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Superalloys for Jet Engine and Gas Turbine Applications: Evolution and Revolution for the Future

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Conventionally cast (CC), directionally solidified (DS) and single crystal (SC) Ni-base superalloys are used for high temperature components, typically turbine blades and vanes that determine the thrust and thermal efficiency of jet engines and power generation gas turbines. The SC superalloys have the highest temperature capabilities; a 6th generation SC superalloy TMS-238, containing Re and Ru, exhibits world highest 1120°C temperature capability. New superalloys beyond Ni-base superalloys, such as Ir-base refractory superalloys, are also being developed as possible alternative materials in the future.

Keywords: *Ni-base Superalloy, Single Crystal, Turbine Blade, Jet Engine, Gas Turbine, Refractory Superalloy*

1. Introduction

Turbine blade and vane materials with higher temperature capabilities are crucial to improving thermal efficiency in jet engines and gas turbines for reducing fuel consumptions and CO_2 emissions. The turbine blades and vanes are made of Ni-base superalloys and produced by vacuum investment casting, with ceramic moulds holding complex shaped cores, to hollow components for air-cooling inside. The cooling air flow, however, must be minimised not to lose the efficiency, and for this reason, the temperature capability of superalloys as well as casting technologies must be improved.

2. Ni-base Superalloy Development

The superalloy was first developed and used in jet engines during the World War 2. The first Ni-base superalloy, Nimonic 80, was a wrought alloy and had temperature capability as high as 730°C (Fig.1). In 1950s, vacuum induction melting and casting technology was established for conventionally cast (CC) superalloys, and then for directionally solidified (DS) and single crystal (SC) superalloys. In NRIM (National Research Institute for Metals, Tokyo) we started our alloy design and development work for Ni-base superalloys in 1975. We developed an alloy design computer program (ADP) and, using the program, developed CC, DS, and SC superalloys [1]. A typical microstructure of the SC superalloy is shown in Fig.2. The NRIM work has been succeeded in NIMS. Newer generation SC superalloys, up to 6th

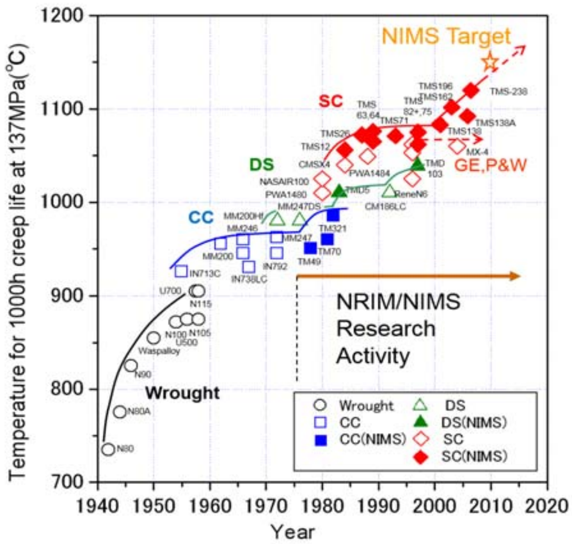

Fig.1 Improvement in temperature capability of Ni-base superalloys, with NIMS project target for new Ni-base SC superalloys.

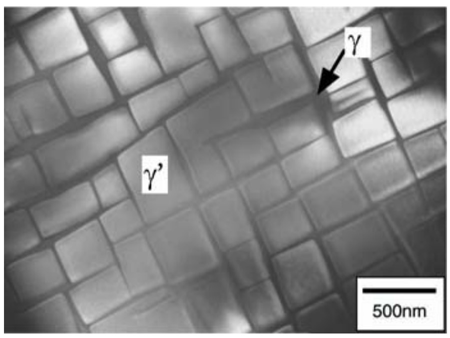

Fig.2 Typical microstructure of the Ni-base SC superalloy with a γ/γ' coherent structure.

generation SC superalloy TMS-238 (Ni-6.5Co-4.6Cr-1.1Mo-4W-5.9Al-7.6Ta-0.1Hf-6.4Re-5Ru,wt%) with world highest 1120°C temperature capability, have been developed [2] and further improvements are expected.

Some of the superalloys we developed so far are now being brought into actual practical applications. Typically, an SC superalloy (TMS alloy, the alloy number is not disclosed) has been used in Rolls-Royce Trent1000 engines powering more than 100 Boeing 787 airplanes operated by All Nippon Airways (Fig.3), British Airways and many others. A high temperature high pressure turbine blade with thermal barrier coating is shown in Fig.4.

Fig.3 First application of NIMS advanced SC superalloy was made in Rolls-Royce Trent1000 engine powering Boeing 787.

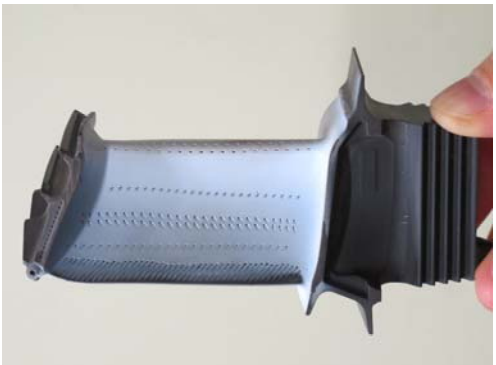

Fig.4 An example of Rolls-Royce hollow turbine blade with thermal barrier coating and holes for film cooling.

A high cost-performance SC superalloy TMS-1700 /MGA1700 (Ni-9Cr-0.6Mo-7.6W-5.4Al -10Ta, wt%) has been developed under collaboration with Mitsubishi Heavy Industries, Ltd. [3], and is going to be applied into a 1700°C gas turbine for combined cycle power generation system of 57% (HHV) thermal efficiency in the year 2020. A casting trial to SC blade of 300mm long and 10kgs weight has been successfully made. Casting defects such as freckles, stray grains and re-crystallisation have been eliminated by selecting right alloy chemical composition and casting condition.

For the cost reduction of the alloys containing many rare metals, a new recycling technology, that is, direct recycling process, has been developed in our group. By remelting in CaO crucible, scrapped turbine blades are refined to a quality as good as the genuine superalloy in laboratory scale [4]. Scale up trials targeting finally 2 tons are planned with ingot makers.

3. Beyond Ni-base superalloys

Much effort has also been paid to develop new alloys beyond Ni-base superalloys. They include refractory metals and alloys such as Mo or Nb silicide base alloys, Co-base γ/γ' alloys and some others.

In NIMS the author and his group developed "refractory superalloys" composed of the γ/γ' structure based on platinum group metals (PGMs). For instance, alloys using Ir (iridium, 2447°C melting point) as a base metal exhibit temperature capability as high as 1750°C [5]. We are trying to lower the alloy density (~ 22) and also reduce cost by using such techniques as mixing it with Ni-base superalloys. PGMs base refractory superalloys may become a new field of high temperature materials in the future.

4. Conclusions

Ni-base superalloys, especially single crystal (SC) superalloys, and their casting technologies have been the key technologies in jet engine and power generation gas turbine systems. For higher thermal efficiency to reduce CO_2 emission, these technologies are becoming even more important. Alloys beyond Ni-base superalloys are also expected in future, though more research and development work will be needed.

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