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The Genesis of Product Making

Building Targeted Shapes into Steel Sheets

When straight piece of steel wire is slightly bent by an applied force, it will return to its original shape when the force is removed. This property is called “elasticity.” However, if force continues to be applied to the wire, it will not return to its original shape; instead, it will deform permanently when the force is removed. This property is called “plasticity.” Steel is worked and processed by making the best use of and exercising adequate control over these two properties.

This three-part series (issue nos. 313, 314 and 315) highlights both how to build targeted shapes into hot rolled steel sheets and today’s most advanced rolling technologies.

The first major hurdle in the plastic working of steel is hot rolling. On the surface, the technology for “rolling hard steel into thin sheets” seems simple enough. But hidden within is the technological challenge of building in targeted shapes, a task that Nippon Steel is tackling head-on by analyzing a range of dynamic phenomena and by finding ways to bridge difficulties. In this and the following issue, we will introduce mechanisms for realizing highly precise dimensions and shapes, i.e. reducing crown values, which is a major difficulty in hot rolling. Nippon Steel’s world-class technologies in this area will also be introduced.

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Steel processing occurs in two major stages. One is the manufacture of steel products at a steelworks. The types of processing carried out at this stage include “casting” whereby steel is cast into a mold of the desired shape, “forging” whereby steel ingots are forged into swords etc. and “extrusion” whereby red hot billets are passed through dies. Steel sheets, rails, pipe and tubes and some other steel products are generally produced by “rolling.” Steel products produced in this way are then delivered to secondary fabricators or end users where they are subjected to the second stage of processing. This stage includes a variety of processing methods, such as forming and stamping, whereby automobile components and other end products are manufactured.

“Rolling” operations can be divided into two types: hot and cold. Taking steel sheets as an example, reheated slabs that start out with a thickness of about 250 mm are reduced by hot rolling to an eventual minimum thickness of 1.2 mm by passing them between horizontal rolls. In cold rolling, the hot rolled steel strip is subjected to further rolling at room temperature to thicknesses of less than 1 mm in order to prepare it for use in beverage cans, etc. By spotlighting “hot rolling” which is the basis for the plastic working of steel, this issue will discuss the rolling mechanisms used primarily for the manufacture of steel sheets.
At present, a typical hot strip mill used for steel sheets consists of several stands of roughing mill train and six to seven stands of finishing mill train, all of which run in a straight line. Steel slabs that have been reheated to over 1,000 degrees C are then reduced by rolling to an eventual thickness of some 1.2 to 19 mm and elongated to an overall length of several km. The steel strip is cooled as it runs on the run out table and is wound at the terminal into a huge coil, much like a roll of toilet paper. At the final stand of the hot strip mill, the strip is traveling at more than 100 km/h (Fig. 1).

This process features a high concentration of advanced technologies and a wealth of know-how.

For example, with regard to the rolling and stretching of a solid, the underlying principle of hot rolling is similar to that of stretching flat well kneaded wheat dough with a rolling pin. The major difference between the two is hardness. Being soft, wheat dough can be stretched thin using a rolling pin made of wood or other rela-

Fig. 1 Hot Strip Mill (Continuous Hot Rolling Equipment)

Steel slabs that have been heated to over 1,000 degrees C are continuously rolled on a number of mills arranged in a straight line, reduced by these mills to a thickness of 1.2 to 19 mm and then wound into coils. At the last stand, the steel strip is traveling over 100 km/h.

Fig. 2 Difference between Steel and Wheat Dough

The underlying principle of hot rolling is akin to that of spreading wheat dough with a rolling pin. The major difference between the two is hardness. In the case of steel, the load acting on the rolls is nearly 2 tons per mm of the steel width.
tively hard material under a small load. When hot rolling steel strip, on the other hand, a load of nearly 2 tons per mm of the strip width is placed on the work rolls. Even when heated to 1,200 degrees C in a reheating furnace, steel is still hard. Assuming a steel strip 1 m in width, an unimaginable load of about 2,000 tons would occur.

This can cause the rolling mill rolls to deform (elastic deformation), resulting in unexpected phenomena. Basically, if the difference in hardness between the steel and the work rolls were as great as that between kneaded wheat dough and a rolling pin, the rolls would be neither bent nor dented. In reality, though, roll materials that far exceed steel in hardness do not exist (Fig. 2). As a result, the history of hot rolling technology has proved truly challenging. Throughout, higher degrees of precision in the thickness, width and flatness of products have been pursued by devising new rolling methods and analytically studying the shapes of roll deformation (Fig. 3).
Feature Story

Major Technical Theme: How to Reduce Crown Values to an Accuracy of 50 µ or Less

A major historical impediment to the effective rolling reduction of hard steel has been a phenomenon known as crown (deviations in the cross-wise thickness of strip). When rolls deform under heavy loads during rolling operations, the thickness of the rolled steel deviates subtly across the width of the strip, becoming greater at the center compared to the edges. This heavier center is known as crown. Seeking a means to reduce crown in steel strip and to eliminate deviations in thickness across strip width was a technological task in need of a breakthrough. More specifically, a major theme has been to reduce crown to a minimum and to produce sectional shapes with higher precision while building in targeted qualities.

Let us examine the mechanism of crown generation by taking 4-high rolling mills as an example (Fig. 4). Being basic rolling mills, they are widely adopted and they consist of a total of four rolls per stand, including top and bottom work rolls and their respective backup rolls. When the screwdown, or the amount of reduction per pass, of the rolls is increased to make the steel strip thinner, a larger load is generated. This not only causes the four rolls to bend due to elastic deformation but also causes greater thickness through the center of the strip than at the edges, depending on the configuration of the roll deformation.

In the case of 4-high mills, the resultant crown value is minimal 50 µ or less and is far thinner than a typical bank note. Yet, in instances where special application needs demand steel strip with crown values of exceptional precision, hot rolled steel strip is subjected to cold rolling for reduced thickness. This is true in the case of electrical steel strip that is widely used in the cores of motors and transformers and is wrapped in overlapping layers. If the crown value of the strip is excessive, gaps form between the overlaps, producing electrical equipment of poor efficiency.

![Fig. 4 Mechanism of Crown Generation](image-url)
Until the late 1960s, both edges of steel strip were cut off to reduce deviations in thickness across the width of the strip. But, since this tactic reduced product yields, the development of new rolling mills capable of reducing the generation of crown became imperative.

**Innovative Hot Rolling Methods Developed: HC Mill and Pair-cross Mill**

Nippon Steel’s battle with crown control began with improvements to the rolling mills. In 1974, the HC 6-high rolling mill made its appearance. Jointly developed by Nippon Steel and Hitachi Ltd., this mill places intermediate rolls between the backup and work rolls of a 4-high mill. Its innovation lies in the intermediate rolls, in that they are designed to adjust to the width of the strip by shifting laterally, thereby preventing the rolls from coming into direct contact with each other. This, in turn, made it possible to control deformation of the work rolls (Fig. 5). Shifting the intermediate rolls laterally so that they correspond to the width of the strip prevents the work rolls from deflecting, thereby making available steel strip with smaller crown values even when larger screwdown percentages are used.

The revolutionary HC mill controls deformation of the work rolls using intermediate rolls inserted between the backup and work rolls. Its advent has prevented strip edges from being reduced to extremely thin gauges.
Another new and revolutionary technology was the pair-cross mill that was introduced in 1984. This mill was jointly developed by Nippon Steel and Mitsubishi Heavy Industries, Ltd. with the top and bottom work rolls and backup rolls crossed in pairs at an offset angle of about one degree. This pair-cross design changes the gap between the top and bottom rolls across the width of the strip, thereby making available steel strip with minimum crown values (Fig. 6).

Nippon Steel has put these two innovative hot rolling technologies into practical use.

(The text has been prepared under the supervision of Executive Advisor Toshio Kikuma of Nippon Steel.)

Toshio Kikuma

He assumed the position of Fellow and Director of Process Technology Research Laboratories in 1995 and took the post of Executive Advisor in 2002. He has received major prizes in the field of technology development. Among these awards are:

1987: Okouchi Award (outstanding R&D achievement) for “Development of High-precision, Schedule-free Rolling Technology for Large-capacity Hot Rolling Mills”

1994: Director’s Award of the Science & Technology Agency for “Development of High-precision, Schedule-free Rolling Technology for Hot Rolling of Steel Sheets”

2001: Komura Award of the Iron and Steel Institute of Japan for “Development of Plastic Working Technology for Steel and Promotion of R&D on Iron and Steel Technologies”

2002: Purple Ribbon Medal (national award) for “Development of High-precision, High-efficiency Technologies for Hot Rolling of Steel Sheets”