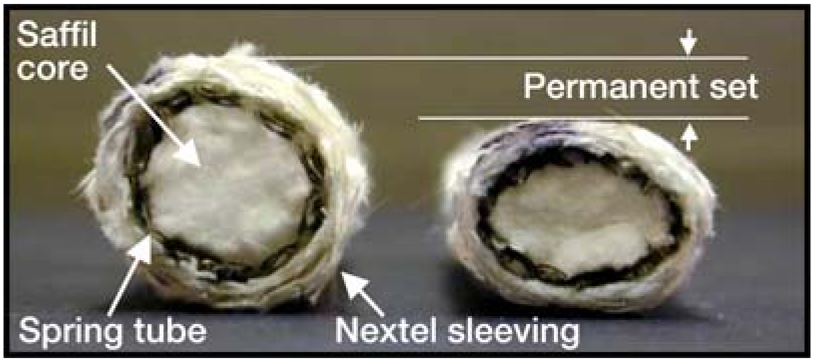
High-Temperature Knitted Spring Tubes Improved for Structural Seal Applications

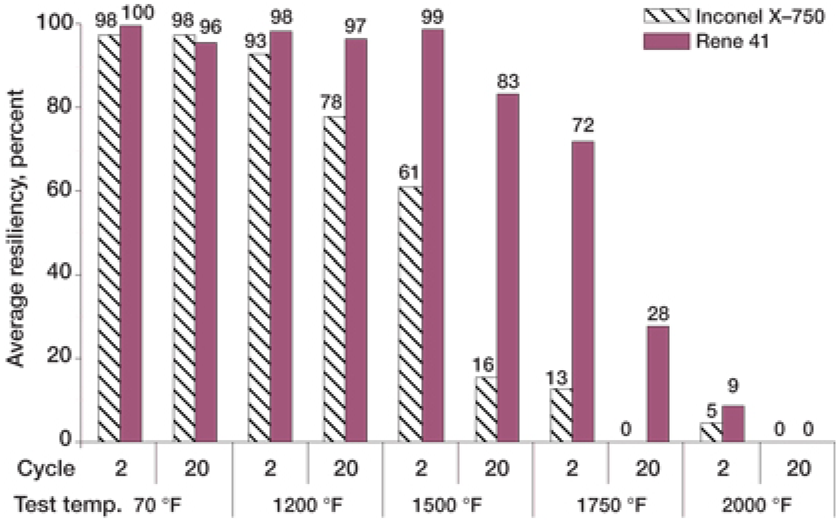
To meet the needs of current and future space vehicles, the NASA Glenn Research Center is developing advanced control surface seals. These seals are used to fill the gaps surrounding actuated structures, such as rudders and body flaps, to shield underlying lower temperature structures, such as mechanical actuators, from the hot gases encountered during atmospheric reentry. During previous testing, the current baseline seal design, which is used on the space shuttle as a thermal barrier and was selected as the rudder-fin seal on the X-38 crew return vehicle, exhibited significant permanent set following compression at 1900 °F (see the following photograph). Decreased resiliency (springback) could prevent the seal from contacting both of the opposing sealing surfaces and allow the ingestion of damaging hot gases during reentry, which could have detrimental effects on vehicle subsystems.



Current baseline control surface seal before (left) and after (right) compression during 1900 °F exposure, showing loss of seal resiliency. Initial seal diameter was approximately 0.62 in.

As illustrated in this photograph, the baseline control surface seal comprises three main components. The primary source of resiliency in the seal is an Inconel X-750 (Special Metals Corporation, New Hartford, NY) knitted wire spring tube. The passage of hot gases through the seal is limited by stuffing the spring tube with Saffil batting (Saffil Ltd., Cheshire, UK) and then overbraiding the tube with two layers of Nextel 312 ceramic fabric (3M, St. Paul, MN). The Nextel fabric acts as a thermal barrier, provides a uniform sealing surface, and prevents the loss of Saffil batting through the spring tube walls.

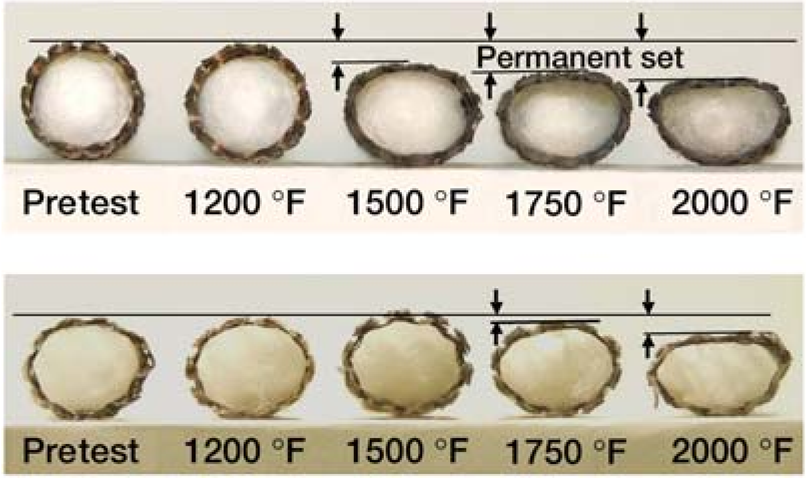
The loss of resiliency in the current seal design has been attributed to the limited high-temperature strength of the Inconel X-750 spring tube. Hot compression testing at Glenn of the spring tube alone showed significant resiliency degradation at temperatures as low as 1200 °F, which is much lower than the target temperature range of 1800 to 2200 °F for future seal designs. For this reason, the Glenn seals team worked to enhance the performance of the baseline control surface seal design by improving the spring tube component. To accomplish this task, a material with high-temperature strength properties superior to Inconel X-750 was required. Following an exhaustive materials database search, Rene 41 (Allvac, Monroe, NC) was selected to replace the Inconel X-750 wire material. Spring tubes were knitted of Rene 41 wire using the baseline spring tube geometry. These samples were then evaluated through a series of cyclic compression tests conducted at multiple temperatures using a state-of-the-art test rig.



Comparison of spring tube resiliency at the start of compression cycles 2 and 20 for heat treated samples of Inconel X–750 and Rene 41 using the baseline knit geometry at multiple test temperatures.

As shown in the bar chart, substitution of heat-treated Rene 41 alloy for heat-treated Inconel X-750 improved resiliency significantly. Rene 41 spring tubes maintained greater than 95-percent resiliency through 20 compression cycles at 1200 °F, whereas Inconel spring tube resiliency dropped as low as 78 percent at cycle 20. At the start of compression cycle 20 at 1500 °F, Rene 41 spring tubes exhibited a 5.2 times resiliency improvement over the baseline design. Rene 41 spring tubes maintained reasonable resiliency up to 1750 °F.

For a sustained resiliency of 75 percent, Rene 41 samples showed a temperature improvement of approximately 275 °F over Inconel X-750 specimens. Resiliency improvements due to material substitution were visually confirmed during post-test spring tube inspection as illustrated in the following photographs. Permanent set in the Inconel X-750 spring tubes was clearly evident at 1500 °F, whereas permanent deformation in the Rene 41 samples was nearly undetectable until 1750 °F.



Post-test photographs showing permanent set in spring tubes at multiple test temperatures after 20 compression cycles (20 percent compression). Top: Heat-treated Inconel X–750. Bottom: Heat-treated Rene 41.

The improvements in spring tube performance achieved by substituting Rene 41 for Inconel X-750 in the baseline knit geometry can be directly applied to current seal applications. By replacing existing Inconel X-750 spring tubes with new Rene 41 spring tubes, the benefits of more resilient control surface seals can be realized immediately. Technical specialists within the space shuttle program have expressed interest in possibly applying this advancement to the shuttle main landing-gear door thermal barriers to provide a greater temperature margin over the baseline design.

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