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PROCESS DEVELOPMENT AND MICROSTRUCTURE AND MECHANICAL PROPERTY EVALUATION OF A DUAL MICROSTRUCTURE HEAT TREATED ADVANCED NICKEL DISC ALLOY

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Today's large civil gas turbine engines rely on chemically complex nickel-base superalloys for turbine discs and other critical rotatives. These alloys are typically produced via powder metallurgy before being formed into shape by forging. Through appropriate forging and subsequent heat treatment parameters, components can be produced with grain sizes lying in one of three size ranges, fine grain (ASTM 13-10, 4-11 μm), midi grain (ASTM 10-7, 11-32 μm) or coarse grain (ASTM 7-3, 32-125 μm).

Hot-section gas turbine components, such as turbine discs, experience a large radial thermal and mechanical loading gradient. The bore region of the disc operates at relatively low temperatures and high stresses whilst the rim is subject to less severe mechanical loading at a higher temperature. The rim region requires good creep and fatigue crack growth resistance best achieved in coarse grain microstructures, whereas the bore region requires maximum tensile and fatigue strength optimised by fine grain microstructures.

Components produced with a single microstructure throughout inevitably result in a trade-off in design and/or component life. Therefore, it is desirable to produce a dual-microstructure component with the grain size optimised at different locations, based upon the likely in-service requirements. Depending upon the starting microstructure, this may manifest itself in either an increased temperature capability or an increase in allowable rotational speed.

In recent years a number of methods for the production of dual-microstructure components have been reported.[1,2,3,4] The techniques that have been developed by individual parties are all subtly different in terms of approach and each have their respective merits and limitations. However all of the methods developed rely upon the same basic principle of maintaining a temperature gradient throughout the component during the solution heat treatment. In fine grain regions, grain growth is restricted by Zener pining by primary γ'. Solution heat treating a portion of the component above the γ' solvus removes the primary γ' and allows grain growth. A uniform coarse grain structure can be produced if stored energy within the grains is minimised through appropriate thermo-mechanical working.

This paper concentrates on Rolls-Royce's efforts in developing an industrially robust, production capable process and presents detailed results for a number of components that have been produced to date in the high temperature nickel disc alloy, RR1000.[5] This paper will focus on two different turbine disc geometries that have been produced with a dual-microstructure as part of the development programme, Figure 1.

The method developed utilises sets of thermal insulators located at key locations on the component, for example the bore of a turbine disc, whilst other areas are left exposed. When the assembly is placed into a standard production furnace at a temperature above the γ' solvus, grain coarsening occurs in the exposed areas. Process modelling, careful selection of insulation material, furnace parameters and geometrical information are all combined to define an appropriate heat treatment. This allows grain coarsening in the rim, whilst the bore temperature is maintained close to the subsolvus solution temperature.

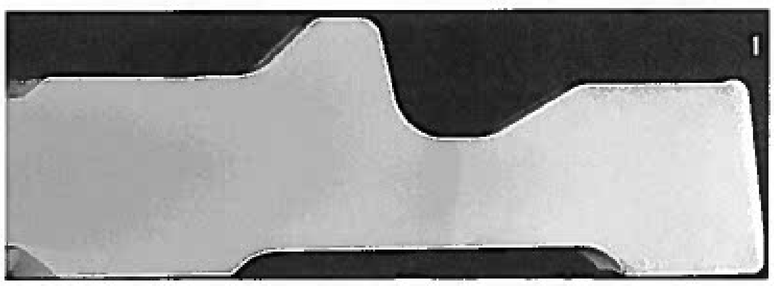
This paper will focus on the microstructural and mechanical property characterisation of two dual-microstructure components with very different geometries. The microstructures have been extensively characterised in terms of grain size, boundary serration, γ' size, morphology and volume fraction. The results of which have been linked to thermal history. Results of mechanical property testing will be included in the paper and discussed with reference to the thermal history and microstructure.

In developing and evaluating dual-microstructure components, it is vital to understand the transition region between the fine and coarse grain microstructures. This work has studied the effect of a range of parameters pertinent to the transition region. These include factors such as the location, width, shape and angle of the region. These are in turn linked to the alloy chemistry in terms of grain growth and γ' dissolution kinetics and the effect these have on the microstructure of this region along with the resultant mechanical properties.

Figure 2 shows how some aspects of the microstructure (grain size and γ' volume fraction) vary with radial position. Irrespective of the differences in component geometry, the transition region width is the same and grain growth is associated with a minimum level of primary γ' above which no grain growth occurs.

Figure 3 shows the effect of microstructure on the tensile properties and creep life. As expected the increased grain size results in a reduction in the proof strength, but increased time to rupture. The coarse grain RR1000 offers a greater than ten fold increase in stress rupture life compared to the fine grain. This is due partly to the increased grain size and partly to the way in which dislocations interact with the secondary and tertiary γ'. This has been observed using transmission electron microscopy on interrupted creep samples and discussed in detail in the paper. This paper also discusses the variation in γ-γ' misfit (as measured using neutron diffraction) for the different microstructures within the component and links this to the γ' distributions observed.

In summary, this paper will show that Rolls-Royce has developed a production capable and industrially robust process for the production of dual-microstructure components. This has been possible through the judicial use of process modelling, full-scale validation trials, detailed microstructural assessment through a variety of destructive and non-destructive methods and mechanical property evaluation. This paper reports the fundamental underlying relationships between thermal history and microstructural evolution and how these directly influence mechanical properties. This work has enabled a deeper understanding of the opportunities and difficulties faced in the application of this technique for producing dual microstructures, from the research laboratory to production.



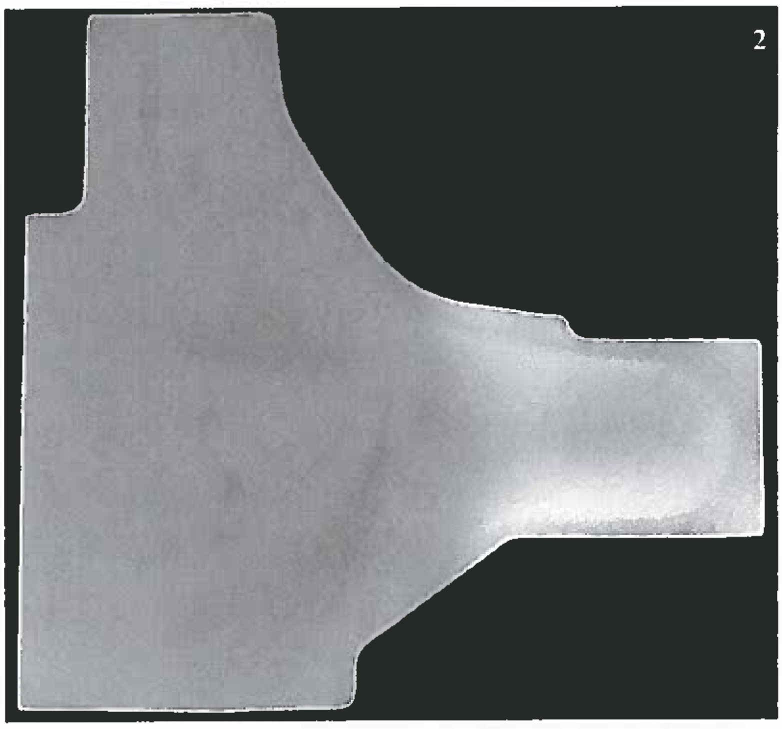


Figure 1 Macro-slices of two components produced with a dual-microstructure
(the fine grain region is matt grey in colour and the coarse grain region appears as lighter grey)

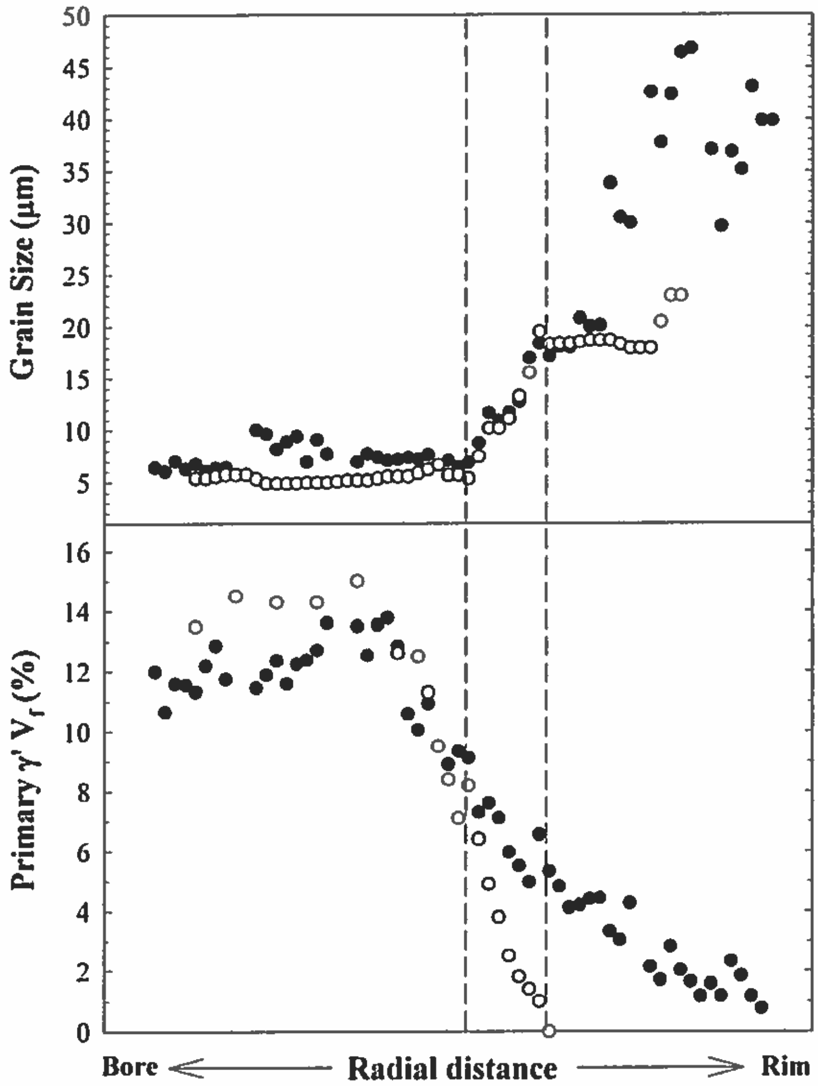


Figure 2 Grain size and Primary γ' volume fraction as a function of radial distance in two dual-microstructure components shown in Figure 1. The closed circles are component 1, the open circles are component 2. The dotted lines represent the transition region, based upon grain size.

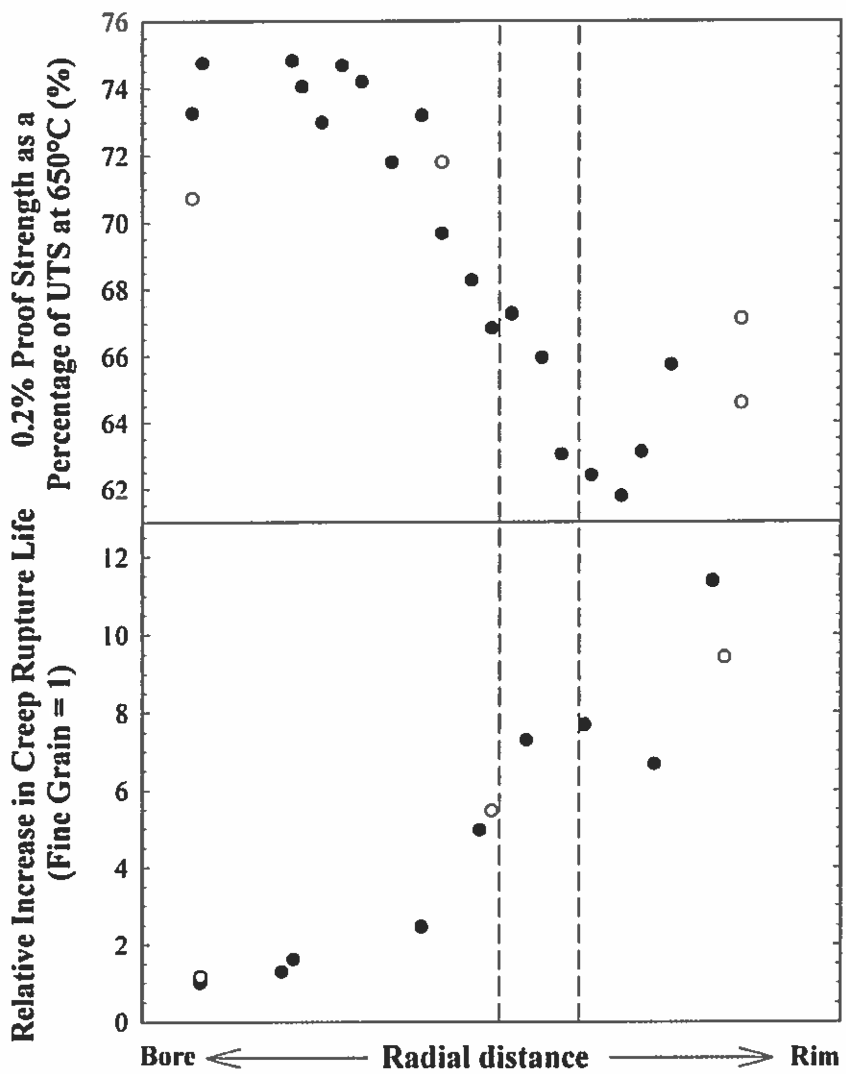


Figure 3 0.2% proof strength at 650°C as a percentage of UTS and creep rupture life (750°C, 460MPa) as a function of radial distance in two dual-microstructure components shown in Figure 1. The closed circles are component 1, the open circles are component 2. The dotted lines represent the transition region, based upon grain size.

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