Integration of Basic Application Technology in the NKK Group

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Among various elementary technologies which are common to NKK's steel division and engineering division, the Applied Technology Research Center has identified certain technologies which are both particularly important and competent in NKK's business as SCT (Strategic Core Technologies) and targeted those technologies for strategic R&D. This paper presents an outline and typical examples of the application of SCT in each of the nine technology areas of the Applied Technology Research Center (instrumentation systems, control systems, scheduling and simulation, mechanical systems, civil engineering and building technology, ceramic engineering, physical and chemical analysis, biology for environmental solutions, and catalysis for energy).

1. Introduction

Considered as businesses, NKK's steel division and engineering division have different characters. Technically, however, the two share many common elements. For example, among elementary technologies, the company began research on some items in response to needs in the steel division, but those same items then became key technology of engineering products. Conversely, technologies which were originally developed as part of the product development program in the engineering division have led to breakthroughs in the improvement of iron and steel processes.

It is also a frequent experience that the accumulation of elementary technologies opens the way to the development of new areas of business or provides the impetus for rationalization and new product development, including group businesses. Moreover, when elements are combined, they often demonstrate a synergy, which gives birth to new products and process technologies.

For these reasons, NKK's Applied Technology Research Center, which is responsible for technologies common to the steel business and engineering business, has identified certain elementary technologies as SCT (Strategic Core Technologies) and targeted those items for strategic R&D. SCT are defined as technologies which are particularly important and competent as a technical basis for the steel and engineering businesses. Because SCT are applied widely in both business divisions, they may be discussed elsewhere among the articles in this Special Issue. While attempting to avoid unnecessary repetition, this paper presents an overview of SCT in the NKK Group and important examples of their application.

2. SCT (Strategic Core Technologies)

NKK's Strategic Core Technologies are shown in **Table 1**, together with important examples of application. The 27 SCT in the table are classified into nine areas of technology. Outlines of representative SCT in each technology area are presented in Chapter 3 and following.

3. Sensing systems (instrumentation)

3.1 Advanced signal processing

(1) Digital ultrasonic testing[1),2)]

Progress in advanced technology has been accompanied by continuing demands for stricter quality assurance standards for steel products. To meet these social requirements, NKK Corporation has devoted great effort to developing quality assurance technologies and has constructed a high level quality assurance system. As one example, digital ultrasonic testing utilizes digital signal processing technology to improve discrimination between flaw signals and noise, making it possible to detect minute flaws and ensuring reliability in UT flaw detection.

As shown in **Fig.1**, in place of the spike pulse used in conventional UT techniques, this new technology use a sine wave form called a chirp signal, which is frequency-modulated to a longer time duration, while also applying pulse compression to the received wave form by digital correlation with the transmitted wave form. This

Table 1 SCT (Strategic Core Technologies) and their applications

	SCT	Application
Sensing systems (instrumentation systems)	Highly sensitive magnetic sensing for minute defect detection	Inclusion detectors for cold rolled and coated sheet steels
	Advanced signal processing	Level meters for molten iron and steel ladles Lining flaw detector for subsurface polyethylene-lined steel pipes Automatic ultrasonic testing for plates and welded pipes
	Internal quality testing	Crystallographic grain size meter, transformation meter
	Surface quality testing	Real time oil film measurement for tinning line Stripe-type surface defect meter (Delta-Eye)
	Shape (profile) measurement	3-dimensional curved surface shape measurement device Overhead traveling crane coil position recognition device
	Radiation thermometry	Immersion-type thermometer for molten iron and steel
Control systems	Control theory applications (based on state space expression)	Active vibration control for bridge towers Molten steel level control for continuous casting mold Flying gage change and hot rolling/bar heater control
	Hybrid control (combination of model prediction and fuzzy control)	Hot stove combustion control system Stoker furnace hybrid ACC (Automatic Combustion Control)
Scheduling (production scheduling and logistic simulation)	Mathematical programming and simulation	Automatic diagram scheduling system for steelmaking process Shift operation planning for container terminals SCM (Supply Chain Management) planning and optimization system
Mechanical systems	Mechatronics and automation	Automatic equipment for pipeline construction New material handling systems (RISA, PALS, CATS)
	Actuators/mechanism analysis/mechanical elements	Waste recycling system, New deburring machine, Precision shearing for steel sections, DME-fueled vehicle (dimethyl ether vehicle)
	Acoustic and vibration control	Equipment health monitoring and maintenance optimization Stable high speed rolling of thin-gage products
Civil engineering and building technology	Wind-resistant technology	Vibration control for suspension bridges, cable-stayed bridges, and pylons of long span bridges, Windborne salt simulation
	Steel-concrete composite structures	Hybrid caisson, Composite bridge piers, Composite bridge decks Steel segments for MMST (Multi-Micro Shield Tunneling) method, CFT (Concrete Filled Tube)
	Fire-resistance evaluation	Multi-level car-parking buildings using FR (Fire-Resistant) steel, CFT tubes without fire insulation
	Earthquake resistance evaluation (seismic capacity evaluation technology)	Hysteretic damper using low yield strength steel, Earthquake-resisting joints, NKK Frame Kit, Steel bridge piers, Low temperature storage tanks
	Foundation and ground analysis	Tsubasa screw pipe with toe wing, NKK Screw, Drain SP, Soil-cement composite steel pipe pile (HYSC pile), Inclined bottom caisson, Double sheet pile wall structure
	Water treatment and environmental assessment	Caisson with wave-breaking function, Seawater exchange caisson
	Thermo environment evaluation (for warm and hot environments)	Steel house, Heat-insulating folding sheet roof
Inorganic materials (ceramic engineering)	Soil recycling	Pipeline backfill method (R70, SR80 methods)
	Slag and refractory use technologies	Marine Block, Slow-release potassium fertilizer, Granulated blast furnace slag for marine sand capping, Refractory brick for DC electric furnace bottom
Physical and chemical analysis (microbeam/chemical analysis)	Surface and interface characterization and control	Film analysis for chromate-free conversion-treated sheets, Cross-sectional characterization for galvanized steel
	Inclusion/precipitate characterization	Nano-level precipitate characterization, Estimation technique for inclusion size distribution, Estimation technique for cleanliness of TULC material slabs
	Real time chemical analysis	On-site analysis of hot steel slabs (laser ablation ICP atomic emission spectrometer), On-site dioxin analysis (dioxin precursor analyzer), On-site analysis of heavy metal content of fly ash
Biotechnology (environmental solutions)	Biological characterization and control	Sewage sludge volume-reducing system, Fertilizer evaluation technique for slag-based potassium fertilizer, Microbiological ammonium deodorizing system
	Environmental remediation by chemical techniques	Dioxin decomposition by Mn ore injection
Catalysis	Industrial process catalyst design	Purification catalyst for COG (Coke Oven Gas) DME (dimethyl ether) synthesis and utilization catalyst

sharply enhances the flaw signal, realizing a high sensitivity, high time-resolution capability. Synchronous averaging, which takes advantage of the fact that the ultrasonic signal is a repeated pulse, is also used effectively to reduce noise. These technologies are applied practically in automatic UT devices for plate, UOE pipe welds, ERW pipe welds, etc.

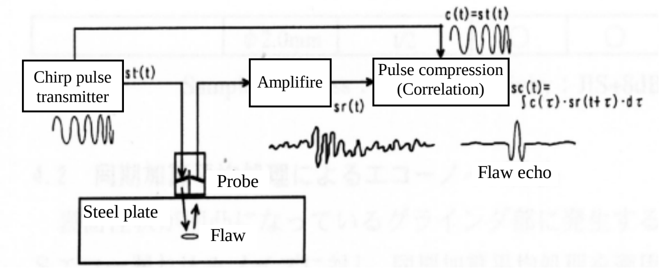


Fig.1 Chirp pulse compression for ultra-sonic test

(2) Two clock m-sequence signal processing[3),4)]

In the iron- and steelmaking processes, technical development is necessary to realize high accuracy process measurements in poor environments characterized by high temperature, high humidity, dusty atmospheres, and other adverse conditions. Two clock m-sequence signal processing is a revolutionary technology which not only provides satisfactory detection sensitivity for weak signals below the noise level in measurement systems applying wave methods, but also enables both high accuracy time measurements and distance measurements in poor environments using a simple analog circuit configuration.

Fig.2 shows an example of application in a molten steel level meter for auto start casting in the continuous casting process. The maximal length sequence signal (m-sequence signal) is a two-valued pseudo-random signal with a long period. One of the m-sequence signals formed by two slightly different clock frequencies is output to an electrode as the transmitted wave, and correlation is performed by beat processing on the received signal, which is returned by reflection from the molten steel surface, and the other m-sequence signal. As a result, the pulse signal is enhanced and appears with good sensitivity at a time position corresponding to the round-trip propagation time of the signal. The position of the molten steel meniscus level can be measured with high accuracy from the sharp peak position of this signal. This technology has been widely applied in high-sensitivity microwave level meters using microwave modulation, optical fiber temperature distribution meters using light modulation, and similar devices.

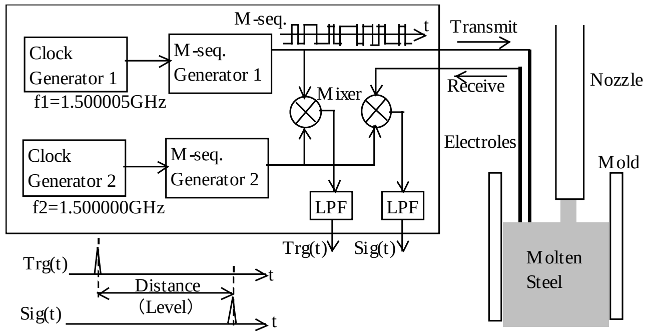


Fig.2 Two clock m-sequence signal processing

3.2 Radiation thermometry (immersion-type optical fiber radiation thermometer)[5)]

In the ironmaking process, the molten iron temperature is the most important index for blast furnace heat control. Likewise, in the steelmaking process, the molten steel temperature is critical from the viewpoints of quality control and reduction of energy unit consumption in all the processes from hot metal pretreatment through blowing and continuous casting. Conventionally, immersion-type thermocouples have been used in temperature measurements of molten iron and steel. However, because the thermocouple is consumed in the measurement process, this method had various drawbacks, including the high cost of temperature measurements, difficulty of automation, and unsuitability for high accuracy measurement. To overcome these problems, NKK developed an immersion-type optical fiber radiation thermometer as a new temperature measurement method for molten metals.

As shown in **Fig.3**, temperature measurements are performed with the immersion- type optical fiber radiation thermometer by immersing the tip of the optical fiber in the molten metal which is being measured and conducting the direct radiation from the interior of the molten metal to the radiation thermometer by way of the fiber. As a feature of this device, accurate temperature readings are possible because the tip of the optical fiber forms a minute cylindrical glass cavity when immersed in the molten metal, becoming a black body with an emissivity of 1. Even though the tip is melted and consumed by the high temperature metal, the fast response speed of the thermometer makes it possible to obtain the temperature reading before the tip melts. When a measurement is complete, the tip is retracted from the molten metal. When the next measurement is made, the fiber is simply reimmersed as-is, enabling repeated measurements with the same thermometer. Application of the new thermometer has also been extended to molten iron temperature measurement at the skimmer of the blast furnace iron runner and molten steel temperature measurement at the continuous caster tundish.

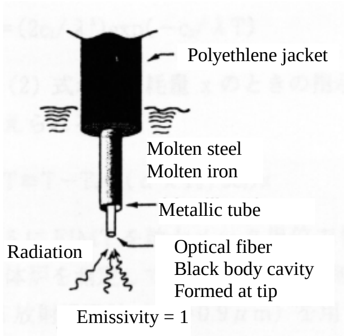


Fig.3 Immersion-type optical fiber radiation thermometer

4. Control systems

In recent years, robust control, as represented by H-infinity control, has been widely used in the field of mechanical control such as vibration control because of its simplicity of the design in the frequency domain. NKK has also applied this technology to vibration control of bridge towers[6] and control of the molten steel level in the continuous casting mold[7]. For rolling mill control, it is necessary to design multiple controllers in advance, as required by the steel grade and the width and thickness of the rolled material. Because the system order is small in these computations in comparison with H infinity control, sliding mode control is applied, as this method makes it possible to reduce the computation time[8].

In contrast, because process control for chemical reactions is a distributed system and also a nonlinear system, it is difficult to apply a type of control theory which assumes a lumped parameter system as a precondition. Therefore, NKK developed a hybrid control technology which combines predictive calculation based on a process model and fuzzy control which is used to cope with disturbances that cannot be predicted by the model. This technology has proven effective in a combustion control system for the hot stoves at blast furnaces[9] and a combustion control system for refuse incineration plants[10].

Fig.4 shows a block diagram of the combustion control system for refuse incineration plants. In this system, the amount of heat generated from the refuse is estimated by a model, and predictive control is applied to the refuse feed rate, supply of air for drying, combustion, and cooling, and similar factors, while fuzzy control is used to compensate for disturbances. As a result, stabilization of the steam flow from the boiler could be realized simultaneously with reductions in harmful gases such as dioxins and nitrogen oxides (NOx).

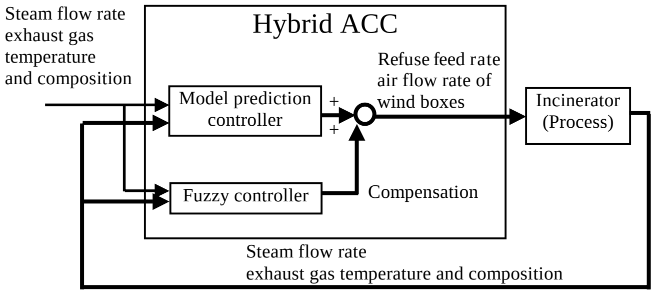


Fig.4 Block diagram of Hybird ACC

An operator training simulator[11] which incorporates this system model was also developed and has won a favorable reception. **Fig.5** is an example of the simulated furnace condition display of the operator training device. Real motion picture display, including movement of the rising flame, is possible based on the results of model calculations.

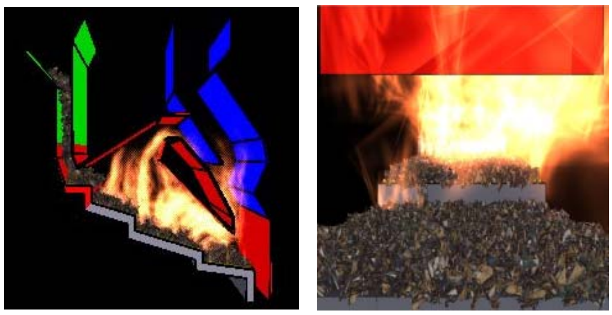


Fig.5 CG motion pictures

5. Scheduling and simulation

Taking advantage of the remarkable improvement in the computational speed, memory capacity, and telecommunication speed of computers in recent years, as well as the merits of low cost, NKK has aggressively applied simulation and algorithmic technologies to optimization of production and logistics. And substantial benefits have been achieved, as outlined below.

(1) Optimization of production planning and scheduling

Many of the production planning problems in the steelmaking industry are classified as sequencing problems, such as scheduling for the hot rolling mill[12] and diagram scheduling for the steelmaking process[13]. (For a more detailed discussion of these subjects, see “Advanced Equipment Technology for Steel Manufacturing” in this issue.) Others are classified, for example plate design problems, as assignment[14]. For the most part, the search strategy called metaheuristics was applied to the latter class of problems as a technique for automating plan preparation and improving planning accuracy. More recently, a mixed strategy was realized by combining sequencing problem techniques and combinatorial optimization problem techniques as part of an SCM (Supply Chain Management) system called SPEED-XU for thin-gage products. In concrete terms, this mixed system optimizes simultaneously both the diagram scheduling for the steelmaking process and the planning for charging (lot making by consolidating orders for the same steel components).

(2) Logistic simulation

Discrete event simulation is necessary in evaluating the numbers and capacities of component equipment in plant design, and in verifying the operation plan of production and material handling. Functions of general-purpose commercial tools are often insufficient, and the NKK Group uses either tools developed in-house or general-purpose tools, as follows, depending on the purpose:

(a) In-house tools: Verification of complex events such as movements in movable equipment (e.g. crane travel, traversing, hoisting), etc.

(b) General-purpose tools: Verification of the capacity of general-purpose equipment

(c) Object-oriented tools: Verification of operation plan in logistic with frequent interference

In these simulation studies, it is also necessary to develop operation plans which improve efficiency in addition to the models themselves. **Fig.6** shows the display of a simulation which is performed to verify the capacity of an underground automobile warehouse. As the operating method, the system searches for the position which will minimize the work time required when entering incoming inventory into lines which are waiting for shipment so as to maximize the receiving and disbursement capacity. In comparison with the conventional method of estimation, it gave the improved inlet and outlet efficiency by approximately 15%. Then the certification of increased upper limit capacity of the facility by about 10% was achieved.

6. Mechanical systems

6.1 Mechatronics and automation technology

Mechatronics and automation technology have a long history in NKK's steel division and have played important roles in the efficient development and improvement of equipment for increasing productivity and building quality into products, as well as realizing rationalizations which were impossible in the past. From these viewpoints, the company has developed and installed a succession of unique equipment.

Likewise, in the engineering division, it goes without saying that mechatronics and automation technology are important elements in developing new products and improving the competitiveness of existing products. As one example, this chapter will describe the application of these technologies to the development of material handling equipment.

(1) High-speed sorting equipment for logistics centers

A logistics center can be considered to be a large-scale mechanical system in which equipment with the diverse functions required for receiving, storing, sorting, picking, and shipping a wide variety of goods and goods in large lots is systematically integrated. Therefore, high efficiency and stable operation are required in the system as a whole. NK-RISA and NK-CATS[15] are material handling systems which realizes storage of a wide variety of goods packaged in cartons and high-speed sorting in the proper delivery order (**Fig.7**). In developing this equipment, the development time and cost were reduced by using motion analysis, CAE, and logistics operation simulation. Where the equipment itself is concerned, the tracking system was configured with sensor fusion technologies such as brand recognition and operation condition recognition, realizing stable operation of the equipment system group.

Fig.6 Simulation of automobile warehouse

Fig.7 NK-CATS (example of NK-CATS application)

(2) High-speed inventory receiving/disbursement device

NKK developed a Pallet Sorter (NK-PALS)[16] as a logistics system which is capable of coping with improvement of the shipping function at diverse logistics bases. By incorporating small rollers in the turntables at separating and merging conveyors and controlling the angle and circumferential velocity as required by the direction of pallet transportation, the Pallet Sorter makes it possible to turn pallets 90° while maintaining a high linear speed even at junctions. By realizing non-stop transportation, this device increases system throughput to twice the conventional level. As part of the development work, NKK researchers constructed a multi-body dynamics model which quantifies the interaction of the pallet and drive rollers and applied mechanical dynamics simulation technology (**Fig.8**) to obtain a theoretical understanding of the turning mechanism as it affects a pallet during transportation, thereby optimizing both the structure and the control system in a short development period.

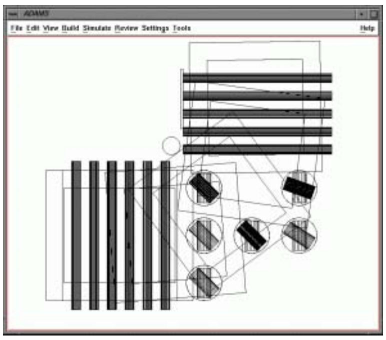


Fig.8 Results of mechanical dynamics analysis

6.2 Actuators and mechanical element technologies

Together with mechatronics and automation technology, one distinctive technology in NKK's iron and steel plant equipment and engineering division products is mechanical elements, beginning with actuators. NKK has also devoted much effort to the development of elementary technologies such as fluid power and processing. As one example, this section will describe the deburring system used in the company's Endless Bar Rolling System (EBROS™)[17].

The EBROS™ equipment enabled continuous "endless rolling" of bars and wire rod material for the first time in the world, and comprises a flash welding machine which joins hot billets by flash butt welding and a deburring machine which removes the weld burr. Hot cutting is required in the deburring process, but it was necessary to solve the problems of tool wear and formation of residual cutting edges at the corners of square billets. Therefore, a deburring system using multi-stage free rotational disk cutters (**Fig.9**) was conceived as a means of simultaneously extending tool life and achieving a complete cutting shape. This device has been applied successfully in a commercial plant, as shown in **Fig.10**. To date, orders for EBROS™ have been received from Fundia Wire (Finland), Shiu Wing Steel (Hong Kong), Xingtai Iron and Steel Works (Hebei, P.R. China), and Dongkuk Steel Mill (Korea). The first unit has already been delivered and is operating smoothly. The technology has also been licensed to two other companies, VAI-UK (Voist-Alpine Group) and the SMS Demag Group (Germany). This device received the Japan Society of Mechanical Engineers' JSME Medal for New Technology in fiscal year 2001.

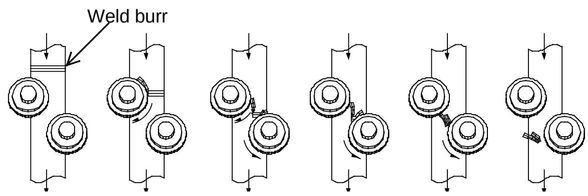
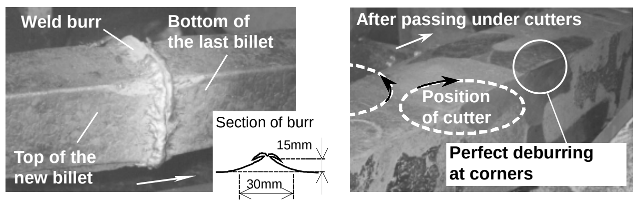


Fig.9 Principle of deburring by free rotational disk cutters



(a) Befor deburring (b)After deburring

Fig.10 Weld burr of billets and results of new deburring

7. Civil engineering and building technology

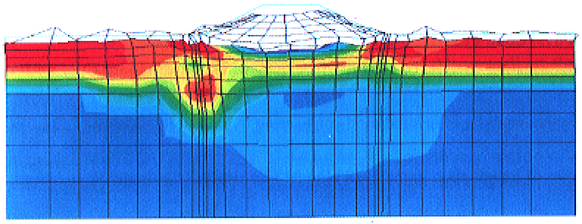
7.1 Geotechnical analysis

In the development and design of civil engineering structures, it is necessary to evaluate and quantify a large number of static and dynamic interactions between the ground and structure, including the load bearing capacity and stability of the ground, liquefaction in earthquakes, and others. Since the mid-1980s, NKK has considered numerical simulation of ground-structure systems as one important technology in the field of civil engineering, and has developed both static and dynamic analysis methods.

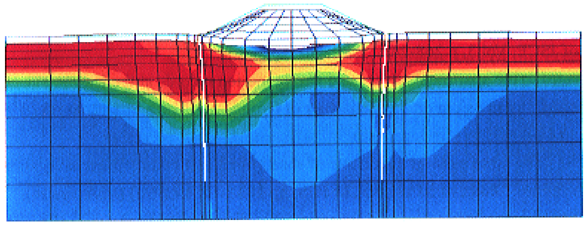
In the field of static analysis, in the mid-1980s, NKK independently developed a non-linear analysis program for geotechnical engineering[18]. Because this program is capable of stably solving contact problems between structures and the ground by using stabilized elasto-plastic joint elements based on the theory of viscoplasticity, it has played an important role in the development of various port structures using either steel structures or steel-concrete composite structures. These include (1) analysis of jacket-type artificial islands[19], (2) stability of hybrid caisson-ground systems[20], and (3) advances in design technology for double sheet pile wall structures[21], among others.

On the other hand, in field of dynamic analysis, beginning around the end of the 1980s, NKK undertook the development of a multi-dimensional effective stress analysis technology (program name: LIQCA)[22] as a joint project with Kyoto University and Gifu University with the aim of establishing a design method for the gravel drain method, which is a countermeasure against liquefaction. The LIQCA technology played a critical role in elucidating the causes of liquefaction damage by reproducing, in numerical simulations, a large number of cases of liquefaction damage in the 1995 Kobe Earthquake[23]. Based on these study results, a variety of construction methods were investigated and developed as countermeasures against liquefaction, including the sheet pile coffering method of river embankment[24] and the ultra-multi-grouting method[25]. The results of this study also contributed to the development of the wedged caissons method[26], which is a new concept for economical construction of earthquake-resisting quaywalls.

This overview will present an example of analysis of the sheet pile coffering method of river embankment. As a countermeasure against liquefaction of river embankments, this construction method suppresses ground deformation by using sheet pile walls which are driven at both edges of an embankment constructed on a liquefiable sand deposit. Shaking table tests and an analysis of an actual scale embankment were carried out to verify the effectiveness of the method[24]. The conditions in the actual scale embankment analysis included a 5m thick liquefiable layer, embankment base width of 24m, and embankment height of 4m. The analysis was performed using input motion and the flexural rigidity of the sheet pile wall as parameters. **Fig.11** shows a comparison of the deformation at the end of shaking (displayed at 2x) and the distribution of the mean effective principal stress variation when Hachinohe wave was input for (a) no countermeasures and (b) countermeasures using sheet pile. In the ground without countermeasures, deformation of the foundation and embankment was severe, but in contrast, with steel sheet pile walls, lateral deformation of the ground and settlement of the embankment were suppressed by the rigidity of the sheet piles, even though an extensive liquefaction region existed around the sheet piles. Using this construction method, we have proposed practical design methods based on the results of the shaking table scale test and liquefaction analysis discussed here.



(a) Without countermeasure



(b) With steel sheet pile walls

Fig.11 Deformation and distribution of excess pore water pressure ratio

7.2 Seismic capacity evaluation technology

This section will discuss NKK's seismic capacity evaluation technologies with special emphasis on the field of building construction.

Seismic capacity evaluation technologies play an important role in the company's development and supply of products with excellent seismic capacities, both as a maker of the heavy steel products and members which are used as components in building structures, and as a maker of buildings, centering on plants.

In many recent high-rise buildings, energy absorption type dampers have been adopted to minimize damage to the main frame. **Fig.12** is an example of a hysteretic damper of low yield point steel, in which the optimum width-to-thickness ratio, details of joints, and energy absorption capacity were clarified in the development stage by analysis by the finite element method (FEM)[27].

Fig.13 is an example in which the damping performance of a viscous oil damper installed in the boiler structure of a waste treatment plant was confirmed by time history response analysis[28]. It was found that the maximum displacement can be reduced to approximately 1/3 by applying this damper.

In addition to analysis technology as such, it is also necessary to provide supporting empirical data for verification of analytical results. NKK has developed a variety of testing apparatuses for this purpose, as seen in the following examples.

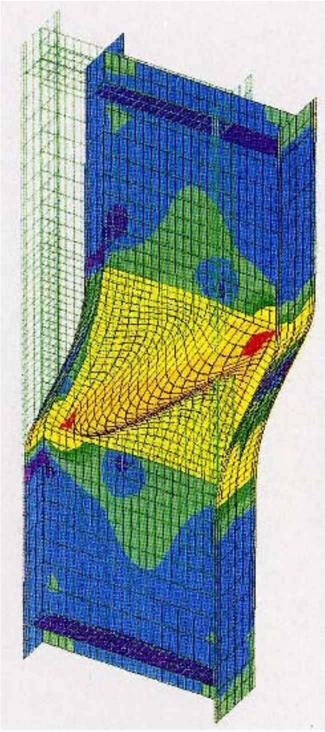


Fig.12 FEM analysis of hysteretic damper

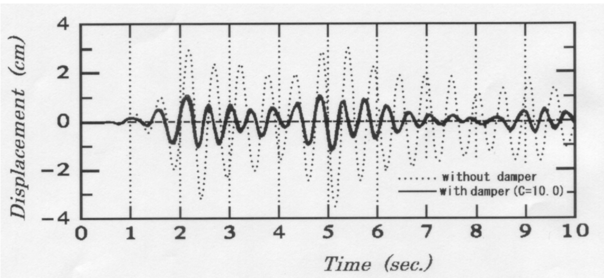


Fig.13 Seismic analysis of boiler structure with viscous oil damper

The hi-speed testing apparatus shown in **Photo 1** makes it possible to confirm the effect of the strain rate on fractures of welded joints at beam to column connections[29] and the response to seismic waves of such joints by applying a maximum 150 kine rate of loading. The hysteretic damper effect with low yield point steel, which is one of NKK's building material products, was also confirmed using this testing apparatus[30),31)].

Photo 1 Hi-speed testing apparatus

The 10000kN structural testing apparatus in **Photo 2** and multi-purpose loading frame in **Photo 3** were used to apply seismic loads in order to confirm the structural performance of simple members such as columns and beams and performance of welded joints of column and a through diaphragm and to clarify the behavior of beam to column connections. These apparatuses have also been used to verify the structural performance of cold-formed square hollow sections of 590N/mm^2 steel and a product called NT Column, which consists of a circular hollow section with an outer ring stiffener[32)].

NKK's line of seismic products was developed based on tests using these advanced analytical technologies and NKK testing apparatuses, which set the standard in their field in Japan. The same technologies are also contributing to new product development in both the steel division and the engineering division.

Photo 2 10000kN structural testing apparatus

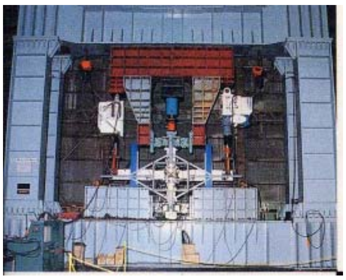


Photo 3 Multi purpose loading frame

7.3 Wind-resistant technology

Because wind causes a variety of vibration phenomena such as vortex-induced vibration, flutter, and gust response in the bridge girders of suspension bridges and cable-stayed bridges, pylons under construction, and cables, the aerodynamic stability of such structures must be evaluated in advance of construction, and countermeasures must be taken when necessary. NKK owns two wind tunnels, the Wind Tunnel for Industrial Aerodynamics (working section width: 2m, height: 3m, length: 15m; maximum wind velocity: 50m/s) and Boundary Layer Wind Tunnel (working section width: 4m, height: 2m, length: 26.5m; maximum wind velocity: 23m/s). Employing these facilities, the company has evaluated wind-resistant performance and proposed vibration countermeasures for a number of representative long-span bridges in Japan and other countries, including the Akashi Kaikyo Bridge, Tatara Bridge, Tsurumi Tsubasa Bridge, and Suez Canal Bridge, and thus can take pride in possessing world-class technologies for long-span bridge construction. As one example, **Photo 4** shows a wind tunnel test during cantilever erection of a long-span cable-stayed bridge using a boundary layer turbulent flow designed to resemble the turbulent characteristics of natural wind. **Fig.14** shows a girder cross section which was proposed by NKK and the Public Works Research Institute (an independent administrative corporation) as part of joint research carried out by the Public Works Research Institute, Honshu-Shikoku Bridge Authority, Public Works Research Center (foundation), and eight private-sector companies in preparation for projects involving large-scale structures spanning straits, including the construction of super-long suspension bridges with a center span length exceeding 2000 meters. In the above-mentioned Akashi Kaikyo Bridge (center span length, 1990m), which is currently the world' s longest suspension bridge, box girders were adopted in place of the truss type which had been used previously, resulting in excellent economy. Assuming application to a suspension bridge with a center span length of 2800 meters, a goal of withstanding strong winds of up to 80m/s has been established.

Although wind tunnel experiments are indispensable for evaluating the wind-resistance of bridges, analysis technologies are also of high importance. These include, for example, flutter analysis to calculate the onset wind speed for flutter in an actual bridge, as a 3-dimensional system, using the measured results of the unsteady wind force obtained with a 2-dimensional sectional model. Recently, NKK has taken up the challenge of developing a numerical wind tunnel technology which will make it possible to obtain analytically the unsteady wind force itself. **Fig.15** shows an example in which numerical analysis technology for evaluating wind resistance in long-span bridges was applied in an evaluation of a windborne salt simulation. Using a wind velocity field, which can be obtained spaciotemporally from Reynold's equation and a continuous equation, it is possible to calculate the distribution of salt concentration, considering the influence of land topography, by solving Fick's diffusion equation (shown in **Fig.15**). As an application of this technique, in response to the rising need for LCC (Life Cycle Cost) reduction in bridges, an increasing number of bridges have been constructed recently using weathering steel, which does not require repainting. However, as one weakness of weathering steels, stable rust formation is difficult when the salt concentration is high. Thus, this simulation tool is expected to be effective in evaluating whether construction of a weathering steel bridge is appropriate or not. **Fig.16** shows the results of an evaluation of the distribution of salt concentration in a salinity simulation of a 2 box girder. This type of analysis makes it possible to determine which parts of a bridge are subject to high salt concentrations, and also shows that salt entrapment in the space under the deck can be prevented by ingenuity in the design of the cross-sectional configuration.

Photo 4 Wind tunnel test for the aerodynamic study on a cable-stayed bridge under construction

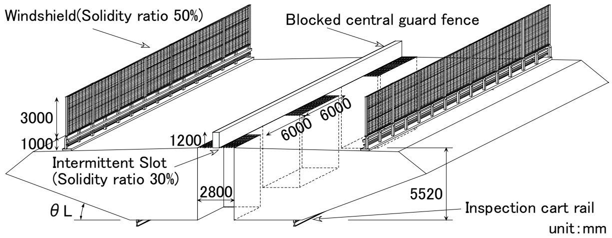


Fig.14 Proposed girder section for super-long suspension bridge project

$$\rho\frac{\partial\bar{C}}{\partial t}+\rho U_j\frac{\partial\bar{C}}{\partial x_j}=\frac{\partial}{\partial x_j}\left((\mu+\mu_t)\frac{\partial\bar{C}}{\partial x_j}\right)+\bar{C}_g-\bar{C}_{cut}$$

Fig.15 Example of numerical simulation result of windborne salt

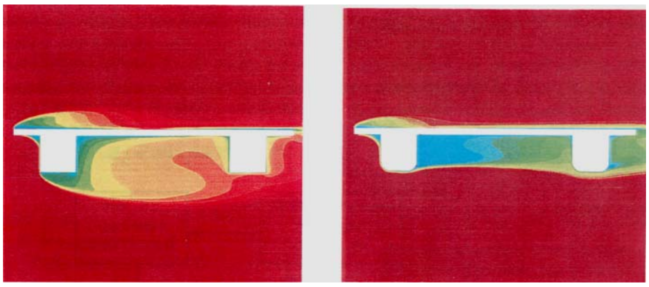


Fig.16 Distribution of salt concentration around a bridge girder section

8. Inorganic materials (Ceramic engineering)

The technical domain of ceramic engineering consists of SCT in the areas of slag/refractory technology and use technologies for various types of surplus soils, which are common to the steel and engineering businesses and answer needs in both divisions. As one example of these technologies, this section will describe environmental improvement technologies using iron and steel slag.

In recent years, an increasing number of coastal marine areas have lost shoals due to dredging for reclamation and extraction of beach sand. Environmental improvement can be expected if artificial shoals where algae can grow are created in such marine areas, providing a living environment for fish and shellfish.

Research by NKK, centering on the company's Applied Technology Research Center, showed that granulated blast furnace slag positively prevents the formation of hydrogen sulfide, and as a result, is more effective than natural sand in suppressing "blue tide"[35),36)]. This type of slag as a practical sand capping material at the Nakami coastline in Shimane Prefecture was then applied. NKK researchers also turned their attention to the fact that steelmaking slag contains CaO and developed a manufacturing technology for a carbonated solid (registered trademark: Marine Block) which utilizes the reaction between this component of the slag and carbon dioxide gas. The company is now in the process of applying this material as algae plantation bed[37)]. Environmental improvement by shoal creation, in combination with sand capping material and carbonated solid, is currently in the demonstration test stage at Innoshima in Hiroshima Prefecture as a subsidized business of the prefecture. An image of the demonstration test is shown in **Fig.17**.

This business effectively utilized byproduct materials including granulated blast furnace slag sand capping material (approximately 1000 tons; 800m^3) and pseudo-rock Marine Blocks (20 blocks) manufactured by Fukuyama Works and is expected to improve a marine environment with an area totaling approximately 600m^2.

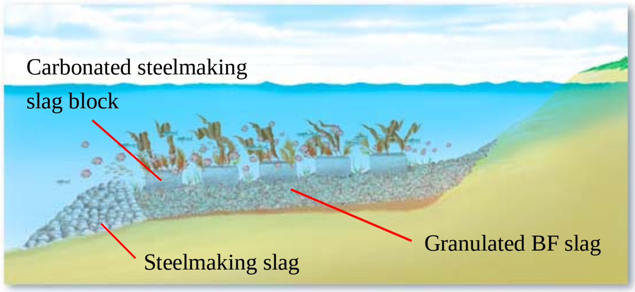


Fig.17 Scheme of demonstration test using iron and steelmaking slag and blocks

9. Physical and chemical analysis

9.1 Microbeam analysis

NKK's strengths in microbeam analysis include microstructure characterization, centering on electron microscopy, and chemical state analysis utilizing surface analysis and synchrotron orbital radiation. Through its role in clarifying the mechanisms of why a certain property appears, microbeam analysis has supported the development of a variety of new steel products/processes in the fields of iron and steel materials/processes and environmental engineering products.

In microstructure characterization, pinpoint analysis of the microstructure of materials is possible using an combination of FIB (Focused Ion Beam) technology and the field emission TEM (Transmission Electron Microscope), enabling quick and accurate analysis of the controlling factors in material properties. **Photo 5** shows an example of FIB-TEM analysis of the interface of an Al-killed steel. Wustite was formed on the surface of this steel by oxidation treatment at 1073K, and was then decomposed into a ferrite phase and magnetite at 673K. Using specimens prepared by FIB, it was possible to observe the entire oxide layer from the steel-oxide interface to the topmost oxide layer. The oxides immediately above the steel sheet were continuous magnetite with a thickness of the order of 1 μm. This analysis, this magnetite was crystallographically coherent with the matrix and thus possesses high adhesion with the steel substrate. This is an example in which an advanced analytical technique provided knowledge that will contribute to the design of adhesion and peeling of oxides on the surface of steel sheets. The company is also making great use of this method in designing the interface structure of coated steel sheets. Moreover, the same method is effective in analyzing inclusions in steel. For example, an analysis of the morphology of complex inclusions of the CaS-CaO-Al_2O_3 system clarified the mechanism by which groove corrosion in electric resistance welds is suppressed[38].

Photo 5 FIB-TEM observation of oxide layer on Al-killed steel

NKK was among the first to recognize the usefulness of the ultra-low voltage scanning electron microscope and employed this instrument to observe the extreme surface of iron and steel materials. Analysis of the material surface was possible with the conventional surface analysis methods, but their lateral spatial resolution was not generally high enough, resulting in poor analytical accuracy when attempting to investigate non-uniformity of the surface chemistry and structure. Therefore, NKK installed the steel industry's first ultra-low voltage scanning electron microscope (manufactured by LEO Co., shown in **Photo 6**), which has spatial resolution of 2.1nm at an accelerating voltage of 1kV, and is capable of surface observation of bulk specimens at ultra-low accelerating voltages as low as 100V. The introduction of this SEM accelerated the development of new coated steel sheets. **Photo 7** is an example of SEM observation of annealed sheet steel measured at different accelerating voltages. Here, it should be noted that the contrast reflecting the structural non-uniformity of the surface could only be observed at the lower accelerating voltage.

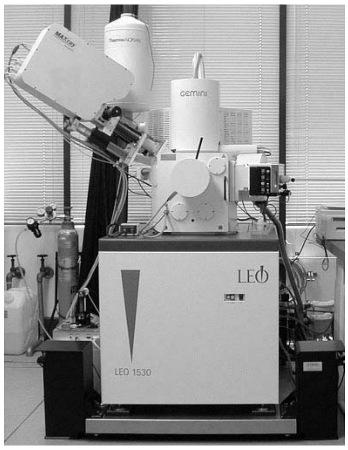


Photo 6 Ultra-low voltage SEM, Gemini

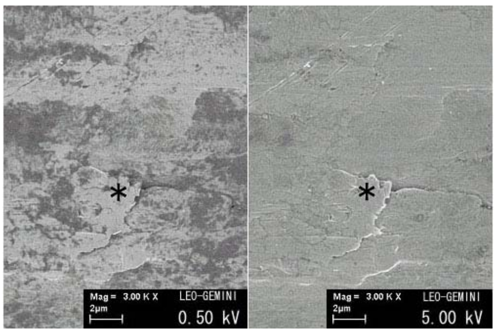


Photo 7 SEM micrographs of CAL anneled sheet steel surface at 0.5kV and 5kV

In analyzing the chemical bonding states of various types of elements in materials, surface analysis techniques such X-ray photoelectron spectroscopy are generally used. At NKK, these methods have provided knowledge which was useful in the development of coated steel sheets. As a method of analyzing the bonding chemical of elements of interest, not under a vacuum, but even in air or in liquids, NKK's Applied Technology Research Center turned its attention to the XAFS (X-ray Absorption Fine Structure) method using high intensity synchrotron radiation and developed techniques for using the transmission mode, total electron yield mode, and fluorescence yield method as suited to the specimen shape and concentration of elements. As one example, the following will discuss the results of an analysis of fly ash from municipal solid waste incinerators which was performed by fluorescence X-ray detection at beam line BL01B1 of Spring-8 at the Japan Synchrotron Radiation Research Institute. **Fig.18** shows the PbL_3 XAFS spectrum of various Pb compounds and Pb in the fly ash before and after stabilization treatment. Based on the fact that the PbL_3 spectrum of fly ash A before stabilization treatment is closest to that of $PbCL_2$, whereas the same spectrum of fly ash B is closest to that of PbO, it is probable that the Pb in these two fly ashes exists mainly in the form of chlorides in fly ash A and oxides in fly ash B, respectively. Although the chemical state of the Pb in the two fly ashes, A and B, was different before the treatment, the PbL_3 spectrum of fly ash A and B after mixing with a liquid chelating agent (trade name: A200) showed an extremely close resemblance to the spectrum (Pb + A200) of the filter residue obtained by mixing an aqueous solution of lead chloride with the liquid chelating agent. This showed that Pb forms the same chelate bond as an insoluble chelate complex, and thus is stabilized, when fly ash is treated with the liquid chelating agent.

In the characterization of chemically treated sheet steels, NKK also applies a method which combines pinpoint analysis by electron microscope and chemical state analysis using synchrotron radiation in a complementary manner[39].

9.2 Chemical analysis

In the field of chemical analysis, NKK has developed advanced analysis technologies such as ultra-trace element determination as well as real time chemical analysis and inclusion/precipitate characterization. In real time chemical analysis, NKK developed a laser ablation ICP atomic emission spectometer[40] and applied this instrument to quick analysis of surface defects in cold rolled steel sheet for automotive panel use, on-site analysis of slabs, etc. To reduce waste incinerator dioxin emissions, NKK developed an analyzer which enables quick on-site measurements of dioxin precursors[41] and is continuing to apply it to combustion control. The following presents an outline of this instrument.

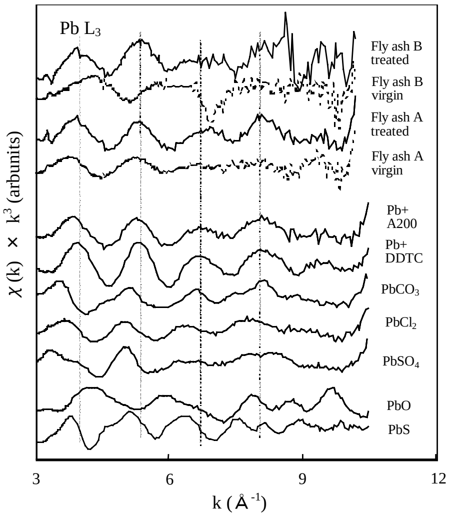


Fig.18 Pb L_3 EXAFS spectra from fly ash and standard materials

The concentration of dioxins generated by combustion is extremely small, at below the ppt level. At the present time, no method which is capable of detecting such low concentrations has been applied practically. However, NKK researchers took note of the high correlation between the concentration of chlorobenzenes and chlorophenols, which are dioxin precursors, and the concentration of dioxin, as shown in **Fig.19**, and developed a commercial analyzer which performs automatic, on-line measurement of the concentration of dioxin precursors. The configuration of this analyzer is shown in **Fig.20**. The instrument is capable of measuring the concentration of precursor substances to below the ppb level (limit of detection, 0.001 μg/Nm^3) at a minimum interval of 15 minutes. This means that it is possible to estimate the concentration of dioxins from the above-mentioned correlation in a short time of 15 min. The analyzer is demonstrating excellent performance in investigations of dioxin generation behavior at a large number of waste incinerators.

NKK has also developed a method of measuring the concentration of elements contained in molten steel and a instrument which enables quick, on-site measurements of the amount of inclusions in slabs.

In inclusion/precipitate characterization, NKK developed an estimation technique for the size distribution of inclusions in steel[41] and a precise quantitative analysis

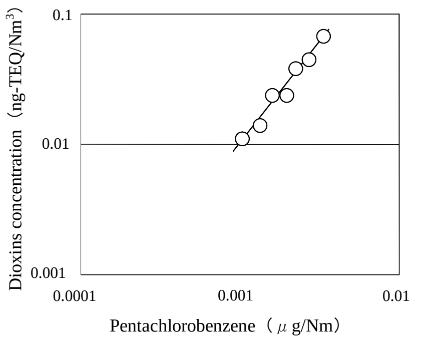


Fig.19 Relationship between dioxins concentration and dioxin precursor concentration

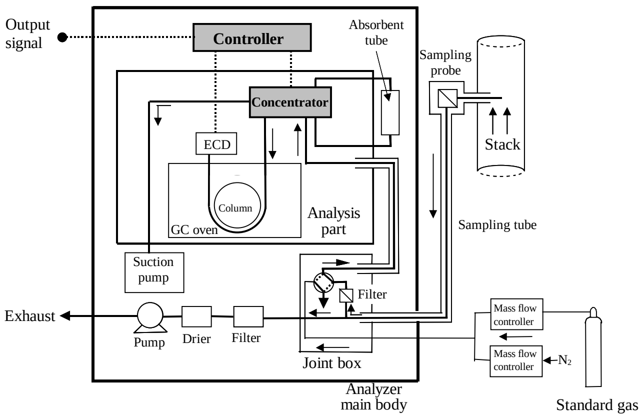


Fig.20 Configuration of dioxin precursor analyzer

method for precipitates in Ti-bearing IF (Interstitial-Free) steel[43]. The estimation technique for inclusion size distribution uses a combination of the acid-extraction method and photo scattering method, and has made it possible to clarify the behavior of inclusions in the steelmaking process. As one example, **Fig.21** shows the difference in the inclusion size distribution to different bearing steel manufacturing processes. In comparison with the conventional method, it was found that the PERM (Pressure Elevating and Reducing Method) is particularly effective in reducing large size inclusions[44].

Recently, NKK is trying to develop a technique to quantify the trace amounts of non-alumina clusters which exist in steel as a result of slag and powder entrapment, and a technique to quantify trace amounts of carbon in steel by mode of existence.

These inclusion/precipitate characterization have been used in the development of the PERM, improvement of the purification process for TULC material and amber material, development of ultra-low S type high efficiency electrical steel sheets.

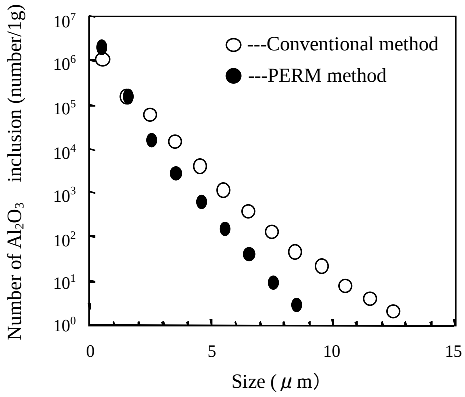


Fig.21 Comparison of size distribution of Al_2O_3 in the bearing steel obtained by conventional method and PERM (Pressure Elevating and Reducing Method)

10. Biotechnology (environmental solutions)

In the field of environmental remediation by chemical techniques and biological analysis and regulation technology, NKK has carried out research to develop for the purpose of highly efficient chemical and biological treatments for the purpose of decomposition of toxic materials and effective utilization of by-products and waste.

One example is a technology for reducing the content of dioxins in incinerator flue gas using manganese ore. With this technology, dioxins are decomposed and removed by blowing Mn ore powder into the flue gas, taking advantage of the oxidation decomposition capacity of Mn. The results of tests in which Mn ore was injected into an actual operating waste incinerator showed that the dioxin content of the flue gas can be reduced by a maximum of 80%, while that of the incineration fly ash can be reduced by approximately 65%. These findings suggests that Mn injection offers an economical alternative to the conventional active carbon blowing method of dioxin removal.

NKK has also been promoting microbiological technologies, which are a composting technique for organic waste and sludge[45], a sludge volume-reducing technique[46], and a deodorizing technique for the odors generated by composting systems[47], using biological reactions.

The microbiological phase in the microbiological treatment tank could not be analyzed by techniques conventionally. However, NKK analyzed the microorganisms which are actually responsible for the high effective decomposition reaction, and identified the conditions which maximize microorganism function and thus accelerate the decomposition reaction. **Fig.22** shows one example of a DNA analysis by electrophoresis to determine the optimum conditions for sludge volume reduction by the microbiological treatment. NKK is trying to apply this technology to biological decomposition reaction for environmental pollutants.

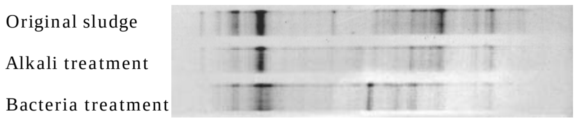


Fig.22 Bacteria monitoring in the sludge treatment using PCR-DGGE methods

In addition to biological treatment techniques, eco-system evaluation is also essential. In the utilization of by-products or wastes in the natural environment, it is necessary to evaluate the effect of these product on the eco-system. For example, detailed investigations of the ecological effects of the products were carried out in the development of the carbonated steelmaking slag blocks mentioned previously and a slow-release potassium fertilizer using steelmaking slag produced in the desiliconization process (**Photo 8**), to design optimum utilization of these products.

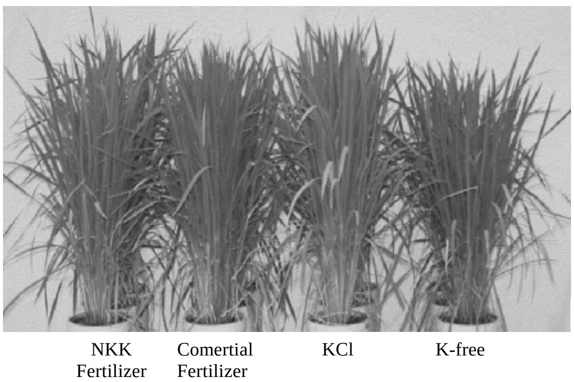


Photo 8 Response of paddies to NKK potassium silicate fertilizer

11. Catalysis

To date, NKK has developed catalyst technologies in the respective fields of resources (coal and natural gas conversion technologies, etc.), energy (sensible heat recovery technology utilizing chemical reactions, high calorie gas production technology, DME (dimethyl ether) synthesis, etc.), the environment (purification technologies for various types of combustion off-gas, etc.), and the production of chemicals (high value-added technologies for by-product gases and tar derivatives from steel works). This has resulted in the development of numerous new catalysts, including a catalyst for oxidative decomposition of ammonia, refining and high calorie gas conversion catalyst for COG (Coke Oven Gas), phenol synthesis catalyst[49),50)] , benzoic acid synthesis catalyst[51)], DME synthesis catalyst,[52)-54)] and others. The development of catalysts, as shown in **Fig.23**, is carried out by repeating the processes of preparing catalysts, evaluating their performance, and analyzing their properties. The key point is to establish appropriate working hypotheses in each of these processes. Formerly, new catalysts were discovered by accident or as a result of shotgun-style trial-and-error experimentation, and catalysts were considered to have a black-box existence. However, by applying advanced physical analysis technologies such as XAFS (X-ray Absorption Fine Structure) analysis using synchrotron radiation, NKK has arrived at the point where it can collect various kinds of useful information which was unobtainable heretofore, for example, on the morphology and electronic state of active component particles scattered on the catalyst surface, metal particle size, and interatomic distance.

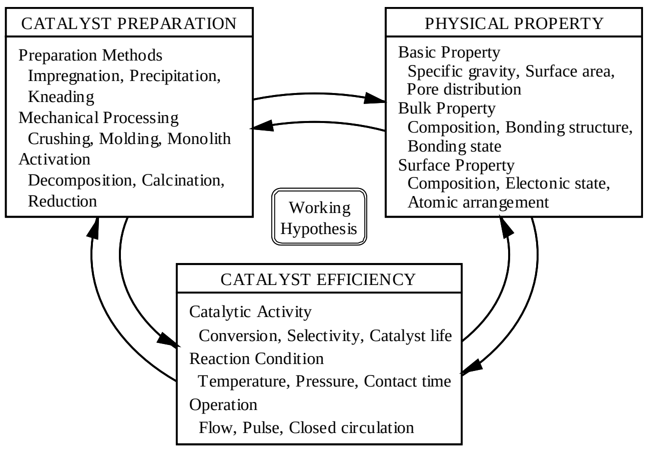


Fig.23 Catalyst design method

12. Conclusion

This paper has presented an overview of the basic application technologies which are common to NKK's steel division and engineering division, with particular emphasis on SCT (Strategic Core Technologies) developed by the company's Applied Technology Research Center.

In a future characterized by increasingly intense world-wide competition, new and more advanced basic application technologies, as well as the integration of such technologies, will be indispensable to the development of pioneering new products and process technologies which provide a higher customer's satisfaction. The Applied Technology Research Center and its staff intend to make even greater efforts to achieve this goal and ensure that

NKK technologies and human resources continue to contribute to the newly-established JFE Group.

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