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Development of Chance-Free Bulge Roll (CBR) Forming Process for Manufacturing ERW Pipe*

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1 Introduction

The diversification of requirements placed on ERW pipe in recent years has been remarkable, while on the manufacturing side, in addition to the need to cope with trends toward small-lot, multi-kind production, higher valued added/higher quality products, a greater range of production size, and shorter delivery terms, broad cost reductions have also become an urgent necessity in order to strengthen international competitiveness. Although a great deal of research[1-8)] and technical development [2,9-21)] have been done to date in response to these needs, mutually incompatible factors exist in the items mentioned above, and a stage has not yet been reached at which major improvement can be realized simultaneously in these various areas.

Kawasaki Steel Corp. introduced the first 26" ERW full cage roll forming mill (IHI-Yoder) in Japan in 1978.[14)] In addition to production, the establishment of this cage roll forming technology was a goal. A grasp of the advantages and weaknesses of the cage roll forming mill was obtained through experimental investigation using the actual production mill[7,9)] and a program of fundamental research[8)] using a model mill, and various technical development tasks were promoted.

On the basis of this research data in connection with cage roll forming, the authors investigated a new forming process for ERW pipe with which it would be possible to achieve all the above-mentioned goals. The chance-free bulge roll (CBR) forming process was conceived as a new ERW pipe forming process which, in comparison with the conventional forming process, would possess outstanding features from various points of view, including flexibility of forming roll use, strip formability, and weldability.

The course of research and development experiments from the laboratory scale to pilot plant scale covered

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more than seven years, and the original goals established with the aim of application to a production ERW stainless steel pipe mill were substantially realized. On the basis of these research and development results, a production ERW pipe plant for stainless steel designed by Kawasaki Steel was introduced at the small diameter ERW pipe plant at Chita Works in June 1990. The new mill had a smooth start-up and is functioning as originally expected, making an important contribution to the improvement of ERW stainless steel pipe product quality.

This paper presents an outline of the CBR forming process and its features in comparison with the conventional method, and reports on the results of its application to a production mill.

2 Outline and Features of CBR Forming Process

Roll forming technology for ERW pipe is comprised of two component technologies, (1) the forming "flower," which determines how the steel strip is bent ("soft" technology), and (2) the equipment for forming the strip in the manner indicated by the forming flower ("hard" technology).

In recent years, flexible forming mills[10-13] have been developed for the principal purpose of realizing forming roll flexibility, but their development has centered on forming hardware and has not progressed to the development of the soft technology represented by the forming flower. In contrast, the CBR forming process had as its goal technical development in both areas in an effort to achieve forming roll flexibility and improved formability and weldability, which stand in a mutually incompatible relationship, and made it possible to produce ERW steel pipe with high product quality. The features of the CBR forming process are discussed below.

2.1 Forming Flower

Figure 1 shows the forming flower in the CBR forming process in comparison with that in conventional forming process. In the conventional method, bend-forming (mainly circular bending) is first applied to the entire sheet by the breakdown rolls or by cage roll forming, after which repetitive forming by reduce-bending over full circumference and reducing the horizontal diameter are applied in fin pass forming. In contrast, the CBR forming process uses edge bending and sheet center bend-forming to form a oval shaped semi-finished pipe in upstream forming before the fin pass rolls. In fin pass roll forming, horizontal bulge-bend-forming is applied in combination with distinctive (distributed) forming in the circumferential direction at each stand. A particular feature is over-bend forming at the No. 1 fin pass roll (1F), in which the semi-finished pipe is bent at four portions in the circumferential direction to radii less than those of the final product.

Figure 2 shows these features of fin pass roll forming in the CBR forming process in comparison with those of the conventional forming process. Figure 2(a) shows the fin pass forming flower for the two forming process. In comparison with a two radii design of the conventional forming process, the CBR forming process has a five-radius design. In the No. 1 fin pass (1F), bending is

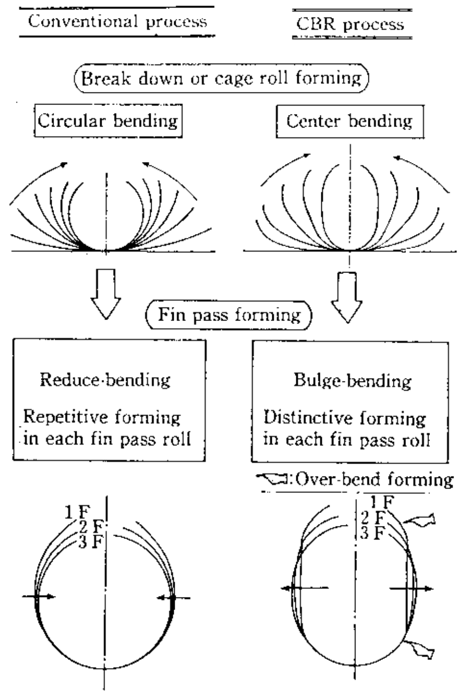


Fig. 1 Comparison of the forming flowers between conventional forming process and CBR forming process

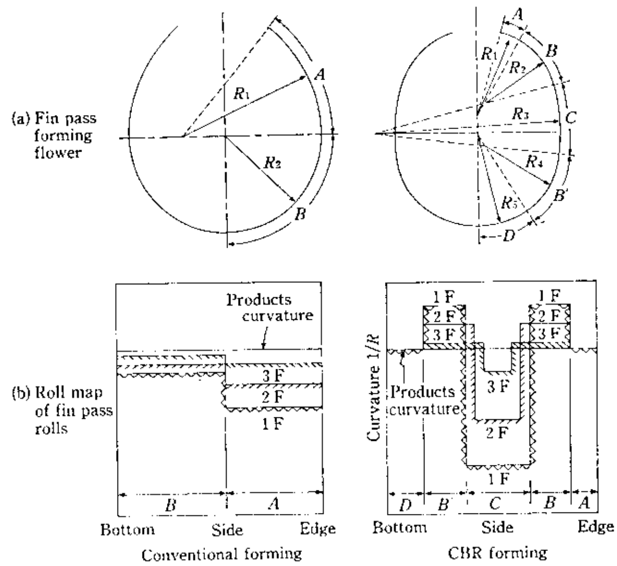


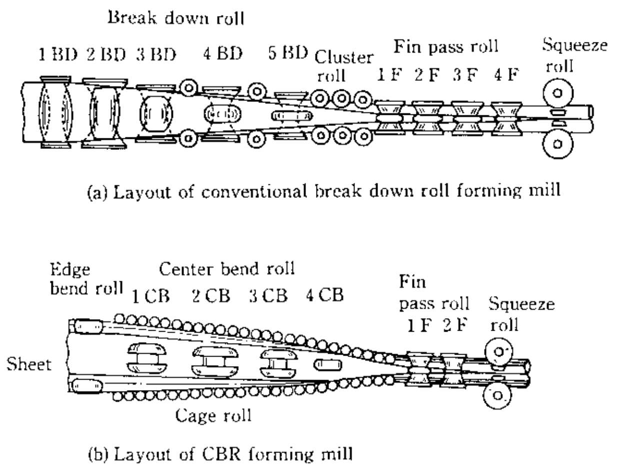
Fig. 2 Comparison of fin pass forming flower between conventional forming process and CBR forming process

restrained at portion C, which corresponds to the side of the semi-finished pipe, and over-bend forming to radii less than those of the final product is given at portions B and B′. At the No. 2 and No. 3 fin pass rolls (2F, 3F), portion B is progressively bulge-bend-formed, while unbend-forming is applied at portions B and B′, so that the entire piece approximates the product curvature. It should be noted that portions A and D are formed to approximately the planned curvature in upstream forming. In Fig. 2(b), the characteristics of the above mentioned forming flower are shown in terms of roll maps for conventional and CBR forming; it can be understood that forming in the circumferential direction of the semi-finished pipe is distributed among the each fin pass roll in CBR forming. The unique fin pass forming flower in the CBR process provides several outstanding features, including an enlarged V-convergence angle, as discussed below, prevention of roll marks, and a reduction in residual stress.

2.2 Forming Equipment

Figure 3 shows the concept of the forming equipment (mill) which produces the CBR forming flower in comparison with a conventional breakdown roll forming mill. In the conventional forming mill (a), because the strip is formed in steps by the breakdown rolls (BD), spring-back between the rolls is large and the amount of bending by each set of BD rolls becomes great; in addition, roll marks occur because of the problem of roll peripheral speed. Further, BD rolls are inferior in forming roll flexibility and roll changes are necessary for each pipe with a different outside diameter.

On the other hand, the CBR forming mill has the line layout shown in Fig. 3(b) in order to improve the weaknesses of the conventional BD forming mill and cage roll forming mill, and first performs edge bending in upstream forming, after which bend-forming of the strip center is carried out by center bend rolls (CB) positioned at the strip center and cage rolls (CR) which continuously restrain and support the edge of the strip. In the downstream fin pass rolls, it was found that forming with two roll stands was possible except for materials with high t/D (t, wall thickness; D, outside diameter) ratio as the results of the investigation of strip deformation behavior in the fin pass forming[9] and the developmental experiments in connection with the present CBR forming process. Additionally, because it was desirable to reduce the number of stands to the minimum in consideration of work efficiency, the commercial mill has two stand fin pass roll layout, after which the rotary seam guide roll (RSG) is installed. Further, from the viewpoint of forming roll flexibility, the upstream forming rolls in the CBR forming mill are of the design shown **Fig. 4**, and 1CB~3CB rolls, which bend the center portion of the strip, are of a segmented twin-type roll construction which allows both control of roll movement in the lateral direction in response to changes in wall thickness and outside diameter of pipe, and adjustment of roll clearance in the wall thickness direction. At such times, cage rolls (CR) flexibility is obtained by positional adjustment of the CR rolls in the directions of the arrows in the figure.



(a) Layout of conventional break down roll forming mill

(b) Layout of CBR forming mill

Fig. 3 Comparison of layout of forming mill between conventional forming process and CBR forming process

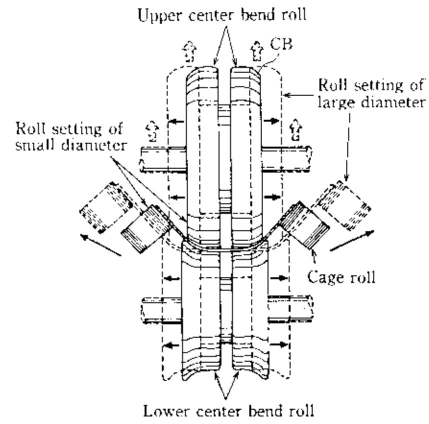


Fig. 4 Conception of common use of forming rolls in wide diameter and thickness range

2.3 Features

The features of the CBR forming process are as follows:

(1) Forming Roll Flexibility
Time savings when outside diameters and/or wall thicknesses are changed.

(2) High-Accuracy Roll Setting and Compact Mill Construction
Reduction of time for roll setting adjustment by total set-up of mill.

(3) Stabilized Forming
Reduction in lost time and improvement of the

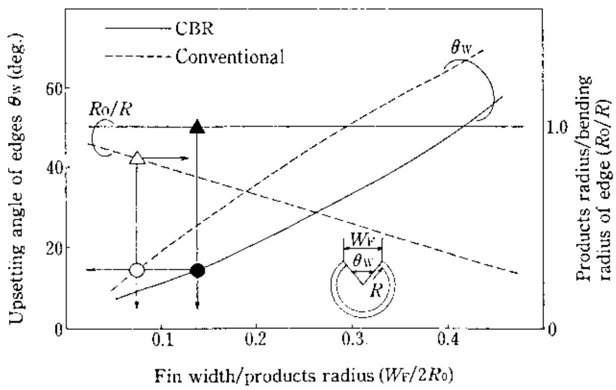


Fig. 5 Relation between fin width, upsetting angle of edges and bending radius of edge

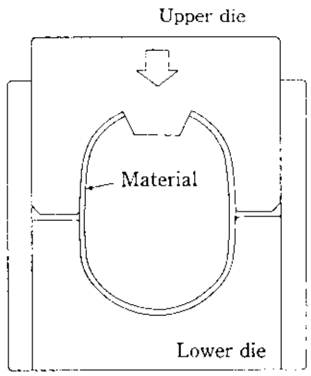


Fig. 6 Press forming simulation of fin pass forming

yield and dimensional accuracy of pipe by suppression of edge wave, restraint of strip rolling, prevention of roll marks in forming without lubrication, and control of increases in wall thickness at the strip edge.

(4) Stabilized Welding and Improved Product Quality
Wider range of acceptable welding temperatures and improved quality of welded seam as a result of an increase in the V-convergence angle, minimizing of the upsetting angle, and reduction of variations in edge forming.
Figure 5 shows the relationship between the ratio of the fin width to the outside diameter of the pipe ($W_F/2R_O$) and the upsetting angle of the edges (θ_W), and between the same fin width ratio ($W_F/2R_O$) and the bending radius ratio of the edge (R_O/R). For the same θ_W in both forming process, the fin width is approximately twice as great in the CBR forming process, which naturally means that the V-convergence angle is greater at the time of welding. Thus, if θ_W and $W_F/2R_O$ are selected in view of the intended purpose, the increase in the V-convergence angle and I-type butting of the edges can be more easily obtained than with the conventional forming process. Moreover, edge bending is performed in the upstream edge bend roll and at No. 1 fin pass roll, and positive forming is not conducted at the following fin pass roll.

(5) Production of High Grade ERW Pipe with High Product Quality and High Workability Efficiency
Production of high-grade ERW pipe by reduction in residual stress in the circumferential direction, suppression of work hardening, and improvement of weld quality.

3 Fundamental Study by the Two-dimensional Press Forming Experiment

As the first step in the development of the CBR forming process, the deformation behavior and bulge-bend-formability of semi-finished pipe in fin pass roll forming were investigated in two-dimensional press simulation experiments. Although there is a considerable difference between material deformation in two-dimensional press forming and three-dimensional roll forming and it is difficult to call this an adequate simulation, the experiment was performed for the purpose of making a simple evaluation of the features of this forming process.

In the experiment, a U-shaped semi-finished pipe (without edge bending) corresponding to upstream forming was formed by three point bending with a 50-t press. Next, a fin pass forming simulation was performed by press forming the same formed semi-finished pipe in the order IF – 2F – 3F(RSG) – SQ die using caliber dies with fin shown in **Fig. 6**.

Figure 7, as one example of the results of this press forming experiment, shows the changes in the curvature distribution in the circumferential direction of the formed sheet in the fin pass and squeeze roll (SQ)

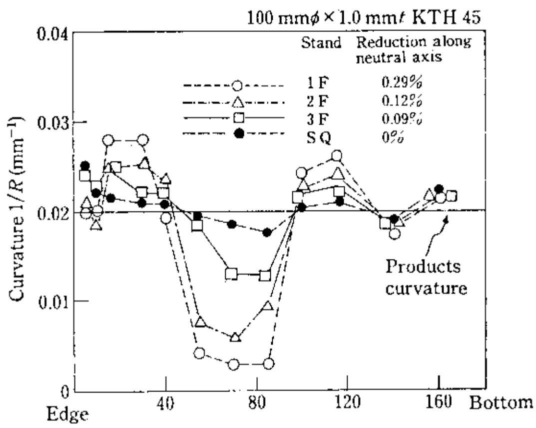


Fig. 7 Change of curvature distribution of formed sheet in circumferential direction after passing through fin pass and squeeze roll stands

forming processes. At 1F, overbending to a curvature greater than that of the finished product is applied at portion approximately 30 mm and 110 mm from the edge, while bending is restrained on the side of the pipe, at a portion about 70 mm from the edge. It can be understood that at 2F and 3F, the portions overbent at 1F are steadily unbent while at the same time bulge forming is progressively applied to the pipe side, and in SQ forming, all portions in the circumferential direction are formed to approximately the curvature of the finished product. In this manner, the press forming experiment made it clear that the unbent-forming of the semi-finished pipe and bulge-bend-forming at the side portion of it, which was a major feature of the CBR forming process could be substantially realized.

4 Experiment with Thin Wall Forming Using 4″ Model Mill

4.1 Experimental Method

As a second step in the development of the CBR forming process, developmental experiments were conducted by actual roll forming using the 4″ model mill.

Figure 8 shows the line layout of the 4″ CBR forming model mill used in the experiments. This mill was an improved one of the IHI-Yoder type cage roll forming mill (conventional forming mill), in which, after the strip is formed into an approximate U shape by the center bend rolls (1CB~4CB) and the cage rolls in the upstream forming zone, this U-shaped semi-finished pipe is bulge-bend formed by the fin pass (FP) rolls and then finished into a circular shape. Although, in consideration of forming roll flexibility, 1CB~3CB are rolls of the construction shown in Fig. 4, in which the upper and lower rolls are separable into two sections in the width direction, the experiment of forming roll flexibility was not conducted in these experiments. In addition, non-edge bend forming was applied as the standard in these experiments.

As the experimental size, a cold-rolled sheets 100 mm $\phi \times 1.0$ mm$t \times 4000$ mm$l$, $t/D = 1\%$, $\sigma_y = 337$ MPa was used. The standard for the down-hill amount were set at 0.8 × OD, and the line speed was approximately 7.5 m/min.

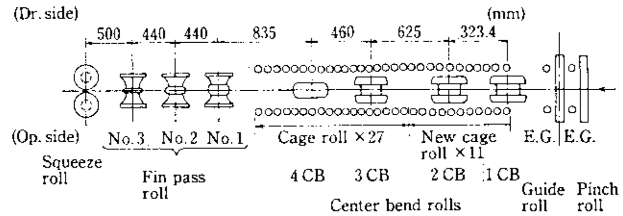


Fig. 8 Schematic diagram of the 4″ CBR forming model mill

Table 1 Dimensions of fin pass roll caliber

	1F	2F	3F
R_1 (mm)	50.00	50.00	50.00
R_2 (mm)	40.00	44.00	49.00
R_3 (mm)	250.00	152.12	79.88
R_4 (mm)	37.39	42.00	49.00
R_5 (mm)	50.00	50.00	50.00
W (mm)	93.06	96.54	100.46
H (mm)	120.57	114.21	107.10
W_F (mm)	41.42	28.20	15.00
θ_F (deg)	25.00	15.54	8.10

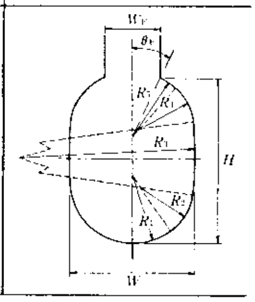


Table 1 shows the dimensions of the roll calibers of the fin pass rolls used in the experiment. R_2 and R_4 are given overbend and unbend-forming. R_3 is the side portion with suppress, and bulge-bend-forming is applied to this portion at 2F and 3F. In comparison with the fin pass roll calibers of the conventional forming process, the fin angle (θ_F) at 1F is reduced to the 72% level and the fin width (W_F) at 3F is increased to 174% level with the aim of increasing the V-convergence angle in electric resistance welding. Reduction of the circumferential length of semi-finished pipe along the neutral axis of sheet (γ_N) was adopted as the fin pass reduction and it was calculated from the value of the roll gap under load. In investigating the acceptable range of fin pass reduction values within which edge wave would not occur, experiments were conducted on the various conditions of total reductions and reduction distributions.

4.2 Results of Experiments

In this model mill forming experiment, first a study was made of the forming of the U-shaped semi-finished pipe in cage roll forming, and forming was stabilized. Next, developmental experiments on fin pass roll forming were conducted beginning with a one-stand experiment at 1F, and then with an increasing number of stands.[22]

Figure 9 shows the curvature distribution in the circumferential direction of the semi-finished pipe after 1F and after 3F in comparison with designed values. The semi-finished pipe after each FP roll has been formed to a curvature close to designed value. The possibility of materializing this CBR forming process was demonstreted in also actual roll forming.

Figure 10 shows the curvature distribution in the circumferential direction of the unwelded pipe after SQ forming in comparison with the results of the conventional process. In the CBR process, bending at the side portion is found to be somewhat inadequate, but the circumference as a whole shows a curvature close to that of the finished product; in particular, in spite of the fact that edge bend was not performed, edge bending is good when compared with the conventional process in which edge-bend-forming was used, from which it can

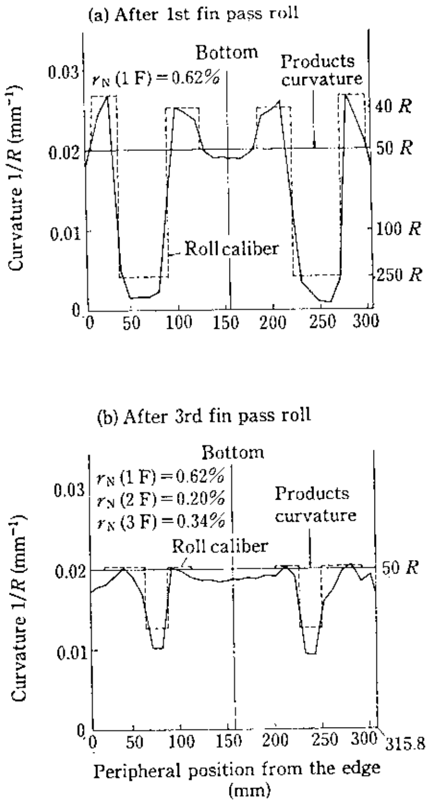
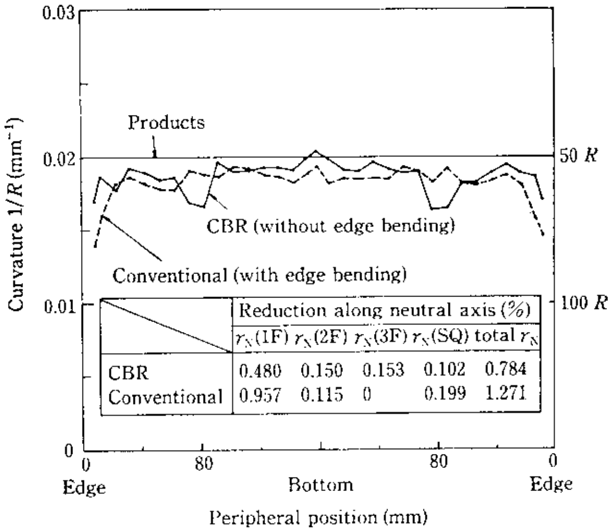


Fig. 9 Change of curvature distribution of formed sheet in circumferential direction after passing through fin pass roll stands



	Reduction along neutral axis (%)				
	r_N(1F)	r_N(2F)	r_N(3F)	r_N(SQ)	total r_N
CBR	0.480	0.150	0.153	0.102	0.784
Conventional	0.957	0.115	0	0.199	1.271

Fig. 10 Comparison of curvature distribution of formed sheet in circumferential direction after SQ roll forming

be understood that the CBR forming process has a excellent formability of edge-bending.

Figure 11 shows a comparison of the acceptable range

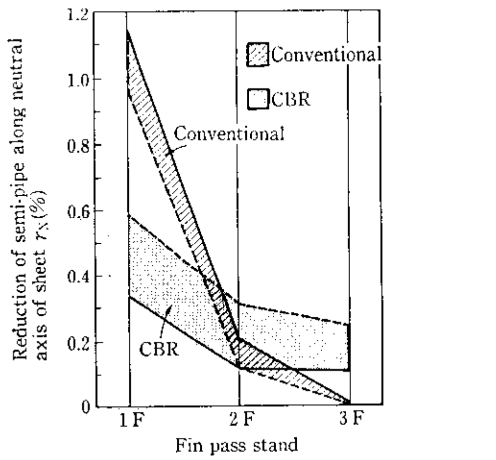


Fig. 11 Comparison of acceptable reduction range without edge wave in fin pass roll forming

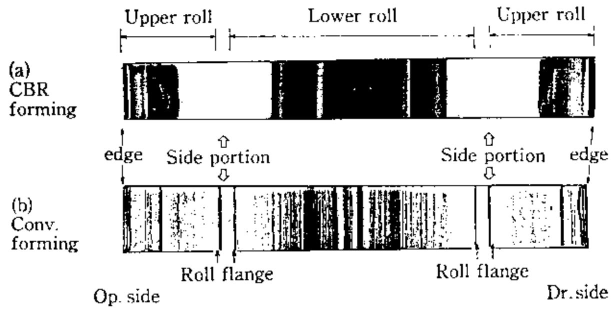


Fig. 12 Comparison of contacting state of formed sheet with 1st fin pass roll

of fin pass reduction values without edge wave in fin pass roll forming between the two processes. The CBR forming process has the wide acceptable range of fin pass reduction values and can decrease the amount of reduction at 1F and/or the total reduction. Moreover, because it is possible to reduce the semi-finished pipe at 3F, which is the final FP roll, and to increase gripping force as a result of it, more stable welding can be expected in the CBR forming process. The fact that the acceptable range of fin pass reduction values is wide gives a great advantage in roll set-up.

In the CBR forming process, the above-mentioned decrease in fin pass reduction and decrease in the fin angle at the upstream FP make it possible to prevent increases in wall thickness at the strip edge; the wall thickness increase ratio is on the order of 50% of that in the conventional process.[22)]

Figure 12 shows the results of a measurement of the contacting state between the formed sheet and No. 1 fin pass roll by using a paper sensor for pressure measurement. In CBR forming, because of the light contact between the roll and the material in the area corresponding to the roll flange (roll gap) of the two-roll

Table 2 Comparison of V-convergence angle and opening width of semi-pipe after squeeze roll

	*V-convergence angle		Opening width of semi-pipe after squeeze roll		
	l*(mm)	θ_V(deg.)	Fin width of 3F, W_{3F}(mm)	After SQ W_E(mm)	Comparative ratio
Conventional	12.87	0.13	8.6	26.7	1
CBR	6.00	0.29	15.6	20.7	0.775

* l is the distance from squeeze roll center, where opening width of edges is 0.03 mm

type fin pass roll , it is possible to prevent the roll marks which occur in this area in the conventional process.

Table 2 shows a comparison of the V-convergence angle (θ_V), which is shaped by the both edges of the unwelded semi-finished pipe (W_E) after the squeeze roll in the two processes. The distance l, which is the distance from the center of the SQ roll to the point at which the edge opening width just before SQ roll is 0.03 mm, is measured and θ_V is determined from the geometric relationship. Because the value θ_V is at a point immediately before the center of the SQ roll, it is small in comparison with commonly reported value of θ_V at $l = 50\sim100$ mm, but in the CBR forming process, as shown in the table, θ_V is more than double the conventional value and can be seen to satisfy the originally expected results. Incidentally, in connection with the size of θ_V and the incidence of welding defects, it has been reported by Haga et al.[23] that the 3rd welding phenomenon, in which short circuit between the edges happen, is suppressed when θ_V become large, and penetrator defects decrease. From this report, it is considered that the acceptable welding range expands if θ_V is increased, and it is therefore expected that in CBR forming process it will be easier to stabilize welding than in the conventional process.

As one distinctive feature of the CBR forming process, there is a reduction in residual stress (moment) in the circumferential direction of the pipe because overbending and unbend-forming are conducted at four portions on the circumference of the semi-finished pipe in FP forming, and as one evaluation of this, the opening widths (W_E) of the unwelded pipe edges after SQ forming were measured and compared. As shown in Table 2, the W_E after SQ forming becomes a small value in the CBR forming process even though the fin width at 3F(W_{3F}) is wider than that in the conventional process. Assuming W_E is equal to 1 in the conventional process, it is 0.775 in the CBR forming process. From this fact, residual stress in the circumferential direction of the welded pipe is estimated to be smaller in the CBR forming process. This reduction in residual stress is considered to contribute to a decrease in sizer reduction and the suppression of hook-crack defect generation at welded portion.

5 Developmental Experiments Using Pilot Mill

5.1 Experimental Equipment and Method

The line layout of the CBR forming pilot mill is shown in **Fig. 13**. The pilot mill is equipped with an uncoiler and pinch roll/leveler at the mill entry side, so continuous pipemaking is possible. Twelve cage rolls are installed on each side, and can be adjusted unit-by-unit for position in the width and height directions and roll angle. Both the upper and lower rolls at 1CB~3CB are segmented-type width-adjustable rolls. Driving rolls are used at EB, 1CB, 1F, and 2F. The line speed is a maximum 22m/min, and HF-induction welding (300 kW, 350 kHz) is possible. Further, for mill set-up the line has been equipped with pre-load system of stands, load cells and roll position sensors, resulting in improved mill accuracy.

Figure 14 shows schematically the concept of the common use of edge bend rolls. The lower roll has two roll calibers with different redii. The upper step is used for large outside diameter pipes, while the lower step is

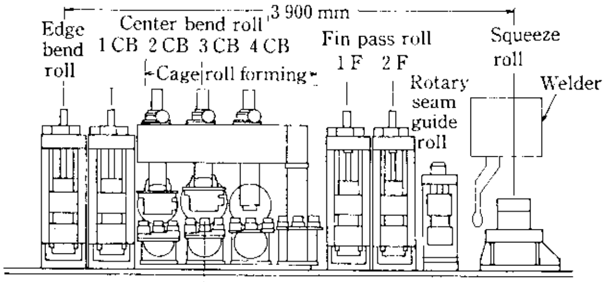


Fig. 13 Layout of CBR forming pilot mill

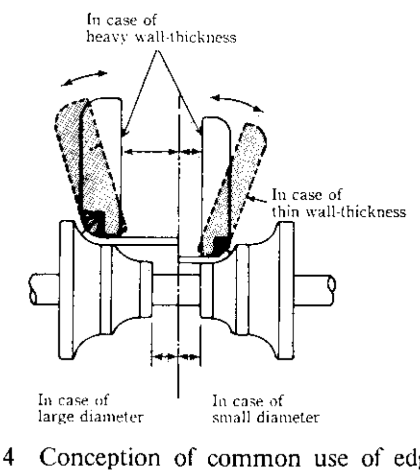


Fig. 14 Conception of common use of edge bend rolls in wide diameter and wall-thickness range

used for small diameters, and the position of the lower roll is laterally adjustable in accordance with strip width. The position of the lower roll is fixed on the roll shaft, using the newly developed hydraulic mechanism, in which in-roll hydraulic sleeve is operated by oil pressure, as with the center-bend-rolls (CB).

Further, the upper roll has two sets of rolls, for use with large outside and small outside diameters, and each roll has two bend radii for roll profile (the inner radius being for heavy wall thicknesses, and the outer for thinner material). Therefore, the upper roll can also be adjusted in the lateral direction for various outside diameters and the use of curved surface of roll caliber is changed depending on strip thickness by using the developed method in which the rolls can be inclined in accordance with strip thickness as shown in Fig. 14. In this manner, the common-use edge bend roll developed by Kawasaki Steel was designed in consideration of simultaneously satisfying the requirements of two features which stand in a mutually incompatible relationship, namely, forming roll flexibility and edge-bendability.

Figure 15 shows the projected available size range of ERW stainless steel pipe and the range of common use of rolls in upstream forming rolls (EB~4CB), as well as the sizes tested at the pilot mill. In this development project, because the object material was stainless steel, special attention was to the subjects of roll marks, pipe shape, and weld quality. Thus, it was regarded as goals that the common-use range of the upstream forming rolls excluding the cage rolls (CR) was set at an outside diameter ratio (= max./min. diameter) of 1.4, the number of reserve rolls was to be reduced from 15 sets to 3 sets, and forming and welding of ERW stainless steel pipe with high product quality were to be achieved.

It should be noted that the cage rolls are used commonly for all sizes in the available range shown in the figure.

The developmental experiments with the pilot mill were conducted with outside diameters of 31.8 mm and 42.7 mm and wall thicknesses of 0.8~3.0 mm, as indicated by the circular marks in the figure, and the flexibility of forming roll use, sheet formability, weldability, weld quality, and changes in mechanical properties were investigated.

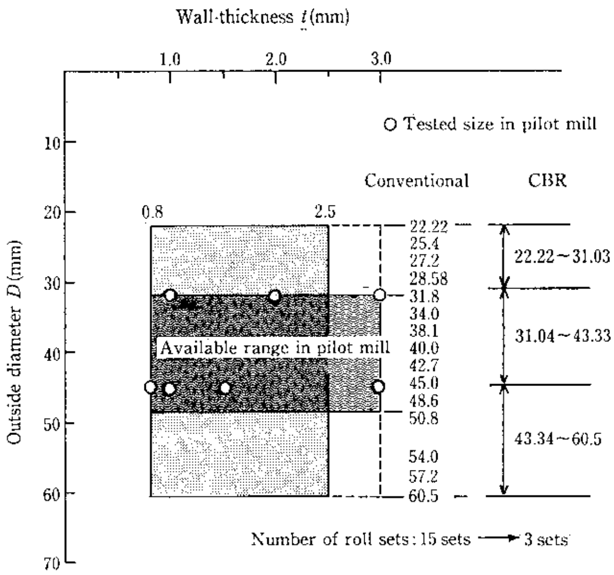
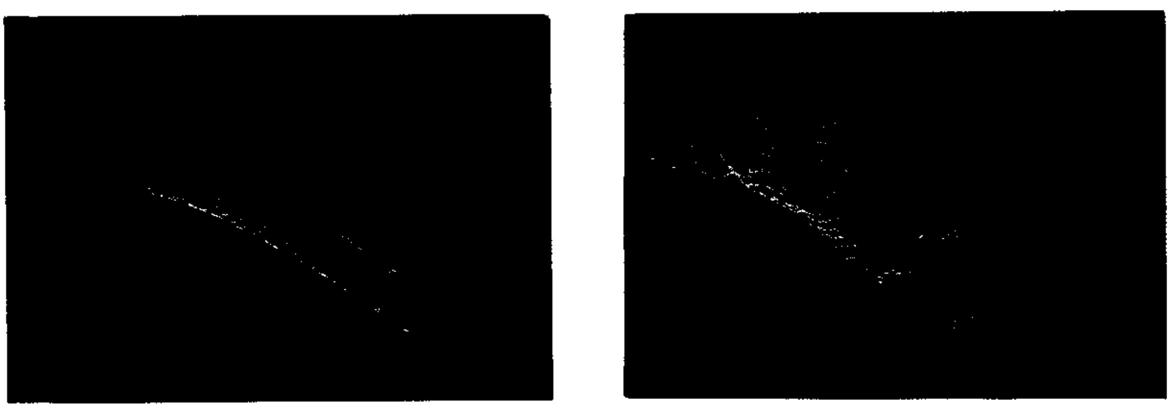


Fig. 15 Available size of ERW stainless steel pipes and range of common use of forming rolls in CBR forming mill

Incidentally, in the development of the CBR forming process, the design of the forming flower was extremely important and the design work was also complex since the CBR forming flower has a greater number of bending radii than that in the conventional process as mentioned above. A computer aided roll design (CARD) system was therefore developed with the aims of improved efficiency of CBR forming flower design and advance evaluation of the flower. An example is shown



(a) Three dimensional forming model (b) Transition of longitudinal membrane strain

Photo 1 Example of design of CBR forming flower by CARD system in **Photo 1**, where (a) shows a three-dimensional forming model, and (b) shows a transition of longitudinal membrane strain in the three-dimensional forming model. By means of this type of macro-level quantitative study, advance evaluation of the forming flower was made possible. The development of the CARD system contributed greatly to making the development of the CBR forming process more efficient.

5.2 Results of Experiments

This section reports the main results of the developmental experiments with the pilot mill.

Photo 2 shows the cross-sectional shape of unwelded semi-finished pipe formed by common use of the upstream forming rolls in the pilot mill experiments. From thin-wall material 42.7 mm ϕ × 0.8 mm$t$ to thick-wall material 31.8 mm ϕ × 3.0 mm$t$, formability (prevention of roll marks in forming without lubricant, suppression of strip rolling, improvement of bend shape, prevention of edge wave, etc.) was excellent, and stable forming of stainless steel pipe with satisfactory shape was achieved.

Further, as a result of the improvements realized in roll setting position accuracy, variations in the edge height of semi-finished pipe prior to welding were reduced to an extremely small value of only ±0.08 mm, and the V-convergence angle in welding was expanded over the former value to 4.5°. By these improvements, high-frequency welding of the semi-finished pipe has been substantially stabilized in comparison with the conventional forming process. As one example of the results, **Fig. 16** shows the relationship between welding temperature and welding toughness test results of welded pipe in this pilot mill. Based on the results of 90° flattening test and the segment expanding test, it was found that the acceptable range of welding temperatures within which weld defects will not occur is extremely wide at approximately 200°C, and it is thus possible to produce ERW stainless steel pipe with stabilized high product quality.

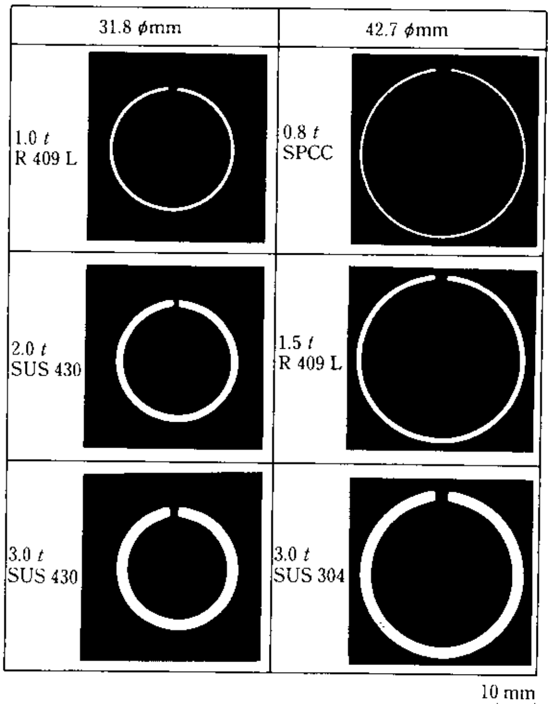


Photo 2 Shape of cross section of formed sheet passing through after squeeze roll without welding

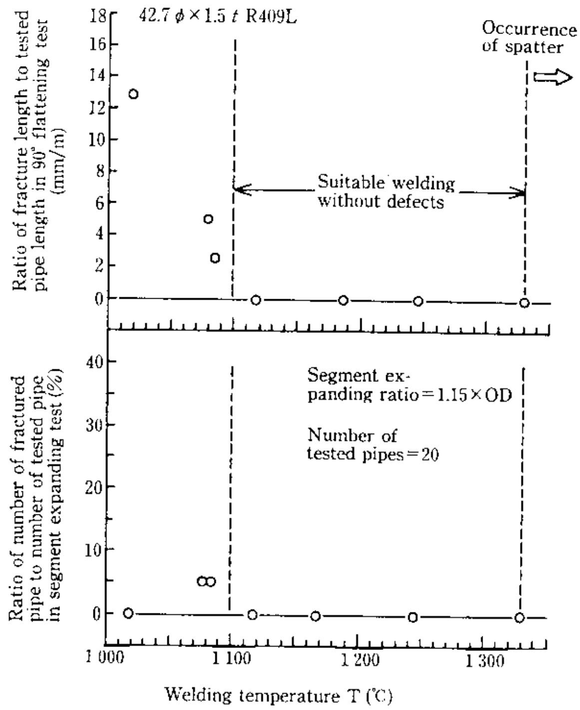


Fig. 16 Relation between welding temperature and results of welding toughness test in CBR forming pilot mill

6 Introduction of CBR Forming Mill for ERW Stainless Steel Pipe

6.1 Production CBR Forming Mill

Photo 3 shows the appearance of the actual production CBR forming mill for manufacturing ERW stainless steel pipe, installed at the Small-Diameter ERW Plant at Chita Works. Because this mill is installed in an existing mill line and was designed to share line facilities with a forming mill for carbon steel, it is mounted on a carrier deck, and the entire mill is moved into the line in order to change the mill for carbon steel at the production change of stainless steel pipe. The construction of the mill stands is essentially the same as that of the pilot mill, and compact design has been achieved in the length of the forming mill, which is approximately 4.2 m.

Photo 3 Apperance of the actual production CBR forming mill for manufacturing ERW stainless steel pipe

6.2 Results of Production

The actual production CBR forming mill showed a smooth startup after introduction, and the originally expected results have been obtained. This section reports production results, focusing on weld quality and pipe product quality.

Table 3 shows comparisons of two kinds of reductions of the circumference length along the neutral axis of the sheet and the outer circumference, and the V-convergence angle at the squeeze roll (SQ) in the conventional forming mill and CBR forming mill. In the CBR forming mill, the strip can be formed into pipe with less than half the reduction needed in conventional forming mill, and the strip can thus be bent into circular shape without applying undue reducing strain. This has been achieved by continuous forming with the upstream cage rolls and bend forming using the bulge-bend-forming flower which is the most important feature of the CBR forming process. This decrease in the reduction in the pipemaking process has brought about not only an increase in the production yield, but also major benefits related to reduced roll wear and the suppression of work hardening. Further, the V-convergence angle at the SQ

Table 3 Comparison of reduction of formed sheet and V-convergence angle in squeeze roll

	Reduction of semi-pipe along neutral axis of sheet, γ_N(%)			V-convergence angle θ_V*2(deg)
	Fin pass rolls	Sizing rolls*1	Total reduction	
Conventional*3	2.20	1.50	4.39	3.2
CBR	0.30	0.99	2.00	4.6

*1 Reduction of welded pipe along outside surface of pipe

*2 Measured value in distance of 40~80 mm from squeeze roll center

*3 Pipe size: 38.1 mm $\phi \times 2.0$ mm$t$ R409L

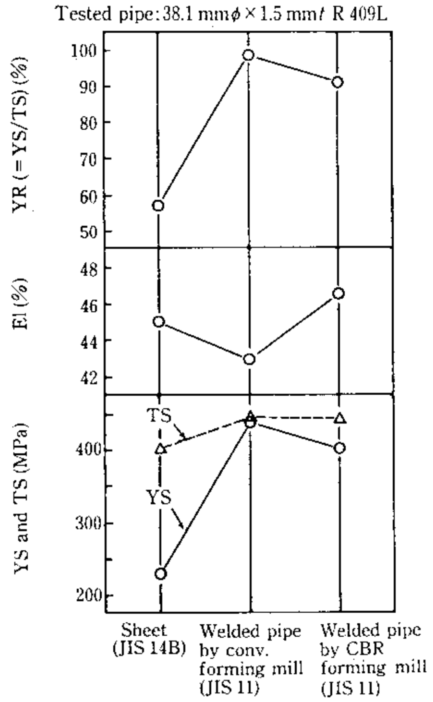


Fig. 17 Improvement of mechanical properties of ERW stainless steel pipes by CBR forming mill

roll has been expanded by about 1.5 times the conventional value to 4.6° as the results in the pilot mill, and at the same time, I-type butting of the edges has been achieved. Thus it has become possible to produce ERW stainless steel pipe with stabilized weld quality.

Figure 17 shows a comparison of the mechanical properties of pipe products manufactured by the CBR and conventional forming mills. It can be understood from the figure that the CBR-formed material has a higher El and smaller YR (YS/TS) than conventionally formed material, and that work hardening of the material has been suppressed. In bend forming of the strip in the width direction in the conventional forming, quite large redundant strain in the logitudinal and shearing directions, that are not necessary for pipe forming, are generated during bend forming by the breakdown and other rolls, because strip spring-back between stands is great. However, in the CBR forming process, bending strain in the width direction is mainly given and the strip can be adequately formed into a small oval shape with little generation of useless redundant strains at cage roll forming. Further, the fin pass reduction is decreased by bulge-bend-forming at the subsequent fin pass rolls and the sizer reduction is also decreased by the improvement of roundness of the semi-finished pipe after the squeeze roll. It is considered that the above-mentioned CBR forming process lessens the amount of working strain given to the strip and reduces the work-hardening of the material.

By the development and introduction of the CBR forming mill, not only flexibility of forming roll use but also excellent results in terms of strip formability and weldability and pipe features have been obtained, and it has been possible to substantially achieve the original goals.

7 Conclusions

A chance-free bulge roll forming process (CBR forming process), which is a new forming process for ERW pipe, was conceived, and developmental experiments from the laboratory scale to the pilot plant scale were conducted to demonstrate its forming capabilities. On the basis of these results, an actual production CBR forming mill designed and developed by Kawasaki Steel was then introduced, and the following results were obtained:

(1) The CBR forming process, comprising overbending and unbend forming of semi-finished pipe and bulge-bend-forming at the side portions of semi-finished pipe, was established.

(2) By flexible use of the upstream forming rolls, the number of reserve roll sets was reduced to 1/5 the number with the conventional process, and, in addition, intermediate sizes for which rolls were not kept in stock can now be formed.

(3) Not only flexible use of the forming rolls, but also a number of other excellent results have been obtained in terms of sheet formability and weldability, which stand in a mutually contradictory relationship, and it has become possible to produce ERW high-grade stainless steel pipe with high product quality.

(4) In the CBR process, the acceptable fin pass reduction is wide, and it has become possible to reduce FP and SZ reduction. Further, the prevention of roll marks in forming without lubrication, suppression of wall thickness increases at the edges, and control of strip rolling have been achieved.

(5) The reduction of residual stress in the circumferential direction of pipe and the suppression of work-hardening of the material have been achieved, by which a production of the pipe with excellent mechanical properties has been possible.

(6) Expansion of the V-convergence angle, I-type butting of edges, and a reduction in variations in edge forming have been achieved, by which an increase in the range of acceptable welding conditions and improved weld quality have been obtained.

(7) New hardware of mill has been developed to realize high-accuracy roll setting, by which pipe production with total presetting of rolls has been possible.

Although the CBR forming process with the outstanding features mentioned above has been developed, it is considered that in the future, application of this forming process to carbon steel and expansion of the range of common use of the forming rolls should be studied; the authors therefore intend to continue their research and development efforts.

In conclusion, the authors would like to express their deep appreciation for the valuable advice on cage roll forming with the model mill given in the course of the model mill experiments by Professor Yoshitomi Onoda of Mechanical System Engineering, Technical Dept., Yamanashi University.

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