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Trends in Research and Development of Fine-Grained Metallic Materials

— Aiming at the Next-Generation High Strength Materials —

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6.1 Introduction

Metals are basic materials for industry; especially, steels are the most commonly used metallic materials utilized as structural materials. As industrial technologies are developed, requirements for mechanical and functional properties of metals become higher and higher, demanding superior materials with such properties as lightweight, high strength, and long service life. On the other hand, domestic demand for steel has decreased to about 60 million tons in 2000 from about 80 million tons in 1990 as a result of the maturity of society, and the recovery of the demand for steel cannot be expected in the future. While the demand for steel is decreasing, generation of scraps is gradually increasing, and it is expected that the generation of scraps will become equal to the production of steel in around 2030.[1] Therefore, in order to answer the social requirements for energy saving, resource conservation and environmental protection, it is of urgent necessity to develop materials having high recyclability in addition to lightweight and long service life.

In the past, technologies such as heat treatment and addition of alloying elements have been used to improve the properties of metals; however, it has become impossible to satisfy the above-mentioned new requirements for advanced properties relying only on these technologies. In order to effectively utilize resources and energy, breakthrough technologies that provide high recyclability and excellent environmental friendliness, as well as making the most of the characteristics of materials, are strongly sought for.

It has been confirmed by recent basic studies that properties of metals such as strength, toughness*1, and corrosion resistance are significantly improved by refining the grain size.[2, 3] Establishing the technology to create structural materials for general use with high strength and highly functional characteristics will greatly contribute to the economy and social life by enhancing the foundations of society for secure safe social life and by constructing a sustainable society. According to one estimate, for example, the use of materials having "double strength and double service life" will reduce the total emission of CO_2 in Japan by 2 to 3% due to the improvement of fuel consumption rate resulting from the reduction in vehicle weight.[1]

This report, while laying stress on ferrous materials, summarizes the past achievements and future trends in the research and development of fine-grained metallic materials targeting the creation of light and strong materials.

6.2 Strengthening mechanisms of materials

Various methods are known as means to strengthen materials, all of which make it a basic principle to restrict the motion of dislocations (disorder of atomic arrangements) in crystals so as to suppress plastic deformation (hardening), which is the permanent deformation beyond the elastic deformation range. The strengthening mechanisms are classified according to the processes to restrain the motion of dislocations as follows:[5,6]

(1) Solid-solution strengthening

A strengthening mechanism in which impurity atoms are introduced into crystals to form a solid solution*2 in order to restrain the motion of dislocations.

(2) Dispersion strengthening and precipitation strengthening

A strengthening mechanism in which the motion of dislocations are suppressed by fine particles (second-phase particles) that are dispersed in crystals. In precipitation strengthening, the second phase is precipitated from a solid solution, whereas the second phase is formed by other processes than precipitation (e.g., formation of oxide particles) in dispersion strengthening. Precipitation strengthening is particularly important from the practical point of view, and most of the strengthening processes for ultra-high tensile strength steels, aluminum alloys, and titanium alloys employ this mechanism.

(3) Phase transformation strengthening and strengthening by martensitic transformation

A strengthening mechanism in which fine, dense structures are formed by rapid cooling from high temperature ranges. The martensitic phase in the Fe-C system is a typical example.

(4) Strengthening by grain refinement and strengthening on the grain boundaries

A strengthening mechanism in which the grain size is made very fine. The difference of the strength of material increases in inverse proportion to the particle size raised to the power of 0.5, and it is known by experience that the relationship between yield strength (or tensile strength) σ_y and particle diameter d is expressed by the following equation,

$$\sigma_y = \sigma_i + k_y d^{-1/2} \text{ (Hall-Petch's relationship)}$$

where σ_i is the average yield strength of single crystals and k_y is a parameter that represents the effect of grain boundaries on the increase of yield strength.

(5) Work hardening and strain hardening

A strengthening mechanism in which materials are hardened by increasing the number of dislocations as a result of plastic deformation of crystals. When the hardened material is heated, the strength obtained by the work hardening is lost through three stages: recovery, recrystalization, and grain growth.

The mechanisms (4) and (5) are based on inherent characteristics of material in the sense that the additional strength is obtained without changing the composition of the material to be strengthened. In consideration of such conditions as weldability and possibility of recycling, the choice of the appropriate method for a particular application is limited. In the strengthening by grain refinement, in addition to the increase in strength due to the grain boundary effect, materials become tougher because the ductile-brittle transition temperature*3 is lowered. On the other hand, in the work hardening, materials become brittle because the ductile-brittle transition temperature*3 is raised making the process less practical.[7] Furthermore, the development of basic research has revealed that "ultra-refinement in a simple-component system" may provide not only additional strength but also ductility, toughness, durability and corrosion resistance[2,3], making the grain refinement process the most promising method for material strengthening.

6.3 Outline of the various projects for developing fine-grained metallic materials

6.3.1 Ferrous materials

The development of fine-grained metals is most intensively advancing in ferrous materials. Since ferrous materials are the most widely used among the structural materials, breakthrough technologies for weight saving and strengthening of steel have far more impact on society than any other material. Table 1 shows the outline of representative projects for developing fine-grained steels in Japan.

Table 1: National projects for fine-grained steels

Project name	Period	Major executing organization	Target of development
New millennium structural materials "Ultra-Steel" (STX-21)	First stage: 1997 to 2001 fiscal year Second stage: 2002 to 2006 fiscal year (scheduled)	Frontier Research Center for Structural Materials, National Research Institute for Metals of Science and Technology Agency Steel Research Center, Independent Administrative Institution National Institute for Materials Science (NIMS)	**First stage**: Development of "double strength and/or double life" steels **Second stage**: Creation of "Factor 4" steel used for "new urban infrastructures" and "high-efficiency coal-fired power plants" (doubling the strength and life at the same time).
Super Metal Technology (Ferrous material)	1997 to 2001 fiscal year (1995 to 1996 fiscal year, leading research for super metal)	The Japan Research and Development Center for Metals (Nippon Steel Corp., NKK Corp., Kawasaki Steel Corp., Sumitomo Metal Industries, Ltd., and Kobe Steel, Ltd.)	To establish the technology to create fine-grained steel that is at least 1 mm thick in shape and has a grain size of 1μm or less by obtaining uniform multi-phase structures.
Developmsent of basic technology for creating ultra-fine grained steels harmonious with the environment (Super Metal 2)	2002 to 2006 fiscal year (scheduled)	Undecided as of July 9, 2002	To develop basic technologies for forming, processing and utilizing ultra-fine grained steel with an intention for application to the steels widely used in the automobile industry.
Nano Metal Technology	2001 to 2005 fiscal year (scheduled)	The Japan Research and Development Center for Metals (Nippon Steel Corp., NKK Corp., Kawasaki Steel Corp., Sumitomo Metal Industries, Ltd., and Kobe Steel, Ltd.), Osaka Science and Technology Center, Hitachi Metals, Ltd.	1. **Ultrahigh-purity metals** To develop and systematize the structure control technology, laying stress on the composition control technology that enables the reduction of impurity elements in metals to the order of nanograms. 2. **Practical metals** To elucidate the nano-cluster and nano-precipitation behaviors and the behaviors of micro grain boundaries and interfaces in the nano-range of steels, in order to establish the guiding principles for structure control and the basis of designing and processing technologies that will lead to the creation of new generation multi-phase steel by nano-control.

Sources: Authors' compilation on the basis of references [1, 2, 3, 11, 13, 14] and [15]

Present status of each project is as follows.

• Ultra-Steel (STX-21)

In April 1997, "Research on structural materials for the new millennium (Ultra-Steel) project" (STX-21) started at the Frontier Research Center for Structural Materials, the National Research Institute for Metals of Science and Technology Agency, which is now reorganized as the Steel Research Center of the Independent Administrative Institution National Institute for Materials Science (NIMS). The target of this project is to develop steels having "double strength and/or double life." More specifically, the target is to realize easily recyclable steels having properties of "double strength and/or double life" that do not require the use of rare metal alloying elements, taking the conservation of resources and protection of the environment into consideration. In the first stage of the project (1997 to 2001 fiscal year), the following four subjects were chosen. Subjects relating to the enhancement of the strength of steels are: (i) development of easily recyclable and weldable ultra-fine grained steel of 800 MPa (megapascal) class (800 MPa is twice the tensile strength of the present typical 400 MPa structural steels), and (ii) development of ultrahigh-strength steel of 1500 MPa class that is resistant to delayed fracture and fatigue; and subjects relating to the elongation of life were: (iii) development of alloying-element saving, high performance steel that is resistant to marine environments, and (iv) development of heat-resisting steel used for the ultra-supercritical pressure power station. These studies proved on the laboratory level that it is possible to create ultra-steel.[8]

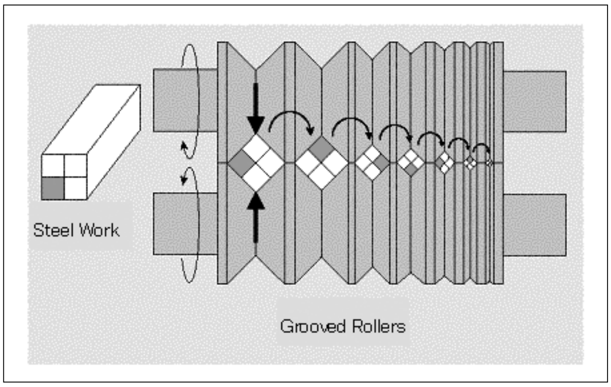
Figure 1 is a schematic diagram of the rolling process employed in the development of 800 MPa steels in this project using multidirectional caliber rollers.[7] This method is a rolling process using multidirectional grooved rollers, and a kind of multi-pass, multidirectional warm working. By repeating the rolling of a steel rod in two directions (vertically and horizontally) in the temperature range of warm working under heavy deformation, a rod of 18 mm square and 20 m long having ultrafine grains of 1 μm was successfully obtained. As the material to be tested, low-carbon silicon manganese steel was chosen, which is widely used and easily recycled.

In the second stage of the STX-21 project scheduled for 2002 to 2006 fiscal year, "Ultra-Steel project aiming at realizing new social and urban infrastructures," the target is to establish the technology to create "Factor 4" ultra-steel that doubles the strength and life. "New urban structures (such as tall buildings and ultra-long bridges)" and "high-efficiency thermal power plants (5% higher power generation efficiency of coal-fired power plants by raising the steam temperature from 600°C to 650°C)" have been selected as the targeted structures, and basic studies are scheduled to be started from the laboratory level taking the commercialization viewpoint into consideration so that development research can be started after five years.[9] In order to promote this project, the Steel Research Center was organized in NIMS this April.[10]

• Super Metal

The "Super Metal Technology" project was started in New Energy and Industrial Technology Development Organization (NEDO), based on the Program for the Scientific Technology Development for Industry sponsored by Ministry of International Trade and Industry (present Ministry of Economy, Trade and Industry). After conducting leading research for two years from the 1995 fiscal year, the project was carried out for five years from the 1997 fiscal year. There are two major subjects for the super metal project: technology for creating mesoscopic*4 structured steel (ferrous super metal), and technology for creating mesoscopic structured bulky aluminum materials (aluminum super metal). The ultimate target for the ferrous super metal is "to establish

Figure 1: Schematic diagram for rolling using multi-directional grooved rollers

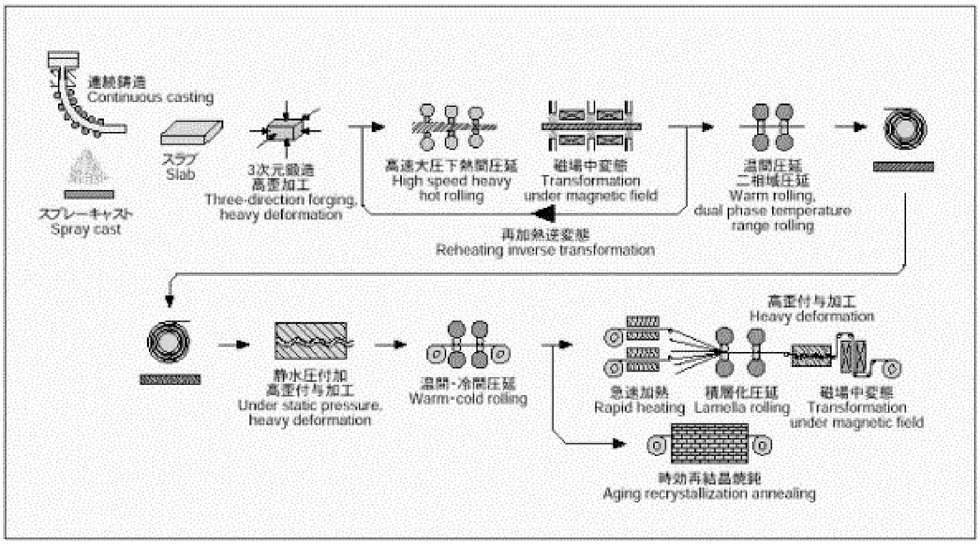


Source: reference [7]

the technology for manufacturing microstructure steel with grain size of less than 1 μm and a thickness over 1 mm using carbon steel and by even multi-phase structuring." This has been planned based on the basic metallurgical concept for producing fine-grained steel constructed from the results of the leading research. The results made it clear that heavy deformation caused by working is effective for creating ultrafine grained steel, and that making a structure of simple composition steel ultrafine without adding special alloying elements is the best way to make the most of the ultimate properties of steel and improve recyclability. [2,3]

Therefore, they have carried out research selecting the following three major themes: (i) research on ultra-refinement of steel structure by giving heavy deformation by hot working; (ii) research on ultra-refinement of steel structure by working and heat treatment under a strong magnetic field; and (iii) estimation studies on the structure and characteristics of ultrafine grained steel with multi-phase structure. The driving force for nucleation in transformation and recrystalization processes was dramatically increased by the heavy deformation caused by hot working, and the growth of nuclei was thoroughly suppressed by making use of the second phase. In this way, they have practically established the guiding principles for obtaining ultrafine grain size of 1 μm or less in the process of ultra-refinement of steel. Then, using a high-speed, heavy-reduction rolling mill, they produced a fine-grained steel plate by hot rolling of laboratory scale, and succeeded in obtaining a 5-mm thick steel plate having a grain size of less than 1 μm. The fine-

Figure 2: Schematic diagram for the manufacturing process of ferrous super metals



Source: "Super Metal" Web site of NEDO [13]

grained steel plate having a strength of 900 MPa class obtained without adding alloying elements proved the improvement in strength and toughness, and it was confirmed that they had achieved the objective of the project.[11, 12] Figure 2 shows a schematic diagram for the manufacturing process of ferrous super metal.

Reflecting the recognition that it is necessary to elucidate the mechanism of grain refinement, basic studies to elucidate the mechanism of grain refinement are being conducted in the Nano Metal project that started in the last fiscal year.

Taking the results of the super metal project into account, a succeeding project, "Development of basic technology for creating ultra-fine grained steel harmonious with the environment (super metal 2)" is scheduled to newly start from the 2002 fiscal year as a part of the 3R (Reduce, Reuse, and Recycle) project sponsored by NEDO. The development period of this project is scheduled to continue for five years, and its target is to develop basic technologies relating to ultrafine grained steel including forming processing and utilization technologies that can be applied to widely-used steels such as those for automobile manufacturing. There are four research and development themes for this project: (i) advanced heavy deformation working technology; (ii) innovative rolling and lubrication technology; (iii) innovative joining technology; and (iv) research and development of a heavy deformation working model making use of computational science.[14]

- **Nano Metal**

In the 2001 fiscal year, the "Nano Metal Technology project," which is scheduled to continue for five years, was started as a part of the "Materials Nanotechnology" program of NEDO.[15] "Materials Nanotechnology," the innovative technology of the 21st century, is expected to radically change the technologies related to materials, which is the basis for various fields of industry including information, environment, safety, security and energy. The "Materials Nanotechnology" program aims to carry out basic research and development on material nanotechnologies, and to systematize the knowledge obtained from the results.

An objective of this project is to dramatically improve mechanical properties (e.g., strength and ductility) and functional characteristics (e.g., corrosion resistance, electrical properties, and magnetic properties) by ultra-precise and ultra-fine control of the composition and structure of metallic materials. Such technologies will provide light and heat-resistant materials for various fields of industry including the automotive industry and information industry, contributing to the promotion of energy saving. It is a further objective of the project to establish "nano-metallurgy" (metallurgy at the nano-level) by systematizing the obtained knowledge and to build the technological basis for creating new metallic materials. To realize these objectives, it is planned, relating to metallic materials, to establish ultra-precise crystal composition control technology (e.g., purification and addition of effective elements), ultra-precise and ultra-fine crystal structure control technology (e.g., grain size control, precipitation control, and structure control of grain boundary/interface), and measuring techniques for composition analysis and structure analysis as well as to systematize these technologies. Specifically, the following four themes have been selected: (i) composition control technology for metals in the nano range; (ii) structure control technology for metals in the nano range; (iii) design technology for metallic materials making use of calculation science; and (iv) the systematization of technologies. In pursuing these themes, it is intended to emerge from the metallic material creation technology hitherto that resorts to empirical and experimental methods; to enable development of metallic materials having highly-advanced functions and to provide metallic materials with desired functional characteristics; to deal with resource conservation, energy saving, and global environmental issues; to establish a secure and safe society; and to contribute to the realization of nano-devices that open the road to next-generation information communication.

6.3.2 Nonferrous metals

Although we have so far introduced technology development projects mainly related to fine-grained ferrous materials, in the nonferrous metal field developments of fine-grained materials are also being carried out relating to aluminum and copper materials. Table 2 shows the outline of major national projects relating to fine-grained nonferrous metals. Among the specific themes are: development of thin aluminum sheets for automobile application from the viewpoint of reducing vehicle weight, development of high-performance wrought copper products having high conductivity and strength two times that of conventional materials or more, and realization of ultra-fine thin film copper wiring of less than 100 nm wide for next-generation Si devices.[16]

6.4 Developing practical fine-grained steel

On November 1, 2001, Nakayama Steel Works, Ltd. announced that they had succeeded in producing hot rolled fine grain steel plates for the first time in the world and started production and

Table 2: National projects for fine-grained nonferrous metals

Project name	Period	Major executing organization	Target of development
Super Metal Technology (Aluminum Materials)	1997 to 2001 fiscal year (1995 to 1996 fiscal year, leading research for super metal)	The Japan Research and Development Center for Metals	To establish the technology for creating bulky aluminum materials having an ultra-fine grain size of about 3μm or less, mechanical properties (strength and corrosion resistance) 1.5 times better than those of conventional materials of the same kind, and a sheet width of about 200 mm or more.
Nano Metal Technology (Aluminum Materials)	2001 to 2005 fiscal year (Scheduled)	The Japan Research and Development Center for Metals (Furukawa Electric Co., Ltd., Sky Aluminum Co., Ltd., and Sumitomo Light Metal Industries, Ltd.)	Relating to aluminum alloys of practical compositions, to elucidate the structure in the nano range and its formation mechanism, to establish the structure control technology, and to systematize the technology by constructing a database of material properties.
Nano Metal Technology (Copper Materials)	2001 to 2005 fiscal year (Scheduled)	The Japan Research and Development Center for Metals (Yamaha Metanix Corporation, and Nippon Mining & Metals Co., Ltd.)	(1) **Bulk group** To establish basic technology for producing high-strength, high-conductivity copper materials by controlling nano-clusters and grain size. (2) **Thin film group** To establish the guideline for designing the materials, and processing of high-conductivity materials for the wiring of next-generation highly-integrated devices.

Sources: Authors' compilation on the basis of references [13] and [16] sales of them on commercial basis.[4] In this original technology for producing hot rolled fine grain steel plates, which has been developed in cooperation with Kawasaki Heavy Industries, Ltd., high-reduction rolling and vigorous cooling are repeated to produce the product. Using six continuous finishing rolling mills, the thickness is drastically reduced to less than half with the last three mills, and, at the same time, the material is rigorously cooled (cooling speed: 40°C/sec) by curtain wall cooling systems installed between the rolling mills. Table 3 shows the progress of development of hot rolled fine grain steel plates at Nakayama Steel Works, and Figure 3 shows a schematic diagram of the production process.

These steel plates have a very fine grain size of 2 to 5 μm, which is less than one-third that of conventional materials (grain size of conventional steels is between 10 and 15 μm), and a tensile strength of 500 to 600 MPa class, which is from 1.5 to 1.6 times that of conventional steels. As the strength was increased by grain refinement, it is possible to reduce the Si and Mn content of conventional hot rolled steel plates to half. Furthermore, the new material shows high toughness, high workability and excellent weldability, as well as high resistance to fatigue. Although the strength attained does not reach 800 to 900 MPa, the target value of STX-21 and Super Metal (ferrous materials) projects, it is highly appreciated that they have realized a practical fine grain steel having a grain size of several micrometers and have put it into practical use and mass production in advance of the national projects.

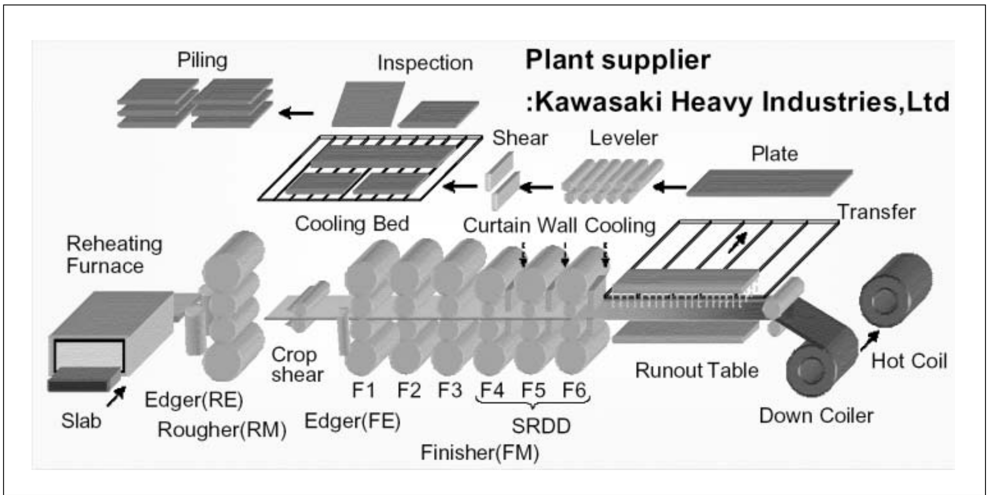
The production technology of this material cleverly combines the high reduction rolling technology using the single roll drive with different diameter rolls*5 and the vigorous cooling technology using curtain wall cooling systems*6, and has attracted the attention of the industry. The fact that manufacturers of industrial machinery, construction equipment, and automobiles are requesting quotations for sample

Table 3: Progress of the development of hot rolled fine grain steel plates at Nakayama Steel Works, Ltd.

Product name	Progress of development	Executing organization	Outline of the development
Hot rolled fine grain steel plates NFG (Nakayama Fine Grain)	**1996:** Planning the construction of the hot rolling plant. **January 2000:** Started hot line test. **August 2000:** Started commercial operation. **January 2001:** Started full-scale development of hot rolled fine grain steel plates. **October 2001:** Succeeded in developing a steel with a tensile strength of 500 to 600 MPa class. **November 1, 2001:** Press release. **December 2001:** Started production and sales.	Nakayama Steel Works, Ltd., Kawasaki Heavy Industries, Ltd.	Developed hot rolled fine grain steel plates having a grain size of 2 to 5μm, which is less than one-third that of conventional materials and a tensile strength of 500 to 600 MPa class.

Source: Authors' compilation on the basis of reference [4]

Figure 3: Schematic diagram for the production process of hot rolled fine grain steel plates at Nakayama Steel Works, Ltd.



Source: reference [17]

delivery indicates that much hope is placed on the material. At present, the range of dimensions that can be produced is limited to 1.6 – 16 mm thick × 600 – 1219 mm wide, but it is expected that the strength will be increased as well as the dimensions that can be produced in order to expand the fields of application.

6.5 Present status in foreign countries

Innovative projects such as "STX-21" and "Super Metal Technology" have made an impact on research activities on fine-grained steel in foreign countries, and Europe, Korea, and China have independently started projects of fine-grained steels aiming to catch up with Japan.

6.5.1 Europe: ECSC Steel Program [18]

The first-stage project for ultrafine-grained steels started in 2000, as a one-year EU project. Research mainly on "heavy deformation rolling + annealing" was carried out in order to investigate the properties of steels with a grain size of 1 μm and evaluate their effectiveness.

Furthermore, a three-year ECSC (European Coal and Steel Community) project, whose participants are mainly private companies and universities, started in 2001 for developing controlling technology of fine structure to provide high strength. It is intended to apply the results of the project to industrial fields such as automobile manufacturing, buildings and infrastructures, and pipelines. The target is narrowed down to the development of an extra-high speed cooling technique and production of fine-grained steel using hot rolling lines in order to create steels with a grain size of 2 to 3 μm, which seems to be rather easy to realize, and to attain prospects for the technology. Practical application of steel plates and rods to the automobile industry without making significant changes in the manufacturing process is being considered. Efficient and consistent research and development is being made from the preparation of hot-rolled material, through processing, to characterization. Weldability is considered to be a key issue; however, experiments on punch joining and other methods that can substitute spot welding are being made.

The new ECSC2002 Project scheduled from 2002 to 2007 has started, and it is aimed at searching for high performance, durability, and recyclability.

6.5.2 Korea: HIPERS-21 [18]

The five-year Hipers-21 project started in 1998, and studies on ultra-refinement of grain size is being conducted, making use of dynamic transformation induced by strain as in the case of the Japanese Super Metal Technology project. They have reported that strain induced dynamic transformation (SIDT) is effective for creating fine-grained steels, and that dispersion of TiN particles is effective for suppressing the grain growth in the heat affected zone (HAZ). The average grain size of created fine-grained steel is fine in the surface layer at 2 to 3 μm, but coarse in the center part at 5 μm. Not only the steel industry but also the heavy industry and construction industry are participating in the project, and specification design from the practical point of view is also being investigated.

In the second-stage project scheduled from 2003 to 2007, the following themes are planned based on the results of the first-stage project: (i) research and development of a production method for new ultrafine-grained steel; (ii) development of a pilot plant for the new ultrafine-grained steel; (iii) proving the production method for ultrafine-grained steel; and (iv) research on the application of the ultrafine grain steel to large-scale structures.

6.5.3 China: New Generation Steels [18]

The national project, "New Generation Steel," started in 1998 aiming at "double strength and/or double service life" with grain refinement, purification and homogenization as the key technologies. Realization of fine-grained structural steel with a grain size of 2 to 3 μm is targeted, and the actual objective is to catch up with Japan. They are positively collecting information from Japan, by frequently holding international conferences.

In the United States, on the other hand, no research project for fine-grained steel exists at present. However, in the "National Nanotechnology Initiative" announced by then

President Clinton, it was mentioned as an example of the Grand Challenges to develop materials that are ten times stronger but lighter than steel. And we should keep an eye on the future movements in research and development.

6.6 Conclusion

In addition to higher strength, grain size refinement of metallic materials has brought about various improvements such as a lower ductile-brittle transition temperature, better corrosion resistance, ductility and weldability. As a result, metallic materials that have been considered as structural materials are now recognized as new functional materials owing to the new functions created by innovative processing. In order to promote further improvement of material properties and establish control techniques, it is necessary to develop, in addition to the grain size control, advanced technologies for designing and controlling composition and precipitation within the fine structure as well as to elucidate leading principles for these studies. A technological breakthrough is also required for putting these materials into practical use. For example, it is hoped that, while the properties of a fine-grained material are maintained, the technology that enables joining will be developed.

Since the development of such materials requires not only large-scale equipment such as full-sized rolling mills but also a long period of research and development activities that separate private companies cannot afford, the roles of national projects become very important. In the projects for the development of fine-grained metallic materials, mutual exchange of information has been actively done. Particularly in Workshop on the Ultra-Steel, international committee on ultrafine grains, International Conference on Advanced Structural Steels and the Intensive Forum held by the Iron and Steel Institute of Japan, researchers actively discussed technical matters for the sake of mutual communication, significantly contributing to the advancement of Japanese technological development relating to steel and other metallic materials. Five years have passed since the research and development of fine-grained metallic materials started, and it seems to be about time to evaluate the results. From now on, it is necessary, in addition to the development of material and processing conducted by the material industry that has the seeds, to develop applications from the viewpoint of practical use in industries that have the needs. Materials can be called materials only when they are practically used. Therefore, effective and sufficient research and development must be conducted by unifying the direction of development, with close communication among the material industry, researchers of materials and processes, end users of materials, and product designers. Especially, adequate cooperation among the national projects, STX-21 second phase, Super Metal 2, and Nano Metal is essential for the attainment of technology breakthrough.

The recent growth of the iron and steel industry in China and Korea is magnificent. They are now competing with Japan backed by the newest equipment and low labor costs. For the Japanese iron and steel industry, as well as the other metal industries, to keep the position of basic industries maintaining international competitiveness, it is necessary to distinguish their products by adding extra values. Japan is now running ahead of other countries in the development of fine-grained metallic materials with fine-grained steel as a major target. In order for the Japanese material industry to maintain sufficient international competitiveness and attain the position to establish de facto standards in material development, significant roles are expected from these projects.

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Glossary

*1 Toughness

Property that indicates how much energy can be absorbed before fracture. The higher the toughness, the tougher is the material.

*2 Solid solution

State in which foreign atoms are present as solutes in the crystal lattice of a metal in solid state.

*3 Ductile-brittle transition temperature

The temperature at which the fracture mechanism of steel changes from the ductile fracture at higher temperatures to the brittle fracture at lower temperatures. The ductile fracture occurs after significant plastic deformation, whereas the brittle fracture occurs with little plastic deformation.

*4 Mesoscopic

A scale used for the evaluation of the characteristics of metals. When characteristics are evaluated based on a grain size of about 10μm or larger, the evaluation range is called macroscopic; when the evaluation is based on the level of atoms or electrons, the range is called microscopic. Mesoscopic refers to the intermediate range between macroscopic and microscopic.

*5 Single roll drive with different diameter rolls

While both upper rolls and lower rolls (having the same diameter) are driven in normal finishing rolling mills, in this method, rolls on one side only are driven in the last three stands; furthermore, the diameters of the upper rolls and lower rolls are different.

*6 Curtain wall cooling systems

Equipment is installed on the outgoing side of the last three stands in order to cool the rolled material. The thickness of the water stream falling on the material is 24 mm or more and the stream forms a wall (laminar flow), providing a high cooling capacity.

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