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Effects of blade material characteristics on the high-speed rubbing behavior between Al-hBN abradable seal coatings and blades

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ABSTRACT

Abradable seal coatings have been widely used in aero engines to reduce gas path clearance. Research has been performed to evaluate the abradability of the seal coating. In addition, the high-speed rubbing test rig has been employed to simulate the interaction between the seal coating and blade. However, almost all previous studies tested blades made of one type of material. In real engines, the blade material for a seal coating is changeable. In this work, blades made of different titanium alloys were tested and rubbed against the same Al-hBN seal coating. Macro-morphology and micro-morphology observations with scanning electron microscopy (SEM) were employed to examine the wear behavior of the blade-coating couple. The results indicated that the Ti6Al4V blade exhibited the most severe coating adhesions and almost no blade wear; the Ti-8Al-1Mo-1V blade experienced less coating adhesions; and the Ti-5Al-2Sn-2Zr-4Cr-4Mo blade exhibited the least coating adhesions. The mechanical strengths at room and high temperatures and the rub performances during the single pendulum scratch test were checked to find the relationship between the mechanical properties and high-speed rub performances. Unfortunately, high mechanical strength did not appear to guarantee the absence of blade wear, and the thermal properties of the different materials blades were identified as the main reason for the different wear behaviors.

1. Introduction

Abradable seal coatings are used in aero engines to reduce the clearance between the rotating and stationary parts. However, rubbing between the rotating blade and seal coating frequently occur. When an abradable seal coating is sprayed onto the case, the coating wears preferentially to the blade during rubbing, and the gas path clearance is maintained at the smallest scale without blade wear. Lots of researches have been carried out to study the wear behavior during the rubbing between the blade and the seal coating.

Fois [1] investigated the material adhesive transfer between the Al-hBN coating and the Ti-alloy blade. Xuan [2] performed an evaluation on the abradability of an AlSi-polyester seal coating at different test conditions. Gao [3] compared the tribological behaviors of two different seal coatings rubbed by the same blade and discovered that the square root ratio of the thermal diffusivity between the blade and the coating could be taken as an indicator to predict the blade wear status and the damage mechanism. Watson [4] focused on the effects of blade surface treatments on the wear mechanisms during high-speed rubbing with a seal coating. Recently, Fois [5] incorporated the coating material properties and found that the soft coating generated blade wear, and the hard coating adhered to the blade at a low incursion rate. Xue [6,7] characterized the wear behaviors of different blade-coating couples and recognized frictional heat as a key factor in high-speed rubbing wear. Romain [8] built a test rig to estimate the blade–seal interacting force from indirect measurements and the obtained results were found to be in phase with the wear profile of the abradable coating. Irissou [9] studied the microstructural and tribological characterizations of plasma-sprayed CoNiCrAlY-BN abradable coating. It was found that coating hardness needed to be lower than 70 and 50 HR15Y for slow and fast blade incursion rate conditions respectively to obtain an optimal abradability performance. Bérenger [10] carried out a phenomenological model of the abradable coating wear and found that wear results are significantly influenced by abradable coating material properties. A. Millecamps [11] carried out experimental investigations of blade-casing interactions and thought that the thermal-mechanical phenomena at the contact had to be considered. A. Dadouche [12] studied the effect of temperature on the rub performance of abradable coatings and found that testing abradables at high temperature affects the rub characteristics. As can be seen, high-speed rubbing tests have been performed to evaluate the abradability of the seal coating and to examine the wear behavior of the friction pair.

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It is essential that an abradable seal coating not damage the opposite blade or adhere to it. However, given that the material of a corresponding blade with a certain coating is not changeable, published works almost never consider the blade material. In fact, an abradable seal coating can be sprayed onto the case with blades of different materials. Though this mildly alters the blade material, the impact on the wear behavior requires further examination to characterize blade material selection and reveal the effects of the blade material properties on wear behaviors.

In this work, a commercial Al-hBN seal coating used in the compressor was rubbed by three Ti-alloy blades with different compositions at a high linear speed to represent the actual rotating speed in an aero engine. The resulting different wear behaviors were related to the different material properties.

2. Materials and methods

2.1. Materials

Three titanium alloy blades, namely Ti-6Al-4V, Ti-8Al-1Mo-1V, and Ti-5Al-2Sn-2Zr-4Cr-4Mo, were chosen to rub against an Al-hBN coating. All three different blade materials are frequently used in the compressor of the aero engine to make blades, wheels and compressor stages etc. In most of times, the employed seal coating couple is the Al-hBN coating. Their main chemical compositions are shown in Table 1 (from CINDAS aerospace structural metals database), of which the Ti17 blade exhibited a high molybdenum content. Ti64, Ti811, and Ti17 are the designations for Ti-6Al-4V, Ti-8Al-1Mo-1V, and Ti-5Al-2Sn-2Zr-4Cr-4Mo, respectively, and will be used for convenience in the following paragraphs.

All three titanium alloys were annealed. Their metallographic structures are shown in Fig. 1. The Ti64 and Ti811 samples exhibit a duplex microstructure but different α-phase shapes given that Ti811 exhibits a secondary α-phase. The Ti17 sample has a Widmanstätten microstructure as well as secondary α laths in the main position.

Al-hBN coatings are widely used as an abradable seal coating in the compressor of aero engines. In general, spray powders have a nominal compositions of 75 wt% Al, 20 wt% BN, and 5 wt% Na_2SiO_3 binder. Air plasma is employed in the coating spray, of which the detailed spray parameters are presented in reference [7]. The dimensions of the blade and seal coating samples can also be found in the reference [7]. The HR15Y hardness of the sprayed coating samples are tested and samples with a hardness around 50 are used in the rubbing test. The final coating section morphology is shown in Fig. 2. Pores can assist the coating to be easily wiped off. Solid lubrication hBN intends to reduce the adhesion preference and decrease friction. The rest is metal matrix aluminum, which enhances the strength of the coating.

Table 1
Main chemical compositions of the three titanium alloys (wt%).

	Al	V	Cr	Zr	Mo	Sn	Ti
Ti64	5.60–6.30	3.60–4.40	–	–	–	–	Bal.
Ti811	7.50–8.50	0.75–1.25	–	–	0.75–1.25	–	Bal.
Ti17	4.50–5.50	–	3.50–4.50	1.50–2.50	3.50–4.50	1.50–2.50	Bal.

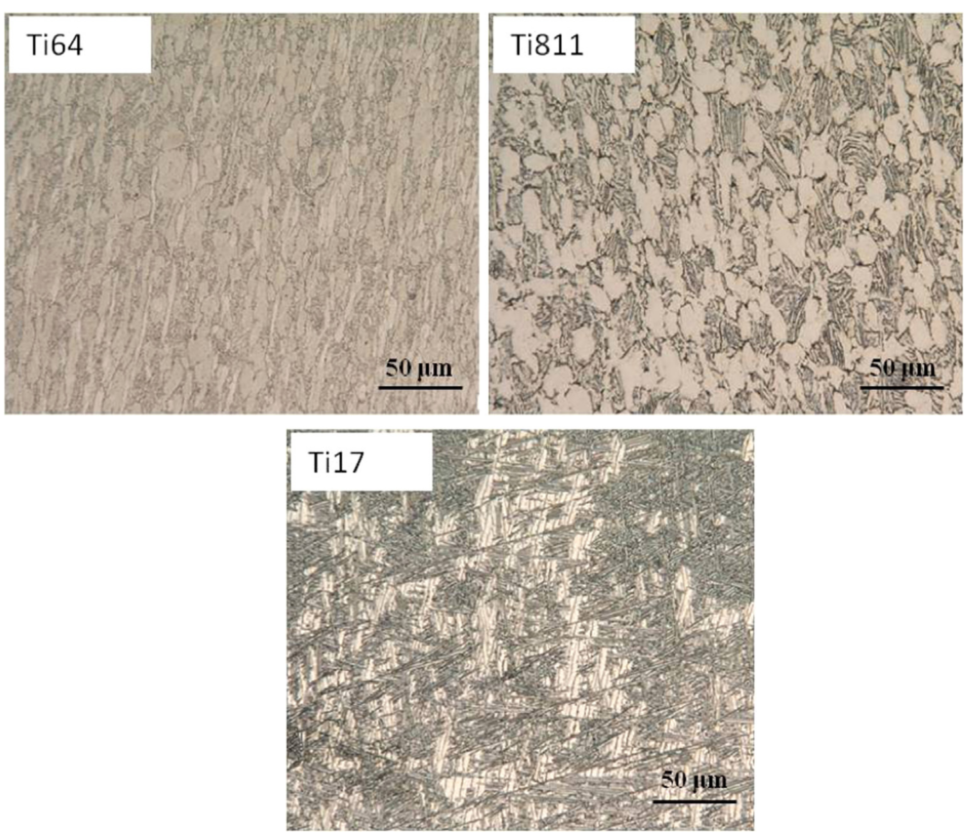

Fig. 1. Metallographic pictures of the three titanium alloys.