NATIONAL
INSTITUTE FOR
MATERIALS
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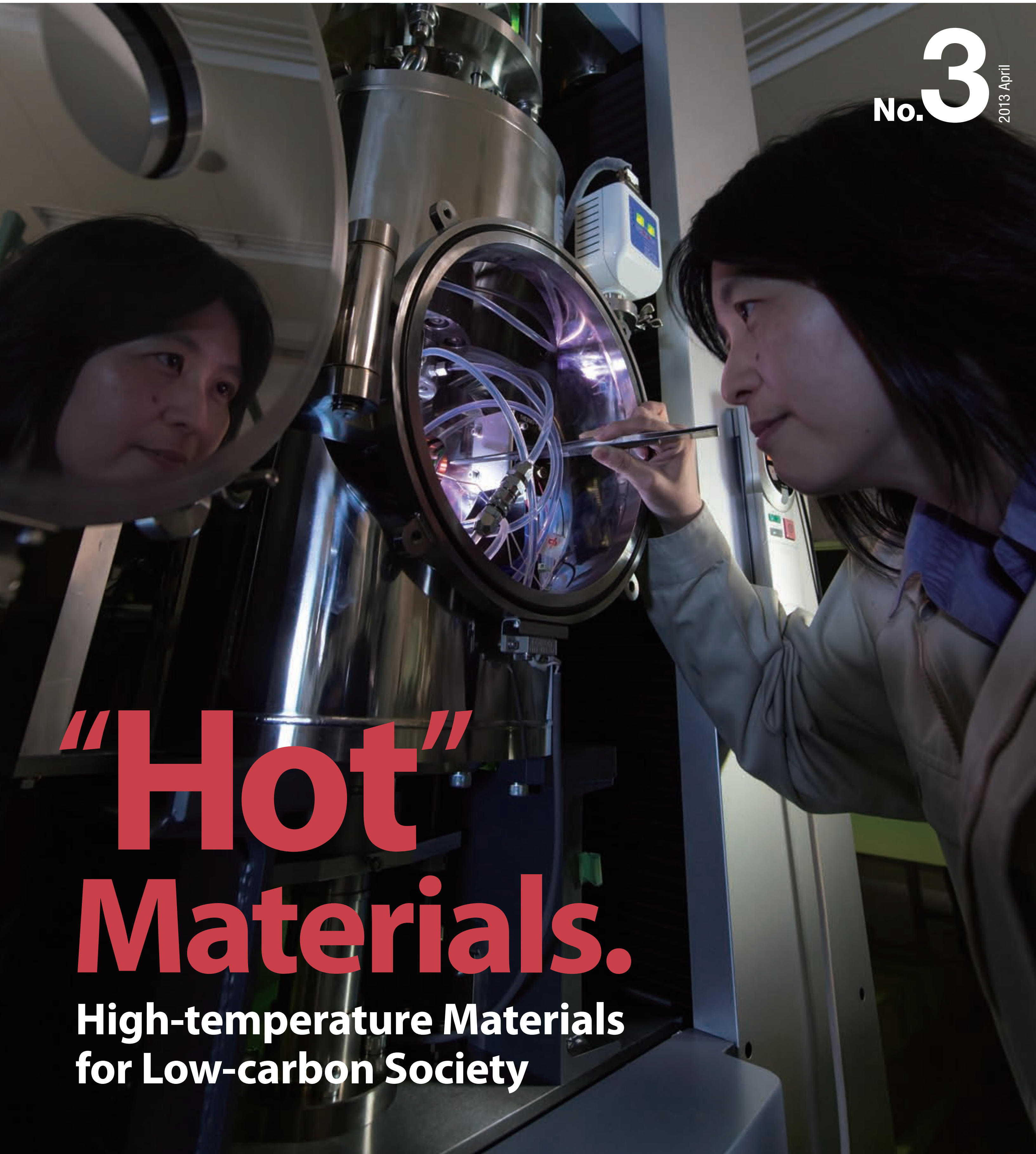
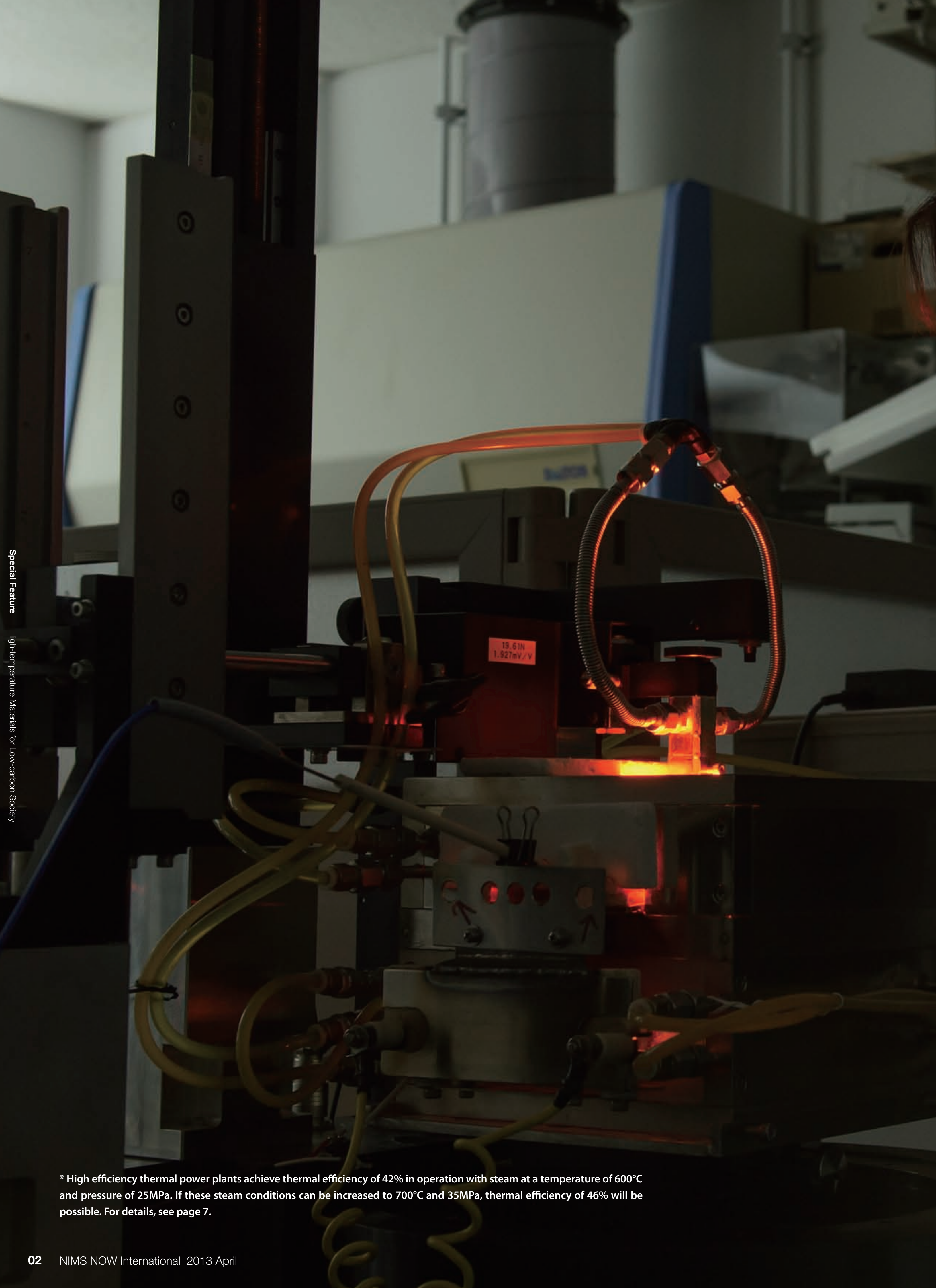
NIMS NOW International

No.3
2013 April



“Hot” Materials.

High-temperature Materials for Low-carbon Society



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* High efficiency thermal power plants achieve thermal efficiency of 42% in operation with steam at a temperature of 600°C and pressure of 25MPa. If these steam conditions can be increased to 700°C and 35MPa, thermal efficiency of 46% will be possible. For details, see page 7.

Creating metals that can withstand high temperatures plays a key role in solving energy problems. Although this is frequently said, it isn't immediately clear just what it means.

For example, electric power plants must continuously withstand high temperatures. If heat resistant materials which can withstand higher temperatures are used, this will improve thermal efficiency and reduce fossil fuel consumption.

The same is also true of jet engines for aircraft. By using heat-resistant materials, it is possible to reduce fuel consumption.

If the heat resistance of the materials used in power plants can be increased by 100°C, power generating efficiency will improve by 4%. As a result, it will be possible to reduce CO_2 emissions by about 420,000 tons per year,* and this means you can make an important contribution to realizing a low-carbon society.

One unique point of the project is that it is not limited to simply developing heat-resistant materials by creating new metals, but also combines those metals with the advanced coating technologies of NIMS.

In one of these projects, groups focused on high temperature oxidation, the selection of coating materials, and the interaction between the coating film and the bulk are jointly carrying out research.
These are important challenges, and they can only be met in this NIMS project.

"Hot" Materials.

High-temperature Materials for Low-carbon Society

Development of High Pressure Warm Spray Process

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Thick overlay coatings protect components from harsh environments

Thick overlay coatings are essential in protecting key components of jet engines and power plants from hot and harsh environments. Examples include thermal barrier coatings (TBC) to protect combustors and blades, cermet coatings for abrasion and erosion resistance, and abradable coatings to control the clearance between rotating blades and the casing. Our project conducts research to improve the protection capability of such coatings for materials developed in the High Temperature Materials Unit from both the materials and processing perspectives.

Development of a novel warm spray process and high temperature oxidation performance

Thermal spraying is a process most widely used for forming thick overlay coatings. Conventional thermal spraying forms a coating by depositing a feedstock material on the substrate in the form of molten particles. Since it was invented, this technique has a history of approximately 100 years. As shown in Figure 1, it is now classified into a wide variety of spray processes, such as wire arc spraying, in which a wire material is melted by an electric arc, flame spraying using combustion gas as the heat source, plasma spraying using an ultra-high temperature plasma as the heat source, high-velocity flame spraying using a supersonic combustion gas flame as the heat source, cold spraying, in which solid powder is deposited by expansion of a high pressure gas, etc., and has developed as a group of processes that enables coating of a diverse range of materials including metals, ceramics, plastics, and composite materials.

However, depending on the material, degradation reactions such as oxidation may occur in the atmosphere, and pores and other defects are common.

We developed a novel spray process based on high-velocity impact of solid powder particles in a thermally-softened state, which we named "Warm Spray." We have demonstrated the capability of the process by depositing highly dense coatings of titanium and WC-Co with little degradation of the materials even processed in the air.

In this process, the proper gas temperature and a supersonic gas velocity are realized by mixing room temperature nitrogen gas in a high pressure combustion gas, which is obtained by combustion of fuel and oxygen. Recently, we conducted joint research with Kagoshima University and Plasma Giken Co., Ltd., and developed a high pressure (4MPa) warm spray device with which the velocity of the particles projected on a substrate exceeds 1,000m/s. When this process was applied to coating of the high strength titanium alloy Ti-6Al-4V, which is widely used in jet engines, it was possible to obtain a coating film with excellent density and cleanliness (low oxygen content) in comparison with the conventional type (1MPa), as shown in Figure 2. Because titanium alloys undergo violent oxidation at high temperature, it is difficult to suppress oxidation in high temperature thermal spraying. On the other hand, with cold spraying, low porosity around 1% has been reported only when particles were accelerated using expensive helium gas. Our process can be performed using inexpensive fuels, i.e., kerosene, oxygen and nitrogen, and thus also offers very high cost performance. In the future, this process will be useful in the development of coatings with excellent high temperature oxidation resistance.

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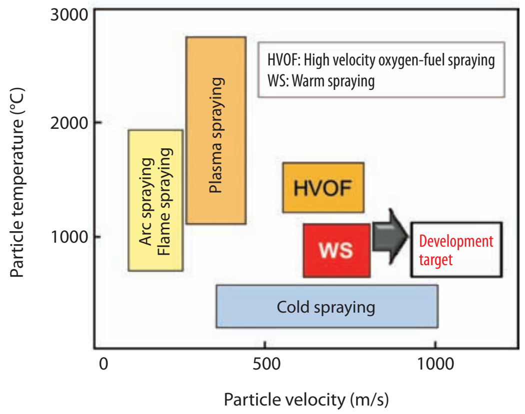

Fig. 1 Temperatures and velocity regions of sprayed particles in various spraying processes, showing the regions covered by the first-generation warm spray process and the newly-developed high pressure warm spray process.

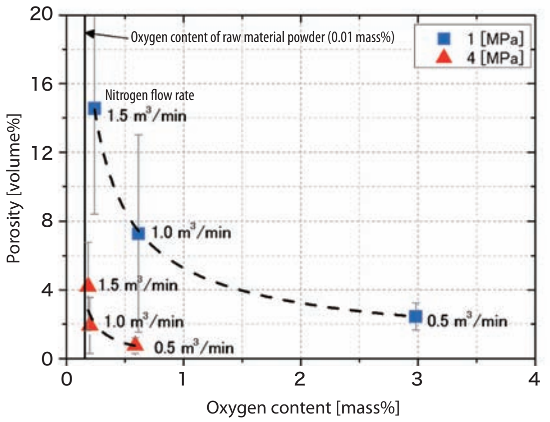

Fig. 2 Comparison of porosity and oxygen content of Ti-6Al-4V alloy coating by warm spray process. The values beside the plots show the mixed nitrogen gas flow rate. The coatings formed by the high pressure warm spray process (4MPa) have superior density and cleanliness in comparison with the conventional process (1MPa).

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Creating Strong, Lightweight, High Temperature Functional Structure Materials

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Replacing Ni-based superalloys with Ti alloys

Improvement of the thermal efficiency of the engines of aircraft and automobiles is necessary in order to reduce fuel consumption and decrease emissions of global warming gases such as CO_2. Improving the heat resistance and reducing the weight of engines and other parts are critical for achieving these goals. Because the operating temperature of aircraft jet engines differs depending on the part, titanium (Ti) alloys are used in the low and medium temperature regions, and nickel (Ni)-base superalloys are used in the high temperature region.

To date, NIMS has conducted an active program of research on Ni-base superalloys. The aims of the present project are to further activate the research potential of NIMS in high temperature materials, and to carry out research on high temperature Ti alloys that make it possible to use of high temperature materials in diverse conditions and locations.

Since the density of Ti alloys is 4.4g/cm^3, while that of Ni superalloys is approximately 9g/cm^3, replacement of the Ni superalloys now used in engines will enable a significant reduction in total engine weight, and this in turn will contribute to improving fuel efficiency and reducing emissions of global warming gases.

Success in development of Ti alloys with high service temperatures

Although various Ti alloys for high temperature use exist, the highest actual service temperature is still around 600°C. If higher service temperatures can be realized, it will be possible to substitute Ti alloys for the Ni superalloys that are now used in the high temperature region.

With conventional Ti alloys, high temperature strength is obtained by solution strengthening, in which various alloying elements are added, or by precipitation strengthening, in which strength is improved by precipitation of Ti_3Al, silicides, or other precipitates. In this project, we are attempting to develop novel alloy designs using precipitates that are stable at high temperature with the aim of achieving further increases in service temperature.

Figure 1 shows the results of a 650°C creep test of an alloy which is precipitation-strengthened using oxides. Creep is a phenomenon in which a material gradually deforms when subjected to constant stress in a high temperature environment. Materials which show smaller deformation for long time possess a higher creep property. Although 650°C is a high temperature for Ti alloys, we succeeded in developing a Ti alloy that does not fracture after 800 hours at this temperature and displays small deformation, at only 1.5%. 1) 2)

We also succeeded in forming a new precipitate called germanide in Ti alloys. As shown in Figure 2, small precipitates (100-200 nm) form in a regular arrangement. Using these precipitates, we are designing alloys with excellent high temperature strength.

Possibilities of high temperature shape memory alloys

As a new field, we are developing high temperature shape memory alloys. 3) Shape memory alloys are materials which are based on the phenomenon of phase transformation and return to their original shape in response to temperature change. At present, shape memory alloys can only be used at temperatures of 100°C or less, but if shape memory alloys that function at temperatures of more than 400°C can be developed, use in variable parts of jet engines, etc. will become possible. For example, it will be possible to replace a conventional mechanism, which is moved by a motor when a sensor detects temperature, with one that operates by movement of the material itself in response to temperature changes. Until now, research on high temperature materials is to efficiently use conventional systems by increasing the heat resistance temperature of materials. However, research on high temperature shape memory alloys has the possibility to revolutionize the system itself.

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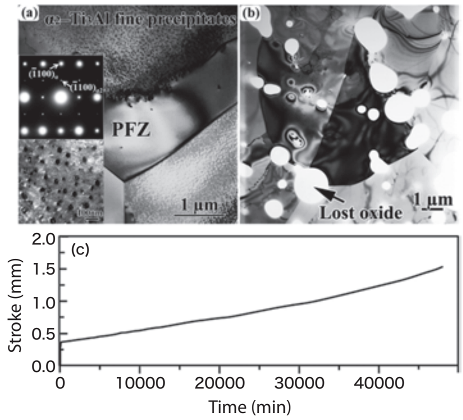

Fig. 1 Microstructure and creep property of the developed alloy. **(a)** Precipitates which undergo embrittlement due to coarsening at high temperature are eliminated. **(b)** Oxides with high temperature stability are formed. **(c)** Creep curve.

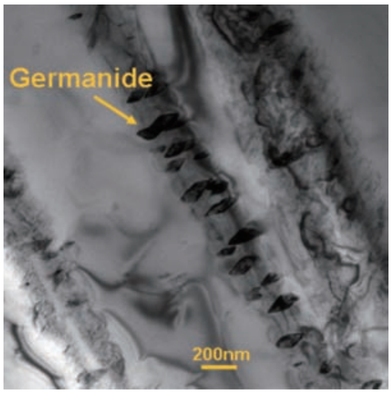

Fig. 2 Novel precipitate formed in the developed alloys.

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Development of Low Frictional Coating under High Temperature Environment

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Increased friction due to the oxidation reaction in high temperature, high humidity environments

Research on low friction materials has attracted considerable attention from the viewpoint of effective energy use, for example, for realizing a low carbon society, as these materials can substantially reduce friction loss in bearings, gears, and other mechanical drive parts.

Conventionally, lubricating oil is used in lubrication, but because oil also has a cooling function in drive systems, a large amount of oil is consumed during drive operation. Moreover, oil additives frequently contain harmful substances, and deterioration with age and environmental pollution, such as the problem of waste oil treatment, are also concerns. Various ceramics are used as solid lubricants which do not require oil or drastically reduce the amount of oil necessary, including sulfide systems, carbon/carbide systems, and others. However, under the corrosive atmosphere in high temperature, high humidity environments like those in gas turbines and steam turbines, increased friction due to the oxidation reaction of the sliding part surface becomes a problem.

Developing high temperature lubricating coatings by optimized control of coating processes

For application to sliding drive mechanisms, a technique for coating oxides, nitrides, and similar substances, which have excellent high temperature oxidation resistance, corrosion resistance, and durability, as lubricating thin film materials has been desired.

In previous work, this group developed high temperature lubricating coatings by optimizing control of coating processes using ceramics such as copper oxide, [1] zinc oxide, [2] boron nitride, etc.

High expectations are placed on zinc oxide (ZnO) as a stable material under oxidizing atmospheres, as it is an abundant raw material, does not contain harmful substances, and is suitable for use as a high temperature material, having a sublimation temperature of more than 1300°C. However, ZnO sinters have a high friction coefficient (μ) of approximately 0.6. The high friction coefficient (μ= approximately 0.3) of ZnO films has been obtained by conventional sputter coating without any optimization. Using a combinatorial approach, we found that a large reduction of μ is possible if the crystal preferred orientation of the ZnO coating can be best optimized with high accuracy. We also discovered that this ZnO might generate an electrical polar interaction in oil, and succeeded in further reducing friction by molecular addition to oil.

Reducing friction in high temperature by developing extremely hard BN coating films

Boron nitride (BN) is a ceramic with excellent heat resistance and corrosion resistance, and in its cubic crystal form, it is an extremely hard material. Thus, a large improvement in high temperature durability is expected.

In order to measure friction at high temperatures exceeding 400°C, we designed and manufactured a prototype of a high temperature tribological tester, as shown in Figure 1(a), and fabricated coating films comprising a mixture of hexagonal and cubic crystals of BN using a magnetic field excitation type ion plating system. When the change in the friction coefficient in air was measured from room temperature to elevated temperatures, a reduced friction coefficient across a wide temperature region was observed, as shown in Figure 2.

Future research objectives include further improvement in lubricating performance at high temperature in combination with extended life time.

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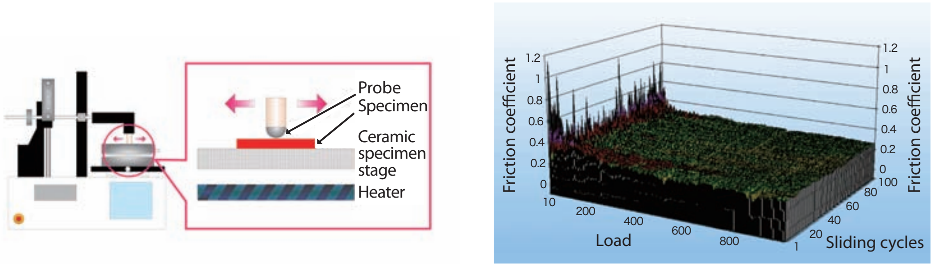

Fig. 1
a) Schematic diagram of the prototype high temperature tribological tester.

b) Change in coefficient (μ) of the developed BN coating with load and sliding cycles (in air; approximately 600°C).

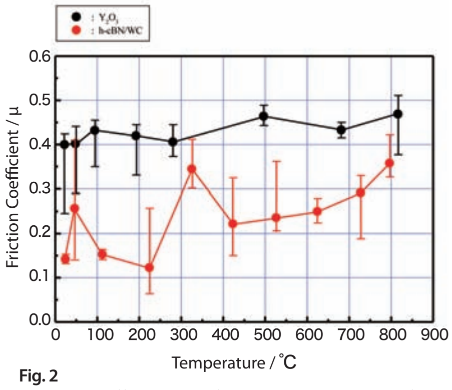

Fig. 2
Friction coefficient (μ) after 100 sliding cycles of the developed BN coating (h-cBN/WC) under a load of 100gf at various temperatures. For reference, the measured values of a Y_2O_3 plate are also shown. The error bars indicate the maximum and minimum friction coefficients.

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New Ferritic Heat-resistant Steel for Advanced High-efficiency Thermal Power Generation

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Improvement in the energy efficiency of thermal power plants is an urgent task.

Nearly all of Japan's gross electric power has been generated by thermal power plants since the nuclear power plant accident triggered by the Great East Japan Earthquake of 2011. As a result, the carbon dioxide (CO_2) emission by burning fossil fuels has increased to 37% of Japan's gross CO_2 emission. Imports of natural gas and other fuels have also increased, and this has developed into an economic problem. To save energy resources and reduce CO_2 emissions, there is a growing need to improve the energy efficiency of thermal power plants.

Increasing the temperature and pressure conditions of the steam which rotates steam turbines is effective for improvement of the energy efficiency of thermal power plants. The latest high-efficiency thermal power plants are operated under steam temperature and pressure conditions of 600°C and 25MPa, and their thermal efficiency is 42%. If these thermal power plants could be operated under steam conditions of 700°C and 35MPa, thermal efficiency would be improved to 46%. This would mean a saving of about 180,000 tons of coal and a reduction of about 420,000 tons of CO_2 emissions per year at each large thermal power plant.

Long-term creep strength is important for high-temperature structural materials

When a metal material is used at elevated temperature, even under low stress, plastic deformation progresses with time through the diffusion of atoms or dislocations, and the material finally ruptures. This process is called creep deformation. The creep rupture strength after 100,000 hours (about 11 years and 5 months) of high-temperature structural materials, which are exposed to steam, is one of the indicators which determine the steam conditions in thermal power plants. Development of heat-resistant materials with high long-term creep strength is an urgent task for increasing steam temperature and pressure.

Conventional 9-12% Cr ferritic heat-resistant steels, which are applied to the latest thermal power plants, are strengthened by a tempered martensitic microstructure including lath and block structures with dense dislocations and fine precipitates of carbides and/or nitrides. However, recovery of the lath structure and coarsening of the precipitates occur during long-term creep exposure at elevated temperatures, and as a result, creep strength decreases drastically. This has developed into a serious problem.

Ferrite matrix precipitation-strengthened by intermetallic compounds

In contrast with conventional steels, NIMS has developed a new heat-resistant steel with a higher chromium content than that of conventional steels. The new steel has a ferrite matrix, which is precipitation-strengthened by intermetallic compounds, with low-dense dislocations through heat treatments (Fig. 1). Fig. 2 shows the creep rupture strength of the conventional and developed steels at 650, 700, and 750°C using the Larson-Miller parameter (LMP) 1). The two vertical lines in the figure correspond to LMP values for 100,000 hours at 650 and 700°C, respectively. The creep rupture strength of the developed steel after 100,000 hours can thus be estimated to be 130MPa at 650°C and 45MPa at 700°C. Thus, NIMS succeeded in improving the long-term creep strength of the newly-developed steel by two times in comparison with the conventional steel.

The newly-developed steel is expected to have excellent steam-oxidation resistance, which is one of the required properties for high-temperature structural materials in thermal power plants, since the steel has a higher chromium content than that of the conventional steels. As the developed steel is expected to contribute to realizing a low-carbon society, NIMS is continuing research for practical use.

1) Larson-Miller parameter: A parameter which makes it possible to compare all data for creep rupture times by the same standard by compensating for differences in the creep test temperature.

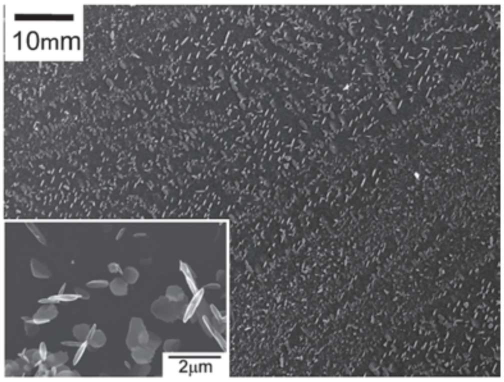

Fig. 1 Electron microscopic image of new ferrite steel, which is precipitation-strengthened by intermetallic compounds.

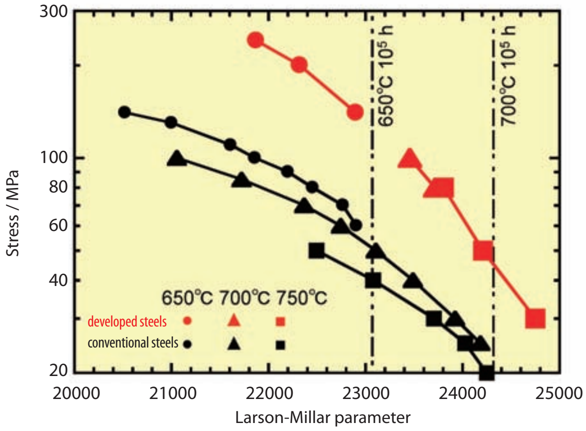

Fig. 2 Creep rupture strength of the conventional and developed steels using the Larson-Miller parameter.

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Development of high-performance cast-and-wrought alloys for the applications up to 750 °C

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Cast and wrought alloys for A-USC power plants

There is a strong demand for high efficiency power generation to meet environment regulation and energy saving requirements. Many efforts have been made to develop advanced cast-and-wrought alloys that allow advanced ultra-supercritical (A-USC) power plants to operate at steam conditions of 35MPa/700℃/720℃ /720℃ (double reheat cycle), called 700℃-class advanced ultra-supercritical (A-USC) power plant, or at higher conditions.

Advanced in the field of iron and steel development during several decades have resulted in improved boiler and rotor materials which enabled the operating temperature and pressure, and hence turbine efficiency, to be greatly increased. However, the steels formerly used as the boiler and rotor materials are not applicable to the steam turbine in 700℃-class A-USC power plant because such steel materials have maximum durable temperature of about 650° C.

Accordingly, it is necessary to use Ni-based superalloy having higher durable temperature than that of iron and steel materials. Long-term creep strength, normally 100,000 hour creep-rupture strength, will be one of the primary limiting factors in the use of these Ni-base superalloys for the key units such as boiler (high-pressure steam piping and header, super-heater tubing and waterwall tubing) and rotor in 700℃-class A-USC power plants. However, several shortcomings including structure stability, weldability, manufacturability and affordability are noted in existed Ni-base superalloys. Therefore, a significant materials effort is required for the development of the steam turbines having main steam temperature of 700℃ or higher.

SINM alloy and TMW alloy with high performance and low cost

The objective of this sub-team is trying to develop new cast-and-wrought alloys with high performance and low cost for the applications up to 750 ℃, which are now expected as key-materials in 700℃-class A-USC power plant.
New Fe-Ni-base superalloys, named as SINM (Super Iron Nickel Metal) alloy and designed by new concept, have excellent workability and high temperature strength (Figure 1), may provide a 60℃ temperature advantage in 0.2%-strain creep life performance loaded under 150MPa over GH 2984 Ni-Fe-base superalloy. New generation of cast and wrought Ni-Co-base superalloys, named as TMW alloy, can have a 75℃ temperature advantage over U720Li superalloy currently in operation.

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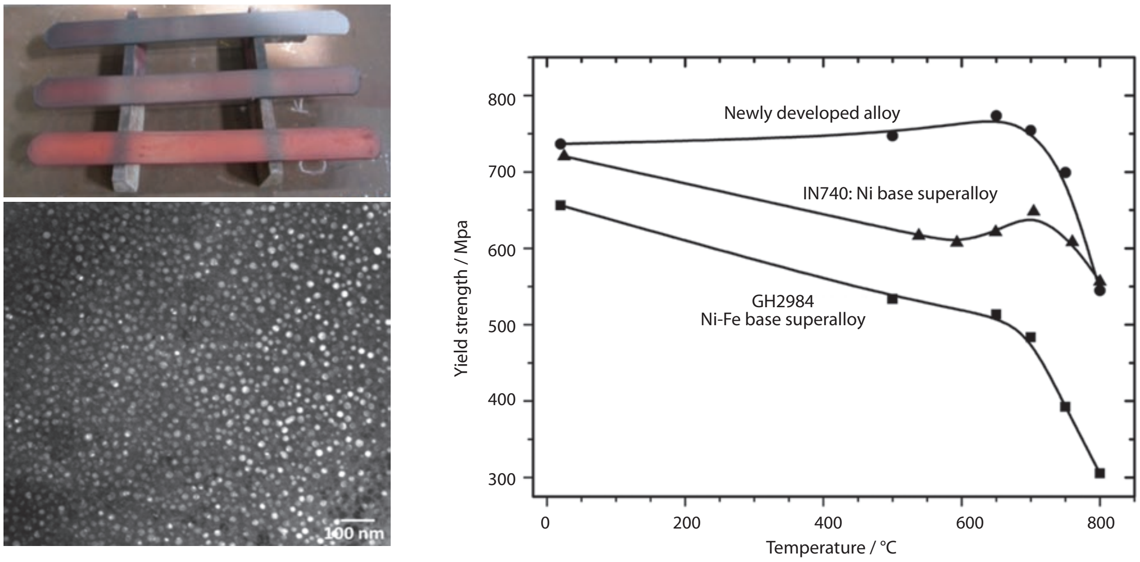

Fig. Workability, microstructure and tensile strength of new developing alloys

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Designing Coating Methods Matched to Materials

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Coatings demanded for high temperature materials

Materials which are to be used in high temperature environments must possess not only mechanical strength in the use environment, but also the chemical stability to withstand oxidation and corrosion at elevated temperatures. With Ti alloys, which are the object of development in this project, material design related to high temperature strength is comparatively smooth, but inadequate oxidation resistance is a serious barrier to practical application. If it is not possible to satisfy all the properties demanded in parts with the base material itself, as seen in this case, it is necessary to complement those properties by surface modification, in other words, coating. If adequate oxidation resistance can be obtained by coating, the possibility of practical application is also heightened.

Nevertheless, it is not sufficient simply to coat the surface with a material that has excellent oxidation resistance. When a substrate is coated with a different type of material and the coated material is subjected to high temperature, the elements that make up the two materials may diffuse between the substrate and the coating material, and formation of phases that deteriorate the mechanical properties of the substrate is possible. The oxidation resistance provided by the coating material can also be reduced by diffusion. It is necessary to develop coating materials and processes that will not affect the properties of the substrate, and will make it possible to maintain its original properties for an extended period of time.

Thus, development of materials and design of coatings suited to those materials are truly two sides of the same coin. However, research in these two areas tends to proceed independently, and this often slows the speed of development.

Close collaboration between material development and coatings

Therefore, in this project, we are engaged in research based on a system that enables close collaboration between the materials development group and coating group, quick and efficient discovery of the optimum matching of alloys and coatings, and evaluation. The following presents one example of this process.

Our group discovered that the tensile strength of Ti alloys at room temperature and high temperature can be improved by addition of Sc. 1) However, the obtained alloy is damaged by surface oxidation when it is exposed to high temperature in the air. We also found that this tendency becomes more severe as the amount of Sc addition increases, as can be seen in Figure 1.

Oxidation resistance treatment by aluminizing

The surface treatment called aluminizing was performed on a variety of alloys. Aluminizing is a type of chemical vapor deposition (CVD) process. A film with a high Al concentration can be formed on the specimen surface by embedding the specimen in a mixed powder of Al, Al_2O_3, and NH_4Cl and heating under an inert gas atmosphere. Figure 2 shows the relationship between holding time and the change in the mass of specimens when specimens were held in the air at 750°C after this treatment. Since the mass of specimens increases as a result of oxidation, from this figure, it can be understood that the non-aluminized material was intensely oxidized, and the amount of oxidation increased with increasing addition of Sc, but in contrast, when aluminizing was performed, oxidation was held to an extremely low level, and the effect of Sc addition was similarly reduced.

To promote application of surface treatment methods to these newly-developed materials efficiently, modeling of the oxidation process by numerical calculation is also necessary. Recently, the process by which oxides are formed after dissolution of oxygen in solid solution in Ti and straining of the Ti crystals was clarified by modeling. We are also engaged in research aimed at developing ceramic coating materials with low thermal conduction and high resistance to molten salt corrosion.

References
1) WL Xiao, SQ Wu, DH Ping, H Murakami, Y Yamabe-Mitarai Effects of Sc addition on the microstructure and tensile properties of Ti–6.6 Al–5.5 Sn–1.8 Zr alloy, Materials Chemistry and Physics, 136 (2012), 1015-1021.

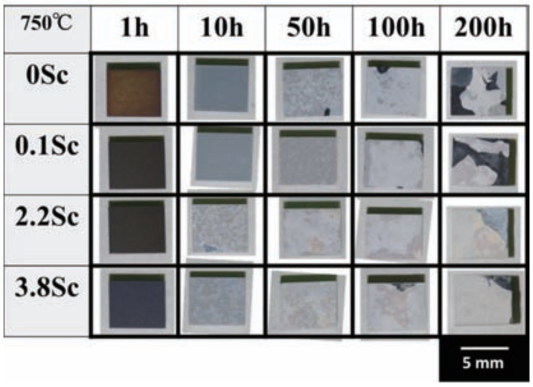


Fig. 1 Change of specimen surface when specimens with various contents of Sc were heated to 750°C in air and held for certain periods.

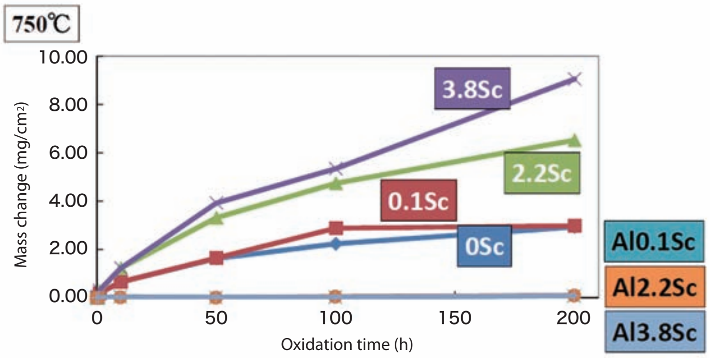


Fig. 2 Change of specimen mass when heated to 750°C in air. Here, Al means an aluminized specimen, and the numbers before Sc indicate the amount of Sc addition (mass%). The aluminized materials show absolutely no mass increase due to oxidation.

Hideyuki Murakami Completed the doctoral course in engineering at the University of Tokyo Graduate School of Engineering in March 1991, and joined NRIM (a predecessor of NIMS) in April 1991. From April 2002 to March 2005, he was an Associate Professor in materials engineering at the University of Tokyo Graduate School. Appointed to present positions as NIMS Principal Researcher in April 2005 and Group Leader in April 2011. **/ Byungkoog Jang** Completed the doctoral course in the Department of Materials Science and Engineering, Graduate School of Engineering of the University of Tokyo in 1994, and has been a NIMS Chief Researcher from April 2007 to the present. In previous positions, Dr. Jang was a Chief Researcher at the Japan Fine Ceramics Center from April 2002 to March 2007 and a part-time Lecturer at Meijo University from April 2003 to March 2007. **/ Tomonori Kitashima** See profile on page 5.

Interview

The new relationship between alloys and coatings. Metal materials that can withstand higher temperatures.

Unit Director,
High Temperature Materials Unit,
Environment and Energy Materials Division
Seiji Kuroda

Group Leader, Functional Structure Materials Group,
High Temperature Materials Unit,
Environment and Energy Materials Division
Yoko Yamabe-Mitarai

Because the materials used in aircraft engines and power generating turbines are continuously exposed to high temperatures, extremely high performance is demanded in terms of resistance to those environments.
An increase of 100°C in the temperature that a material can withstand can improve energy efficiency by a corresponding amount, and also reduces environmental impacts.
However, achieving a 100°C increase in heat resistance is no simple matter.
At NIMS, the High-Temperature Materials for a Low-Carbon Society Project is grappling with this difficult problem.
These efforts are not limited to alloying techniques.
This project is also addressing this problem by the new approach of coating technology.
In this interview, the Project Leader, Dr. Seiji Kuroda, and Dr. Yoko Yamabe-Mitarai,
Vice Project Leader explain why the project is investigating coatings and alloys and what difficult issues they face.

—— First, how do you perceive the significance of research and development of heat-resistant and environment-resistant materials?

Kuroda(K): How we should deal with energy in the years to come has become a major global issue. What we should do about nuclear power, how to introduce renewable energy – these and similar questions are still being debated. Even assuming there are options like the one Germany is taking, if we look at the world as a whole, including the developing countries, it appears that we must unavoidably depend on thermal power at least for the next 20 years or so.

If that is true, then clean use of coal, in other words, how to extract energy from fossil fuels by efficient combustion becomes important. High temperature materials are the key to achieving this. There is no doubt that power generation efficiency increases with temperature.

Seiji Kuroda See profile on page 4.

—— So it's desirable to burn fuels at higher temperatures?

K: Efficiency is undoubtedly higher at higher operating temperatures, but in gas turbines and similar equipment, nitrogen oxide emissions, or NOx, tend to increase when the combustion temperature is too high. For this reason, we can't simply say that higher is better.

In addition to conventional thermal power generation, new technologies such as combination with liquefied coal and solid oxide fuel cell (SOFC) will become more important in the near future.

For the high-temperature, high-pressure parts inside aircraft engines and the gas turbines used to generate electric power, the highest level of heat resistance and creep strength to withstand centrifugal force are necessary. The performance of materials for these applications is increased by applying a thermal barrier coating (TBC) to metal materials with the highest heat resistance, such as the nickel-base superalloys. NIMS is among the world's top research centers in the field of ultra-high temperature materials. However, from a somewhat different viewpoint, our project is aiming at materials used at slightly lower temperatures. One example is heat resistant steels. Our target is to develop ferritic steels usable at 700°C and austenitic steels at 750°C. These materials are used in the main steam pipes of power plants and similar applications, and are important as they are directly linked to the generating efficiency. Our goal is to increase the service temperature of these materials by 100°C.

Yamabe-Mitarai(Y): One difficulty with high temperature materials is that the strengthening methods for materials that are used at room temperature cannot be applied in some case. Although the microstructure of materials is carefully controlled, as temperature increases, the movement of atoms becomes physically more violent, and this causes coarsening of the microstructure and growth of nanocrystals to large size. When this happens, deformation resistance deteriorates and the material is easily deformed. Since few new methods are available, in order to prevent this, strengthening must inevitably be performed by the methods used with high temperature materials to date. Melting point is also a problem, and this limits the materials that can be used. Given this situation, we have to search for some breakthrough.

—— And how do you consider new methods…?

Y: Things that aren't described in textbooks don't come all that easily. However, for example, our group members obtained good results when we applied a strengthening method that is normally used with nickel alloys, rather than the strengthening methods that have become common sense in the steel industry. This can't really be called a "breakthrough," but it is an approach in which we try using techniques that are used other alloys. Oxidation resistance is also a problem that must be considered in high temperature environments. High temperature oxygen oxidizes the surface and forms oxides (scale) which cause deterioration of the material. So, to increase temperature capability by 100℃, it is necessary to apply an oxidation resistant coating like those used with nickel alloys so as prevent deterioration due to oxidation of the material surface. Until now, it had been enough simply to consider the bulk, but if a coating is to be used, it is important to find a coating material that is suitable for the surrounding environment. In that sense, the challenge of improving heat resistance by 100℃ is extremely difficult.

Therefore, not only development of bulk materials, but also joint research by groups focusing on oxidation resistance, coating materials, and the interaction between the coating film and the bulk is necessary. This is one reason why this project is so interesting.

At the moment, I'm studying high temperature titanium alloys with our group members, and thinking about a more effective strengthening method by using precipitates that have not been used until now, while using the technique of conventional precipitation strengthening method. I'm also doing research on high temperature shape memory alloys. These are materials that have the function of shape recovery at elevated temperatures. If alloys of this type can be developed, they will have the potential to change system design. In conventional research on high temperature materials that increase the heat resistant temperature, the approach is to increase thermal efficiency without changing the design of the system, but high temperature shape memory alloys have the potential for improving thermal efficiency by changing the design of the system itself. This is an interesting possibility that did not exist with high temperature materials in the past.

— I believe that your work also extends to manipulating individual atoms?

K: That's right. Predicting what kind of reactions will occur at high temperatures is a new issue, since it's essential for determining the best composition for the coating, and in some cases, embrittlement or peeling of the coating may occur as a result of reactions between the coating and the substrate.

— I understand that heat resistance also decreases over time. How are you dealing with this problem?

Y: By securing the stability of the microstructure. This means finding some means of preventing diffusion, in other words, delaying the movement of atoms. It is necessary to maintain a certain state as long as possible. In power plants and similar facilities, simply supplying materials that can be used for a longer period of time at the same temperature without increasing heat resistance has a major impact.

— Incidentally, I imagine that the target value of a 100℃ increase is a quite difficult value.

K: It is a quite challenging target. This is a target that will have a clear effect if it can be achieved, but even an achievement rate of around 60% would have quite effective results for industry. However, NIMS intends to achieve this target.

— Isn't there a gap between achievement of the target and practical application?

Y: Yes, there is. The largest problem is perhaps the size of samples. The question is whether materials with the same properties as the small samples that we use in our experiments can be produced in a factory or not. As another issue, parts are manufactured by combining various materials, but problems frequently occur when joining dissimilar materials. When we have discovered the basic possibility of a new material and are approaching the stage of practical application, we will carry out joint research with companies.

— What is the future outlook for coatings?

K: In any case, many new materials and processes have been proposed, among which good ones are applied practically. One direction may be coatings that not only increase heat resistance, but also produce a film with resistance to thermal shock. In that sense, the wings of birds might be the ultimate structure. The down feathers of birds hold a large amount of air, which makes them extremely strong against shock. As this example suggests, it may also be necessary to learn from living creatures.

— Are you conscious of costs?

Y: Of course, if we don't think about costs to some extent, nobody will actually use the materials that we develop. But what is more important, I think, is how to utilize the properties of materials. Since nickel-base superalloys have high strength at high temperature, they can't be machined at room temperature. However, there is no material other than the Ni-base superalloys that can be used in severe environments like those in jet engines. For this reason, the special manufacturing method called precision casting is used, even though this results in higher manufacturing costs. If there are properties that other materials can't provide, there is a possibility that the superior material will be used, even if the process cost is somewhat higher. In other words, cost performance is important.

— What gives you pleasure as a researcher?

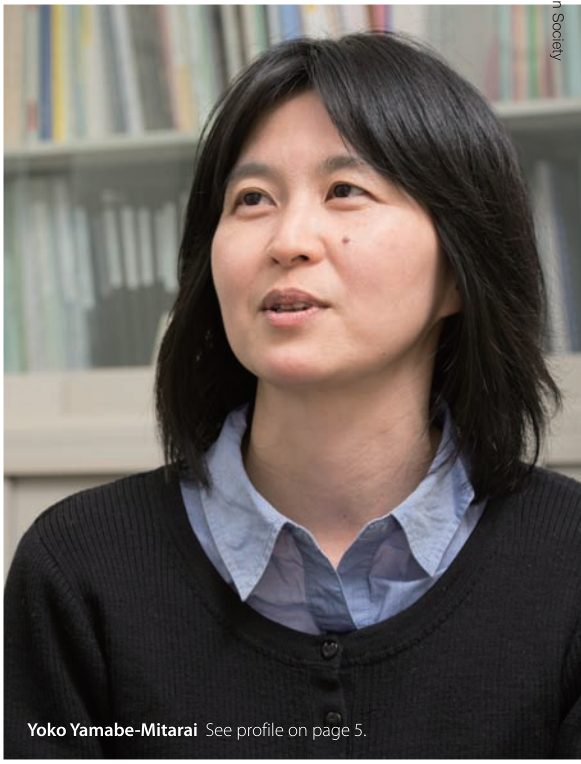
Y: The alloys that I've made myself are a still far from practical application, but when I make a new material, I enjoy imagining various possibilities, for example, that the new material might display good properties.

K: I'm happy when I'm the first to discover something that nobody knows.

— On the other hand, what is hard for you as a manager?

K: Since researchers are generally enthusiastic about research, I rarely feel that managerial work is too difficult. However, I would like to keep them highly motivated even when they face some difficulties to achieve the targets. For this reason, perhaps it's also the manager's job to obtain a reasonable budget for this. It is also important to find a way to industrialize our good results.

Y: There aren't any particular hardships, but I want people to do work that are interesting for them as researchers. I think that they'll be able to do good research because they feel it's truly interesting.



Yoko Yamabe-Mitarai See profile on page 5.

NIMS NEWS

1 Appointment of Mr. Harumasa Miura as New Executive Vice President of NIMS

NIMS appointed new Executive Vice President as follows. The term of this appointment began on April 1, 2013.

Harumasa Miura, Executive Vice President

Graduated from the University of Tokyo with Bachelor of Laws degree. Previous positions include Higher Education Bureau, Ministry of Education, Science and Culture (MESC) Government of Japan; Lifelong Learning Policy Bureau, MESC; Higher Education Bureau; Director Attached to Director General for Science and Technology Policy, Cabinet Office; Manager for Information Division, Research Promotion Bureau, Ministry of Education, Culture, Sports, Science and Technology (MEXT); Vice President and Head of Administration Office, Mie University; Trustee, Vice President and Head of Administration Office, Tokyo University of the Arts; and Vice President, Ochanomizu University. Mr. Miura was appointed Vice President of NIMS in 2013.

2 NIMS Researchers Receive the Commendations for Science and Technology by MEXT

On April 16, 6 NIMS researchers were honored with Commendations for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology (MEXT) at the Award Ceremony held at MEXT on that date. The Minister's Commendation recognizes the work of individuals who have made remarkable achievements in research and development and public understanding of science and technology. The NIMS recipients and their achievements are listed below.

Awardees from NIMS

—Science and Technology Award (Development Division)

Izumi Ichinose, Unit Director, Polymer Materials Unit, Advanced Key Technologies Division

"Development of High Performance Filtration Membranes with Organic Solvent Resistance"

—Young Scientist's Award

Alexei Belik, MANA Independent Scientist, International Center for Materials Nanoarchitectonics (MANA)

"Research on Novel Oxide Materials with Multi-Ferroic Properties"

Yuka Kobayashi, Principal Researcher, Organic Materials Group, Polymer Materials Unit, Advanced Key Technologies Division

"Research on Development of Electronic Functions of Organic Salt-Bridge Materials"

—Science and Technology Award (Research Division)

Takayoshi Sasaki, NIMS Fellow

"Research on Creation of Nanosheets by Delamination of Layered Compounds and their Applications"

Masanobu Naito, Principal Researcher, Catalytic Materials Group, Environmental Remediation Materials Unit, Environment and Energy Materials Division

"Research on Self-Assembled Functional Materials Based on Low-Dimensional Semiconductor Nanomaterials"

Yusuke Yamauchi, MANA Independent Scientist, MANA

"Research on Synthesis of Functional Inorganic Nanoporous Materials and their Applications"

Hello from NIMS

Dear NIMS NOW readers,

It was the end of year 2006 when I came to Japan for the first time as a visiting researcher. Having no experience with such a different culture, that step was slightly scary for me but once here, I was intrigued by everything I could see around me. At that time, my host in Tokyo Women's Medical University told me that despite the thousands kilometers standing between Italy and Japan, the two Countries were not that far. He was definitely right.

Me and my wife with some friends in Takaragawa Onsen.

After going back to Italy, Japan never went really out of my mind, and when I had the chance to join NIMS in 2010, I took it immediately and moved to Tsukuba with my wife, Stefania.

We both started working in NIMS (she is a JSPS post-doctoral fellow), where we found a very familiar environment, together with very high level scientists. Given the amount of time we spend side-by-side for scientific purposes, some of NIMS people became good friends and, from time to time, we get out together.

Besides the amazing experience of working in NIMS, we really appreciate Japanese culture and quiet life. We enjoy visiting Japanese temples and the unique spots that this Country offers. In particular, we were amazed by the special atmosphere of Takaragawa and Hakone Onsen, the relaxing atmosphere of Kyoto religious area, but also modern and crowded places like Shibuya or Shinjuku.

Finally, a special place in our hearts is dedicated to the Sakura season, when Japan dresses up like if it were in a fairy tale.

My wife Stefania with our friend Alma, a former NIMS postdoc from Mexico, during Sakura period in Asakusa temple.

Giancarlo Forte (Italy)
From December 2010 – April 2013
MANA Scientist, Smart Biomaterials Group, Biomaterials Unit, MANA

NIMS NOW International 2013 vol.11 No.3
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cover image: High temperature testing machine

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