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Effects of blade surface treatments in tip–shroud abradable contacts

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ABSTRACT

In aero engines a thermally sprayed abradable lining is applied to the inside of the casing in order to provide a seal around the tips of the compressor blades. As engines become more efficient the materials used must be able to endure higher temperatures and moving parts must be made lighter. This combination is not currently possible in late stages of the compressor as hard abradable materials can cause titanium blades to wear excessively. One solution to this is to add a surface treatment to the blade tips.

Two surface treatments have been investigated, firstly cubic boron nitride (cBN) grits are bonded to the tip of the blade by electroplating. Secondly blades are coated in Cr(Al)N by cathodic arc deposition. The performance of these surface treatments is investigated on a test rig capable of monitoring the blade length, rub forces and abradable temperature during the test. Additional tests are performed against stepped coatings giving insight into the condition of the blade and abradable during the test. S.E.M., E.D.S., X.R.F., profilometry and wear debris have been used to characterise the wear mechanisms produced during the tests.

Grit (cBN) tipped blades load with abradable material after a period of efficient cutting causing grit pull out and fracture. Flat Cr(Al)N coated blades failed due to thermal damage to the coating caused by adhesion of abradable material onto the Cr(Al)N coating, while chamfered blades cut efficiently at low incursion rates.

1. Introduction

Abradable materials are composite materials which are often used to maintain air seals in aero engines and other turbo machinery [1–3]. When used in aero engine compressors they should wear in preference to the blades that contact them with low forces in the rub, leaving smooth surfaces to reduce drag. However they must not degrade in the heat and pressure of the engine or erode excessively if the engine ingests water for example [4]. This combination of properties is normally pursued by thermally spraying a composite lining material which consists of a metal matrix and a non-metal dislocator phase along with some porosity [5]. However ex-service components and numerous experimental studies have shown the potential for excessive blade wear [1–3].

Works on abradable materials largely fall into four categories, firstly much work has been done on characterising these materials in laboratory tests. Methods for the measurement of bulk mechanical properties [6–8], erosion resistance [9] and abradability [10] have been suggested and form an important measure used in the development of new abradable materials. Experimental investigations have used scaled test platforms to test these materials in situations similar to those they will face in service, these tests typically cover a variety of blade speeds and rates of incursion of the blade into the abradable lining. Other works have attempted to thermally model the rub using bulk properties for the materials, these models are normally validated using data from a test platform [11]. Lastly some attempts have been made to model the microstructure of the abradable materials using an image based finite element approach although these works are largely unverified by experimental findings [12,13].

Xiao and Matthews [10] compared results from simple scratch tests with those from a full scale test rig and concluded that these results showed good agreement. However more recent tests [1] and models [11] have indicated the importance of heat generation and dissipation during continuously rubbing systems, additionally further characterisation of rubs has shown significant variation of behaviours at different incursion rates and to a lesser extent blade speeds [2,3]. Due to their porosity it has also been found that the properties of these materials can locally change during the rub due to compaction [1,14].

Further experiments on test rigs have focused on characterising rubs either by examining a small number of rubs or attempting to obtain steady state conditions during a test which includes hundreds or thousands of individual rubs. Padova et al. [15,16] investigated rubs with a spin pit facility capable of measuring

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forces during a single strike concluding that the abradable linings have the greatest effect when the blade is rubbing within the initial surface roughness produced during the thermal spray procedure, they also noted the possibility of low blade speeds allowing for axial deformation of the blades during the rub due to the loss of stiffness produced by high centrifugal forces.

Taylor et al. [14] investigated the In-718 vs NiCrAl–Bentonite rub, which is the subject of this work, on an experimental rig capable of recreating the speeds found in in-service engines. Each test consisted of hundreds of individual rubs and the forces in the rub were measured with a dynamometer attached to the abradable sample. They observed significant blade wear in rubs where the abradable had become compacted and lost some of its initial porosity near the rubbing surface. The changes in material properties found by Taylor et al. [14] for this abradable material and high temperatures measured in previous scaled test rig experiments [1] suggest that a scaled test platform is the most accurate means of assessment of new material combinations in this case.

The potential for research into these interactions is vast due to the many different types of abradable materials available and the variation possible within each by manipulation of the spraying process parameters. Crucially experimental tests that have found compaction in the abradable materials indicate that these materials may not be directly comparable and a single rubbing mechanism is unlikely to be found that can generally describe all of the possible interactions [1,14].

As aero engines are pushed for higher efficiency and lower weight losses associated with blade wear are of increasing importance. With the current move to single piece bladed discs surface treatments at the blade tip could also allow lighter materials to be used without the risk of blade wear or titanium fires. As an attempt to limit the potential for damage to the blades, this work will investigate the effect of the addition of two different surface treatments to the tip of the blade. Firstly abrasive grains of cBN have been added the effects of changes in size and type of grain have been investigated. Secondly a thin hard coating of Cr (Al)N has been added and the effect of changing the shape of the blade tip has been investigated.

2. Methodology

2.1. Abradables

The tests presented in this work were performed with NiCrAl–Bentonite clad coating samples, these were rubbed against Inconel 718 blade samples. The coating is produced by flame spraying a powder consisting of roughly spherical 120–135 μ diameter bentonite particles which have been chemically clad with a thin layer of NiCrAl (Ni 4Cr 4Al) [17] this powder is commercially available as Sultzer Metco 314. The coating has been sprayed in a 60 mm square patch onto 80 mm square stainless steel backing plates as shown in Fig. 1a. Before testing the coatings were aged in air at 750 °C for 100 h. A polished cross section of the abradable material used was obtained using vacuum impregnation (buehler epothin 2), further coating sections, discussed below, have been obtained using the same method. The image obtained by backscattered electrons is shown in Fig. 1b, S.E.M. was used to limit the effect of crack opening during metallographic preparation [18]. Eight adjacent backscattered micrographs were taken across the entire sample, these were analysed by automatic selection of two threshold values based on the image histogram [19] this method was adapted from Deshpande et al. [18]. The results of the image analysis indicated the coating is composed of 32.3%vol (stdev=1.77%) porosity, 29.0% (stdev=0.97%) bentonite and 38.7% (stdev=1.06%) metal phase. Variations in coating structure and composition can be introduced by the flame spraying process, because of this, coating samples used were sprayed in a single batch. The mean superficial hardness of these coating samples as given by the R15Y scale is 23.1 with a standard deviation of 9.3 across 100 measurements taken on 10 different samples. The hardness values of the coating samples were compared using a single factor ANOVA the result was not significant $f(1.98)=1.40$ indicating that there is not significant variation between the coating samples.

2.2. Blade surface treatments

Blade specimens have been cut from 2 mm thick Inconel 718 which had been vacuum heat treated for 8 h at 700 °C. The blade specimens are 20 mm wide and 25 mm long with a shape shown in Fig. 2a. These blades were prepared with two different surface treatments and are contrasted to a control set which had no surface treatment. Two sets of blades were coated with a multilayer Cr(Al)N coating using cathodic arc deposition, a coating of thickness 9.6 μm was measured with a microhardness of 24 GPa the appearance of this coating is shown below in Fig. 2g. One set of these blades was prepared with a flat tip while another set was given a 30° chamfer on the tip to resemble a cutting tool, these are shown in Fig. 2e and f respectively.

Further sets of blades were tipped with a coating of electrolytically deposited nickel partially covering grains of cBN. This was created by first holding the samples in a PTFE mixture before masking off the entire blade apart from the tip using Kwiky-mask

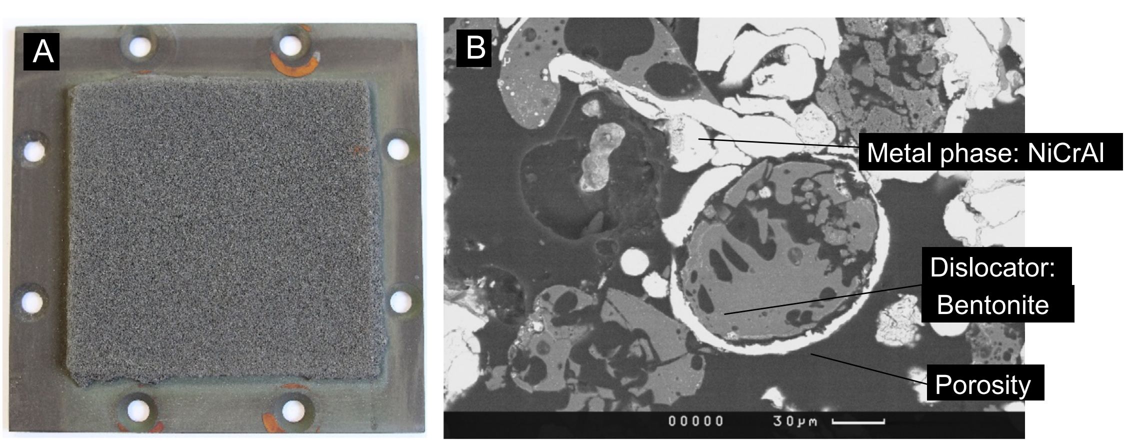

Fig. 1. (a and b) Showing a coating sample before testing and a backscattered electron image of the abradable lining material's microstructure.