Role of Research in the New Era of Steel Production Technology*

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Synopsis

Today is the time when the system of steel production technologies accumulated over the past few centuries is systematically reviewed and is constructed into a more rational system of production technologies. Drastic changes in the system of steel production technologies have been markedly increasing the capability of steel manufacturing processes, bringing about new steel products impossible to produce commercially in the past and accomplishing the diversification of steel products and the improvement of quality and homogeneity of steel products. As a result of this situation being reflected on the steel market, there are rapidly increasing calls for further product diversification, special performance characteristics and quality homogenization. It will be difficult to fully meet the customer’s quality assurance requirements, unless the steel maker is involved in the customer’s production process or the product’s service conditions, conducts research to know the functional elements demanded of steel and produces steel that satisfies the combination of functional elements required. In order to cope with these situations, the important role of research in the new era of steel technology should be clearly recognized. Today, the value of steel products does not become perfect before the properties the steel has as a group of functional elements are combined with information required to effectively utilize such properties in service. In such a sense, software will rise in relative value instead of hardware.

I. Introduction

Because of its high cost, energy is a matter of serious concern in the steel industry, and articles and new proposals concerning energy saving have become so common that it appears to be the main concern of the steel industry. Though energy saving and cost saving in general are vitally important, there is a more important matter which the industry has to clearly recognize and respond to. That is the important role of research in the current innovative era in the history of steel production technology. If we fail to recognize this matter, it is feared that we may be too late in taking necessary action. Here, we would like to discuss this point and express a few personal opinions.

II. Present Situation of Technological Innovations in the Steel Industry

It is a well known fact that the steel industry has reached the present state of technology after many innovations. In particular, the advent of the Bessemer converter and the Siemens–Martin open-hearth furnace in the middle of the 19th century enabled the mass production of steel. Coupled with the large tonnage of pig iron made available by the use of coke as blast-furnace fuel substitute for charcoal, the converter and open-hearth furnace processes laid the foundation for the mass production of steel products, the marked progress of the steel industry and the realization of the steel age in the last half of the 19th century.

During the same period, microstructures of steel were systematically studied, relations between steel microstructures and phase diagrams, phase changes or transformations were clarified, and new physicochemical research techniques were introduced extensively. As a result, it may be said that steel property research joined the family of modern sciences. Nevertheless, it is an undeniable fact that steel production technology still involves empirical factors handed down from medieval alchemy.

In general, the recent period of technological innovations for steel production is regarded as running from the 1920s to the 1960s, with some 20 postwar years being considered as the most active period. In fact, the advent of the hot strip mill in the 1920s, followed by the development of the cold strip mill,† and the appearance of the top-blown basic oxygen furnace, the large scale industrial application of which was delayed by the war, marked the outstanding progress of steel production technology.

Science, engineering and technology, such as chemical kinetics, heat technology and plastic deformation dynamics, were applied to the study of steel production technology with excellent results. X-ray investigation of textures, electron microscopic examination of microstructures, progress of chemical analysis, application of physical techniques to chemical analysis, development of state analysis methods, etc., were noticeable for their powerful effects in elucidating in principle the properties of steel by correlating them with microstructures. With steel production and consumption growing to a considerable extent, the steel

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† In the 19th century, steam engines advanced further and large power sources spread, bringing about the rapid expansion and development of modern industry, an outcome of the Industrial Revolution. As the result of the Industrial Revolution, there arose the necessity of transportation network by which large amounts of raw materials and industrial products could be delivered from the production site to the consumption area.
To cope with this necessity, railway networks on the lands and shipping networks on the sea linked by harbors were built. This phenomena along with the mass production technology induced by the Industrial Revolution also dramatically increased the demand for steel.
†† Huge demand was created for hot- and cold-rolled steel sheet by the mass production of the automobile. This is another example of the interaction between market and the steel industry.
industry had increasing impact on the development of society and economy, and played a vital part worth special mention in upgrading the life of people through the mass production of durable consumer goods like automobiles and electric household appliances. In this way, the steel industry altered the life pattern of people and brought about what is called a “life revolution”.

When viewed from a different standpoint, however, “true technological innovations for steel” really began in the 1960s and are now about to leave the “incubation period” after about 20 years.

Then, what is meant by the term “true technological innovation for steel”? It is unjust to say that the switch from the open-hearth furnace to the top-blown basic oxygen furnace was made without any metallurgical basis. The top-blown basic oxygen furnace process is considered to have bloomed and become a mainstream steelmaking technology, supported first by the experience and learning-based insight of inventors, and secondly by the establishment of methods for producing large volumes of oxygen at low cost and thirdly by the progress of many other fields of science and technology.

After the top-blown basic oxygen furnace process had firmly established itself in the steel industry, however, the simultaneous hitting ratio at the end point, a ratio that the carbon content and temperature of the steel bath at the end point can be brought within for example ±0.01 % and ±12 °C of the aimed carbon content and temperature, respectively, was an unbelievably low 50 % or so, even for ordinary low-carbon grades.

In the field of rolling, the 1960s was the period when the automatic gauge control of hot and cold roll strip mills was practically applied for the first time and few technological leaders believed the feasibility of computer control over the entire rolling operations.

Thereafter, supported by the progress of physical chemistry and reaction theory, the steel refining technology developed from a very empirical technology into an automatic steelmaking process backed up by modern science, engineering and technology, and came to attain a simultaneous hitting ratio of over 90%.

If the terminology of quality control is used, it can be said that the steel refining technology has improved in the process capability of simultaneous hitting ratio and joined the family of modern technologies.

In the field of rolling, the theoretical and experimental research of plastic working in rolling and the progress of control theory of tandem mills, coupled with the advancement of control equipment, enabled the computer control of entire rolling mill operations and led to the emergence of full-continuous tandem cold mills and full-continuous tandem shape mills, for example.

The continuous casting technology that had been long practiced for nonferrous metals was initially applied to steel with limited success. Along with the progress of mechanical and control engineering, such as the thorough understanding of the solidification mechanism and its related phenomena and the role of a lubricant in the mold, continuous casting has recently matured to such a degree that in many cases the quality of continuously cast steel is superior to that of ingot cast steel. In the manufacture of cold-rolled steel sheets, facilities have been developed which finish cold-rolled steel strip into a product in one operation by continuous annealing.

When one compares these latest technological innovations with former technological innovations in the steel industry, one notices that there exists needs to improve process performance in both cases, but while many of the previous technological innovations were accomplished through flashes of genius and groping efforts over extended periods of time, the latest technological innovations were attained, based on the understanding of underlying metallurgical or plastic phenomena and in pursuit of more rational processes.

This is the most noteworthy point. If a technology is regarded as forming a part of a more rational production technology system or producing a steel with properties better suited for a given purpose, it becomes quite common in steel industry that every effort should be made at the realization of that technology, although the technology may be totally different from the conventional system of production technologies empirically accumulated.

Among the examples are hot direct rolling of ingots, hot charging of continuously cast slabs and hot direct rolling of continuously cast slabs, all based on the production of defect-free ingots or continuously cast slabs; rolling practices for obtaining desired properties, an outgrowth of controlled rolling of plates; and various refining techniques in converter or ladle that have expanded the range of grades manufacturable by the basic oxygen furnace process. In the fields of blast furnace ironmaking, sintering and coke manufacture where many factors were in a “black box”, positive efforts are being expended to clarify the essential nature of each process.

Now is the time when the system of steel production technologies accumulated and integrated over the past few centuries is reviewed from the standpoint of rationality and is restructured into a more rational system of production technologies. Today is a truly innovative period in that rationalism and modern scientism have played principal roles for the first time in the history of steel production technologies and efforts are being consciously made to reform the production technology system.

Steel production engineers and researchers are recognizing anew their duties as those of technological innovators.

III. Effects of Innovations in Steel Production Technologies on Society's Requirements for Steel Products

When production technology in an industry changes as mentioned above, the industry can improve the process capability and manufacture desired products with less quality variations at higher yield, because of improvement in production technology itself and of the increased ease of applying control technology to
production technology. This makes it possible to meet the requirements of customers or markets, but also induces the customers to call for products of better quality or different performance. For the requirements of the customers for advanced and diversified products are limitless.

An industry can be said to have reached the stage of technological maturity when its production technology has attained a high degree of development or its production process can be understood in terms of science and engineering and has unlocked the mysteries of the black box. It is already known that the industry or companies belonging to the industry will be unable to follow up on the move of the market unless they recognize the arrival at the stage of maturity and take necessary measures.

One of the most conspicuous examples of such nature is Henry Ford I and his Model T coupe. As is well known, the Model T Ford sold explosively thanks to its performance, price and styling when it was placed on the market. In a matter of a few years, however, the people were not satisfied with the model and called for more varied styles and colors, and better performance but the Ford Company stuck to manufacture of only the black Model T, so that the Company lost its share of the automobile market to such a degree as to stand on the brink of bankruptcy. Steel is not a consumer product and may not suffer such a clear-cut result as the automobile. As long as the steel industry remains as one industrial field, however, it is not permitted to think that the steel industry alone is immune from the general phenomena that have repeatedly occurred in the history of industry.

There is a saying: “The day is over when steel can be sold as much as it is made”. The saying was first heard more than ten years ago and appealed to steel men to some degree, irrespective of whether or not the coiner of the saying recognized that steel production technology was just to jump from an empirical system to a rationalistic system and the steel industry entered the stage of maturity in terms of production technology.

What does the saying mean? To answer this question, it may be easier to begin with the question: “What image do ordinary people have of steel?”

In photo contests sponsored by the Japan Iron and Steel Federation under the theme of life with steel, many of the photos submitted are concerned with steel structures, generally represented by steel frames, steel towers, railways, including steam locomotives, scissors, and knives.

The steel industry should act to change the sense of value of steel represented by and born of such images and should open up new demands over a wide range. This is favorable to society and to this end, the steel industry should endeavor to have the customers better understand the performance of steel and advise the customers on the use of steel, should time and circumstances permit.

Such an age has arrived. This is an engineer’s interpretation of the saying: “The day is over when steel can be sold as much as it is made” or an interpretation of the saying from a point of view of technological history. Fortunately, until recently steel has been sold as much as it has been made. How about the situation for other industrial materials?

Many fields of steel production technology depend on metallurgical technology. If metallurgical technology is taken as one of two successors to alchemy, the other is chemical technology. Metallurgical technology has empirically developed up to recent years, because it is mainly concerned with high-temperature chemistry, which in turn has delayed its elucidation in terms of science and engineering. In the field of chemistry, organic chemistry made remarkable progress in the middle of the 19th century and organic synthetic chemistry enjoys great prosperity today. Customarily for products of organic synthetic chemistry, or synthetic resins or plastics in general and engineering plastics in particular, research work is widely conducted on utilization and fabrication technologies, such as molding and painting methods, as soon as manufacturing technology is completed or before manufacturing technology is completed in some cases, and at the same time as products are put on the market, rich data on utilization and fabrication technologies are made available for use by customers.

Similar activities are performed in nonferrous metal fields to a considerable extent, and some in-depth studies are carried out on the application development of copper, aluminum and other nonferrous metals.

There are types of steel that have performance characteristics not generally considered as of steel itself. In the case of stainless steel that is practically immune to rusting in ordinary atmosphere in spite of the general belief that steel is liable to rust, for example, steel companies have conducted more in-depth investigations into the utilization and fabrication technologies of stainless steel than conventional grades of steel.

Take a look at the enormous volumes of research work carried out by steelmakers concerning the utilization and fabrication technologies of stainless steel as well as tin-free steel. Everytime the steel industry has found a particular material to be of extremely high novelty and felt the need to create the demand for the material, they perform the study of in-depth utilization and fabrication technologies for the material. If compelled by request for a particular grade of steel from a consuming industry, like the shipbuilding or automobile industry, the steel industry has performed in-depth research on the utilization and fabrication technologies of the steel in parallel with study on the development of the steel.

Drastic changes in the system of steel production technologies have been markedly increasing the capability of steel manufacturing processes, bringing about new steel products impossible to produce commercially in the past and accomplishing the diversification of steel products and the improvement of quality and homogeneity of steel products. As a result of this situation being reflected on the steel market as described above, there are expected rapidly increasing calls for
further product diversification, special performance characteristics and quality homogenization. Calls are also expected to increase for quality assurance related to machinability, plastic formability, surface treatability, heat treatability and other properties required to ensure trouble-free performance in fabrication as well as for quality assurance associated with finished appearance, fatigue strength, fracture toughness, corrosion resistance and other properties required for fabricated products to function properly throughout their intended service life.

Of particular importance are calls for steel quality assurance to ensure trouble-free performance during fabrication by customers and calls for steel quality assurance for end products to satisfy functional and life requirements.

Why does the customer use steel? He uses steel because he judges that he can effectively utilize the combination of functional elements, including cost, that steel possesses, when making a product from steel and placing the product on the market.

The functional elements required include many elements related to the case of fabrication and the degree of product finish, based on the use of the customer's existing equipment, and several elements necessary for the end product to satisfy the desired function and life when it is put to use.

The steelmaker's full contact with the customer may still leave many details unknown concerning the combination of functional elements the customer demands of steel to be purchased for a given purpose and the degree of demand the customer places on specific functional elements, among other things. It will be fortunate if the steelmaker can technologically investigate and analyze the customer's production process through joint research with the customer. It will be difficult to fully meet the customer's quality assurance requirements, unless the steelmaker is involved in the customer's production process or the product's service conditions, conducts minimum research to know the functional elements demanded of steel and produces steel that satisfies the combination of functional elements required. For example, take pressure vessel steel that is now being highlighted as material for coal liquefaction and gasification units. It is only natural that the steel should have strength required under high temperature and pressure. The steel shipped from the mill is plastically deformed and fabricated into the desired shape. The steel must not break during this fabrication process. The inside of the fabricated steel vessel is then surface treated if the contents to be handled are corrosive. The first step in this connection is scale removal. The maker of the pressure vessel will make a complaint if scale is embedded deep. Improper internal treatment will also lead to a complaint from the end user. To prevent weld cracking, it has become commonplace to minimize the carbon equivalent of the steel as well as to furnish information on preheating, welding, stress relief annealing and other welding conditions. Toughness of the heat-affected zone of welds is especially important and a variety of performance evaluation tests are conducted on the initiation and propagation of brittle fracture. When the pressure vessel is completed and put into use, the steelmaker will be required to furnish basic findings on many points, such as the progress of stress corrosion cracking at welds, the progress of embrittlement of the entire vessel by hydrogen under high temperature and pressure, in-service inspection frequency and estimated service life, and also will be required to provide quality assurance on the respective items under limited conditions.

What is steel with high reliability? It is the steel that has a minimum of quality variations and keeps at a certain level the group of functional elements required from the customer's point of view.

It may be said that the basis for winning popularity and reliability among customers is to find out the required combination of functional elements from the standpoint of customers and to produce and supply steel having such a combination of functional elements at stable levels.

IV. Value of Steel Products in Information Society

Today's society is called an information society.

Today is, on the other hand, referred to as the "service age" or "software age".

There is a Japanese saying: "Dumplings rather than cherry blossoms." It means that the physical value of eating dumplings takes precedence over the mental value of seeing cherry blossoms.

If dumplings can be abundantly eaten anytime and anywhere, however, seeing cherry blossoms will take precedence over eating dumplings.

If hardware is extensively spread, hardware will fall in relative value and software will rise in relative value.

As the system of steel production technologies is presently moving to a more rational system from the viewpoint of modern science and technology, steel of acceptable quality can be obtained anywhere, to say with some exaggeration. Along with this move, greater importance must be attached to software rather than hardware.

Furnishing information services, such as on how to use steel to ensure cost savings, good product performance or long service life, assumes the same importance as providing more numerous and more advanced functional element groups.

This trend is already actualized in many fields.

If requested by shipbuilders or automobile makers for cooperation in substantial cost reduction or performance improvement as mentioned previously, steelmakers must often conduct joint research with them as well as to develop steel products they demand.

In the case of a large civil engineering project or pipeline project, the steel industry and individual steel companies take part in various investigations many

* The properties of steel correspond to the functional elements required. In steel production control, the grade of steel is determined according to the combination of properties.
years before the actual construction of the project. The nature, environment and service conditions of the project are investigated, the group of functional elements required of steel to be used in the project is examined and studied, the combination of necessary functional elements is determined, steel is developed accordingly, the manufacturing process or production technology for the steel is prepared, how to use and maintain the steel in the project is studied, and relevant technical information is furnished.

Such actions indicate the posture the steel industry should assume in today's information society. The value of steel products does not become perfect before the properties the steel has as a group of functional elements are combined with information required to effectively utilize such properties in service.

In the steel industry faced with the new steel age, a major role will be played by research on steel fabrication and utilization technologies and by research on the group of functional elements required of steel until end products discharge their functions and complete their life.

Lastly, it is pointed out that product technology research will assume increasing importance along with process research for production technology innovations in future.