Superalloy Takes the Heat Off

A heat-resistant nickel-based alloy developed in Japan is being used in the manufacture of Boeing's new fuel-efficient commercial jet, the 787. Takashi Sasaki spoke with the superalloy's lead developer, ***Dr. Hiroshi Harada***.

“It is said that an increase of 40°C in the temperature that the turbine blades can withstand translates into a 1% improvement in fuel efficiency for commercial passenger jets. While some people may think that a mere 1% improvement is no big deal, such an improvement allows airlines to cut their fuel expenditures by one million U.S. dollars per plane annually. Improved fuel efficiency in commercial jets also contributes to reduced carbon dioxide emissions, which is crucial in environmental terms.”

So says Dr. Hiroshi Harada, managing director of the High Temperature Materials Center at the Japan National Institute for Material Science. The aforementioned turbine blades are components, similar to runners, which serve as the heart of the jet engines. The fan jet engines that are used with passenger and other commercial jets employ the turbine blades to transform the energy of combustion gases at high temperature and pressure into a rotatory force, and to turn the huge fans that are mounted in the forepart of the engines, achieving thrust of approximately 90% in the process. For the past thirty-five years, Dr. Harada has been engaged in research into nickel-based superalloys that are used in the manufacture of these selfsame turbine blades.

TAKASHI SASAKI

Dr. Hiroshi Harada, managing director of the High Temperature Materials Center at the Japan National Institute for Material Science, points to an illustration of the Boeing 787 jet engine.

Commercial jets are most in need of massive amounts of thrust at take-off, when the combustion gases can reach temperatures in excess of 1,600°C. At the same time, currently commercially available turbine blades can withstand maximum temperatures of 1,050°C. The temperature of the engine components is accordingly maintained below this maximum temperature threshold, on the order of 1,050°C or thereabouts, by causing air that is sucked in via the forepart of the engine to pass through interior portions or over the surfaces of the turbine blades. Given, however, that the air that is being sucked into the engine to cause fuel combustion is also being circulated to cool the turbine blades, the efficiency of the combustion process deteriorates as a natural consequence. Hence, increasing the heat resistance of the turbine blades is critical to reduction of the cooling air and to improving the fuel efficiency of commercial jets.

"When heat resistant alloys first became commercially available, which was around 1940, the threshold for heat resistance of these alloys was on the order of 700°C," Dr. Harada says. "This heat resistance threshold was elevated, little by little, by combining nickel with a wide range of other elements, such as aluminum, chromium and titanium, as well as forming single crystal blades, eliminating the boundaries between crystals. There are limits to the properties of such single crystal formation, however, and these limits were effectively reached by the 1990s, when the heat resistance threshold of these superalloys topped out at about 1,050°C. At that point, we turned our attention to the crystal faults causing degradation of these superalloys instead. We discovered that disrupting the homogeneity of the crystal layers by doping them with such rare metals as molybdenum, rhenium and ruthenium counterintuitively caused more crystal faults than before to make a finer network and thus make them inactive, thereby succeeding in significantly increasing the heat resistance threshold of the superalloys."

In 2004, the High Temperature Materials Center applied this technique of refining the network of the crystal faults to develop the world's first nickel-based superalloy with a heat resistance threshold of 1,100°C. As of this writing, the Center is working with Rolls-Royce of England on the final stages of an effort to develop turbine blades capable of withstanding temperatures of 1,150°C by further refining the network in the crystals. Turbine blades made with such generation of superalloys are expected to be used in the engine of the new Boeing 787 high-efficiency mid-sized commercial jet, which will enter service sometime in 2011.

Other Applications

There are great expectations as well that this new generation of superalloy that Dr. Harada and his group have developed may also be used in such applications as the big gas turbines that are used in thermal power plants. A comparison of the efficiency in converting the energy contained in fuels to electricity, vis-à-vis the heat efficiency, of different technologies, gives 42% efficiency of coal-fired power and 52% efficiency or thereabouts for even the most cutting-edge combined cycle thermal power generation, while big gas turbines built with this new generation of superalloy are capable of raising these efficiencies to between 56% and 60%. It is further estimated that replacing just one of Japan's own domestically operated coal-fired power plants with one of these more efficient gas turbine thermal power plants would effectively reduce the amount of carbon dioxide gas emitted by Japan by 0.4% as well. Such an outcome would make for a real ace in the hole when it comes to the matter of reducing greenhouse gas emissions, without a doubt.

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