1. Condition of the Japanese Iron and Steel Industry

This review of the production and technology of iron and steel during 2008 will begin by examining the current condition of the Japanese iron and steel industry.

The year 2008 marked the 150th Anniversary of modern steel manufacturing in Japan. For persons concerned with iron and steel, this was a pivotal year for reflecting on the hard work of Takato Oshima, a retainer of the Nanbu Clan, who succeeded in continuously tapping iron with a “Japanese style” blast furnace, and the subsequent development of the Japanese iron and steel industry, and for looking ahead to the future. The year was also one of change, as the first half was characterized by increased production in response to external demand and expansion of exports, but beginning in the autumn, the financial crisis in the United States, which had been building since 2007, swept through the world economy with a ripple effect that forced an abrupt change to reduced production. The fundamental model of industry was called into question, and in addition to reform of the financial system, strengthening of the constitution of the real economy was demanded.

For Japanese industry, the time has come to improve technologies, constantly bearing in mind the changes in the global industrial structure as such, with the aim of maintaining and improving industrial competitiveness. More specifically, as is clear from the dynamic statistics of the Japanese population, the effects of low birthrates and the aging of Japanese society are unavoidable. There are also continuing concerns over the declining interest of human resources in the basic material industries, beginning with the iron and steel industry.

Against this background, let us examine the conditions surrounding the iron and steel industry in Japan.

Looking at the dynamic statistics of the world population from 1990 to 2030 and the working population (represented by the population from age 15 to 64) as part of the world population of 7 billion (Fig. 1), the total working population in the advanced nations (Japan, United States, Canada, Europe, Australia, and New Zealand) will be stable at roughly 800 million. In contrast, that in the developing nations will grow by more than 1 billion. As a result, the global working population will exceed 5 billion in 2020. In the steel industry, focusing on the important BRICs nations, the working populations in Japan and Russia will be stable, at 70 to 80 million, whereas in Brazil, the working population is expected to increase by approximately 50 million from the current 100 million. In China, the working population will become essentially stable, at somewhat under 1 billion. On the other hand, India’s working population will grow rapidly from its current level of around 800 million, and that country is expected to become a great economic power with a working population of 1 billion, outstripping China by the mid-2020s. Consumption of steel products is often used as a measure of the level of economic advancement. Taking India as an example, that country’s steel consumption was 30 kg/person-year in 2004, while the world average was 140 kg and the average in Asia was 100 kg. Assuming the population of India increases by roughly 300 million by 2030, and its steel consumption approaches the Asian average, demand in India is expected to increase by 21 million tons, while average world demand increases by 33 million tons. It is calculated that this will require the equivalent of one new steel company of the world’s second largest scale.

1.1. Economic Environment

“Change” can be mentioned as a keyword characterizing the year 2008, which was certainly a year of “dramatic change.” Intense changes in the economic world began on September 15, 2008. The steel industry was no exception to these problems, and greeted the New Year with all companies being forced to make rapid production cuts. Because the Japanese steel industry has experienced changes in the business adjustment every several years, some were of the opinion that there was no need for an excessive sense of crisis in the face to this unprecedented “once in a 100 year” recession. However, in addition to the need for a substantial response to the insufficient cash flows caused by problems in the system itself, going beyond simple fluctuations in the business climate, various reforms and innovations in the real economy are also needed, and speed is required in the response to this need. Where China is concerned, as a major holder of US Treasury securities, its relationship with US is more important than in the past. On the other
hand, because reliable real demand exists in China itself, the condition that steel is indeed necessary remains unchanged. Thus, for the Japanese steel industry, the economic recovery and trends in steel demand in the BRICs nations, beginning with China, are even more important than ever.

The “BRICS” were originally named by a security company which expected growth in those countries. (The term is a coinage which Goldman Sachs began to use in 2003 for the group of countries as an object of investment.) The following will examine the recent economic conditions of those countries. Brazil has a GDP of $7000/person and automobile sales on the order of 3 million units. At present, 300 Japanese-affiliated companies are operating in Brazil, and approximately 30 more are studying moves into the country in the future. Due to sluggish demand for resources in the second half of 2008, consumption (loans, home electrical appliances, automobiles) has been low, but expanded internal demand is expected to support a recovery in the economic climate. In Russia, the economic activity had been somewhat overheated, with GDP growth of 6% for the last 9 consecutive years, but this is expected to decrease to a “crushing speed” of 2–3% in 2009 due to the current global economic downturn. Although the economic climate has weakened due to the fall in the price of crude oil, the fundamentals of the economy are strong and the slowdown in consumption has not been severe. As a result, Russia is expected to make the earliest recovery, depending on direction of government financing. India is in its 5th year under the current government of Prime Minister Singh, and political conditions were unstable due to the Mumbai terror attacks at the end of 2008. The appreciation of the rupee and stock prices were abnormally high, but the direct effects of the subprime crisis are thought to be slight. GDP growth for 2008–2009 is expected to fall below the 9% growth plan, at around 7%. India is committing $5.7 billion in public funds in an effort toward corporate cooperation, M&A, and diversification, mainly with Japanese companies. While some companies such as Tata Motors have attracted attention, industry as a whole appears to be entering a period of adjustment. In China, infrastructure construction associated with Expo 2010 Shanghai China is active, but exports to the United States and Europe have slowed due to the global recession. In China, and the construction of a new system and the search for new fields for growth are continuing, with no expectations of a sudden reflation.

1.2. World Steel Industry

World crude steel production in 2008 was 1,329.72 million tons. In order, production by country was China, 502.01 million tons, Japan, 118.74 million tons, United States, 91.49 million tons, Russia, 68.51 million tons, India, 55.05 million tons, Korea, 53.49 million tons, and Brazil, 33.71 million tons. Due to the recession in the second half of 2008, annual production declined by approximately 17 million tons from the previous year. Although the following data are from 2007, the rank of companies by crude steel production in 2007 was (1) Arcelor Mittal, 116.4 million tons, (2) Nippon Steel Corporation, 35.7 million tons, (3) JFE Steel Corporation, 34.0 million tons, (4) POSCO, 31.1 million tons, (5) Baosteel, 28.6 million tons, and (6) Tata Steel, 26.5 million tons. Thus, Japan’s total crude steel production was approximately the same as that of the top-ranked company, Arcelor Mittal. China, which has enjoyed remarkable growth in recent years, was the largest steel-producing country, with production of approximately 502.0 million tons. Although the Chinese steel industry is said to comprise several hundred companies, the top ten companies accounted for production of 160 million tons, or about 30% of the country’s total, suggesting that a large number of medium-scale companies are located in demand regions scattered throughout the country. Infrastructure construc-
tion for Expo 2010 Shanghai is in progress, and China also has latent demand and growth capacity. However, because the country is expected to play a key role in checking the global economic downturn, it made a decision to commit public funds without delay.

In the Indian economy, due to sluggish demand for automobiles and home electrical appliances, demand for steel is seen as centering on infrastructure construction for the time being.

In Korea, orders received for automobiles, machinery, and construction have all declined, and POSCO has reduced its production for the first time since it began operation. Steel exports and imports have both decreased. In the United States, which is the epicenter of the current global recession, reconstruction of the industrial structure following the general collapse of the automobile industry is an urgent challenge. High expectations are placed on the creation of new industries under the new President’s “Green New Deal.”

Looking at monthly crude steel production, China’s production declined from a peak of 46.94 million tons in June in the run-up to the Olympics to 35.19 million tons in November. On the other hand, large declines in production could be seen in various other countries as a result of the recession following the meltdown of the financial system in September (Fig. 2). By country, large decreases in production were seen in the United States, where production decreased from 7.84 million tons in September to 4.06 million tons in December, Russia, from 6.34 million tons in August to 3.31 million tons in December, and Brazil, from 3.20 million tons in July to 1.65 million tons in December. In Japan, production peaked at 10.78 million tons in March and had remained above 10 million tons/month until October, but then was rapidly adjusted downward to 7.48 million tons in December due to reduced production of automobiles and other products. Russia and Brazil experienced particularly large changes during the year, as production fell by roughly half in December in comparison with the peaks for 2008. Among these countries, the adjustment in annual production by integrated (blast furnace) steel makers was, in order from the largest decrease, Russia, ▲53.1%, Brazil ▲43.4%, United States, ▲39.8%, India, ▲33.2%, China, ▲22.8%, and Japan, ▲19.7% (comparison of maximum productivity at mid-year and at year-end). As these numbers suggest, steel makers were forced to idle a considerable number of blast furnaces.

1.3. Japanese Steel Industry

The longest economic expansion in postwar history, passed its peak in November 2007. It has been pointed out that, during the period of more than 5 years up to that time, the nature of overseas expansion by Japanese companies changed from one centering on the transfer of production to countries such as China, Vietnam, and others in pursuit of cheap labor markets, to a division-of-labor system characterized by wide-ranging logistics involving intermediate goods in the production process. From this viewpoint, trends in imports from Asia have attracted attention as a leading indicator of changes in the economic trends in Japan.

Japan’s crude steel production in 2007 was 120.20 million tons, and remained on substantially the same level in 2008 on an annual base, at 118.74 million tons. However, on a half-year base, production was 50.69 million tons in the second half of 2006, 59.80 million tons in the first half of 2007, 61.71 million tons in the second half of 2007, and 61.50 million tons in the first half of 2008, and then fell from this high level to 56.84 million tons in the second half of 2008. Production had continued on a high level until September 2008, with monthly crude steel production exceeding 10 million tons, and set new record highs for three consecutive quarters (30.44 million tons in the second quarter), but was 30.45 million tons in the third quarter and 26.40 million tons in the fourth quarter. The pace of this decline in production was ▲14%/month from October through December, and the decrease in blast furnace production during this period was ▲8%/month, from 7.29 million tons in October to 6.12 million tons in December (Fig. 3). It can be said that the reduction in blast furnace production during this period was implemented at a more rapid pace than in the past. However, it should be noted that this response was possible due to progress in blast furnace operating technologies, beginning with burden distribution control and furnace body sensing technologies.

(1) Steel Consumption

Where domestic steel consumption is concerned, in the first half of 2008, a modest recovery could be seen in consumption of building materials, which had collapsed during 2007 due to a decrease in construction starts caused by delays in approval of construction accompanying a revision of Japan’s Building Code during the year. However, toward the end of 2008, shipments to all customers declined and inventories increased. Although the domestic market price of steel products had increased rapidly due to the high level of
demand in manufacturing industries and anticipation of higher prices for raw materials since the start of the year, the price of scrap dropped sharply after August, and the economic recession beginning in the autumn strengthened pressure for further price corrections. Regarding steel exports, in the first half of fiscal year 2008 (April to September), supply and demand were in balance globally due to anticipation of higher prices for steel products and firm demand in the emerging economies, coupled with measures by China to reduce exports, and exports increased by 1.56 million tons from the previous year, reaching 20 million tons.

(2) Raw materials for Iron and Steel
Looking at market conditions for raw materials for iron and steel, continuing from 2007, the balance of supply and demand remained tight in the first half of 2008 due to growth in real demand accompanying the economic growth of the Asian region, centering on China. Oligopolization of raw material supplies progressed, and as a result, three companies accounted for 70% of iron ore supplies, these being RIO Tinto Ltd. and BHP Billiton Ltd. (both Australian companies), and Companhia Vale do Rio Doce S.A. (Brazil). Japan depends on Australia for 60% of its iron ore supply. Demand for iron ore increased worldwide, led by China, and a record high of around 800 million tons is foreseen, exceeding the 780 million tons of 2007. A condition under which expansion of supply capacity failed to keep pace with the growth in demand continued until the first half of 2008. However, due to the recession which began in the autumn, the spot price plummeted, falling to approximately 30% of its high level in May. A full-scale correction to a price system more in line with the recessionary conditions existing from mid-year was carried over to the next year. The majority of coking coal is produced in Australia, with five Australian companies (BHP Billiton Ltd., RIO Tinto Ltd., Xstrata plc, Anglo American PLC, and Elk Valley Coal Partnership) holding a 60% global share. Japan depends on the first two of these companies for 30% of its imports. As acquisition plans aiming at further consolidation of this industry also exist, it is critical that the steel industry improve its negotiating position vis-à-vis the mines.

Coal shipments were reduced sharply by heavy rains in Queensland, Australia at the beginning of 2008, but production recovered and remained stable after summer. Demand for good quality strongly-caking coal was firm. Due to a decrease in the supply from Ukraine and a Chinese policy restricting exports, a condition in which supply capacity did not overtake the growth in demand continued. With regard to steam coal, due to limits on Australia's shipping capacity, supplies did not keep pace with the growth of demand in China and India, and a record high price was recorded during 2008. However, prices dropped sharply in the second half of the year.

(3) Condition of Related Industries in Japan
Steel-consuming industries in Japan enjoyed favorable business conditions in the first half, from the beginning of 2008, but the economy deteriorated rapidly from the autumn onward.

The number of housing starts, at 950,000 units/year, was on the same level as that after the sharp drop due to the enforcement of the revised Building Standards Law of 2007, and declined for the third consecutive year. Domestic automobile sales saw a moderate recovery at the beginning of the year, but in spite of an increase in light automobiles, total sales of 4-wheel vehicles decreased from mid-year and then essentially collapsed from the autumn onward. For the year as a whole, unit sales were 4.86 million, falling below the previous year for the third consecutive year. Production also fell below the previous year, declining to 11.56 million units, and all companies suffered lower profits and strengthened adjustments in production. Orders for industrial machinery declined continuously from the start of the year, in both private sector and government-public sector demand, and then fell further from the autumn. In particular, at year-end, construction machinery fell by approximately 40% from the previous month, vividly revealing the rapid deterioration in conditions. In shipbuilding, the order backlog (tonnage on order) was high at year-end, at 67.75 million gross tons, representing 10-plus months to 2 years of work, but from autumn onward, there was a trend toward a reduced pace in completions and deliveries, reflecting a decline in contracted tonnage from the autumn. Annual new shipbuilding orders set an all-time high, at 19.75 million gross tons, for an increase of more than 30% from the previous year.

(4) Orders Received and Prices of Steel Products
In the monthly transition in orders received for steel products, orders for construction in November 2007 decreased by approximately 10% in comparison with the same period in 2006, and did not show an increase after the start of 2008. Beginning in the autumn, and in particular at year-end, the drop in orders reached 30%. On a calendar-year basis, Japan's crude steel production was the 3rd highest in its history, at 118.74 million tons (following 120.20 million tons in 2007 and 119.32 million tons in 1973). However, on a quarterly basis, there was a declining tendency from the middle of 2008, as production fell from 31.06 million tons in the second quarter to 30.45 million tons in the third quarter and 26.39 million tons in the fourth quarter. On a monthly basis, crude steel production decreased rapidly, from 10.10 million tons in October to 7.48 million tons in December. Accompanying a decline in domestic shipments from the second quarter onward, inventories of mild steel exceeded 5.90 million tons, or more than 130%. In the field of special steels, tool steel and stainless steel decreased from the previous year, and only bearing steel increased by approximately 15%.

As a result of price negotiations reflecting the international rises in the prices of crude oil and raw materials, steel prices reached a high at mid-year, with H-shape steel and plates at ¥130,000/ton. However, due to the recession triggered by the financial meltdown, which occurred immediately after this peak, the price of H-shapes had fallen to the ¥90,000 level and small bar steel had decreased to ¥80,000 at year-end. On the other hand, no large movements could be seen in the price of heavy plates, which was supported by strong shipbuilding demand.

In response to requests for reductions in the price of steel products from the automobile industry and other steel-con-
summing industries beginning in the autumn, the steel industry began negotiations to reduce raw material prices. The effort for searching a new level of price corresponding to economic conditions is likely to continue.

(5) Steel Exports and Imports

Where exports and imports of steel products are concerned, among imports of mild steel, decreases were seen in materials from Korea and Taiwan through year-end, but imports from China showed an increasing tendency, centering on hot-rolled steel strip. As a result, imports for the year were on the order of 6.0 million tons. Exports of steel products showed a firm trend, as the level of 37.0 million tons in 2007 continued from the start of the year, and were on basically the same level in the statistics for the year as a whole. However, a sharp decrease could be seen from mid-year, and particularly at the end of the year. The breakdown of export destinations in the totals for 2008 included Asia, and particularly at the end of the year. The breakdown of export destinations in the totals for 2008 included Asia, 25.34 million tons, the United States, 1.61 million tons, and China, 6.78 million tons.

2. Technology and Equipment

2.1. Technical Environment of the Japanese Iron and Steel Industry

In spite of sharp increases in the prices of raw materials for iron and steel, global crude steel production appeared to face no immediate problems at the beginning of fiscal year 2008 due to the rapid growth of the BRICs countries and, in particular, large increases in production in China. As issues from the technical viewpoint, attention had been focused on the development of technologies for treatment/use of low quality raw materials, responding to the rapid rise in raw material prices, and securing quality in overseas bases. 2008 was a year when different responses were required in the first half and second half of the year. Reflecting economic conditions, technology development in manufacturing industries tends to center on stable production and equipment control during periods of increasing production, or on reducing costs and maintaining quality during reducing production.

It can be said that the “financial crisis” which triggered the current global recession was caused by the problem of securitization of financial risk and absence of regulations on the system handling it (i.e., it was possible to pursue leverage due to the absence of regulations on the shareholders’ equity ratio, such as those applied to banks). However, it is clearly known that manufacturers are not in a position where they can say that they are “devoting their full attention to manufacturing.” If it is remembered that technology is a means, and its purpose is to create value and improve the quality of life in society, the role which persons and companies responsible for technical development should play is without limits. Precisely in times such as these, such persons and companies should go back to the basics of processes, earnestly reexamine the current equipment and processes, and ensure that these efforts can bear fruit in products with merit for the user when the business activity is improved.

Japan’s iron and steel industry developed after the World War II has been based on the principles of “competition and coordination.” Now, however, it is considered that the “upstream process” (ironmaking process, solidification process) and environmental technologies are topics with which steel makers should grapple jointly from the fundamentals. There are considered to be an increasing number of common themes such as environmental technologies, or resource recycling through which the steel industry as a whole can contribute to society and the world, based on a sectoral approach, which will be described later in this paper. This reconfirms the pivotal role which the ISIJ should play. Good examples include observation of the interior structure of a blast furnace using cosmic rays (muons; see Sec. 2.6) and in-situ visualization of the solidification processes of iron and steel materials, which had not been observed directly until now, as “Development and Application of an In-situ Observation Technique for the Solidification Structure Processes of Iron and Steel Materials” adopted in Industry-Originated Iron and Steel Research for Project Development for 2008 (see Sec. 6.3).

2.2. Ironmaking

In 2008, pig iron output decreased substantially through the end of the year, resulting in a decline of 0.7% from 2007, to 86.17 million tons. Average productivity was 2.01 ton/m³·d, compared with 2.08 ton/m³·d in 2007, and decreased according to an increase in blast furnace inner volume accompanying blast furnace relining in 2007.

Although four blast furnaces were relined during 2007, no furnaces were relined in 2008. As of the end of 2008, a total of 28 blast furnaces were in operation in Japan, of which 11 had inner volumes of 5 000 m³ or larger.

The pulverized coal injection (PCI) ratio of blast furnaces in 2007 increased slightly from the previous year, reaching an average of 125 kg/t, as shown in Fig. 4, while the coke ratio decreased from 2006, at an average of 370 kg/t.

As regards coke ovens, in May, Nippon Steel Corporation Oita Works completed the construction of a new No. 5 coke oven battery (64 ovens in total) as the first commercial plant using the world’s first innovative coke making process “SCOPE 21” (Super Coke Oven for Productivity and Environmental enhancement toward the 21st century; see Chap. 3). At JFE Steel Corporation West Japan Works, CDQ (Coke Dry Quenching) equipment was constructed at Kurashiki No. 1 and 2 coke oven batteries and the Fuku-yama 5D coke battery, which had not had CDQ equipment previously, as a measure for CO₂ reduction and energy saving.

As a new technology for the blast furnace, Nippon Steel Oita Works developed a technique for measurement inside the blast furnace using cosmic ray muons (see Sec. 2.6), and the same company’s Nagoya Works and others developed a system for early detection and 3-dimensional display of changes in the blast furnace (Real-Time 3D-VENUS; see Sec. 2.6).

At JFE Steel East Japan Works Keihin District, an advanced shaft furnace was constructed for use in melting ferrous scrap, and was put into operation as a measure for preventing global warming. JFE Steel also recycles ferrous scrap with higher energy efficiency by introducing advanced sensing techniques and waste gas recovery tech-
niques developed in blast furnace operation. As a result of the introduction of these advanced techniques, the CO2 generation of this furnace has been reduced by half in comparison with the blast furnace process.

2.3. Steelmaking

The condition of steelmaking operation in 2008 is shown in the results of BOF operation in Table 1 and electric arc furnace operation in Table 2. In BOF steelmaking, the production index trended on a generally high level except for the end of year. The mixing ratio of pig iron decreased, continuing the same trend from the previous year, and the use of cold iron sources (ferrous scrap) increased. The results of electric arc furnace operation showed basically the same values as in the previous year. The alloyed steel ratio was decreased from the previous year.

The ratio of continuous casting steel in semi-final steel for rolling is shown in Fig. 5. The continuous casting ratio for mild steel was 99.8% for the 5th consecutive year, and special steel showed an increasing tendency, at 95.8%.

Looking at steelmaking-related equipment, steel makers continued their efforts to respond to more advanced environmental measures, including energy saving. The main equipment which was put into operation in 2008 is as follows.

JFE Steel Bars & Shapes Corporation Sendai Works introduced a high heat efficiency electric arc furnace which achieves high efficiency in energy utilization by continuous charging of ferrous scrap as a raw material into a preheating vessel which is connected directly to the body of the electric furnace. With conventional electric arc furnaces, the top cover of the furnace must be opened completely when charging raw materials, but this reduces energy efficiency and productivity. In contrast, this electric arc furnace achieves revolutionary improvements in energy consumption and productivity in unit time in comparison with the conventional electric arc furnace since the interior of the furnace is kept in a near-sealed condition and the scrap is preheated.

Nippon Metal Industry Co., Ltd. Kinuura Works installed

Table 1. Operation performance of converter.

<table>
<thead>
<tr>
<th>項目</th>
<th>2005 Average</th>
<th>2006 Average</th>
<th>2007 Average</th>
<th>2008 Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity index per steelmaking hour*</td>
<td>100</td>
<td>100</td>
<td>101</td>
<td>100</td>
</tr>
<tr>
<td>Steelmaking time index per tap to tap*</td>
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<td>102</td>
<td>104</td>
<td>101</td>
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<td>Pig iron mixing ratio(%)</td>
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<tr>
<td>Ratio of continuous cast steel(%)</td>
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<td>98.8</td>
<td>98.7</td>
<td>98.7</td>
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<tr>
<td>Ratio of vacuum treated steel(%)</td>
<td>75.4</td>
<td>74.7</td>
<td>74.8</td>
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</table>

* The index is based on the average of 2002 to 2004, 100
Source: The Iron and Steel Federation

Table 2. Operation performance of electric furnace.

<table>
<thead>
<tr>
<th>項目</th>
<th>2005 Average</th>
<th>2006 Average</th>
<th>2007 Average</th>
<th>2008 Average</th>
</tr>
</thead>
<tbody>
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<td>Electric power consumption per ton of good ingot (kWh/t)</td>
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<tr>
<td>Yield of good ingots (%)</td>
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<td>89.3</td>
<td>88.9</td>
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<tr>
<td>Ratio of alloy steel (%)</td>
<td>40.0</td>
<td>40.5</td>
<td>40.3</td>
<td>40.2</td>
</tr>
</tbody>
</table>

* The index is based on the average of 2002 to 2004, 100
Source: The Iron and Steel Federation
a smelting reduction furnace for smelting reduction treatment of by-products (dust, sludge, scale, etc.) generated in the stainless steel production process, making it possible to recover valuable metals such as nickel, chromium, and others, and reduce the amount of industrial waste. Previously, much dust, sludge, scale, and other by-products had been discharged as industrial waste. However, a large cost reduction effect is expected by recovery and recycling of these resources.

The main steelmaking-related technology developments are as follows.

Sumitomo Metal Industries, Ltd. Kashima Steelworks developed the Porosity Control of Casting Slab (PCCS) method, making it possible to produce high quality thick steel plates, in which the central area porosity in the slab thickness direction is reduced, by applying a method of reduction at the end of solidification in the continuous casting machine. Conventionally, in the production of high quality thick steel plates, casting had been performed from large ingots through a process of working at a high reduction ratio (=slab thickness/product thickness) because the central porosities which occurred in the stage of solidification of the central part of the slab remained even after the rolling process. However, with the newly-developed process, it was found that thick steel plates can be produced with a conventional continuous casting machine by applying further reduction with rolls at the end of solidification, when the temperature difference between the center and surface of the slab is large, in order to crush these central porosities efficiently.

Sumikin Iron & Steel Corporation Wakayama Works developed a mold flux that resists entrainment in the molten steel in the continuous casting machine. With high basicity, high viscosity mold fluxes, increased fluctuations in the thermal flux in the mold, which is considered to result from instability in crystallization of the film, had been an impediment to practical application. Wakayama Works succeeded for the first time in stabilizing the crystallization of a high basicity/high viscosity mold flux by using melilite crystallization.

2.4. Plates, Pipes, and Shape Products

In plate-related equipment, in January 2008, JFE Steel achieved monthly production of 507,000 tons as a total for three mills at its East Japan Works Keihin District and West Japan Works Kurashiki District and Fukuyama District. In December, the plate mill at West Japan Works Fukuyama put its augmented third heating furnace into operation, thereby establishing a 6 million ton/year production system. Basic improvements at Chubu Steel Plate Co., Ltd. and an expansion at Nippon Steel Oita Works are ongoing. In the area of development/new products, a large number of high tensile strength steel plates and other high functionality products were announced. JFE Steel adopted DQ-HOP type high tensile strength steel plates for spherical gas tanks for the first time in the world. The company also developed a corrosion-resistant steel plate for ship ballast tanks, a low YR 780 MPa class steel plate using control of the martensite–austenite structure, a heavy gauge steel plate for shipbuilding with excellent crack arrestability, and a heavy-plate precoated steel plate with excellent laser cutting performance. Sumitomo Metal Industries, Ltd. developed the world’s first high tensile strength steel plate which improves the fatigue strength of welded joints.

In equipment for shape products, JFE Bars & Shapes Himeji Works completed construction work in the modernization of its medium and small rolling equipment, which is now operating smoothly. In this modernization project, the existing first rougher rolling mill was renovated from the conventional 4-stand type to a 6-stand compact mill, one new intermediate vertical mill was added, and the mill motors were also improved to independent drive, resulting in an increased production capacity.

As pipe-related equipment, Sumitomo Metal’s Wakayama Works, Steel Tube Works (Amagasaki) completed capital investment for high speed setup at the medium-bore pipe mill, expansion of the heat treatment equipment at the small-bore pipe mill, expansion of threading equipment, and expansion of the finishing equipment for 13% Cr and high alloy oil well pipes, thereby increasing its seamless pipe production capacity by 100,000 tons (9% increase). At the Steel Tube Works (Amagasaki), the production equipment for heat exchanger pipes for steam generators (SG tubes) in nuclear power plants was revamped, and its production capacity was increased by approximately 30% in expectation of increased global demand.

JFE Steel Chita Works also expanded its medium-diameter seamless pipe rolling equipment, heat treatment equip-
ment, and finishing treatment equipment, increasing its production capacity from 160,000 tons/year to 250,000 tons/year.

In pipe manufacturing technology, JFE Steel developed a 980 MPa class electric resistance welded (ERW) tube and adopted this product in automotive frame structural materials for the first time in the world. In this product, JFE Steel succeeded in the development of a 980 MPa class ERW tube with extremely high formability by using a high ductility 980 MPa class cold-rolled steel sheet produced by a continuous annealing process by the water cooling method, in combination with its original CBR forming mill (Chance free Bulge Rolling mill: rolling mill for electric resistance welding pipe adopting the bulge forming and bending method and gage roll method), which the company developed independently to prevent deterioration of ductility during pipemaking.

In bar and wire rod-related equipment, in addition to revamping equipment and renovating aged facilities, all companies increased their production capacity in order to respond to increased demand for high grade steels for automotive applications. In addition to a high rigidity compact roughing mill at Nippon Steel Muroran Bar and Wire Rod Making Department, Sumitomo Metals (Kokura), Ltd. decided on renovation of the final rolling mill.

2.5. Sheet Steels

In equipment related to cold-rolled steel sheets and coated steel sheets, a series of major capital investments in Japan was completed up to the previous fiscal year, and there were no investments in plants and equipment which required special mention in fiscal 2008.

Where products were concerned, in the field of galvanized (Zn-coated) steel sheets, promotion of mass production of new products can be noted. (See New Products.) In hot-rolled steel sheets, Nakayama Steel Works, Ltd. started operation of a coil box, and expansions are underway at JFE Steel East Japan Works Keihin and Nissin Steel Co., Ltd. Kure Works.

2.6. Instrumentation, Systems, and Analysis

Nippon Steel developed a method of estimating the condition in the interior of blast furnaces based on the fact that cosmic ray muons undergo attenuation corresponding to density and thickness when they penetrate a structure, and installed a measuring device on the outer side of the furnace bottom at Oita No. 2 blast furnace. Measurements were performed, and the density in the bottom hearth and the remaining thickness of the furnace bottom bricks were estimated from the measured results. For early detection of changes in the blast furnace, Nippon Steel’s Nagoya Works developed a system called Real-Time 3D VENUS, which displays sensor data for the stave temperature and shaft pressure in three dimensions, achieving visualization of images of furnace conditions and sharing of information. Because the display is updated in a 1 s cycle, the system supports judgments of urgent actions. The system also enables single-screen monitoring of other monitoring data in addition to the temperature/pressure in the shaft and furnace bottom, thereby avoiding delays in response due to overlooking the signs of abnormal phenomena. As a result, optimalization of operation has been realized.

At Sanyo Special Steel, an eddy current edge inspection device was introduced at the medium-diameter steel pipe inspection line. In this improvement, a theta probe, which is substantially unaffected by surface roughness, was introduced for detection of edge cracks for the first time in Japan.

2.7. Others

Sumitomo Metal Osaka Steel Works expanded its heat treatment equipment, machining line, and other equipment for solid rolled railroad wheels, and established a production system with a capacity of 240,000 wheels/year (20% production increase).

As steelmaking dust recycling equipment, Nippon Steel Kimitisu Works began full-scale operation of a rotary hearth reduction furnace with the world’s largest treatment capacity (310,000 tons/year) in recycling of ferrous dust by-products. Similarly, JFE Steel’s West Japan Works Fukuyama District constructed steelmaking dust recycling equipment which reduces ferrous oxides and zinc oxides in by-product dust. Together with recycling and effective utilization of dust, JFE also plans to expand its use of market scrap containing zinc.

3. Environment

Under the Kyoto Protocol, which was adopted by the Third Session of the Conference of Parties (COP3, 1997) to the United Nations Framework Convention on Climate Change and took effect in 2005, Japan is committed to reducing its emissions of CO₂ by 6% from the baseline year of 1990. 2008 was the first year of the First Commitment Period (2008–2013) under the Kyoto Protocol. Furthermore, because a conclusion regarding the framework after 2013 is to be obtained by the end of 2009, various discussions are developing. The Annual Meeting of the World Economic Forum (Davos Forum) began in 1971 and was held in January 2008. Following the start of the Davos Forum, various series of other meetings have also been held, including the Major Economies Meeting on Energy Security and Climate Change (MEM), the Asian-Pacific Partnership on Clean Development and Climate (APP), and the Intergovernmental Panel on Climate Change (IPCC). At the Group of Eight Summit held at Lake Toya, Japan in July 2008, there was an appeal to the Chair to “reduce global CO₂ emissions by half by the year 2050.”

In October 2008, the World Steel Association (WSA) held its general conference in Washington in the United States. The WSA Panel on Climate Change confirmed that Phase 1 data collection for promoting the sectoral approach to reducing CO₂ emissions is progressing smoothly and set the end of 2008 as a target.

Under the global steel sectoral approach CO₂ emissions per ton of steel are calculated for each process and published in plant units. Because equipment and process capacities are expressed as numerical values, the technologies and equipment elements which require improvement can be clarified. This technique enables technical cooperation with the developing nations by assigning priority ranks for improvement of equipment. This approach is expected to con-
tribute to efficient reduction of CO₂ emissions by the world steel industry.

According to the statistics of the Japan Iron and Steel Federation (2008 edition of “Iron and Steel Industry of Japan”), the steel industry accounts for 44% of the CO₂ emissions by Japan’s industrial and energy conversion sector and 15% of the country’s total CO₂ emissions. In fiscal 2006, Japan’s crude steel production was 118.74 million tons. In spite of the fact that this was a 5.4% increase from fiscal 1990, the industry reduced its energy consumption by 5.2% in comparison with fiscal 1990, to 2.394PJ, by aggressively promoting energy saving measures. According to a trial calculation, the amount of energy-originated CO₂ emissions in the steel industry was 193.26 million tons, which is a decrease of 5.1% from fiscal 1990.

In research and development for reduction of iron and steel-related CO₂, in March 2008, the Ministry of Economy, Trade and Industry (METI) compiled the “Cool Earth—Innovative Energy Technology Program” for realizing Japan’s “Cool Earth 50” initiative. Consequently, the New Energy and Industrial Technology Development Organization (NEDO) solicited proposals for research and development projects for realizing its “21” technologies. The Japan Iron and Steel Federation and six steel-related companies (Nippon Steel, JFE Steel, Sumitomo Metal, Kobe Steel, Ltd., Nippon Steel, and Nippon Steel Engineering Co., Ltd.) proposed development of innovative steel manufacturing process technologies, and this proposal was adopted in July. In Japan, which is the Chair (host nation) of the above-mentioned APP, the Japan Iron and Steel Federation and four steel companies (Nippon Steel, JFE Steel, Sumitomo Metal, and Kobe Steel) were commissioned to carry out NEDO’s “Basic Survey of Energy Saving and Environmental Countermeasures related to the Steel Industry in the Republic of India” and began this work in September 2008. Also in fiscal 2008, Sumitomo Metal et al. adopted “Development of Materials for High Efficiency Plants using USC Steam Exceeding 700°C” as a candidate contractor for METI’s “Grants for Development of Element Technologies for Practical Application of Advanced Ultra Super Critical Pressure Thermal Power Generation.” Thus, a variety of projects are being promoted with public funding.

As concrete measures for CO₂ reduction, Nippon Steel Oita Works No. 5 coke oven introduced the technology of the “Super Coke Oven for Productivity and Environmental enhancement toward the 21st century (SCOPE 21)” (FY1994-FY2003, Japan Coal Energy Center and Japan Iron and Steel Federation), which was developed with support from METI’s Agency for Natural Resources and Energy. Construction was completed in May 2008, and this plant is now operating smoothly. In August, JFE Steel blew in a new type of shaft furnace which uses scrap as an iron source at its East Japan Works Keihin District, and this plant is also operating smoothly. Construction of coke dry quenching (CDQ) equipment is scheduled for completion at JFE Steel West Japan Works Kurashiki District (February 2009) and Fukuyama District (May 2010), Sumitomo Metal Wakayama Works (June 2009), and Mitsui Mining Co., Ltd. Kita-Kyushu Coking Works (April 2011). In 2008, JFE Bars & Shapes Corporation Sendai Works constructed a new environment-conscious high efficiency electric furnace which uses waste heat to preheat the raw material. The introduction of these CDQ plants and electric furnace were adopted as projects under NEDO’s program of grants to businesses for rationalization of energy use. JFE Bars & Shapes is also changing over from C heavy oil to natural gas as a fuel for the heating furnaces in its billet and bloom rolling shop under the Toshi-gas Shinko Center (city gas promotion organization) program of grants for adoption of natural gas in energy-intensive equipment for fiscal 2008.

The Kyoto Protocol provides an approach called the Clean Development Mechanism (CDM) for supporting greenhouse gas reduction in the developing nations. The Japan Iron and Steel Federation and Japanese steel companies are actively promoting CDM to ensure achievement of the target of the steel industry’s Voluntary Action Plan.

The Japanese steel industry is also positively promoting recycling and reuse of wastes and by-products. The main efforts in this field are as follows. Nippon Steel Kimitsu Works started up a 5th rotary hearth furnace (Kimitsu No. 3RHF) to recycle steel dust by-products. JFE Steel constructed steelmaking dust recycling equipment for reducing ferrous oxides and zinc oxides at West Japan Works Fukuyama District. Nippon Metal Industry Co., Ltd. started operation of a plant at its Kinuura Works, which recovers valuable metals and reduces the volume of waste by melting and reduction of by-products generated in the stainless steel production process. Sumitomo Metal introduced a pressurized steam aging process for steelmaking slag at its Wakayama Works, which accelerates the recycling of steel-making slag. Nippon Steel started up plastic recycling systems by a waste plastics recycling process using coke ovens at both Nagoya and Kimitsu in 2000. Since then, the company has developed a system with nationwide coverage by constructing additional plants atYawata, Muroran, and Oita Works. In 2008, the company’s cumulative treatment of waste plastics reached 1 million tons. In October 2008, Nippon Steel and Kobe Steel established a joint venture company for recycling of steel dust by-products and production and use of reduced iron.

In 2008, the ISIJ began developmental research on dust making technology under a 3 year plan, in which it will study recycling technologies for electric furnace dust by-products/formation products and separation/recovery technologies for scarce resources (see Sec. 6.3).

The efforts of the steel industry are not limited to direct environmental improvements at steel works and other production plants. During 2008, all companies also announced a large number of new products which contribute to environmental improvement, including high strength plates, hot-rolled sheets, tubular products, chrome-free coated steel sheets. (See items on New Products.)

4. Technology Trade and Development
4.1. Technology Trade

As a breakdown of technology trade in 2008, the results of a survey of the Sustaining Members of the ISIJ (79 companies) are shown in Table 3. Technology exports increased to 41 items from 17 in 2007. Although the number of imports had been zero since 2004, there was one technology import item in 2008.
By region, Asia accounted for 51% to technology exports, followed by North America (22%). By field of technology, processing/heat treatment accounted for 76% of the total, followed by steelmaking (10%) and raw materials/ironmaking (7%).

Figure 6 shows the balance of technology trade in the steel industry up to fiscal 2007. The amount of considerations received for technology exports decreased by 9% from the previous fiscal year, while considerations paid for technology imports increased.
4.2. Research Expenditures/Number of Researchers

Figures 7–9 show the trends in the ratio of corporate research expenditures to sales, number of researchers per 10,000 employees, and research expenditures per researcher according to the “Report on the Survey of Research and Development” published by the Statistics Bureau, Ministry of Internal Affairs and Communications. In all industries, the ratio of research expenditures to sales has been substantially flat since 2002. In the steel industry, the ratio had shown a decreasing trend since 1998 due to increases in total sales, but after 2005, this ratio increased at around 1.00% for three consecutive years due to rapid increases in research expenditures (in fiscal 2007, the increase was ¥14.5 billion in comparison with the previous fiscal year).

The number of researchers per 10,000 employees in the steel industry increased greatly from 312 in 2007 to 357 in 2008. This was due to an absolute increase in the number researchers, from 4,345 to 4,562, in combination with a significant decrease in the total number of employees, from 139,332 to 127,666.

Research expenditures per researcher had decreased in the steel industry and were approaching those in all industries, but due to the sharp increase in research expenditures beginning in 2005, expenditures per researcher also increased in 2007 for the 3rd consecutive year.

4.3. Trends in Research and Development Utilizing Public Funds

As iron and steel-related technology development projects using public funds, the themes which were completed in fiscal 2008 were:

① “Development of new building structure with innovative high tensile strength steel plate,”
② Development of innovative process technology of advanced titanium alloy,” and
③ “Leading study of innovative iron making process.”

The following two new projects were begun in fiscal 2008:
① “Technology development of environmental harmonic iron making process” (FY2008–2012, development of technology for CO₂ discharge reduction from the blast furnace and development of separation technology for CO₂ from the blast furnace gas and

One continuing project is in progress, “R&D project on fundamental technology for steel materials with enhanced strength and functionality” (FY2007–2011, development of innovative technology for welding and joining of high quality steel and fundamental development of advanced technology of controlled forging).

The results of a survey of iron and steel-related research/technology development themes which are being carried out with public funding, covering the main Sustaining Member companies of the ISIJ, are shown in Table 4. In particular, members have undertaken a large number of themes in the environment and energy field, and the materials field.

5. Development of Human Resources in Technical Fields

Because securing and training human resources in technical fields is considered to be an issue that affects all industries, two years ago, the Ministry of Economy, Trade and Industry (METI) and the Ministry of Education, Cul-
ture, Sports, Science and Technology (MEXT) cooperated in launching the “Industry-Academia Partnership for Human Resource Development” project. Beginning in fiscal 2007, the ISIJ cooperated in compiling the issues and responses related to human resources development in the materials field as the joint Secretariat of the Materials Sub-committee, which is responsible for discussions in this area. Based on the results, in fiscal 2008, preparation and trials of concrete educational materials and curriculums though industry-academia cooperation were developed under a 3 year plan centering on the Japan Research and Development Center for Metals (JRCM). Advanced technical contents are being provided by private corporations, and preparation of educational materials and trial courses for students in materials-related fields are being planned in cooperation with university students. In this concept, a trial of a long-term internship system is being planned. Under the system, companies propose the contents of themes and participate in providing instructors, and it will be possible for industry to succeed to the results following the completion of the project.

The purpose of the traditional educational programs of the ISIJ (Steel Engineering Seminar, Steel Engineering Specialized Course, Steel Engineer Advanced Seminar) is to develop core technical human resources on a cross-industry basis. In contrast to this, the results of the above-mentioned Partnership project are intended to fill the gap between academia and the industrial world, and to maintain and enhance Japan’s industrial competitiveness through cooperation in this effort.

6. Technology Creation Activities of the ISIJ

6.1. Technical Committees

In the ISIJ, research on iron and steel production technology and dissemination of the results of technology development are mainly conducted by the Technical Society. The classification and contents of those activities are shown in Table 5. In particular, Technical Committees, which are engaged in activities unique to the ISIJ, are organized so as to correspond to the Divisions in the Academic Society, by dividing the committees into groups by the content of activities, and thereby promote industry-academia collaboration. Exchanges such as participation of university researchers in Technical Committee Meetings, joint planning with the Divisions of the Academic Society, and mutual involvement in administration have taken firm root.

On the other hand, periodic programs within the Committees are also active. As of the present time, a number of Committee Meetings have been held in fiscal 2008 to take up important topics as common/priority themes, as shown in Table 6. A total of 35 meetings have been held (Spring: 17 meetings, Autumn: 18 meetings), which is the same as in fiscal 2007. The total number of participants was 2,867 (fiscal 2007: 2,826), and a total of 61 university researchers participated in the Committee Meetings (fiscal 2007: 63). Thus, the number of participants in both cases was on substantially the same level as in the previous fiscal year.

Among noteworthy events, the Quality Control Committee reached an important milestone, holding its 100th meeting, which was celebrated with a Commemorative Lecture.
Technical Subcommittees are established to jointly study designated technical issues on a priority basis. In fiscal 2008, a total of 22 Technical Subcommittees were active, including eight new Technical Subcommittees launched during fiscal 2008. Eleven items were completed, including “Cooling Technology for Run-out Table” (Rolling Theory Committee), and eight new items were started, including “Reducibility Analysis of CO₂ in Model Steel Plant” (Heat Economy Technology Committee).

Plans aiming at activation of Committees were also implemented, continuing from fiscal 2007. These included seminars for young engineers, study tours/seminars with other industries.

### 6.2. Interdisciplinary Technical Committees

Each interdisciplinary technical committee studies interdisciplinary, inter-industry technical issues with a period of within 3 years.

The Joint Research Committee on Automotive Materials, which was organized jointly by the ISIJ’s Interdisciplinary Technical Committee on Desirable Steel Materials for Automobiles and the Materials Committee, Society of Automotive Engineers of Japan, Inc., edited and published a “High Strength Steel Handbook.” In commemoration of its publication, a symposium was held jointly with the 156th ISIJ Meeting (September 24, 2008). In the Handbook, Application Guidelines for High Strength Steel were compiled jointly by material makers and users. The Handbook, which has attracted interest in both Japan and other countries, is a comprehensive summary of the distinctive features of high strength steels from the viewpoint of materials science, as well as important points related to use technologies and the application of parts.

The activities of the Interdisciplinary Technical Committee on Microstructural Effects on Fracture Properties of Modern Structural Steels were concluded in fiscal 2008. The Committee organized the results of a survey of the literature and study tour meetings in connection with recent visualization techniques from the viewpoints of both the metallic microstructure and fracture properties of steels for welded structures and steels for machine structural use, and summarized this work in a report. As a successor to this Committee, the Interdisciplinary Technical Committee on Technology for Saving Resources and Energy in Modern Structural Steels is scheduled to begin work from fiscal 2009.

### 6.3. Research Support and Research Groups

The program “ISIJ Innovative Program for Advanced
Technology," which is an activity that was adopted by the ISIJ 3 years ago and is supported by this organization with the aim of creating a path for early use of ideas from universities and others in industry. One theme which was begun in the first year of the program was completed in fiscal 2008. In addition to two other themes that are currently in progress, two new themes which were adopted in fiscal 2008 have already been started.

During fiscal 2008, 23 research groups were active. Six of these concluded their work in March 2009. An outline of the research groups which concluded their activities is shown in Table 7.

<table>
<thead>
<tr>
<th>Research Group</th>
<th>Research period</th>
<th>Division</th>
<th>Group leader</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology for New Refining Process using Multi-phase Flux</td>
<td>April 05 to March 09</td>
<td>High Temperature Process</td>
<td>Fumitaka Tsukihashi, the Univ. of Tokyo</td>
<td>The roles of the solid phase and liquid phase in multi-phase fluxes will be clarified, and their reactions and interfacial phenomena will be investigated. A new process using multi-phase flux will be proposed based on a study of design guidelines for the composition/microstructure of new fluxes.</td>
</tr>
<tr>
<td>New Sintering Process through Designing of Composite Granulation &amp; Bed Structure</td>
<td>April 05 to March 09</td>
<td>High Temperature Process</td>
<td>Eiki Kasai, Tohoku Univ.</td>
<td>Fundamental research on the optimum designs of raw material blending, granulation, bed structure, and metallurgical properties will be performed for the purpose of establishing the technical principle of a new sintering process based on the composite granulation and bed-structure, aiming to cope with the drastic shift of the raw materials to limonitic resources, which are characterized by large reserves but lower density, Fe grade, and strength.</td>
</tr>
<tr>
<td>Novel steel process control based on on-line optimization technology</td>
<td>April 05 to March 09</td>
<td>Instrumentation, Control and System Engineering</td>
<td>Toshiharu Sugai, Kyoto Univ.</td>
<td>Based on advanced feedback control including online optimization, nonlinear control and hybrid systems modeling and control, fundamental technologies for the next-generation iron and steel manufacturing process control will be established to rapidly cope with changes in operating conditions due to new product developments, etc.</td>
</tr>
<tr>
<td>High-accuracy, High-function Leveling Process</td>
<td>April 05 to March 09</td>
<td>Processing for Quality Products</td>
<td>Matsuho Ataka, Tokyo Denki Univ.</td>
<td>A fundamental review of the leveling process, which is the final process for iron and steel products, will be carried out from the viewpoints of both the deformation characteristics of materials and leveling theory for the purpose of developing a high-accuracy, high-function leveling process. There is a high possibility that these results can be developed to smooth production operations and improve product accuracy.</td>
</tr>
<tr>
<td>Materials Science of Ultrahigh Plastic Strain</td>
<td>April 05 to March 09</td>
<td>Microstructure and Properties of Materials</td>
<td>Minoru Umemoto, Toyohashi Univ. of Technology</td>
<td>The principle of the change in microstructure such as grain refinement or dissolution of precipitates and the change in mechanical properties such as strength and ductility by applying ultra high plastic strains will be clarified. The usage of clarified principle to extend the life of machine parts and the development of materials with superior properties by applying ultra high plastic strains will be discussed.</td>
</tr>
<tr>
<td>Cut Edge Corrosion Mechanism and Life Predictions of Pre Painted Steel Sheets for Residential Use</td>
<td>April 05 to March 09</td>
<td>Microstructure and Properties of Materials</td>
<td>Tadashi Shinozaka, National Institute for Materials Science</td>
<td>An analysis of the factors influencing rust prevention characteristics will be carried out through elucidation of the mechanism of edge corrosion in painted steel sheets for use as construction materials and establishment of a life prediction technology, with the aim of improving existing materials and proposing design guidelines for chrome-free painted steel sheets.</td>
</tr>
</tbody>
</table>

A new research group system was inaugurated in fiscal 2007, consisting of knowledge-intensive type groups (Type A), technology development type groups (Type B), and groups involved in the search for new fields related to iron and steel (Type C). Seven new research groups will begin activities under this system in fiscal year 2009 (Table 8).

Acknowledgement

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<table>
<thead>
<tr>
<th>Research Group</th>
<th>Type</th>
<th>Division/Committee</th>
<th>Group leader</th>
<th>Outline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental construction for hydrogen embrittlement</td>
<td>A</td>
<td>Microstructure and Properties of Materials</td>
<td>Kenichi Takai, Sophia Univ.</td>
<td>Fundamental construction of a common basis for research on hydrogen embrittlement which, while essential in this research, includes problems that cannot be solved by a single research institution. Concretely, this will include construction of techniques enabling hydrogen charging and analysis of trace amounts of diffusable hydrogen with high accuracy and good reproducibility, detection of defects, and hydrogen embrittlement evaluation method, etc.</td>
</tr>
<tr>
<td>Control of micro- and macro-segregation</td>
<td>A</td>
<td>High-Temperature Process</td>
<td>Hisao Esaka, National Defense Academy of Japan</td>
<td>Review of micro-segregation models, and construction of a model which enables prediction of interdendritic precipitates with good accuracy. Understanding and modeling of the mechanism of macro-segregation originating in transfer of liquid phase + solid phase, and proposal of measures for achieving a drastic reduction in macro-segregation based thereon.</td>
</tr>
<tr>
<td>Technological Principle for Low-Carbon Sintering</td>
<td>A</td>
<td>High-Temperature Process</td>
<td>Eiki Kasai, Tohoku Univ.</td>
<td>Lower limit of the agglomeration agent rate for the iron ore sintering will be quantitatively represented based on the analyses of their combustion/oxidation rate and heat transfer rate in the sintering bed. Further the possibility of the utilization of other agents than carbonaceous materials, such as biomass, wastes containing metallic iron, etc. will be studied. Finally, a new technological principle to minimize the CO₂ emissions will be proposed.</td>
</tr>
<tr>
<td>Standardization of analytical methods for characterization of free-CaO in steel slag</td>
<td>B</td>
<td>Analysis Technology Committee</td>
<td>Tatsuhiko Tanaka, Tokyo Univ. of Science</td>
<td>Standardization of an analytical method for characterization of free-CaO in steel slag, and development of a technique for separation and analysis of CaO by morphology for further improvement of analytical accuracy and improvement of evaluative reliability in research and development on slag production processes, aiming at expansion of the usability of iron and steel slag.</td>
</tr>
<tr>
<td>Development of heat transfer model of run-out table in hot strip mill</td>
<td>B</td>
<td>Rolling Theory Committee</td>
<td>Hidetoshi Ohkubo, Tamagawa Univ.</td>
<td>Construction of a cooling model for cooling on the run-out table in the hot strip mill by elucidation of the water flow velocity distribution by numerical analysis of the laminar impact point and water flow areas on steel plates, and experimental clarification of the effects of heat transfer properties and scale at respective flow positions.</td>
</tr>
<tr>
<td>High Precision Process Control via Large Scale Database and Simulation Models</td>
<td>C</td>
<td>Instrumentation, Control and System Engineering</td>
<td>Yasumasa Fujisaki, Kobe Univ.</td>
<td>Development of iron and steel process control techniques which realize deviation-free production by estimation and control of material conditions and process conditions that cannot be measured directly, including their deviations, via a large-scale database of data collected in the field and knowledge of physical simulation models.</td>
</tr>
<tr>
<td>Application of advanced neutron source for research of elemental operation in steel</td>
<td>C</td>
<td>Process Evaluation and Material Characterization</td>
<td>Masato Ohnuma, National Institute for Materials Science</td>
<td>Establishment of a time-slice measurements applicable under various environments utilizing the features of neutron as nondestructive probes, by performing fundamental research through experiments and data analysis under a system of close cooperation among industry, academia, and government, with the aim of efficiently promoting research on iron and steel materials using neutron techniques.</td>
</tr>
</tbody>
</table>

(Note) Knowledge-intensive type (type A), technology development type (type B), search for new fields related to iron and steel (type C)
1. **Blast Furnace**

**Reline of Kobe No. 3 Blast Furnace**

Kobe Steel, Ltd.

Kobe Steel completed the 4th reline of No. 3 Blast Furnace at Kobe Works on December 17, 2007, which was shut down on November 1, 2007 and relined during 45 d. This period for relining which include furnace shell replacement work is the shortest record in Japan.

No. 3 Blast Furnace (3rd) was operated for 24 years and 7 months since April, 1983.

In order to shorten the period for furnace shell replacement, Kobe Steel introduced ring-method, in which shell is divided to 5 pieces and they are replaced respectively.

To ensure adaptability for iron production, the inner volume of No. 3 Blast Furnace was extended from 1 845 to 2 112 m³. Permeability was improved to reduce coke rate and using low-grade ore for reduction of CO₂ discharging. In this relining work, remote control system at cast house and new slag grinding system were also introduced.

After 17 d later from the furnace blow in, 4 000 t/d of iron production was achieved and has been continued stable operation. The furnace campaign life is expected to be 25 years through installation of high conductivity carbon brick for hearth.

2. **Heavy Plate**

**Development of “FCA-W Steel Plate,” the World’s First High-Tensile-Strength Plate for Improving the Fatigue Strength of Welded Joints**

Sumitomo Metal Industries, Ltd.

Sumitomo Metal Industries, Ltd. (Sumitomo Metals) has developed “FCA-W (Fatigue Crack Arrester-W) steel plate,” which exhibits high fatigue strength in welded joints. In developing this plate, Sumitomo Metals improved the outstanding resistance against fatigue fracture of its high-tensile-strength FCA (Fatigue Crack Arrester) steel plate.

It has generally been thought that fatigue strength in welded joints was constant, and that this couldn’t be improved with steel plates, no matter what kind of steel plate was used. For this reason, in order to ensure a predetermined fatigue strength, various other methods have been employed, such as increasing the thickness of plates, attaching reinforcement members to welded joints and employing weld-toe grinding to avoid the concentration of stress.

In developing “FCA-W steel plate,” Sumitomo Metals strictly controlled the chemical composition of the steel, to make it function to prevent the initiation of fatigue cracks in welded joints as well as to control the propagation of fatigue cracks, a property possessed by FCA steel plate.

This property of “FCA-W steel plate” of being able to prevent the initiation of fatigue cracks can be directly reflected in the fatigue design of steel structures, allowing the structure of ships to be designed more freely. Furthermore, the plate extends the life of ship parts to which it is applied without increasing the thickness of plates and attaching reinforcement members, and fuel efficiency is improved since increases in hull weight are avoided. Moreover, cost reductions can be expected through the elimination of weld-toe grinding and other processing.

The “FCA-W steel plate” will be first applied to parts of the LNG carrier where larger fatigue damage can be expected: the area connecting the tank covers and the upper deck (Refer to Fig. 1). When applying “FCA-W steel plate” to ship structures, ClassNK, one of the world’s leading shipping registers, has formulated a new “fatigue design S–N curve” for “FCA-W steel plate” based on Sumitomo Metals’ fatigue test results.

According to the design S–N curve, the basis of fatigue design for ships, the fatigue life of the areas to which the steel plates will be applied will be markedly improved to around double that of conventional plates.

The mechanical properties other than fatigue resistance, and basic performance as steel plates, including weldability and workability, are equal to, or higher than general high tensile strength steel plates.

Sumitomo Metals will contribute to the improvement of not only ship but other steel structures safety and reliability and the reduction of lifecycle costs by using this newly developed steel plate.

![Fig. 1. Areas of the LNG carrier using “FCA-W steel plate.”](https://example.com/fig1.png)

(The above figure was drawn by the calculation model for evaluation of hull structure provided by ClassNK.)

**Achieving a Month Total Steel Plate Production over 500 Thousand Tons**

JFE Steel Corporation

JFE Steel has achieved a month total steel plate production on a slab base over 50 thousand tons for the first time on January 2008. JFE has three plate mills at West Japan
Works (Kurashiki and Fukuyama) and East Japan Works (Keihin). 161 thousand tons come from the mill at Keihin. The mills at Kurashiki and Fukuyama produced 184 and 162 thousand tons, respectively.

In recent years, customers’ quantity as well as quality requirements are becoming increasingly sophisticated, stricter, and more diverse. To increase plate capacity and ensure a stable supply of high performance steel plates, in 2005, JFE Steel launched an equipment modernization project aiming at increased its plate production capacity, beginning with system renovation for rolling and shearing at the Keihin plate mill. As a result, the company’s plate production in FY2007 has achieved to be 5.7 million tons on a slab base. JFE Steel is also continuing its efforts such as, the installation of No. 3 Reheating Furnace at Fukuyama. The plan to increase plate production to approximately 6 million tons by the end of fiscal 2008 (the end of March 2009) has been set. The achieving a month total over 50 thousand is the first step for the above mentioned target.

In Korea and China, not only increases in production capacity but also constructions of new mills are being planned and some of these plants are beginning to come on stream. Against this background, JFE Steel, as a pioneer of TMCP, is also developing new high performance steel plates utilizing, such as, Super-OLAC (On-Line Accelerated Cooling) and HOP (Heat treatment On-line Process) equipments, while also increasing its production capacity for high performance plates. Those materials are shown in the table below.

<table>
<thead>
<tr>
<th>Application Fields</th>
<th>New high performance plates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship Buildings</td>
<td>400MPa class yield strength for container vessels</td>
</tr>
<tr>
<td></td>
<td>Heavy thickness steel plate with superior crack arrestability</td>
</tr>
<tr>
<td></td>
<td>Steel for ship inside protection for Ballast Tank</td>
</tr>
<tr>
<td>Building construction</td>
<td>On-line production type low-YI 760MPa plate</td>
</tr>
<tr>
<td>Energy</td>
<td>DQ – HOP type JFE-HITEN610U2 for large LPG storage Tanks</td>
</tr>
<tr>
<td>Industrial machinery</td>
<td>960/1030MPa class yield strength plates with high hydrogen embrittlement resistance</td>
</tr>
</tbody>
</table>

The First Application of JFE-HITEN610U2 Produced by Combination of Applying DQ and the On-line Heating Technology, HOP (Heat treatment On-line Process) for a Large LPG Storage Tank

JFE Steel Corporation

JFE Corporation’s high strength steel plates, JFE-HITEN 610U2, produced by combination of applying direct-quenching (DQ) with Super-OLAC (On-Line Accelerated Cooling) and the on-line heating technology, HOP (Heat treatment On-line Process) have been qualified as a suitable material for pressure vessels by the China Standardization Committee on Boilers and Pressure Vessels.

The plates have been manufactured and shipped for a 3000m³ capacity LPG storage tank in China on July 2008. Those showed excellent formability and weldability through press forming and man holes’ installing processes of the spherical tank.

JFE-HITEN 610U2 produced by DQ followed by tempering with furnace (DQ-FT) has been qualified as [Weldable High Strength Steel Plates] and [Supplementary Requirements High Strength Steel Plates with Low Susceptibility to Cold Cracking] by the Japan Welding Engineering Society’s Standards of WES 3001 and WES 3009. The material has also been qualified by the China Standardization Committee on Boilers and Pressure Vessels and widely used for pressure vessel constructions.

At the timing of annual renewal of qualification of the material by the China Standardization Committee on Boilers and Pressure Vessels and widely used for pressure vessel constructions, the material produced by DQ followed by on-line tempering with HOP has also been applied for the qualification. After evaluations of weldability and formability as well as production stability of the material, the qualification has made on May 2008.

3. Cold Rolling Steel

Stainless Steel Sheet Developed for Cylinder Head Gaskets

Sumitomo Metals Industries, Ltd. and Sumitomo Metals (Naoetsu), Ltd.

A stainless steel (NAR-301L HS1) for cylinder head gaskets of automobiles was developed. The fatigue strength of HS1 after press forming had been improved by 36%.

The cylinder head gasket is a metallic part for the automobile engine. The gasket is inserted between the cylinder head and the engine block to prevent the leak of flue gases and cooling water. Sealing properties are by bead on the gasket. The bead is trapezoidal shaped section, formed by press forming. To retain a good seal, spring properties and fatigue strength are required for the stainless steel sheet used for the gasket.

In HS1, the average diameter of crystal grain is refined to 1–2 μm, by adjusting chemical composition (adding the niobium and nitrogen etc.) and the totally designed manufacturing condition (low temperature annealing etc.).
Consequently, the surface roughness after the bead forming become smooth and it prevents the initiation of the fatigue fracture. As a result, the excellent fatigue property is realized.

This material won the 31st Japan Institute of Metals Technical Development Award in 2008.

Recently, to make improve in the efficiency engine such as fuel consumption, high performance and reliable gasket material is demanded. The number of automobiles and automotive companies that adopts HS1 is increasing.

Development of 1320 MPa Grade Cold-rolled Ultra High Strength Steel Sheet with Excellent Formability

JFE Steel Corporation

JFE Steel Corp. developed the 1320 MPa grade cold-rolled ultra high strength steel (UHSS) sheet with excellent formability suitable for automotive structural parts, which is expected to contribute to the reduction of CO2 emission by weight reduction. Tensile strength of 1320 MPa is the highest strength level in automotive structural use. The developed steel improved the shape accuracy of formed parts by its minimized mechanical properties scattering taking advantage of WQ-CAL (Continuous Annealing Line with Water Quenching equipment) process. Hydrogen embrittlement of high strength steel is another principal problem. The developed steel can be produced with low alloy content by rapid cooling of WQ process, which is effective to reduce the risk of hydrogen embrittlement.

The developed steel has been roll-formed by MARUJUN Co., Ltd and has been applied to bumper reinforcement for the North American models of “Fit” and “CR-V” of Honda Motor Co., Ltd. since 2006. In recent years, bumper reinforcement parts were partly produced by new forming processes, as hot-stamping or extrusion of Aluminum alloys for weight reduction. However, those processes have problems of high cost and low productivity. The developed steel can be formed into automotive parts by cold-working, which provides both high crash worthiness of parts and low production cost.

Environment-friendly, High-strength Ni, Mo-free Case-hardening Steel [ECOMAX]

Sanyo Special Steel Co., Ltd.

Sanyo Special Steel Co., Ltd. has developed Ni, Mo-free high strength case-hardening steel ECOMAX. It boasts of improved toughness and fatigue strength as well as excellent formability.

Recently, high strength steel is increasingly in demand for miniaturized and light-weighed automobile parts for better gas mileage. Although high strength case-hardening steels are conventionally alloyed with considerable amounts
of as Ni and Mo, the wild fluctuating price of these elements has raised the demand for less expensive materials. In addition, worldwide environmental concerns have been forcing industries to save finite natural resources and to reduce energy consumption.

ECOMAX contains no Ni or Mo but is alloyed with properly balanced amounts of Si, Mn, Cr and other additives. Figure shows charpy impact value and roller pitting life of ECOMAX in comparison with JIS SCM420. Both properties are greatly improved due to ECOMAX's controlled microstructure stemming from optimized combination of alloy designing and manufacturing process. Since additions of Ni and Mo degrade cold-formability and machinability, Ni, Mo-free ECOMAX can also reduce energy consumption and production cost.

ECOMAX contributes to both ecology and economy. ECOMAX is expected to be used for transmission gears, differential gears, CVJs and other automobile powertrain parts.

5. Steel Pipes and Tubes

SG Tube Capacity Expansion for 3rd Generation PWR

Sumitomo Metal Ind., Ltd.

Sumitomo Metal Ind., Ltd. (SMI) increased its production capacity for steam generator (SG) tubes by about 30%, and remodeled the production lines for longer length SG tube for the new type pressurized water reactor, so called 3rd generation PWR, in Steel Tube Works in Amagasaki JAPAN in October 2008.

SMI won the order for SG tubes to be fitted to the first AP1000, a new type of reactor developed by Westinghouse Electric Company, in both China and the USA. This is due to appreciation for SMI's superior performance and high technical capability cultivated for the conventional PWR. Since SG tube is difficult to manufacture because of alloy 690, a nickel-base alloy, and extremely high quality requirement, only three world's suppliers including SMI can produce it.

SMI's SG tubes have a unique feature that is very low base noise at eddy current examination during pre-service inspection (PSI) and/or in-service inspection (ISI). This is because the dimensional variation of SG tube is quite small by applying the patented technology that is “Cold Drawing with pressurized lubricant”. As a result, the detectability of flaws can increase and the reliability of SG tubes can be enhanced (Fig. 1). Customers have been grateful for this feature.

Rising demand for power and need to reduce CO₂ emissions have caused many nations to consider building new nuclear power plants. Therefore the demand of SG tubes is also expected to increase in the future. SMI will contribute by supplying the high quality SG tubes as well as the steel pipe and tubes to the energy industry.

New Finishing Line for High End OCTG (Oil Country Tubular Goods)

Sumitomo Metal Industries, Ltd.

The expanding energy demand, driven by the economic growth of BRICs, has been accelerating the exploration and production of oil and gas wells. In response to the growing demand and customers’ requests for High End OCTG (Oil Country Tubular Goods), Sumitomo Metal Industries, Ltd. has built new finishing line at the Wakayama Steel Works (Kainan), complete with integrated finishing lines for heat treatment, threading and packing. The new facility began operations at the end of June 2008.

In the past, small-diameter OCTG pipes were identified by bundled lots, and fabrication records were maintained only on paper. In response to the stringent demands from our customers for technical information and better quality assurance, process-control computers and automatic identification systems are introduced to all relevant parts of the finishing lines. This has allowed us to meet the technical demands of our customers by implementing fully piece-by-piece identification control. We now maintain fabrication records and technical information for each piece of steel pipe in digital format to facilitate secure long-term storage and easy distribution to customers.

The new finishing lines have on-line non-destructive testing equipment, which not only conform to all grades of standards but also contribute to high productivity.

Moreover, Joint tightening equipment with high torque capacity is introduced to meet the increasing demand for
To improve industrial safety, we deployed protective fences and electromagnetically interlocked doors to all relevant parts of the finishing lines to ensure worker safety. Thus, nobody can access the finishing lines without taking safety measures. To decrease the frequency of access to finishing lines, we undertook extensive automation particularly of subordinate processes that often used to require manual labor. In this way, we succeeded in meeting the strict safety requirements imposed on us by our customers.

A High Strength Line Pipe Was Adopted in Earnest
JFE Steel Corporation

In 2008, high strength line pipe X80 and high strain X80 line pipe was adopted by China and North American project in earnest.

The natural gas is likely used to reduce of the CO₂ emission while energy consumptions is increased worldwide. Use of the high strength line pipe such as X80 is effective to lower the cost of a long-distance transportation pipeline. However, it was with big challenge when the long-distance pipeline was laid by severe environment including seismic zone and the permafrost zone. In these environment, there are potential danger of the large deformation and local buckling by activity of the fault and liquefaction of the ground in the seismic zone and the frost heaving phenomenon of the permafrost zone as shown in Fig. 1.

To improve local buckling performance without heavy wall thickness of pipe, the high strain line pipe which balanced safety and low cost pipeline was developed by controlling a work hardening characteristic of materials as shown in Fig. 2. A high-strength steel pipe confirmed a re-liability of the pipeline by evaluating the buckling characteristic in cooperation with consumers and the adoption at realized in 2008.

6. Instrumentation, Control and System Engineering

Measurement of the Inside of the Blast Furnace Using Cosmic Ray Muons
Nippon Steel Corporation

Nippon Steel, in a joint research program with the High Energy Accelerator Research Organization and Riken, has developed the technology to detect internal states of the blast furnace using cosmic-ray muons.

Cosmic-ray muons can be used for measurement of the internal structure of a substance, because the amount of transmission attenuates according to density multiplied by thickness. Using two 1 m×1 m plastic scintillators, where each were divided into 10 cm squares and arranged in parallel to each other, as detectors, we obtained the intensity rates on the transmission side and the opposite side of the furnace, then compared them with the results of the theoretical calculations.

With our Oita No. 2 BF, relined in 2004, by first taking measurements of the hearth-bottom after the furnace was blown out, we ascertained that the density-distribution corresponded to the respective survival states of the remaining-iron portions and the brick parts. Subsequently, taking measurements of the hearth-bottom of the blast furnace about one month after in operation, we estimated the density distributions within the furnace. Using density differences between the iron portions and the brick parts, and from the comparison of the actual measurement values with the calculated values, we estimated the brick wear amounts. By taking these measurements, we have clarified that, by using cosmic-ray muons, we can estimate both density distributions inside the blast furnace and levels of wear of hearth-bottom brick.
7. Environment

One Million Tons of Waste Plastics Recycled
Nippon Steel Corporation

Nippon Steel, with the objectives of contributing to the implementation of energy conservation and CO₂ reduction, being held in the voluntary action plan of the JISF, and the formation of a recycle-oriented society, is endeavoring to make effective use of waste plastics by the coke oven chemical materials process.

Since the fall of 2000 when we started recycling waste plastic, the cumulative total of waste plastics that we recycled reached one million tons, on May 1, 2008. This social contribution is equivalent to a reduction of 3.2 million tons of CO₂, or a reduction of 4 million cubic meters of landfill.

For each of our steelworks, the total quantity disposed of may be broken down into: Kimitsu 430 000 tons, Nagoya 240 000 tons, Yawata 160 000 tons, Muroran 120 000 tons, and Oita 40 000 tons.

For our waste-plastic recycling, mainly targeted at general household garbage, based on the Act on the Promotion of Sorted Collection and Recycling of Containers and Packaging of April 2000, we mainly use the preparation equipment consisting of foreign-substance remover, crusher, volume-reducing former, etc. and the coke-oven charging equipment, all installed in the compound of the steelworks. Installing the equipment at Nagoya and Kimitsu in 2000, at Yawata and Muroran in 2002, and at Oita in 2005, we now have a total disposal capacity of 250 000 tons a year, the world’s largest capacity for recycling plastic. With our recycling system nearly covering the entire country, we recycle about 30% of all the container and package plastic entrusted to the Japan Containers and Package Recycling Association by individual local governments.

By making full use of our existing coke-oven batteries, we treat plastic by high-temperature dry-distillation at about 1 200°C and thermal decomposition into hydrocarbon oil (40%), coke (20%), and coke-oven gas (about 40%). In this way, we achieve an approximately 100% effective utilization of waste plastics, as a chemical raw material, an ironmaking raw material and a source of energy. This technology has been awarded the Gold Medal for Good Design Award (2002), the Japan Institute of Energy Award (2003), and the Nikkei Global Environment Technology Award (2003).

Pressurized-type Steam Aging Process for Steel Slag
Sumitomo Metal Industries, Ltd.

In Wakayama steel works, Sumitomo Metal Industries, Ltd., pressurized-type steam aging process has been developed and introduced to improve slag aging efficiency and slag product quality.

Conventional Problems

The volume of the unmelted quicklime (CaO) in steel slag expands when it meets water. Therefore, before using as product, steel slag needs aging treatment, in which quicklime reacts with water or steam and finishes its expansion completely. The natural aging of steel slag requires two years. The conventional open yard steam aging of steel slag requires at least 2 d. But it has some problems, such as the requirement of huge aging yards with cover sheets.

Developed Features

Sumitomo Metal Industries’ recent technology attained increase of aging efficiency. This technology allows steel slag to have reaction under pressurized steamy atmosphere, thus making it possible to increase reaction speed 24 times as high as that of open yards. To apply this technology for actual process, Sumitomo Metal Industries has developed pressurized-type steam aging equipment with some devices, which are large-scale pressure container and automatic slag charging bucket. In Wakayama steel works, as a result of...
introducing two sets of equipment, treatment time is shortened into only 2 h. In addition, the process improves stability of product quality by equalization of hydration reaction. Also aging yard area, labor cost and energy consumption are mitigated. Thus the developed process greatly contributes for realization of a recycling society with reduction of environmental load. These results were so evaluated that Sumitomo Metal Industries won Industrial Science and Technology Policy and Environment Bureau, METI’s Director-General’s Prize in 2007 at Clean Japan Center Resource Recycling Technology and System contest. Introduction of this process to other companies are making progress.

8. Others

High Thermal Conductivity Tool Steel for Die Casting “DHA-Thermo”
Daido Steel Co., Ltd.

Daido Steel Co., Ltd. has developed a new high thermal conductivity tool steel for die casting “DHA-Thermo” which will offer shorter die-casting cycle time and refined microstructure product. (Thermal conductivity: 1.7 times of that of JIS SKD61 (AISI H13).

It’s essential to maintain the die at low/stable temperature during die-casting in order to ensure adequate die life, reduce die-casting cycle time and increase solidification rate of product. In general, cooling capability of tool steel is improved by increase of thermal conductivity. Therefore the commercial interests had been mainly focusing on high thermal conductivity tool steel.

Generally, reduction of alloying elements in steel for higher thermal conductivity leads to lower mechanical properties. For the development of DHA-Thermo, it was very important to ensure both high thermal conductivity and proper toughness/strength at elevated temperature. To balance high thermal conductivity with adequate mechanical properties, the influence of alloying elements on steel properties was fully investigated. Consequently, the optimal chemical composition steel “DHA-Thermo” was developed.

Die-casting test results of DHA-Thermo show that the die temperature is decreased by approximately 100°C compared with that of JIS SKD61 and the microstructure of products is refined. Cost savings through reduction of die-casting cycle time and improvement of microstructure will be also expected in commercial production.

![Outline of pressurization-type steam aging equipment.](image)

Fig. 1. Outline of pressurization-type steam aging equipment.

![Difference in die temperature on die casting tests.](image)

Fig. Difference in die temperature on die casting tests.