Development of Innovative Technology of High Temperature Ti- and Ni-based Alloys and TiAl Intermetallic Compounds

Towards practical use of innovative process technologies of super-heat resistant metals and innovative TiAl alloys for aero engines.

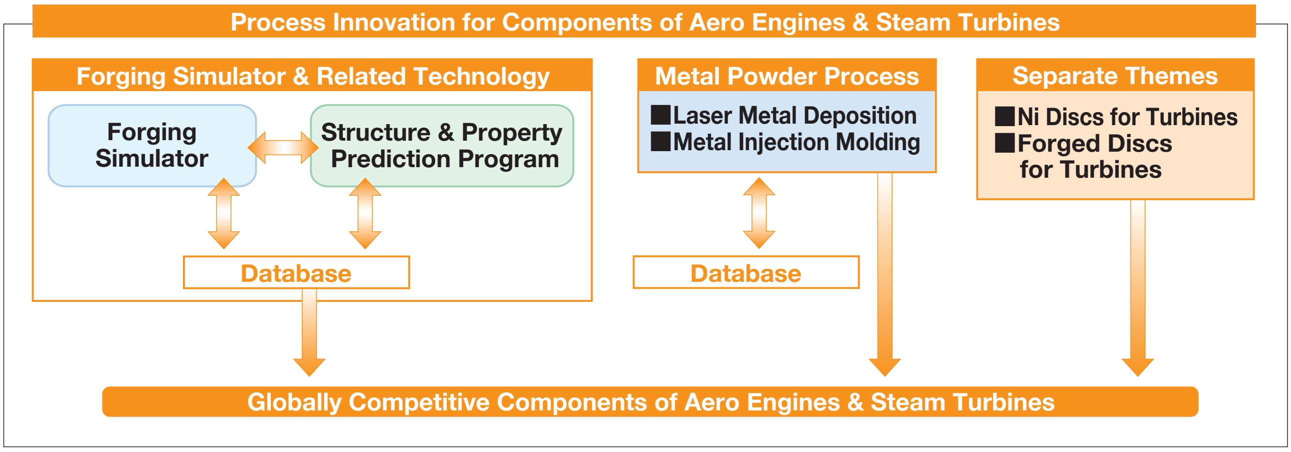
SIP-SM4I
Structural Materials for Innovation

- With regard to titanium and nickel alloys, the following themes have been developed: forging technology, structure & property prediction programs and databases, and process technologies of laser metal deposition and metal injection molding.
- The material design, forging and casting technology, additive manufacturing techniques by electron beam melting of new attractive TiAl alloys will be developed for the high-pressure compressors and low-pressure turbine blades of airplanes, and steam turbine blades of power generations.

SIP Cross-ministerial Strategic Innovation Promotion Program

Concept & Approach

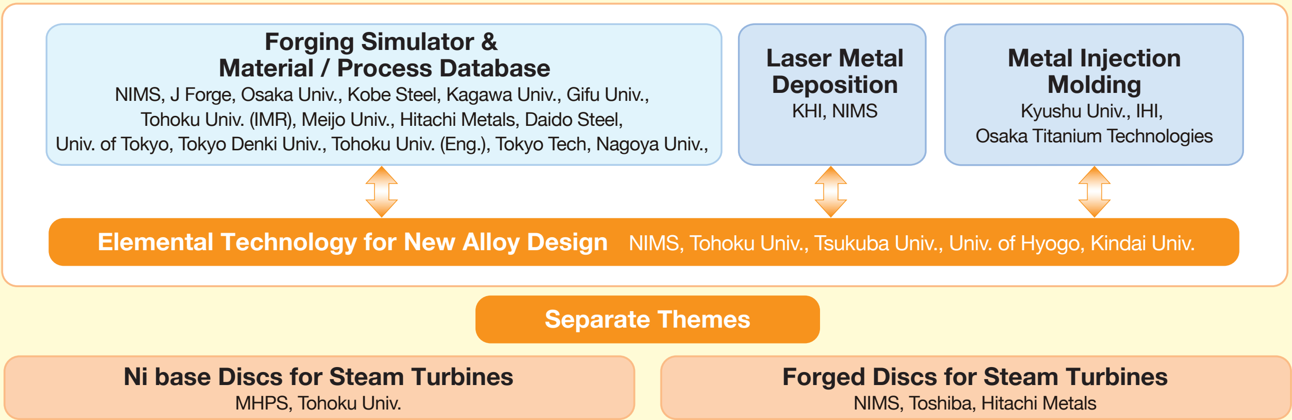
PRISM (Process Innovation for Super-heat resistant Metals)



Innovative process technologies for super-heat resistant metals have been developed, in order to produce globally competitive components of aero engines and steam turbines.

In addition to developing databases of titanium and nickel alloys forged by the forging simulator (a large forging press machine), highly reliable prediction programs for structures and properties of those alloys have also been developed. A center operating the forging simulator and others is to be constructed, where the best forging conditions for aero engine components with required properties are able to be provided in the shortest delivery time. In metal powder processes, such as laser metal deposition and metal injection molding, highly productive and low cost “near net shape” manufacturing processes are going to be established with the use of each database made in each theme. In the separate themes, fabrication technologies of nickel alloy discs and forged discs for steam turbines have been developed by their original process methods.

PRISM Formation of units and their roles



Fifteen organizations from industry, academia, and national R&D agencies have been participating in the theme of the forging simulator and developing forging technology of titanium and nickel alloys and prediction programs for structures and properties of those alloys, in addition to constructing their databases. In other themes, collaborations between industry, academia, and national R&D agencies are also promoted and their efforts are being dedicated to developing practical applications. In the theme of elemental technology for new alloy design, a company has served as the main advisor and fundamental research leading to manufacturing is being conducted.

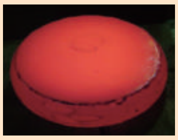
Research and development in PRISM

Forging Simulator & Related Technology

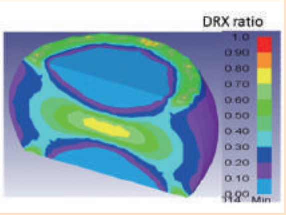
NIMS Center

Database

Forging Simulator



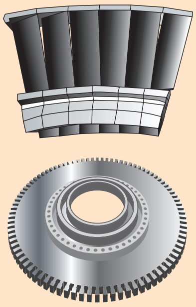
Forged Material



Structure & Property Prediction Program

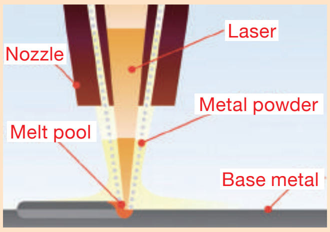
Target for Practical Use

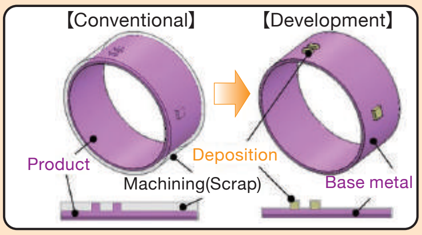
Short-time delivery of the best forging conditions for heat-resistant aero engine components



Turbine Stator, Disc etc.

Laser Metal Deposition (LMD) technology





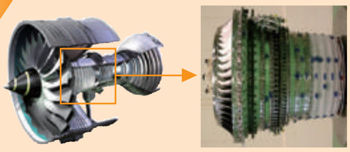
・To achieve high productivity and low cost

【KHI】 The development of a method for production technology

【NIMS】 The development of non-destructive inspection technology

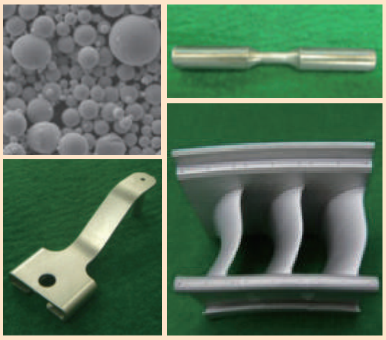
Target for Practical Use

Practical application to aero engine components (～CY2020)

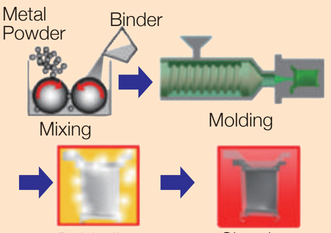


Ex : IPC(Intermediate Pressure Compressor)

Metal Injection Molding (MIM) Technology



- Performance improvement of MIM material (Kyusyu University)
- High quality titanium powder production (OTC)
- Manufacturing technology development of MIM component (IHI)



Target for Practical Use

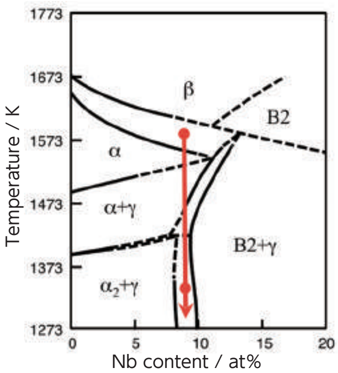
Application of high quality and highly accurate MIM technology to aero engine components

●MIM nickel alloy ：
To establish material data base and to apply practical components

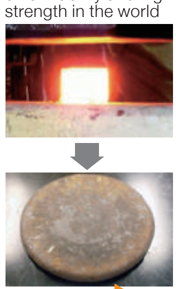
●MIM titanium alloy ：
To improve fatigue strength and to show the capability for practical use

Innovative Design and Production Technology of Novel TiAl Alloys for Jet-engine Applications
Research and Development in TIT Research Center

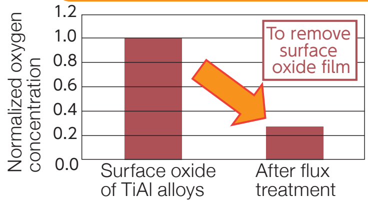
Design Principle of Microstructure and Processing【TIT】

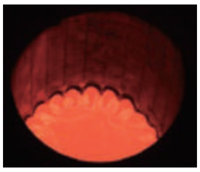


First improvement in both of formability and high strength in the world



New Manufacturing Process for High Quality and Low Cost【Kobe Steel】

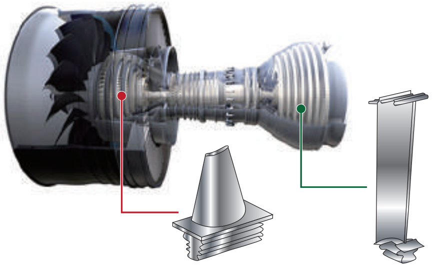




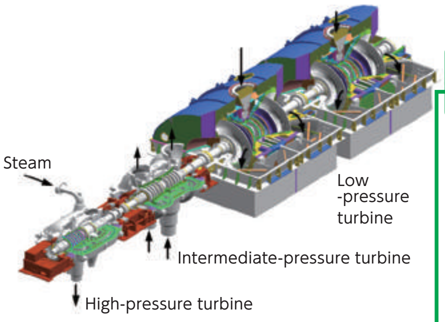
To remove oxide film on surface
To reduce cast defects and fluctuation components

Evaluation of Mechanical Properties for Compressor / Turbine Blade【IHI】

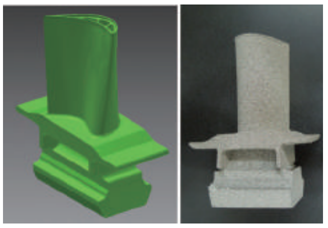
Application to jet-engine of airplane
(800 °C grade forged HPC and casted LPT)



Application to Rotors of 650℃ Grade Steam Turbines【MHPS / TIT】



Additive Manufacturing Technique by Electron Beam Melting【Osaka Univ./ Metal Tech. Co. / NIMS】



Formation of Units and their Roles in TIT Research Center

Design Principle of Microstructure and Processing for Innovative TiAl Alloys
TIT

Innovative Design and Production Technology of Novel TiAl Alloys for Jet-engine Applications

Development of New Manufacturing Processes for High Quality and Low Cost TiAl ingots
Kobe Steel

Development of Innovative Manufacturing Processes for TiAl Blades
IHI

Development of Manufacturing Technique for TiAl Turbine Blade with Oriented Lamellae
Osaka Univ., Metal Tech. Co., NIMS

Development of Wrought TiAl Alloy Blade for Steam Power Generation
MHPS, TIT

Principle of microstructure and processes is designed by Tokyo Institute of Technology (TIT) for innovative TiAl alloys with high specific strength and heat-resistance. For the proposed alloys based on the principle, the melting process techniques is developed by Kobe Steel and the manufacturing techniques of forging and casting for jet-engine blades is developed by IHI. They aim to apply the new alloys to practical airplanes in 2020 through their close collaboration of university and industries. In addition, additive manufacturing techniques by electron beam melting and the application of wrought TiAl alloys to steam turbine blades of power generations are researched in other unit project.

Japan Science and Technology Agency

Department of Innovation Platform
Japan Science and Technology Agent (JST)
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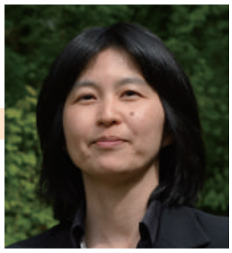
http://www.jst.go.jp/sip/k03.html

High hopes for the development of technologies for creating heat-resistant alloys, intermetallic compounds, and similar materials

The development of heat-resistant alloy technologies

TERUO KISHI
Program Director, SIP Innovative Structural Materials for Innovation

This research and development is expected to take full advantage of forging technology in manufacturing actual parts, simulation technology for structure, characteristics prediction, and other techniques and related technologies, thereby establishing plastic processing methods for precisely forging large heat-resistant components that excel in functionality, strength, and reliability, and thus promoting technologies for the use of new materials. It is also a goal to establish and achieve opportunities for industry, academia, and government to collaborate with one another in developing technologies for processing innovative metallic materials that lead to large sizes and mass-production as new manufacturing technologies.



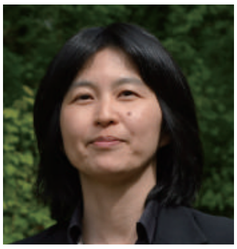
Director of PRISM
YOKO YAMABE - MITARAI
National Institute of Materials Science

PRISM has mainly developed innovative process technologies for aero engine components, instead of individual components themselves. With regard to forging technology, structure and property prediction programs and databases are being constructed by utilizing the forging simulator installed at NIMS, which will contribute to productions of competitive forging components in the industry. The laser metal deposition and the metal injection molding will yield huge reductions in workloads and raw materials by utilizing a direct forming method, contrary to a scraping-out one. The separate themes also try to renovate the existing technologies by using original processing techniques.

Forging simulator and related fundamental technologies

Keywords : Ti alloy, Ni alloy, Forging technology

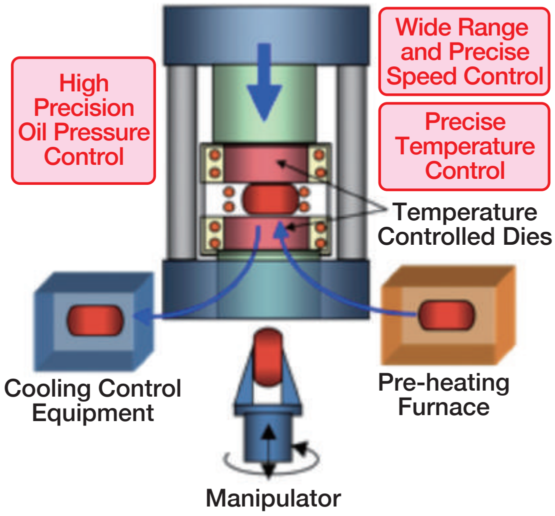
YOKO YAMABE - MITRAI
National Institute of Materials Science

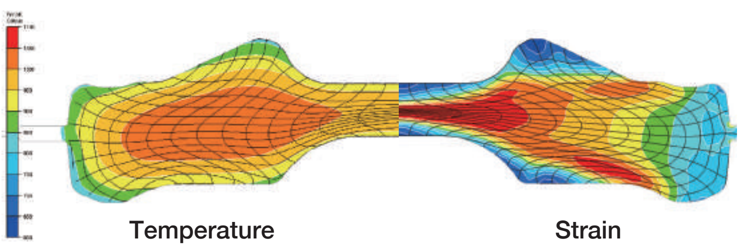


SHINYA ISHIGAI
Japan Aeroforge, Ltd.

Since titanium and nickel alloys have been increasingly used as heat resistant materials for aero engines, it is crucial to produce globally competitive components that utilize them. In this project, the forging simulator, structure and property prediction programs and databases are being developed as a whole package, in order to efficiently provide the best forging conditions for the components with required properties to product companies. Further upgrading of the prediction program and the database is also being promoted by operating the forging simulator as a center. Fundamental research on calculation methods and alloy impurities have been studied, and results will be applied to future programs and the databases.

Large-scale Forging Simulator

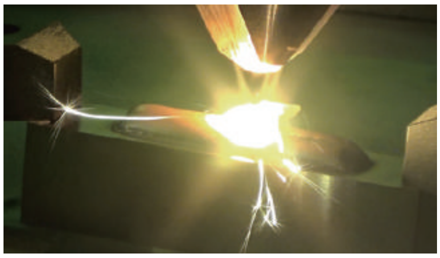




Developing an innovative production technology using the Laser Metal Deposition to produce aero engine components at a low cost and high rate

Keywords : Titanium alloy, Near net shape, Laser, Powder

KENICHIROH IGASHIRA
Kawasaki Heavy Industries, Ltd.



Titanium alloys have been widely used in aero engine components due to their lightweight yet strong characteristics. Because these components are generally machined from large forged materials, much material is wasted during production. Therefore, it is necessary to reduce raw materials and machining costs. We are developing a near net shape forming technology using the Laser Metal Deposition (LMD). Many processing conditions, including laser conditions, have a complex influence on the quality of LMD products. We are going to establish optimal processing conditions for titanium alloy LMD products by making a database that correlates processing conditions with their mechanical properties. We aim to achieve a practical application for aero engine components one to two meters in size by establishing quality assurance technology on the basis of aero engine component quality standards.

Dramatic improvement of fatigue capability of MIM titanium alloy

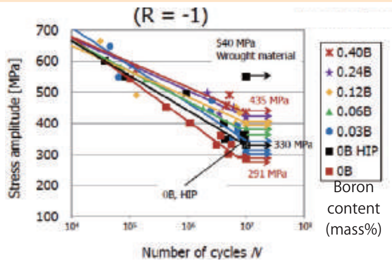
HIDESHI MIURA
Kyusyu University

MIM technology development for aero engine components

HIROSHI KUROKI
IHI Corporation

Keywords : Aero engine, Powder metallurgy, Injection molding, Sintering, Nickel alloy, Titanium alloy, 3rd element

In Kyusyu Univ., static (tensile) and dynamic (fatigue) fracture strength of MIM titanium alloy has been improved by refining microstructure and achieving higher density. The effect of TiB_2 addition has been confirmed. Further improvement has been studied by adding other elements such as Cr, Mo, Fe, C, which are effective to improve the strength of wrought materials. The effect of these elements and heat treatment will be clarified. At IHI, a material database is being built for MIM nickel and titanium alloy. MIM technology will be applied for the production of aero engine components by developing manufacturing technology for large size parts.



Fatigue Strength Improvement of MIM Titanium Alloy by Adding TiB_2

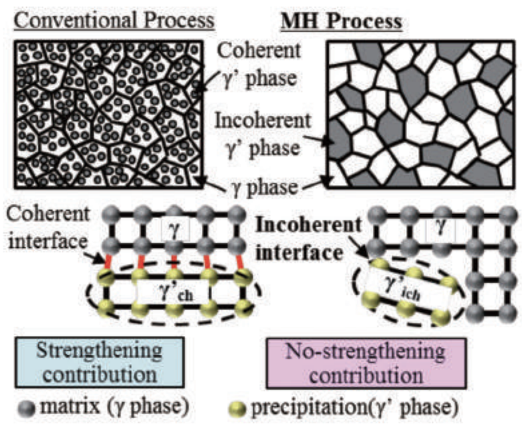
Development of practical manufacturing process of high strength Ni-based superalloys for aircraft engine disks

Keywords : Ni-based superalloy, Alloy design, Mirostructure control

SHINYA IMANO
Mitsubishi Hitachi Power Systems, Ltd.

Recently, high strength nickel-based (Ni) superalloys have been developed for aircraft engine disks, but they have low workability. In order to apply these alloys for gas turbine components, we have dramatically improved their workability by using innovative microstructure control. This is referred to as the MH-process. It is widely known that coherency at the gamma (γ)/gamma prime (γ') interface contributes to strength. However, an incoherent γ/ γ' interface does not contribute to strength. Therefore, forming a γ/γ' two-phase microstructure with an incoherent interface using the hot forging process followed by heat treatment would allow improvement of their workability.

In this study, in order to optimize the microstructure to improve their workability, we clarifed the mechanism of microstructure development. Then, after designing the manufacturing process of gas turbine components, the cost and workability will be evaluated by trial manufacturing. In addition, in order to optimize the manufacturing process, models of the forging simulation (*1DEFORM™) under MH process conditions will be investigated.



*1 DEFORM™ is a product developed by Science Technologies Corporation.
(http://www.deform.com/)

High hopes for the development of technologies for creating heat-resistant alloys, intermetallic compounds, and similar materials

Development of high strength large scale forged disc for Steam Turbine

Keywords : Steam turbine, Forged disc, Microstructure control, Strength and toughness

KAZUHIRO KIMURA
National Institute for Materials Science

Highly strong and durable turbine rotor materials with superior resistance to stress corrosion cracking is fundamental for providing long and high efficiency blades for the last stage of steam turbine, as well as high performance blade material. Currently, however, low alloy steels are used as low-pressure turbine rotors, and it is tough to achieve further strengthening of them, in contrast to turbine blades produced by high alloy steels or titanium alloy. The aim of this project is to develop innovative large scale forged disc material with high strength and high toughness available for the last stage of low pressure turbine rotors with the use of conventional low alloy steel by controlling microstructure.

KAZUO NAKAMURA
Collaboration Coordinator

PRISM consists of 29 organizations (11 companies, 15 universities and 3 national R&D agencies). Among them, 15 organizations (4 companies, 10 universities and 1 national R&D agency) participate in the unit related to the forging simulator. In order to efficiently enhance the research and development of each goal, several working groups have been formed within the unit. Their results have been shared widely with other members in the unit. Since the number of member organizations in the unit is quite large, email discussions and web meetings have been utilized in order for the members to cooperate with each other. Since the forging simulator was the biggest investment in the SIP Structural Materials for Innovation, the success of its application is crucially important for the SIP. Therefore, globally competitive forging technology has been developed, including databases and the structure and property prediction programs. Further, a center for forging technology with industry-academia-national agency collaboration will be established and utilized after the SIP.

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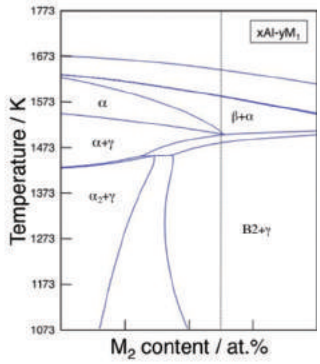
High hopes for the development of technologies for creating heat-resistant alloys, intermetallic compounds, and similar materials

Design principle of microstructure and processing for innovative TiAl alloys

Keywords : Phase diagram of multi-component alloys, Microstructure control, Creep strength, Oxidation resistance

MASAO TAKEYAMA
Tokyo Institute of Technology

In this project, aiming at the mass-production of innovative TiAl alloys by 2020, a research center was established at the Tokyo Institute of Technology (TIT). Through collaboration among Kobe Steel, IHI and TIT, technology for the microstructural design, manufacturing and forming process has been developed for the innovative casting and forging of TiAl-based alloys for the low-pressure turbine (LPT) blades and high-pressure compressor (HPC) blades of jet-engines in next-generation aircraft. The roles of this unit are to develop the microstructural design principles based on phase diagrams, mechanical properties and oxidation resistance for multicomponent TiAl alloys, which can be applied to LPT and HPC blades and are superior to conventional Ni-based alloys. To date, we have investigated the multicomponent phase diagrams as the basis of the microstructural design (figure on the right), and clarified that the microstructure can be freely controlled by using various phase transformations based on the phase diagrams. We succeeded in improving the creep strength and oxidation resistance of the microstructure-controlled alloys. Based on the knowledge obtained, we designed and proposed prototype forging and casting alloys for the mechanical testing of blade-shaped pieces.



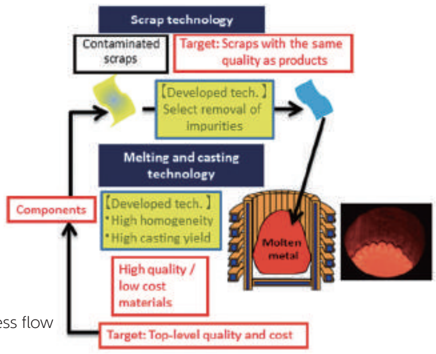
An example of TiAl-based multicomponent phase diagram

Development of new manufacturing process for high-quality and low-cost TiAl ingot

Keywords : Melting and casting, Microstructural homogeneity, Casting yield, Scrap, Impurity removing

KOICHI SAKAMOTO
Kobe Steel, Ltd.

Our aim is to develop a melting and casting process that can control the target chemical compositions of the alloys proposed and designed by TIT with high productivity. Utilizing scrap as the raw materials of melting metals, we will establish technology for manufacturing high-quality TiAl based alloys at low cost and with competitive advantages (figure on the right). To date, in the melting and casting process, we have established melting techniques for precisely controlling the compositions of molten metals, clarified the casting conditions for reducing fluctuations of the composition of ingots, and improved the casting yield rate. In utilizing scrap, we have clarified in principle the effective way of removing surface oxides by the halide flux process, and determined optimum conditions (flux compositions) for the selective removal of oxygen. In future, we will optimize the process conditions in order to demonstrate mass production.



Manufacturing process flow of TiAl based alloys

Development and verification of an innovative manufacturing process

Keywords : Heat resistance, Precision casting, Near-net-shape production, Forging

SATOSHI TAKAHASHI
IHI Corporation

Ti-Al alloys have been intensively studied for a quarter of a century and have recently been incorporated into aircraft engines. With the arrival of higher-temperature engines, however, more highly heat-resistant alloys are in demand. Ti-Al alloys are, on the other hand, less castable and forgeable than their competitor, Ni-base superalloys, calling for the development of alloys that are not only strong but manufacturable, as well. In this project, the knowledge obtained in terms of manufacturability is fed back to alloy design and materials manufacturing. Thus far, we have been casting round bars and forging pancakes (see the right-hand figure) for evaluating the strength of developed alloys, thereby obtaining alloys exceeding our strength targets. We will continue to develop the company's previous Ti-Al casting and forging technology and develop and demonstrate near-net-shape casting and forging technologies suited for the developed alloys.

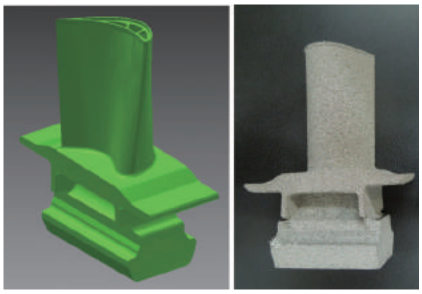
Forged pancakes for strength evaluation

Development of manufacturing technique for TiAl turbine blade with oriented lamellae

Keywords : Ti-Al alloys, Turbine blades, 3D printers, Additive manufacturing, Microstructure control

HIROYUKI YASUDA
Graduate School of Engineering, Osaka University

This project aims to develop TiAl low-pressure turbine blades with their geometry and crystal alignment simultaneously controlled by using electron beam melting in order to help increase the efficiency of aircraft jet engines. More specifically, the project involves optimizing the conditions of the abovementioned process, thereby establishing a method for efficiently manufacturing TiAl components excellent in surface geometry, dimensional precision, and density. We also aim to achieve high strength, good ductility and excellent creep property in TiAl alloys by controlling the microstructure and crystal alignment based on our previous study. We have already succeeded in elucidating the formation mechanism of peculiar microstructure in additively manufactured TiAl alloys and, as shown in the right-hand figure, manufacturing TiAl turbine blade.



CAD data and turbine blade.

Developing rotor blades made of forged Ti-Al alloys for thermal steam turbine plants

Keywords : Ti-Al alloys, Structure control, Forging process, Computational phase diagram

Mitsubishi Hitachi Power Systems, Ltd.

JUN SATO SHINJI OIKAWA

In order to improve the efficiency of thermal power plants, demand for 650°C class steam turbines is increasing. As rotor materials, the service temperature limit of ferrite steel is around 600°C, while Ni-base alloys for 700°C class A-USC have cost-related issues. The lightweight Ti-Al alloys would reduce the stress acting on the rotors, thereby increasing the service temperature limit of ferrite steel rotors to 650°C.

To develop tough, strong materials and manufacturing processes suited for rotor blades, it is necessary to take advantage of micro texture control scheme based on β-phase proposed by Takeyama et al. of the Tokyo Institute of Technology together with the know-how and manufacturing equipment owned by MHPS as a plant manufacturer. The oxidation and creep behavior of Ti-Al alloy in steam are also being evaluated, since Ti-Al alloys have not previously been used in steam.

The developed materials and manufacturing processes are verified through the experimental production of actual blades. As shown the below figure, through the micro texture control scheme based on β-phase, candidate Ti-Al alloys were successfully forged.