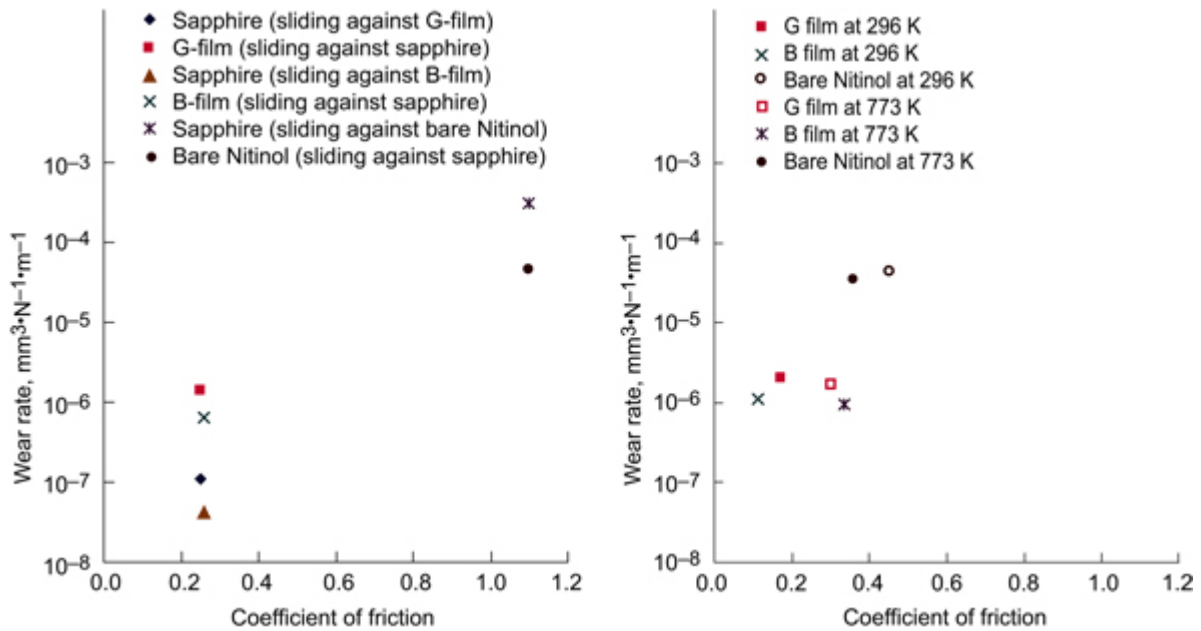


# Oxide Ceramic Films Grown on 60 Nitinol for NASA and Department of Defense Applications

Both the NASA Glenn Research Center and the U.S. Army Research Laboratory, Development and Engineering Center (ARDEC) have worked to develop oxide ceramic films grown on 60 nitinol (60-wt% nickel and 40-wt% titanium) to decrease friction and increase wear resistance under unlubricated conditions. In general, oxide and nonoxide ceramic films have unique capabilities as mechanical-, chemical-, and thermal-barrier materials in diverse applications, including high-temperature bearings and gas bearings requiring low friction, wear resistance, and chemical stability (ref. 1). All oxide ceramic films grown on 60 nitinol were furnished by ARDEC, and materials and surface characterization and tribological experiments were conducted at Glenn.

Titanium oxide,  $\text{TiO}_2$ , was formed on 60 nitinol (B film) using a patented oxide treatment (ref. 2). Another  $\text{TiO}_2$  with additional metallic species (G film) was formed on 60 nitinol by heating the specimen manually in methylacetylene-propadiene in a liquefied propane flame (ref. 2).



*Guideline map of coefficients of friction versus dimensional wear coefficients (specific wear rate) for  $\text{TiO}_2$  grown on 60 nitinol in sliding contact with sapphire balls in air at 296 and 773 K. Left: Data obtained from unidirectional, pin-on-disk sliding friction experiments conducted at 296 K. Right: Data obtained from reciprocating, pin-on-flat sliding friction experiments conducted at 296 and 773 K.*

Long description of figure 1. Coefficients of friction from 0.0 to 1.2 versus specific wear rates from  $10^{-8}$  to  $10^{-3} \text{ mm}^3 \cdot \text{N}^{-1} \cdot \text{m}^{-1}$ . Left: Data for sapphire sliding against G-film, B-film, and bare Nitinol; G-film

sliding against sapphire; B-film sliding against sapphire; and bare Nitinol sliding against sapphire. Right: Data for G-film, B-film, and bare Nitinol at 296 and 773 K.

The tribological characteristics of 60 nitinol were improved by both films. In the graph on the left, the films decreased the friction by a factor of 4 and increased the wear resistance by a two-figure factor for sliding in unlubricated conditions, although the wear resistance and endurance life of the B film were superior to those of the G film. In the graph on the right, the B film increased the wear resistance by factors of 50 and 40 at 296 and 773 K, respectively. Thus,  $\text{TiO}_2$  films grown on nitinol can greatly improve the wear resistance while providing low friction.

The development of commercial applications of nitinol is continuing. For example, nitinol has found application as the race in rolling-element bearing assemblies (see the following photograph). To meet the more stringent thrust-to-weight goals of today's high-performance engines, rolling-element bearings must operate at speeds exceeding 2.4 million DN (the product of the inner race bore in millimeters and the speed in revolutions per minute) and at temperatures up to 478 K using lubricating oil or grease. This temperature limit is imposed primarily by the lubricant (ref. 3). Fatigue is considered to be the life-limiting factor for these bearings, although fewer than 10 percent of the failures are fatigue related. Most failures are due to the lubricant, such as lubricant starvation, contamination, and deterioration (ref. 3). In addition, there are significant adhesion, friction, and wear issues that affect the performance and lifetime of the bearing assembly. The promising results of friction and wear properties obtained in this investigation may fit design needs for high-temperature applications because oxide films may be preferred to oil or grease lubrication. At temperatures above 478 K, oil and grease decompose. Nitinol with oxide surfaces can extend operating temperatures while maintaining low friction and high wear resistance.



*Nitinol rolling-element bearing assembly.*

*Long description of figure 2. A bearing race was made of 60 nitinol to meet the more stringent thrust-to-weight goals of today's high-performance aircraft engines.*

## References

1. Miyoshi, Kazuhisa: Solid Lubrication Fundamentals and Applications. Marcel Dekker, New York, NY, 2003.
2. Miyoshi, Kazuhisa; Lukco, Dorothy; and Cytron, Sheldon J.: Oxide Ceramic Films Grown on 55Ni-45Ti for NASA and Department of Defense Applications: Unidirectional Sliding Friction and Wear Evaluation. NASA/TM--2004-212979, 2004. <http://gltrs.grc.nasa.gov/cgi-bin/GLTRS/browse.pl?2004/TM-2004-212979.html>
3. Zaretsky, Erwin V.: Life Factors for Rolling Bearings. STLE SP-34, 1987.

**Glenn contacts:** Dr. Kazuhisa Miyoshi, 216-433-8758, Kazuhisa.Miyoshi-1@nasa.gov; and Dr. Kenneth W. Street, 216-433-5032, Kenneth.W.Street@nasa.gov

**U.S. Army Research Laboratory, Development and Engineering Center contact:** Dr. Sheldon J. Cytron, 973-724-3368, sheldon.cytron@us.army.mil

**QSS Group, Inc., contact:** Dr. Dorothy Lukco, 216-433-3741, Dorothy.Lukco@grc.nasa.gov

**Authors:** Dr. Kazuhisa Miyoshi, Dr. Kenneth W. Street, Dr. Dorothy Lukco, and Dr. Sheldon J. Cytron

**Headquarters program office:** Aeronautics Research

**Programs/Projects:** LEAP, VSP, AFFT