EJECTA PRODUCTION MECHANISMS ON PAINTED SURFACES

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ABSTRACT

Painted surfaces are frequently used on space vehicles, whether on satellites or on rocket bodies. A bibliographic research allows us to evaluate the painted surfaces in orbit at about 63 000 m² [1]. The observation of impacts on painted surfaces of the LDEF satellite shows that the total ejected mass is large. However, no description of hypervelocity impact tests on painted surfaces has been found in the literature.

An ejecta model has been previously developed at ONERA/DESP [2]. This model is applicable for hypervelocity impacts on homogeneous ductile targets, homogeneous brittle targets and solar cells. The objective of this work is to extend this model to the case of painted surfaces. Consequently, impact pictures on painted surfaces of LDEF were analysed and some laboratory impact tests were performed at the Ernst-Mach-Institut, in Freiburg, under an ESA contract [3].

1. PAINTED SURFACES PECULIARITIES

Painted surfaces are multi-layer materials with a fine layer of brittle material (about 100-150 µm thick) covering a ductile substrate (generally aluminium).

When the size of the projectile is small enough, only the layer of paint is affected. Then, the impact is similar to one into a brittle and thick target.

When the projectile energy is higher, a crater is formed into the substrate and large paint fragments, called spalls, are ejected. The size of the spall zone, which is the zone where the paint is removed from the aluminium surface surrounding the crater, varies from approximately 2 to 5 crater diameters.

In some cases, a shock zone appears, forming rings with a diameter up to 20 times the crater diameter [4].

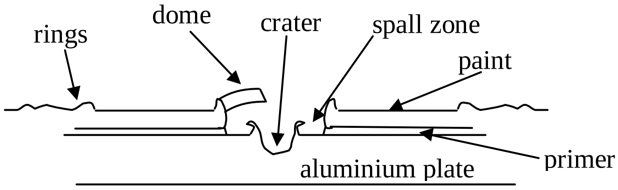

Fig. 1 : Schematic cross-section of a « typical » impact into a painted aluminium plate

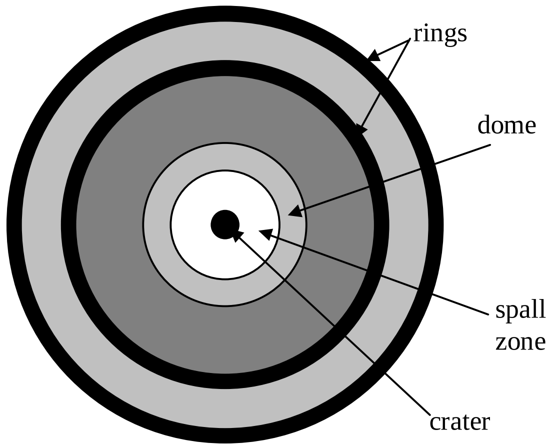

Fig. 2 : Plan view of a « typical » impact into a painted surface

Fig. 3 : Impact on a painted surface

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2. PAINTED SURFACES ON LDEF

During the four months of the dismantling of the satellite LDEF, its surfaces have been inspected in detail and about 4600 impacts with a diameter larger than 500 µm have been photographed (they were listed on CD-ROM by the ‘Meteoroid and Debris Special Investigation Group’). Thus, impacts on the painted surfaces could be observed and their size measured. About 170 impacts on four different paints have been analysed.

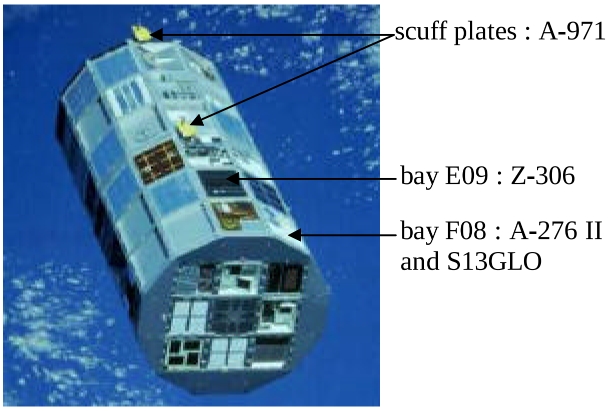


Fig. 4 : Examples of paint surfaces on LDEF

The paint A-971 is yellow. It’s a polyurethane paint used on the scuff plates of the spacecraft. The Chemglaze Z-306 paint is a flexible black polyurethane paint. Under this paint, there is a primer layer that can be seen where the paint is eroded [5]. The paint Chemglaze A-276 II is a white paint, with a polyurethane binder and a dioxide of titanium pigment. The S13GLO is white paint, with a methyl silicone binder and a zinc oxide pigment. The ZnO pigment is encapsulated with potassium silicate for improved stability in the space environment [6].

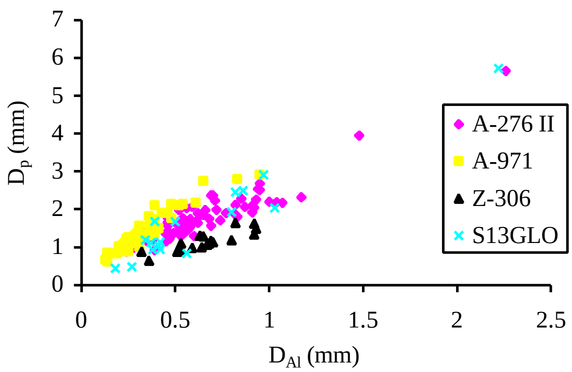


Fig. 5 : Spall diameter as a function of the crater diameter for several paints

The diameter of the spall zone is compared to the aluminium crater size. Fig. 5 shows that the behaviour depends on the paints. For a same diameter in the aluminium, the spall diameter is smaller into the black paint (Z-306) and larger into the yellow paint (A-971). Indeed, the black paint is more flexible (and then less brittle) than the other paints.

3. IMPACT TESTS ON PAINTED SURFACES

Four hypervelocity impact tests on surfaces were performed at the Ernst-Mach-Institut [3]. The samples are aluminium plates with a thickness of 2 mm, covered by a 150 µm thick layer of white paint. The paints used are a silicone paint (SG 120 FD) and a silicate one (PSB) (MAP). The projectiles were aluminium spheres with a diameter of 1 mm. The impact velocity was between 5.2 and 5.8 km/s. For each paint, two tests were performed at two impact angles (0° and 30°).

Table 1 : Test parameters

test n°	paint of the target	projectile mass	projectile velocity	impact angle (θ_i)
4029	SG 120 FD	1.56 mg	5.2 km/s	0°
4030	PSB	1.54 mg	5.8 km/s	0°
4031	PSB	1.55 mg	5.6 km/s	30°
4034	SG 120 FD	1.54 mg	5.6 km/s	30°

In order to analyse the ejecta from the painted samples, a 2 mm thick copper witness plate with a hole in its centre was placed 50 mm in front of the target.

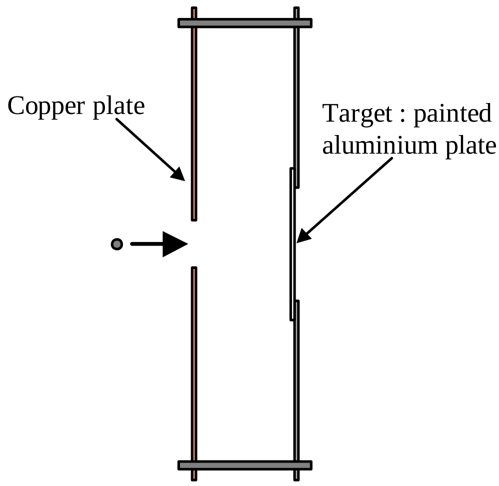
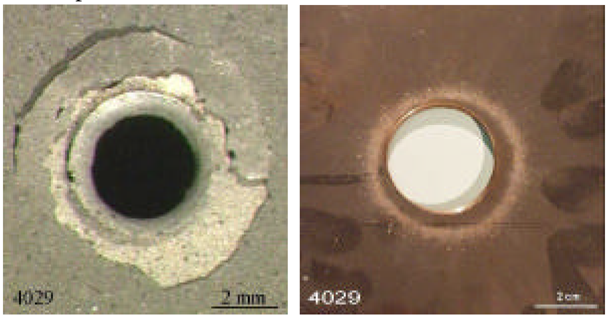


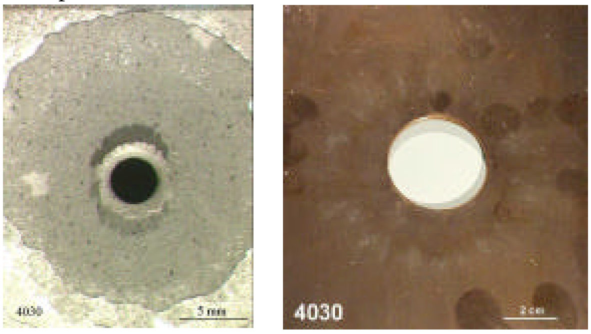
Fig. 6 : Target description

The target plates are all perforated except for the test 4031, because the frame holder plate was in direct contact with the target. The hole sizes were about 3 – 3.5 times the diameter of the projectile. The spall diameter measures about twice the perforation diameter for the SG 120 FD samples. In the case of the PSB paint, the spall diameter is about 6 times larger than the crater diameter.

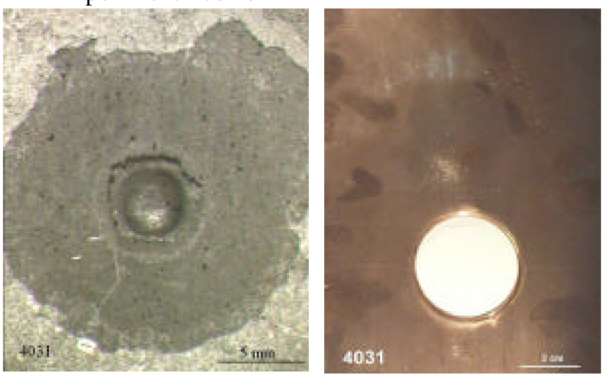
Experiment 4029 :



Experiment 4030 :



Experiment 4031 :



Experiment 4034 :

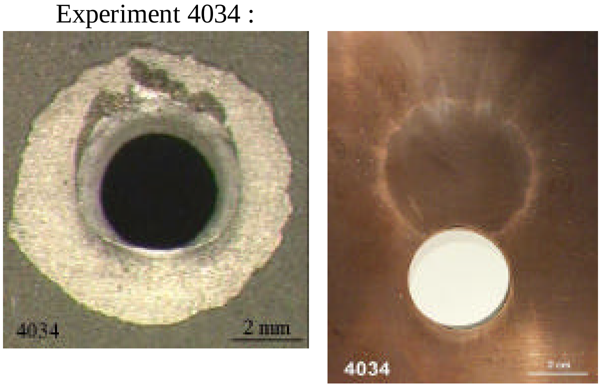


Fig. 7 : Impacts in the painted aluminium plates and damage on the copper plates

In the case of experiment 4031, we can see some craters in the centre of the damage zone on the copper plate. These are from fragments that are ejected perpendicularly to the target surface. The area covered by these impacts measures about 1 cm².

Table 2 : Summary of damage on the samples and on the copper plates

test n°	paint	θ_i	hole diameter	spall diameter	θ_{min}	θ_{max}
4029	SG 120 FD	0°	3.3 mm	7 mm	23.4°	35.1°
4030	PSB	0°	3.5 mm	22.1 mm	28.3°	35.9°
4031	PSB	30°	3.8 mm*	18.8 mm	32.4°	36.1°
4034	SG 120 FD	30°	3.3 mm	7.7 mm	26.2°	37.5°

* The aluminium plate is not perforated, the diameter refers to the crater diameter.
θ_{min} and θ_{max} are the minimal and maximal zenith angles of ejection, deduced from the damage on the copper plates.

The copper plates were observed with optical and scanning electron microscopes.

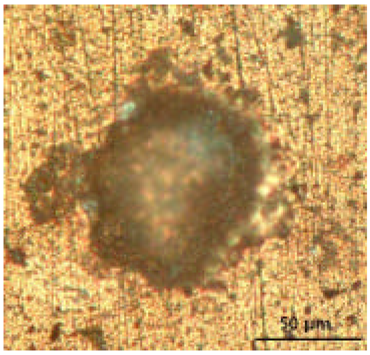


Fig. 8 : Picture of an impact on a copper plate

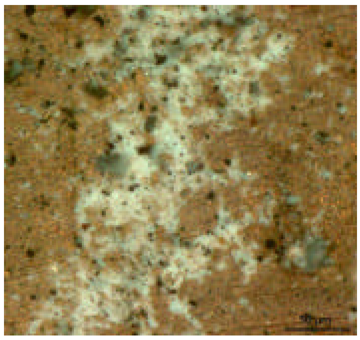


Fig. 9 : Picture of a deposit of paint on a copper plate

These observations show that the craters are formed by impacts of aluminium particles. The depth to diameter ratio is about 0.2 and the shape of the craters are irregular. This suggests that the velocity of ejecta is smaller than 2 km/s. Numerous paint deposits are also observed. They don't form any craters, so their ejection velocity must be very low.

A high-speed video camera was used to assess the ejecta velocity and the ejection angle. 8 pictures for each test were taken with a separation time of 100 µs for the first 6 images and 200 µs for the two others. The exposure time was 1 µs. Due to failure in the triggering system no pictures were taken during test 4034.

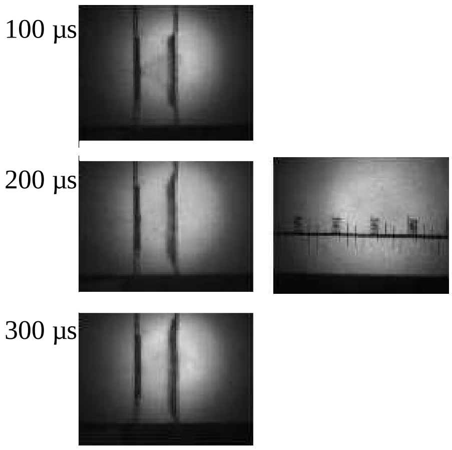


Fig. 10 : Test 4029 : high speed video shadowgraphs

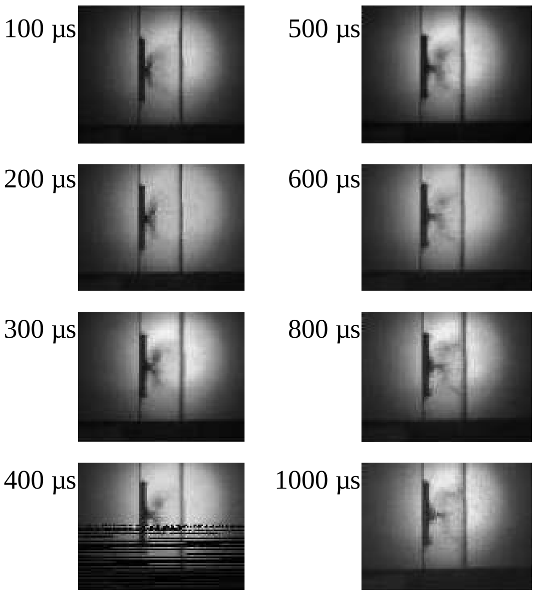


Fig. 11 : Test 4030 : high speed video shadowgraphs

From these photos (Fig. 10, 11, 12), we can say that the ejection velocity of aluminium fragments is higher than 500 m/s. The ejection velocity of paint fragments is between 10 and 150 m/s. We can also observe that some fragments are ejected perpendicularly to the samples.

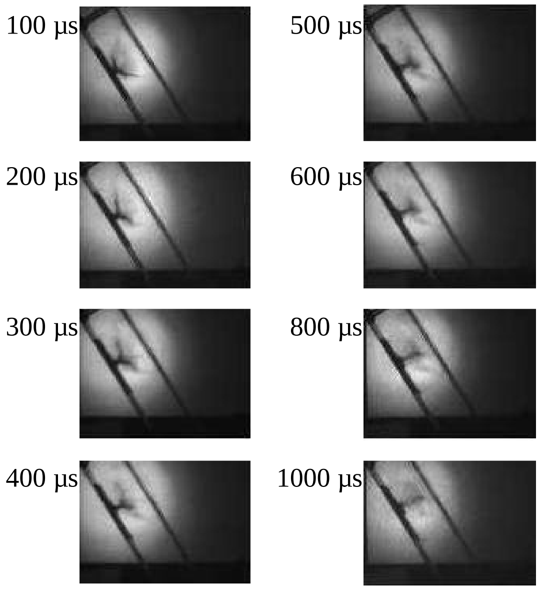


Fig. 12 : Test 4031 : high speed video shadowgraphs

From these tests, we can conclude that the ejected mass of paint varies from 5 to 50 times the mass of the projectile. These paint fragments are quite large and ejected with a low velocity. Therefore, they stay in orbit for a long time after their ejection, polluting the space environment.

4. REFERENCES

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