

Repairing gas turbine engines

by Prof Madeleine du Toit and Dr Warren Miglietti

Dr Warren Miglietti, a recently graduated PhD student in the Department of Materials Science and Metallurgical Engineering, recently developed a new way of repairing wide cracks in turbine components. This method is so successful that it has been accepted by industry and is already used commercially.

A gas turbine engine, whether for an aircraft application or for use in the power generation industry, ingests air from the atmosphere. The air is then compressed by the compressor and mixed with fuel. This mixture is combusted in a combustion chamber, after which the hot gas is expanded through the turbine section, producing thrust. In essence, thermal energy is converted into mechanical energy. Components in the turbine section of a gas turbine engine are generally referred to as blades, nozzles or vanes, with 'blades' referring to rotating components and 'vanes' or 'nozzles' to stationary components.

Blades and vanes are exposed to very high service temperatures and experience severe stresses and strains, oxidation and corrosive attack during service. The blades and vanes are usually manufactured from superalloys, which can operate at 75% and higher of melting point, while retaining adequate mechanical strength for the application. Steels have little mechanical strength and are not used for turbine components.

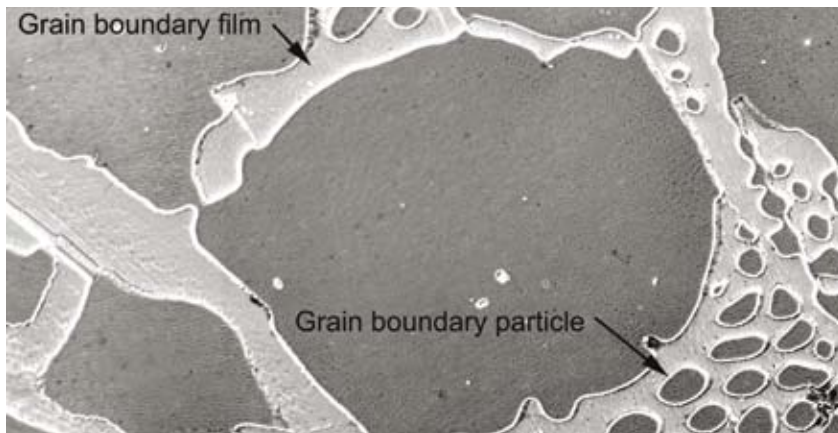
Nickel-base and cobalt-base superalloys are widely used in the manufacture of turbine components. These alloys usually consist of at least 14 major alloying elements, in addition to some minor trace elements. Superalloys exhibit outstanding mechanical strength over the entire operating temperature range in a typical gas turbine engine and maintain good mechanical integrity, including high creep rupture strength over long periods (up to 20 000 hours). These alloys derive their high temperature strength from alloying elements in solid solution in the austenitic matrix, and from the precipitation of hard intermetallic compounds (such as gamma prime, γ') and various carbide phases. Gamma prime, γ' , is an intermetallic compound of composition $\text{Ni}_3(\text{Al}, \text{Ti})$. Primary γ' exhibits a cuboidal structure, whereas

secondary γ' has a more spheroidal morphology. Although the γ' particle size varies, depending on the heat treatment the alloy receives, the typical size of the primary γ' particles is 0.5 μm to 0.8 μm , and that of the secondary γ' phase between 0.1 μm and 0.2 μm . These finely dispersed particles strengthen the material through precipitation hardening.

Turbine vanes or nozzles operating in power generation engines often develop wide cracks during service. When the engine is overhauled, or when cracks propagate to a certain length, new replacement parts either have to be purchased or the damaged components can be repaired at a fraction of the cost. In the past, fusion welding served as the main repair technique for these materials. However, many γ' -strengthened nickel-base super-alloys are difficult to weld successfully.

Through the use of brazing techniques, material can be bonded at the brazing temperature in the presence of a braze filler metal with a melting temperature above 450°C and below the solidification temperature of the parent material. Unlike welding, the parent metal does not melt during the repair process. Since conventional brazing techniques rely on capillary action to draw the molten braze filler metal into the joint gap, these processes are only suitable for repairing narrow cracks (less than 0.25 mm in width). Wide-gap brazing techniques have therefore been developed to repair cracks up to 1 mm in width. These techniques are widely used in applications involving the repair of turbine components for aircraft engines, where wide cracks are seldom encountered.

When wide-gap brazing techniques are applied to repair cracks wider than 1 mm, the repaired areas normally achieve only 60% to 70% of the mechanical properties of the



→ 1. Scanning electron micrograph of the Ni-Hf braze showing the phases identified as γ or austenite (labelled 'grain boundary particle') and Ni_7Hf_2 (labelled 'grain boundary film').

base metal, and tend to degrade prematurely and crack in service. Most commercially available braze alloys for superalloys contain boron as a melting point depressant. When used to repair wide cracks, these boron-alloyed braze alloys tend to form brittle boride-containing intermetallic phases in the braze joint. In order to address the need for a reliable technique suitable for repairing the wide cracks often observed in land-based turbine engine components, Warren Miglietti examined the feasibility of liquid phase diffusion brazing using novel nickel and cobalt base braze alloys containing hafnium (Hf) or zirconium

(Zr) as melting point depressants. Liquid-phase diffusion brazing is a patented process where a fine nickel-base superalloy powder is mixed with the lower melting point braze alloy in the joint. The molten braze alloy sinters the nickel-base superalloy powder particles together to fill the gap and produce a metallurgical bond.

During the course of this project, binary eutectic Ni-Hf and Ni-Zr braze filler metals were produced in powder form and mixed with MarM247 Ni-base superalloy powder in a simulated wide gap joint. An optimised braze cycle was developed and the joints were evaluated using various metallographic

techniques and mechanical tests. Microstructural examination revealed the presence of Hf- or Zr-rich intermetallic phases (Ni_7Hf_2 or Ni_5Zr) in the braze joints (Figure 1). These intermetallic compounds were observed to be significantly softer and more ductile than the brittle boride phases routinely found in commercially available braze alloys with boron as melting point depressant. As a result, the novel wide gap brazed joints displayed excellent mechanical properties (ranging from 80% to 100% of the base metals' properties), with excellent ductility. The low cycle fatigue (LCF) properties of wide gap braze joints performed, using a combination of MarM247 superalloy powder and the novel braze filler metals, were found to be superior to those of the widely used commercial Ni-Cr-B braze filler metals. Within the intermediate strain range where most cracks occur in nozzle segments (0.4% to 0.8% strain), the Ni-Zr and Ni-Hf braze joints displayed 70% and 74%, respectively, of the LCF properties of the base metal, compared to 11% for a boron-containing braze alloy.

The novel braze alloys developed during the course of this investigation are now used commercially and can outperform all existing commercial braze alloys. ➔

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Dr Warren Miglietti graduated recently and the first of three papers on this project published internationally won the Best Paper Award presented at the International Gas Turbine Institute of the American Society for Mechanical Engineers (ASME). This project was sponsored by GE Energy Services in the USA.

