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Recent Activities in Research of Rolling Technologies

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For the purpose to improve the productivity and quality of high value added steel products, various rolling technologies such as sizing press, fully continuous finishing hot rolling, edge drop control, have been developed on the basis of rolling theory, elasticity and plasticity theory, tribology, numerical analyses including FEM in the last ten years. In this paper, the research activities of the rolling technologies are described. Representative technologies are as follows: (1) Hot strip rolling: schedule free rolling, tribological technology and new technologies in No. 3 hot strip mill in Chiba Works, (2) Cold strip rolling: development of K-WRS mill and its application to edge drop control, and improvement of surface brightness of stainless steel strip, (3) H-shape rolling: dimension control and cooling contorl and (4) Numerical analysis of rolling.

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1 Introduction

Technological development of rolling in the last decade has been aimed at the continuous, synchronized and automatic operation and the efficient production so as to reduce production cost and to control qualities of highly value-added products exhaustively. In this period, rapid progress in rolling technologies and their operations has been made with the newly applied systems, such as high-functional profile control, high-speed hydraulic reduction, and AC mill motors. Furthermore, with bright prospects for the 21st century, hot endless rolling technology was developed and applied to No. 3 hot strip mill in Chiba Works of Kawasaki Steel, here in Japan, and compact hot strip mills were consecutively constructed overseas.

In respect of rolling materials, especially thin steel strips for example, IF steel sheets and high strength steel sheets have become the major products. And the high accuracy in thickness, width and flatness and the surface quality in the rolling process have become the main issues.

Under such circumstances, in our research laboratory, we have been making numerous successful accomplishments related to hot and cold rolling of steel sheets and H-shape steels. Those have been based on the expertise such as rolling theory, elasticity and plasticity theory, tribology and numerical analyses including FEM. The outline of the R&D activities is shown in **Fig. 1**.

In hot rolling of steel sheets, we exerted ourselves to develop heavy width reduction technology with sizing press, crown and flatness control technology and work roll shifting control technology for schedule-free rolling in the late 1980's. In the 1990's, for the construction and the starting operation of No. 3 hot strip mill in Chiba Works, we focused on thickness, width, crown and flatness control technologies and comprehensive temperature control technology from finisher rolling through coiling (FDT, CT). Furthermore, we also concentrated on lubricated rolling over the full coil length in rougher and finisher mills for new products with improved surface quality.

In cold rolling, we have concentrated on high-quality and high-efficiency rolling of thin products and hard rolling materials. That is, edge-drop control technology with one-side tapered work roll shifting mills for electromagnetic steel sheets and tin plates in continuous rolling process, improred technologies for surface brightness in both reverse and tandem rolling, and so on. And then, we have got improvement in canoeing phenomenon of stainless steel sheets in bright annealing furnaces and in cross buckling and bowing of tin plates in finishing process. We analyzed these phenomena with elasto-plastic FEM.

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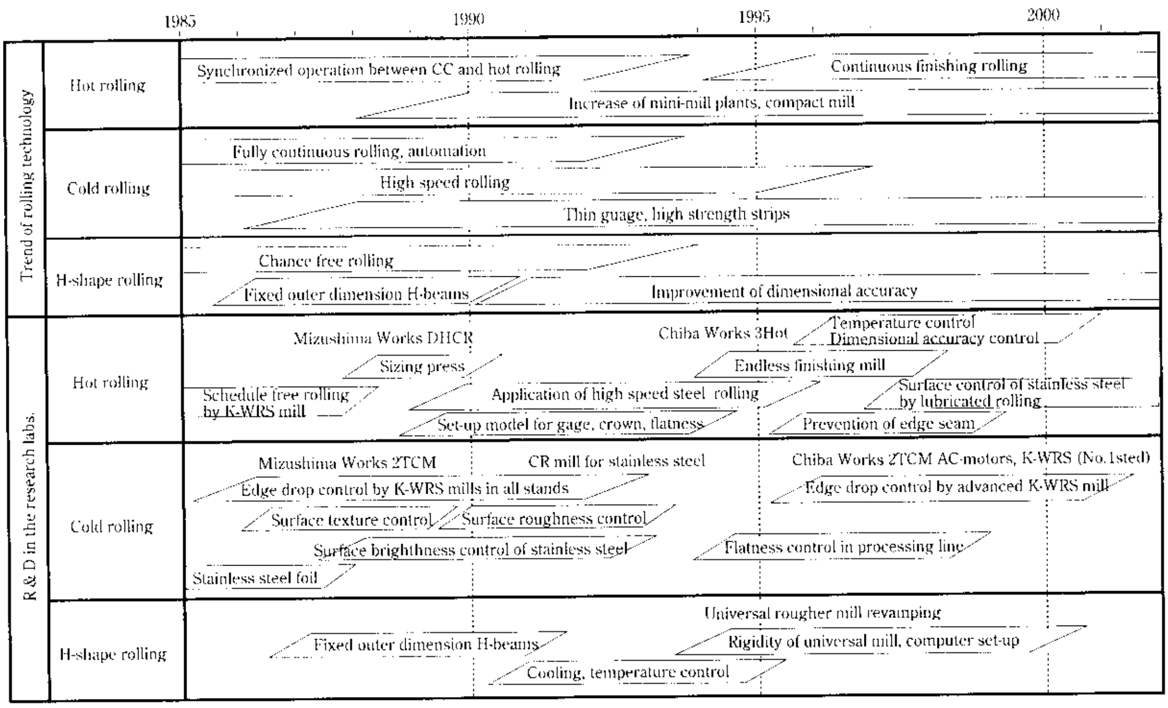


Fig. 1 Recent activities on steel rolling technology in the last ten years

In H-shape steel rolling, we have contributed to rolling technologies of fixed outer dimension H-shape steel with web inner width reduction method, dimension and temperature control technologies. In addition, we have inclined to develop universal mills and automatic set-up models for a new universal rougher mill in Mizushima Works.

These fruitful results of our R&D have brought us numerous awards from academies and institutions. And domestic and foreign rolling mill manufacturers have introduced our technologies, sizing press in hot rolling and K-WR shifting, in a large number of rolling processes.

2 Hot Rolling Technologies for Steel Sheets

2.1 Schedule Free Rolling Technology

In order to actualize synchronized operation of continuous caster and hot strip mill, it had been necessary to produce steel sheets with varieties in width from same slab width in rougher rolling as well as to make "wide out rolling" possible in finisher rolling. Our laboratory found out "sizing press", pressing slabs in width direction before rolling, was more efficient to produce varieties of width. Furthermore, we clarified the deformation mechanism in width when slabs are pressed in sizing press and in unsteady state, top and tail ends of slabs, for example. Then these researches established computerized automatic width control technology.[1] Besides, we developed cyclic shifting method in finisher rolling with K-WR shifting mills which diverges roll wearing and thermal crown. This technology made wide out rolling around 600 mm possible. Moreover, excellent accuracy in flatness and profile was obtained even in schedule free rolling by the newly developed set-up control model.[2]

2.2 Triboloby in Hot Strip Rolling

High-speed steel rolls (HSS roll) had been developed for good performance in wear resistance in hot rolling. But, the friction coefficient was higher with HSS rolls and scale defects remaining on strip surface were a grave issue. We quantified friction coefficient effect on strip surface temperature, and then, we found out that the defects can be prevented with lubricated hot rolling and optimal strip cooling. Accordingly we established the technology to use HSS rolls properly.[3]

On the other hand, heavy lubricated rolling had been impossible in conventional rougher and finisher rolling because of slip between a strip and rolls at the top of the strip. Heavy lubricated rolling technology over full length of coils was established with a proper lubricant and its optimal supplying method which can prevent galling defects without slippage. This technology has been contributing to improved surface quality of both mild steel sheets and stainless steel sheets, as well as newly developed material properties with the low friction coefficient in hot rolling.

2.3 New Technologies for No. 3 Hot Strip Mill in Chiba Works

At the construction of No. 3 hot strip mill, which

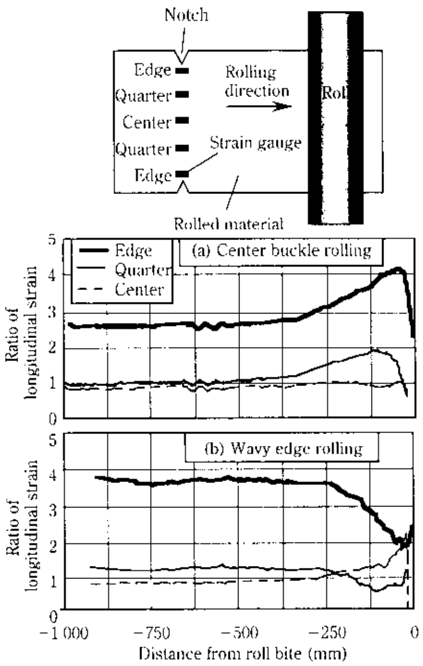


Fig. 2 Change of longitudinal strain in inlet zone

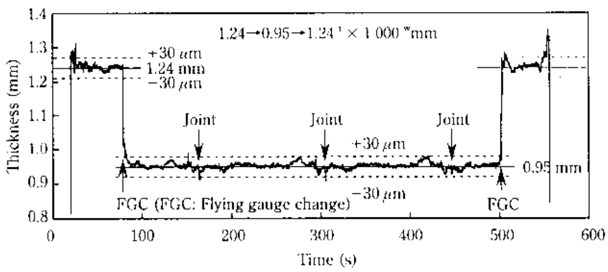


Fig. 3 Example of thickness accuracy of ultra-thin hot strip

would have a number of new and advanced functions as a hot strip production line in the 21st century, we developed numerous rolling and control technologies such as temperature and cooling control in finisher rolling mills, and on the run out table,[4] thickness, width, profile and flatness control[5] and so on.

The main feature in the mill is "endless rolling", in which sheet bars are welded between rougher and finisher rolling mills and supplied to the finisher mills unintermittingly. It can realize rolling with steady tension and heavy lubrication over full coil length. We had poured our efforts to threading technology in finishing mills, which can make finisher rolling possible without ruptures at joints, as well as thickness and flatness control technology.

We had feared ruptures at joints caused by edge cracks due to rolling. Therefore, we studied conditions for rolling and threading joints steadily by experimental rolling in a laboratory mill. As shown in **Fig. 2**, we

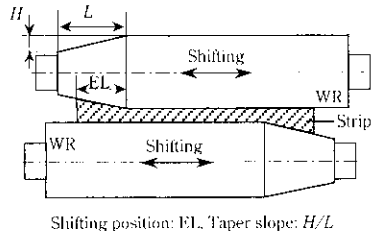


Fig. 4 K-WR shifting mill

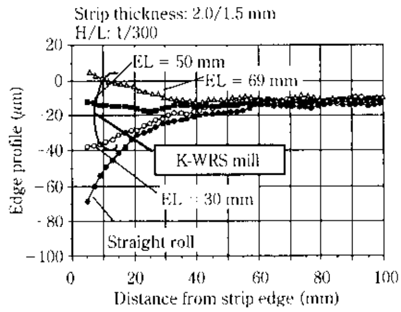


Fig. 5 Improvement of edge drop by K-WR shifting mill

found out that wavy edge rolling is effective to prevent propagation of cracks because longitudinal strain at edges near the roll bite is smaller than that of center buckle rolling. We established reliable finisher rolling technology of strip joints with clarifying limit tension against ruptures based on the findings above as well as applying high-response automatic thickness and tension control, flatness control at joints and so on.[5]

Endless hot rolling technology has made it possible to produce new advantageous products, such as ultra thin hot steel sheets, under 1.0 mm in thickness, thin and wide hot steel sheets, high tensile strength thin hot steel sheets, high formability steel sheets. One example of thickness charts of ultra thin hot steel sheets with 0.9 mm thickness is shown in **Fig. 3**.

3 Cold Rolling Technologies for Steel Sheets

3.1 Development of K-WR Shifting Mill

We had been developing strip crown and edge drop control technologies with K-WR shifting rolling in both hot and cold rolling.[6] The front view of K-WR shifting mill is shown in **Fig. 4**. The mill is featuring one-end tapered work rolls, which are shifted in the axial direction. In **Fig. 5**, the effect on reducing edge drop in a commercial mill is shown. In K-WR shifting mills, accurate and uniform thickness profile in width direction can be obtained with the optimal taper position shifted on strips. We have achieved high accuracy in thickness over full length and full width of strips with feedforward and feedback control technology.[7] And we have clarified deformation mechanism of reducing edge drop in K-WR shifting mill.[8] Moreover, we have developed advanced K-WR shifting mill in which WR shifting and crossing technologies are combined for further high performance. This technology is currently being tried to be applied for a commercial mill.

K-WR shifting technology have achieved numerous fruitful outcomes in No. 2 tandem cold mill in Mizusima Works[9] and in No. 2 tandem cold mill in Chiba Works,[10] as well as in a number of domestic and foreign rolling mills under our license introduced widely.

3.2 Technologies for Improving Surface Brightness on Stainless Steel Sheets

The important qualities of stainless steel strip are surface brightness, less defects, dimensional accuracy and flatness. We have engaged in technological developments; high efficient serial production in Chiba Works and higher quality of thin and BA products in Nishinomiya Works. Our laboratory has contributed to several important technologies mentioned below.

3.2.1 Brightness control technology

We found out that surface brightness of stainless steel sheet is dominantly affected by surface micro defects as well as clarified quantitative generation mechanism of each defect respectively.[11-14] These findings and countermeasures were applied effectively in facility specifications and operating conditions of annealing and pickling of hot strip, cold rolling, finisher annealing and pickling and skinpass rolling.

These technologies are being utilized in tandem cold rolling of stainless steel sheets for automobiles.

3.2.2 High reduction technology, and thickness and flatness control technology

We had applied cluster type rolling mill with 800 m/min-speed and 5 feet-width at its maximum to stainless steel rolling. At the operation, we drastically improved thickness accuracy with several thickness control technologies, that is, set-up control with the accurate estimation model for deformation resistance,[15] feedforward and BISRA automatic gauge controls and so on. Furthermore, accurate analytical model[16] and set up model[17] coded in our laboratory for complicated flatness control in 12-high and 20-high mills, which have numerous rolls, have contributed to achieve steady high speed rolling.

Moreover, we analyzed the buckling phenomenon called canoeing in bright annealing furnaces and established the countermeasure for the defects caused by canoeing.[16,18]

4 H-shape Steel Rolling Technology

In the field of shape steel rolling, we have concentrated on rolling and cooling technologies of H-shape steel with fixed outer dimension, preventing rolling and cooling buckle, for example. Conventional H-shape steel had fixed inner dimension of web because of the restricted horizontal roll width in universal mills. We made it possible to produce H-shape steel with fixed outer dimension by variable horizontal roll width in universal finisher mills, by which inner dimension of web can be shortened in universal finisher rolling shown in **Fig. 6**. This technology could be actualized only by the proper rolling conditions and the optimal cooling conditions in both rougher and finisher universal mills, studied in our laboratory to prevent web buckle and defects.[19,20] And, recently, the successful construction of new rougher universal mill in Mizushima Works was dominantly contributed by our specifications making, for which we had studied effects of mill rigidity and mechanical accuracy on product qualities.[21] Automatic set-up technology was also by our studies for calculation models of rolling load as well as mill and material deformation.[22]

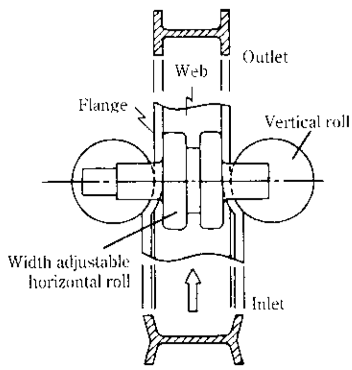


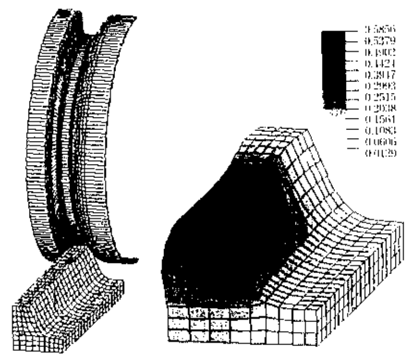
Fig. 6 Web inner height reducing rolling

5 Analytical Technologies

As capabilities of computers have been enhanced in recent years, 2D and 3D finite element method have become applicable to more practical and intricate problems. We have developed various FEM codes for detailed analyses of deformation, stress and strain in thin strip rolling, leveling and so on.

We applied 3D rigid-plastic FEM to those problems and issues: camber in thin strip rolling,[23] flatness defects in universal rolling of H-shape steel by stress-deformation analysis,[24] edge seam defects in sizing pressing and multi-pass rougher rolling by deformation behavior analysis of slab edges,[25] etc.

And elasto-plastic FEM were to those problems and technologies: stress and deformation analysis in breakdown rolling of H-shape steel (**Fig. 7**),[26] strip rolling analysis,[27] canoeing phenomenon of stainless steel strips in bright annealing furnaces,[28] optimal leveling



(a) Mesh system (b) Equivalent strain

Fig. 7 Analysis of break down rolling of H-beam by dynamic explicit elasto-plastic FEM

conditions of thin steel strips in tension and roller levelers by quantifying bending curvature,[29] etc.

6 Closing Remarks

The outline of our laboratory in the last decade was shown above. We have got numerous fruitful achievements in high-speed continuous processes with concentrating on progressive rolling technologies for uniform and high quality in dimensional accuracy, flatness, surface and mechanical property of rolled products, especially in cost efficient rolling. Particularly, the construction of No. 3 hot rolling mill in Chiba Works was the comprehensive compilation of our technologies cultivated so far. And we focused on and developed endless finisher rolling, automatic control in thickness, width, crown, flatness and temperature and surface quality control by lubricant rolling as the most important issues, together with colleague engineers in our steelworks.

Among various rolling technologies that are pursuing higher-speed, automated and shortened processes, we have stricter demand for technologies that can produce highly functional steel products uniformly and stably under severe conditions of high speed and heavy reduction rolling toward the 21st century. Furthermore, in the present globalizing social environment, it is strongly expected that we propose processing technologies from the user's point of view, as well as establish rolling technologies to produce moderate products to meet customer's demands.

So we must go back to our starting point of mechanical processing, that is a field of our expertise: (1) forming accurately in shape and dimension, (2) producing uniformly in properties, (3) producing finely in surface quality. We will challenge new subjects along with these points, not only for rolling technologies but for processing technologies from the standpoint of our rolling product users.

References

1) T. Hira, K. Isobe, H. Abe, H. Nikaido, T. Fujitu, and M. Duyama: *Kawasaki Steel Giho*, **21**(1989)3, 188
2) M. Kitahama, S. Onda, I. Yarita, and K. Narita: *J. Jpn. Soc. Technol. Plast.*, **33**(1992)383, 1386
3) H. Seki, T. Hiruta, M. Yamashita, T. Imae, K. Tominaga, and M. Koide: *CAMP-ISIJ*, **9**(1996)5, 972
4) N. Nakada, T. Hashimoto, and I. Maeda: Proc. 48th Jpn. Joint Conf. Technol. Plast., (1997), 293
5) T. Imae, N. Nomura, and S. Miyoshi: *Kawasaki Steel Giho*, **28**(1996)4, 219
6) K. Kitamura, I. Yarita, N. Suganuma, T. Nakanishi, and M. Toyoshima: *Kawasaki Steel Giho*, **23**(1991)4, 265
7) T. Hiruta, I. Akagi, and S. Mizushima: *Kawasaki Steel Giho*, **28**(1996)2, 103
8) J. Tateno, K. Kenmochi, I. Yarita, T. Kaneko, and T. Yamada: Proc. 48th Jpn. Joint Conf. Technol. Plast., (1997), 577
9) S. Mizukami, T. Ono, S. Kuroda, M. Shitomi, K. Hirohata, and K. Kitamura: *CAMP-ISIJ*, **2**(1989), 456
10) T. Reiba, H. Imai, T. Kaneko, T. Fukaya, J. Tateno, and K. Kenmochi: *CAMP-ISIJ*, **10**(1997), 1105
11) K. Kenmochi, I. Yarita, H. Abe, A. Fukuhara, T. Komatsu, H. Kaito, and A. Kishida: *Tetsu-to-Hagané*, **78**(1992)10, 1546
12) K. Kenmochi, I. Yarita, E. Kawasaki, K. Kobori, and H. Seino: *Tetsu-to-Hagané*, **81**(1995)8, 809
13) K. Kenmochi, I. Yarita, H. Abe, K. Kobori, M. Yoshioka, and H. Seino: *Tetsu-to-Hagané*, **83**(1997)8, 485
14) K. Kenmochi, I. Yarita, H. Abe, A. Fukuhara, T. Komatsu, and H. Kaito: *J. Materials Proc. Tech.*, **69**(1997), 106
15) Y. Hoshi, Y. Watanabe, K. Kenmochi, I. Yarita, H. Nagai, and E. Kawasumi: Proc. Jpn. Spring Conf. Technol. Plast., (1994), 9
16) Y. Watanabe, K. Kenmochi, H. Kano, A. Kamimaru, J. Yamada, and J. Yamamoto: Proc. 46th Jpn. Joint Conf. Technol. Plast., (1995), 309
17) H. Kano, Y. Watanabe, K. Kenmochi, A. Miyajima, A. Umetu, and A. Kamimaru: Proc. 46th Jpn. Joint Conf. Technol. Plast., (1995), 307
18) J. Tateno, M. Hoshino, Y. Watanabe, M. Saisu, K. Kenmochi, and T. Fukaya: Proc. 46th Jpn. Joint Conf. Technol. Plast., (1995), 321
19) H. Hayashi, I. Yarita, S. Saito, Y. Fujimoto, A. Kawamura, and K. Takebayashi: *Kawasaki Steel Giho*, **23**(1991)1, 16
20) H. Yoshida, N. Kondo, Y. Miura, T. Okui, T. Hashimoto, and M. Kawano: *Kawasaki Steel Giho*, **23**(1991)1, 23
21) R. Kojo, M. Kitahama, H. Yoshida, H. Hayashi, and K. Marui: Proc. Jpn. Spring Conf. Technol. Plast., (1997), 489
22) R. Kojo, M. Kitahama, H. Yoshida, I. Imae, and K. Hayashi: Proc. 48th Jpn. Joint Conf. Technol. Plast., (1997), 279
23) T. Iguchi and I. Yarita: Proc. 41th Jpn. Joint Conf. Technol. Plast., (1990), 75
24) T. Iguchi, H. Hayashi, and I. Yarita: *J. Jpn. Soc. Technol. Plast.*, **35**(1994)403, 959
25) T. Iguchi, M. Kitahama, and I. Yarita: Proc. 49th Jpn. Joint Conf. Technol. Plast., (1998), 21
26) T. Iguchi, D. R. J. Owen, and G. Q. Liu: Proc. 48th Jpn. Joint Conf. Technol. Plast., (1997), 63
27) I. Yarita and Y. Satou: *Advanced Tech. Plasticity*, **2**(1990), 613
28) Y. Watanabe, A. Kamimaru, and H. Kano: *Kawasaki Steel Giho*, **28**(1996)2, 119
29) H. Kano, K. Kenmochi, and I. Yarita: Proc. 48th Jpn. Joint Conf. Technol. Plast., (1997), 447