Journal of ASTM International, October 2009, Vol. XX No. XX
Paper ID
Available online at www.astm.org

S. Peralta[1], *Keisa R. Rosales,*[2] *and Joel M. Stoltzfus*[3]

Liquid Oxygen Rotating Friction Ignition Testing of Aluminum and Titanium with Monel® and Inconel® for Rocket Engine Propulsion System Contamination Investigation

ABSTRACT: Metallic contaminant was found in the liquid oxygen (LOX) pre-valve screen of the shuttle main engine propulsion system on two orbiter vehicles. To investigate the potential for an ignition, NASA Johnson Space Center White Sands Test Facility performed (modified) rotating friction ignition testing in LOX. This testing simulated a contaminant particle in the low-pressure oxygen turbo pump (LPOTP) and the high-pressure oxygen turbo pump (HPOTP) of the shuttle main propulsion system. Monel® K-500 and Inconel® 718 samples represented the LPOTP and HPOTP materials. Aluminum foil tape and titanium foil represented the contaminant particles. In both the Monel® and Inconel® material configurations, the aluminum foil tape samples did not ignite after 30 s of rubbing. In contrast, all of the titanium foil samples ignited regardless of the rubbing duration or material configuration. However, the titanium foil ignitions did not propagate to the Monel and Inconel materials.

KEYWORDS: Rotating friction ignition testing; liquid oxygen environment; aluminum; titanium; metallic contaminant particles

List of Notations

Abbreviations	
HPOTP	High-pressure oxygen turbo pump
LOX	Liquid oxygen
LPOTP	Low-pressure oxygen turbo pump
WSTF	NASA White Sands Test Facility

[1] Mechanical Engineer, NASA Test and Evaluation Contract, P.O. Box 20, Las Cruces, New Mexico 88004.
[2] Chemical Engineer, NASA Test and Evaluation Contract, P.O. Box 20, Las Cruces, New Mexico 88004.
[3] Project Manager, NASA White Sands Test Facility, P.O. Box 20, Las Cruces, New Mexico 88004.

Introduction

NASA Johnson Space Center White Sands Test Facility (WSTF) performed (modified) rotating friction ignition testing in liquid oxygen (LOX). The testing was performed because metallic contaminant particles were found lodged in the LOX pre-valve screen of the shuttle main engine propulsion system on two orbiter vehicles. The contaminant was considered, as worst case, to be either aluminum or titanium. Particle size was estimated to be approximately 1.8 x 1.8 x .08 mm (0.070 by 0.070 by 0.003 in.). The concern was that a contaminant particle could cause an ignition if it were to become dislodged from the screen and travel downstream into either the low-pressure oxygen turbo pump (LPOTP) or the high-pressure oxygen turbo pump (HPOTP). This paper summarizes the testing performed to determine if the contaminant was vulnerable to frictional ignition in the presence of LOX, and if it could lead to ignition of the turbo pump materials of construction.

Rotating friction ignition testing was one of four phases of testing performed to support the investigation of contaminant in the pre-valve LOX screen. Promoted combustion, modified mechanical impact, and frictional testing were also performed in support of this effort.

Test Materials and Sample Preparation

Simulated particle samples were constructed from aluminum foil tape and titanium foil, materials similar to those used on and around the shuttle main engine. The sample length was determined by a cut strip of the material with a measured mass between 0.3 and 0.4 mg for the aluminum tape and between 0.5 and 0.6 mg for the titanium foil. The width of the strip was 1.8 ± .08 mm (0.070 ± 0.003 in.). Once the sample length was determined, a blank piece with a tail was cut. The tail would be used to fasten the particle sample to the stationary friction sample. The tail was no longer than 6.4 mm (0.25 in.) and no shorter than 2.54 mm (0.1 in.). To simulate the “crumpled” shape of the particle found on the orbiter pre-valve screen, the strip was folded into an “accordion” shape approximately 0.90 mm (0.035 in.) long. Using tweezers, the tail end was twisted 90 degrees (Figures 1 and 2). Each simulated particle was then fastened to a stationary sample using a brass flathead screw (Figure 3). The rotating and stationary

samples were fabricated from Monel®[4] K-500 and Inconel®[4] 718 to represent the LPOTP and HPOTP materials of construction. The stationary sample was made of Inconel; and the rotating samples varied, being Monel or Inconel. Figure 4 depicts the rotating and stationary samples.

Test Procedures and Conditions

The rotating frictional tests were conducted using the WSTF LOX frictional heating test system to simulate what could occur inside the LPOTP and HPOTP if contaminant were to reach those parts. The location and configuration of the samples in the test system is depicted in Figure 5. The test chamber was assembled and installed in the test system, and the data acquisition system was activated. After pressurizing the test system, the chamber was pressurized and checked for leaks, then vented to ambient pressure. With flowing LOX, the test chamber was chilled down and pressurized to the target pressure of approximately 400 psia. Once the LOX pressure stabilized, the drive motor was turned on. The rotational speed of the rotating sample was approximately 30,000 r/min to represent the linear velocities found in the turbo pumps. The data acquisition program operated a pneumatic cylinder that controlled the linear travel of the rotating sample to and from the stationary sample. This allowed the foil sample to be "crushed" to a target gap of 0.51 mm (0.02 in.) for Monel and 0.76 mm (0.03 in.) for Inconel. These crush heights were the gaps found in the turbo pumps where the particle could become lodged and possibly ignite.

Each test with the aluminum foil tape was terminated after rubbing for a maximum duration of 30 s. Tests with the titanium foil were terminated at ignition, which was 1 s in most cases (see Table 1).

Because the Monel K-500 was not considered flammable at the test conditions, only one titanium with Monel sample was tested. However, several tests were run for titanium with Inconel samples, because it was not certain whether the titanium foil would propagate to the Inconel material.

At each test termination, the acquisition program reversed the motion of the pneumatic cylinder, pushing the rotating sample away from the stationary sample and foil test sample. After the test system

[4] Monel® and Inconel® are registered trademarks of Inco Alloys International, Inc., Huntington, West Virginia.

was shut down and the test chamber vented to ambient pressure, the sample specimens were removed, visually inspected, and photographed. Observations were recorded, and the test results were analyzed.

Test Results

For the aluminum foil tape with the Monel and Inconel samples, five tests were performed with each sample material in 100 % LOX. The aluminum did not ignite after being rubbed for 30 s (Figures 6 through 9). For the titanium foil with the Monel sample, one test was performed. The titanium ignited after being rubbed for 30 s (Figure 10). For the titanium foil with the Inconel sample, five tests were performed. In all five of the tests, the titanium ignited (Figures 11 through 15).

In both the Monel and Inconel material configurations, the aluminum foil tape samples did not ignite. In contrast, all of the titanium foil samples ignited regardless of the rubbing duration or material configuration. However, the titanium foil ignitions did not propagate to the Monel and Inconel materials.

TABLE 1—*Summary of results for rotating friction testing.*

Sample Configuration	Simulated Location	Target Gap mm (in.)	Pressure (psia)	Rub Duration (s)	Speed (r/min)	Sample Ignition
Titanium/ Monel – 1	LPOTP	0.51 (0.02)	512	30	30,100	Yes
Aluminum/ Monel – 1	LPOTP	0.51 (0.02)	446	30	30,300	No
Aluminum/ Monel – 2	LPOTP	0.51 (0.02)	400	30	30,500	No
Titanium/ Inconel – 1	HPOTP	0.76 (0.03)	430	5[a]	30,600	Yes
Titanium/ Inconel – 2	HPOTP	0.76 (0.03)	480	1	30,200	Yes
Titanium/ Inconel – 3	HPOTP	0.76 (0.03)	440	1	30,000	Yes
Titanium/ Inconel – 4	HPOTP	0.76 (0.03)	420	1	30,200	Yes
Titanium/ Inconel – 5	HPOTP	0.76 (0.03)	356	1	30,000	Yes
Aluminum/ Inconel – 1	HPOTP	0.76 (0.03)	445	30	30,300	No
Aluminum/	HPOTP	0.76 (0.03)	443	30	30,000	No

Inconel – 2						
Aluminum/ Inconel – 3	HPOTP	0.76 (0.03)	446	30	29,800	No
Aluminum/ Inconel – 4	HPOTP	0.76 (0.03)	448	30	30,300	No
Aluminum/ Inconel – 5	HPOTP	0.76 (0.03)	435	30	30,200	No
Aluminum/ Monel – 3	LPOTP	0.51 (0.02)	421	30	29,900	No
Aluminum/ Monel – 4	LPOTP	0.51 (0.02)	492	30	30,000	No
Aluminum/ Monel – 5	LPOTP	0.51 (0.02)	410	30	29,900	No

[a] Bearing failure caused the rub duration to last longer than 1 s.

FIG. 1—*Aluminum foil tape sample (top); titanium foil sample (bottom).*

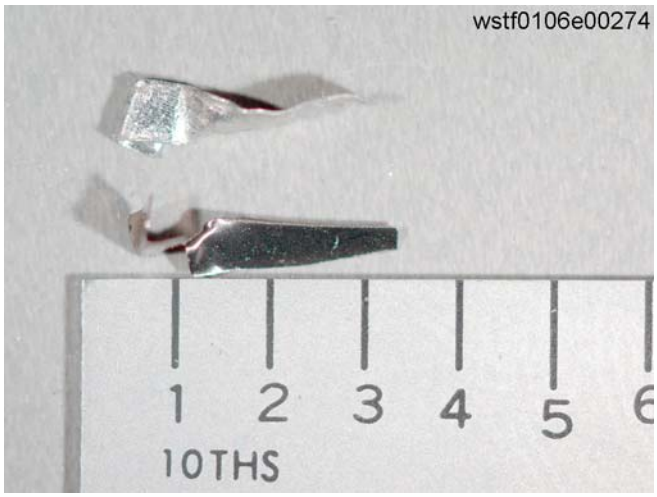

FIG. 2—*Aluminum (top) and titanium (bottom) foil samples, second view.*

FIG. 3—*Aluminum foil tape simulated particle mounted to Inconel stationary sample.*

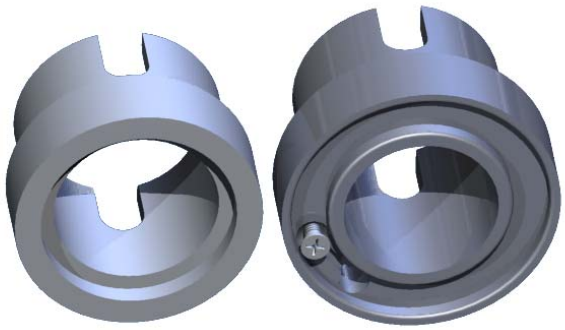

FIG. 4— *Rotating sample (left); stationary sample (with particle holder) (right).*

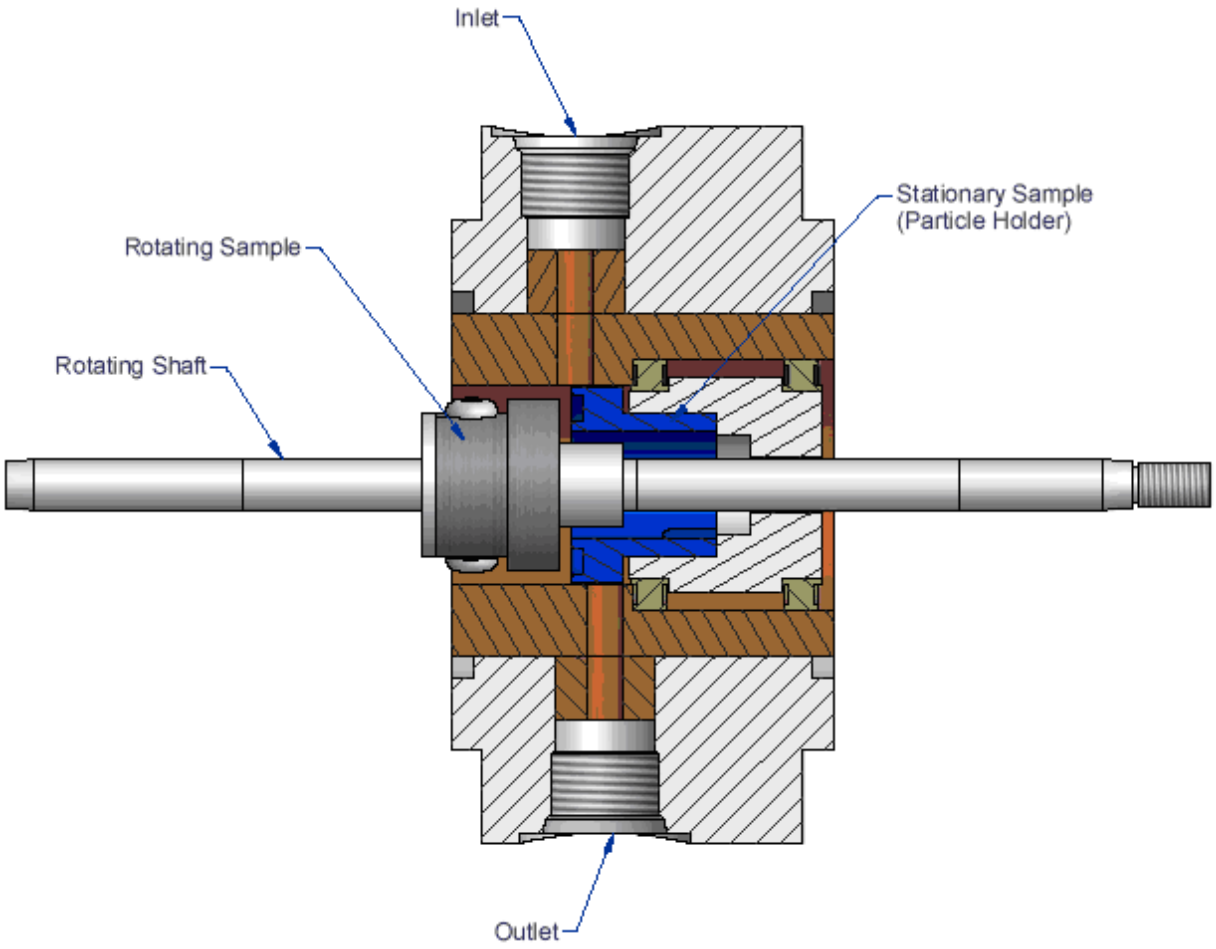

FIG. 5—*Location of sample holders in test system.*

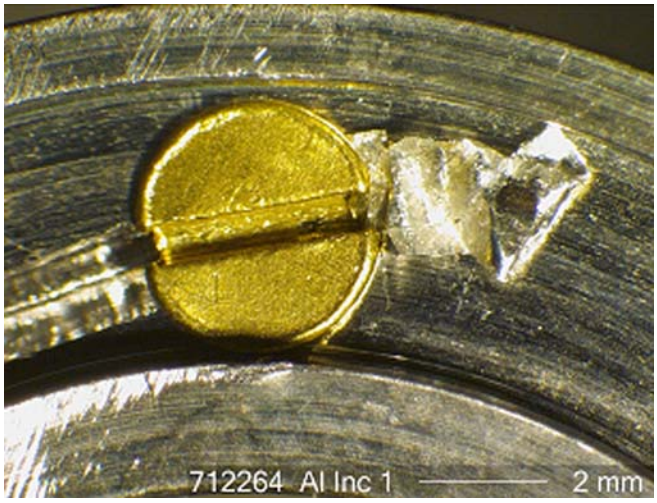

FIG. 6—*Aluminum/Inconel – 1 (no ignition).*

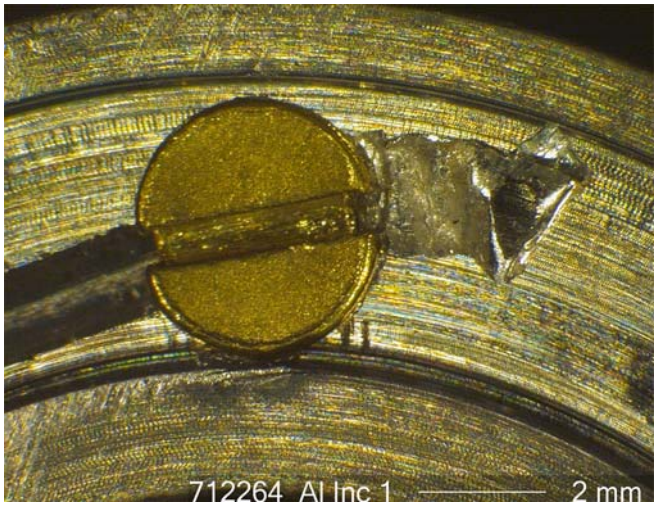

FIG. 7—*Aluminum/Inconel – 2 (no ignition).*

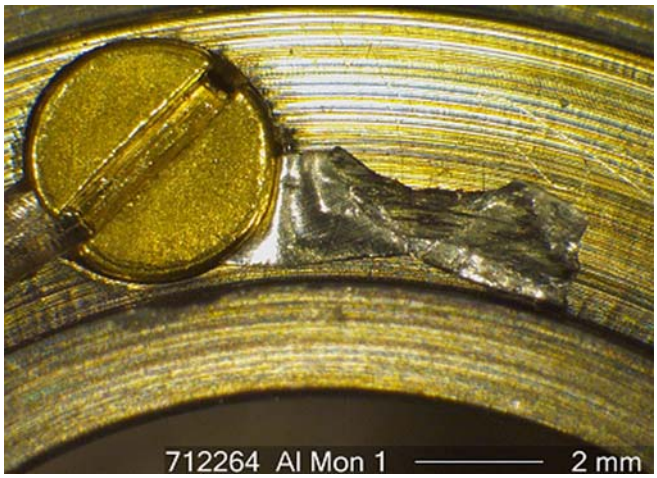

FIG. 8—*Aluminum/Monel – 1 (no ignition).*

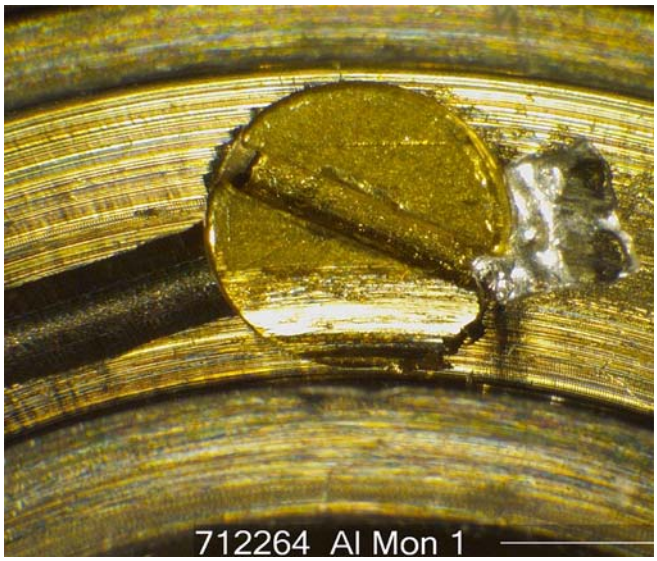

FIG. 9—*Aluminum/Monel – 2 (no ignition).*

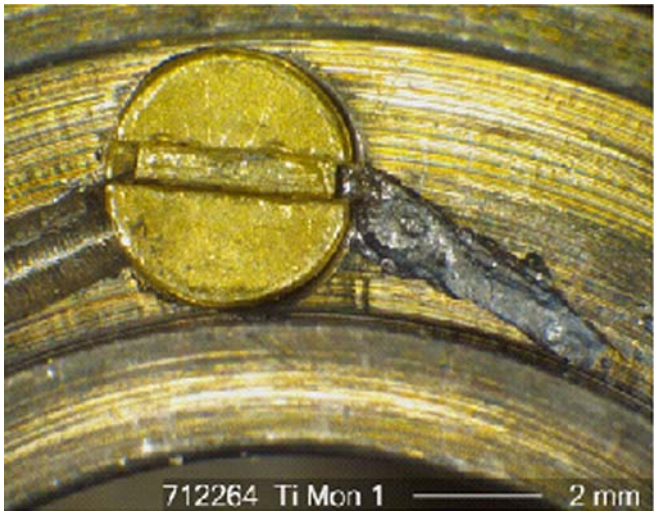

FIG. 10—*Titanium/Monel – 1 (ignition).*

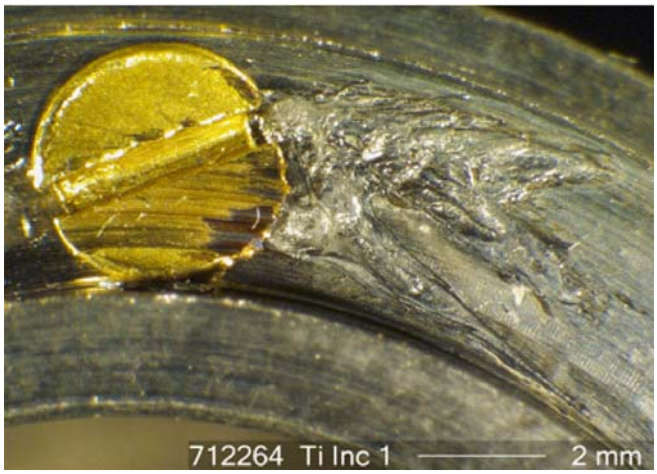

FIG. 11—*Titanium/Inconel – 1 (ignition).*

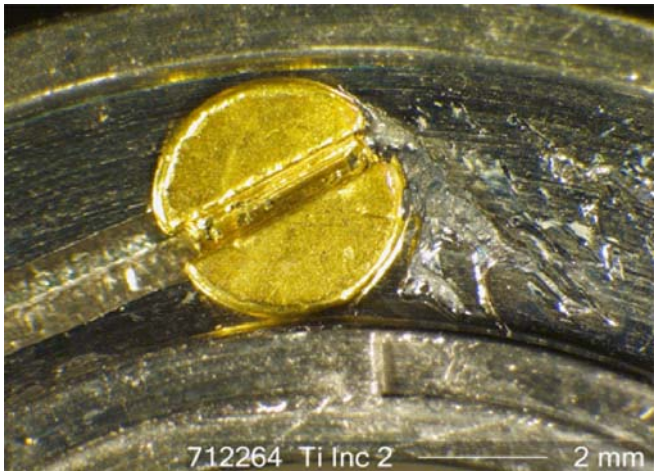

FIG. 12—*Titanium/Inconel – 2 (ignition).*

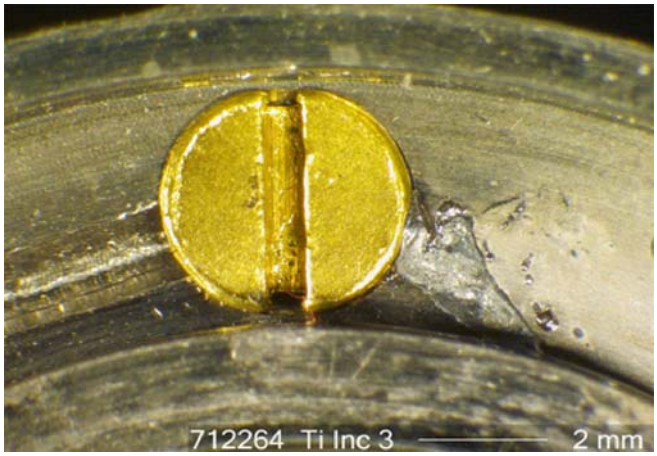

FIG. 13—*Titanium/Inconel – 3 (ignition).*

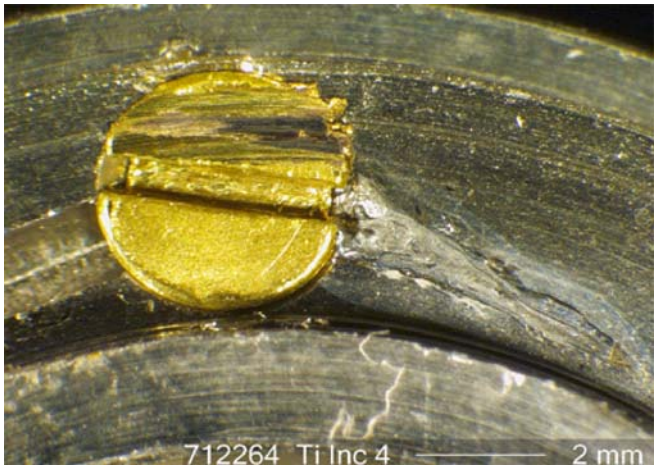

FIG. 14—*Titanium/Inconel – 4 (ignition).*

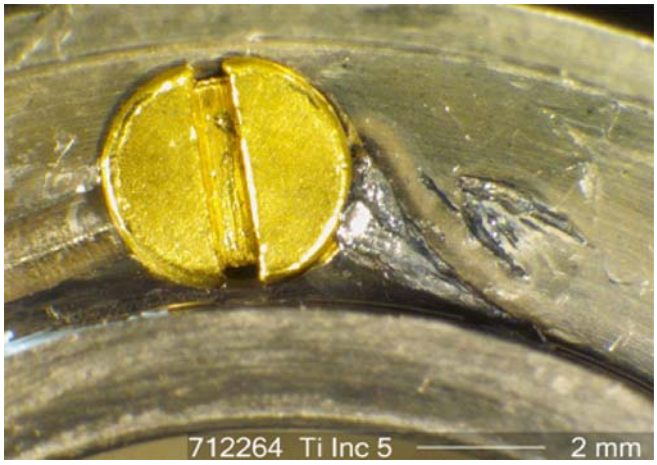

FIG. 15—*Titanium/Inconel – 5 (ignition).*