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TRIBOLOGICAL EVALUATION OF AN $\text{Al}_2\text{O}_3\text{-SiO}_2$ CERAMIC FIBER CANDIDATE FOR HIGH TEMPERATURE SLIDING SEALS

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SUMMARY

A test program to determine the relative sliding durability of an alumina-silica candidate ceramic fiber for high temperature sliding seal applications is described. This work represents the first reporting of the sliding durability of this material system. Pin-on-disk tests were used to evaluate the potential seal material by sliding a tow or bundle of the candidate ceramic fiber against a superalloy test disk. Friction was measured during the tests and fiber wear, indicated by the extent of fibers broken in the tow or bundle, was measured at the end of each test. Test variables studied included ambient temperatures from 25 to 900 °C, loads from 1.3 to 21.2 N, and sliding velocities from 0.025 to 0.25 m/sec. In addition, the effects of fiber diameter, elastic modulus and a pretest fiber heat treatment on friction and wear were measured.

In most cases, wear increased with test temperature. Friction ranged from about 0.36 at 500 °C and low velocity (0.025 m/sec) to over 1.1 at 900 °C and high velocity (0.25 m/sec). The pretest fiber heat treatment, which caused significant durability reductions for alumina-boria-silica ceramic fibers tested previously, had little effect on the alumina-silica fibers tested here. These results indicate that the alumina-silica ($\text{Al}_2\text{O}_3\text{-SiO}_2$) fiber is a good candidate material system for high temperature sliding seal applications.

INTRODUCTION

Sliding seals are needed to meet the needs of advanced propulsion systems such as the new generation of launch vehicles and especially hypersonic vehicles such as NASP, illustrated in figure 1. In these applications, engine and airframe components must be sealed from hot engine combustion gases and the frictional heat of the atmosphere to prevent damage (ref. 1). New materials like metal and ceramic matrix composites are currently under development for these applications (ref. 2). Since new technologies and approaches for control surface seals will be needed to meet future applications, a research program is underway here at NASA Lewis Research Center to develop advanced high temperature sealing technology for hypersonic vehicles.

A key technology area for these seals is materials evaluation and seal tribology. Several proposed hypersonic vehicle designs will, for example, require sliding seals to operate in adverse environments encountered in engines and on control surfaces such as flaps and elevons. It has been estimated that linear sliding seals will need to operate successfully at temperatures near 1000 °C (ref. 3). One current approach to solve some of these advanced sealing problems is to use a braided linear rope seal in sliding contact with an actively cooled metallic counterface (ref. 3). The rope seal is woven from ceramic fibers and is required to be able to withstand high temperature, oxidative and reducing environments which may contain water vapor. Figure 2 shows, schematically, one such rope seal design.

For long seal life and low seal actuation forces, friction and wear of the rope must be minimized. Recent research shows that, in sliding contacts, unlubricated ceramics exhibit high friction and wear

(ref. 4). Therefore, the determination and understanding of high temperature friction and wear properties of candidate ceramic seal materials are important issues.

Previous work with alumina-boria-silica fiber materials (Nextel 312 and 440) indicated their potential use as high temperature seal materials was limited. After exposure to elevated temperatures they became measurably less durable (ref. 5). This behavior was attributed to the reactive nature of their boria constituent, a commonly used glass forming ceramic additive.

To avoid this weakness, complex carbide-oxide fibers were evaluated which were based on silicon-carbon-oxygen chemistry (ref. 6). These fibers, however, are not fully oxidized and rely on a passivating oxide layer for high temperature oxidation resistance. During sliding, this layer was worn off leading to increased wear via an oxidation/abrasion mechanism especially at elevated temperatures (ref. 6). These studies highlight the need for suitable candidate seal fiber materials with the potential for high temperature sliding service.

The following paper addresses these issues by evaluating the durability of a candidate alumina-silica ($\text{Al}_2\text{O}_3\text{-SiO}_2$, Nextel 550) ceramic fiber material sliding against a nickel based superalloy (Inconel 718) in air from 25 to 900 °C. This fiber is believed to be a good candidate because it does not contain any boria, which can be reactive, and also is a fully oxidized fiber and will not be susceptible to an oxidative/abrasion wear mechanism.

To determine the sensitivity of the tribological properties to test conditions, some tests were conducted at varying loads and sliding velocities. The effect of fiber diameter and a pretest heat treatment on fiber durability and friction was also determined. In addition, to investigate the effect of fiber elastic modulus, alumina (Al_2O_3 , Nextel 610) fibers, which have twice the elastic modulus of the $\text{Al}_2\text{O}_3\text{-SiO}_2$ fibers, were tested. The results presented in this paper represent the first reporting of the sliding behavior of this material system. As such, the findings of this work may play a key role in guiding the material selection process for high temperature sliding seals for advanced propulsion systems.

MATERIALS

Nextel 550 fiber, manufactured by the 3M Company, was tested in both the heat cleaned and heat treated condition as described in the next section. Nextel 550 has an amorphous structure and contains 73 wt % Al_2O_3 and 27 wt % SiO_2 . It is prepared by a polymer pyrolysis processing route. The Nextel 550 fibers have a slightly oval cross section. Two different diameters, approximately 11 and 15 μm , were tested.

To determine the effect of fiber modulus on durability, Al_2O_3 fibers (Nextel 610), which have approximately twice the modulus of the Nextel 550 fibers, were also evaluated. The Nextel 610 fibers have a round cross section and were 10.5 μm in diameter. The fibers' compositions and mechanical properties are given in detail in table I.

Fiber Treatments

All of the samples were heat cleaned at 500 °C, in air for 1 hr to remove an organic sizing compound (PolyVinylAlcohol, PVA) used by the manufacturer during processing (ref. 7). Furthermore, the Nextel 550 samples which are designated with an HT suffix, Nextel 550HT, were heat treated in air at 950 °C for 12 hr. This treatment is believed to make the fibers more resistant to moisture degradation at

temperature and was shown to cause significant durability reductions in previous testing of alumina-boria-silica fibers (ref. 5). The heat treatment is conducted here to determine if the alumina-silica fiber, Nextel 550, is susceptible to similar strength degradation.

Counterface Material

The test disks were made of Inconel 718, a nickel-chromium alloy precipitation hardened to 34 on the Rockwell C scale. Table II gives the composition and some representative properties of the disk material. This material is being considered as a possible candidate for seal applications because of its high temperature strength and oxidation resistance.

Prior to testing, the disk surface is lapped with an alumina abrasive to a surface finish of about 0.1 μm rms. After lapping, the specimens were cleaned with freon, ethyl alcohol, scrubbed with a paste of levigated alumina and deionized water, rinsed with deionized water and air dried.

APPARATUS AND PROCEDURES

The purpose of the tribotests performed here is to determine the friction and durability (wear) characteristics of advanced ceramic fibers. This is accomplished by sliding a small sample bundle of fibers against the flat face of a rotating disk in a friction and wear rig. To test the fiber materials, a bundle of the fibers to be tested is wrapped over the tip a hemispherically tipped pin then loaded against the rotating counterface disk surface. The bundle is held in place with loops of circumferentially wound stainless steel wire (fig. 3). The pin has grooves machined into the tip and shank to accept the fiber strand and prevent its slippage during testing. Friction is continuously monitored during the test and fiber wear, which is determined by the number of fibers that break during sliding, is measured after testing. This testing technique has been used successfully by the authors to evaluate other ceramic fibers (refs. 5 and 6) and is a variation of a technique developed for woven fabric durability testing (refs. 8 and 9).

The pin has a small flat spot at its tip, 3.2 mm in diameter, to better support the fiber bundle and provide a uniform sliding area. The bundle is given a one half or 180° twist across the flat contact spot to help contain the bundle in the sliding contact and to orient the fibers at approximately a 45° angle with the sliding direction to better simulate proposed braided seal configurations (fig. 4).

To test a fiber candidate, a bundle of fibers, usually containing about 6000, 11 μm diameter fibers, is mounted on the pin specimen. The pin is then slid against a counterface disk in a high temperature pin-on-disk tribometer. The disk is 63.5 mm in diameter and 12.7 mm thick. The pin generates a 51-mm wear track on the disk. Figure 5 shows a schematic of the tribometer used in this work. The tribometer has been described in detail elsewhere (ref. 10) and its main features will only be briefly described here.

The pin-on-disk tribometer is capable of sliding pin and disk specimens at loads from 0.1 to 100 kg at sliding speeds from 0.025 to 22 m/sec. The specimens can be heated using a SiC glowbar furnace to temperatures of 1200 °C. For most of the tests conducted here, the sliding speed was 0.025 m/sec and the load was 0.270 kg (2.65 N) giving a nominal contact pressure of 330 KPa which is considered typical for anticipated seal applications. Some tests were run at varying loads, 1.3 to 21.2 N, and varying speeds, 0.025 to 0.25 m/sec, to determine their effect on fiber performance. The test atmosphere was ambient air with a relative humidity ranging from 50 to 75 percent at 25 °C. Test temperatures were 25, 500, or 900 °C. The test duration was 120 min. Friction was continuously measured during the tests. Wear was quantified after each test. Previous tests using this technique indicated that fiber wear occurs in a

fairly uniform manner during the tests (refs. 5 and 6). Fiber wear data, within an uncertainty of about 5 percent, was determined using SEM micrographs and from posttest visual observations.

At least three repeat test runs were conducted for each material and test condition combination. The friction data uncertainties reported represent one standard deviation of the sampled data and the wear data uncertainties represent the data scatter of the durability or cycles to failure measurements.

RESULTS

The friction and wear results for the tests conducted are given in table III. Wear is given by Cycles To Failure, CTF, which is a common wear parameter for fiber materials (ref. 9). The wear results are shown graphically in figure 6. For these tests, the CTF is determined by first dividing the number of cycles tested by the number of fibers broken during the test and then multiplying by the total number of fibers in the bundle tested (in our case there are usually 6000 fibers). For example, if 50 percent of the fibers in a bundle (3000 fibers) break after a 2-hr test (1200 revolutions or cycles) the CTF is $(1200) \cdot (6000/3000)$ or 2400. That is to say it would take 2400 disk revolutions or cycles to break through the entire 6000 fiber bundle. This measurement assumes that the fiber breakage rate is linear with time and is, therefore, simplistic. However, CTF is a standard measure for fiber durability in the textile industry and proves to be a useful measurement for these tests.

A typical friction plot is given in figure 7. Each data curve in this plot represents the average of at least three experiments. The data scatter values are shown in table III. The friction values for the Nextel 550 at 0.025 m/sec sliding velocity and 2.6 N load averaged about 0.54 at room temperature, dropped to about 0.36 at 500 °C and increased at 900 °C to about 0.63. The friction for the pure alumina fibers, Nextel 610, was very similar to the alumina-silicate fibers except that the friction remained low at 900 °C averaging about 0.32.

The larger diameter (15 μm) Nextel 550 exhibited equivalent friction coefficients to the standard diameter (11 μm) fibers but had much higher durability (CTF). This effect is probably due to the increased fiber strength and will be discussed later. Since the friction for both diameter Nextel 550 fibers was about the same, it appears that changes in mechanical aspects like diameter do not significantly affect friction. The larger diameter fibers, however, were much stiffer and more difficult to mount on the pin specimen than the 11 μm fibers and this stiffness may inhibit their application in complex woven seals.

Effects of Load and Velocity

The results for Nextel 550 at 900 °C at varying load and varying velocity are shown in figures 8 and 9 respectively. The load has only a slight effect on the friction coefficient but has a dramatic effect on the durability. Fiber durability decreases substantially from about 40 000 CTF at a load of 1.3 N to only 1000 CTF at a load of 4.5 N (fig. 8).

The velocity, on the other hand, causes a gradual increase in the friction and an increase in the durability although there is considerable data overlap. For instance, the friction is about 0.7 at 0.025 m/sec sliding velocity. This increases at higher velocities to about 1.0 and remains fairly constant up to the maximum tested velocity of 0.25 m/sec. The CTF at the lowest velocity, 0.025 m/sec, is about 3000 and this increases to about 5500 at the highest velocity. Again, however, there is overlap in the data ranges (fig. 9).

DISCUSSION

The relative durability of the fibers can be judged by examining the cycles to failure data. The most durable fiber over the entire temperature range is the 15 μm diameter Nextel 550. Theoretical considerations reported previously indicate that fiber diameter has a significant effect on durability (ref. 5). Therefore, when making an assessment of the durability of a specific fiber composition it is important to consider fibers of similar diameters.

Friction: Relation to Fiber Composition

The friction coefficients measured for the fibers studied here are similar to values measured in previous work by this author (refs. 5 and 6) and by others working with unlubricated ceramic sliding (refs. 4, 11, and 12). For the alumina-silica fiber, Nextel 550, the friction drops to 0.36 at 500 °C perhaps due to the growth of a low shear strength oxide film at the sliding interface. At 900 °C, however, the friction coefficient increases to about 0.6. This may be caused by increased surface oxidation of the disk and possible interaction between the metal oxides from the disk and the fibers. Energy Dispersive x-ray analyses after testing at 900 °C indicate the presence of oxygen and metallic disk constituent elements like nickel and chromium at the fiber wear surface.

The alumina fibers, Nextel 610, displayed good durability and relatively low friction. The friction coefficient was highest at room temperature, 0.51, and decreased at elevated temperatures to about 0.3. This is in excellent agreement with results reported by Sliney and Deadmore for monolithic alumina rub blocks sliding against Inconel 718 (ref. 13). In their work, they attributed the decrease in friction to the formation of a lubricating metal-ceramic oxide film at the sliding interface which reduced friction and wear.

A metal oxide layer may be forming at the sliding interface during these tests causing a similar effect on friction. For the alumina fibers, the durability at elevated temperatures is better than at room temperature indicating that an oxide film may have formed during sliding which reduces wear as well as friction.

One drawback of the alumina fibers, however, is their stiffness. Since the elastic modulus for alumina is almost twice that of the other fibers tested they are very stiff and difficult to handle much in the same way the larger 15 μm Nextel 550 fibers were. This high stiffness may limit their use in woven seals.

Durability: Relation to Fiber Properties

To better understand the factors affecting fiber durability, a dimensional analysis of the fiber durability was conducted taking into account mechanical factors which are likely to affect durability such as tensile strength, load, and friction coefficient. The dimensional analysis is described in detail in reference 5 and only the highlights will be reviewed here.

The dimensional analysis is based upon the assumption that the dominant fiber wear mode is by brittle fracture. Fiber wear occurs when the friction forces imposed by sliding exceed the fiber strength in tension. Previous experiments with other oxide fibers (i.e., Nextel 312 and Nextel 440 alumina-boria-silica fibers) indicate that fiber fracture does indeed characterize the wear process (ref. 5). SEM photomicrographs of the worn alumina-silica (Nextel 550) fibers tested here are shown in figure 10. The sharp

faceted surfaces of the broken fibers confirm that the wear mode is by brittle fracture. The brittle wear behavior observed verifies the appropriate basis and underlying assumption of the dimensional analysis.

The dimensional analysis conducted to determine the important test and material parameters on fiber durability resulted in the development of a durability parameter or ratio. The durability ratio is defined as the ratio of the fiber strength in tension (tensile strength·fiber diameter²) divided by the sliding friction force (friction coefficient·applied normal load), or, $(TS \cdot D^2)/(\mu \cdot F_n)$. The relationship established by the dimensional analysis and the identification of an important dimensionless parameter helps to explain and understand the data.

Since the durability ratio combines material properties (tensile strength and fiber diameter) with experimental measurements and conditions (friction coefficient, test load and CTF) it is a parameter which facilitates the comparison of durability data from tests conducted under a variety of conditions. For example, changes in test temperature can affect both the friction coefficient and also the fiber tensile strength. See tables III and I respectively. By using the measured average friction coefficient and the fiber tensile strength at the test temperature when calculating the value of the durability ratio, data from tests at different temperatures can be compared to one another. The same is true for tests at differing loads. Therefore, the use of the durability ratio analysis can lead to a more general understanding of fiber durability behavior for a wide range of test conditions.

The usefulness of the analysis and the dimensionless durability ratio can be seen by examining a plot of fiber durability (CTF) versus the durability ratio, $(TS \cdot D^2/\mu F_n)$, for data previously reported (ref. 5) on alumina-boria-silica fibers (Nextel 312 and 440) as shown in figure 11. Though the data is not comprehensive, a trend is apparent. That is that, rather than a simple linear function, the CTF seems to be a step function of fiber strength to fiber breakage forces. Others have found similar connections between ceramic wear and fracture behavior (ref. 13).

The CTF is low for $(TS \cdot D^2/\mu F_n)$ ratios lower than about 0.15. Above this point the CTF rises dramatically. This implies that a threshold exists around a ratio of 0.15 below which poor fiber durability is exhibited and above which good fiber durability is observed. The dimensional analysis model helps to delineate the important variables and helps to explain the data we measure.

The model indicates that durability can be enhanced by reducing the loads or by lubricating the fibers. Both of the options are available to seal designers and have been shown to be effective in previous research with these materials in woven fabric form (refs. 8 and 9).

When the data for the Nextel 550 and 610 oxide fibers is plotted using the durability ratio as in figure 12 it is seen that the agreement of the Nextel 550 data with the previously reported data for the alumina-boria-silicate is reasonably good. The agreement for the alumina fiber data, Nextel 610, however, is poor. This may be due to the difference in the elastic modulus between the Nextel 610 and all of the other fibers tested. The modulus for the Nextel 610 is about twice that of the other fibers tested making it much stiffer and this may have a significant effect on the durability. These results indicate that mechanical properties have a major impact on the fiber durability and hence may affect seal durability as well.

Effects of Fiber Diameter

By examining the data for the Nextel 550, table III, it is clear that fiber diameter has a significant effect on durability as predicted by the durability ratio. Friction is not greatly affected by the diameter

as discussed previously. The 15 μm diameter fibers are about twice as durable as the 11 μm fibers and more so at 900 °C. It may be that the 15 μm fibers are well above the durability ratio threshold for this material system.

However, the larger diameter fibers were very awkward to work with and may be even more difficult to braid into a seal and for these reasons may not be suitable. Also, recent research (ref. 3) indicates that seal leakage is a function of the fiber diameter to the third power making larger diameter fibers poor choices from a leakage rate standpoint. Therefore a balance must be made between leakage level, braidability/flexibility and seal durability in order to optimize the sealing system.

Further work is needed to understand the relationship between fiber diameter and modulus (stiffness) and durability. From these results, it seems that the elastic modulus and the fiber diameters of different fiber materials must be approximately equal in order to make comparisons between fibers using the simple dimensionless model presented.

Effects of Load

When the durability data for the tests at varying load is plotted using the dimensionless analysis (fig. 13), behavior is observed which is similar to the previously established curve. Below a durability ratio of about 0.15 the CTF is low. But above a durability of 0.15 the durability is high.

These results suggest that steps taken to increase the durability ratio may also increase the fiber wear life. Some examples include seal lubrication to reduce friction, load reduction, perhaps through pressure balancing, fiber development to improve tensile strength and the use of larger diameter fibers (assuming adequate flexibility is retained). Any of these approaches, of course, must be further investigated. However, the reasonably good agreement of the durability data obtained from the varying load tests with the durability ratio curve enhances confidence in the applicability of the dimensional analysis and its implications for durability improvement.

Effects of Pretest Heat Treatment

The data for heat treated and non heat treated Nextel 550 fibers are plotted in figure 14. From the figure it is apparent that the heat treatment reduces the room temperature durability of the fiber by about a factor of two. At elevated temperatures, however, the durability of the heat treated fibers is about equal to the non heat treated fibers. These results suggest that Nextel 550 is a good candidate for high temperature use.

CONCLUSIONS

1. In general, fiber durability decreased and friction increased with temperature. This may be due to a variety of factors including lower fiber strength and possible surface changes at the fiber/counterface sliding contact such as disk oxidation.

2. Because Nextel 550 displayed good durability over the temperature range studied it may be a suitable candidate seal material for advanced applications.

3. A simple model developed from a dimensional analysis indicates that fiber durability is related to a durability ratio of the fiber strength to the frictional stresses imposed on the fibers due to sliding. This model is useful in analyzing the data for the alumina-silica fibers tested here.

4. Fibers that were either of higher elastic modulus, such as Alumina (Nextel 610) or larger diameter (15 μm) than the other fibers tested and were difficult to handle due to their decreased flexibility. Although their durability was good, their stiffness may preclude their consideration as seal candidate materials.

5. The results from the application of the dimensional analysis and the sliding experiments suggest that significant improvements in fiber durability can be achieved through fiber strength improvements, seal lubrication and pressure balancing to reduce seal loads.

ACKNOWLEDGMENTS

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REFERENCES

1. Steinetz, B.M.; DellaCorte, C.; and Sirocky, P.: On the Development of Hypersonic Engine Seals. NASA TP-2854, 1988.
2. Stephens, J.R.: HITEMP Program Overview. HITEMP Review 1990: Advanced High Temperature Engine Materials Technology Program, NASA CP-10051, 1990, pp. 1-23.
3. Steinetz, B.M.; DellaCorte, C.; and Tong, M.: Seal Concept and Material Performance Evaluation For the NASP Engine. Proceedings of the Seventh NASP Technology Symposium, Cleveland, OH, Oct. 1989, Paper No. 60.
4. Yust, C.S.; and Allard, J.F.: Wear Characteristics of an Alumina Silicon Carbide Whisker Composite at Temperatures to 800 °C in Air. STLE Tribol. Trans., vol. 32, no. 2, 1989, p. 331-338.
5. DellaCorte, C.; and Steinetz, B.M.: Relative Sliding Durability of Two Candidate High Temperature Oxide Fiber Seal Materials. NASA TM-105199, 1991.
6. DellaCorte, C.; and Steinetz, B.M.: Sliding Durability of Two Complex Carbide-Oxide Candidate High Temperature Fiber Seal Materials in Air to 900 °C. NASA TM-105557, 1992.
7. Holtz, A.R.; and Grether, M.F.: High Temperature Properties of Three Nextel Ceramic Fibers. Advanced Materials Technology '87: 32nd International SAMPE Symposium and Exhibition, R. Carson, ed., SAMPE, 1987, pp. 245-246.
8. DellaCorte, C.: Tribological Properties of Alumina-Boria-Silicate Fabric From 25 to 850 °C. STLE Tribol. Trans., vol. 32, July 1989, pp. 325-330.
9. DellaCorte, C.; Steinetz, B.M.; and Brindley, P.K.: Tribological Properties of Ceramic/Ti₃Al-Nb Sliding Couples for Use as Candidate Seal Materials to 700 °C. NASA TM-102401, 1989.

10. Sliney, H.E.; and DellaCorte, C.: A New Test Machine for Measuring Friction and Wear in Controlled Atmospheres to 1200 °C. *Lubri. Eng.*, vol. 47, no. 4, Apr. 1991, pp. 314-319.
11. Kear, B.H.: *Tribology of Ceramics*, National Academy Press, 1988, pp. 1-12.
12. Boch, P.; Platon, F.; and Kapelski, G.: Effect of Temperature and Environment on Wear and Friction of Al_2O_3 and SiC Ceramics. *Proceedings of the Fifth International Congress on Tribology*, Vol. 3, K. Holmberg and I. Nieminen, eds., Finnish Society for Tribology, Helsinki, Finland, 1989, pp. 114-119.
13. Sliney, H.E.; and Deadmore, D.E.: Friction and Wear of Oxide-Ceramic Sliding Against IN-718 Nickel Base Alloy at 25 to 800 °C in Atmospheric Air. NASA TM-102291, 1989.

TABLE I.—FIBER COMPOSITION AND SELECTED PROPERTIES^a

Fiber material	Composition, wt %	Diameter, μm	E, GPa	Tensile strength, MPa		
				25 °C	500 °C	900 °C
Nextel 550	$73\text{Al}_2\text{O}_3\text{-}27\text{SiO}_2$	11	190	2201	1964	1761
Nextel 550HT ^b	$73\text{Al}_2\text{O}_3\text{-}27\text{SiO}_2$	11	190	2201	1964	1761
Nextel 550	$73\text{Al}_2\text{O}_3\text{-}27\text{SiO}_2$	15	190	2201	1964	1761
Nextel 610	Al_2O_3	10.5	366	2235	2032	2032

^aData taken from manufacturers' information literature.

^bHT denotes heat treated fibers. Tensile strength after heat treatment presumed not measured.

TABLE II.—COMPOSITION AND HARDNESS OF INCONEL TEST DISK SPECIMENS

Property	Value
Composition, wt %	70Ni, 16Cr, 7.5Fe, 2.5Ti, 1Al, 1Co, 1Mn, 0.1C, and 0.9 other
Rockwell hardness	RC34

TABLE III.—FRICTION AND DURABILITY DATA SUMMARY

Fiber material	Composition, wt %	Diameter, μm	E, GPa	25 °C		500 °C		900 °C	
				μ	CTF	μ	CTF	μ	CTF
Nextel 550	73Al ₂ O ₃ -27SiO ₂	11	190	0.54±0.8	9 231±2500	0.36±0.05	7 500±1 500	0.73±0.26	3 000±1 000
Nextel 550HT	73Al ₂ O ₃ -27SiO ₂	11	190	.52±.03	4 300±1600	.61±.10	4 800±1 000	.41±.06	5 000±1 500
Nextel 550*	73Al ₂ O ₃ -27SiO ₂	15	190	.53±.06	13 300±4000	.36±.14	20 000±10 000	.53±.06	24 000±15 000
Nextel 610	Al ₂ O ₃	10.5	366	.51±.04	2 927±900	.28±.07	5 455±2 500	.32±.03	3 636±600

Notes:

- HT designates fibers which have been heat treated (exposed in air at 950 °C for 12 hr).
- Uncertainties represent data scatter for the CTF values and one standard deviation for the friction coefficients.
- All tests done on twos of ≈ 6000 fibers except those marked with an * which denotes test of only ≈ 3200 fibers.

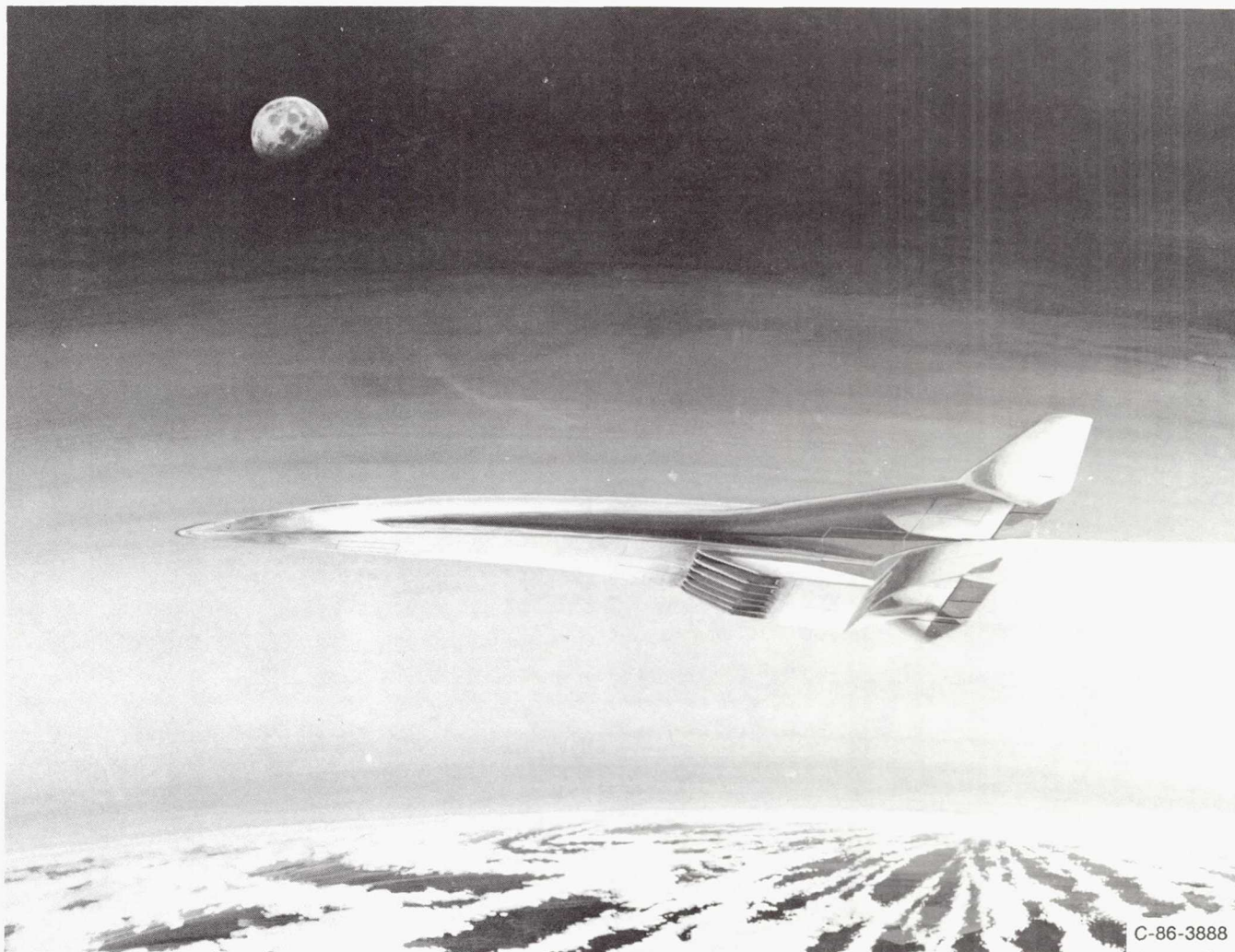


Figure 1.—Artist's conception of hypersonic flight vehicle (NASP).

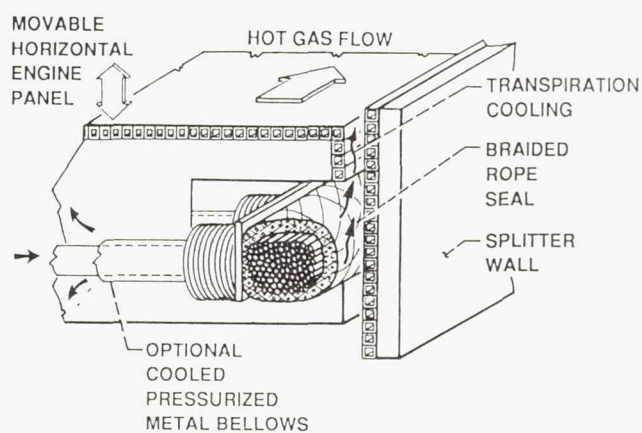


Figure 2.—Cross section of proposed engine seal.

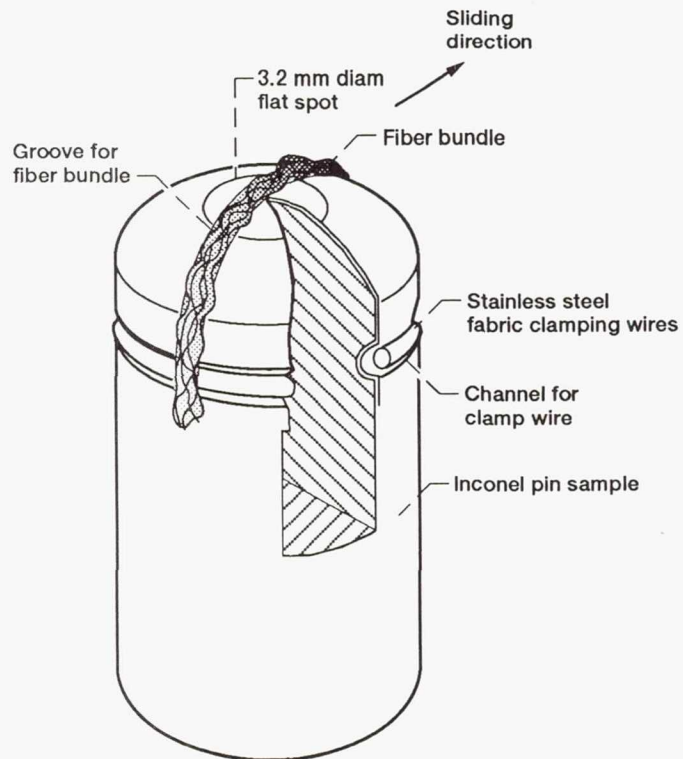


Figure 3.—Pin test specimen.

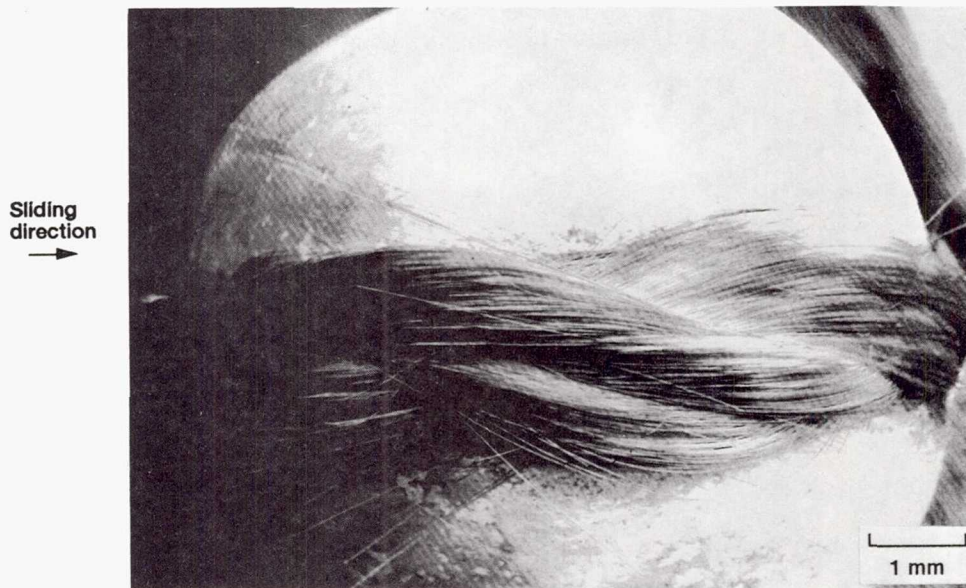


Figure 4.—SEM photomicrograph of fiber-pin specimen prior to testing. Sliding direction is from left to right.

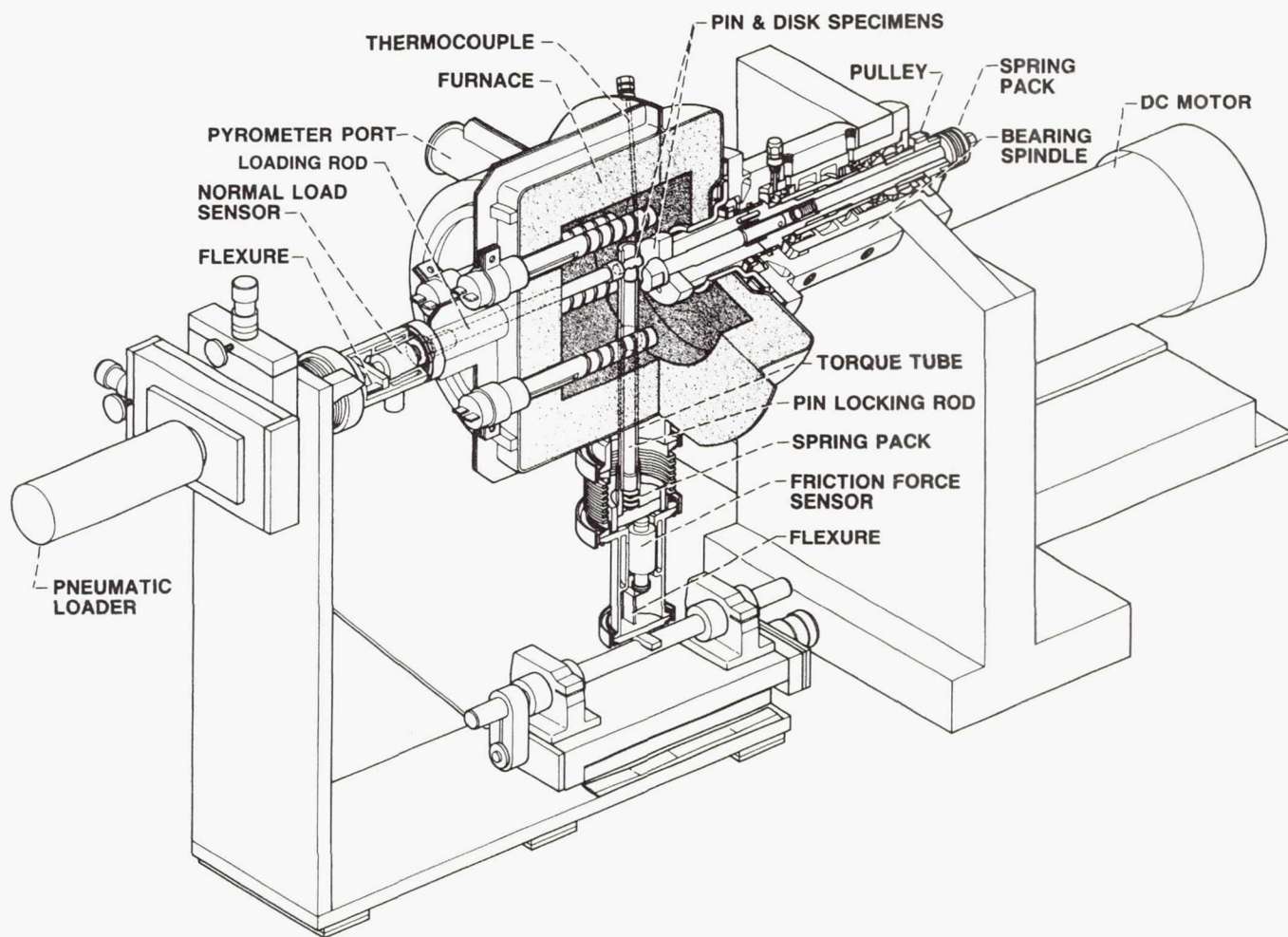


Figure 5.—High temperature pin on disk tribometer.

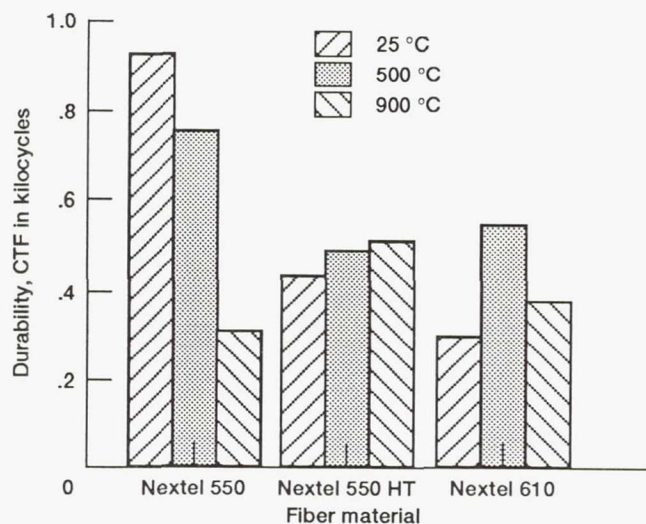


Figure 6.—Durability data (CTF) for ceramic fibers ($\approx 11 \mu\text{m}$ diam) in sliding against Inconel 718 disks in air, 0.025 m/s velocity, 2.6N load. Fiber tow (sample) contained ≈ 6000 fibers.

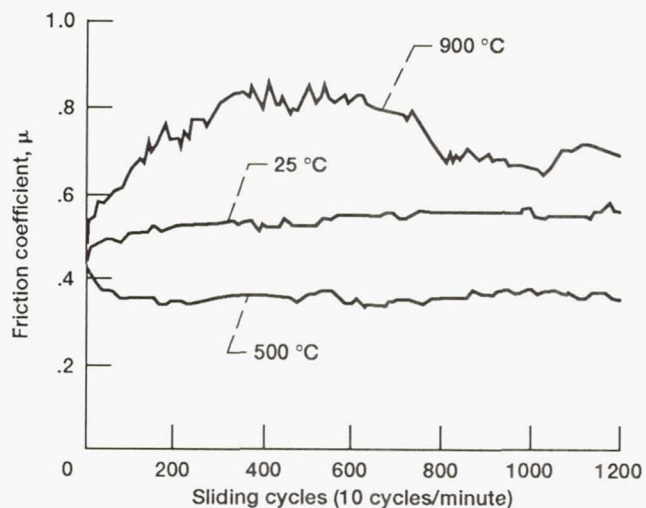


Figure 7.—Friction coefficient versus sliding cycles for Nextel 550 fibers against Inconel 718 disk at 2.6N load, 0.025 m/s velocity.

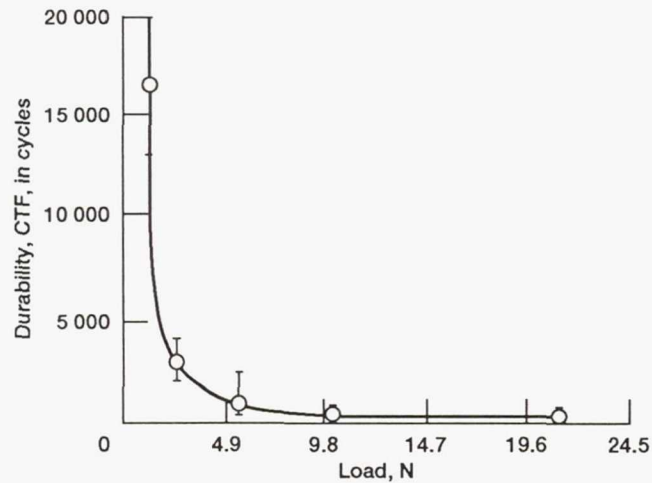


Figure 8.—The effect of test load on the durability of Nextel 550 fibers at 900 °C when sliding against Inconel 718 disks. Error bars represent data scatter from repeat experiments.

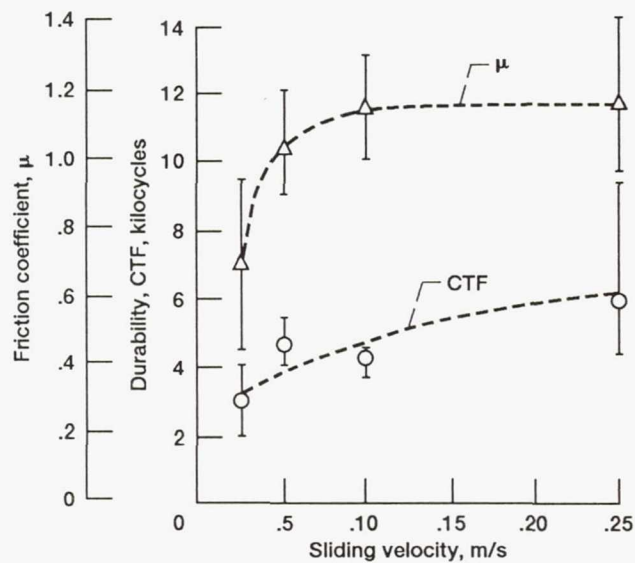
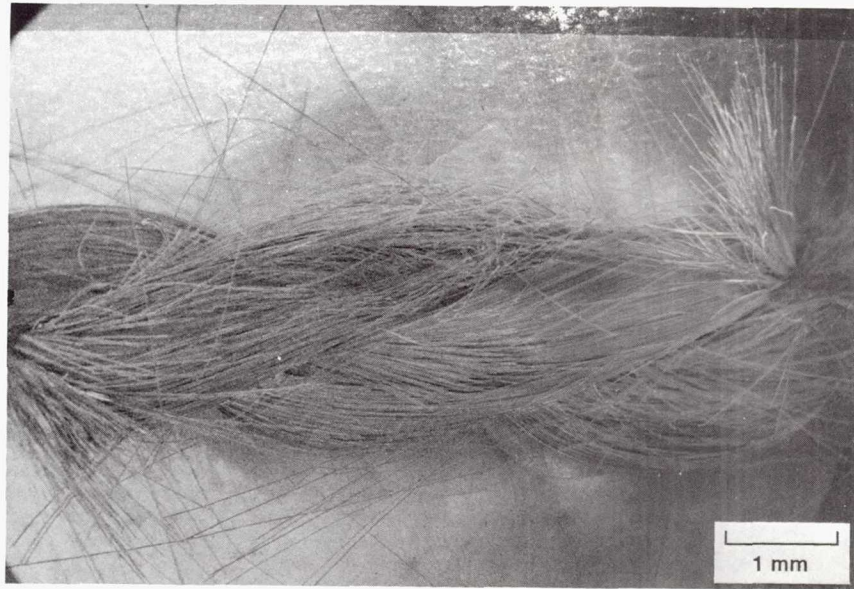


Figure 9.—The effect of sliding velocity on the friction and durability of Nextel 550 fibers at 900 °C, 2.6N load. Error bars represent data scatter for the CTF values and one standard deviation for the friction coefficient values.

Sliding direction →



(a) 25 °C test temperature.

Sliding direction ↘



(b) 500 °C test temperature.

Figure 10.—SEM photomicrographs of worn Nextel 550 fiber specimens after sliding against an Inconel 718 disk at 0.025 m/s, 2.6N load.

Sliding direction



(c) 900 °C test temperature.

Figure 10.—Concluded.

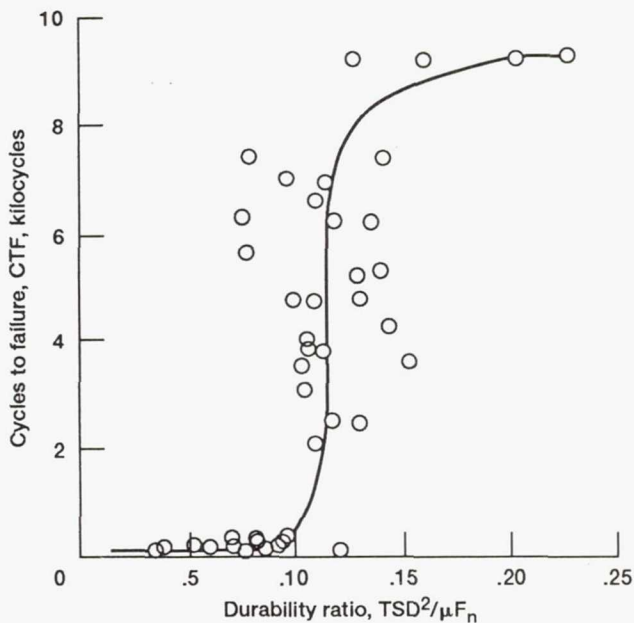


Figure 11.—CTF, cycles to failure for Nextel 312 and Nextel 440 $Al_2O_3-B_2O_3-SiO_2$ fibers versus durability ratio, $TSD^2/\mu F_n$ from reference 5. Data curve fit resembles step function with discontinuity or transition occurring between 0.075 and 0.15 data taken at 0.025 m/s sliding velocity, 2.6N load and at 25, 500, or 900 °C.

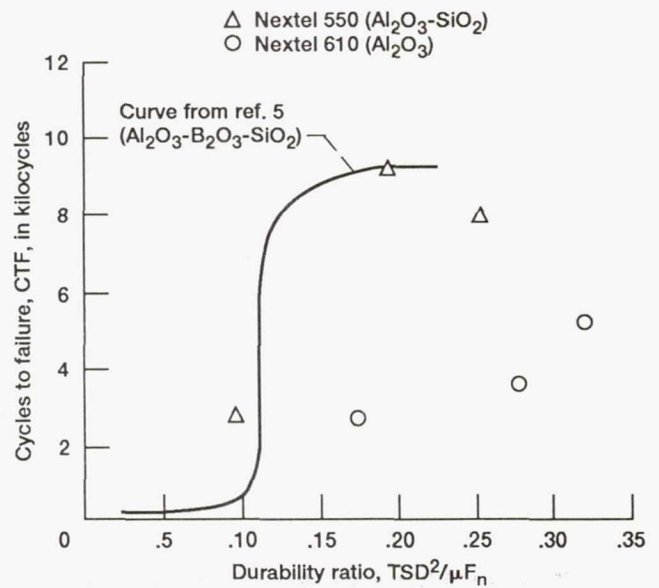


Figure 12.—Durability data for Nextel 550 and Nextel 610 fibers plotted versus dimensionless durability ratio. Nextel 550 data shows good agreement with data curve generated in reference 5 for $Al_2O_3-B_2O_3-SiO_2$ fibers (Nextel 312 and Nextel 440). Nextel 610 data shows poor agreement which may be due to high stiffness of the Al_2O_3 fibers.

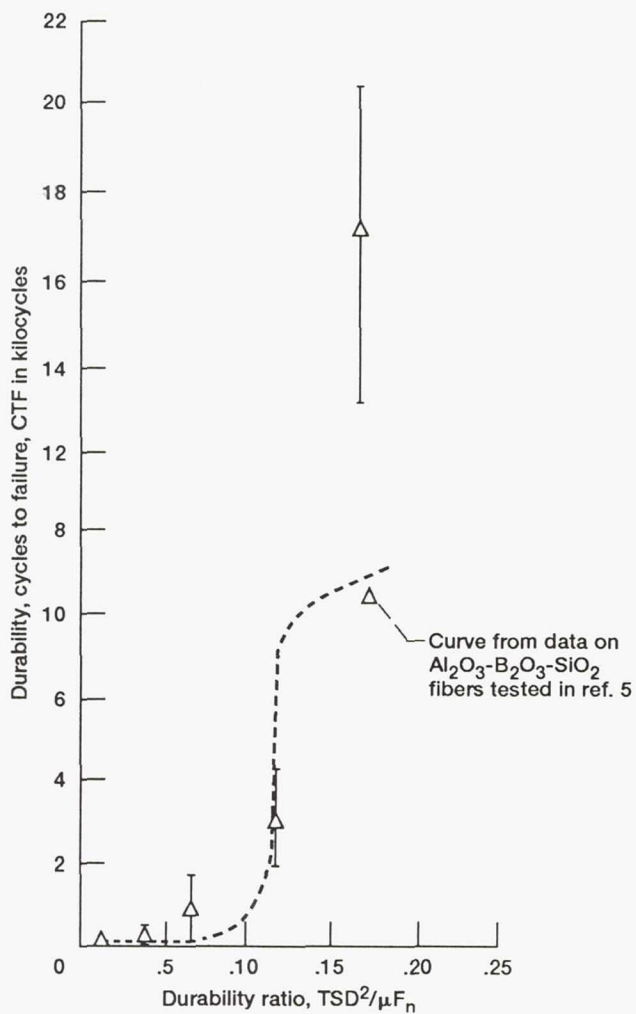


Figure 13.—Fiber durability at 900 °C for Nextel 550 versus the dimensionless durability ratio, $TSD^2/\mu F_n$ at test loads ranging from 1.3 to 21.2N. Data points indicate a durability transition or threshold around 0.15 in general agreement with data curve shown (from $Al_2O_3-B_2O_3-SiO_2$ fibers, ref. 5) as a dashed line. Error bars represent data scatter from three repeat experiments.

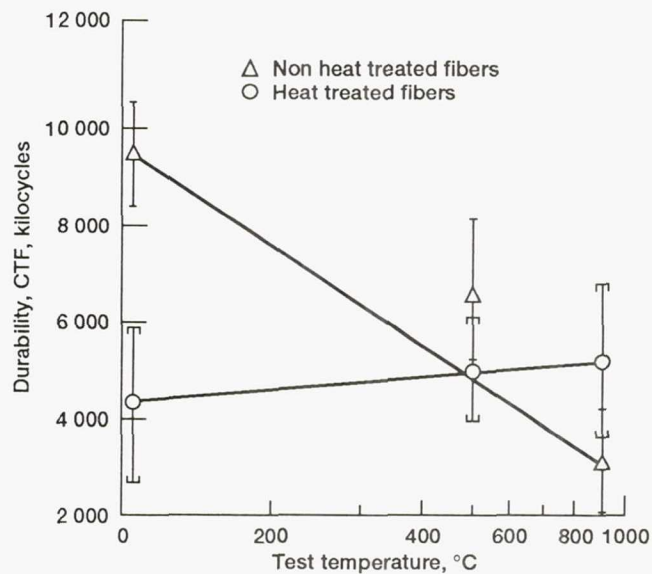


Figure 14.—Durability (CTF) of Nextel 550 fibers comparing the heat treated to non heat treated condition. Heat treatment was 950 °C for 12 hours in air. Sliding tests performed in air, 2.6N load 0.025 m/s velocity at 25, 500 and 900 °C. Error bars represent data scatter from repeat experiments.

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13. ABSTRACT (Maximum 200 words) A test program to determine the relative sliding durability of an alumina-silica candidate ceramic fiber for high temperature sliding seal applications is described. This work represents the first reporting of the sliding durability of this material system. Pin-on-disk tests were used to evaluate the potential seal material by sliding a tow or bundle of the candidate ceramic fiber against a superalloy test disk. Friction was measured during the tests and fiber wear, indicated by the extent of fibers broken in the tow or bundle, was measured at the end of each test. Test variables studied included ambient temperatures from 25 to 900 °C, loads from 1.3 to 21.2 N, and sliding velocities from 0.025 to 0.25 m/sec. In addition, the effects of fiber diameter, elastic modulus and a pretest fiber heat treatment on friction and wear were measured. In most cases, wear increased with test temperature. Friction ranged from about 0.36 at 500 °C and low velocity (0.025 m/sec) to over 1.1 at 900 °C and high velocity (0.25 m/sec). The pretest fiber heat treatment, which caused significant durability reductions for alumina-boria-silica ceramic fibers tested previously, had little effect on the alumina-silica fibers tested here. These results indicate that the alumina-silica (Al ₂ O ₃ -SiO ₂) fiber is a good candidate material system for high temperature sliding seal applications.				
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