NIPPON STEEL TECHNICAL REPORT No. 90 July 2004

UDC 621 . 774 . 21

Outline of New Forming Equipment for Hikari 24” ERW Mill

Michitoshi TANIMOTO*1 Isamu KAWATA*2
Osamu SOTOKAWA*2 Tomohiro NAKAJI*1
Tetsuya MAGATANI*1 Eiji TSURU*3
Hiroyuki MIMURA*3 Masanori NAKAMURA*1

Abstract

Nippon Steel Hikari 24” ERW Mill had employed the cage roll forming mill for long time to get the advantage for producing thin-walled pipes and saving the time for roll-exchange. However, a new forming mill is desired for meeting the recent market needs, such as pipes with ultra-thin wall-thickness and/or high formability. We remodeled the forming process in 24” ERW Mill and got the planned results: stable manufacturing of ultra-thin-walled pipes, high dimensional accuracy and high forma bility of pipes, and saving the time for roll-exchange.

1. Introduction

Nippon Steel Corporation produces electric resistance welded (ERW) steel pipes 10.5 to 609.6 mm in outer diameter on 7 pipe production lines in total. The 24” mill (for an outer diameter up to 609.6 mm) of Medium Diameter ERW Pipe Plant, Hikari Pipe & Tube Division (hereinafter referred to as the Hikari 24” Mill), has a capacity for the largest outer-diameter among the lines, and produces mainly line-pipes. The mill was constructed in 1958 as a 14” mill (for an outer diameter up to 355.6 mm), and various revamps and new technologies have since been introduced to the mill to respond to changing market needs.

Requirements in the line-pipe market have tended to be ever-more sophisticated over the last years as seen typically with increasing demands for ultra-thin-wall pipes, high-deformability pipes and the like. In order to cope with such market demands, Nippon Steel determined that it was necessary to modify the forming equipment of the Hikari 24” Mill. Therefore, in the autumn of 2003, they installed new forming equipment as a major revamp of the mill.

This paper outlines the new forming equipment and its effects verified through actual production operation.

2. Market Requirements about Line-pipes

The principal requirements in the line-pipe market related to pipe forming methods are as follows:

(1) Increasing demands for large-diameter, thin-wall and high-strength steel pipes

High-pressure operation of a large-diameter pipeline is effective in enhancing the transportation efficiency of natural gas and the like. Increase in the strength of line-pipe products has been pursued for this reason[1)]. On the other hand, there has been a trend towards reducing material and welding costs in pipeline construction by decreasing the wall thickness of high-strength line-pipes.

(2) High strength and good deformability

Pipelines are often laid underground or under the ocean, and therefore, if the pipes are destructed locally by deformation due to causes such as seismic force, it will be very costly to repair the damaged portions. For this reason, line-pipes are required to have good resistance to local buckling, or high deformability[2)]. Yield ratio (yield strength (YS) / tensile strength (TS), hereinafter referred to as YR) is used as an indicator for simple evaluation of deformability, and a line-pipe product having a low YR is preferred. Generally speaking, the YR of a steel material tends to be higher as its strength increases. For this reason, it is not easy to cope with the increasing needs for high-strength line-pipes and, at the same time, satisfy the market requirement for a high-grade line-pipe having a low YR. The YR of a material steel sheet affects not only the properties of a product pipe but also the work hardening during the pipe forming process, and for this reason, a technology of pipe forming at a low strain is important for producing low-YR line-pipes.

*1 Pipe & Tube Division
*2 Environment & Process Technology Center
*3 Steel Research Laboratories

3. History of Remodeling of Hikari 24" Mill and New Forming Method

Fig. 1 shows the manufacturing processes of the Hikari 24" Mill. A flat steel strip is continuously formed into a tubular shape, the butt seam is welded, and after hydrostatic test, non-destructive inspection and so forth. Then, the ERW steel pipes are shipped as finished products. The material quality including chemical composition of the steel strip, the technologies of forming and welding and non-destructive inspection constitute the key technologies that determine the quality of an ERW steel pipe.

The equipment revamps in and introduction of new technologies to the Hikari 24" Mill[3,4] were focused on these key technologies in addition to the expansion of product size range, as seen in **Table 1**. The forming method of the mill, especially, was changed from the step roll forming method using contoured rolls to the cage roll forming method in 1984, and then to the flexible forming method (hereinafter referred to as the FF method) in 2003.

The characteristics of the old forming methods and the history leading to the introduction of the FF method are explained below.

3.1 Forming method with contoured rolls

The forming method with contoured rolls, which was the initial forming method of the Hikari 24" Mill, is a method of bending a steel strip stepwise into a tubular shape using contoured rolls. **Fig. 2** shows the configuration of the forming equipment of the mill after the expansion of maximum outer diameter to 24" in 1976. Since there were many forming stands and the contoured rolls mounted on these stands had to be changed every time the outer diameter or wall thickness of the product pipe was changed, there were problems such as a long time required for changing the rolls and adjusting their positions and a large space for storing a great number of these forming rolls. There was another problem in the forming of thin-wall steel pipes: spring back of the material steel strip often occurred, a large forming strain was imposed on it, the strip suffered work hardening, and all these resulted in an increase in the YR of a product pipe. In consideration of these problems, the forming method of the mill was changed in 1984 into the cage roll forming method, which is described in the following sub-section.

3.2 Cage roll forming method

The cage roll forming method, which was developed in the late 1960s for medium diameter steel pipes, is characterized by continuously forming a steel strip into a tubular shape using many small rolls, called cage rolls, arranged along the outer surface of the steel strip to be formed. The cage forming method introduced to the Hikari 24" Mill was the one where the intermediate forming section of the previously used step roll forming method was replaced with a cage roll section. **Fig. 3** shows the configuration of the forming equipment. The same 52 small rolls that constituted the cage forming section could be used for forming product pipes of any size, and as a result, roll changing time was significantly reduced[4]. On the occasion of the revamp of the forming equipment, the forming method in

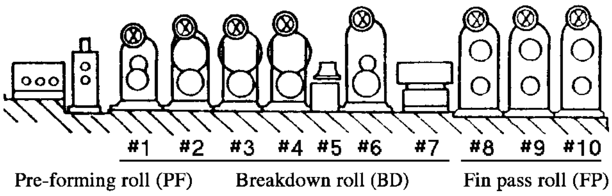


Fig. 2 Step roll forming mill of NSC Hikari 24" ERW mill in 1976[3)]

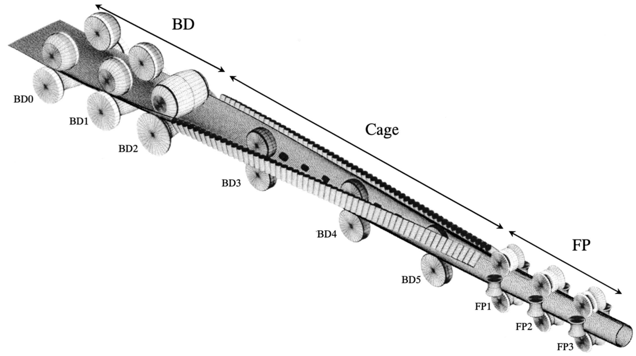


Fig. 3 The former forming mill (cage roll forming mill) of NSC Hikari 24" ERW mill

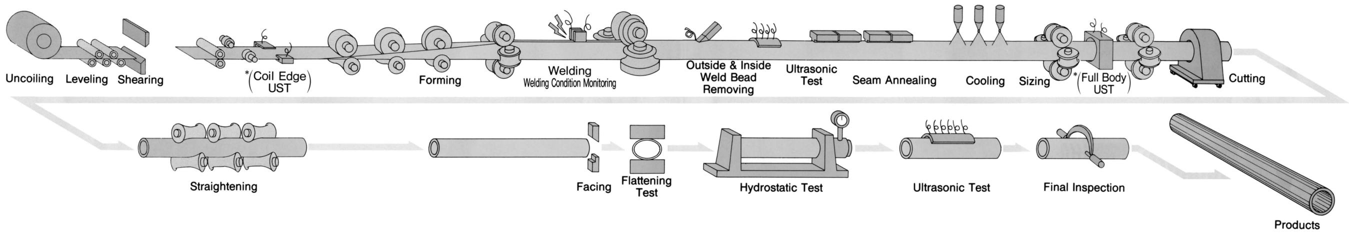


Fig. 1 Manufacturing process of NSC Hikari 24" electric-resistance-welded (ERW) pipe mill

Table 1 History of manufacturing facilities of NSC Hikari 24" ERW mill[3,4)]

Year	Forming	Size range		Welding	Non-destructive inspection	Others
		Outside diameter	Thickness			
1958	Step roll forming mill	14"(355.6mm)max.	0.5"(12.7mm)max.	Low frequency welder		
1960s		16"(406.4mm)max.		High frequency welder		Seam annealer
1970s		24"(609.6mm)max.	0.63"(16.0mm)max.		Seam UST, rotary UST	
1980s	Cage roll forming mill		0.75"(19.1mm)max.			Computer-aided quality control system Seam QT equipment
1990s			0.87"(22.0mm)max.	Replacement of welder	Replacement of seam UST, rotary UST	
2000s	Flexible forming mill					

Note: UST = Ultrasonic Tester, QT = Quenching and Tempering the initial forming stands was changed into the W bending method, and this, in combination with smooth forming by the cage rolls, reduced the strain at edge forming in the production of thin-wall pipes[4].

After the revamp of the forming equipment in 1984, while the above good effects were fully enjoyed, there still remained problems such as the roll change of the breakdown (BD) stands and the work hardening of the material due to the forming by rolling at the BD stands, which resulted in an increase in YR. Therefore, Nippon Steel judged that a further change of the method of forming was necessary in order to cope with the requirements of the line-pipe market flexibly, and began studying introduction of new forming equipment based on the FF method, which is described in the following subsection.

3.3 Flexible forming method and study of new forming equipment by the method

The FF method is the latest pipe forming method developed in Japan, and its characteristics are as follows[5,6]:

(1) Roll profile in involute curves that comprise all curvatures of product outer diameters

With this method, it is possible to form a steel strip to the curvature of any outer diameter within the product range by clamping the strip at the position of a roll, as shown in **Fig. 4**, the curvature at which is best suited for the outer diameter and wall thickness of the product pipe. As a result, no excessive deformation is imposed, and it is possible to form thin-wall pipes at a low strain.

(2) Mechanism for freely changing roll position setting

The roll support mechanism of forming stands is so designed as to allow a very wide freedom of roll positioning such as vertical shifting and axial tilting. Because of this mechanism, as seen in **Fig. 5**, pipes of different diameters can be formed by simply changing the positioning of the same set of rolls. Therefore, roll change is not necessary. The roll stands are designed to have enough strength to withstand the forming force.

(3) Numerical control system

Since the change of the positioning of the rolls is done automatically, the time for roll adjustment is short. In addition, the roll positioning of all the stands for forming a certain product size can be stored in the mill control computer as a complete package. Therefore, any past forming condition can be replicated instantaneously.

However, at the time of the study for the revamp, the FF method had been commercially applied to the production of pipes up to 16” in outer diameter. Thus, in applying the method to forming pipes as large as 24” in outer diameter, there were various technical difficulties to overcome. One of the principal difficulties was how to secure mill rigidity while enjoying the advantages of forming a wide range of product sizes by the flexible positioning of the variable rolls. The authors carried out the following studies to solve the problems.

Initially, stress at various portions of roll stands was analyzed employing the finite element method to identify the weakest portion in each of the stands, and a stand structure having sufficient rigidity as a whole was worked out for each forming stand by dispersing the reaction force. Then, the influence of low-strain forming over YR was also analyzed. A finite element analysis model was constructed for each of the rolls used in both the cage roll forming method according to Fig. 3 and the FF method according to **Fig. 6**, and the incremental strain at each of the forming rolls was calculated for a wide range of product sizes. **Fig. 7** shows an example of the analysis results with respect to the change of forming strain in the circumferential direction at a point of a pipe opposite (at 180˚ from) the welded seam. It is understood from the graph that, in the case of the FF method, the equivalent plastic strain is lower than that by the cage roll forming method by approximately 40%, and that the YS after pipe forming is lower. Since TS is the same in either of the forming methods, the YR by the new method is lower than that by the old method.

The introduction of new forming equipment by the FF method was decided on the basis of these analysis results.

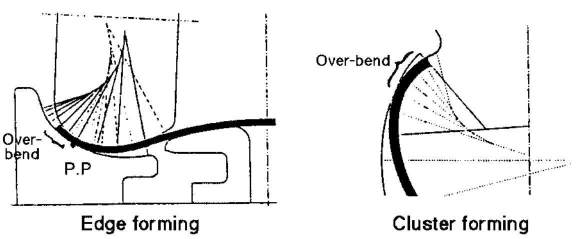


Fig. 4 Forming by rolls with involute profiles (PP: pinching point)

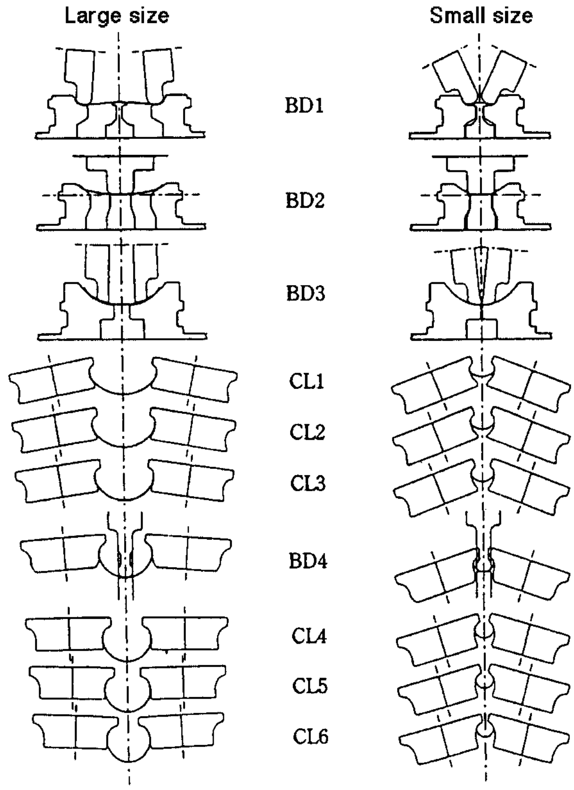


Fig. 5 A typical roll set of flexible forming mill[5] (CL: cluster roll)

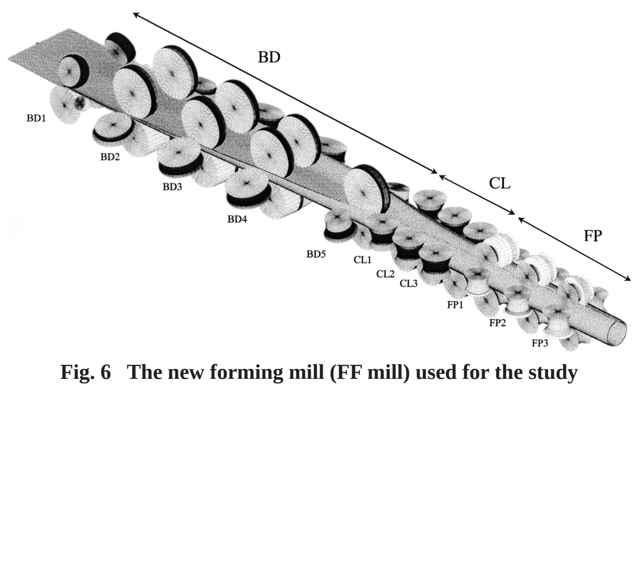
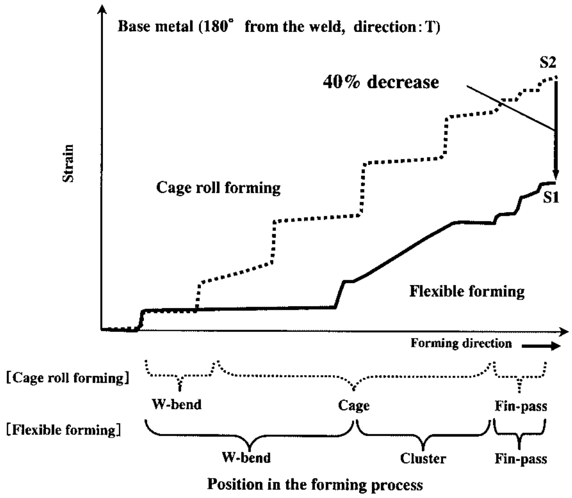
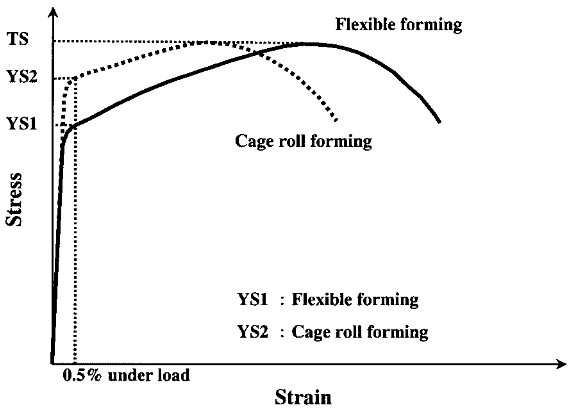


Fig. 6 The new forming mill (FF mill) used for the study



(a) Forming strain



(b) Yield strength

Fig. 7 Comparison of calculated forming strain and yield strength of pipes between the cage roll forming mill and the new forming mill

4. Effects of New Forming Equipment

Photo 1 shows the appearance of the new forming equipment installed in the Hikari 24” Mill.

Some examples of the advantages of the new forming equipment that have been verified through actual operation are explained below.

4.1 Stable production of thin-wall steel pipes

Photo 2 shows examples of steel pipes produced using the new forming equipment. The new equipment enables optimum forming of all the product sizes, and as a result, it has become possible to produce ultra-thin-wall steel pipes, such as the one in the left-hand side of Photo 2, having a t/D ratio (wall thickness divided by diameter) as low as 1.0%, which was difficult by conventional methods.

4.2 Improvement of dimensional accuracy

The new forming method enables to form steel pipes having a

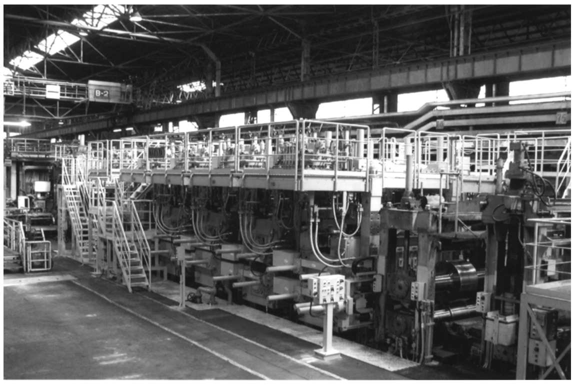
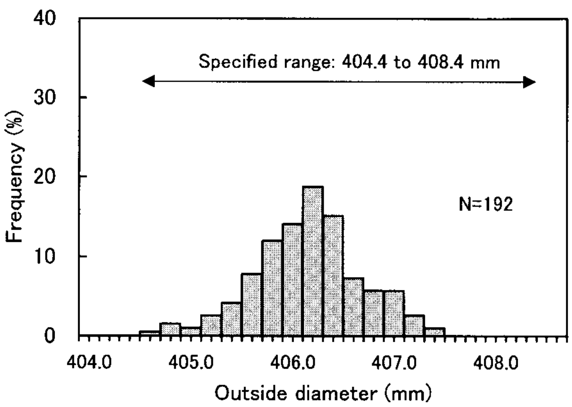


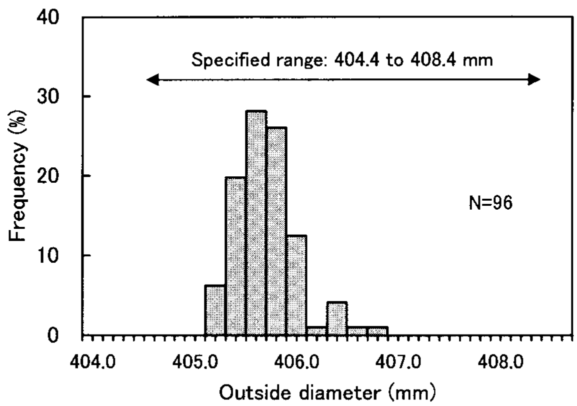
Photo 1 Appearance of the new forming mill

Left: 609.6mmϕ × 6.0mmt (24”ϕ × 0.24”t), t/D = 1.0%,
Right: 609.6mmϕ × 22.0mmt (24”ϕ × 0.87”t), t/D = 3.6%

Photo 2 Examples of pipes manufactured by using the new forming mill



(a) The former mill (cage roll forming mill)



(b) New forming mill (flexible forming mill)

Fig. 8 Examples of improvement in the distribution of outside diameter (406.4mmϕ × 16.0mmt (16”ϕ × 0.63”t))

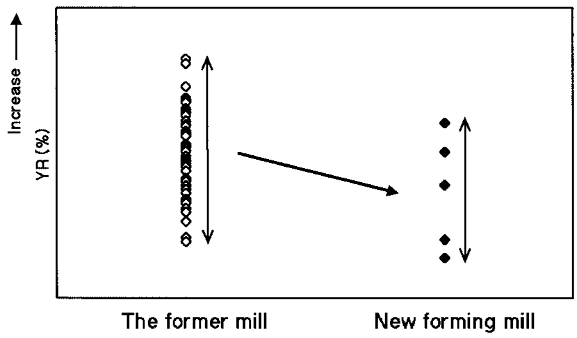
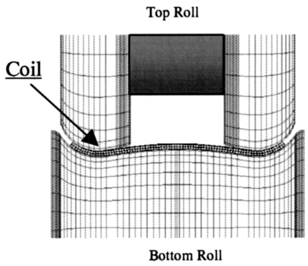
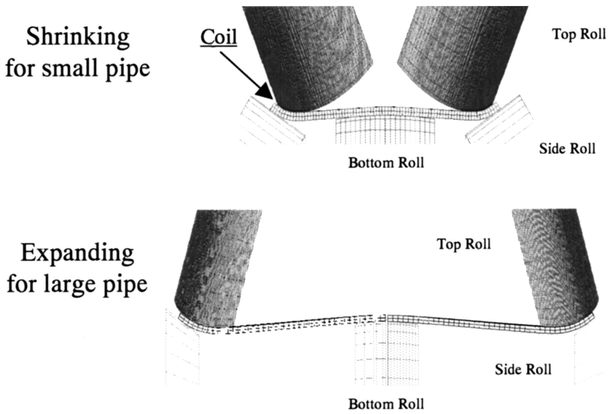


Fig. 9 Change in yield ratio of pipes by introducing the new forming mill



(a) Cage roll forming: fixed rolls



(b) Flexible forming: flexible rolls

Fig. 10 Comparison of the way of changing of breakdown roll size between the former mill and the new forming mill

wide range of wall thickness stably, and as a consequence, the dimensional accuracy of products has improved. As exemplified in **Fig. 8**, the dispersion of outer diameter has decreased. The new forming method is effective also in enhancing roundness.

4.3 High forming capacity

Fig. 9 shows the difference of YR before and after the introduction of the new forming equipment. It is clear from the graph that YR has lowered as a general trend.

4.4 Improvement in productivity

Fig. 10 shows the difference of size changing methods between the old and the new forming equipment. Whereas, at a product size change, all the rolls of BD0 to BD5 of the old equipment shown in Fig. 3 had to be changed, the rolls of BD1 to BD5 of the new equipment are variable rolls and thus none of the rolls of the BD stands have to be changed. As a result, the time it took for product size change has been markedly shortened and in addition, the number of rolls required for forming different product sizes has been drastically decreased.

5. Closing

In order to respond to the increasing demands in the line-pipe market for high-grand products, typically such as ultra-thin-wall pipes and high-deformability pipes, new forming equipment based on the flexible forming method has been introduced to the Hikari 24" Mill. The authors confirmed through commercial operation that the introduction of the new forming equipment brought about advantages such as stable production of thin-wall steel pipes, enhancement of the dimensional accuracy and deformability of product pipes and reduction of roll changing time as initially envisaged.

References

1) Kimura, F.: Piping Engineering. Extra Number, 19(2002)
2) Suzuki, N.: Piping Engineering. Extra Number, 43(2002)
3) Muramatsu, S. et al.: Seitetsu Kenkyu. (297), 94(1979)
4) Shibano, H. et al.: Proc. 3rd Int. Conf. on Steel Rolling. Tokyo, ISIJ, 1985, p.280
5) Nakata, T.: Journal of the Japan Society for Technology of Plasticity. 38(443), 1061(1997)
6) Kiuchi, M.: Journal of the Japan Society for Technology of Plasticity. 38(443), 1051(1997)