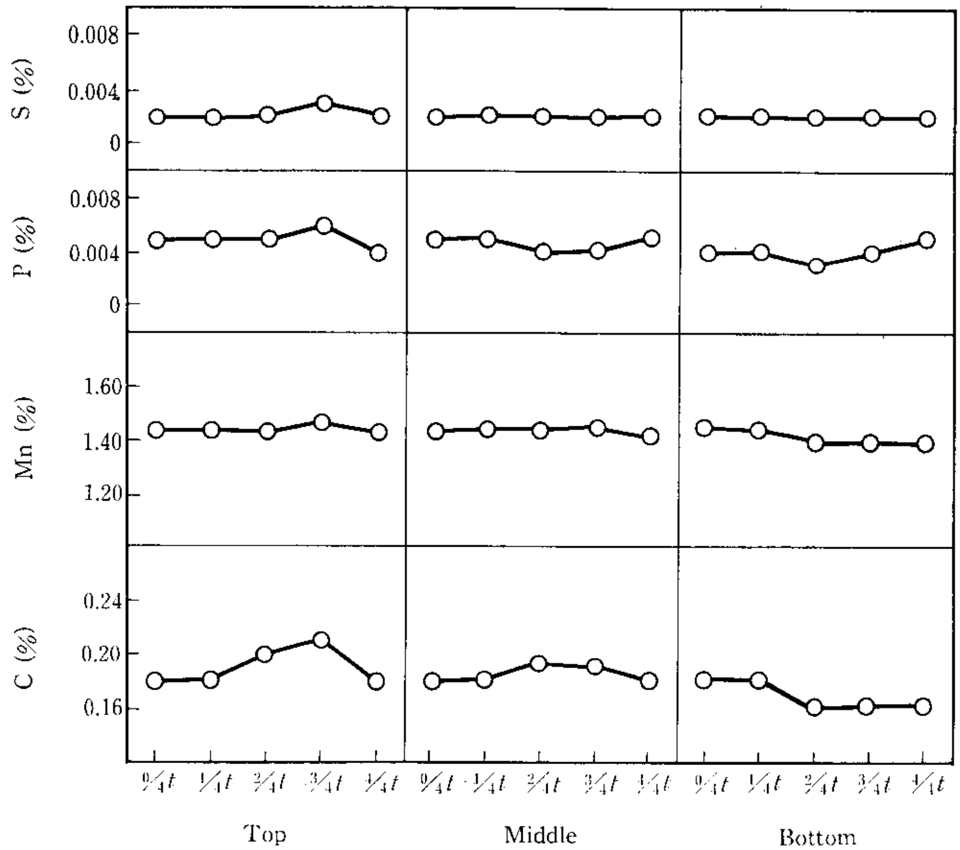


Fig. 10 Distribution of chemical composition (Mn-Ni-Mo shell ring)

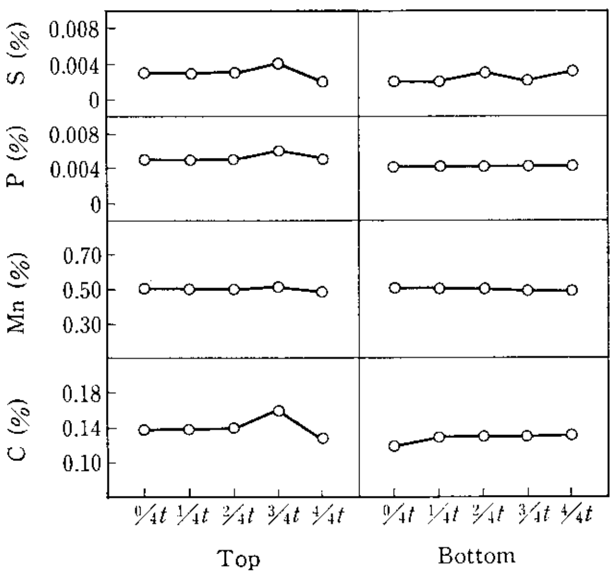


Fig. 11 Distribution of chemical composition (Cr-Mo shell ring)

have been revealed, which proves the superiority of the hollow ingot making process by the BOF-RH and bottom pouring with Ar seal.

5.3 Mechanical Characteristics

Figs. 12 and **13** indicate, respectively, distribution of mechanical properties of Mn-Ni-Mo shell ring and Cr-Mo shell ring. **Figs. 14** and **15**, on the other hand, show influence of test temperature on tensile properties and results of tensile test at elevated temperatures, respectively. In both cases, there was almost no difference in strength between surface and central positions, and even in the central position of wall thickness the target strength is attained. At the same time, satisfactory values could be obtained also for impact and drop weight characteristics.

6 Conclusion

To meet the growing trend toward large-sized equipment and high-quality product in a variety of industrial facilities, a 4 400 t press has been installed based on our own design intended for finish forging of large-sized shell ring and wide plates that surpasses

Table 5 Cleanliness $d60 \times 400$ by JIS G 0555 of Mn-Ni-Mo shell ring

(JIS G 0555)

Sampling position		dA (60×400)	dB (60×400)	dC (60×400)	dT (60×400)
Top	0/4 t	0.029	0.004	0.000	0.033
	1/4 t	0.025	0.004	0.000	0.029
	2/4 t	0.025	0.000	0.000	0.025
	3/4 t	0.029	0.000	0.000	0.029
	4/4 t	0.021	0.000	0.000	0.021
Bottom	0/4 t	0.017	0.004	0.000	0.021
	1/4 t	0.017	0.000	0.000	0.017
	2/4 t	0.012	0.000	0.000	0.012
	3/4 t	0.025	0.004	0.000	0.029
	4/4 t	0.033	0.004	0.000	0.037

Note Type A inclusion: Sulfide, silicate
Type B inclusion: Alumina
Type C inclusion: Globular oxide

Table 6 Cleanliness $d60 \times 400$ by JIS G 0555 of Cr-Mo shell ring

(JIS G 0555)

Sampling position		dA (60×400)	dB (60×400)	dC (60×400)	dT (60×400)
Top	0/4 t	0.029	0.000	0.000	0.029
	1/4 t	0.037	0.000	0.000	0.037
	2/4 t	0.033	0.000	0.000	0.033
	3/4 t	0.033	0.000	0.000	0.033
	4/4 t	0.033	0.000	0.000	0.033
Bottom	0/4 t	0.037	0.000	0.000	0.037
	1/4 t	0.025	0.000	0.000	0.025
	2/4 t	0.033	0.000	0.000	0.033
	3/4 t	0.033	0.000	0.000	0.033
	4/4 t	0.037	0.000	0.000	0.037

Note Type A inclusion : Sulfide, Silicate
Type B inclusion : Alumina
Type C inclusion : Globular oxide

manufacturing capability of the existing 6 000 t press. At the same time, auxiliary facilities have been added to succeed in establishing the production system for large-sized shell rings, together with the establishment of a production system for large-sized hollow ingots. Kawasaki Steel has obtained satisfactory results in trial tests on shell rings of two steel grades: one for nuclear power reactor pressure vessels and the other for chemical engineering.

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2) H. Wanaka et al.: *Kawasaki Steel Technical Report*, **12** (1980) 1, p. 52 (in Japanese)
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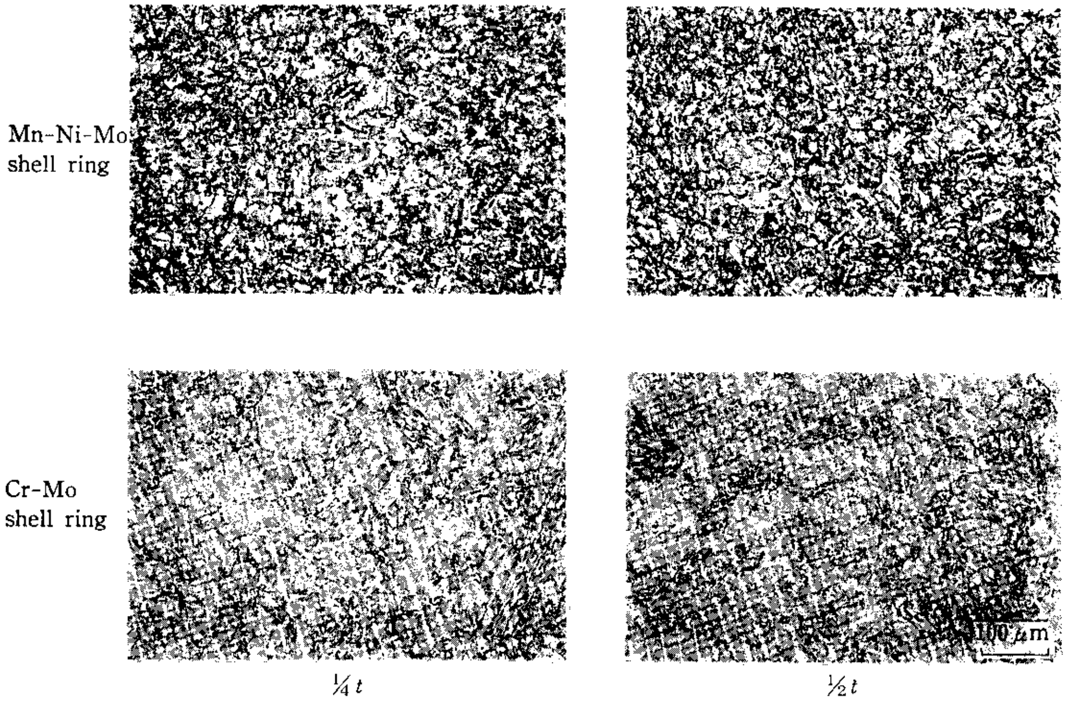

Photo 6 Typical austenite grain structure

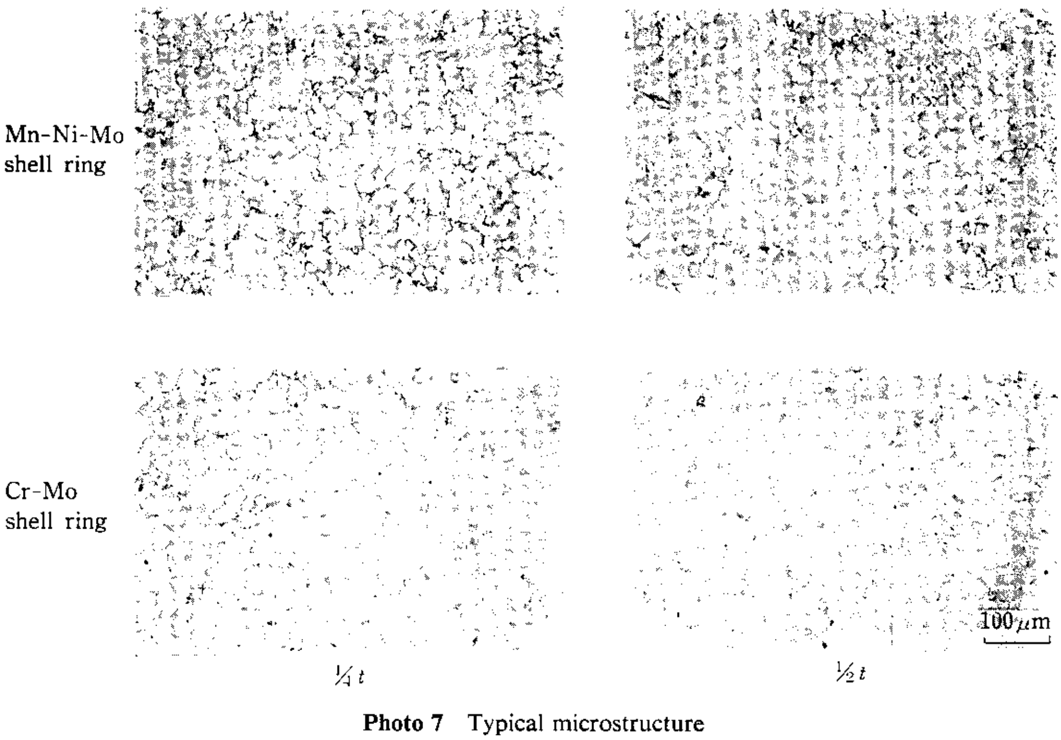

Photo 7 Typical microstructure

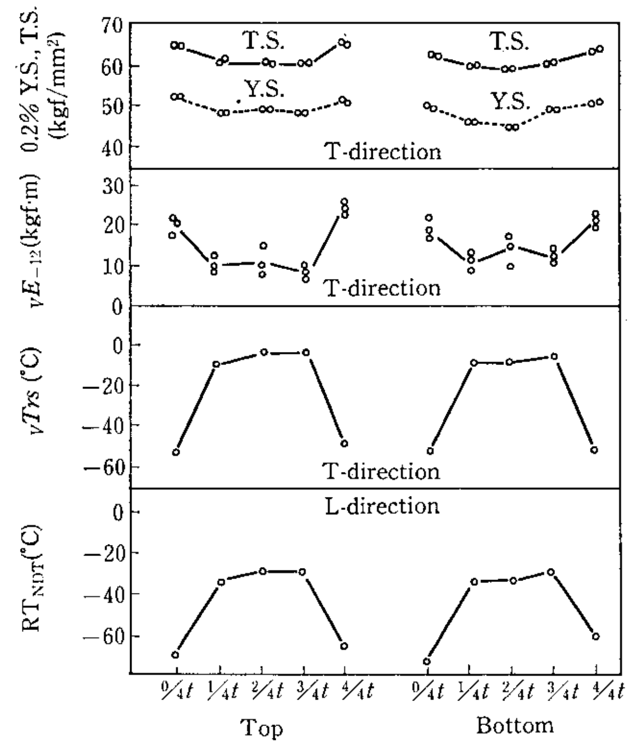

Fig. 12 Distribution of mechanical properties of Mn-Ni-Mo shell ring (615°C × 26 h F. C.)

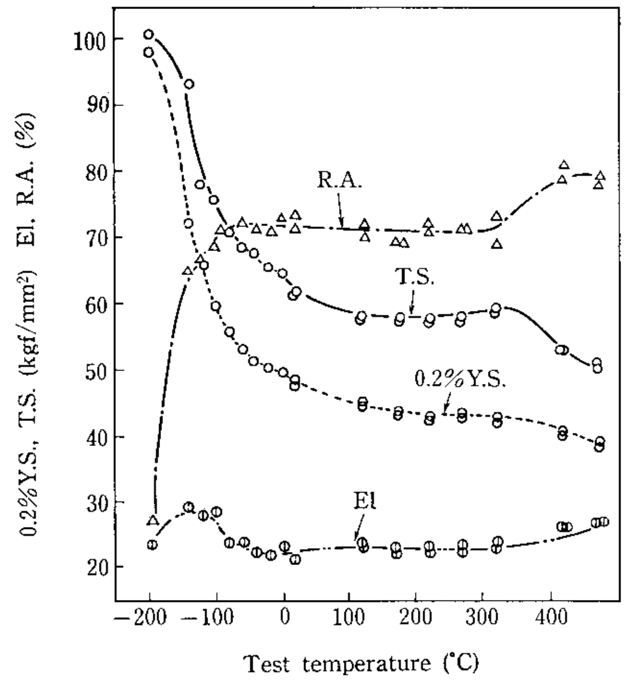

Fig. 14 Influence of test temperature on tensile properties (Mn-Ni-Mo shell ring, $^3/_4\ t$, L-direction)

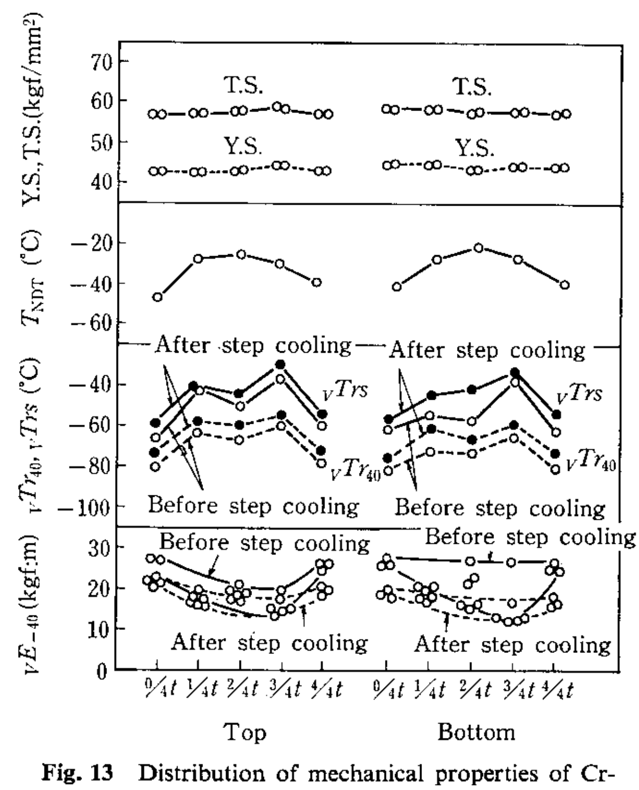

Fig. 13 Distribution of mechanical properties of Cr-Mo shell ring (690°C × 24.5 h T.P. = 20.60, T-direction)

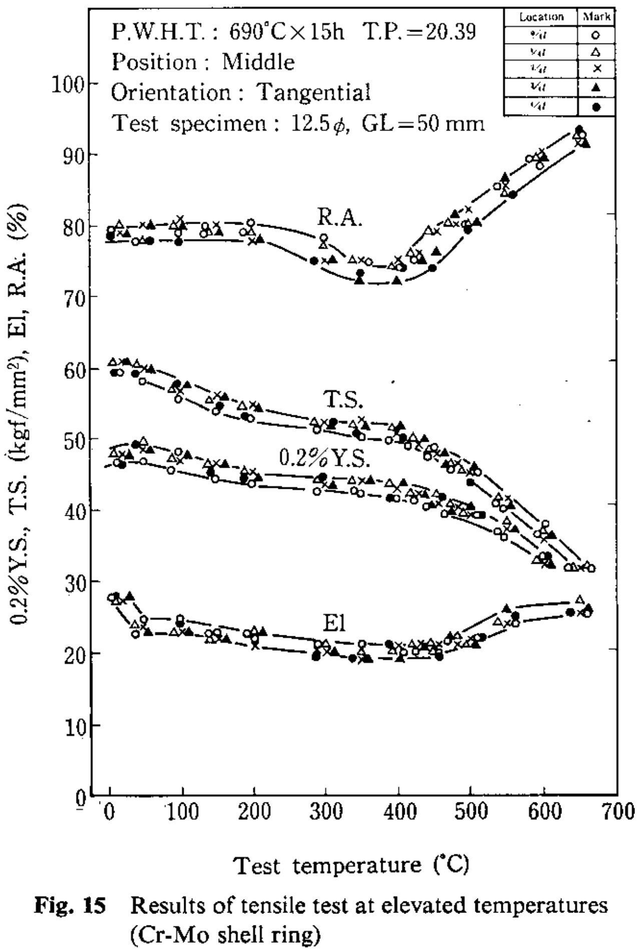

Fig. 15 Results of tensile test at elevated temperatures (Cr-Mo shell ring)