*NRIM has changed to NIMS

Ultra-Steels

— *STX-21 Project* —

Center for Structural Materials Research

2001

NIMS

National Institute for Materials Science

Preface

In the early 21st century, a large portion of the infrastructure that was built during the era of great economic growth of Japan will be outdated and will need renewal. We will need to guarantee the safety and service life of structural materials and infrastructure. The increase in concern over global environmental matters has increased the importance of such concepts as low environmental load and conservation of resources. Steels will remain the principal components of most structures and so innovations in steels should have a great impact on these issues.

The National Research Institute for Metals (NRIM) has founded the Frontier Research Center for Structural Materials with the goal to create radical advances in structural material, in the form of ultra-steels for the 21st century. At the Frontier Research Center, revolutionary concepts rather than modifications of conventional technology will be the main objective of world-class staff with backgrounds from both industries and universities.

Organization of the Frontier Research Center for Structural Materials

Director

Materials Creation Research Station (1st to 5th Unit)

This Station conducts research on four topics with the aim of doubling the strength or prolonging the service life of steels. The Station will seek the creation of ultra-fine microstructures that are stable at high temperatures by applying innovative processes in refining, solidification, deformation, and heat treatment, resulting in the controlled dispersion of inclusions and depositions.

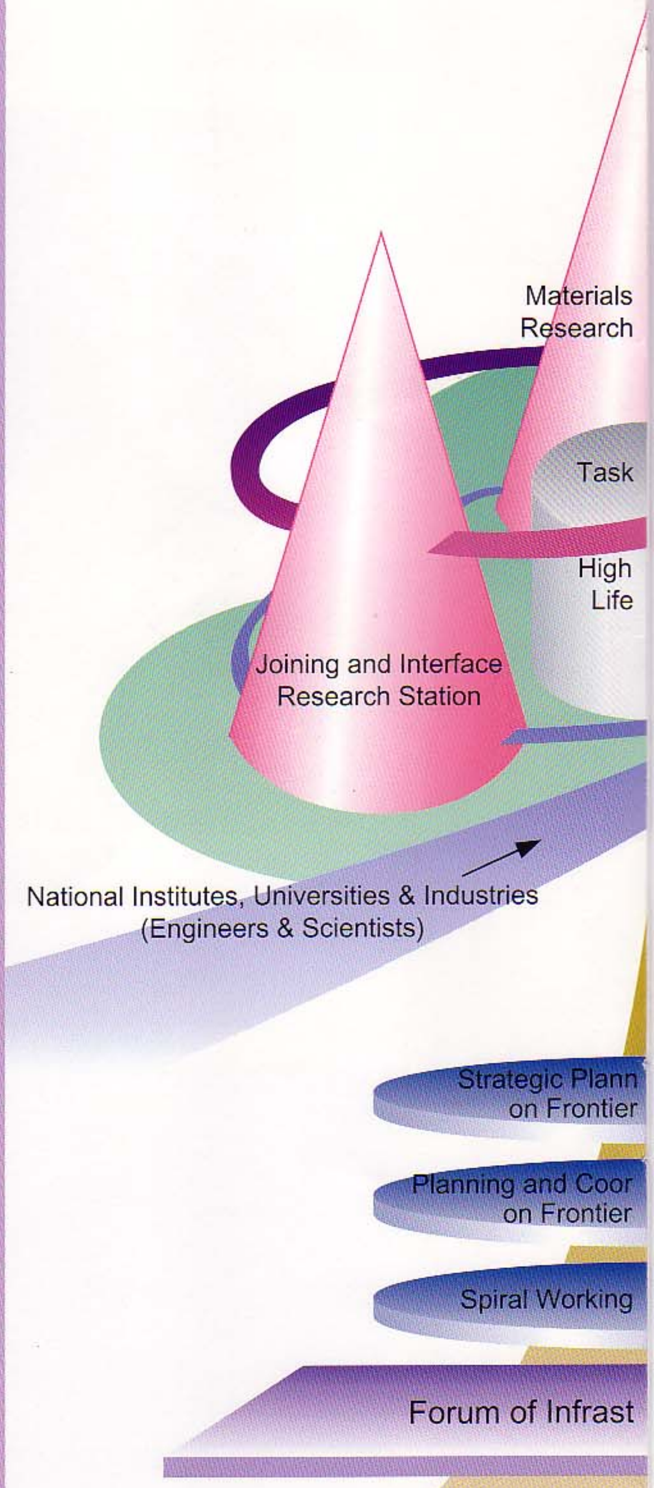
Joining and Interface Research Station (1st to 6th Unit)

This Station conducts basic research on development of optimum joints suited for new materials and environments. By modeling phenomena associated with joint formation, and by establishing the predictive simulation of microstructures and residual stresses, the Station aims to improve mechanical properties and prolong service life for assembled structures.

Strength and Life Evaluation Research Station (1st to 6th Unit)

This Station investigates the fundamental nature of such phenomena as fracture, long-term fatigue and creep using advanced technologies in the form of nanoscopic and atom-scale analysis, and establish the guiding principles for improving these mechanical properties. This Station will aim to standardize evaluation methods and to establish acceleration tests after testing in various environments.

Creation of

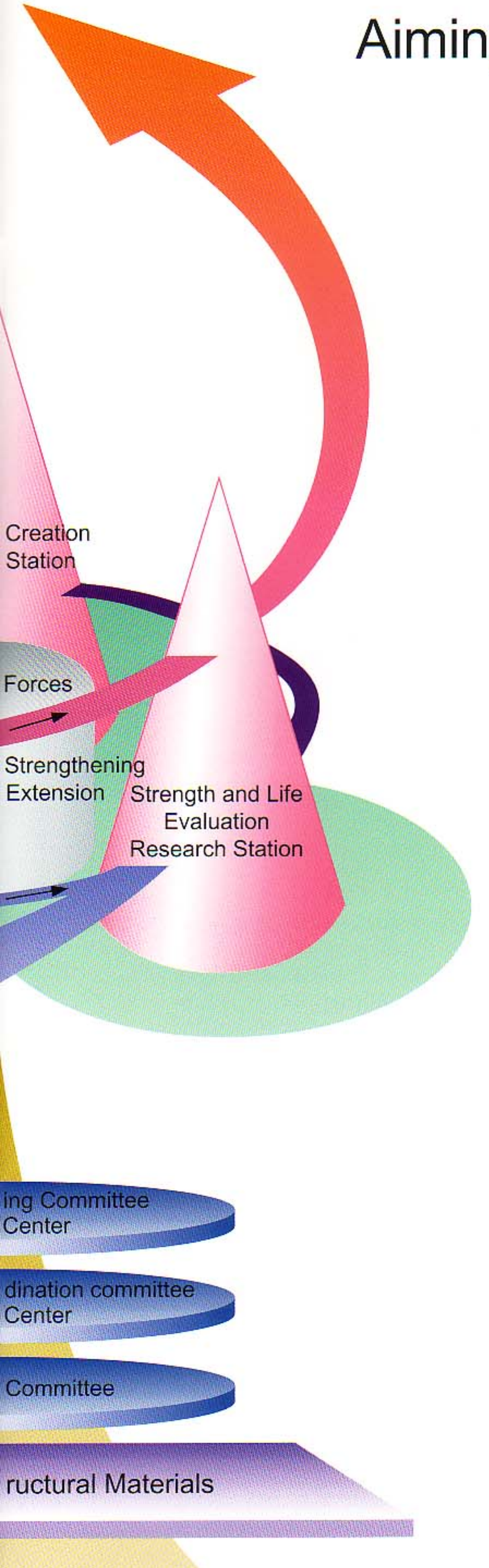


What is STX-21?

STX-21 stands for Structural
ST also implies Science and
a number of creative outputs

Ultra-Steels for the 21st Century

Aiming to Double Strength and Life



Materials for the 21st Century.
Technology and the letter X symbolizes
expected.

Basic Concept of the Project

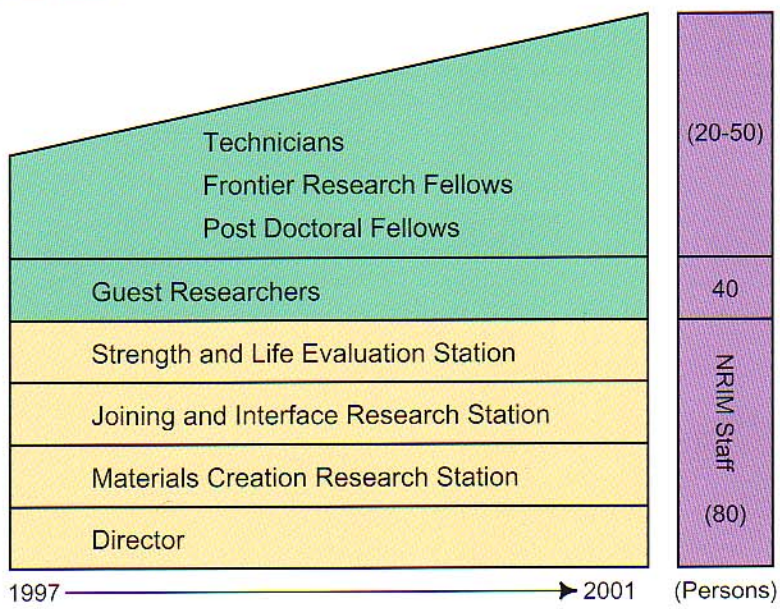
The motto of our project is "to decrease the environmental load and the total life cost of structural materials by doubling the strength and life of steels". In pursuit of this objective, we have launched the following research topics:(1)800-MPa-class,(2)1500-MPa-class high-strength steels, (3)heat-resistant steels, and (4)corrosion-resistant steels. Tentatively, a ten-year research period is planned, during the first five years of which, the focus is on basic studies seeking to break the barriers of traditional technology.

Research & Development through "Network Synergy": Stations and Task Forces

The Frontier Research Center for Structural Materials consists of three Research Stations: Materials Creation, Joining and Interface, and Strength and Life Evaluation. In addition to the Research Stations, the Center consists of a network structure based on Task Forces, which facilitates each individual project. This cross-linking was designed for effective projects through strengthened communication, cooperation and competition among the Stations and Task Forces. Such a network is called "Spriral dynamism system" which creates excellent network-synergy effect.

An Open Institution: Cooperation with Industries and Universities

Over one hundred researchers have joined the Center. About thirty came from industries and universities and the rest from other groups of NRIM. The Center is expected to grow as a focal point of human resources by attracting more scientists both from industries and universities. The technical reputation as an R&D center of structural materials will increase by distributing achievements in the form of technical papers and other forms of information.



Creation of 800MPa-class high-strength ecologically beneficial steels for welded structures

Task force for 800MPa high-strength steels

It is hard to maintain weldability of steel when high-strength is achieved by the presence of alloying elements. The target of this research is to transform low-cost mild steels with low alloying elements and easy-recyclability into fine-grained high-strength steels, and develop new welding techniques suited to this newly developed steels. These innovations will double the strength of steels without sacrificing dependability and decrease their overall environmental load.

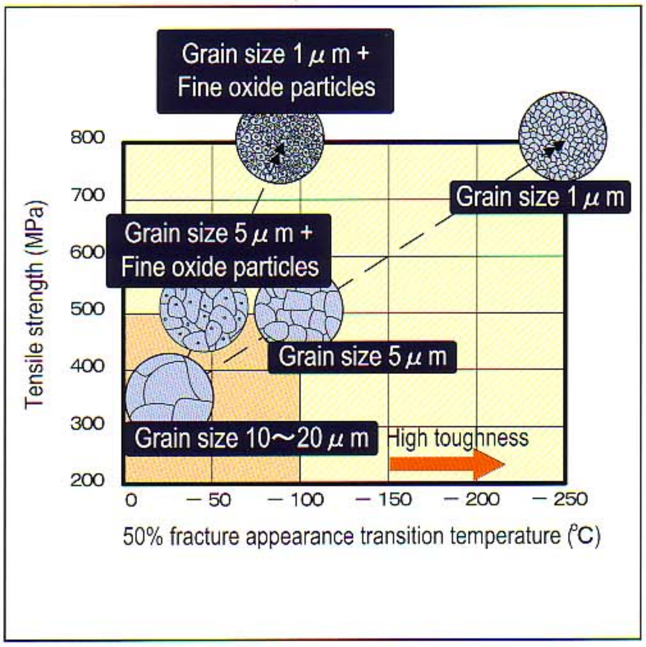


Fig.1 Creation of fine grained microstructure in steel is expected to realize high-strength and high-toughness, whereas the refining of microstructure in the welding heat-affected zone is achieved by the dispersion of fine oxide particles.

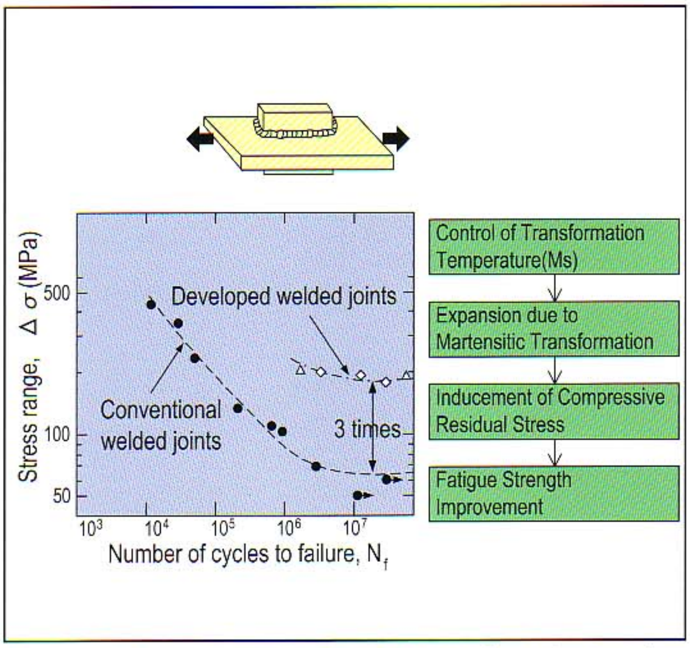


Fig. 2 Utilization of martensitic phase transformation at a low temperature achieved a dramatic improvement of fatigue strength by induction of compressive stress in the weld.

Creation of fine-grained steels

Based on the composition of mild steel (400MPa tensile strength steel), challenges are carried out for creation of ultra-fine grained microstructures with grain size less than 1 μ m, and simultaneous realization of doubled-strength of 800MPa, high toughness and high elongation which are required for structural materials. The use of dispersions of fine oxide particles is investigated to suppress coarsening of HAZ microstructure caused by elevated temperature during welding which leads to softening and reductions of toughness (Fig. 1) .

New welding technique for fine-grained high-strength steels

The welding of microstructurally fine steels generally presents difficulties. Unwanted changes in microstructure can be reduced by minimizing the area of the heat-affected zone due to welding. To achieve this, extremely narrow gap arc-welding techniques and high-power one-pass laser welding of thick steel plates are being developed to create high efficiency joints with narrow HAZ. Low-temperature joining techniques to preserve fine microstructure and welding procedures developed for improved fatigue properties and toughness are also investigated (Fig. 2) .

Computer simulation and nondestructive measurement

Nondestructive in-situ measurement techniques are being developed which detect various manufacturing process phenomena, such as deformation, degradation of microstructures, thermal stresses, defects and dynamic properties of welded joints. In conjunction with this, computer simulation techniques related to these measurements are carried out. The combination of these two factors creates rational and efficient research, management of manufacturing process and reliability of material performance.

Development of high-strength steels with high resistance to fracture

There is an increasing demand for ultra-high-strength steels with a tensile strength exceeding 1500 MPa, to be used for higher-strength bolts in the construction industry, weight reduction of automobile parts and main cables of long-span suspension bridges. The key is to control microstructures and inclusions of steel to prevent delayed fracture and improve fatigue properties. Atomic-scale analysis and nanoscopic evaluation techniques are of great utility in attaining this goal.

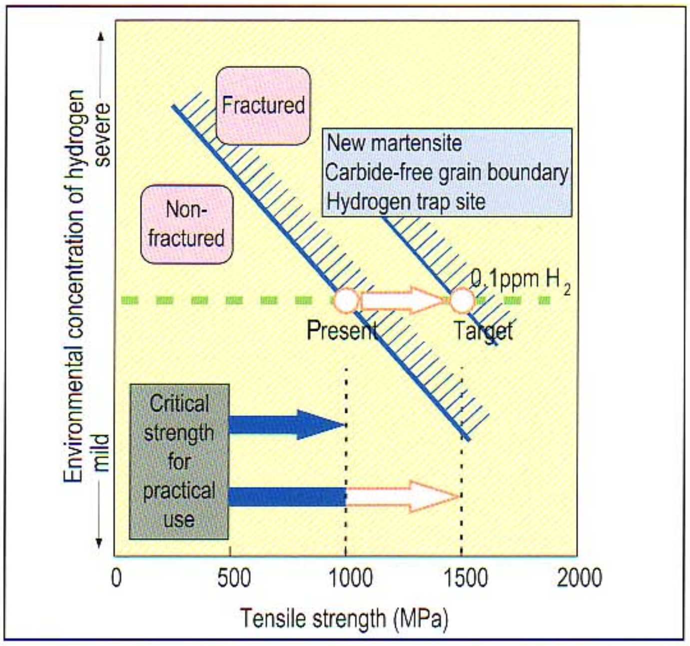


Fig. 3 Possibility of delayed fracture increases with both increasing hydrogen concentration and increasing strength of steel.

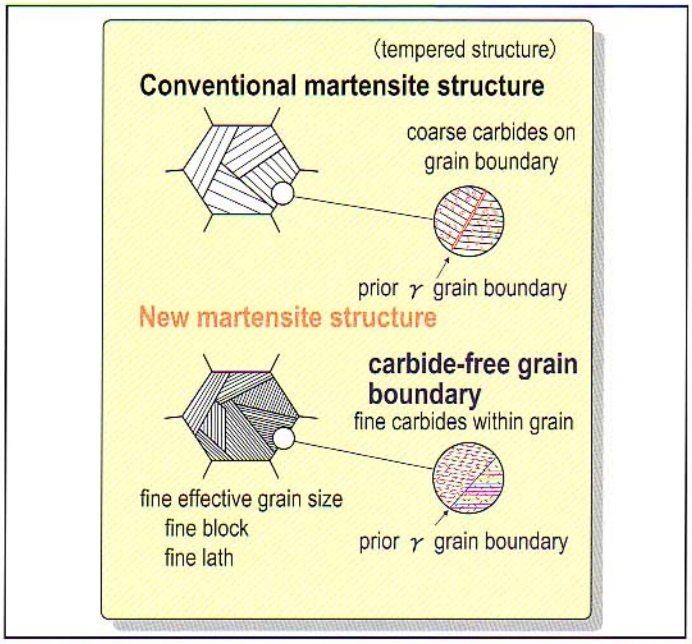


Fig. 4 Schematic drawing of the concept of steel microstructures with high resistance to delayed fracture. In the newly developed martensitic structure, grain boundaries are free from carbides, which tend to be the initiation site of delayed fracture.

Development of high-strength steels with high resistance to delayed fracture

In general, present steels consist of grains with a few 10 μm diameters. Hydrogen in the atmosphere penetrates into the material and gathers at grain boundaries, hence cracks initiate at the boundaries and delayed fracture subsequently occurs. In order to avoid the delayed fracture, the precipitation of carbides on grain boundaries must be controlled. Accordingly, some particles that attract hydrogen more strongly than grain boundary should be dispersed inside grains (Fig. 3, Fig. 4) .

Development of high-strength steels with high resistance to fatigue fracture

Fatigue fracture occurs when cyclic force is applied for one to two million cycles even at a low magnitude. Especially for high-strength steel with a tensile strength over 1200 MPa, fatigue fracture is dominated by internal fracture, initiated at foreign substances such as inclusions. This is why fatigue strength can remain constant even when already high tensile strengths are increased. To increase fatigue properties, it is essential to reduce both the size and hardness of the inclusions.

Application of atomic-scale and nanoscopic analysis

In order to improve the properties of delayed fracture and fatigue fracture, it is important to reveal their mechanisms in atomic or nanoscopic scale, which are closely related to the material's macroscopic behavior. Since atom probe analysis can accurately detect each atom in a material, 3-dimensinal configuration of atoms can be resolved. Nanoindentation technique can prove the mechanical properties of materials in nano-meter scale. The technique is very useful for direct evaluation of a deformation behavior in nanoscopic scale, which then dominates the macroscopic properties.

Development of advanced ferritic steels for 650°C-USC boilers

At the start of the next century, coal fired power generation will be carried out by ultra-supercritical (USC) plants using steam condition of 650°C and 350atm. For this project, it is necessary to develop advanced ferritic heat-resistant steels with acceptable service lives at these high temperatures (Fig. 5).

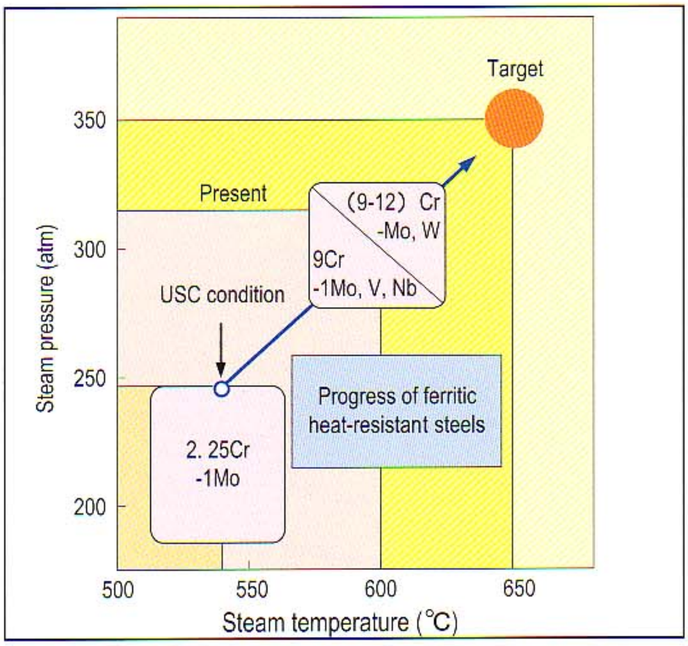


Fig. 5 Classes of steels required by the service condition.

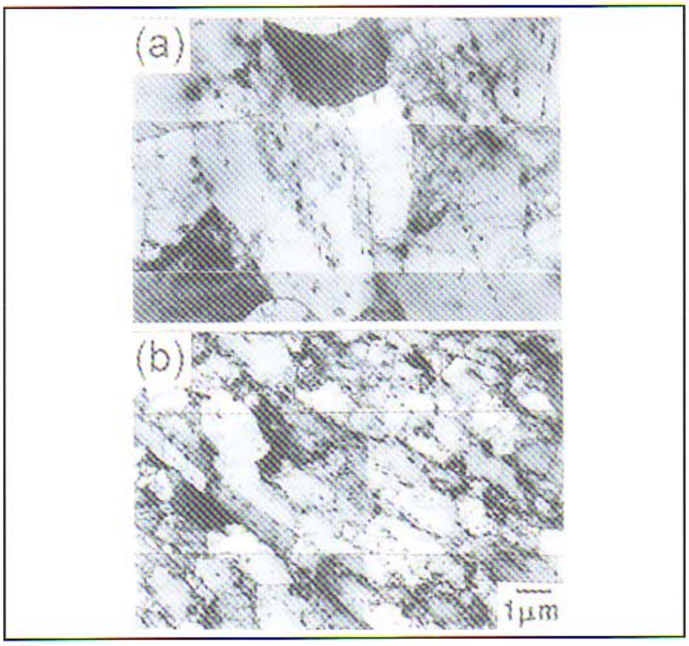


Fig. 6 TEM micrographs of crept 9Cr-steels
(a) conventional 9Cr-1W steels, (b) new 9Cr-3W steels.

New class of steels required by the service steam conditions

Extensive improvement both of long-term creep strength and oxidation resistance is necessary for the development of ferritic steels for use at 650°C. Since boilers are constructed by welding, it is required that joints in these materials perform as well as the materials themselves.

Alloy design : long-term stability of microstructure

Creep strength decreases with temperature and exposure time because of the recovery and the coarsening of precipitates. It is important to stabilize microstructure for improvement of creep strength. Alloy design and creation of these steels is being pursued by a combination of both advanced thermo-mechanical treatments and computational material science such as thermodynamic simulation (Fig. 6) .

Improvement of oxidation resistance

The maximum service temperature of heat-resistant steels may be governed by oxidation resistance, and that of current ferritic steels is 630°C. Alloy design for oxidation resistance is also studied for the development of ferritic steels used at 650°C.

Optimization of microstructure in weld joints

Creep behaviors in weld joints are preferentially investigated to make clear the mechanism of damage accumulation and fracture. The microstructures are also design to improve creep properties of welded joints.

Investigation of oxide dispersion alloys (ODS Alloys)

Creep strength is extremely improved through stabilizing of microstructure by dispersion of oxides. The aim of this research is the establishment of solid-state processes for manufacturing ODS-ferritic steels.

Evaluation of long-term properties

A database of creep properties and creep fatigue properties, which are important for high temperature structural materials, has been constructed. In addition, techniques to predict long-term properties from short-term tests are studied.

Marine and offshore areas are very severe corrosive environments for iron and steel. Despite this, there is a great activity in the construction of infrastructure in these areas. In this task force, the following development programs are in progress: 1) low-alloy weathering steels resistant to marine atmosphere, 2) stainless steels for seawater use and 3) coatings with excellent corrosion resistance in the splash zone. In parallel with the materials development, basic studies from nanoscopic measurement to nationwide exposure tests are carried out.

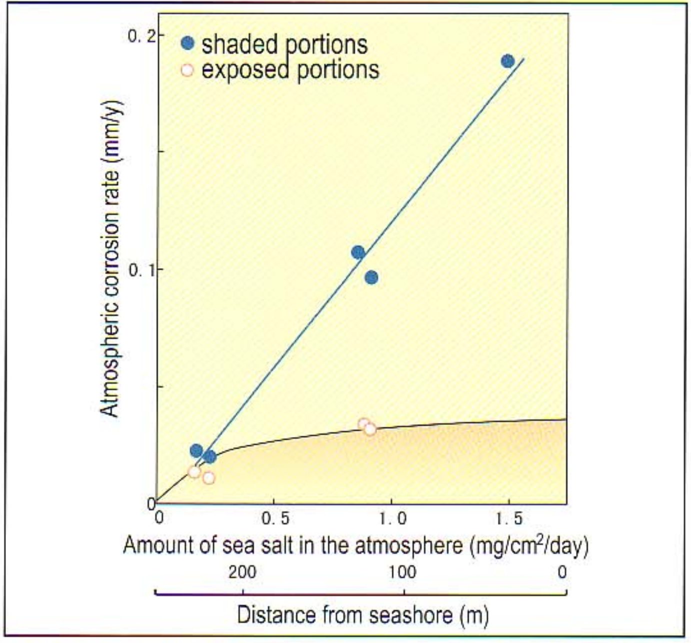


Fig. 7 Effect of the amount of sea salt in the atmosphere on corrosion rate of unpainted steel.

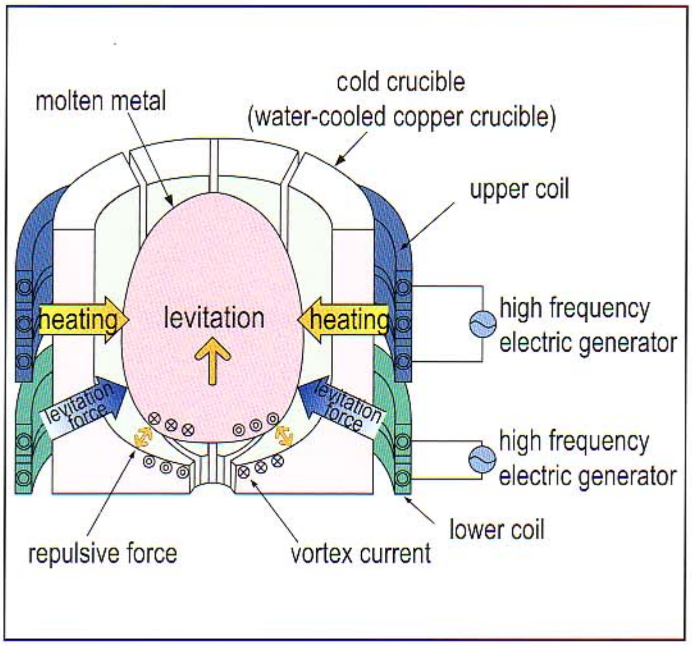


Fig. 8 Cold crucible levitation melting furnace.

Nanoscopic technology in corrosion

To understand rusting and corrosion, several types of scanning probe microscopes (SPM) have been developed including atomic force microscope (AFM) and Kelvin force microscope (KFM). These tools are mostly used under the in-situ conditions which simulate seawater, microbial corrosion and atmospheric corrosion. These investigations are shedding light on the mechanisms of marine corrosion and the basic concepts of corrosion resitant materials.

Development of the low-alloy weathering steels

Low-alloy weathering steels can be safely used in unpainted conditions in atmospheres of low air-born salinity. In steel structures, it is known that corrosion rates are higher in shaded portions than that in those exposed to rainfall because of the accumulation of saline particles (Fig.7). It is thus necessary to establish acceleration tests for atmospheric corrosion in consideration of the accumulation and removal of saline particles in rust. Sophisticated exposure test facilities were constructed in NRIM whereby simultaneous environmental data collection and electrochemical corrosion monitoring can be conducted. The development of the low-alloy weathering steels is in progress based on proposed guiding principles obtained by micro- and macroscopic measuring technique.

Development of stainless steels for marine and offshore use

A research is in advance for the improvement of seawater resistance for stainless steels with minimum alloy addition. Our alloy design goal is the development of a resource-saving super stainless steel. It is based on a principle of maximum addition of nitrogen as a passivating element thus minimising addition of less common elements such as Cr, Ni and Mo, and removal of nonmetallic inclusions in the matrix. High nitrogen is attained by melting the alloy under the pressurized atmosphere. For obtaining ultra-pure metals, a non-contact type melting is used in which molten metal is levitated in a cold crucible by electromagnetic force (Fig.8).

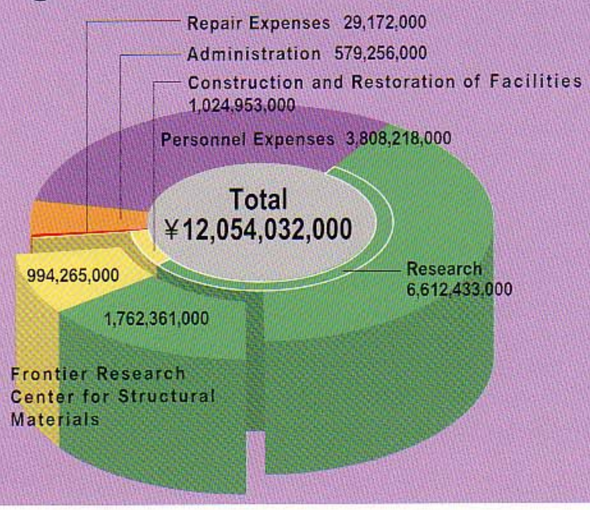
Development of spray coatings resistant to splash zone corrosion

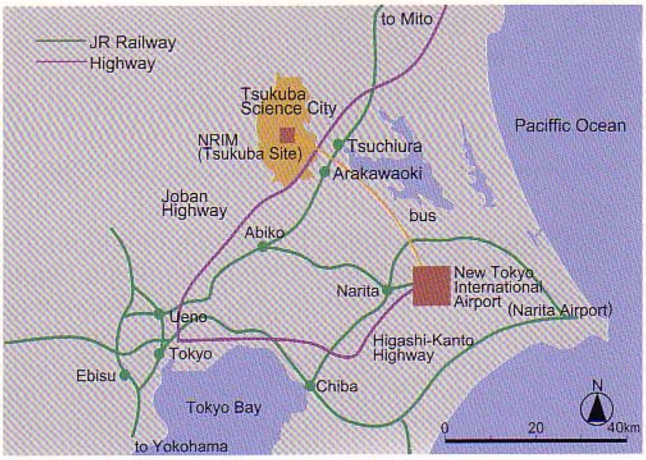
Thermal spraying technique is applied for the formation of corrosion-resistant films in seawater. We have conducted both instrumental developments of spray techniques and searches for coating materials. In the optimal combination of the spray system and material, the coating is expected to perform as well as possible substitutes or repair metal claddings, even in the highly aggressive corrosion environment of the splash zone.

Organization Chart of NIMS

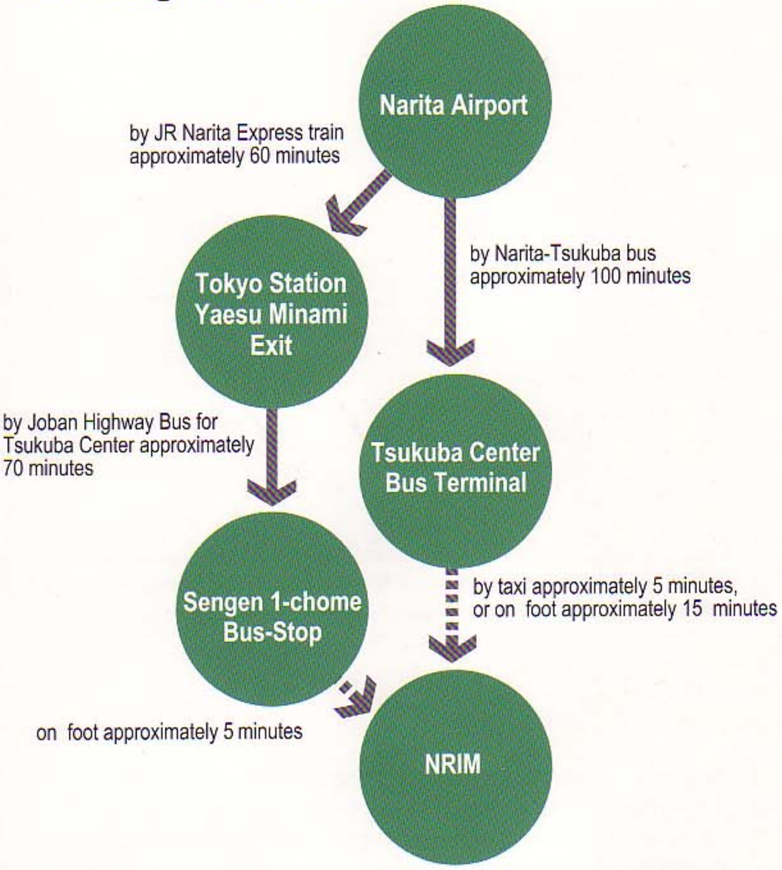
- President
  - Office for Research Strategy and Policy
  - Planning Office
  - Advanced Materials Lab.
  - Nanomaterials Lab.
  - *Materials Engineering Lab.*
    - Center for Fundamental Materials Research
    - *Center for Structural Materials Research*
      - *Materials Creation Research Group*
      - *Joining & Interface Research Group*
      - *Strength & Life Evaluation Research Group*
      - *Corrosion Resist Materials Research Group*
      - High Temperature Materials Research Group
      - Mechanical Properties Research Group
      - Materials Testing Office
      - Ecomaterials Research Team
  - General Affaires Division
  - Research Promotion Division

Budget in Fiscal Year of 1999





How to get to NRIM



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