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Development of Fixed Outer Dimension H-Shapes "Super HISLEND-H"

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1 Introduction

H-shape steel has a long history of architectural and structural application, and has been produced in Japan for about 30 years. Because of the ease of use offered by its parallel flanges and the cost effectiveness of its cross-sectional performance, this material is the most widely used of all shape steel products. Hot-rolled H-shapes are mass-produced by a universal mill rolling process, which makes it possible to produce compound shapes economically. On the other hand, the structural characteristics of this type of rolling mill and the productivity-related restrictions which roll-changing places on the product line give the universal mill process only limited application in the market for premium grade and special application products.

Users have long desired a more functional H-shape, and in recent years have turned to welded H-shapes as an alternative to the hot rolled product. On the producer side, most steelmakers have taken an incremental approach to improvement of the hot rolling process. In contrast, Kawasaki Steel adopted a radically new, comprehensive approach. As a result, the company has developed a technology for the production of "fixed outer dimension" H-shapes by hot rolling, something which was not possible with conventional techniques. The new product line is marketed under the trade name Super HISLEND-H.*1

The new technology is the result of approximately ten years of research and development and forms part of a chance-free rolling technology for shape steel products, which has been a major unfinished task for many years. Moreover, the new technology not only makes it possible to produce fixed outer dimension H-shapes, but has also given tremendous impetus to the development of process technology for shape steels in general.

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*1 HISLEND: High web, Structural, Light, Economical, New-Dimensional

The following is a background report on the development of a manufacturing technology for fixed outer dimension H-shapes. The history and philosophy of the project are discussed in the context of user requirements, and the features of the new product line are described in some detail.

2 Background of Development

2.1 History of H-Shape Rolling Techniques

Historically, H-shape steel were developed in response to building and construction industry needs for a flanged structural material with a web of minimal thickness. H-shapes have been produced and marketed in Europe and the United States since early in the 20th century, but full scale production in Japan dates from 1961, when the first universal mill H-shape shop went into operation. Since then, demand has expanded rapidly, since the outstanding functional and economic advantages of H-shapes offered a good solution to problems associated with the trend toward very large structures.

From the late 1960s through the 1970s, a succession on new plants was erected to meet the need for increased production capacity. With the aim of establishing mass production methods for H-shapes, techniques for partially or fully continuous operation of the universal mill were introduced, and progress was made in the development of instrumentation-based control technology. However, following the oil shock of 1979, Japanese steel mills shifted their focus from quantitative expansion to cost reduction, and concentrated their efforts on reducing unit energy costs, improving yield, and increasing productivity. In line with these new priorities, the steelmaking division, which supplies material for H-shape production, underwent a radical change from ingot casting to continuous casting, and for all practical purposes is now a fully continuous operation. In the rolling division, numerous new techniques were introduced. New H-shape techniques developed by Kawasaki Steel included the rolling of multiple H-shape sizes from a single beam blank size,[1] and the "slab-H" process for rolling shapes directly from slab.[2,3] These efforts have borne major results in improved yield, unit cost performance, and productivity, as well as in reduced inventory in process and shortened production periods.

Although makers responded flexibly to the shift from high economic growth, which required continually expanding production, to an era of cost-cutting, the philosophy of high-volume output of a limited number of goods remained fundamentally unchanged. Users naturally value the stable supply of inexpensive goods which mass production can provide, but dissatisfaction began to grow as the need for more diverse and sophisticated products became apparent in the early 1980s. For example, structural requirements became increasingly diverse as high-rise and broad-span construction increased, and improved performance was needed in building materials.

For H-shapes, this meant a larger size repertoire, which would allow more economical material selection, along with improved dimensional accuracy and fixed outer dimensions. Since the conventional rolling process was unable to respond fully to these requirements, welded H-shapes became the material of choice for many applications. More recently, however, market forces have focused renewed attention on rolled H-shapes, since the construction of steel and steel reinforced concrete structures has shown dramatic growth, and demand for building materials has increased accordingly. Welded H-shapes are a labor intensive product, and output is limited by the availability of skilled welders. During the 1980s, supplies of welded H-shapes failed to meet demand, resulting in delays in construction projects and increased prices, and users began to express a strong need for the development of a line of fixed outer dimension H-shape which could be produced in mass quantities, at low cost, and within short lead times by hot rolling.

2.2 Problems with Conventional H-Shape Rolling Techniques

H-shapes are generally manufactured by the process shown in **Fig. 1**. The universal rolling mill, as shown in **Fig. 2**, is an excellent rolling method for obtaining parallel flanges; H-shapes with differing plate thicknesses can also be produced easily by adjustment of the roll gap. However, in spite of the economic advantages of the universal rolling process, it also has the following funda-

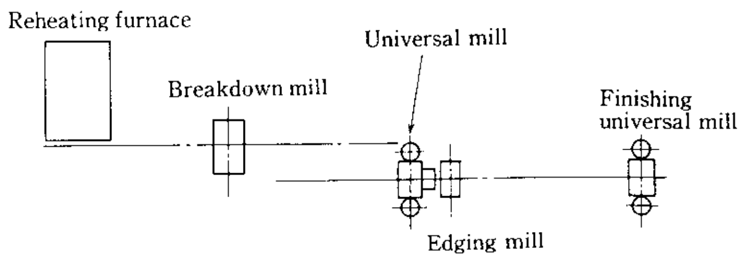


Fig. 1 Typical manufacturing process of H-shapes

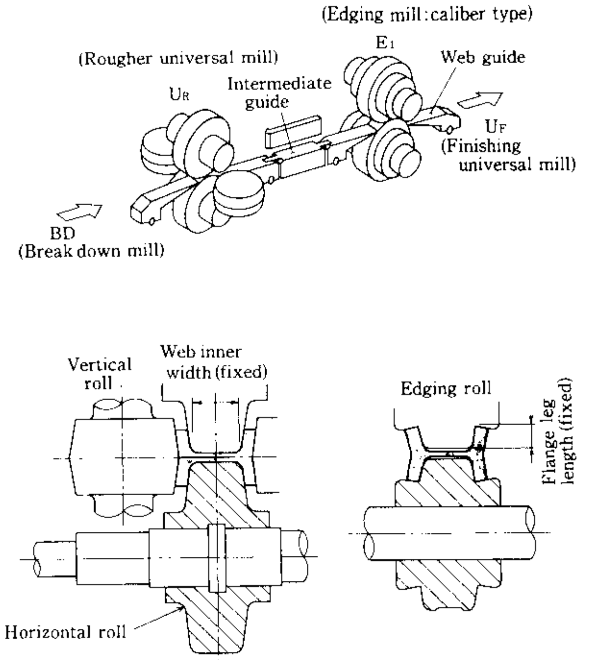


Fig. 2 Conventional rolling method for H-shapes by universal and edging mill

mental shortcomings, which limit the range and quality of products which can be produced efficiently with this type of mill.

2.2.1 Problems with producing fixed outer dimension H-shapes

As shown in Fig. 2, the web inner width dimension is determined by the width of the horizontal rolls, while the flange width and flange leg length are determined by the caliber depth of the edger rolls. In order to produce all sizes in the series with the same set of rolls, the inner dimensions (web inner width, flange leg length) must be fixed. However, flange and web thicknesses vary within the same series (nominal dimensions) of H-shapes, which means that the outer dimensions of the product will necessarily vary when the inner dimensions are fixed.

A comparison of H-shapes with fixed inner dimensions and fixed outer dimensions is shown in **Fig. 3**. Fixed outer dimensions cannot be obtained by universal rolling without changing the horizontal rolls and edger rolls for each desired size, with a negative impact on productivity, and hence on cost. Thus, for economic reasons, it has been considered impossible to produce fixed outer dimension H-shapes by universal mill rolling.

2.2.2 Problems with producing thin web H-shapes

Differences in the thickness of the flange and web, as well as the geometric relationship between the two, cause differences in temperature during rolling and cooling, resulting in tensile stress in the flange and compressive internal stress in the web. In thin web products, cooling is particularly fast; such products are susceptible to buckling. Web wave is thus a common problem, making thin-web H-shapes a particularly difficult product to manufacture, and material properties may also be affected by the drop in temperature. All these factors have made it impossible to manufacture thin web products to the quality levels required by users.

2.2.3 Limits of dimensional accuracy

In the universal mill, which gives the H-shape product its final shape, the material is not restrained in the flange width direction, which leads to variations in flange width dimensions and to off-centering. Variations also occur in web depth, since a certain amount of roll wear must be tolerated for reasons of economy.

2.3 Requirements for H-Shapes

With the exception of H-shapes, the standards for all shapes used in construction are based on outer dimensions. Actual design work is also based on outer dimen-

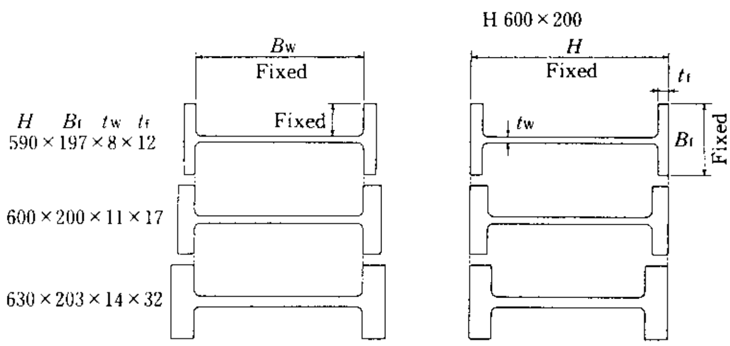


Fig. 3 Comparison of fixed inner and outer dimension H-shape

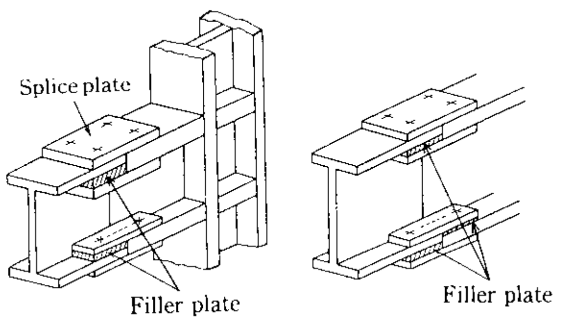


Fig. 4 Application of fixed inner and outer dimension H-shape

sional standards. Fixed outer dimension H-shapes have therefore been considered highly desirable since H-shapes first appeared on the market. Users of rolled H-shapes have also expressed other needs, but it should be noted that each of these problems has its origin in basic features of the conventional manufacturing process.[4] The main areas of user needs are listed below.

(1) Fixed outer dimensions in each product series
(2) Thin web products and increased flange thickness/web thickness ratios
(3) Greater number of sizes
(4) Improved dimensional accuracy

Kawasaki Steel made numerous technical improvements in response to these needs and in 1984 introduced HISLEND-H, an H-shape product for use in steel reinforced concrete construction (SRC-H). HISLEND-H was an improvement over existing H-shapes, and answered some of the requirements of users. The company continued to make improvements and expanded the product line from its original 48 sizes to 72 and then 158 sizes. On the other hand, HISLEND-H could not provide features comparable to those of welded H-shapes, which were winning a favorable reputation. In particular, HISLEND-H was a fixed inner dimension H-shape, since the technology developed to that point was still inadequate to produce fixed outer dimension H-shapes.

An example of structural connections with fixed inner and fixed outer dimension H-shapes is shown in **Fig. 4**. With fixed inner dimension H-shapes, several filler plates are generally required at bolted joints; finished dimensions are also nonuniform, which is a disadvantage from the viewpoint of work execution.

Similarly, it was not possible to achieve the required level of dimensional accuracy. When fitting up is based on the flange end, drilling may result in web misalignment. Conversely, if work is based on the web position, flanges may fail to meet properly. These and other problems remained to be solved in the development of an optimum line of rolled H-shapes.

3 Development of Fixed Outer Dimension H-Shapes

3.1 Features of New Product

The most important feature of the new line of H-shapes, which is called Super HISLEND-H, is that all outer dimensions are uniform within each series, as shown in Fig. 3. This solved one fundamental problem with conventional H-shapes, but the new line was also designed to meet several other user requirements. The main improvements incorporated into the product design concept are discussed below.

3.1.1 Fixed outer dimensions

Outer dimensions are fully fixed. In other words, within any series, the outer dimensions of the web depth and flange width are all uniform. Because of the simple, regular dimensions of the line (400, 450, . . .), the design and execution of structural column connections and girder joints are simple. The dimensions are also easy for designers and draftsmen to remember and enter into drawings.

3.1.2 Number of series and sizes

The number of series and sizes has been greatly increased. In addition, web thicknesses have been reduced and flange thickness/web thickness ratios increased to provide a more economic range of size choices.

The study of series and sizes was based on an analysis of actual design records, users' requests, and manufacturing restrictions. An example of the results of an investigation of size variations is shown in **Fig. 5**. The series breakdown includes web depths of 400-900 mm and flange widths of 150-300 mm, since the need for fixed outer dimensions was great in these ranges. The new products compete with the JIS (Japanese industrial

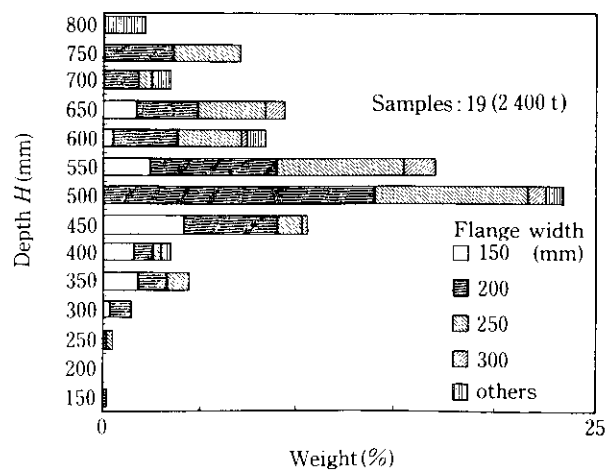


Fig. 5 Results of investigation for size variations (Welded H-shapes used for 19 buildings)

standard) H-shape series in some size ranges, but cover a different range from conventional fixed inner dimension H-shapes (**Fig. 6**).

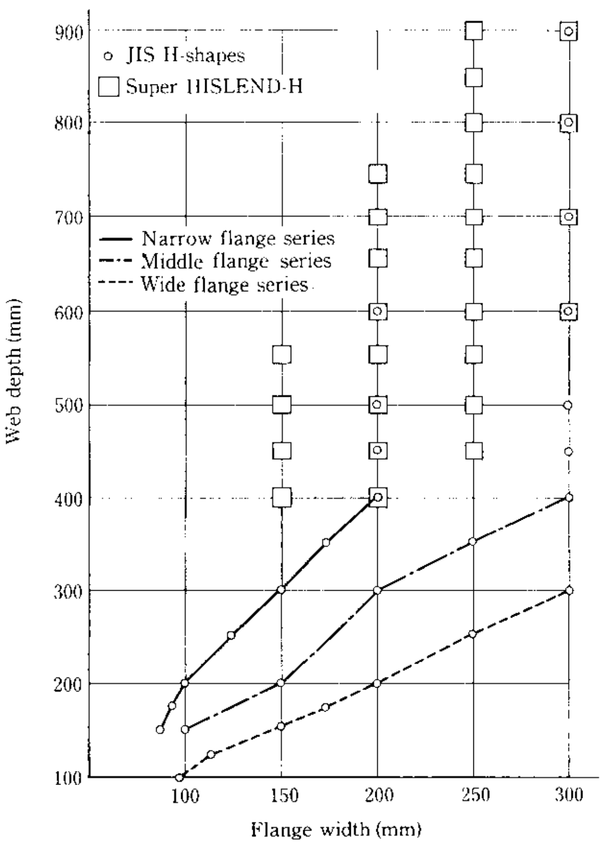


Fig. 6 Super HISLEND-H series in comparison with JIS H series

The size breakdown includes web thicknesses of 6-16 mm, which are commonly used. Flange thicknesses are designed at web thickness/flange thickness ratios of up to about 1:3 in consideration of shear resistance and bending resistance, providing a range which is considered adequate to cover virtually all needs. This size breakdown, as shown in **Fig. 7**, allows an economic choice of materials to meet users' cross-sectional efficiency requirements.

Plate thicknesses were selected to match the normal range of standard sizes used by designers (i.e. the plate sizes available on the market as stock items). The aim here was to ensure that the design and fabrication of plate items for fitting up with the H-shapes at connections and elsewhere would be convenient and the specifications easy to remember.

The commercially available sizes of Super HISLEND-H are shown in **Table 1**. The first-step sizes were offered when the line was originally marketed, and the second-step sizes were added thereafter in response to users' requests.

3.1.3 Corner radius

The corner radius at the intersection of the web and flange has been sharply reduced in Super HISLEND-H in comparison with that in conventional H-shapes, as shown in **Table 2**.

The corner radius section is not entirely without function, since it makes a contribution to cross-sectional efficiency which corresponds to its own cross-sectional area, but its presence requires some extra end work during joining and when seating washers. For these reasons and for better compatibility with welded H-shapes, users have requested that its size be minimized.

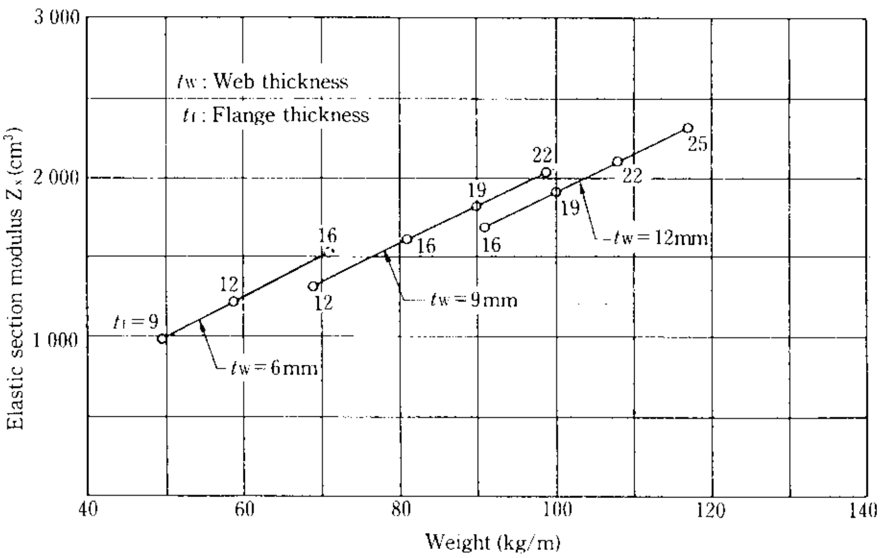


Fig. 7 Cross-sectional efficiency distribution of Super HISLEND-H shapes (example of H-450 × 200 series)

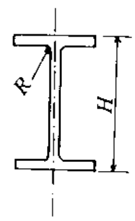
Table 1 Super HISLEND-H shape size availability

H	t_w \ t_f	150					200							250						300			
		9	12	16	19	22	9	12	16	19	22	25	28	12	16	19	22	25	28	19	22	25	28
400	6	○	○	○			●	●	○														
	9			○	○	○		●	●	●	●												
	12										●												
450	6	○	○	○			●	●	○					●									
	9			○	○	○		●	●	●	●			●	●	●	●						
	12								●	●	●	●					●	●	○				
500	6	○	○	○			○	○	○					○									
	9			○	○	○		●	●	●	○			●	●	●	○						
	12								●	●	●	●					●	●	○				
550	6	○	○	○			○	○	○					○									
	9			○	○	○		●	●	●	○			●	●	●	○						
	12								●	●	●	●					●	●	○				
600	6																						
	9							●	●	●	○				●	●				○			
	12								●	●	●	●	○			●	●	●	○	○	○	○	○
650	6																						
	9							●	●	●	○				●	●							
	12								●	●	●	●	○			●	●	●	○				
700	9							●	●	●	○				●	●				○			
	12										●	●	○			●	●	●		○	○		
	14																	●	●		○	○	○
750	9							●	●	○													
	12									●	●	●	○		●	●	●						
	14																●	●	●				
800	14																○	○			○		
	16																	○	○		○	○	○
850	14																○	○					
	16																	○	○				
900	16															○	○	○	○	○	○	○	○

● 1st step (95 size) ○ 2nd step (82 size) Total 177 size
B: Flange width t_w: Web thickness t_f: Flange thickness H: Depth (mm)

Table 2 Comparison of corner radius R (mm)

Shape \ H	400~550	600~750	800~900
Conventional H	16~20	22~28	28
Super HISLEND-H	12	15	18



3.1.4 Dimensional accuracy

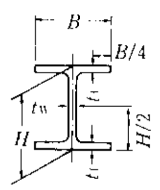
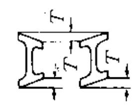
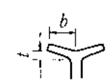
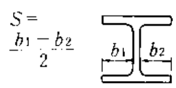
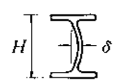
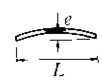
The dimensional accuracy of Super HISLEND-H fixed outer dimension H-shapes is designed to meet the requirements of both factory processing and on-site work. As can be seen from **Table 3**, the dimensional accuracy of Super HISLEND-H is significantly better than that of conventional H-shapes and compares favorably with the standards of the Architectural Institute of Japan (JASS). In certain respects, Super HISLEND-H actually outperforms the specifications of the JASS code.

3.2 Outline of Development of New Technology

The necessary techniques for the production of fixed outer dimension H-shapes are listed in **Fig. 8**. The new technology is a composite of numerous component techniques, none of which was available in conventional practice. Further, the techniques are all essential to achieving the goals of the product design and are interrelated in such a way that development in a single area would only emphasize the shortcomings of other tech-

Table 3 Improvements in dimensional accuracy of Super HISLEND-H shapes

(mm)

		Section nominal size	Permissible variation: JIS G-3192 (1990)	Permissible variation: JASS 6*	Permissible variation: Super HISLEND-H	
Flange width B		$100 \leq B < 200$ $200 \leq B$	±2.5 ±3.0	±2.5 ±3.0	±2.0 ±2.0	
Depth H		$H < 400$ $400 \leq H < 600$ $600 \leq H < 800$ $800 \leq H$	±2.0 ±3.0 ±4.0 —	±2.0 ±H/200 ±H/200 ±4.0	±2.0 ±2.0 ±2.0 —	
Thickness	t_f	$t_f < 16$ $16 \leq t_f < 25$ $25 \leq t_f < 40$ $40 \leq t_f$	±1.0 ±1.5 ±1.7 ±2.0	— — — —	±1.0 ±1.5 ±1.7 —	
	t_w	$t_w < 16$ $16 \leq t_w < 25$ $25 \leq t_w < 40$ $40 \leq t_w$	±0.7 ±1.0 ±1.5 ±2.0	— — — —	±0.7 ±1.0 ±1.5 —	
Flange out-of-square	T		$H \leq 300$ $T \leq B/100$ but $T_{min} = 1.5$ $H > 300$ $T \leq 1.2 \times B/100$ but $T_{min} = 1.5$	$T \leq B/100$ and $T \leq 3.0$	$B \leq 200$ $T \leq B/100$ $B > 200$ $T \leq 2.0$	
	t		—	$t \leq b/100$ and $t \leq 1.5$	$t \leq b/100$	
Web offcenter S			$H \leq 300$ $B \leq 200$ ±2.5 $H > 300$ $B > 200$ ±3.5	±2.0	±2.0	
Web deformation δ			$H < 400$ 2.0 $400 \leq H < 600$ 2.5 $H \geq 600$ 3.0	$\delta \leq H/150$	$H < 600$ $\delta \leq 2.0$ $H \geq 600$ $\delta \leq 3.0$	
Camber and sweep e			$H \leq 300$ $e \leq 0.15 \times L/100$ $H > 300$ $e \leq 0.1 \times L/100$	$e \leq L/1\,000$ and $e \leq 10$	$e \leq L/1\,000$ (Local $e \leq L/1\,500$)	

*Standard by Architectural Institute of Japan

niques.

While the whole process can be viewed as a single technology, it also forms part of a more comprehensive chance-free rolling technology for H-shapes. Generally speaking, the manufcture of H-shapes by the universal mill technique is a process in which form is given to material by roll calibers, and it is therefore necessary to change the rolls for each size. Universal rolling of H-shapes is an outstanding technology in as much as it is possible to adjust plate thickness efficiently, but it is fundamentally a type of caliber rolling.

The roll changing operation, the preparations required for the roll change, and equipment downtime during the exchange have a serious negative effect on productivity and unit energy consumption, and place serious restrictions on products and delivery. The development of a chance-free technology which would solve these problems has therefore been an important task for shape steel technology for many years. In a broad sense, it is no exaggeration to say that many of the techniques developed in the past are related to this goal. For example, the previously mentioned "slab-H" process is a chance-free technique for the use of materials. The process is not directly related to fixed outer dimension technology, but the local rolling technique developed as part of slab-H rolling was the starting point for the development of a technique for control of the web depth.[5)]

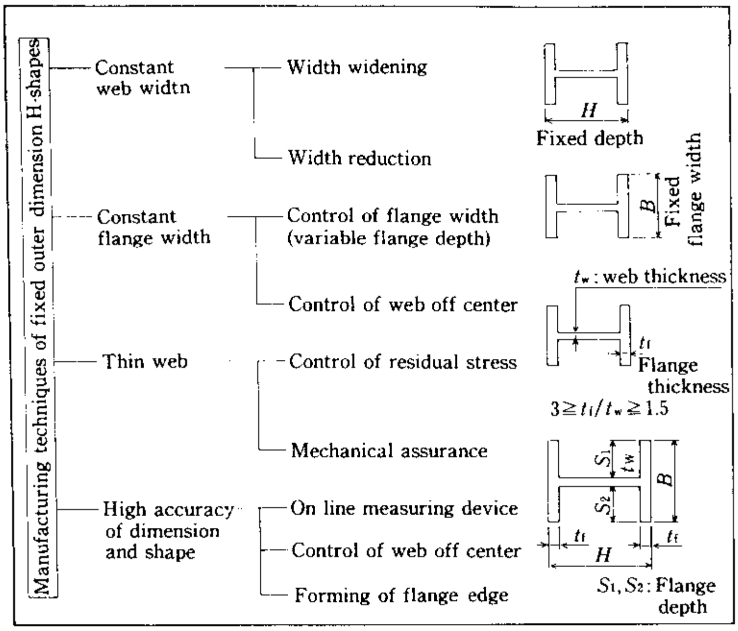


Fig. 8 Technical subject of rolling process in fixed outer dimension H-shapes

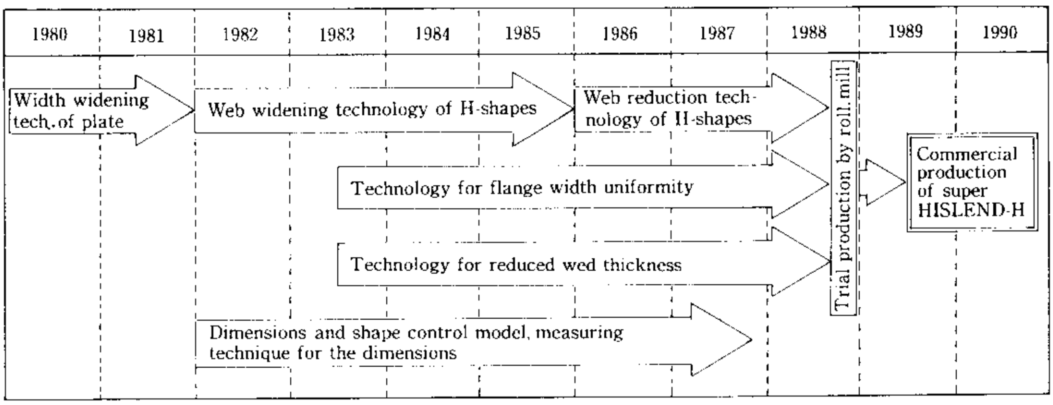


Fig. 9 Progress of technical development at Kawasaki Steel

Thus, in establishing the technical targets for a fixed outer dimension H-shape technology, the necessary techniques were consolidated and then developed as a total technology. The development process is summarized in **Fig. 9**. The individual techniques listed in the figure each contributes to the realization of chance-free H-shape rolling.

The above has been a brief discussion of the philosophy which guided the development of this technology. The actual techniques have been reported in more detail elsewhere.[6-8] Examples of Super HISLEND-H are shown in **Photo 1**.

4 Conclusions

Hot-rolled fixed outer dimension H-shapes have long been desired, but production was not possible with existing manufacturing techniques. However, as the result of a ten year research and development effort, Kawasaki Steel has succeeded in commereializing a product line of fixed outer dimension H-shapes which is marketed under the name.

The most significant feature of Super HISLEND-H is that all outer dimensions are uniform within each size series. With a range of web depths of 400-900 mm and web thicknesses of 6-16 mm, a wide variety of sizes is available, allowing the optimum choice of materials for design economy. Super HISLEND-H also festures small corner radii and outstanding dimensional accuracy. This

Photo 1 Examples of super HISLEND-H

product line thus solves a number of problems presented by conventional fixed inner dimension H-shapes. Because it offers both economic advantages and the reliable product quality associated with rolled H-shapes, Super HISLEND-H has won an excellent reputation with users.

The new production technology is based on chance-free rolling techniques for H-shapes. Thus, the new technology not only makes it possible to produce fixed outer dimension H-shapes by hot rolling, but has also made a major contribution to the rationalization of the manufacturing process. From the viewpoint of chance-free operation, however, a number of development tasks remain, and new and more sophisticated problems are likely to arise. This is, of course, a natural outcome of any development effort which sets progressively higher technical goals for itself, but through ongoing research and development and the application of new technology to the development and improvement of products, the authors hope to continue to satisfy the requirements of users.

Note: Super HISLEND-H was awarded the 1989 Award for Creative Excellence in Products and Services by the Nikkei Industrial Daily (Nihon Keizai Shinbun Inc.), and the 1990 Okochi Memorial Grand Technology Prize for new technology.

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