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Development of Environmentally Friendly Steel Products (Eco-products) at Nippon Steel

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Abstract

Global environmental problems, including global warming, are extremely important and urgent issues for mankind. Human society, which has pursued and enjoyed only the development of global civilization, now faces the challenging proposition of sustainable development. In recent years, Japan's steel industry has positioned global environmental compliance as an important objective in its corporate activities and has taken various initiatives to contribute to this sustainable development. These environmental initiatives can be considered in three main categories: 1) reduction in CO_2 emissions and energy consumption; 2) recycling and waste reduction; and 3) environmental protection and environmental improvement. Based on the above ideas, Nippon Steel has implemented environmental measures for steel production processes and has promoted the development of various environmentally friendly products to meet the requirements of diverse consuming industries. Here are introduced the initiatives launched by Nippon Steel in the development of environmentally friendly steel products (eco-products) for specific consuming industries. The main industries targeted are: 1) automobiles; 2) household electric appliances and electric machinery; 3) containers; 4) electric power and energy; 5) building construction and civil engineering; and 6) ships and railroads. Representative eco-products that meet the requirements of these industries are described.

1. Introduction

Global environmental problems, including global warming, are extremely important and urgent issues for mankind[1]. Human society, which has pursued and enjoyed only the development of global civilization, now faces the challenging proposition of sustainable development (see **Fig. 1**).

In recent years, Japan's steel industry has positioned global environmental compliance as an important objective in its corporate activities and has taken various initiatives to contribute to this sustainable development. Here are introduced the initiatives launched by Nippon Steel in the development of environmentally friendly steel products (eco-products).

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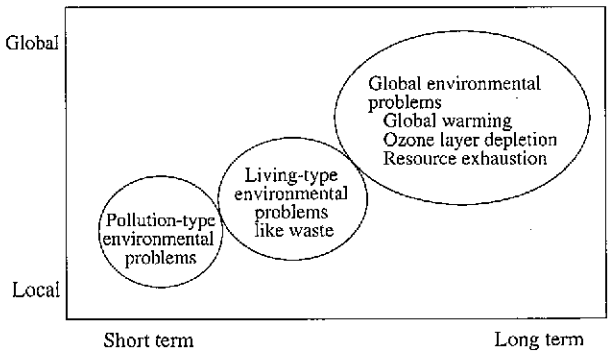


Fig. 1 Expansion of environmental impacts[1]

2. What Are Environmentally Friendly Steel Products (Eco-products)?

2.1 Life cycle and environmental contribution of steel

Fig. 2 schematically illustrates the life cycle of steel. Life cycle assessment (LCA) is important in minimizing the total environmental load of steel from the mining of raw materials though manufacturing, assembly and fabrication into steel, and the use of final products to discard steel as shown in **Fig. 2**. Attention is focused on the LCA technique and the evaluation[2].

Steel can contribute to the environment from the standpoints of steel manufacture and products in the following three main phases:

1) Steel manufacturing (from raw materials to finished steel)
2) Fabrication and assembly of products using steel
3) Use of products

The first phase is concerned with the steel manufacturing process itself. It is essential to establish steel production processes with small energy and environmental loads, or eco-processes. The steel industry is a large energy consumer. Two successive oil crises in the 1980s prompted the Japanese steel industry to implement positive energy-saving measures. Now, steel production is one of the most energy-efficient processes in the world[1, 3]. Various environmental measures have been traditionally instituted against air pollution, water pollution, dust generation, and noise, among other things. Many other measures continue to be studied for further environmental improvement.

The second phase is concerned with contribution to the manufacturing processes of customers that use steel. The user can improve or reduce its environmental load by using a given type of steel. For example, the use of appropriate steel helps the customer to enhance manufacturing efficiency in its fabrication process, eliminate some of its fabrication steps, or simplify the fabrication process itself.

The third phase is concerned with contribution to the environment when end products made by using steel are actually used. For example, better steel products contribute to the fuel mileage improvement of automobiles and the efficiency enhancement of motors.

In the second and third phases, steel products contribute to the environment when they are utilized as commercial products by customers and end-users. These steel products can be called environmentally friendly steel products or eco-steel products.

2.2 What is meant by "environmentally friendly"?

What is meant by "environmentally friendly"? Here, the term "environmentally friendly" is used in a conservative sense of "low in environmental load" or "not environmentally polluting" as well as in a more proactive sense of "improving the environment" or "creating a better environment". Although the classification of this environmental compliance differs with different people, environmental compliance can be considered in three main categories.

This classification can also be applied to steel manufacturing processes, but it is considered here in relation to environmentally friendly steel products (eco-products).

1) Compliance with reduction in CO_2 emissions and energy consumption

Use of eco-products improves the efficiency of the process or merchandise in question (e.g., weight reduction of automobiles and efficiency improvement of motors), helps to eliminate or simplify manufacturing processes (e.g., elimination of a painting process by use of prepainted steel sheets), or contributes to use of clean energy.

2) Compliance with recycling and waste reduction

Among the measures in this class are development of easy-to-recycle steel and contribution to the design of recyclable products (e.g., recycling of household electrical appliances). Being itself a material suited for recycling, steel can be used in many more applications (e.g., steel-framed houses) and can contribute to longer service life of products (e.g., increased corrosion resistance or earthquake resistance). Longer service life contributes to less energy consumption and more resource conservation through less waste

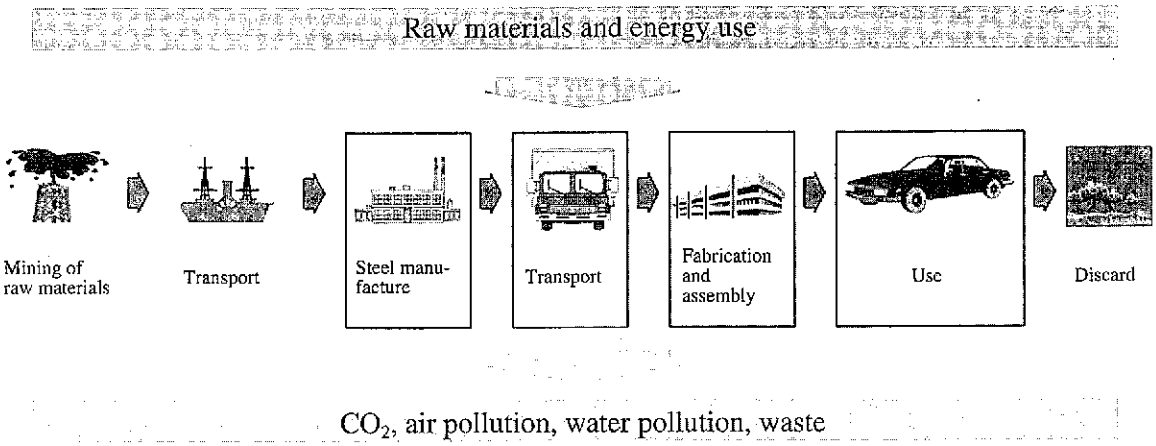


Fig. 2 Schematic illustration of steel life cycle

generation and material consumption. This is greatly significant for stock-type products, such as civil engineering structures and buildings.

3) Measures for environmental protection and improvement

Development of products that do not contain designated environmental load substances that are environmentally harmful or are feared to be environmentally harmful (e.g., lead-free or chromium-free products) is one of the measures in this category. If a designated substance has been used to improve a particular function, it is necessary to maintain that function. Eco-products can be used to prevent environmental pollution in the application stage or improve safety (e.g., improvement in impact safety of automobiles). There also are products that create a good environment by beautifying landscapes, providing bacterial resistance, or reducing noise.

Table 1 Eco-products for various consuming industries

Industry	Reduction in CO_2 emissions and energy consumption	Recycle and waste reduction	Environmental protection and improvement
Automobiles	Weight reduction and safety improvement §2 Automotive high-strength steel sheets §3 Impact-absorbing high-strength steel sheets §4 High-strength steel bars and rods Fuel economy improvement §5 Exhaust system heat-resistant stainless steel	Compliance with automobile recycle • Longer service life ……Higher corrosion resistance Various coated steel sheets • Scrap recycle promotion	Countermeasure against noise and vibration • Vibration damping steel sheet (Vibless) Exhaust gas cleaning performance improvement §5 Heat-resistant stainless steel for exhaust system
Household electrical appliances and electrical machinery	Motor efficiency improvement §10 High-efficiency electrical steel sheets Formability improvement §6 High-lubrication steel sheets Painting process elimination §9 Prepainted steel sheets	Compliance with household electrical appliance recycle Longer service life and higher corrosion resistance • Coated steel sheets and prepainted steel sheets	Freedom from environmental load substances §7 Lead-free alloy coated steel sheets §8 Chromium-free zinc-coated steel sheets Compliance with noise reduction and electromagnetic shielding §10 High-performance electrical steel sheets
Containers	Weight reduction of steel can materials • Ultra-thin tinplate Process elimination §11 PP-laminated steel sheets	Steel can recycle promotion →Recycling rate increase to 80% • Steel easy open end (EOE)	LCA of steel as container material Compliance with endocrine disrupters
Electric power and energy	Electric power generation efficiency improvement §14 High-efficiency boiler steel pipes and tubes (for ultra-supercritical pressure use) Transformer efficiency improvement • Grain-oriented electrical steel sheets for transformers Energy transport efficiency improvement • High-strength, high-corrosion resistance line pipe steel pipe	Compliance with refuse-fired power generation §14 Austenitic stainless steel tubes for the refuse incineration boiler Longer service life	Compliance with clean energy • Compliance with nuclear power generation • Compliance with coal IGCC • Compliance with LNG combined cycle §12 Corrosion-resistant steel plates for LNG-fired boiler stacks Compliance with environmental pollution §13 Dope-free premium joints
Civil engineering and building construction (including bridges)	Construction efficiency improvement • High-heat input weldable steel • Hyper beams (fixed-outer-dimension H-shapes) Process elimination • Fire-resistant steels for buildings	Longer service life, higher durability, and improved reliability • High-strength building structural steels • High-strength steel wire for long bridges Corrosion resistance §15 Coastal weathering steel §16 High-corrosion resistance Zn-Mg alloy coated steel sheets §20 Titanium-clad steel plates Steel application expansion §17 Steel-framed houses • Megafloats (large floating structures)	Environmental protection (construction surplus soil, noise, vibration, etc.) §18 Gantetsu pile method §24 Road noise absorption panels Landscape and environmental beautification §19 Steel pipe for landscaping material §20 Titanium-clad steel plates Freedom from environmental load substances (especially polyvinyl chloride) §23 Olefin-laminated steel sheet
Ships and railroads	Weight reduction • High-strength steel plates for ships (e.g., TMCP steel) • Substitution of stainless steel for railroad cars	Compliance with railroad car recycle §22 Stainless steel car recycle Longer life and higher corrosion resistance • Stainless steel cars • Fatigue-resistant rails	Impact resistance and safety improvement §21 HIAREST steel (brittle crack propagation arrest steel) • Stainless steel plates for chemical tankers
Others (future materials)	Super steel (super metal, ultra steel) ……Functional limit pursuit of single material		

3. Overview of Eco-products in Consuming Industries

Table 1 lists main eco-products developed to meet the requirements of specific consuming industries on the basis of the ideas discussed in the previous chapter. The eco-products numbered in the table will be individually introduced in the chapters that follow. Past developed products corresponding to various application fields are cited from The 80th Anniversary Special Issue[4], Tstsu-to Hagané by ISIJ.

3.1 Automobiles

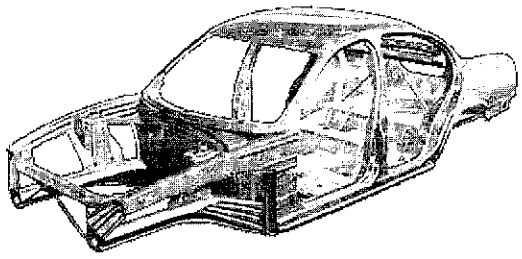
(1) Weight reduction of automobiles

Improvement in fuel economy is the greatest issue for energy conservation in automobiles. The weight reduction of automobiles has been pursued over many years. Automotive high-strength steel sheets that combine weight reduction and impact safety, coupled with improved formability, have been adopted to a considerable level (§2. Automotive high-strength steel sheets). Especially, Japanese steel-makers lead this field. The percentage of high-strength steel sheets used in the white bodies of automobiles is now approaching 30% and is expected to increase further in the future. Special steel bars and rods that support the functional parts of automobiles are under development to meet requirements for higher strength and lower weight (§4. Automotive high-strength steel bars and rods).

In line with these lightweight body development trends, the International Iron and Steel Institute (IISI) started a joint development project, dubbed ULSAB (Ultralight Steel Auto Body), with the participation of 35 steel companies from 18 countries[5] (see **Fig. 3**). ULSAB is designed to demonstrate that steel auto bodies can be reduced in weight with satisfactory functionality and crash safety by making the most of leading-edge technology. The project achieved the intended goal (27% weight reduction) with the completion of bodies-in-white in 1998 and has entered its second phase, ULSAB-AVC (Advanced Vehicle Concept) project, since January 1999, which aims to achieve the total environmental conformity of vehicles (more weight reduction, safety improvement, compliance with recycle and so on).

(2) Impact safety

Concerning impact safety, dual-phase (DP) steel and TRIP (Transformation Induced Plasticity) steel are rated and adopted as high-strength steels with a high energy absorption capacity upon an impact (§3. High-strength steel sheets with excellent impact absorption performance).



	Average for comparative car	Result
Torsional stiffness (Nm/deg)	11,531	19,024
Flexural stiffness (Nm/deg)	11,902	20,408
Vibration frequency (Hz)	38	59
Weight (kg)	271	208

Fig. 3 ULSAB (ultra-light steel auto body) development project, IISI

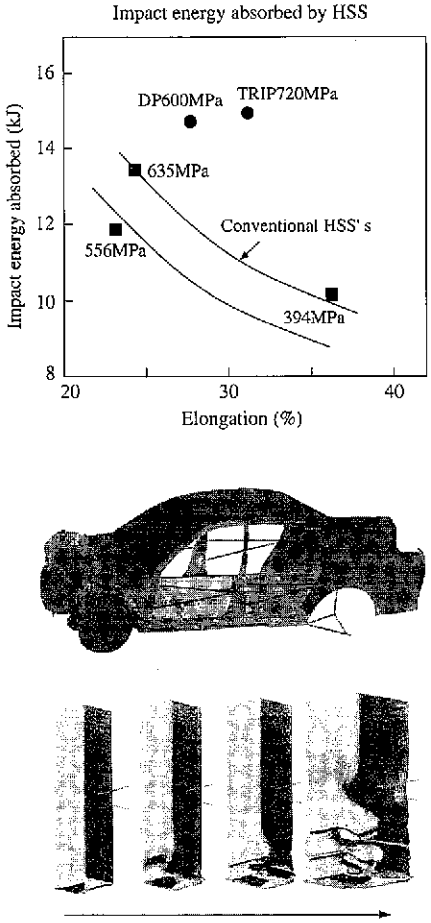


Fig. 4 Impact energy absorbing steel sheet

Fig. 4 shows the impact energy absorption performance of three types of sheet steels. The DP and TRIP steels exhibit higher impact energy absorption than conventional high-strength steels (HSSs)[6]. Among the energy-saving measures in automobile production (fabrication) is improvement in workability and press formability to increase work efficiency and decrease work load. Extra-deep drawing steels like IF steel and bake-hardenable steel (BH) have been traditionally used in automobile body panels. At present, TRIP steel is spotlighted as high-strength steel with good formability in this area. New steel application and fabrication technologies, such as tailor-welded blanking (TB) and hydro-forming introduced in the ULSAB project, are expected to develop further.

(3) Automobile exhaust system materials

Coupled with the lightening of weight, fuel economy is being enhanced by various improvements being made to engine combustion efficiency. To improve exhaust gas cleaning performance, it is necessary to raise the exhaust gas temperature. Exhaust pipe heat-resistant stainless steel was developed for an exhaust gas temperature increase to about 1,000°C. The new steel is finding increasing usage in exhaust manifolds and catalytic converters (§5. Exhaust system heat-resistant stainless steel).

3.2 Household electrical appliances and electrical machinery

(1) Eco-design with electrical steel sheet (§10. High-efficiency and high-functionality electrical steel sheets)

In the household electrical appliance and electrical machinery fields, reducing the amount of electric energy consumed by the appliances and machinery in the usage stage is the largest issue. Of late, manufacturers are attaching importance to improvement in energy efficiency by top-runner energy management. They have taken the initiative in increasing the energy efficiency of generators, transformers, motors, and compressors, among other things, by using electrical steel sheets of higher efficiency. Thanks to their superior functions, electrical steel sheets are also utilized in many other applications as eco-materials that control the environment, including noise abatement and electromagnetic shielding.

(2) High-function coated steel sheets

Various types of coated steel sheets and chemical conversion coated steel sheets are developed as household electrical appliance materials. These materials are adopted to meet such requirements as lubricity, fingerprint resistance and aesthetic design as well as corrosion resistance. Development of lubricating steel sheets, or steel sheets coated with a lubricating film, has made it possible to eliminate the use of lubricant during press forming (§6. High-lubricity steel sheets). Use of these materials greatly contributes to improving the environment in the fabrication stage, as represented by increased efficiency in the press forming process, press forming without lubricant, and elimination of washing. High-performance prepainted steel sheets developed in recent years have enabled users to eliminate their painting process, and are finding gradually increasing usage. Prepainted steel sheets must have high formability as well as stain resistance. Excellent products that can meet these requirements are developed (§9. Prepainted steel sheets).

(3) Freedom from designated environmental load substances

In recent years, mounting environmental consciousness has increased demand for products that do not contain designated environmental load substances that are feared to cause environmental problems. Household electrical appliances call for the development of products that do not contain lead or chromium, but retain necessary functions.

A lead-free, Zn-Sn-Ni alloy coated sheet steel developed by Nippon Steel in recent years features excellent corrosion resistance, solderability, and whisker resistance as coated steel for electronic parts. This lead-free steel is expected to find new applications (§7. Lead-free electronic part coated steel sheets).

Some of the coated steel sheets are given a chromate treatment that contains hexavalent chromium, an environmental load substance. Products that do not contain chromium are in demand from the standpoint of eliminating this hexavalent chromium. In response to the demand, Nippon Steel successfully developed a zinc-coated steel sheet and prepainted electrogalvanized steel sheet that do not contain chromium (§8. Chromium-free zinc-coated steel sheets). Work is now under way to improve these steels for use in wider applications.

(4) Compliance with recycle of household electrical appliances

The longer life and longer use of household electrical appliances will assume increasing importance in the future. For those types of household electrical appliances whose discard cost must be paid by consumers as Japan's Household Electrical Appliance Recycle Law has been recently put into force, it is important from an LCA point of view to organize a maintenance and repair system for promoting their reuse and to improve their corrosion resistance and service life. In this respect, various precoated and prepainted steel sheets are developed and adopted in the same way as for automobiles.

The establishment of the Household Electrical Appliance Recycle Law has imposed on household electrical appliance manufactures the tasks of handling and disposing of discarded household electrical appliances. Emphasis will greatly shift to materials and designs conductive to recycling. Materials capable of meeting this shift will have to be developed.

3.3 Containers

In response to the recent lifestyle of Japanese people, containers in general and beverage cans in particular are substantially growing in production. The total annual demand for beverage cans in Japan amounts to about 34 billion. Of this total, about 60% are steel cans. Steel is high in strength, gas tightness, heat resistance, light barrier property and water resistance, among other properties, and it is excellent on the whole as material for assuring the safety of contents.

Aluminum and plastics (e.g., PET) as well as steel are used as container materials. In this field of fierce competition between these materials, their economy, environmental load, and recyclability advantages are discussed in various ways.

(1) Ultrathin-gauge tinplate

Steel cans lead other container materials with a recycling rate of 80%. To contribute further to energy conservation, steel-makers have taken the initiative in reducing the weight and thickness of steel for beverage cans from the standpoints of environmental load and economics. Tinplate is a consumer material in close contact with beverage cans and other daily necessities, and is required to have high enough quality for use in food cans. Two-piece cans have an especially severe product fabrication process, and light-gauging for the lightening of the weight of cans is a challenge for the two-piece can production process.

Fig. 5 shows the change in the thickness of tinplate used for beverage cans. Two-piece cans (350-ml DI cans) measured about 0.32 mm in tinplate thickness 20 years ago and decreased in tinplate

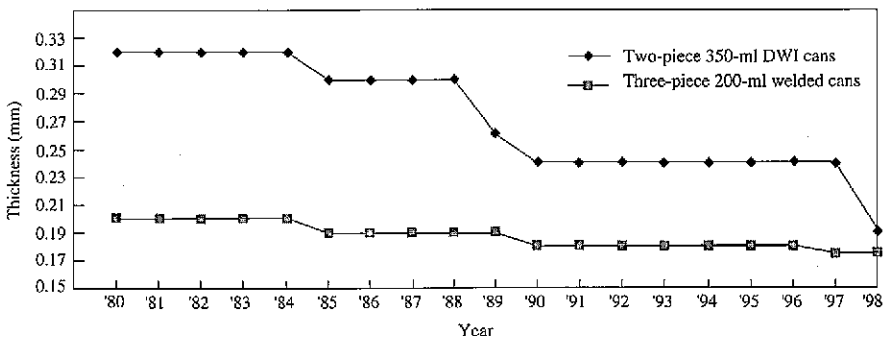


Fig. 5 Change in thickness of tinplate for beverage cans

thickness to 0.24 mm 10 years ago. In 1998, an ultra-thin tinplate of 0.19 mm thickness was developed to the great attention of those concerned[7]. If used to make 350-ml beer cans, this ultra-thin-gauge tinplate can reduce the weight of the beer cans by about 15% as compared with conventional beer cans. It is expected to contribute greatly to resource and energy conservation.

(2) Ultra-thin-gauge laminated steel sheets

Metal food cans are mostly used with their inside surface lacquered. The painting and baking processes that use organic solvents are shunned due to the environmental problems involved. Elimination of these processes can markedly improve the environment. Film-laminated steel sheets, or steel sheets laminated with plastic films, are developed and used to substitute for lacquers in the canmaking industry. This type of can is rated far better than the conventional lacquer type in terms of LCA. Laminated cans are rapidly expanding in usage, not only because they provide this energy-saving benefit, but also because they can retain the taste and flavor of contents over a long period of time and they are environmental compliant or free from endocrine disrupters (see **Photo 1**).

In above situations, Nippon Steel having been commercializing one after another ultra-thin laminated steel sheet as thin as 0.18 mm for steel cans through joint developments with can manufactures, has more improved their material-workability and developed the new one endurable for the higher-rate working.

The sheet has already been commercialized for the material of the 350-ml can in the domestic market, being highly prized. Two-piece laminated steel can made of it has achieved becoming the lightest among 350-ml cans in the world.

Most recently, as the another manufacturing process of laminated steel sheets, Nippon Steel developed laminated steel sheet by the T-die laminating process that melts and extrudes polypropylene (PP) directly on steel strip (§11. T-die laminated steel sheets). This process assures formability and corrosion resistance superior to those provided by conventional lamination processes, and is expected to expand its application to polyethylene (PE) and polyethylene terephthalate (PET).

3.4 Electric power and energy

(1) Improvement in power generation efficiency

Environmental compliance in the stage of usage in the electric power and energy fields is nothing but finding ways to improve energy efficiency.

In the electric power industry, the development and commercialization of technology for converting fossil fuel into electric energy with high efficiency are being steadily carried out. The development of these highly efficient electric power generation systems place demand of increasing severity on steel. For example, the efficiency of ultra-super-critical-pressure power generation is markedly improved by the development and application of highly efficient boiler steel tubes and pipes (e.g., NF616) that meet the higher temperature and pressure requirements (§14. Highly efficient boiler steel tubes and pipes). In the transformer field, highly efficient transformer electrical steel sheets are developed. The reduced core loss of the new electrical steel is notably improving the conversion efficiency of transformers as noted for motors.

Photo 1 Two-piece laminated steel cans

(2) Clean energy

Now that measures for reducing CO_2 emissions are advocated as global environmental issue, compliance with clean energy is an important problem in the energy field. The growth of nuclear power generation is presently stagnant. To achieve the CO_2 levels agreed upon at COP3, however, it is essential to install additional nuclear power plants.

As clean energy, LNG is faced with ever increasing expectations, and in the electric power industry, LNG combined cycle power generation is rapidly expanding. With the growth of LNG-fired boilers, new corrosion-resistant steels capable of eliminating linings and preventing rust pieces from scattering were in strong demand as materials for their smokestacks. To meet this demand, Nippon Steel developed a new corrosion-resistant plate steel for LNG-fired power plant stacks (WELACC5) that assures long-term maintenance-free operation. The new product was commercially adopted for the first time in 1997, is growing in applications, and is expected to find more usage in the future (§12. Corrosion-resistant steel plates for LNG-fired boiler smoke stacks).

The IGCC (integrated gasification combined cycle) process is under development for cleaner and more efficient coal-fired power generation. It will become a dominant method of coal-fired power generation in the near future.

(3) Improvement in energy transport efficiency

In the energy transport field, pipeline energy transport is expanding worldwide with increasing production of oil and natural gas. For example, 80% of the world's natural gas is transported through pipelines, and the remaining 20% is transported by LNG carriers. These pipelines are strongly demanded to raise the transport pressure to improve the transport efficiency. High-strength steel pipes are developed to meet this demand. Pipelines are increasingly installed in more punishing locations than ever, like arctic and deep-sea sites. In this respect, high strength and corrosion resistance are assuming increasing importance for line pipes.

The measures for achieving this high durability extend the service life of pipelines and reduce the amount of steel used in the construction of pipelines, and also contribute to the reduction in the environmental load in the fabrication stage. The increasing strength of line pipes allows the weight and wall thickness of steel pipes to be reduced, contributing to lessening of the welding workload in combination with improvement in welding technology.

(4) Environmentally friendly oil drilling (§13. Dope-free premium joints for oil casing)

At oil drilling sites, it was the general practice to apply compound grease to the threaded joints of oil casing during makeup. The compound grease contained heavy metal powders mainly composed of lead, and presented the problems of environmental pollution and work difficulty. Nippon Steel developed dope-free (without grease application) premium joints having an excellent solid lubricant film applied to the threads. The dope-free premium joints demonstrated that they can be coupled without using any

liquid lubricant at all and can provide the same service performance as conventional joints. Nippon Steel's dope-free premium joints are expected to find full-scale usage on oil fields.

3.5 Building construction and civil engineering

(1) Improvement in service life, durability, and reliability

For stock-type structures in the building construction and civil engineering fields, "longer service life" appears to be the most important contribution to the environment. The social capital area attaches importance to durability and reliability. Many types of high-strength steels have been traditionally adopted to meet the requirements for corrosion resistance and earthquake resistance. Low-yield ratio, high-strength steels compliant with earthquake-resistant design methods are adopted in large structures, including building structural high-strength plate steels developed by utilizing the thermo-mechanical control process (TMCP) as done in the shipbuilding field. Super-high-rise buildings, such as the 300-m tall Landmark Tower and the Tokyo Metropolitan Government Office Building Complex, are constructed with large amounts of low-yield ratio steels with high tensile strengths of 50 and 60 kgf/mm^2. Low-yield ratio, high-strength steels of the 80-kgf/mm^2 class are now developed one after another, and are adopted for the construction of not only tall buildings but also long bridges.

(2) High-strength steel wire for long suspension bridges

The Akashi Kaikyo Bridge, a Honshu-Shikoku bridge completed in 1998, carved its name in history as the world's longest suspension bridge with a total length of 3,911 m and central span length of 1,991 m[8] (see **Photo 2**). Developments in the construction of such suspension bridges can be observed in the change in their center span length.

Fig. 6 shows the change in the center span length of suspension bridges in the world. The Akashi Kaikyo Bridge with the center span length of 1,990 m is a quantum jump in the progress of suspension bridges. This feat was clearly made possible by the concomitant increase of suspension bridge wire strength as shown in **Fig. 7**[9]. High-strength steel wire with a tensile strength of 180 kgf/mm^2 was developed and used for the Akashi Kaikyo Bridge. The adoption of the new wire steel reduced the weight of the wire itself and the structural members of the bridge. The amount of energy saved by its use is calculated to be an oil equivalent of 14,600 kl.

(3) Corrosion resistance of structures

Concerning the corrosion resistance of structures, various improvements and developments are accomplished, coupled with the progress of corrosion prevention technology. Weathering steel has long been used in buildings and bridges the world over. However, it had the disadvantage of weather resistance being difficult to be expected at seacoast sites with many wind-blown sea salt particles.

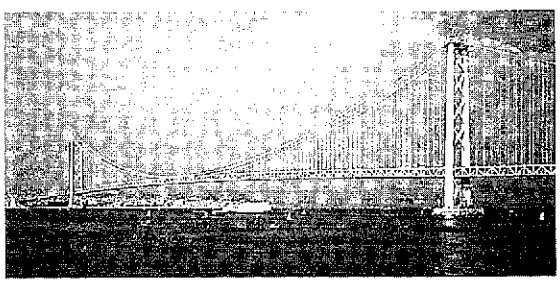


Photo 2 The opening of the Akashi Kaikyo Bridge

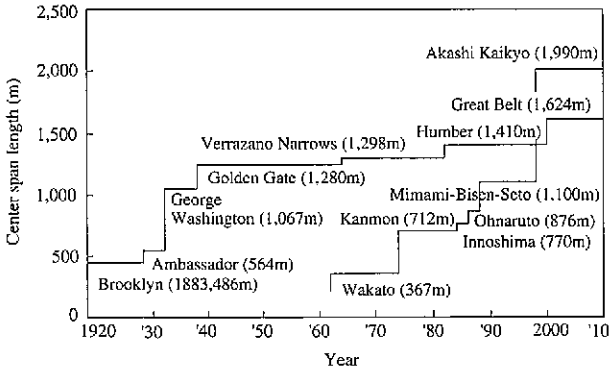


Fig. 6 Change in center span length of suspension bridges[9]

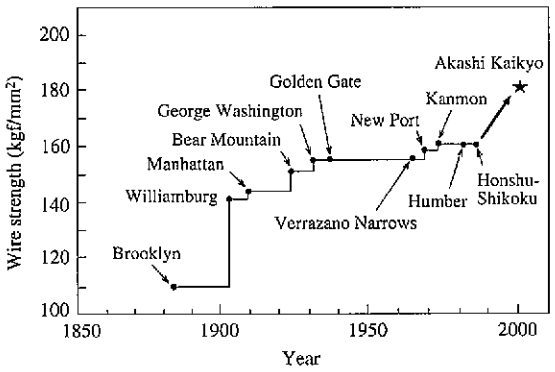


Fig. 7 Change in wire strength of suspension bridges[9]

In 1998, coastal weathering steel with excellent salt damage resistance was developed and found widespread use[10] (§15. Coastal weathering steel). Tidal zone corrosion was a serious problem for bridge piers installed in the sea. The piers of the Trans-Tokyo Bay Highway Bridge "Aqua Line" are covered with titanium-clad steel plates[11] (§20. Titanium-clad steel plates) (see **Photo 3**).

Large structures require huge amounts of cost and labor for their maintenance after their construction. Maintenance-free functions are strongly demanded recently. To this end, greater efforts are expended to develop materials together with construction and corrosion prevention technologies, including zinc-coated steel bridge

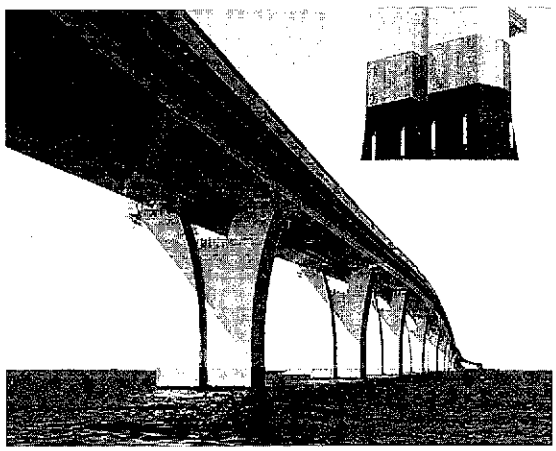


Photo 3 Titanium-clad steel plates used on piers of Trans-Tokyo Bay Highway Bridge

girders and improved weather resistance as noted above.

Coated steel sheets for building materials have requirements to meet for still higher corrosion resistance and longer service life. The hot-dip Zn-Mg alloy coated sheet steel developed by Nippon Steel and dubbed Dymazinc exhibits far higher corrosion resistance than conventional zinc-coated steel sheets and is expected as a future eco-product (§16. Highly corrosion resistant, hot-dip Zn-Mg alloy coated sheet steel).

(4) Expansion of applications for iron

Iron is the most abundant and most stable element in nature. It is an eco-material that has coexisted with humans from the beginning of history. Iron is recyclable after its use and is an environmentally-compliant material in that sense. Here are described the ideas of increasing the uses of iron as eco-material and contributing to sustainable development.

Cold-formed steel-framed houses are houses with wooden structural members replaced by cold-formed steel structural members (§17. Steel-framed houses). Steel-framed houses started to rapidly spread in the United States 25 years ago and are now constructed at a rate of about 100,000 units per year, accounting for 10 percent of single-family houses. In 1998, steel-framed houses were introduced as "environmentally friendly houses" for their durability, environmental load, recyclability and energy conservation, among other features, at the Sustainable Steel Conference of the American Iron and Steel Institute. In Japan, the Great Hanshin Earthquake of January 17, 1995 prompted the introduction of steel-framed houses from the standpoints of their safety and durability. Today, the Kozai Club is leading the activities to promote the spread and expansion of steel-framed houses in Japan.

At present, the megafloats (large floating structures) are under development by making use of Japan's superior shipbuilding technology and large structure manufacturing technology. This project is concerned with the construction of a large floating structure, or "floating land in sea", from steel units[12] (see **Photo 4**). The megafloat system assures the construction of offshore airports and various marine bases in a much shorter time with higher efficiency than the conventional land reclamation system. Its practical application as an environmentally friendly construction method is expected.

(5) Improvement in construction efficiency

Improving the efficiency of constructing large structures is reducing the environmental load in the fabrication stage. For example, the installation of fire-resistant covering is eliminated or simplified by the development of fire-resistant (FR) steel; the efficiency of construction is increased by use of fixed-outer-dimension H-shapes (Hyper beams); and the efficiency of connecting and welding is improved by adoption of high-heat input weldable steel and high-strength steel of the low preheating temperature type. In this way, steel products have been developed and improved with the progress of various construction technologies.

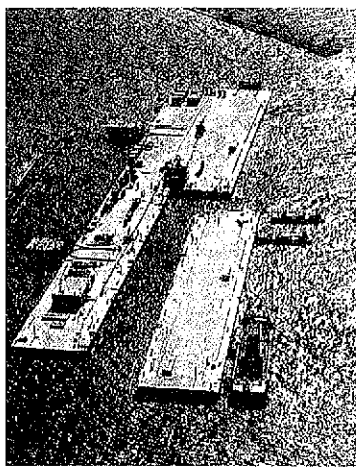


Photo 4 Megafloat demonstration test[12]

The recent development of TMCP heavy-gauge H-shapes has led to the re-appreciation of the advantages of rolled H-shapes over welded boxes that formerly substituted for rolled H-shapes as column materials in super-high-rise buildings. The TMCP heavy-gauge H-shapes are expected to reduce energy consumption and cost through simplification of steel frame fabrication.

(6) Environmentally friendly building and civil engineering materials

In the building and civil engineering fields, environmentally friendly and conscious considerations include the control of noise and vibration, reduction in environmental load substances, and environmental beautification and landscaping.

In the civil engineering field, the Gantetsu pile method developed by Nippon Steel is a steel pipe pile method with a minimum of surplus construction soil and with low noise and vibration. Since its first adoption in the foundation work of the Second Meishin Expressway, the Gantetsu pile method has been employed in many projects (§18. Gantetsu pile method).

Recently, automobile noise reflected at the ceiling of elevated roads has become a social problem. Panels to absorb this noise have been developed and used with good results (§24. Road noise absorbing panels).

Polyvinyl chloride-laminated steel sheets have been traditionally used as laminated steel sheets in many buildings. The problem of dioxin raised by the incineration of polyvinyl chloride products has resulted in demand for disuse of polyvinyl chloride. To meet the demand, Nippon Steel has developed steel sheets laminated with an environmentally friendly olefin film mainly composed of polypropylene (§23. Olefin-laminated steel sheets).

With mounting awareness of our surrounding environment, comfort in our living environment has attracted attention, and the appearance and beautification of structures have come to be emphasized. In urban areas, total harmony is highlighted, and landscape is regulated and newly reviewed. As members of the Landscaping Material Promotion Conference organized by construction companies and related firms, Nippon Steel and its group companies are tackling environmental improvement like landscaping and beautification. They are promoting the development of environmentally friendly eco-products, such as steel pipes and sheets for landscaping purposes and titanium-based landscaping materials (§19. Steel pipes for landscaping materials and §20. Environmentally friendly titanium materials) (see **Photo 5** and **6**).

3.6 Ships and railroads

(1) Weight reduction in transport

Improving the efficiency of transport energy by lightening weight is as important for ships and railroads as for automobiles.

In the ship area, steel accounts for 80 to 90% of ship weight. It is extremely important to reduce the weight of hulls by using steel of higher strength. The development and application of TMCP and other high-strength steel plates for ships to meet this demand have already raised the usage of high-strength steel plates well above the 60% level. These high-strength steel plates are considered

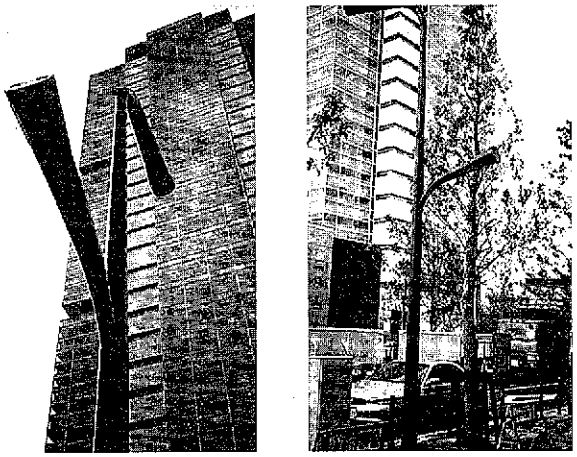


Photo 5 Steel pipes for landscaping materials

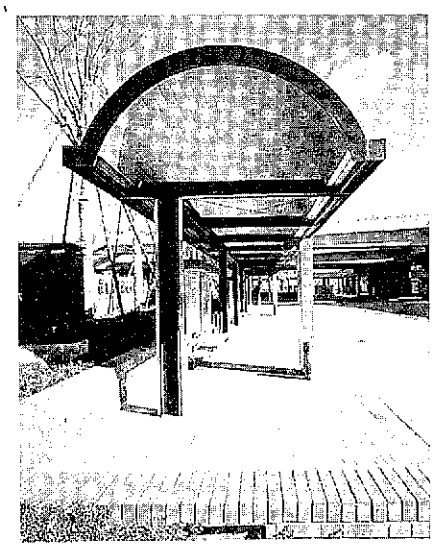


Photo 6 Stainless roof shelter

to find greater usage in ships.

The railroad industry is actively working to reduce the weight of their cars along with increasing speed. In recent years, stainless steel cars have been increasing together with aluminum cars, contributing to energy savings.

(2) Collision safety

The shipping industry is valuing the impact resistance and safety of ships in view of global environmental problems. Development of steel plates with excellent collision safety or crack propagation arrest performance is spotlighted in this respect. Nippon Steel has met many requirements for steels, as represented by construction of double-hull tankers and adoption of stainless steel for chemical tankers from the standpoint of cargo protection.

Recently, Nippon Steel has developed the HIAREST steel plates as material for improving safety and preventing marine pollution in many areas, including large ships and offshore structures (§21. HIAREST steel). The HIAREST steel plates are characterized by the ability to arrest the propagation or extension of brittle cracks that is three to ten times higher than that of conventional shipbuilding steels. The microstructure of the surface layers of the HIAREST steel plates is 1 to 3 μm in grain size. This finest grain

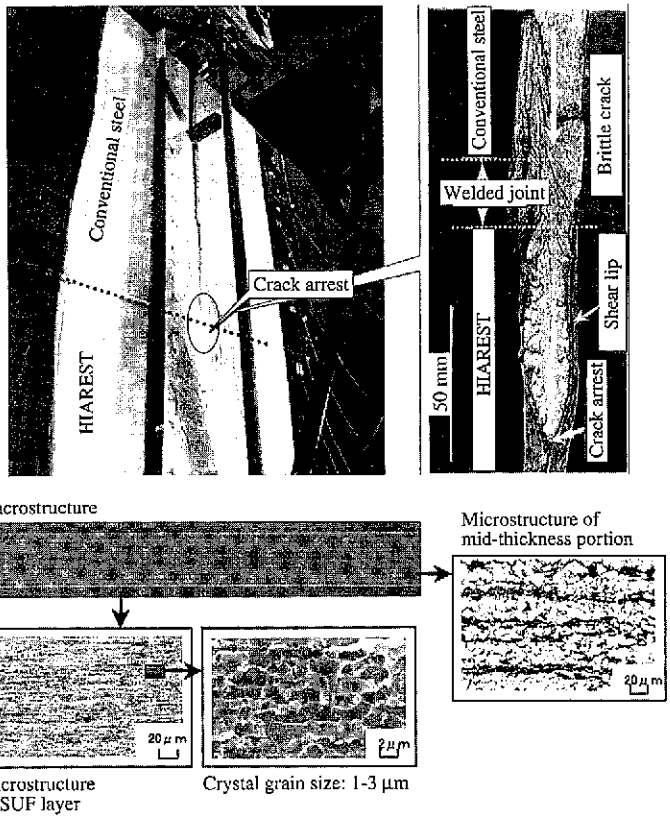


Photo 7 HIAREST steel

size commercially achieved for the first time in the world markedly improves the brittle crack arrest performance of the surface layers and ensures the hybrid structure of the HIAREST steel[13] (see **Photo 7**).

(3) Improvement in efficiency of fabrication and assembly processes

The aforementioned measures for lightening weight also help to reduce the consumption of steel, which in turn reduces the environmental load in the fabrication stage. In the manufacture of ships and railroad cars, the fabrication and assembly steps require large amounts of labor and time. Increasing the efficiency of these fabrication and assembly tasks is important in saving energy.

TMCP steel developed as high-strength steel for shipbuilding provides good weld quality by its low carbon equivalent and greatly contributes to improvement in welding efficiency. Various types of high-heat input weldable steels are developed and used for the purpose of rationalizing welding operations.

Materials for railroad cars are improved in various ways to improve the efficiency of fabrication and assembly, thereby contributing to environmental compliance.

(4) Recycle of stainless steel cars (§22. Recycle of stainless steels)

In the railroad transport field, the service life of cars is prolonged by improving corrosion resistance and fatigue strength, among other properties. This reduces the absolute number of newly built cars and contributes to reduction in the environmental load in the manufacturing (fabrication) stage. Several concrete examples can be cited, including manufacture of stainless steel cars and adoption of high-fatigue strength rails.

The increased number of stainless steel cars is making it necessary to recycle used stainless steel cars. Stainless steel has been traditionally produced based on scrap, so that a system is in place

for its reuse and recycle. Discarded stainless steel cars can be recycled to make new stainless steel cars without being down graded like aluminum cars. This means that stainless steel is more environmentally suitable than aluminum.

4. Toward Further Development of Eco-products

4.1 Future trends in specific consuming industries

Concrete examples of eco-product developments in the individual consuming industries have been discussed above. The trends that take compliance with the global environment into account will accelerate further in each field.

The automobile industry is now energetically working to commercialize electric cars and hybrid cars as measures to cope with environmental and energy issues. Advanced nations are cooperating with their automobile companies to utilize hydrogen as a source of clean energy and to develop fuel cell-powered cars.

In the electric power and energy fields, compliance with clean energy and other new energy sources is an urgent issue. Given the need for reducing CO_2 emissions, the expansion of nuclear power generation will be essential despite various obstacles. The International Thermonuclear Experimental Reactor (ITER) project is continuously carried out. In the electric power supply field, electric power smoothing is one of the important issues. Pumped storage power plants, flywheels, superconductors, and fuel cells are under development and application as technologies for storing electric power.

Pursuit of much faster speed, as represented by the linear motor car, lighter weight and higher efficiency in the railroad field, and of greater durability in the stock-type social capital field, and of higher safety, reliability and comfort will be carried out under the proposition of sustainable development.

Development of new and more advanced steels is essential for new technology development and technology innovation to be promoted to meet these social requirements. Further development and application of diverse properties and potential capabilities of iron is one of the future challenges. Demand for environmentally conscious steel products will continue in the future, and we will have to meet this demand.

4.2 Development of super steel

Iron has been historically used as high-strength material available in large amounts at low cost. As far as this strength advantage is concerned, however, most of today's ferrous materials are used at strength about one-fifth to one-tenth of the theoretical strength of iron, and the maximum strength achieved is still less than a half of the theoretical strength of iron (see **Fig. 8**)[14]. This means that ferrous materials have still ample room for increases in strength.

The commercial application of steels with such high strength calls for the optimum combination of strength with toughness, a property contradicting with strength in many cases, and for further breakthroughs. Development of "super steel" is an example of future material development to go beyond this proposition and to pursue the functional ultimate of iron. "Super steel" is a dream material that may be developed in the twenty-first century as "iron dramatically surpassing traditional iron properties".

There are two projects for the development of super steel. One is the "super metal" research and development project of the Agency of Industrial Science and Technology, Ministry of International Trade and Industry. The other is the "ultra steel" research and development (STX-21) project of the National Research Institute for Metals, Science and Technology Agency. The two projects are

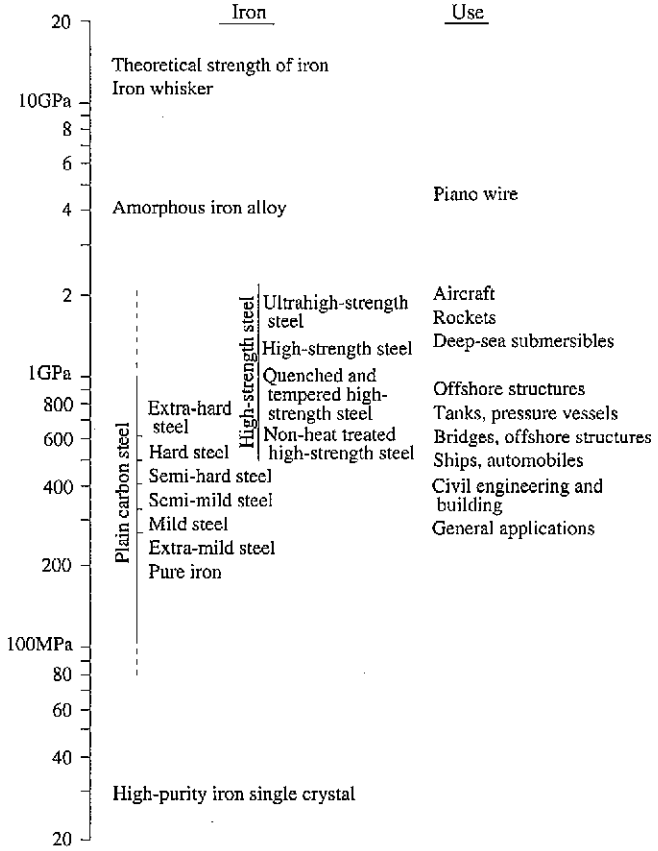


Fig. 8 Iron strength spetrum[14]

carried out by both government and industry. Nippon Steel is a member of both projects. Each project aims at producing "ultra-fine-grained structure steel" through development of microstructure control technology; dramatically improving mechanical strength and various functions in the predicted region extrapolated from the Hall-Petch law; and exploiting the potential performance of pure iron to its fullest[15]. These "super metal" and "ultra steel" are generically called "super steel"[16].

When the "super steel" is successfully developed, applications markedly different from conventional commercial applications will appear. For example, the Eiffel Tower constructed with the most advanced technology then in 1889 is 300 m in height. If today's high-strength steel is used, it is calculated that a 750-m tall tower can be built with the same weight[17].

When the "super steel" is commercially produced in the future, the construction of a 1,500-m super-high tower (what is called a mile tower) will be possible with the same weight of the super steel[16] (see **Photo 8**). The super steel will contribute to the realization of "hyper buildings (ultra-super-high-rise buildings)" advocated in recent years. When the functions of conventional materials are individually pursued to their limits in this way, their phenomenal advances as functional materials can be greatly expected.

4.3 Environmental management

The stance and system of corporate initiatives are important when contributing to these global environmental issues and developing more eco-products. In 1991, the Japan Federation of Economic Organization established the "Global Environment Charter"

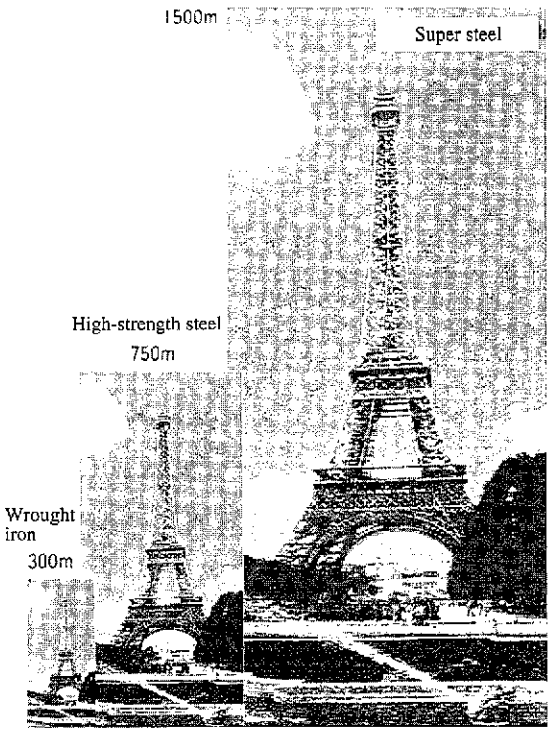


Photo 8 Construction of ultrahigh-rise Eiffel Tower possible

as industry. Following this move, many companies have been positioning "environmentally compliant" corporate activities as one of their ideas in recent years.

Nippon Steel adopted "environment" as one of its management pillars in 1998 and established the "Environmental Management Committee". The committee is divided into the "Environmental Measure Subcommittee" to cope with overall environmental trends and to promote environmental measures in the iron-making and steel-making processes; the "Energy Conservation and Recycle Subcommittee" to study energy conservation and recycling in the iron-making and steel-making processes; the "Environmentally Compliant Material Subcommittee" to handle environmentally compliant materials; and the "Environmental Business Subcommittee" to put the environmental technologies developed through iron and steel production into use in the new environmental business. **Fig. 9** shows the relations between the subcommittees and corporate activities. The four subcommittees cover Nippon Steel's entire corporate activities as environmental management. The development of more eco-products will be promoted under the Environmentally Compliant Material Subcommittee.

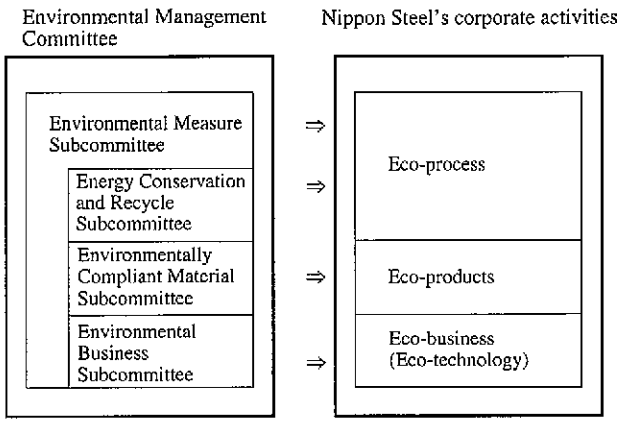


Fig. 9 Relations between Environment Management Committee and corporate activities

5. Conclusions

Mankind has achieved an affluent and comfortable society after phenomenal developments through the industrial revolution of the 19th century and the technological innovation of the 20th century. On the other hand, mankind now faces the limits of the global environment, resources, or social acceptability. Global environmental problems like global warming and air pollution are pressing and most important issues for us humans on the eve of the 21st century. The 21st century is said to be the "century of environment".

All industries will no longer be able to carry out corporate activities without considering the environment. Given this fact, Nippon Steel has developed various environmentally compliant products (eco-products) by making the most of the excellent properties and functions of iron as a member of the steel industry.

Since its discovery by man, iron has contributed to man's culture as low-cost and environmentally friendly material. Now that sustainable development is advocated, iron will continue to be utilized as eco-material in large amounts in the 21st century by exploiting its properties and functions to their fullest.

Nippon Steel will greatly contribute to global environmental protection also in the 21st century as eco-company manufacturing eco-product by eco-processes and eco-technologies.

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