CRYOGENIC AND ELEVATED TEMPERATURE HYPERVELOCITY IMPACT FACILITY

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ABSTRACT

The Hypervelocity Impact Facility at Space Research Institute, Auburn University has recently completed a facility upgrade that permits the impact testing of space materials within the cryogenic and elevated temperature range. Sample temperatures within the range of 24 – 420K have been achieved for polymer films. These wide temperature range capabilities add to the facilities testing experience with a wide variety of testing configurations including grazing angle impacts, electrically biased samples and plasma generation and characterization in the target chamber environment.

The facility utilizes a plasma drag gun to accelerate a variety simulated micrometeorite materials in the 50 to 150 _m range to velocities between 5 and 12 km/s. For each test 5 to 50 particles impact the surface of the target sample within an impact area of approximately 15 cm in diameter. The test chamber can accommodate samples up to a meter wide for ambient and heated tests, and 48 cm for cryogenic samples. The gun and test chambers are evacuated by He cryopumps and dry roughing pumps to produce a clean, oil free environment. Utilizing a streak camera and PMT detection system, the correspondence between individual particle size, speed and impact site can be determined. Standard post analysis yields: micrographs of each impact site, dimensions of the pertinent impact characteristics and individual particle velocity and size estimates.

1. Background

The hypervelocity impact facility at Space Research Institute (SRI), Fig. 1, uses a plasma drag gun to simulate the effect of high velocity micrometeorite and space debris impacts upon spacecraft materials and hardware. The facility can be setup to accommodate a wide range of testing configurations including off angle impacts, electrically biased samples, injection and characterization of plasma in the target chamber and, the most recent addition to the capabilities, cryogenic and elevated temperature control of the sample material. Since it's inception in 1990, SRI's facility has conducted hundreds of tests for numerous aerospace companies, government organizations and academic research groups.

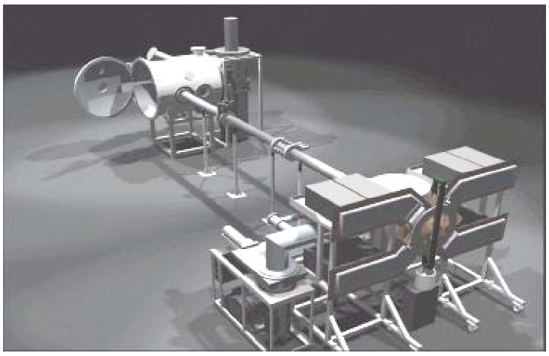

Figure 1: SRI Plasma drag gun

2. Facility Configuration

In the gun chamber, particles are accelerated by the expansion of plasma generated by the discharge of 40kV capacitor bank through a thin aluminum foil. In front of the foil, 50 - 150_m diameter particles are suspended on a thin support film housed in the gun barrel assembly shown in Fig. 2. During the discharge 1.0 mega-ampere is delivered through the foil with a rise time of ~2.0_s. The expanding plasma exchanges momentum with the particles, accelerating the simulated micrometeorite materials to velocities up to 12 km/s.

The nature of the plasma drag acceleration process results in 5 to 50 particles reaching the target with a velocities distribution of 5 to 12km/s. This variation in velocity provides impact data with a kinetic energy distribution representative of a typical mission environment.

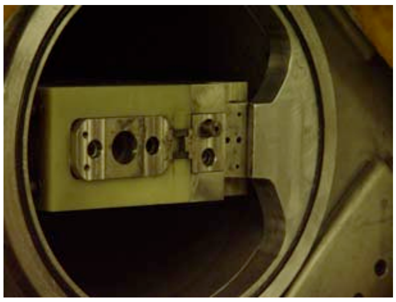

Figure 2: Gun Block

As the particles exit the gun chamber and enters the flight tube, a series of skimmer cones segregate the particles that are not aligned with the flight tube. The

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outline of the skimmer cones can be seen through the view port on the right side of Fig. 3.

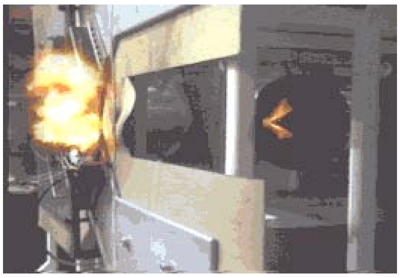

Figure 3: Gun chamber

Mounted in the flight tube, a magneforming shutter, shown in Fig 4., is used to capture slow moving gun debris. This reduces the number of impacts from material ablated from the gun barrel armature. The timing of the shutter is controlled by a digital delay generator, which is triggered by a signal from a Rogowski coil attached to the gun chamber bus bars and can be adjusted to provide any specified particle velocity limit.

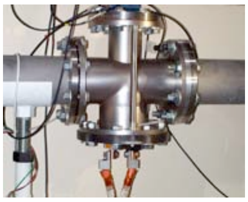

Figure 4: Magneforming shutter

The target chamber can accommodate samples up to 1.5 x 2.0m with a total volume of 1.5 m^3. Multiple access ports, shown in Fig. 4, can be configured to accommodate a variety of customer instrumentation in addition to the facility diagnostic equipment.

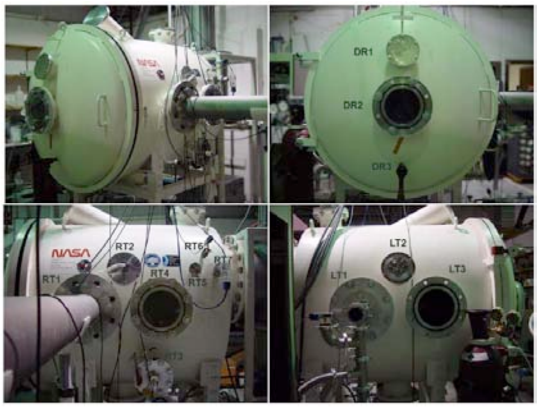

Figure 5: Target chamber angle, front, right and left

3. Data Analysis

During the target chamber set up, a thin witness film is mounted between the sample and the particle flight tube. The film thickness is selected such that the particles are larger than the ballistic limit of the film. Therefore each particle punches out a hole in the film that is representative of the dimensions of the impacting particle. Utilizing a suite of diagnostic and analysis instrumentation the location and velocity of each impact is determined. From the correspondence between the particle's size speed and location, the amount of energy delivered to an individual impact site can be determined.

During post-test analysis, micrograph images of the impact sites are recorded, measured and catalogued. Additional characterization of the impact sites can be conducted based upon the needs of the project, including scanning electron microscopy (SEM) providing high resolution images of the impact sites and energy dispersive X-ray analysis (EDXA) to determine the type and quantity of residue left in the crater.

3. Particle Selection Options

A variety of micrometeorite and space debris simulants can be loaded into the gun including olivine, aluminum oxide and soda lime glass. A majority of tests conducted at the facility use soda lime glass as the simulant, shown in Fig. 6. This low-density material is readily available as spheres and the robust material characteristics decreases fracturing of the particle during the acceleration process. The spherical shape of the impacting particle and its robust nature allows for an accurate determination of the size of each particle that impacts the surface of the sample.

Figure 6: Soda lime glass particles

For simulating the impacts due to extraterrestrial stony micrometeorites, olivine, shown in Fig. 7, is typically chosen because of its compositional similarity to material recovered during space flight experiments. Because the material has a high density, the mean particle velocities are typically slower that soda lime glass. Olivine particles have an irregular shape and tend to fracture during the acceleration process. This can lead to difficulties in identifying the size of the particle prior to impact.

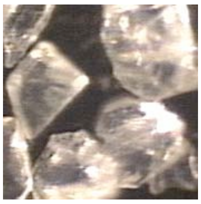

Figure 7: Olivine particles

Aluminum oxide, shown in Fig 8 is often used to simulate the impact due to spacecraft debris. The mechanical properties of this material is similar to the olivine in that it is typically non-spherical and tends to fracture during the test conditions.

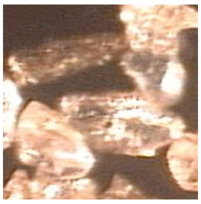

Figure 8:Aluminium oxide particles

In addition to the above materials, other particle compositions have been used including silicon carbide. In general, soda lime glass provides the highest particle speeds and the most accurate determination of the particle size prior to impact.

4. Cryogenic and Elevated Temperature Capabilities

A recently completed upgrade has extended the capabilities of the facility to permit the testing of materials at elevated and cryogenic temperatures. Validation tests have achieved sample temperatures of 24K on metal-coated thermoplastic films. To reach these temperatures, a liquid nitrogen (LN_2) enclosure and a Helium cryogenic refrigerator were installed in the target chamber, as shown in Figure 9.

The LN_2 enclosure can accommodate sample sizes of approximately 50x50cm. Samples are mounted to a copper frame which is attached to the He pump cryohead using indium foil to reduce thermal resistance between the connections. A movable cold shutter, also thermally coupled to the cold head, is installed in front of the sample to provide a heat sink for thermal radiation coming from the sample. The thermally isolated LN_2 enclosure is assembled around the sample frame and view windows to the flight tube are secured. Before the target chamber is sealed, multi layered insulation (MLI) is wrapped around the LN_2 enclosure. The LN2 enclosure removes the majority of heat from the system and shields the sample from ambient temperature chamber walls, while the cryorefrigerator provides heat removal between the LN_2 temperature (70K) to the target temperature.

Figure 9: LN_2 enclosure and Cryogenic refrigerator

The chamber is evacuated using dry roughing and cryogenic pumps. After the chamber reaches 10^{-5} torr, LN_2 flow is initiated and the cryogenic refrigerator is started. Cool down times to reach 24K for the thermoplastic samples were approximately 45 hours as shown in Figure 10.

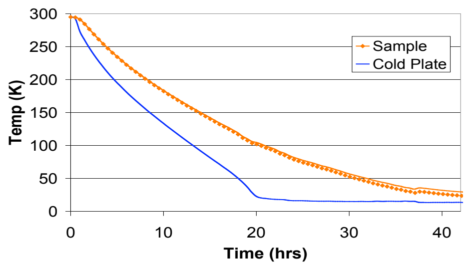

Figure 10: Sample cool down profile

During the cool down the LN_2 windows remain closed. To limit the temperature rise of the sample due to exposure to radiant energy of the target chamber and the flight tube, the windows are remotely lowered to clear the particle flight path seconds before discharging the gun. The sensitivity of the silicon diode temperature monitoring detectors allows resolution of the exact time and temperature of the samples during impact. In Fig. 11 the spike in the temperature change provides a verifiable indication of exact firing time.

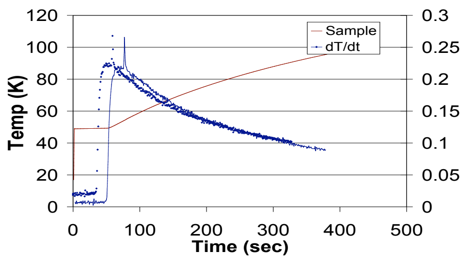

Figure 11: Resolution of firing timing

For an elevated temperature test three 250 W infrared lamps are installed in the target chamber to heat the sample. The full volume of the target chamber can be utilized and various sample-mounting options are available. For thin thermoplastic films, sample temperatures of 460 K have been achieved in less than 5 minutes. The infrared lamps are switched off just prior to discharging the gun to avoid interference with the velocity analysis instrumentation.

5. Oil Free Vacuum System

With the facilities original diffusion pump vacuum system, the back flow of diffusion pump oil could lead to condensation of the oil on the samples at the operational temperatures. Therefore an oil-free system consisting of sets of dry roughing and liquid Helium cryo pumps, Fig. 12, were installed on both the target and gun chambers. Current vacuum levels are approximately 10^{-5} torr and further improvements are expected as Viton seals are replaced with knife-edge gaskets.

Figure 12: Oil-free He cryopump

6. Potential Areas for Future Research

The successful integration of cryogenic and elevated temperature capabilities with Space Research Institute's unique hypervelocity impact testing abilities provides opportunities to verify the performance of materials and hardware at temperatures representative of the mission environment. Initial tests on polymeric materials indicate that distinct differences exist between tests conducted at cryogenic temperatures versus elevated temperatures in the nature of the impact craters formed.

Another potential area of interest is to assess the effect of temperature variation upon the process of impact-initiated arcing of biased solar arrays in the space plasma environment, Fig. 13. When moving from the cold shadow of the earth to a full solar exposure the voltage will instantly surge in the array due to the

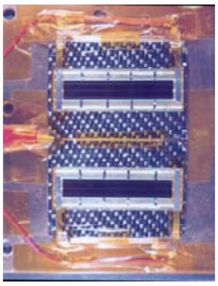

Figure 13: Electrically biased solar cell setup

increase in the semiconductor's output voltage caused by higher efficiencies at cold temperatures. Whether this combination of high voltage and cold temperatures during an impact event affects the probability of initiating an arc is a potentially valuable area of investigation.

Impact events at cryogenic and elevated temperatures may also modify the characteristics and extent of damage that occur to optical components and antireflective coatings. As temperature changes, the stress between layered materials with different coefficients of expansion increases. This stress may lead an increase in the extent of delamination initiated by hyper velocity impacts.

6. Summary

The HYPER facility modification has demonstrated that sample temperatures as low as 24K and as high as 450K have been achieved. Hypervelocity impact testing upon samples at cryogenic and elevated temperatures provides opportunities to simulate micrometeorite impact damage at conditions closer to those experienced by a spacecraft's systems during a mission. The ability to provide a clean oil free testing environment leads to additional opportunities where post impact analysis of optical coatings is desired. In conjunction with HYPER's unique capabilities with regard to particle speed, size, and number of impacts per test, these improvements further increase the reliability of hypervelocity impact damage evaluation and mitigation tasks in the design and construction of spacecraft.