Research and Development of Superalloys for Aeroengine Apprications

National Institute for Materials Science

1. Background

Following the Kyoto Protocol aiming at mitigating CO_2 emission to prevent global warming, the materials with higher temperature capabilities allowing the power systems or the component parts to operate at higher temperatures and thus providing higher efficiencies became of vital importance.

Since established in July 1956 as National Research Institute for Metals, NIMS has been conducting intensive research work on aerospace materials, especially after 1975 when NIMS developed an alloy design computer program and, using the program, developed a series of new superalloys with higher temperature capabilities. In 1999, NIMS launched "High Temperature Materials 21 Project, Phase 1 (F.Y.1999-2005)" led by Dr Hiroshi HARADA, working together with Japanese heavy-industry companies. In the Project 5th generation Ni-base SC superalloys have been successfully developed with world highest temperature capabilities of about 1100°C. Following this, alloy development targeting at 1150°C has been started.

NIMS has been thus leading the Ni-base superalloy development, and the developed alloys are now expected as key-materials in large gas turbines for combined cycle power generation, small gas turbines for high efficiency cogenerations, and advanced aeroengines. These research activities have attracted attentions of engine manufacturers in the world. In order to foster further long term relationship, NIMS and Rolls-Royce have reached an agreement to start a collaboration within a newly established "Rolls-Royce Centre of Excellence for Aerospace Materials at NIMS".

2. Collaborative work share

The requirements from airlines to improve the specific fuel consumption, as well as environmental regulations to reduce CO_2 emission, are becoming stronger due to the continued increase in fuel price. As shown in Fig.1, next generation efficient airliners such as the Boeing 787 are designed to emit about 20% less

CO_2 compared with the latest ones. To achieve this, a high efficiency aeroengine is essential, and to realize it, superalloys with high temperature capabilities are thus, required. Essentially, this concept has provided the incentive and technological impetus to enhance the temperature capability of the speralloys over the past 50 years. In the collaboration, NIMS will be in charge of developing such alloys that can further improve the efficiency. NIMS will conduct fundamental work on the relationship between alloy composition, heat treatment condition, microstructures, and high temperature properties including creep, fatigue, and so on. In Rolls-Royce, we expect that more practical evaluation tests for creating database, as well as parts manufacturing trials, will be conducted. Thus we believe NIMS and Rolls-Royce, working together, will be creating the best superalloys in the most efficient way to be fitted into applications in time.

Fig.1

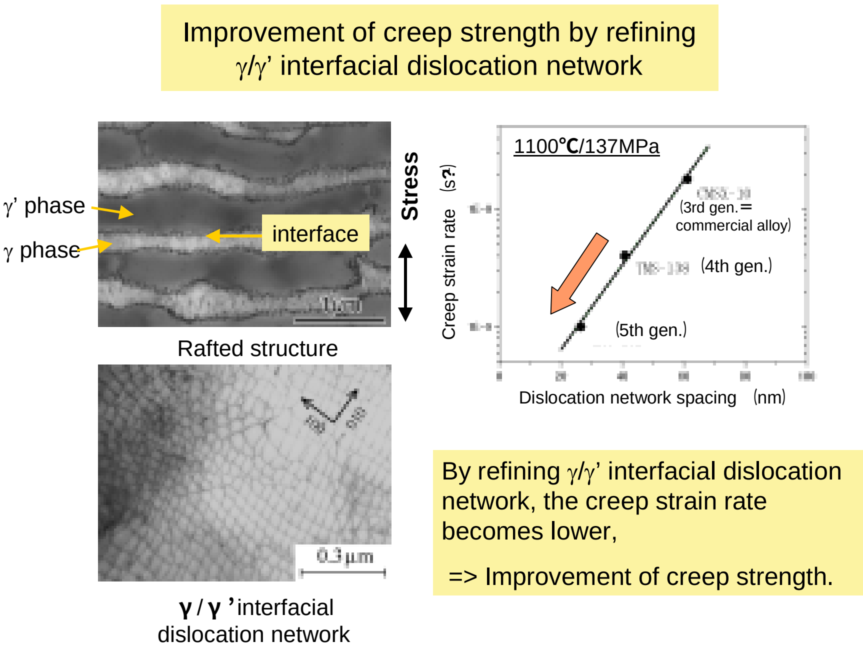
(provided by All Nippon Airways)

3. Expected achievements and developments

Ni-base superalloys, as multi-component alloys containing many alloying elements, including Co, Cr, Mo, W, Al, Ta, Re, Ru, have emerged as the materials of choice for higher temperature operation when creep, tensile, fatigue, oxidation, corrosion, and some other properties are being considered. The alloy must also be easy to cast into a complicated hollow blade as a single crystal structure. Alloy designers must consider all of these properties, while at the same time, meet the turbine design specifications.

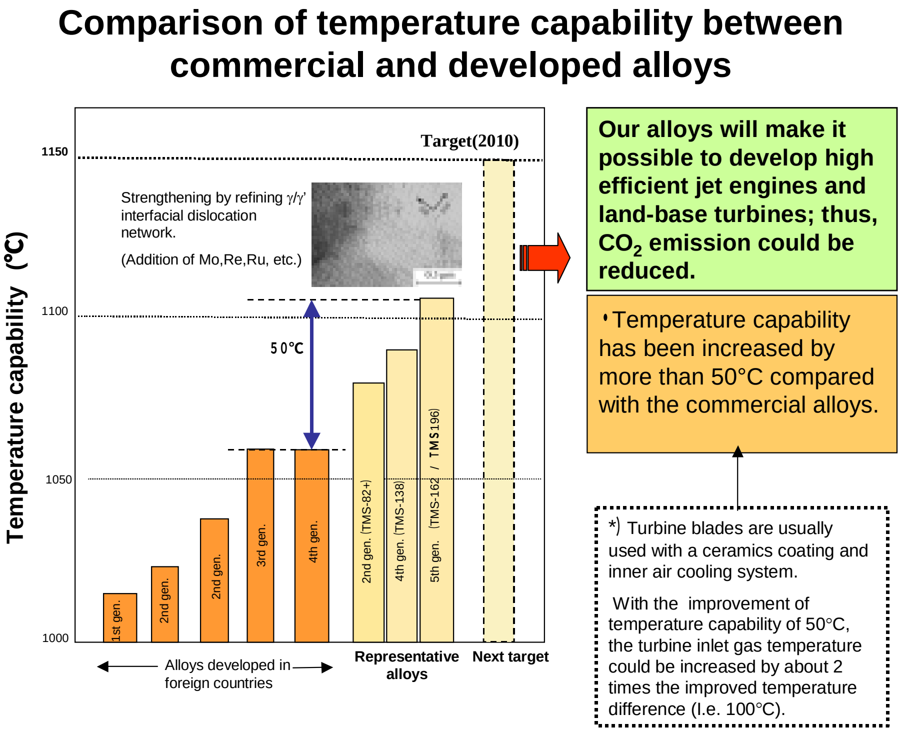
Fig.2 shows one of the most effective ways to improve creep strength, as an example. With NIMS computer programs we can design, by selecting the chemical composition, the γ/γ' lattice misfit and thus the interfacial dislocation network spacing. The finer the network is, the slower is the creep deformation rate; therefore, the corresponding alloy is stronger. Together with other strengthening methods, NIMS will be designing 6th generation single crystal superalloys with a temperature capability approaching 1150°C as suggested in Fig.3.

Fig.2



If the temperature capability is improved by 50°C (from 1100 to 1150°C), the cooling air inside the turbine blades, for example, can be reduced to improve thermal efficiency and thus the specific fuel consumption. The 50°C improvement corresponds to the improvement of about 6 times longer creep rupture life, provided that the alloy is used at the same condition. Subsequently, in this way the reliability of the parts will also be much improved.

Fig.3



NIMS High Temperature Materials Centre (HTMC) consists of very experienced and highly motivated research staff, as well as NIMS original alloy design computer programs that predict various properties from the chemical composition, temperature and applied stress. The HTMC also has state-of-the-art equipment to fabricate and evaluate the designed alloys. Some of the equipment include, a directional solidification furnace to cast single crystal superalloys, heat treatment furnaces, a range of microstructure characterization equipment, including a 3-D Atom-probe Microanalyser for the study of atomic distributions, a 400KV Transmission Electron Microscope for in-situ creep observation at 1200°C, creep testing machines, thermo-mechanical fatigue testing machines, and so on. With using other facilities in NIMS, we will be able to carry out most of the laboratory scale testings with test-pieces to accelerate the alloy development.

Once the superalloy is practically used as turbine blades, the alloy will normally be used for a long time, possibly throughout the engine life. NIMS will be ready to continue the Rolls-Royce collaboration with a long-term vision to support the end users.