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RUB TOLERANCE EVALUATION OF TWO SINTERED NiCrAl GAS PATH SEAL MATERIALS

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INTRODUCTION

The performance of gas turbine engines is sensitive to the operating clearances between the blade tips and gas path seals. Of particular significance to engine operation is the clearance maintained between high pressure turbine blade tips and the turbine seal. Here, each percent increase in clearance gap to blade height ratio typically results in approximately a 0.7 percent decrease in specific fuel consumption.

Gas path seal materials applied to high temperature engine positions must resist three sources of component deterioration that ultimately lead to increased clearances. First, the material must be such as to withstand the temperature and thermal cycling associated with the environment. Oxidation, other corrosive mechanisms, and thermal fatigue can lead to loss of material properties desirable in a gas path seal. Second, the seal must be rub tolerant so that it rather than the blade tips will undergo wear in the event of a rub interaction. It has been observed that some seal materials tend to harden during thermal exposure, becoming less rub tolerant as they age. Third, the gas path seal has to resist surface recession due to erosion, which would obviously lead to increased seal clearances.

The purpose of this study is to assess the rub tolerance of one type of gas path seal material considered suitable for high temperature applications, as might be encountered in some turbine or advanced high pressure compressor applications. Sintered NiCrAl, prepared to two different strength levels, was subjected to rub interactions against simulated blade tips at two levels of rub speed and two incursion rates. Frictional and radial loads were measured, blade tip wear was estimated, and microscopic studies of the rub surfaces and rub debris were undertaken.

APPARATUS

Rub evaluations were conducted on the apparatus shown in figure 1. Twelve simulated blade tips were rotated at speeds up to 10 000 rpm (associated rub velocities of up to 115 m/sec) in this investigation. Drive power was provided by a 3 hp induction motor coupled to a continuous speed variator, permitting control of the rub speed. All tests were conducted under room temperature ambient conditions.

The gas path seal material sample was supported on a slideway feed mechanism so that it could be driven radially into the rotating blade tips. Radial incursion rates of 25×10^{-6} M/sec and 250×10^{-6} M/sec were employed.

During a rub interaction, the rotating speed was held constant, radial loads and frictional torque were continuously recorded, and the blade-tip temperature was monitored and recorded by means of an infrared pyrometer. Note that the pyrometer position is 90^{0} from the rub position. The pyrometer signal was not interpretted as indicating actual blade tip temperatures during rub. Rather, the signal from the pyrometer provided an indication of the number of blade tips simultaneously participating in the rub interaction, and relative degree of frictional heat input to the blade tips.

Wear debris generated during the rub interaction was collected on the fixture indicated in figure 1. Debris particles impinged on a strip of sticky tape, thus being captured for subsequent examination.

Rub interaction depths were monitored during a test by means of a dial gage indicator, showing the relative radial motion of the feed slideway carriage with respect to the rotating disk. Interaction depths could be controlled to within 25 micrometers (1 mil) of the desired depth.

PROCEDURE

Prior to testing, the blade tips were ground so that the tip surface was as nearly parallel as possible to the supporting root. The tip surface finish was about 0.5×10^{-6} M (20 μ-in. rms) after conditioning. The tips were then cleaned with ethanol, and the height of each simulated blade tip was measured. Heights were maintained to within ±4 micrometers.

Selected gas path seal material samples were epoxy bonded to a mild steel backing which was screwed onto a combination specimen support/cantilever load cell. The blade tips were brought to the desired rotating speed, the selected incursion rate was set, and the rub interaction was initiated. In these tests the interaction was continued to a 750 micrometer (30 mil) depth.

Rubbing speeds of 57 M/sec and 115 M/sec were selected for this study. Under 57 M/sec conditions, tests were conducted at incursion rates of 25 micrometers/second and 250 micrometers/second, and under 115 M/sec conditions only the 25 micrometer per second incursion rate was employed.

Post-test evaluation included blade tip and abradable material rub surface microscopic examination, and wear debris examination. A measure of the wear (or transfer) to the blade tips was obtained by observing specimen focus position changes over the tip surface during microscopic examination.

MATERIALS

The blade tip specimens used in this investigation were made of AM 355 steel, the nominal composition of which is Fe-15.5 percent Cr, 4.5 percent Ni, 3 percent Mo, machined from AMS 5594 stock.

Two variations of sintered NiCrAl seal material were evaluated.

Both variations were about 40 percent dense with a particle size of about 150 to 200 micrometers and a typical pore size of 200 to 300 micrometers. One variation, to be designated "Material A" was sintered to an approximate tensile strength of 15.5 N/mm^2 (2100 psi); the other variation, to be designated "Material B" was sintered to an approximate tensile strength of 17 N/mm^2 (2400 psi). These two sintered NiCrAl materials are considered to be candidates for high temperature gas path seal applications (temperatures up to 1800° to 1900° F), as might be found in some turbine or advanced compressor locations.

RESULTS AND DISCUSSION

The results of the friction and wear studies performed on materials A and B are presented in figure 2, along with results for current "state-of-the-art" gas path seal materials. The state-of-the-art materials are comparatively low temperature types, intended for compressor seal applications. They are included as a basis of reference, however, because of the widespread use and data base associated with them.

Friction forces measured for the A and B series materials at a 115 M/sec rub speed were significantly lower than those measured at 57 M/sec. Corresponding "friction coefficients," (friction was very unsteady) were less than 0.1 at the high speed and between 0.15 and 0.2 at the low speed. Increasing the incursion rate from 25 micrometers per second to 250 micrometers per second had only a minimal effect on measured frictional and radial loads. However, under high incursion rate conditions contact was much more continuous than under low incursion rate conditions. During a given revolution of the disk, pyrometer data revealed that virtually all of the blade tips had undergone heavy interaction when the incursion rate was 250 micrometers per second. Rubbing contact was fairly constant throughout the 750 micrometer incursion, with the maximum loads, indicated in figure 2, encountered toward the end of the 250 micrometer per second incursion rate tests. At 25 micrometers per second incursion rate, typically 2 or 3 blade tips came into heavy contact during a typical revolution of the disk. Rubbing contact occurred in a series of distinct events with associated maximum loads indicated in figure 2. Zero load (radial and frictional) was measured between the events. Each event was 0.1 to 0.5 second in duration, with 6 or 7 events occurring during the 750 micrometer incursion. With the exception of the high incursion rate test, frictional and radial loads for the B material (high strength) were 20 to 50 percent higher than those for the A series.

Frictional forces and radial loads for the state of the art materials were generally 1/4 to 1/3 as high as for the A and B series materials. Friction coefficients of about 0.15 were measured.

Wear measurements, also summarized in figure 2, indicated less than 10 micrometers of wear to the blade tip leading edges after rub interactions with the A and B materials at 57 M/sec rotating speed under a 25 micrometer per second incursion rate. At the 250 micrometer per second incursion rate, however, (57 M/sec rotating speed), 30 to 40 micrometers of wear was measured on all blade tip leading edges. Also, regions of local transfer of seal material to the blade tip were observed. Wear was seen to vary considerably from blade tip to blade tip after rub interactions at 115 M/sec rotating speed (25 μm incursion rate); under these conditions, the maximum wear was about 70 micrometers, the minimum being 30 to 40 micrometers. Fifty to 60 micrometers of leading edge wear was taken as being typical for the 115 M/sec rub speed, applicable to both materials A and B.

Figure 3 includes micrographs indicating the type of wear seen on the blade tip leading edges. It is readily seen that material removal extends to about 750 micrometers (30 mils) behind the leading edge. It also appears that wear took place by a mechanism of plastic displacement, or plowing of the tip material.

The appearance of both the A and B seal material rub surfaces suggested that some smearing had occurred. Microscopic examination, however, revealed that the smearing rarely extended over areas of more than a few particles (fig. 4(a)), never approaching a continuously smeared condition. Figure 4(b), typical of both A and B material rub surfaces after all interactions, reveals some areas of "pull-out" where seal material was removed to a depth greater than the interaction depth. These holes or pull-out regions are a couple of mils deep, and may have some significance pertaining to seal performance.

Debris from A and B series materials, shown in figure 5, consists of wear particles in two distinct size range classifications. Debris particles comprising the larger size classification are made up of one or more (often several) sintered material particles. Very few of these larger particles show any evidence of rub surface distress, suggesting that they may have been generated by secondary interactions with particles directly knocked-off by the blade tips. This may be visualized as a self-scouring type mechanism, and is consistent with the "pull-out" holes seen on the rub surfaces.

The very fine particles are thought to have been generated directly by the rub process. X-ray energy dispersion analysis indicates that the small particles consist of both the NiCrAl from which the seal material is made, and the AM 355 blade tip material.

SUMMARY

The results of this investigation indicate the following:

1. Frictional and radial loads of the high strength seal material were 20 to 50 percent higher than those measured for the lower strength material. No significant differences in blade tip wear were observed for the two NiCrAl seal materials.

2. Wear of the NiCrAl seal materials was characterized by material removal to a depth greater than the incursion depth, indicating possible scouring effects or secondary particle interactions.

3. Wear to the blade tips was by a plowing mechanism.

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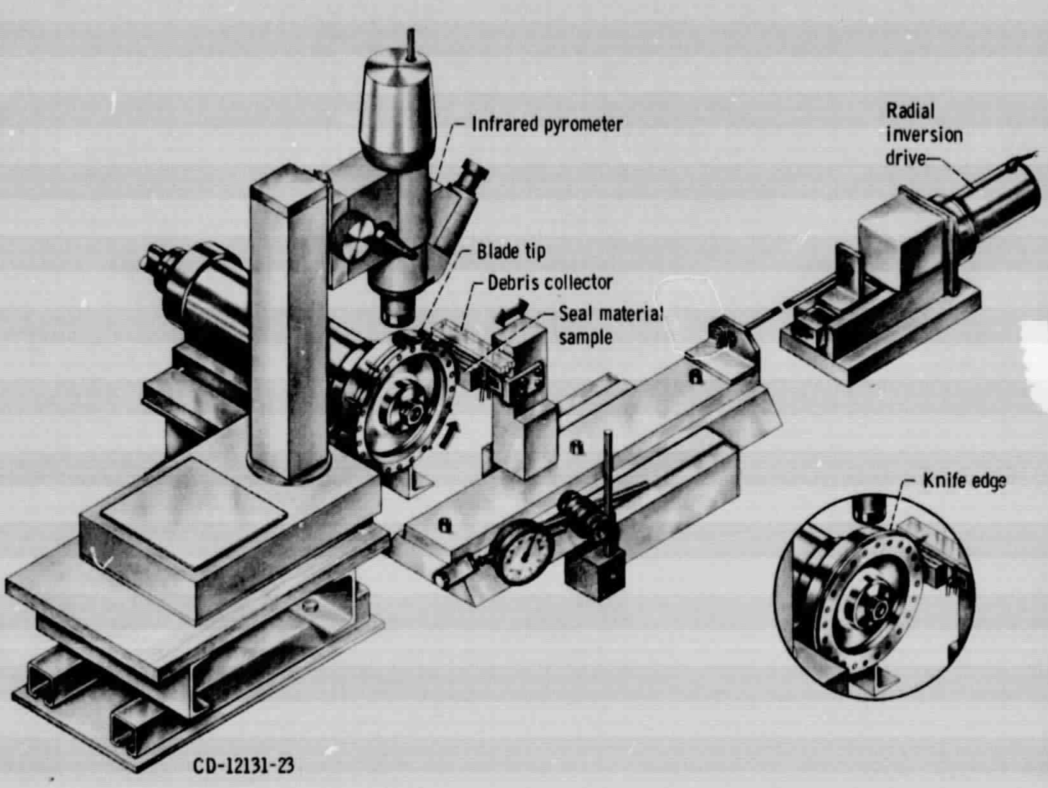
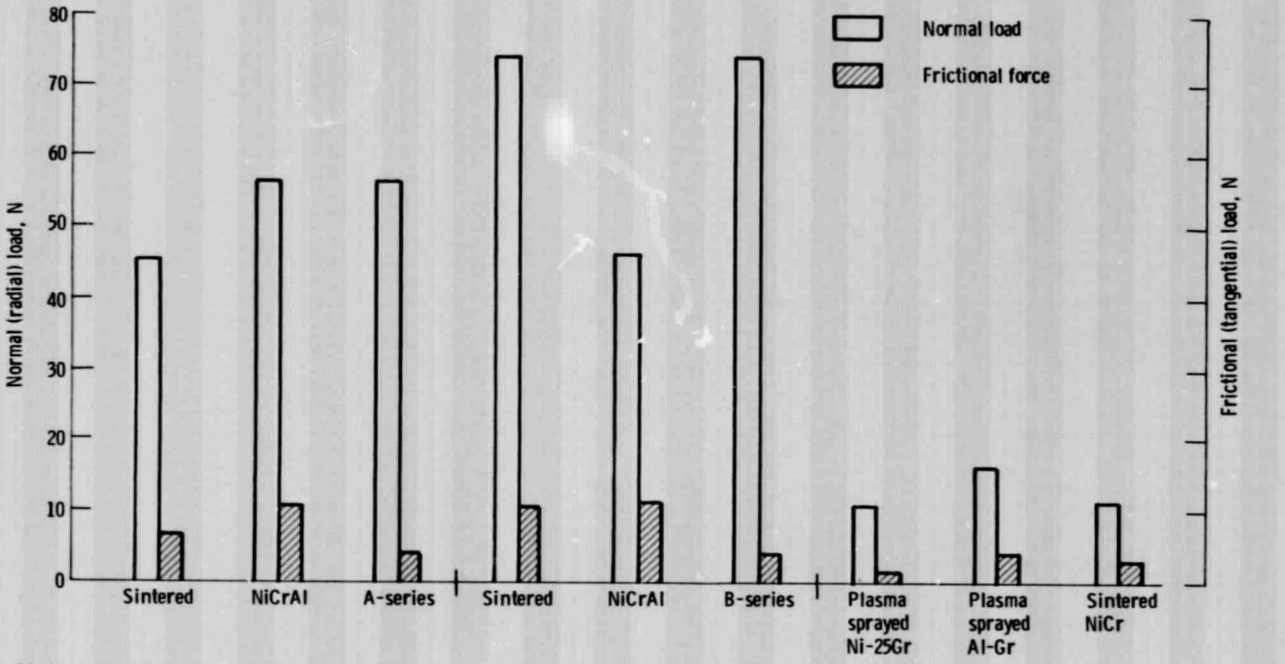


Figure 1. - Test apparatus.



	Sintered	NiCrAl	A-series	Sintered	NiCrAl	B-series	Plasma sprayed Ni-25Gr	Plasma sprayed Al-Gr	Sintered NiCr
Rub speed (m/sec)	57	57	115	57	57	115	57	57	57
Incursion rate (µm/sec)	25.4	254	25.4	25.4	254	25.4	25.4	25.4	25.4
Blade wear (µm)	0-10	30-40	40-60	0-10	30-40	50-60	0	0	0
Transfer (µm)	0	10-20	0	0	20-30	0	0	0	40-60

Figure 2. - Friction and wear results for sintered NiCrAl seal materials subjected to rub interactions with AM-355 blade tips. Incursion depth was 750 micrometers.

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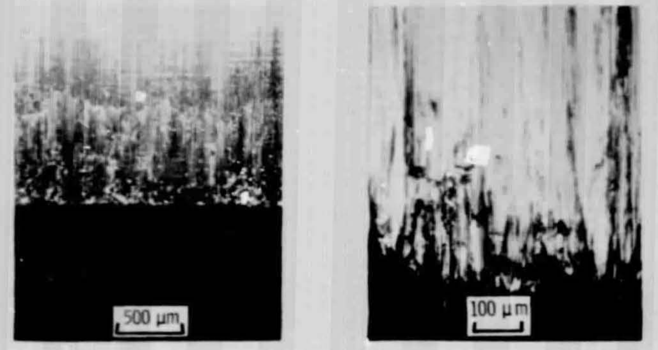
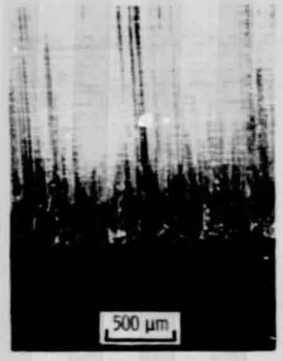


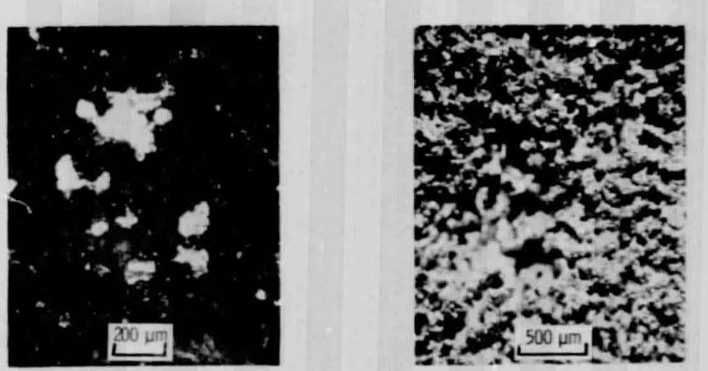
(a) 115 M/sec rotating speed; 25 micrometers per second incursion rate; X35.

(b) 115 M/sec rotating speed; 25 micrometers per second incursion rate, X127.



(c) 57 M/sec rotating speed; 250 micrometers per second incursion rate; X35.

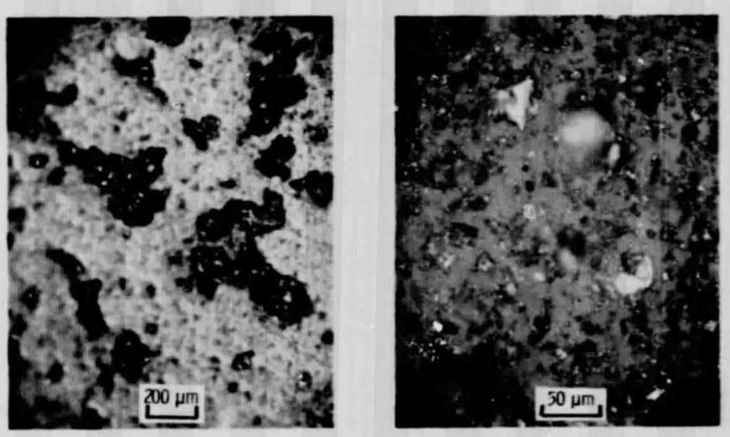
Figure 3. - Photomicrographs illustrating blade tip leading edge wear resulting from rub interactions between AM 355 blade tips and sintered NiCrAlY.



(a) Rub surface showing smeared areas; X65.

(b) Rub surface showing areas of "pull-out"; X35.

Figure 4. - Photomicrographs of sintered NiCrAlY rub surfaces after interaction with AM 355 blade tips.



(a) Large particle size debris; X65. X65.

(b) Fine particle size debris; X327.

Figure 5. - Wear debris collected after rub interaction between AM 355 blade tips and sintered NiCrAlY seal material type A.