Wire-break Electrical Arc Ignition Testing of Spacesuit Materials

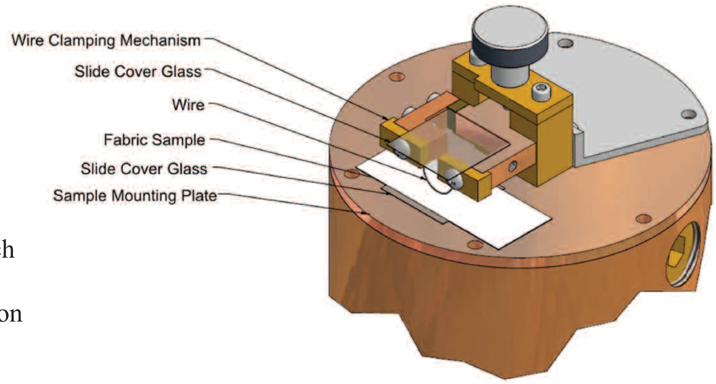
Sarah R. Smith,
White Sands Test Facility, Johnson Space Center
Timothy D. Gallus,
White Sands Test Facility, Johnson Space Center
Susana A. Harper,
White Sands Test Facility, Johnson Space Center
Harold D. Beeson,
White Sands Test Facility, Johnson Space Center

In 2002, a frayed BioMed wire was found during Space Shuttle *Endeavour* flight 113/International Space Station Assembly Mission 11A (flown November 23 – December 7, 2002), extravehicular activity (EVA) 2. This led to concerns that it may be possible to ignite spacesuit materials by electrical arcing. Ignition of materials inside the spacesuit could be catastrophic since it is pressurized with a high concentration of oxygen, which renders many materials flammable and able to support vigorous combustion. Although the subsequent investigation of the spacesuit determined that adequate controls were in place and no hazard was present with the frayed wire, additional testing was requested to fully understand the hazard of electrical arc ignition in the spacesuit. Therefore, Johnson Space Center's EVA Project Office contacted White Sands Test Facility (WSTF), one of the nation's preeminent resources for testing and evaluating potentially hazardous materials, spaceflight components, and rocket propulsion systems, with the purpose of gaining an understanding of the hazard of electrical arc ignition inside the spacesuit. WSTF conducted arc ignition tests on multiple spacesuit materials placed in various oxygen concentrations.

Three test methods were developed to understand what conditions were most likely to produce ignition with the least amount of currents. The most severe method was then used to characterize the materials currently used in the spacesuit for the minimum level of current necessary to initiate combustion at a given voltage. The most applicable and conservative test method developed to test electrical arc ignition of materials was the wire-break test. Data gained during this test program offered insight into the electrical arc ignition mechanism and provided a better understanding of the Apollo (1970s) Program data used to justify the current spacesuit material selection and electrical power use.

Test System

All tests were performed in a test chamber in the High Pressure Test Area at WSTF. Humidity was kept to a minimum through the introduction of dry gases into the chamber, which consisted of a stainless-steel cross with four 4-in. ports that accommodated a gas inlet and outlet, a view window for normal and high-speed video recording, a test sample mounting block, a thermocouple for temperature measurement, and power for the electrical arcing. A water-bath heater and thermocouple were attached to the back of the sample mounting block to allow heating of the test samples. The sample mounting block was heated to 95 ± 5°F. The test system was capable of a maximum test pressure of 100 psia with 100% oxygen or 50% oxygen/nitrogen gas mixtures.



The power supply provided a maximum current of 10 amps at 28 Vdc, and was designed to emulate batteries while allowing flexibility for different voltages and currents during testing. Two identical power supplies were used along with a transistorized current limiter. This power supply scheme was very quick to respond to the rapid load changes produced by arcing events.

Wire-break Test Method

The wire-break test was developed as a way to create arcing events using wires in intimate contact with the test material. A single strand of fine wire was clamped at each end and shaped into a "U" such that the bottom of the "U" was in intimate contact with the test material (see figure). The wire, which was made from silver-coated copper, met the specifications for the wires used inside the spacesuit. To ensure the wire would break, its size was varied depending on the test current and voltage. Applying current and voltage to the wire caused it to heat up and eventually break. As the wire heated up, the test material was preheated. When the wire broke, an arc occurred. This is a realistic scenario inside the spacesuit and could occur if a bundle of wires was damaged and a single strand was left to carry the power.

Wire-break Electrical Arc Ignition Testing of Spacesuit Materials

continued

For ignition to occur, the wire needs to be in direct contact with the test sample because of the importance of preheating. Each wire-break test can be divided into preheating and an arcing event. Calculations for tests where ignition occurs show that the amount of available energy during preheating is roughly three orders of magnitude greater than the available energy during the arcing event. As the wire heats up while in contact with the test material, the voltage will rise slightly because the electrical resistance of the wire increases. With a fixed current power supply, this higher resistance creates both a higher voltage drop across the wire and more heat evolution at the wire. The heat-sinking ability of the wire holder assembly ensures that the hottest location on the wire will occur somewhere near the bottom of the "U." The hot wire preheats the test material, which then begins to vaporize before the arcing event occurs. Once the material is preheated, ignition occurs at a much lower arc power since the vapors are more easily ignited than the bulk material. It is clear from the calculations that the amount of energy available in the arcing events is greater than that required to ignite most hydrocarbon vapors.

The materials chosen for testing were ones that are used in the spacesuit both on orbit and at the Neutral Buoyancy Laboratory, where astronauts receive pre-flight training for planned EVAs. The test materials were cut into test samples and then frayed, when possible. It was possible for the wire to melt through the test materials, creating a short between the wire and the sample mounting plate; therefore, a slide cover glass was placed underneath the test samples. In addition, a slide cover glass was used to roughly hold in the vapors generated by the preheating of the test samples (see figure).

Before testing commenced, the test voltage was set to correspond to the predetermined test conditions and the current was set to slightly lower than the desired test conditions. The appropriate wire size was determined, and the wire was clamped into place. The slide cover glass for roughly capturing the sample vapors was placed on top of the wire-clamping mechanism. The water-bath heater preheated the test sample to 95 ± 5°F. Next, the test chamber was sealed, purged, and pressurized with the correct pressure and oxygen concentration. Power was then applied to the wire, and the test conductor manually increased the current until the wire broke, creating an arcing event. If an ignition occurred, testing was continued at a lower current level. If no ignition occurred, high-speed video and visual inspection were used to verify that the wire broke in the desired location and was touching the test sample. Each test consisted of one wire break event, which was observed for visual evidence of test material ignition. A material failed at the test current if it ignited once in a maximum of 60 tests, or passed if it did not ignite in 60 tests.

Discussion and Conclusions

The wire-break test is conservative because it assumes a worst-case condition, when a bundle of wires has been damaged in such a way that only one strand is left to carry the electrical power. The wire-break test also assumes that the remaining strand could be damaged in such a way that it would break at a lower current than that required to break a pristine flight wire. In addition, the wire, in direct contact with the test material, preheats the test sample, allowing the material to begin to vaporize before the arcing event occurs, resulting in ignition at a much lower arc power.

There were marked differences in the ignitability and burning characteristics of the test materials, but they do not appear to be related to the minimum currents required for ignition. In addition, the configuration of the test materials played an important role in the test materials' ignitability. Frayed materials were easier to ignite; and, in general, fuzzier materials ignited at lower currents than smooth materials, which required the highest currents for ignition.

The wire-break test provided data that can be applied in determining the ignition risks for the spacesuit materials. The data indicate that safe usage of materials inside the spacesuit requires a combination of physical isolation of materials susceptible to ignition and limiting the available current and voltage. The wire-break test method can also be used to assess materials used in other systems, such as hyperbaric chambers and hospitals.

More information on the wire-break test method and other electrical arc ignition test methods can be found in "Electrical Arc Ignition Testing of Spacesuit Materials," American Society for Testing and Materials STP 1479 2006.