Recent Progresses of Rolling Technologies in Japan*

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I. Introduction

For the preface to this special issue on "Recent Progresses of Rolling Technologies”, the present author summarizes the recent progresses in Japan by reviewing the papers of Japanese authorship presented at the Second to the Fourth International Conferences on Steel Rolling, because the proceedings of each conference are comprehensive and available for easy reference in English.

The Second Conference was held in June, 1984 in Dusseldorf, F.R. Germany, on the subject of “the hot rolling of long products” and had the contributions of 15 papers from Japan. The Third Conference, held in September, 1985 in Tokyo, Japan, dealt with “technology of pipe and tube and their application” with the total of as much as 41 papers from Japan, the host country of the Conference. The Fourth Conference on “the science and technology of flat rolling” was held in June, 1987 in Deauville, France with 26 contributing papers from Japan.

For further references, the current progresses in rolling technology have been reviewed each year in the June issue of Journal of The Japan Society for Technology of Plasticity in Japanese.

II. Rolling of Shape, Rod, and Wire

Recent developments in the field of shape rolling are directed to the significant cost reduction through optimization of pass scheduling in rolling of H-beams and sheet piles. In the rolling of rods and wires, research and development are focused on the high dimensional control by the use of three roll mill or sizing mill and on the improved materials properties by thermo-mechanical processing in controlled rolling.

1. Shape Rolling Mill

In 1977, production of H-beams totally from continuously cast slabs was achieved in a structural shape mill. Subsequently in 1980, with the development of a new split rolling technique for large H-beams, the whole range of commercial size was satisfactorily produced without an intermediate reheating from continuously cast slabs. At the same time, another mill was successful to produce all of H-beams from continuously cast beam blanks and slabs.

Recent achievements to be remarked in the rolling technology of shapes include the production of small H-beams with a variety of sizes from blooms of a definite size by a combination of web width expansion and flange width reduction, the rolling of angles, channels, and piling in universal mill, the computer-aided design of grooves for rail and piling, and automatic scheduling of draft in universal rolling. Development of a reheating furnace for 9% Ni steel, a method for roll slitting of slabs, lubricants for section rolling should also be mentioned.

2. Wire Rod Rolling Mill

A wire rod mill, remodeled in 1981, is a continuous rolling mill with one strand for roughing and four strands for intermediate to finishing rolling and has a production capacity of 115 000 t/month for wire rods in the range of 5.5 to 16.0 mm in diameter. The rolling speed is 85 m/s at the finishing stand for wires of 5.5-mm diameter. The mill is capable to produce materials for tire cord besides the production of 20 000 t/month of wire rods for cold forging. Extensive reduction of man-power is attained to raise the efficiency of rolling from 2 to 3 t for a man in 1 hr. Application of hot charge also reduces the fuel consumption.

Development of thermo-mechanical processing by controlled rolling has achieved the production of high-quality wire rods without heat treatments of lead patenting, annealing, and quenching. A new cooling technique is also applied in the process.

Roundness of rolled bars can be accurately measured by development of a rotating type profile-meter; the accuracy is reported to be ±70 µm. Rolls for section rolling are improved in the resistance to both wear and failure by the use of nodular graphite cast iron. Energy saving in soaking for blooming is reported.

III. Rolling of Pipe

Recent advances in seamless pipe production are the development of a press roll piercer and a super rotary piercing mill as the novel rolling technology and a mandrel mill hydraulic screwdown control. New manufacturing methods of welded tubular products are a cage forming mill and a high temperature electric welding mill. High strength and toughness steels are produced for the materials of welded pipes by controlled rolling and accelerated cooling method.

1. Seamless Pipe Mill

In 1983, three seamless mills were constructed.

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The mill for a medium size of 9-5/8' diameter was designed for a surprisingly extensive man-power saving to be operated by 35 workers in a shift. Another new 7-5/8' mill was equipped with a press roll piercer which was employed in the previous 16' mill. The other mill for a smaller size of 5-1/2' applied a newly developed rotary piercing mill, which was characterized by the suppression of initiation and propagation of defects on inner surface through minimization of the rotary forging effects (Mannesmann effects) and the evolution of redundant shear deformation. The mechanism of Mannesmann piercing was theoretically analyzed.

Experimental studies on a mandrel mill include the analysis of rolling mechanism in a model five-stand mill and the formulation of rolling characteristics on the basis of model experiments, the end thinning control by hydraulic screwdown, and the introduction of observer regulation for controlling of the rotating speed of rolls. Stomach phenomenon was theoretically analyzed by the three-dimensional analysis.

The polygonization of inner surface of pipes in the stretch reducer was simulated by the rigid plastic finite element method. In hot extrusion of austenitic stainless steels, surface roughening or score marks that occurred exclusively on as-cast continuously cast round billets was shown to be prevented by the refinement of columnar grains with a combination of cold rolling and reheating prior to extrusion. For enhanced heating capacity and efficiency of induction furnaces for hot extrusion, an analysis was made on the variations of temperature distribution in billets with the frequency.

Papers on cold rolling and drawing of tubes dealt with the theoretical analysis for designing long-life tools in a pilger mill and the development of a drawing process with oil and pressurized oil lubrication. New techniques for quenching of a pipe from both external and internal surfaces by the rotation of pipe were reported.

As the finishing and inspection, the following reports were presented; development of an automatic straightening system based on the theoretical analysis of tube deformation in cross roll straightening, an automatic inspection system of seamless pipes, and a sealing technique for hydrostatic pipe tester.

New products of pipes include high alloy oil country tubular goods and low alloy pipes for super critical power plants.

2. Welded Pipe Mill

The developments in U-O-E process are a system for control and quality guarantee in the production of large-diameter pipes, and a method for reduction of the load in O-forming based on analysis of the effects of U-forming parameters on the O-pressed shape. Recent advances in electric resistance welding (ERW) process are the improvements in high frequency welder, the developments of roll forming techniques in particular for both extremely heavy and thin wall pipes of medium diameters, and the automated design system of optimal roll profiles for roll forming.

A review is available on the recent progresses and future prospects of manufacturing technology of welded pipes including UOE and ERW pipes.

Topics in the continuous butt welding (CW) mill were the world’s first introduction of hot ERW process by reconstructing an existing CW mill and the use of an edge heater for energy saving in continuous butt welding of pipes. Experiments on the production of thin wall pipes with tungsten inert gas (TIG) arc welding of 304 stainless steel were reported.

Extensive works were made to produce high strength and high toughness steel plates for line pipes by a combination of controlled rolling and accelerated cooling and further to enhance the resistance to hydrogen induced cracking and stress corrosion cracking. Development of as-rolled high strength plates for arctic-grade UOE pipes for induction bending should also be mentioned. In the production of high strength and high toughness line pipes and casing in ERW mills, sealing by argon gas and normalizing of seams were reported to be important.

IV. Rolling of Plate and Strip

Remodeling of rolling mills has been progressing to meet the continuing demands for sheets by the introduction of sophisticated techniques such as double chock bender, variable crown (VC) roll, work-roll shift mill, high crown (HC) mill, and pair cross mill. The rolling processes are integrated in such a way as direct rolling of continuously cast slabs without scheduling in hot rolling and direct linkage of pickling, tandem rolling, and continuous annealing in cold rolling process.

1. Plate Mill

Besides the conventional flatness and profile control, new systems were introduced for measuring the plate pattern and for controlling the camber with hydraulic automatic gage control (AGC) to produce plates without trimming. Schedule-free rolling has been achieved by the introduction of work-roll shifting. Improvement of flatness and reduction of deviations in plate thickness are attained through successful rolling at extremely low speeds under high rolling load by the use of thin roller bearings for back-up rolls. These new techniques allow the development of new products such as tapered plates, clad plates, thin hard products, and extremely heavy gage plates.

Thermo-mechanical control process (TMCP) has been established as an extension of controlled rolling and accelerated cooling. For effective application of the new process, an improved cooling equipment for hot strip mill, direct linkage of pickling, tandem rolling, and continuous annealing in cold rolling process.

2. Hot Strip Mill

Direct rolling of continuously cast slabs, hot direct
rolling (HDR), is a remarkable achievement for substantial reduction in fuel consumption by coupling of slab casting and hot rolling processes.\(^{80}\) The existing mills are remodeled to improve the crown of rolled strip by the strengthening of bender capacity and the adoption of VC rolls in F4 to F6 stands, work-roll shifts in F4 and F5 stands\(^{80}\) and by the introduction of pair cross mills in all stands.\(^{71}\) A newly designed mill with a maximum width of 70 inches is provided with work-roll shift mechanism in four high mills of F1 to F3, six high HC mills in F4 to F6 stands, and edge heaters at the entry of finishing stands.\(^{72}\) The mill allows rolling of thin gage strips below 2 mm and needs no separation in scheduling of rolling hard materials and low carbon steels. These mills can guarantee the maximum crown below 20 µm. Other topics were the dependence of shear deformation on lubrication,\(^{73}\) the correlation of recrystallization behavior with the redundant shear,\(^{74}\) surface cracking in hot rolling of a ferritic stainless steel,\(^{75}\) and surface cracking of high chromium cast iron rolls.\(^{76}\) Fish-tail formation in the top and bottom of strip was simulated on the basis of analysis for non-steady rolling with the finite element method.\(^{77}\)

3. Cold Strip Mill

A new system for improved flatness and reduced edge drop was achieved by the development of total control system and work-roll shift mechanism.\(^{79}\) Rolling characteristics of universal crown (UC) mill with small diameter work-rolls were formulated to develop an automatic profile control system.\(^{79}\) A combination of key-less type bearing, feed-forward AGC, interstand tension control, and digitized automatic speed regulation (ASR) lead successfully to high accuracy gage control.\(^{80}\) A numerical model was presented for the prediction of strip shape rolled in Sendzimir mill.\(^{81}\)

Integrated processing of cold rolling has been intensively attempted. Coupling of pickling and rolling was attained as a result of the development of efficient descaling with a combination of tension leveling and mechanical descaling, continuously variable trimming, and flying thickness change mechanism.\(^{82}\) Linkage of a tandem mill and a continuous annealing line was achieved by the introduction of DESCalers, automatic welder, and rapid roll change equipment.\(^{83}\) Remodeling into a fully continuous rolling mill was made by the introduction of a calculation model for high accuracy setting and a method for flying gage change.\(^{84}\)

Numerical studies were reported on the three-dimensional analysis of deformation in rolling such as the slab method, finite element method, energy method, and boundary element method: analysis of roll flattening by the boundary element method,\(^{85}\) prediction of material flow and friction hill in the transverse direction,\(^{86}\) prediction of strip profile in various rolling conditions,\(^{87}\) and mathematical modeling of asymmetrical rolling by the upper bound theorem.\(^{88}\)

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