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N95- 27671

A NEW TECHNIQUE FOR GROUND SIMULATION OF HYPERVELOCITY DEBRIS

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SUMMARY

A series of hypervelocity damage experiments were preformed on spacecraft materials. These experiments employed a technique which accelerates micro flyer plates simulating space debris traveling at 3 to 8 km/sec. The apparatus used to propel the micro flyer plates was compact and fit well into a space environmental chamber equipped with instrumentation capable of analyzing the vapor ejected from the sample. Mechanical damage to the sample was also characterized using optical and scanning electron microscpopy.

Data for this work was obtained from hypervelocity impacts on a polysulfone resin and a graphite polysulfone composite. Polysulfone was selected because it was flown on the Long Duration Exposure Facility (LDEF) which spent several years in low Earth orbit (LEO).

Chemistry of the vapor produced by the impact was analyzed with a time of flight mass spectrometer, (TOFMS). This represents the first time that ejected vapors from hypervelocity collisions were trapped and analyzed with a mass spectrometer. With this approach we are able to study changes in the vapor chemistry as a function of time after impact, obtain a velocity measurement of the vapor, and estimate a temperature of the surface at time of impact using dynamic gas equations. Samples of the vapor plume may be captured and examined by transmission electron microscopy.

Studies were also conducted to determine mechanical damage to a graphite polysulfone composite and a polysulfone resin. Impact craters were examined under optical and scanning electron microscopes.The collision craters in the matrix were typical of those shown in conventional shock experiments. However, the hypervelocity collisions with the graphite polysulfone composite were remarkably different than those with the resin.

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INTRODUCTION

The effects of hypervelocity collisions on the structural integrity of materials have been the subject of numerous studies (Refs.1 through 5). Two different damage effects were looked at in this work. First the chemistry of vapor produced by the impact was studied. Also mechanical damage to a resin target and a resin/fiber target was studied and compared.

The collision process vaporizes the resin and causes it to de-polymerize as would be expected from the pressures and temperature present during the early stages of the collision. The chemistry of the vapor generated by the hypervelocity impact was characterized using a TOFMS. This allows for the studying of the vapor in a time resolved manner. The mass species produced, generation times of different mass species, and velocities of different species may be characterized with this technique, giving insight into the damage mechanisms involved with hypervelocity impact. Characterization of vapor deposited on TEM grids was conducted in a parallel research effort in which vapor deposits were produced by laser ablation of graphite polysulfone. Examination under high magnification revealed that the vapor deposited as very small spheres, many of which were single crystal graphite.

Questions as to the origin of some of the different contamination found on LDEF may be explained by the deposition of vapor caused by the impact of space debris on polymer samples flown on LDEF. An example of this was seen on our aluminum samples adjacent to our polysulfone samples. The deposits on aluminum samples contained sulfur which could have been vapor deposited from impacts on our polysulfone samples. Secondary debris are of importance when considering space environment effects on spacecraft optics and electronics susceptible to contamination damage originating from this source.

The phenomena of damage, while well documented, is not well understood. Most of the work on damage to composites was conducted at low velocities, less than 100 m/s. The usual way to produce damage at hypervelocities involves the use of air guns and rail guns which has made it difficult to look at damage caused by small particles. The technique used in this work has made it possible to produce hypervelocity impact of resin and composite samples with relative ease. The different damage effects, which were seen for the resin and for the composite targets is attributed to changes in density within the materials. Much of what happens inside a material after a hypervelocity collision apparently occurs after the initial compressive shock wave has passed through the material and has reflected back as a rarefaction wave. Reflective rarefaction waves occur when the density suddenly changes as at the back surface or at internal discontinuities such as precipitates or fibers. The nature of the damage observed in composites and resins is the focus of ongoing studies.

EXPERIMENTAL

The flyer-plate technique used in this expermient has several advantages over conventional methods of producing hypervelocity particles. This technique has the following advantages. The method is compact and fits conveniently into the chamber of the TOFMS. It produces very little chemical contamination when accelerating a flyer plate as compared to the electric gun or explosives. Aim is accurate and the flyer may be directed from outside of the vacuum chamber used to simulate space. Finally, the target can be oriented relative to the flyer to maximize the ejecta plume entering a diagnostic device such as an ionization chamber of a TOFMS.

Flyer plates 5 thick and 700 in diameter were accelerated at targets in this work which was carried out in the ultra high vacuum chamber within a TOFMS . A detailed discription of the flyer plate accelerator is found in REF (6). While we generally used an aluminum flyer, materials other than aluminum have been launched; however, alumimum is preferred since it closely represents that of the average particle of space debris (Ref.7). The velocities of the flyer plates are measured using a VISAR System which is a laser interferometric technique (Ref.8)

Figure 1 shows the configuration used to study the chemical species produced by hypervelocity collisions of space structural materials by simulated particles of space debris. In the configuration shown, the flyer plate struck the polysulfone target at an angle of 45° relative to the direction of flight. This arrangement provides a favorable orientation for the vapor ejecta to escape and to enter the mouth of the TOF mass spectrometer.

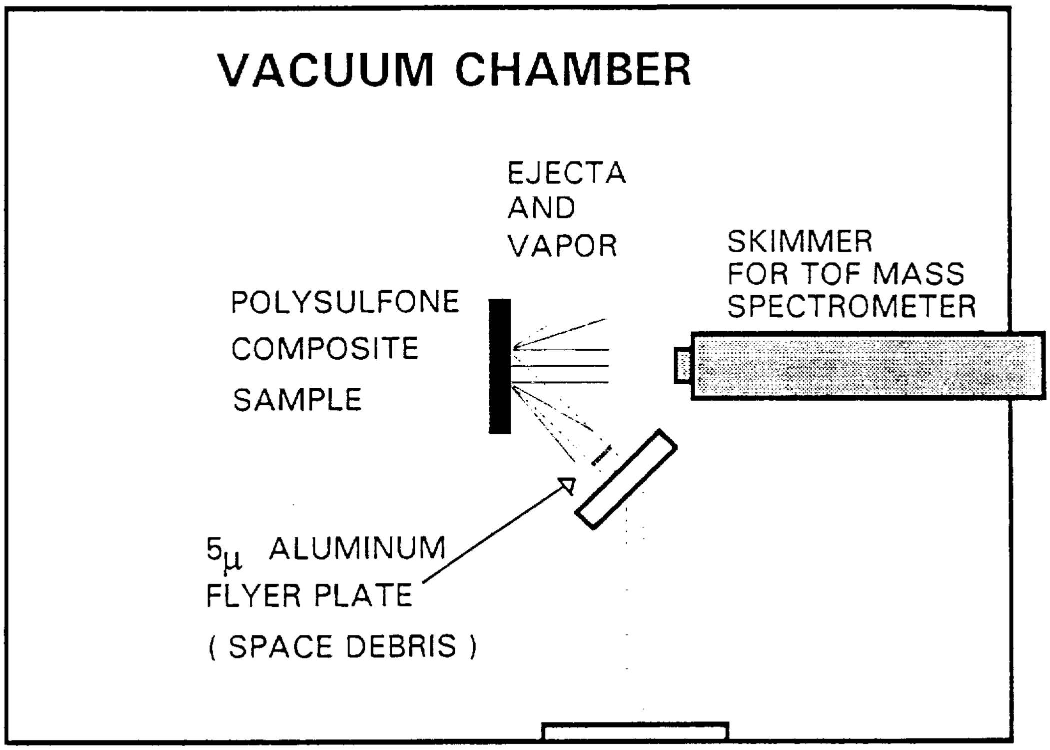

Figure 1. Experimental arrangement used to study chemical reactions from hypervelocity particle collisions.

The TOF mass spectrometer is capable of evaluating a complete mass spectrum from mass 1 to 200 in 12 ms. A hypervelocity collision adiabatically heats the polysulfone and ejects chemical species in the form of vapor. The ejected chemical species generated by the impact travel from the polysulfone target to the throat of the mass spectrometer where the vapor is ionized and accelerated toward the mass spectrometer detector. The chemical species are scanned as a function of time to produce a mass spectrum. Chemical species arriving later than 12 ms will be detected in the next spectral scan. This has the advantage that the chemical species generated first after impact can be differentiated from those which form at later stages.

In order to study the damage mechanism, some preliminary collisions were made in air apart from the TOFMS. In these experiments, an aluminum flyer was fired at a polysulfone resin target and at a polysulfone composite target. The velocities of the collisions ranged from 3 to 7 km/s. The impacted samples were then examined using optical and scanning electron microscopy at the Phillips Laboratory. Samples were first examined and photographed using the Nikon optical system at 50X and 1OOX. After optical studies, the specimens were sputter coated with a thin conductive layer of gold-palladium alloy for viewing in the scanning microscope. The coating prevents excessive charging during the bombardment with the electron beam of the microscope. The samples were also examined using the energy dispersive analysis of X-rays produced by the electron beam excitation of the atoms (EDAX).

RESULTS AND DISCUSSION

The effort to measure chemical species produced by hypervelocity collisions of aluminum with polysulfone resin were successful. The spectrum produced is shown in Figure 2 and is averaged over several scans to provide better statistical results. Esentially no changes in the spectrum were observed once the species were detected, which would have affected the averaging. As can be seen, the spectrum covers masses 1 through 100, and the relevant species are identified on the chart. The mer of polysulfone is also shown for reference. Sulfur, which is one species easily removed from the polysulfone mer, shows up at 32 amu on the spectrum. The sulfur species could have been overshadowed by the oxygen molecule which also has the same mass, 32 amu. However, the amount of oxygen present should be quite small in the vacuum chamber and the oxygen that is present is already combined with the aluminum. Therefore, the peak, at 32 amu is an indication of sulfur and is therefore positive verification that the polysulfone de-polymerized.

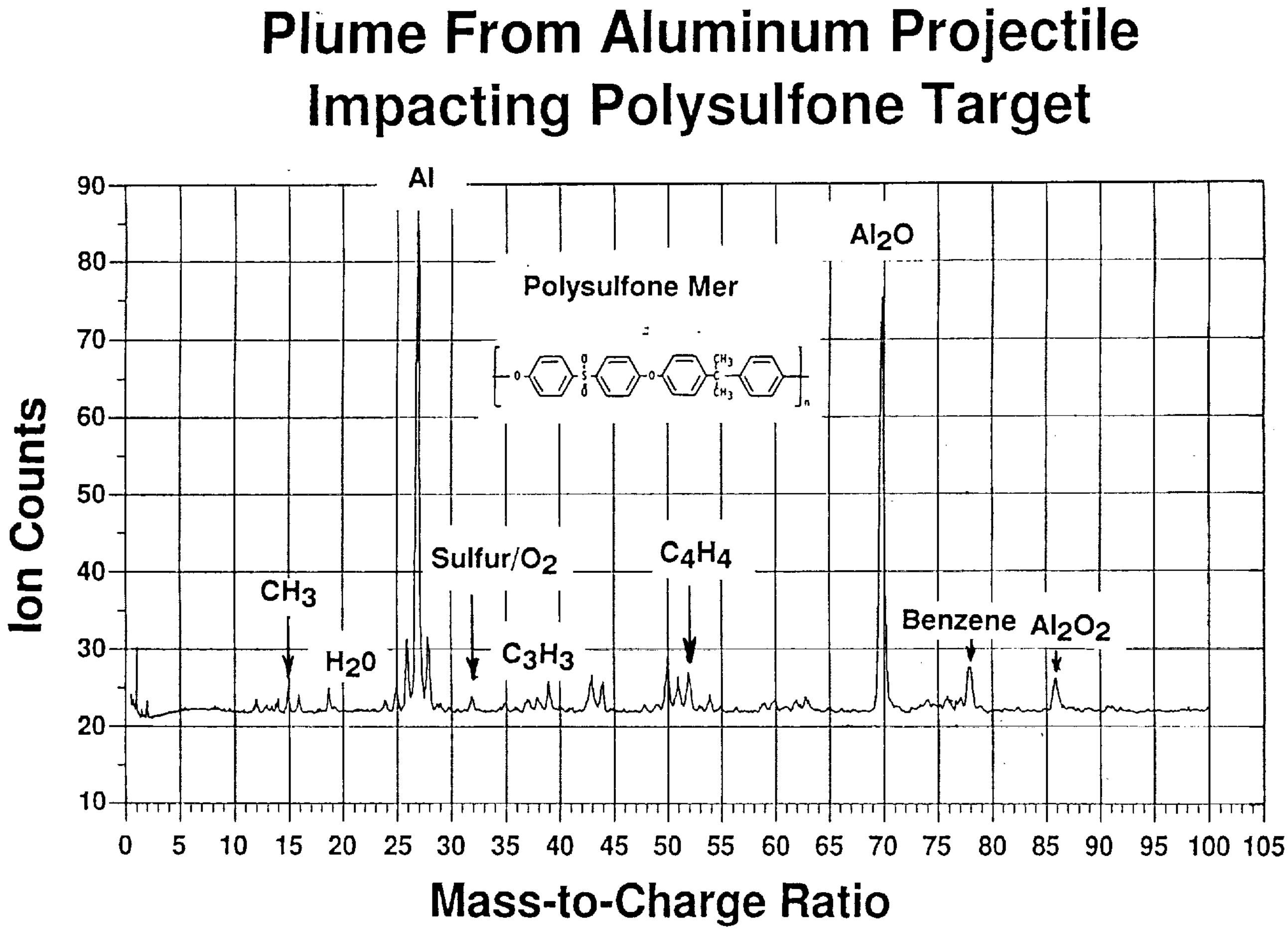

Figure 2. The spectrum produced from hypervelocity collision of aluminum with polysulfone.

Other species which were present undoubtedly came from the de-polymerization of the polysulfone and included the aromatic species, C_6H_x, and monomers of carbon-hydrogen species, such as C_2H_2. In short, the spectrum seen is the direct result of the collision of a hypervelocity particle with the resin. This is the first time shock induced chemical changes from simulated space debris have been observed.

The mechanical damage caused by hypervelocity collisions is also striking. In the case of the resin without fibers, the results are quite similar to those observed in the collision of other homogeneous materials. The impact produces a crater on the surface, the depth and extent of which matches the size of the aluminum particle launched from the quartz. As can be seen, debris from the collision coats the neighboring surface with small sub-particles of aluminum from the flyer plate. The crater in the resin exhibits evidence of melting and a crack, due to shrinkage after melting, forms around the edge of the crater. See Figures 3 through 5. There is nothing unusual about the collisions that has not been observed in shock studies on other materials, except that the scale of these tests is small, leaving the surrounding material in a relatively undisturbed state.

The shock damage in the composite materials is quite different. Craters from the collision are presented in Figures 6 and 7. As can be seen, in all cases except at the very highest velocity, little evidence of the melting of the resin is evident. This suggests that the energy associated with the compression is not totally absorbed by the resin but that it is partly dissipated by the underlying fibers. Moreover, considerable fracture damage to both the matrix and the fibers as a result of the collisions is evident. The matrix is observed to spall off the surface exposing the fibers underneath. Below this matrix layer, the graphite fibers fractured in tension. This fracture process penetrated deep into the composite while surface craters observed in the pure resin were not so deep. Fibers around the edges of the craters were also severely fractured. Thus, damage in a composite material after a hypervelocity collision is fundamentally different than damage in the resin itself.

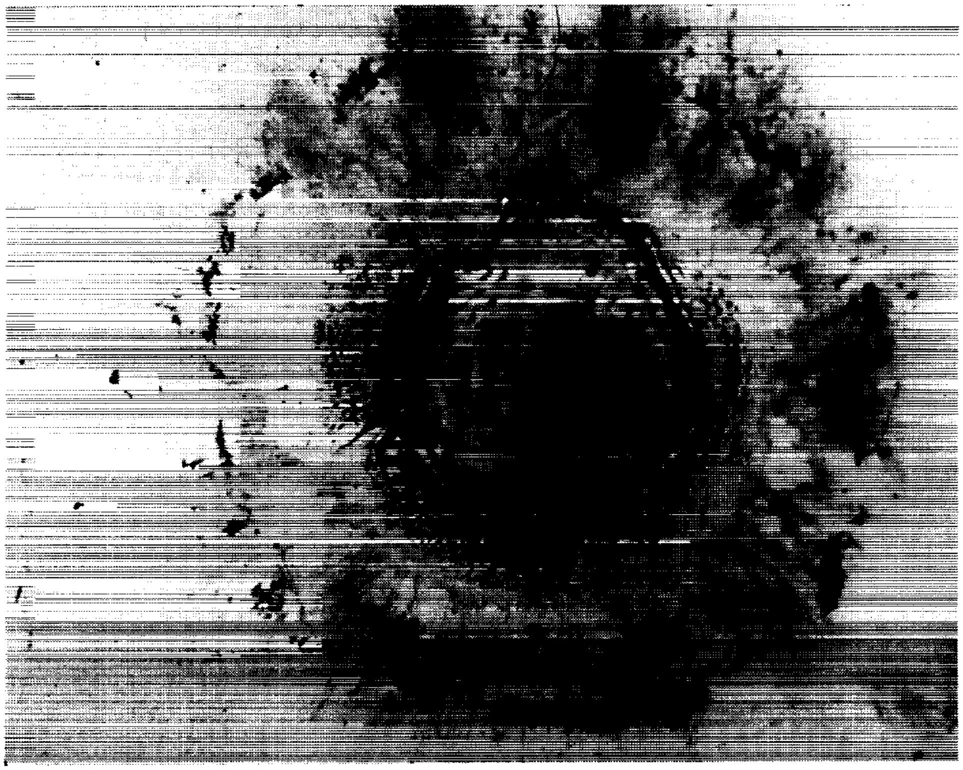

Figure 3. Top view of the crater in polysulfone photographed optically after collision at 6 km/s.

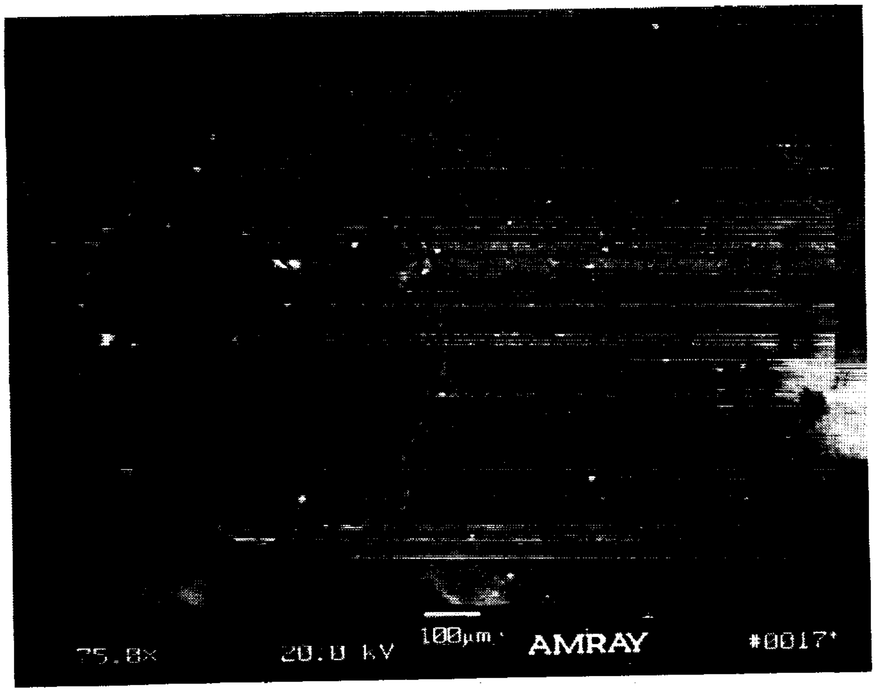

Figure 4. Scanning electron microscope top view of crater formed in polysulfone after collision at 6 km/s.

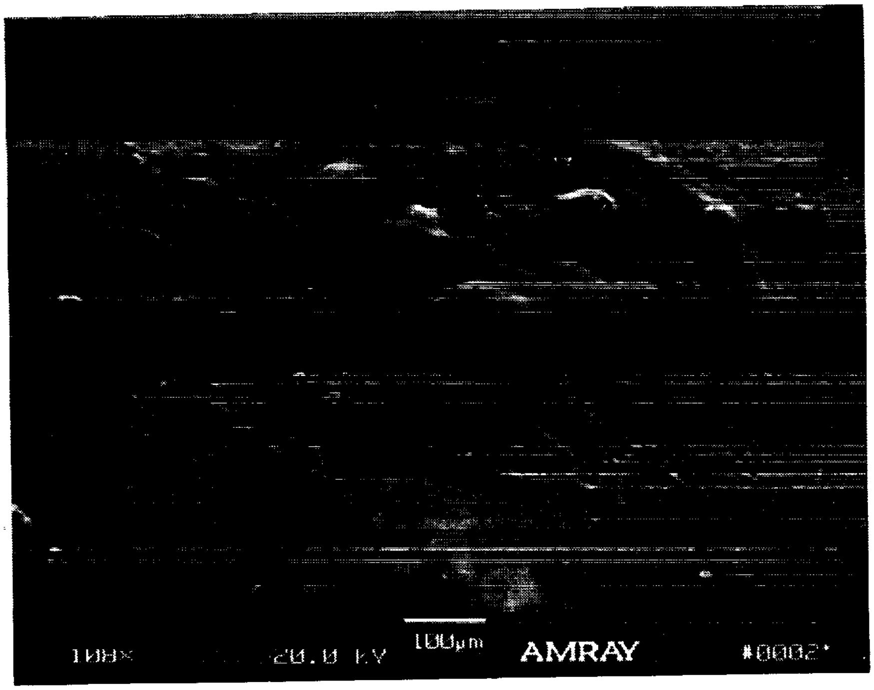

Figure 5. Scanning electron microscope tilt angle view of crater in polysulfone after collision at 6 km/s.

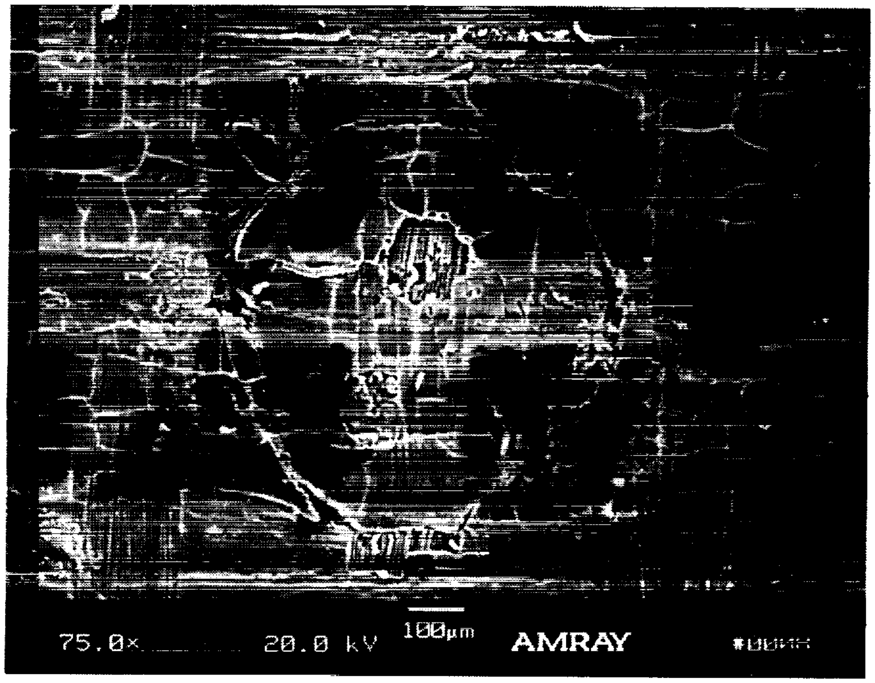

Figure 6. Scanning electron microscope top view of crater formed on polysulfone composite after collision at 5 km/s.

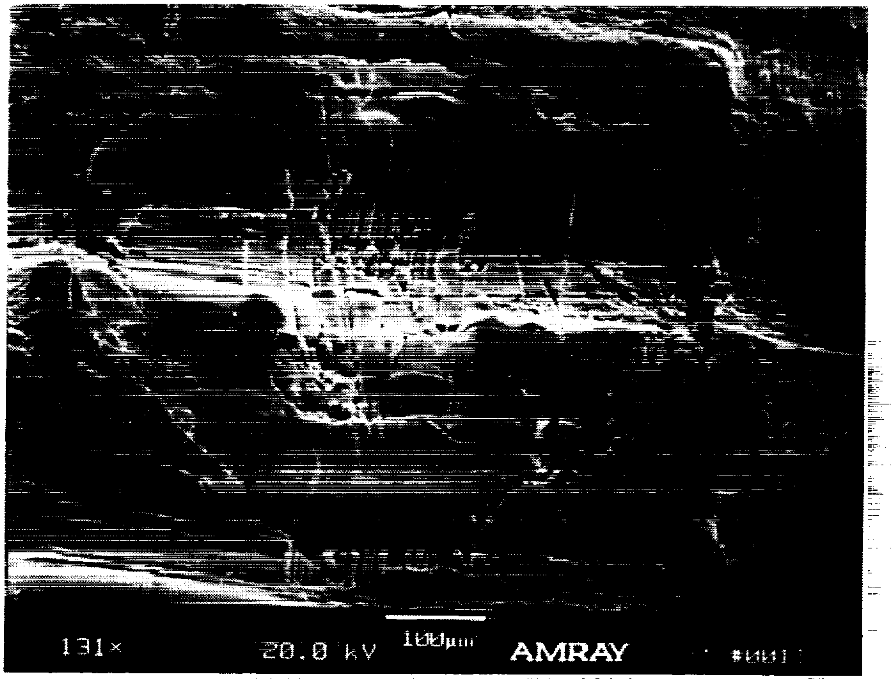

Figure 7. Scanning electron microscope tilt angle view of the crater formed on polysulfone composite after collision at 6 km/s

5.0 CONCLUSIONS AND RECOMMENDATIONS

The use of micro-flyer plates to simulate the effects of space debris has been demonstrated. The damage produced matches damage found on LDEF specimens. The presence of debris over the surface was observed in typical hypervelocity collision experiments. The use of the micro-flyer plate produced sufficient damage in the resin to cause the material to de-polymerize, to vaporize, and to melt. The technique used to produce the small hypervelocity plates is quite convenient and inexpensive compared to the use of the electric guns or mechanical methods such as air-guns, rail-guns, or explosives. The size of the particles launched with this technique are smaller than those launched with other techniques but are still convenient for macroscopic materials such as composites. This micro-flyer method is compatible with space environmental chambers since they can be accelerated from outside the chamber.

The mechanical damage observed differs substantially between the pure resin and the resin-fiber composite in that the resin is seen to melt, and material is ejected from the crater, while in the composites, front surface spalling and fracture of individual fibers dominates. The collisions cause little melting of the matrix on the surface of the composite.

A comparison of the data obtained from LDEF with the data produced by the space debris simulation, points to a conclusion that much of the contamination found on LDEF may have been produced by hypervelocity impact of micrometeorites on hydrocarbon materials depositing ejecta on adjacent surfaces. Mechanical damage comparison is very difficult because the impact craters on the LDEF sample were subsequently subjected to erosion and ashed.

Further studies will be initiated using the micro-flyer plates to cause damage in composites, so that internal examination in the region of the collision can be carried out to determine the depth of the fiber fractures. Specimens will be examined for evidence of delamination between layers which is observed when composites experience low-velocity impacts. Other resins and fibers will be studied, since the matrix and fibers used in these initial experiments are brittle. More ductile fibers are expected to resist breakage during impact, suggesting that the use of thermoplastic resins could partly reduce the brittleness in the matrix. In addition, particulate metal matrix composite materials, such as SiC or graphite particles in an aluminum matrix are expected to be good candidates for future shock studies.

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** February 1995	**3. REPORT TYPE AND DATES COVERED** Conference Publication

4. TITLE AND SUBTITLE 69 Months In Space: Third LDEF Post-Retrieval Symposium	**5. FUNDING NUMBERS** 233-03-02-03
6. AUTHOR(S) Arlene S. Levine, Editor	
7. PERFORMING ORGANZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, VA 23681-0001	**8. PERFORMING ORGANIZATION REPORT NUMBER** L-17430C
9. SPONSORIING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER** NASA CP-3275, Part 3
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified—Unlimited Subject Category 99	**12b. DISTRIBUTION CODE**

13. ABSTRACT *(Maximum 200 words)*

This volume is a compilation of papers presented at the Third Long Duration Exposure Facility (LDEF) Post-Retrieval Symposium. The papers represent the data analysis of the 57 experiments flown on the LDEF. The experiments include materials, coatings, thermal systems, power and propulsion, science (cosmic ray, interstellar gas, heavy ions, micrometeoroid, etc.), electronics, optics, and life science. In addition, papers on preliminary data analysis of EURECA, EOIM-3, and other spacecraft are included.

14. SUBJECT TERMS Space Experiment	**15. NUMBER OF PAGES** 546
	16. PRICE CODE A22

17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT**

NSN 7540-01-280-5500

☆U.S. GOVERNMENT PRINTING OFFICE: 1995-628-064-23072

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102