1995127227

N95-27648

SYSTEM RESULTS FROM FRECOPA

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INTRODUCTION

The work carried out over the past three years on FRECOPA and the LDEF has enabled a large quantity of information to be collected, part of which has already been exploited. As far as CNES is concerned, the major spin-offs of this mission mainly focus on the orbital environment and the behavior of materials in such an environment.

With respect to the environment, we shall develop the lessons learned from expert appraisals on impacts by microparticles, which are the main feature observed in this area. As for the materials, the results show a variety of behavior when subjected to the space environment and even now constitute a wealth of information for the designing and validation of future mechanical systems. Apart from these direct spin-offs, there are repercussions on in-flight and ground testing, the calibration of test benches and improvements to simulation models.

FRECOPA SYSTEM RESULTS

The FRECOPA system includes all materials and mechanisms used on FRECOPA with the exception of technological experiments flown in the three canisters. All these elements were exposed to a low orbit space environment for the 5.7 years of the mission while the specimens inside the canisters were only exposed during the first 10 months. These materials were not designed for such a long mission, yet their overall performance appears very satisfactory, as does the condition of the experiment itself. The most notable damage observed was as follows:

Impact by microparticles

Two types of support were found to show signs of impact: thermal blanket screens in teflonized woven glass fabric and aluminum screens protecting the box seals. 90 impacts over 50 microns in size were counted in one m^2. The largest impact perforated the 0.8 mm thick aluminum screens, projecting a cloud of debris into the experiment (as seen in fig. 1). The position of the crater on the edge of the experiment explains why such an impact caused no internal damage. Another crater on the same screen was at the edge of the perforation.

The impacts observed on the fabric of the flexible screens perforated the fabric but remained local because of the very nature of the fabric. No tearing was observed (as seen in fig. 2). The chemical analyses carried out on these craters did not clearly identify the nature of the impact-causing particles. Either particle velocity was very high and the particles vaporized on impact, or the nature of the substrate (aluminum) masked the nature of the particle, as much debris is also of aluminum - the most commonly used metal on satellites.

Erosion and ageing

All the materials directly exposed to the space environment showed noticeable ageing. Deterioration parameters for FRECOPA are vacuum, U.V. radiation and the numerous thermal cycles to which the structure is subject. Organic materials (adhesives, thread, velcro, anodic protection, fabric used for the thermal blankets etc.) change color, thus revealing their ageing, but do not always show any catastrophic variation in their physical characteristics. Two important cases should however be noted.

The first concerns the flexible thermal blankets of teflonized woven glass fabric combined with an aluminized Mylar film. The environment damaged this fabric considerably, with erosion of approximately 12 microns, thus revealing glass fibers (as seen in fig. 3). A large network of cracks was also visible. The decline in the fabric's mechanical resistance explains this damage, which then allowed U.V. rays to go through the fabric and deteriorate the Mylar on the inner side of the screen. The Mylar then yellowed and became extremely fragile, which meant it was impossible to disassemble or test for mechanical characteristics. This thermal protection proved too little therefore with respect to the actual length of the mission.

The second case of erosion concerns the Delrin parts ensuring the mechanical link when the canisters were shut. The upper, exposed surface of these circular parts revealed erosion of approximately 30 microns (as seen in fig. 4). As the canisters only opened and shut once in orbit, there were no functional consequences. However, if such a mechanism were needed to operate several times, the play induced by ageing could be problematic.

Contamination

Numerous traces of contamination are visible on FRECOPA. Not only are there contaminants induced by outgassing or the deterioration of experiment materials (glass fabric), but external contaminants too. Here again, two phenomena were observed which show the complexity of the problem.

The shadow of one of the canisters was observed on the sides of the experiment. This shadow results from the deposit of contaminants on their surfaces then their polymerization when exposed to U.V. rays. In this particular case, the outgassing products were spread uniformly over all the surfaces which were cold when the structure was in shade. As the sun rose on the most quickly illuminated side, the contaminants were polymerized and as the box carrying structure formed a partial screen, its shadow is seen on the side of the experiment. On the opposite side of the experiment, surface temperature rose due to conduction and as the sunlight reached those surfaces later, outgassing products had time to vaporize and be deposited on other cold surfaces still in shade. The other traces observed were found on both the backside of the experiment (facing LDEF's interior) and along the experiment sides. This time, there was a contamination flux from inside the satellite moving out towards FRECOPA's backside. The shadow of a nut and bolt could clearly be seen on the rear structure of the FRECOPA experiment, as could that of an electric wire (as seen in fig. 5). We think these objects protected the surfaces from the contaminating flux. On the sides of the experiment, rivets played the same role and similarly-protected areas may also be seen there. These multiple traces prove the existence of several different fluxes over time (as seen in fig. 6). The search for sources of contamination shows that they are located on the front of the satellite. The interstices between the various experiments allowed contamination through, and no doubt both atomic oxygen (AO) and U.V. radiation too.

Intermetallic adherence

This phenomenon proves a very controversial subject. The appearance of intermetallic welding requires special conditions as regards pairs of materials, temperature, pressure and mechanical stress (vibration). For FRECOPA, taking both launch and mission parameters into account, two metallic parts were seen to stick together, the parts in question being a steel spring and an aluminum plate. They were used in AO experiments 138-1 and -6. The spring pressed against the aluminum plate which held in place a sample to be exposed to the environment. The force needed to separate the materials was slight and could not be measured. Electronic microscopy revealed a transfer of matter, in that aluminum was found on the spring (as seen in fig. 7). The parameters mentioned above encouraged such a phenomenon but the state of the surface of the two materials themselves is an important parameter. Intermetallic adhesion was thus observed, with a transfer of matter which could, in the case of mechanisms, cause operating problems.

The positive points of this experiment are as follows:

Thermal blankets

Despite visible ageing, they showed good mechanical resistance to the large number of thermal cycles suffered by the structure. The system of attachment using Velcro strips either sewn or glued to the structure allowed sufficient flexibility to avoid the loss of fabric functionality by tearing. This choice of material also enabled impacts to be contained locally, avoiding propagation and destruction of the blanket itself.

Mechanisms and electronics

The canisters opened and closed because both the mechanisms and control electronics worked correctly. No anomalies were found in these components during the technical evaluation, and they worked on the ground with results similar to those recorded during flight.

Materials

All the materials used (structure), kinematic chain, adhesive, Velcro, surface treatment performed well and validated certain technological choices made. Ageing was apparent in certain components, but there was little change in mechanical or physical/chemical properties as a result.

THE SYNERGY OF AGEING FACTORS

The origin of ageing is not always easy to determine. For FRECOPA experiment, located on LDEF's trailing edge, the factors identified as causing ageing were predominantly U.V. radiation, thermal cycling and exposure to vacuum. However, ageing can only be understood in the context of the synergy between all environment parameters. For example, the erosion observed in the thermal blankets is attributed to the effects of thermal cycling and U.V. radiation. Looking at surface morphology, it is possible to think that atomic oxygen also played a role. Indeed, when LDEF was retrieved the trailing edge was exposed to a low atomic oxygen fluence. The dose received was only for a short period of time but with a higher fluence value because at a low altitude. It could thus have interacted with FRECOPA materials already weakened by 5.7 years of exposure to the environment.

Another example of interaction between several different environment parameters is shown by deterioration caused by AO and U.V. radiation following impacts on the structure by microparticles. Not only is there the effect of the impact itself, but also the physical and/or chemical interaction of radiation fluxes. Materials not intended, and therefore not designed, to be exposed to such constraints found themselves on the front line and thus suffered considerable ageing. This typical phenomenon was found on the LDEF in the multilayer thermal blankets (Teflon, silver, Inconel and paint), where the inner silver layer had been oxidized following the penetration of a particle. As far as FRECOPA is concerned, the thermal blankets of teflonized woven glass fabric were eroded and allowed U.V. rays through. The latter damaged the Mylar layer on the inner side of the screens. The criticality of such synergy between impact/AO/U.V. radiation depends on whether the damage caused by the particle remains local or spreads throughout the material.

THE IMPACT PHENOMENON

As seen above, impacts linked with AO or U.V. exposure can cause great damage. As far as the damage related to the impact itself is concerned, the result depends on several different parameters. The nature of both the particle (shape, chemical origin, size, velocity) and substrate is important. On FRECOPA, particles were observed to have pierced aluminum screens 0.8 mm thick, but that multilayer materials used as detectors stopped certain particles more easily. The concept of this kind of protection may avoid damage from part of the microparticle population whilst not adding greatly to the structure's mass.

Such perforating impacts raise the problem of equipment located on "preferable" surfaces. These items of equipment can be directly damaged by the projectile and/or the debris created by the particle crossing through the surface. The velocity of such secondary impacts is less but their geographical dispersion, and thus their zone of interaction, greater.

It is not only important to study the fluxes themselves, as FRECOPA has allowed, but also to determine the nature of orbiting particles. The one parameter currently increasing in the space environment is the number of debris-type particles generated by human activity in space. The determination of sources (ageing of materials, impacts, propulsions, outgassing etc.) should permit such proliferation to avoid densities incompatible with space missions, and particularly manned missions. There is a close relationship between materials, their use and impacts. Knowledge of the environment is closely linked to the collection of particles in the different orbits used for their analysis. The human factor can then be distinguished from the natural factor and protective means and materials better-suited in terms of impacts and ageing can then be proposed so as to limit the generation of debris.

In-flight experiments also provided further knowledge about the Earth's natural environment. Particles of human origin were identified on FRECOPA whereas because of the experiment's rear position on the satellite, only impacts of a natural origin should have been observed. This means that the presence of debris is no longer limited to circular orbits but also elliptical ones.

USE OF RESULTS

Results may be used at several levels. Firstly, they enable ground simulation facilities to be improved by comparing flight samples and accelerated ageing results obtained in a laboratory setting, particularly ageing from U.V. radiation, AO, or impact simulations in which chemical analyses have allowed us to correlate the presence of an element (Fe) with particle velocity. This also leads to an improvement in test benches, making them more lifelike, although this does of course make them more complex too. These tests will never replace real-time in-flight experiments but they help us evaluate ageing problems more quickly. With this in mind, on-orbit tests with telemetry of results have the further advantage of avoiding possible changes in atoms when the materials come in contact with the Earth's environment ("healing" phenomenon by the recombination of free radicals).

The second point is the choice of materials for future missions taking into account their exposure. As seen above, this choice is also linked to the problem of satellite design. Engineers must build into their way of thinking problems relating to geometry (secondary impacts, shadows, contaminations etc.) and the possibility of avoiding defect propagation (choice of multilayers to limit the penetration of impacts, choice of materials to limit the extension of defects).

The last way of using results is as input data for numerical simulation codes which are used to set the parameters for several factors and thus broaden our knowledge of ageing. This is the case for hydrocodes which can model impact phenomena and lead to a better understanding of their dynamics. Structural calculations also use the results from on-orbit experiments to determine behavior at the end of the structure's lifetime.

On the other hand, the application of results from this experiment to other orbits may be problematic, as numerous environment parameters change with altitude and inclination. However, results could be used on a case-by-case basis as an envelope for designing the specific satellite.

CONCLUSIONS

As described above, the main spin-offs from the LDEF/FRECOPA mission concern:

* impacts

  - nature of microparticles
  - impact morphology
  - resulting damage and propagation
  - global fluxes for the orbit and mission considered

* ageing of materials

  - erosion phenomena
  - contamination
  - the effect of U.V. radiation and atomic oxygen
  - thermal cycling

These lessons enable the actual orbital environment to be better taken into account and materials optimized with respect to designing. This knowledge must be extended to other orbits used. An improved characterization of the fluxes of microparticles and their nature would enable an improvement to be made in the measures needed to prevent the proliferation of debris in space. The utility of such scientific missions is evident and it is on the wealth of knowledge gained as a result that reliability, availability, maintainability, and safety aspects of future missions depends.

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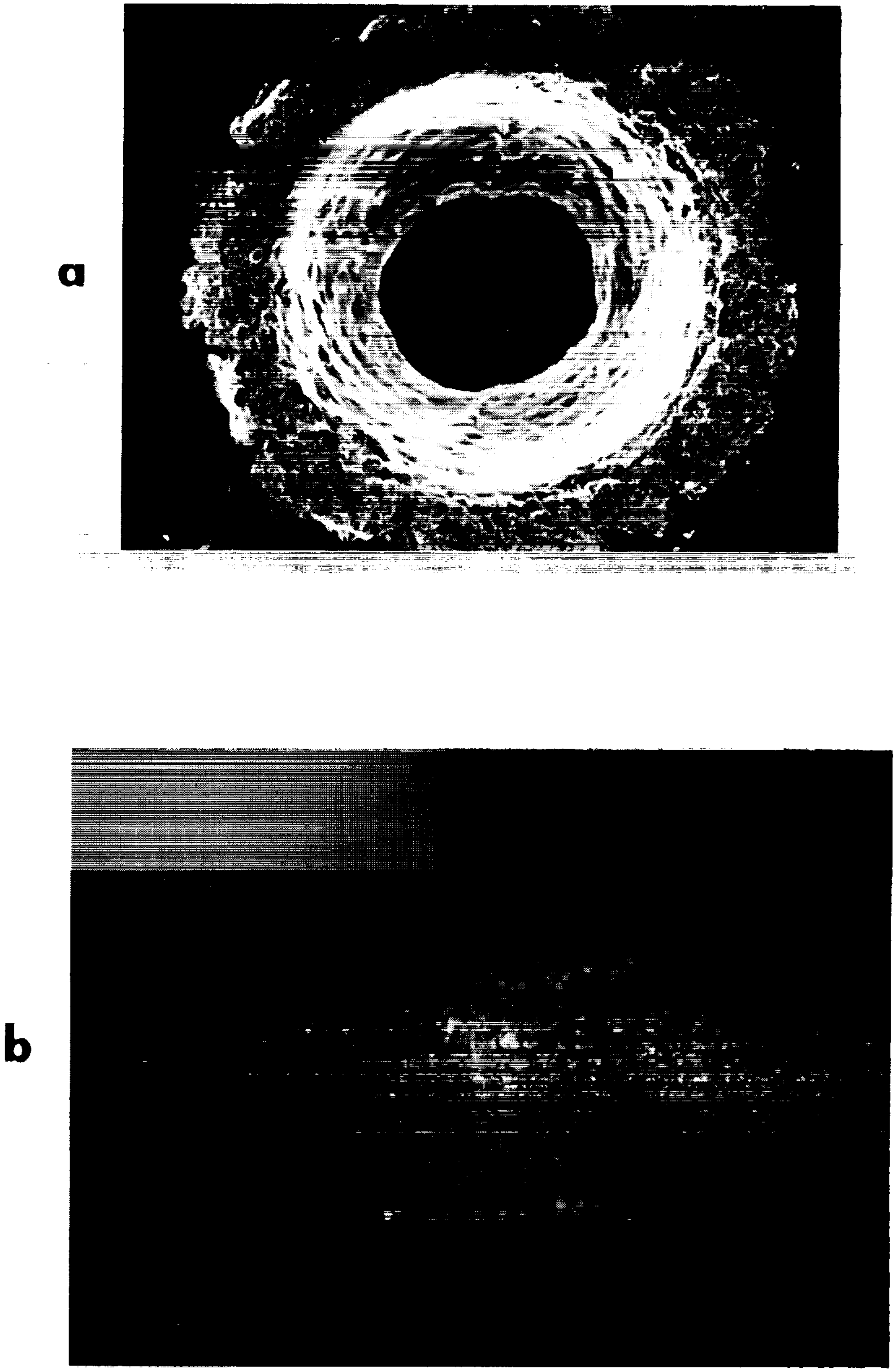


Figure 1 - The biggest crater on FRECOPA tray (a)
cloud of debris on the structure (b)

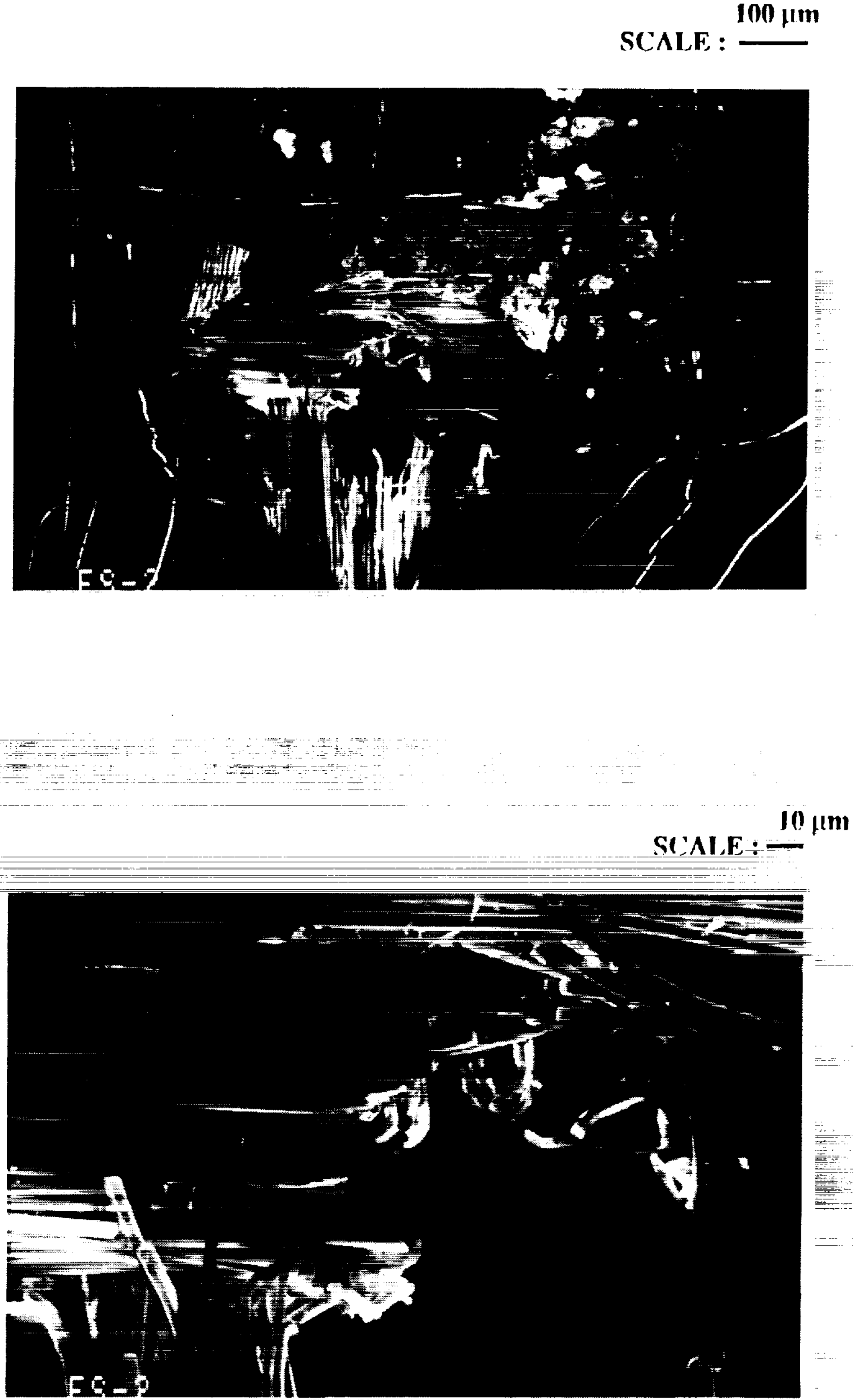
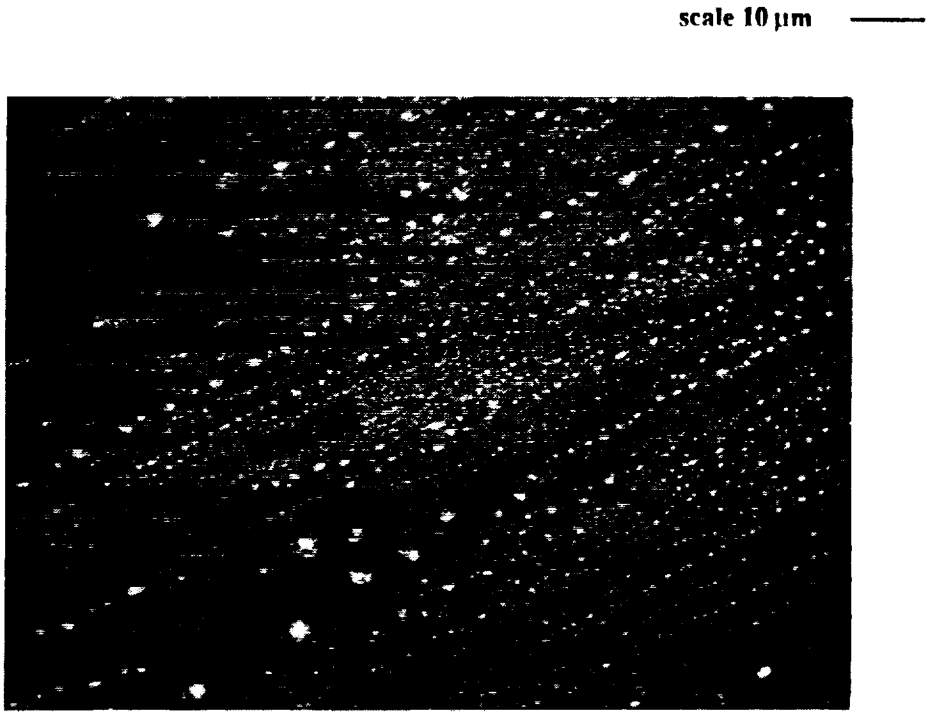
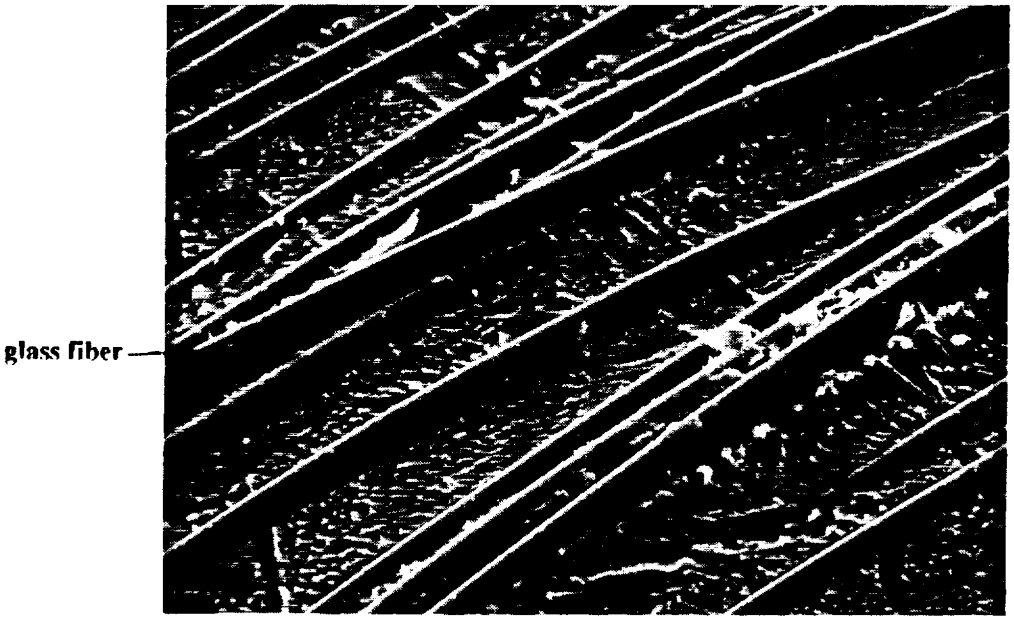


Figure 2 - Impact morphology on thermal blankets



Reference sample

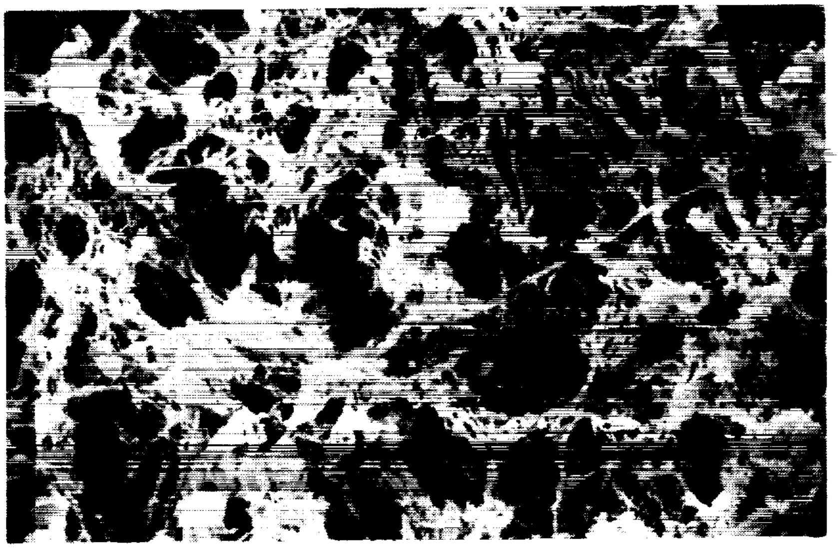


Flight sample

Figure 3 - Surface degradation on thermal blankets

SCALE: **10 µm**

Reference sample



Flight sample (exposed area)

Figure 4 - Erosion on Delrin samples

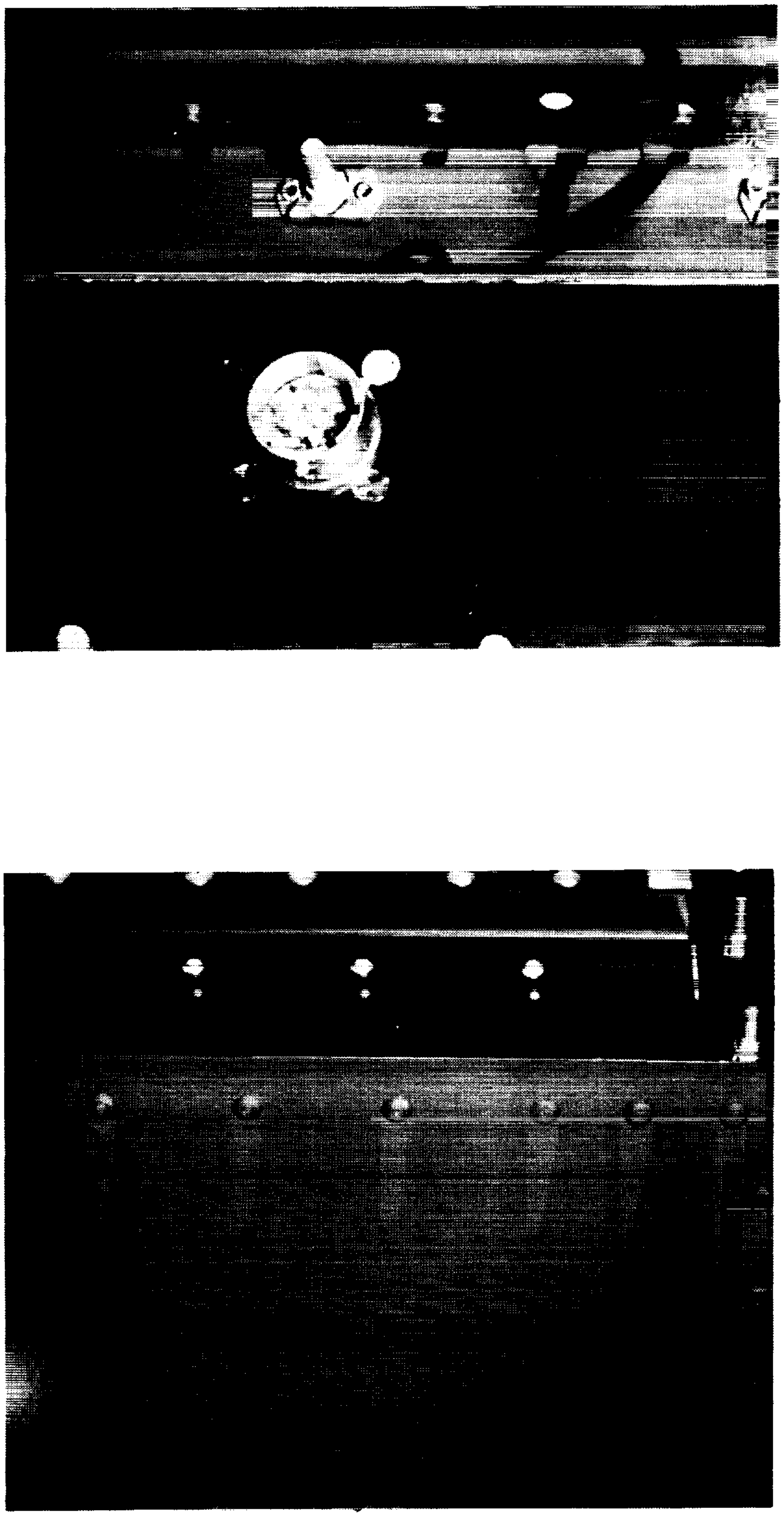


Figure 5 - Bolt, wire and rivet shadows on the back of the tray

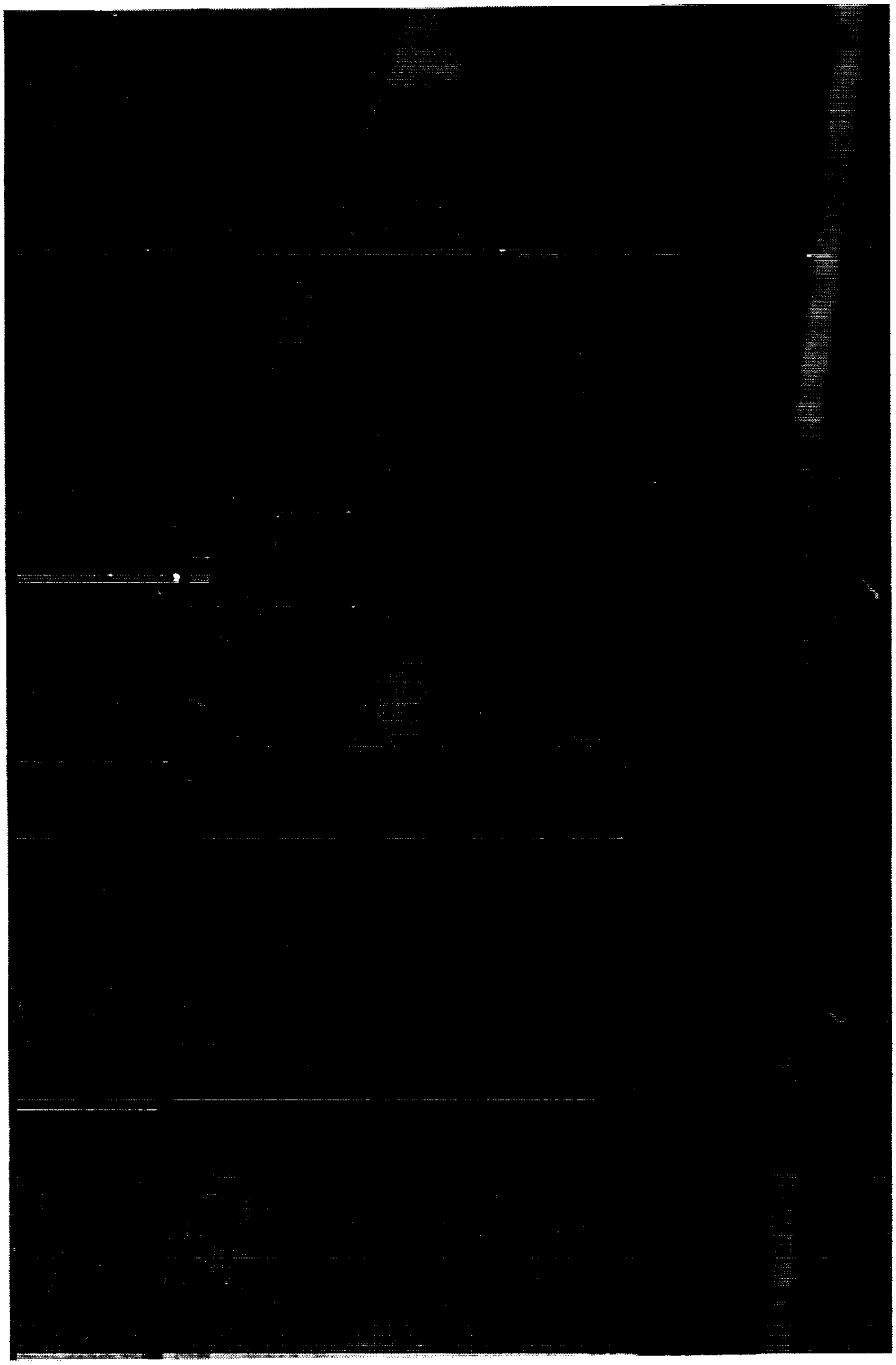


Figure 6 - Multi shadows around rivets

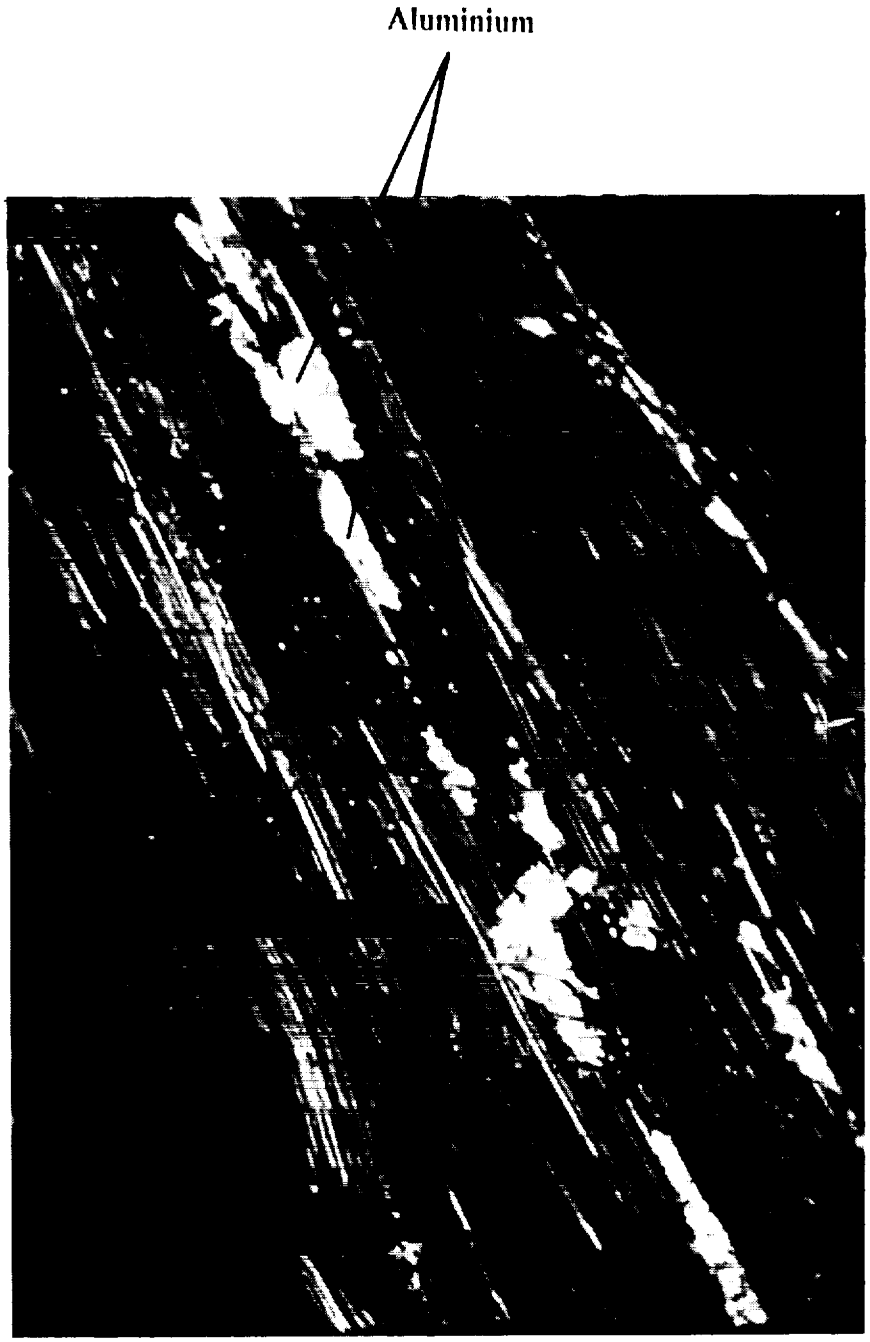


Figure 7 - Aluminium transfer on steel spring