Technical Challenges for the Japanese Steel Industry*

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Key words: steel industry; research and development; productivity; energy conservation; labor saving automation; application for new fields; ironmaking; steelmaking; rolling; steel quality; technical task; Japan.

Being named a recipient of the "G. Watanabe Medal" is both a great honor and a major challenge. On this occasion, I have been requested by the Iron and Steel Institute of Japan to present some observations regarding the technological challenges facing the Japanese steel industry. I chose this subject because I firmly believe that technological progress is the key to resolving the difficult circumstances in which we find ourselves.

I. Looking Back on the History of the Japanese Steel Industry

As Japan's mainstay industry, steel has expanded continuously since the Second World War with technological development as its central strategy. Development has been concentrated on large-scale capital investments in coastal steel works; swift introduction, improvement and development of equipment technology, including converters, strip mills and the like; and technical development centered around the scaling up and speeding up of equipment. During the post-war period, which was characterized by mass production and mass consumption, Japan, which can boast of having the world's most advanced production technology, came to lead the industry worldwide in both cost and quality. Steel, in this way, has contributed to the development of Japanese industry as a whole.

Now that we are in a period of flat economic growth, of escalating energy costs, and of slower growth in demand following the oil crises, we have coped with these changes by technological innovation in the areas of energy conservation and yield improvement in various processes, as well as the information processing techniques required to support such technology.

Figure 1 shows changes in average yield of finished steels, and Fig. 2 the unit consumption of energy per ton of crude steel. The yield of finished steels rose 8% between 1975, shortly after the first oil crisis, and 1985. In energy unit consumption, on the other hand, savings of approximately one million kcal/t of steel, or 19.5%, have been attained.

Figure 3 shows changes in the number of business computers and process computers in the steel industry. The adoption of computers has greatly contributed to manpower reduction, process control, and automation in general.

The industrial structure in Japan, however, has now reached a stage where increased technical sophistication is required, because the demand structure encompassing the steel industry has also been undergoing a transformation.

Furthermore, the rapid, drastic appreciation of the yen in recent years has accelerated these trends, leading to an even more urgent need for measures to further improve both quality and cost.

In these adverse circumstances, improvement and innovation in production processes and technologies are imperative, so that the steel industry can reduce production costs by thoroughgoing rationalization and improved productivity, and manufacture products of a level of sophistication and functional performance which meet the needs of Japanese industry.

II. What Should Be Done from the Technological Viewpoint?

The technological developments achieved by the post-war steel industry were motivated by the need to supply customers with a great many useful, low-cost products through fully utilizing such resources as raw materials, energy and manpower. To that end, efforts were concentrated on the following areas:

- Improved production efficiency
- Energy conservation and yield improvement

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However, Japan has now reached the point where it must transform its export-oriented industrial structure, so the steel industry must make the following changes:

i) Conversion from labor-intensive to knowledge-intensive work. In other words, drastic reductions in manpower and the introduction of fully automated facilities.

ii) Implementation of measures for further energy conservation, and greater utilization of undeveloped and unused material resources.

iii) Development of steel products which will extensively contribute to the progress of society in general, including products answering the needs of technically innovative industries such as new energy resources and the exploitation of the sea and space.

To make these changes, steelmaking technology must seek the following goals.

i) Development of processes for the long-term realization of new manufacturing techniques. As an intermediate goal, various projects associated with higher productivity of existing equipment, such as techniques for prolonging its useful life and allowing inexpensive, short-term repair work.

ii) Thorough energy conservation measures (i.e., not merely energy conservation according to price differentials, but an overall reduction in consumption), and the efficient utilization of hitherto undeveloped and unused resources.

iii) Promotion of the development of end-products with enhanced utility, products which will respond to:

(a) Technical innovation by the users,
(b) Changes in social environment, and
(c) Functional and economical requirements of the material per se.

At this point I would like to consider the major challenges and opportunities facing the various areas of steel production.

1. Ironmaking Technology

Since the oil crises, ironmaking technology has undergone a transformation from quantity-oriented technology to cost- and quality-oriented technology. Major technologies which have been developed during this period include:

(a) Energy saving technology
Coke dry quenching (CDQ), top gas energy recovery turbines (TRT), and the recovery of hot stove exhaust heat and sensible heat from sinters

(b) Low priced fuel consumption technology
Formed-coal mixed charging method, pulverized coal injection, and all-coke blast furnace (BF) operation

(c) Stabilized operation of the BF
Development of sensors and mathematical models, operation control systems, and burden distribution control

(d) Low-silicon ironmaking technology
Low-silicon operation and cold house desiliconization

It appears that the blast furnace process has reached technical maturity; nevertheless, it should be noted that further cost reductions in the current processes are still needed. From the viewpoint of making fundamental process changes, it is now necessary to proceed with the long-term development of an entirely new ironmaking technology.

Figure 4 summarizes tasks requiring future study. I would like to touch on these briefly:

1. Pushing the Current BF Process to Its Ultimate Limit
First, subjects relating to raw materials and fuel
include the use of non-coking coal and pulverized ore. A high mixing ratio of non-coking coal in coke ovens, use of formed coke in BFs, and a high mixing ratio of pellet feed ore in sinter production will shortly become practical techniques, while high-ratio injection of pulverized coal, and the injection of pulverized ore in BFs will be taken up as promising study items.

Second, a number of specific energy-saving-related measures have been implemented to date. However, the most important task remaining is the recovery of sensible heat from BF slag.

Lastly, ideas that relate to the BF process include:
1) Lowering the silicon content of hot metal to 0.1%, down from the 0.2% of present low silicon operation, and the development of techniques for continuous hot metal pretreatment at the cast house; and
2) Development and adoption of operation control systems using artificial intelligence (AI).

It will become necessary to improve the life prognosis techniques of large-sized BFs and develop intermediate repair techniques to extend average service life from the current 11 to 15 years.

2. Development of a New Ironmaking Process (Smelting Reduction Process)

The smelting reduction process, a truly revolutionary process in ironmaking, has been widely discussed in recent years. The features of the smelting reduction process contrast greatly with those of the conventional BF, and can be described as follows:

(a) Raw materials and fuel
- Pulverized ore can be used directly.
- Coal and low-strength coke can be used.

(b) Energy
- Overall energy consumption is lower.

(c) Equipment costs
- Coke ovens and sinter plants are eliminated, reducing overall equipment costs.

(d) Economies of scale
- Even small-scale operations are economically feasible.

No process combining all these advantages has yet been developed, however, the commercialization of a relatively easily developed process incorporating some of these features is likely. Table 1 shows principal smelting reduction techniques now under development. All these processes leave many problems to be
resolved before commercial use is possible, but considering equipment refurbishing costs and the production capacity of the BF, it is likely that the BF process will coexist with the smelting reduction process in the future.

2. Steelmaking Technology

Since the oil crises, steelmaking technology has concentrated on raising the continuous casting ratio, improving productivity, and developing steel purification techniques in the hot metal pretreatment, combined blowing, and secondary refining stages of the steelmaking process.

Figure 5 shows trends in the continuous casting ratios among major countries. The high continuous casting ratio in Japan, exceeding 90%, has played a conspicuous role in reducing the consumption of both resources and energy.

On the other hand, the development of hot metal pretreatment and ladle refining has contributed greatly to meeting the demands for higher quality and process rationalization.

I would now like to make some observations on technical challenges facing the industry in the area of steelmaking.

1. Changes in the Steelmaking Process

(a) In refining, pretreatment such as dephosphorization and desulfurization of hot metal, and ladle refining following tapping from the converter, have been developed to a level where C, S, P, O, and N contents can be controlled to within a few parts per million. This has contributed to enhanced steel properties, as seen, for example, in marine structures with improved ductility for low-temperature service, and line pipe steels with good resistance to hydrogen-induced cracking. Figure 6 shows a process flowchart for high-grade steel refining. It is fair to say that with the use of optional hot metal pretreatment and ladle refining processes, an adequate purification technology has, for the time being, been established. This implies a functional division of the stages in the steelmaking process, with specific requirements placed on each stage. Steelmaking, however, is a struggle against temperature, that is, a struggle against time. Therefore it is desirable that these presently separated functions should be integrated, by simultaneously...
carrying out heating and desulphurization during degassing treatment.

(b) A common example of the continuous linking and integration of processes is seen in continuous casting (CC) technology. Figure 7 shows the progress of continuous linking and integration in the solidification process. At present, process linkage has been brought as far as the CC-DR stage (III). A feasible future goal is the development of a horizontal slab CC machine. This would reduce equipment investment costs, and bring us closer to the near-net-shape CC shown in stages IV to VI of Fig. 7. For instance, with a thin slab CC machine, reheating furnaces and roughing mills can be eliminated, and a predicted 40% reduction in energy consumption compared with that of the CC-DR, can be achieved.

2. Utilization of Inexpensive Main and Auxiliary Raw Materials

(a) To further reduce steelmaking costs, technical developments which permit the use of less expensive main and auxiliary raw materials will be necessary. A recovery method that offers a high yield of Mn in Mn ore and Cr in Cr ore in the converter in order to reduce ferroalloy consumption has already been developed and it is expected that in the near future, the direct use of Cr ore in the converter for all Cr additions to stainless steels will be instituted. To attain this, techniques for heat compensation and forced stirring in the furnace will be essential. Top and bottom blown converters developed in recent years will greatly contribute to this end.

(b) Efficient utilization of resources will include the use of scrap and slag.

Higher standards of living are likely to mean the creation of larger volumes of scrap. Figure 8 shows the trends and forecasted generation of scrap, which is expected to reach 44 million in 1990. It is essential, therefore, that techniques be developed for the recycling of large quantities of inexpensive scrap, with consideration given to the control of tramp elements.

To date, slag created in the refining stage has been used for reclamation work or simply returned to the BF. In the future, however, techniques for upgrading the quality of slag must be developed for more effective use of this by-product.

3. Experiments in Continuous Steelmaking

In response to requirements from the manufacturing sector, the integration of processes involved in complicated refining is being studied in order to develop continuous steelmaking. Operational results for processes of this type are now being reported by test plants, and depending on these results, continuous steelmaking may become a major short cut.

3. Rolling Technology

During the past decade, the greatest urgency has been placed on efforts to reduce energy consumption and raise steel yield. Nevertheless, remarkable progress has been made in upgrading quality to meet customers’ increasingly diverse and sophisticated needs.

Recent major technical projects in the rolling sector include synchronization and continuous linkage of processes, higher-precision rolling, and product quality upgrading techniques.

1. Synchronization and Continuous Linkage

Successful synchronization and continuous linkage of hot rolling will require techniques for producing defect-free CC slab, optimizing capacity and timing between the CC and the rolling mills, and permitting flexible rolling schedules.

Fig. 7. Development of the solidification processes.

Fig. 8. Scrap generation trend and forecast in Japan.
Various techniques have been developed to satisfy these requirements in the hot strip mill operation: Sizing, the control of slab width in hot sheet rolling; heating temperature control including low temperature discharging and CC slab temperature adjustment; thickness–width control using hydraulic AGC (automatic gage control) and AWC (automatic width control); and also crown and flatness control, which uses highly accurate new mills such as high performance multihigh mills and work-roll shift mills. As a result, the unit consumption of fuel for hot strip in Japan (Fig. 9) has reached an average level of less than 250 000 kcal/t.

Plate production has followed a course similar to that of hot strip. Realization of high CC ratios with structural shapes, mainly H-beams, came late due to the variety of sizes involved, but with the development of techniques for rolling shapes from slabs, and techniques for using single-sized beam blanks or blooms in multi-size rolling (Fig. 10), a rate near 100 % has now been achieved.

The progress of synchronization and continuous linkage in the cold rolling process, on the other hand, as shown in Fig. 11, has reached a stage where a single continuous process has been established, incorporating the pickling line, tandem mills, and CAL (Step IV). This has been made possible by improvements in the quality of hot-rolled products, thermomechanical treatment techniques in cold rolling, on-line coil welding techniques and others.

Table 2 shows an example of the results of tandem mill linkage (Step I), which has improved production...
capacity by about 50%, while allowing a 2/3 reduction in manpower. Figure 12 shows the results of the adoption of continuous annealing equipment in Step II; processing time, for example, was cut from 10 days to only 1 day.

2. High Precision Rolling

High precision rolling achieves three ends: first, by responding directly to customers' needs for improved precision and the reduction of variations; second, by using so-called "chance-free techniques" which allow flexible rolling schedules and eventually make possible small-lot, short lead-time delivery (thus indirectly responding to customers' needs); and last, by establishing an economical production system as a result of the improved rolling yield.

Precision rolling has been made possible through AGC, which has been adopted in virtually all fields of rolling; by AWC for hot strip, by edging mill techniques for plate; and by high-performance multi-high mills and work-roll-shifting which controls plate crown. In addition, the use of tension control between the roll stands of continuous multi-stand mills for rods, bars, shapes, seamless pipes, and cold-rolled products has been important.

3. Mechanical Property Control Techniques

Remarkable progress has been made in thermo-mechanical treatment techniques, such as controlled rolling and controlled cooling, which were originally developed for use with hot-rolled sheet and later applied to rods, bars and shapes, leading to the production of "heat-treatment-free steels". A new category of plate, called TMCP (Thermo Mechanical Control Process) has been developed on the basis of this technology. Because it is possible to lower the C equivalent while maintaining high tensile strength, the weldability of such products is excellent, making them suitable for a variety of ship-building and offshore structure applications.

In the field of cold rolling, this thermo-mechanical treatment control, in conjunction with the development of chemical composition design and continuous annealing techniques, is being applied to products such as automotive sheets where strength levels have been improved and formability pursued to its extreme limit. Such cold-rolled steels have even been applied to a new type of products with added bake hardenability.

4. Future Tasks

As discussed earlier, efforts should be directed, even in the rolling sector, to the drastic curtailment of manpower and the realization of fully-automated facilities. Further improvements in synchronization and continuous linkage and more thoroughgoing automation, as well as a faster pace to the implementation of such measures, may well be required.

Effective synchronization and continuous linkage is known to be able to reduce manpower, save energy and raise yield, however, the problems associated with these methods must still be eliminated in order to promote greater integration and automation.

(a) Synchronization, Continuous Linkage and Full Automation

Hot rolling has an immediate need for continuous linkage of a thin slab CC with hot strip mills in the sheet rolling sequence shown in Fig. 13. In the near future, the emergence of strip CC technology is also possible, as discussed earlier.

In the field of cold rolling, continuous linkage of processes for high-grade steels such as magnetic sheets and stainless steel will become an important task.

Figure 14 illustrates the basic concept of continuous linkage in magnetic sheet rolling which is now in practical application. This process incorporates new types of mills with high rolling efficiency, and a laser welding machine with greater reliability. The further extension of this process of synchronization and continuous linkage requires the aggressive development of "chance-free techniques" and techniques for raising quality assurance accuracy levels in all processes. "Chance-free methods" are techniques which respond to user needs for small lot, short lead time delivery and high accuracy. The development of long-life rolls will be an important task.

Among tasks for the near future are the full automation of various finishing processes such as shape steel finishing and cold-rolled sheet packaging. I consider it necessary to accelerate the development of various types of sensors, the fullest possible use of
robots and the development of application technology for computers, especially artificial intelligence.

(b) Upgrading of Mechanical Properties

Through the further development of controlled rolling and controlled cooling techniques, we are striving to achieve even higher functional levels of material properties. Using these techniques, it should be possible to develop methods for producing a wider range of properties from materials of the same chemical composition. Efforts in this area should be promoted from the viewpoints of accommodating small lot orders and conservation of resources.

4. Tasks for Product Development and Improvement

Product development and improvement needs have arisen because of the following factors:

i) Diversification and increasing sophistication of consumer and social requirements

(a) Severe application environments

(b) Trend toward lighter and smaller components

(c) Diversification of taste and fashion

ii) Pursuit of functional properties and greater economy, from the viewpoint of materials

By continuing to produce steel products that meet such requirements, we as steelmen will fulfill our responsibilities for the growth and progress of society, but we will also lay the foundation for the future development of the steel industry.

I would now like to mention some outstanding examples of products successfully commercialized in recent years to cope with such needs, as well as some items expected to see practical application in the future.

1. Severe Application Environments

(a) Steels for Special Uses

The Tristan Project of the High Energy Physics Research Laboratory of the Ministry of Education, Science and Culture has a need for more excellent non-magnetized steel and pure iron possessing higher magnetic properties. Even with the remarkable progress in superconductors recently reported, low-temperature service steels will remain in demand. As such examples suggest, the development of appropriate steel materials is essential for high-technology innovation in a variety of demand sectors.

(b) High Grade Line Pipe and Oil Country Tubular Goods

The development of high purification refining, controlled rolling, and controlled cooling has led to the production of line pipe with extremely good low-temperature ductility, and pipes and tubes with resistance to severe environments, as required for use in regions such as the North Sea and Alaska. There is a high ratio of Japanese steel pipe and tubes in oil and gas drilling rigs, oil country tubular goods and line pipe, with quality assurance checks (Fig. 15) conducted by a U.S. oil company showing excellent results. As application environments are becoming progressively more severe, it is imperative that we continue to supply economical products offering excellent performance under such conditions.

(c) Composite Steel Sheet (Vibration-damping Sheet)

Stimulated by recent social requirements for reduced noise pollution and lighter automobiles, demand for the further development of composite materials, a material type which has a relatively long history, has grown rapidly. Vibration-damping sheets are used for automobiles, home electric appliances, and general industry. Examples of applications are listed in Table 3.

This is an area worthy of more attention. Based on an accurate identification of specific needs and a full understanding of the features of alternative materials, the development of optimum processes and products must be encouraged.

2. Trend Toward Lighter and Smaller Components

There is a current need for lighter and smaller steel structures, and stronger, thinner structural com-
ponents. In response, weldable high strength structural steels, high strength steels for automobile use, as mentioned earlier, and bake hardened steel (BH steel), have been developed as sheet products. There is also a need for greater dimensional diversity, as well as for shapes and tubular products having thinner walls.

3. Diversification of Taste and Fashion

Customer acceptance, it may safely be said, no longer depends on properties such as service life and durability.

Steel products therefore must contribute to the appearance of products, and appeal to the consumer's aesthetic sense. Obviously, surface properties are important. Products in this category are generally consumer goods and those for final applications where product design is important. Examples include household electrical appliances, steel sheet for decorative use, building materials, and colored or color-applied stainless steel sheet.

The aesthetic requirement must not be overlooked when considering new applications for steel as a functional material.

4. Pursuit of Functionality and Economy of Material

Let me introduce two examples here, grain-oriented magnetic steel sheets and coated automotive steel sheets.

(a) Grain-oriented Magnetic Steel Sheets

Since high permeability product was developed in the late 1960s, Japan has led other countries in the field of techniques for the improvement of core loss in grain-oriented magnetic steel sheet. Figure 16 shows the history of such developments.

Subsequently, reduced core losses were realized with the help of techniques for thickness change and magnetic domain refining, and the development of such products is still under way aiming at even greater thinning.

On the other hand, amorphous alloy ribbons (Fig. 17) with core loss 1/4 to 1/5 that of highly grain-oriented magnetic steel sheets have already been developed. The application of this product to the cores of power distribution pole transformers represents a future opportunity.

<table>
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<tr>
<th>Application</th>
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<tbody>
<tr>
<td>Civil work and building</td>
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<tr>
<td>Railway bridges, steel staircases, dust chutes, steel doors, steel shutters, steel furniture</td>
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<tr>
<td>Transportation</td>
</tr>
<tr>
<td>Auto engine parts, engine related parts, cockpit parts, vessel chutes of dump trucks</td>
</tr>
<tr>
<td>Factory (general)</td>
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<tr>
<td>Steel conveyors, containers, stopper liners, compressors</td>
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<tr>
<td>Audio equipment etc.</td>
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<tr>
<td>Audio equipment and devices, business machines, cash register castings, laser apparatus, anti-vibration plates</td>
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<td>Sound-proofing covers</td>
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<td>Sound-proofing covers for various machines, steel sheet structure of large sound-proofing devices</td>
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Table 3. Examples of an application of composite vibration-damping steel sheet.

![Fig. 15. Example of results of quality checks performed by U.S. petroleum company.](image)

![Fig. 16. History of core loss improvement of grain-oriented magnetic steel sheet.](image)
Such attempts at producing lower core loss in magnetic material are an attempt to meet the strong long-term, global need for energy conservation in the power transmission process.

(b) Coated Steel Sheet for Automobile Bodies

Since the problem of auto body corrosion resistance, as represented by the Canadian Code, became a matter of worldwide concern, coated steel sheets for autobodies have come into widespread use. Coated sheets are said to account for as much as 35% of all automotive sheets, with further growth predicted. In this category, products include hot-dipped galvanized sheet, hot-dipped galvanealed sheet, Zn-Ni alloyed electro-plated, Zn-Fe alloyed electro-plated, and organic composite coated sheets.

Because not all characteristics required for automotive steel sheets enhance corrosion resistance, a major task will be the development of superior products incorporating a combination of features.

III. Conclusion

I have introduced various technical challenges which the steel industry is now facing. If the Japanese steel industry is to overcome the unprecedented difficulties now confronting it, it is vitally necessary to seek optimum production scale and pursue the development of new iron and steelmaking technologies, as well as products capable of meeting the most severe competition.

With these points in mind, I would like engineers to recognize the importance of the following:

i) Thoroughgoing process rationalization and the improvement of efficiency in existing iron and steelmaking processes, followed by the early realization of fully automated plants.

ii) Establishment of energy-saving measures and techniques for the utilization of undeveloped or unused resources, and

iii) Development of high grade, sophisticated products.

In addition to these goals, it is also essential that we contribute to the development of the oceans and space, and the development of new materials, both of which are important future tasks for Japan.

It will be no easy task to achieve the objectives I have outlined, some of which can be fully handled by an individual enterprise, but others lie beyond the scope of the steel industry as it now exists. It goes without saying that to solve these technical challenges and to develop such technology, each enterprise must attempt to enhance both its creativity and technical capabilities. Moreover, cooperative studies and basic research, both within the industry and with other industries, universities, laboratories, etc., will assume increasing importance.

In these efforts, I sincerely request the generous support of all of you, distinguished guests and fellow members.

This concludes my remarks.

Thank you very much for your attention.