DEFENSE
Tech Briefs

Using Fiber Metal Abradable Seals in Aerospace Turbine Applications

Saturday, October 01 2011

Limiting leakage in aerospace turbo-machinery has been a focus of engineers ever since the advent of the turbine. An increasing number of companies are finding that fiber metal abradable seals are an efficient solution to reducing the amount of compressed gas that escapes past blade tips in axial-flow compressors and turbines. These seals maintain compartmental pressure to improve sealing effectiveness in critical compression areas. The abradable material permits the blade tip to “machine” its own channel into the case during transients and unsteady-state conditions, minimizing the flow path between the blades and the housing.

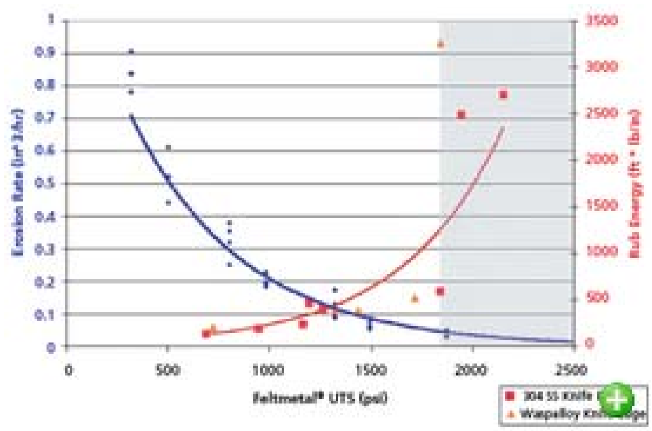

Figure 1. Erosion Rate and Rub Energy vs. Ultimate Tensile Strength

Fiber metal abradable seals are suitable for use in both aerospace propulsion gas turbines and land-based utility steam and gas turbines. These seals balance the conflicting requirements of abradability, erosion and corrosion resistance, as well as resistance to oxidation resistance in high-temperature operations. Constructed of sintered heat- and oxidation-resistant metallic fibers, these seals are designed to be porous. Alternatives include honeycomb materials and metallic thermal sprays. Studies suggest that compared with these options, the use of abradable seals can reduce specific fuel consumption by as much as 2%. This is due to several factors. With abradable seals, there is no blade tip wear or seal material pick-up. Moreover there is less work required to “machine” the seal and less material removed during transients.

These key advantages relax the tolerance requirements compared with systems that incorporate hard-surface sealing that is vulnerable to rubbing and unwanted damage from the blades interfering with the housing.

Abradable Seals

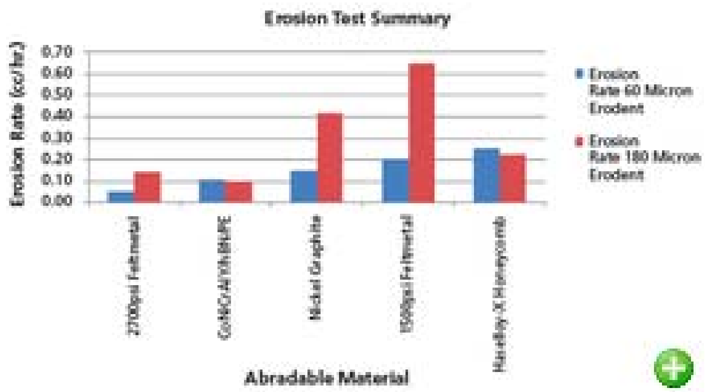

Figure 2. Performance of Various Materials in Erosion Tests

Abradable seals are designed to be rub-tolerant so engine operating clearances can be minimized, thereby improving efficiency by limiting gas leakage between engine stages. As demand for improved performance increases, abradable seals applied to stationary engine components permit complete sealing of blade tips and interstage, labyrinth-seal knife edges through the full 360° of rotation, while minimizing or eliminating wear on expensive rotating hardware.

The selection of an abradable seal for a particular position in a gas turbine engine always involves a compromise of conflicting requirements. Each position has its own specific issues related to operating speed, temperature, pressure, pressure drop, gas velocity, fluctuating pressure and mechanical loadings, thermal cycling, gas impingement angle, size and quantity of particulates present, and gas composition. The seal material must be able to withstand the operational rigors and continue to perform its basic function for the life of the engine. It must be weak enough to abrade away without causing wear when in contact with a high-speed rotating part. The material also must be strong enough to withstand high-velocity gas and particulate erosion.

Blade tip seals are subjected to higher gas velocities and pressure drops in dirtier air than interstage, labyrinth seals, and are designed to withstand more severe erosion. Interstage knife edge seals are subjected to more heat and friction due to the continuous rubbing of the knife edge, unlike the intermittent cutting action of blade tips. Consequently knife-edge seals must be weaker to eliminate wear from this more severe rubbing action. Interstage labyrinth seals experience only minimal gas erosion in the cleaner air and low pressure drops and gas velocities of compressor applications. However these seals can be severely eroded by their own rub debris if it is too large to be blown out of the sealing area by the gases leaking through. This type of erosion has been seen in compressors with powder metal seals when the particles have been larger than 25 microns. It has also occurred in fiber metal seals when coarse debris from an upstream powder metal in the form of an abradable or abrasive coating has blown into the seals.

Seal Selection

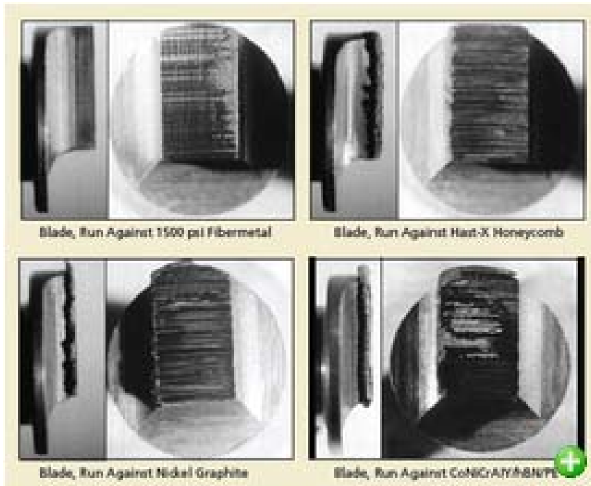

Figure 3. Post-Test Photos

Fiber metal abradable seals are fabricated from fine metal fibers that have an effective diameter of 10-20 microns and a length-to-diameter ratio of 60-90:1. The fibers are primarily Hastelloy-X since it provides the oxidation resistance needed for the vast majority of applications, but stainless steels and FeCrAlY are also available. The fiber is “felted” into sheet form and subjected to a sintering cycle in which bonds form at points of contact between the fibers. The sintered sheet is then rolled to the required thickness and density and cut to size. The final product is a strip of roll-formed fiber metal material ready to be brazed or mechanically attached into the case or onto a shoe. This material is porous by nature with an apparent density typically 15% to 30% that of the wrought material. Ultimate tensile strength (UTS) is dictated by the strength and quantity of the sinter bonds, and is usually in the range of 500 to 3,000 psi. UTS can be set independently of other physical properties in the manufacturing process. This is significant because UTS largely determines the abradability and erosion properties of the material.

Figure 1 illustrates these conflicting properties. The ability to “tune” the abradability and erosion properties gives the designer flexibility to select the optimal material for each application.

Erosion test data for five different abradable seal materials are summarized in Figure 2. Predictably, the erosion rate of the fiber metal material varied inversely with UTS. Erodent size had an effect on both the fiber metal and nickel graphite erosion rates. The increased energy of the larger erodent particles was sufficient to break the sinter bonds in these structures. Results for the CoNiCrAlY/hBN/PE and honeycomb materials were the same for both erodent sizes.

Also compared were volume-to-wear ratios, or the amount of blade material worn away (ideally zero) to the amount of seal material removed, for the different materials. Photographs of the post-run hardware are shown in Figure 3. The fiber metal samples demonstrated a full, clean rub to the final incursion depth. Machining marks were still visible on the blade tips, indicating the rubbing action had little effect and no material pickup occurred. The Hastelloy-X honeycomb samples also demonstrated a clean rub; however, the actual amount of wear was masked by the pickup of Hastelloy-X material on the blade tip. The rub grooves on the CoNiCrAlY/hBN/PE coated samples also showed extensive wear. Local areas of abradable material spallation or rupture were observed in the rub groove. The blades were worn by the full incursion depth and exhibited heat discoloration from the rubbing action. The only measurable wear in the nickel graphite coated samples was in areas where the coating spalled.

A significant amount of heat checking was also visible in the rub track, and the blades were worn by incursion depth and also exhibited heat discoloration.

Conclusions

Fiber metal, honeycomb, CoNiCrAlY/ hBN/PE, and nickel graphite abradable seal materials were evaluated at conditions simulating those found in blade tip applications. Based on the test results, the honeycomb abradable material is not particularly well suited to these applications. Significant pickup of honeycomb material, as well as higher rates of erosion, make it a less attractive candidate. The two thermal-sprayed materials performed very poorly in the high-speed abradability test with excessive blade wear eliminating it from consideration. Of the materials evaluated, the fiber metal exhibited the best combination of abradability and erosion properties, making it the material of choice for use in utility and aerospace turbines.

This article was written by Bob Schricker, Product/Manufacturing Engineer, Technetics Group, EnPro Industries companies (DeLand, FL). For more information, visit ***http://info.hotims.com/34459-501****.*

References

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