HYPERVELOCITY IMPACT AND OUTGASSING TESTS ON ETHYLENE-CO-METHACRYLIC ACID IONOMERS FOR SPACE APPLICATIONS

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ABSTRACT

The ability of a material to self-repair is particularly important in remote or hostile environment applications, where an external intervention is nearly impossible. For example, the development of self-healing (SH) materials for space applications could dramatically improve spacecraft performances and liability, with significant enhancement of mission duration. A number of copolymeric ionomers have been recognized to present self-healing capability under defined ballistic conditions and have risen considerable interest by researchers. On the other hand, when exposed to a vacuum environment for long period, polymers may exhibit considerable mass reduction due to volatile diffusion and loss; this can significantly affect physical and mechanical properties, thus preventing their employment in space applications.

This work aims to give a preliminary evaluation of possible employment of polyethylene-co-methacrylic acid (EMAA) based ionomers in space environment. The SH capability was studied through hypervelocity impact tests in different experimental configurations, in order to simulate the collision events with micrometeoroids or debris typical of space environment. The healing efficiency was evaluated by leakage tests and by observation of the impact area with a scanning electron microscope.

Thermal outgassing tests were performed to explore the material behaviour in conditions similar to those of space environment. Using a high vacuum chamber, specimens were exposed to a vacuum environment; thermal cycles were also applied to favour the outgassing phenomena. Quite limited mass losses were detected after the tests.

1. INTRODUCTION

In recent years, the amount of space debris has increased significantly and the number of small objects (<1cm), which are difficult to monitor by ground stations, is continuously growing due to space collisions or explosions [5]. Even if small, these objects have a great kinetic energy, so impacts are seriously dangerous for space systems, especially for pressurized systems, such as tanks or habitable modules. In this scenario, it would be very important to employ materials which can self-repair after an impact and avoid any pressure leakage.

The ability to self-heal a damage exhibited by polyethylene-co-methacrylic acid (EMAA) based ionomers has already been discussed in previous works [1-4]. Here the possibility of employ EMAA ionomers in space applications has been investigated, with particular reference to self-healing behavior after hypervelocity impacts. In addition, thermal vacuum outgassing test was also carried out on EMAA ionomer as a first step of a space qualification of the material.

2. MATERIAL AND METHODS

2.1 Materials and sample preparation

A ionomer based on poly-ethylene-co-methacrylic acid copolymer was used. This material, provided by DuPont with the commercial name Surlyn® 8940, has a content of 5.4 mol% of acid groups, 30% of which are neutralized with Na ions. It has a density of 0.95g/cm^3 and a melting temperature of 94°C. Flat samples were produced by compression moulding, using an hot press with a moulding temperature of 180°C and a moulding pressure of about 5 bars. These square plates were used as samples both in thermal outgassing test and in hypervelocity impact tests. In these tests different thicknesses were considered from 2 to 5 mm.

2.2 Hypervelocity impact test

Hypervelocity impact tests were carried out using a two-stage Light-Gas Gun (LGG) [6]. Six different test conditions were employed by varying specimen thickness and bullet speed. In all the tests 1.5mm aluminum spheres were used as bullets, while two different velocities were considered, 2 and 4km/s. Samples 2, 3 and 5mm thick were tested.

After the impacts the healing evaluation was performed both by microscope observations of impact zone and by pressure leakage tests. The impact areas of all specimens were observed using an Hitachi TM-3000 scanning electron microscope. To better investigate the healing level, pressure leakage tests were also executed using a specific-designed device developed for this purpose (Figure 1). A pressure gradient of 0.9 bar was applied by a vacuum pump up to more than 15 minutes. When the hole was healed, no appreciable vacuum decay was detected, while non-healed samples showed a vacuum decay within few seconds.

Figure 1: Sketch of the experimental system for leakage test.

2.3 Thermal vacuum outgassing test

Thermal vacuum outgassing test was performed to investigate the possible loss of mass from the material in the form of volatile gases. The test was performed using a thermal vacuum chamber able to perform high vacuum conditions (up to 10^{-9} bar) and equipped with two different heat sources: a conductive heat plate and a radiant heating system. Three square plate specimens were tested. All the specimens were cleaned and pre-conditioned at 22±3°C and 55±10% RH, as prescribed by ECSS-Q-ST-70-02 [7].

During the test a pressure of 10^{-8} bar was maintained in the chamber for 43 hours (Figure 2). Two thermal cycles at 60°C were applied during the test to promote outgassing: a first cycle performed only by conductive plate and a second cycle performed both by conductive and radiant heating systems (Figure 3). The temperature was monitored either on the specimen and on the conductive plate. The mass variations were evaluated comparing the weight of each sample before the test, immediately after the test and after two weeks.

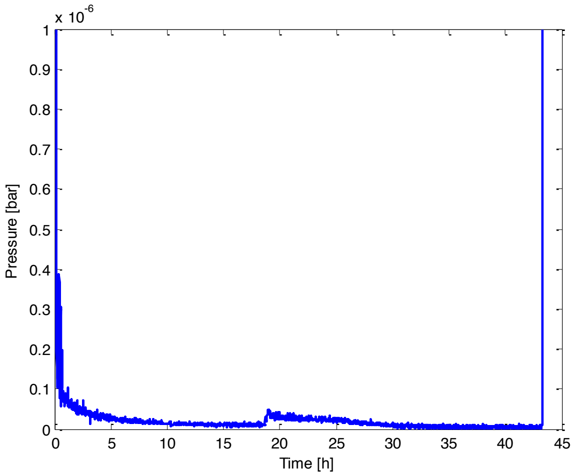

Figure 2: Pressure profile.

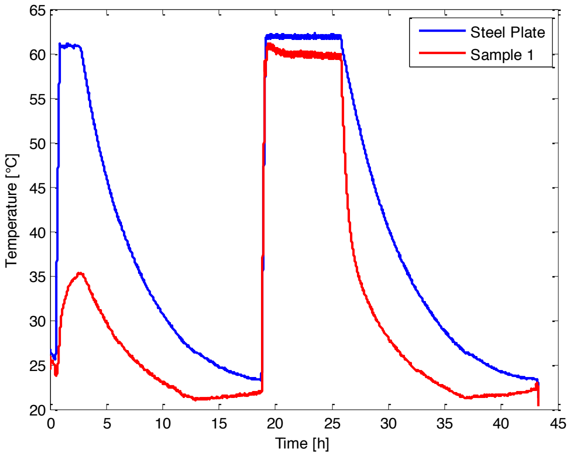

Figure 3: Temperature profile.

3. RESULTS AND DISCUSSION

3.1 Hypervelocity impact test

Hypervelocity impact experiments performed by firing 1.5 mm aluminum spheres proved the healing behavior of EMAA ionomer at the two tested speed ranges; test results are summarized in Table 1. At the lowest projectile velocity, 2 km/s, all samples visually exhibited complete hole closure, but leakage tests showed a loss of pressure of the 3 mm thick specimen. Conversely, at the highest speed, 4 km/s, only the 3 and 5 mm thick samples exhibited complete hole closure.

Table 1: Results of hypervelocity impact test.

Sample ID	Sample thickness [mm]	Bullet velocity [km/s]	Puncture	Visible healing	Leakage test
1	2	1.93	✓	✓	✓
2	3	1.80	✓	✓	✗
3	5	1.64	✗	-	-
4	2	3.90	✓	✗	-
5	3	4.00	✓	✓	✓
6	5	4.10	✓	✓	✓

Morphological analysis after the impact tests showed some debris of the fired aluminum sphere on the bullet entry side of all the specimens, while no residues were detected on the exit side. In every sample the bullet entry zones showed an indented surface, while the exit sides exhibited a clearly defined melted zone of approximately the same diameter as spherical projectile.

3.2 Thermal outgassing test

The results of thermal outgassing test, in terms of weight and mass variations, are reported in Table 2. The test showed that EMAA ionomer considered is not affected by significant outgassing phenomena. The limited mass loss recorded in the two samples immediately after the test is partially due to humidity loss, as confirmed by weight regain exhibited by all samples after storage for two weeks at 22±3°C with a relative humidity of 55±10%.

Observing the temperature profile it can be noticed that in the first thermal cycle the material didn’t reach the target temperature, while in the second cycle immediately reached the target; this is due to the better efficiency of the radiant heating in vacuum compared to conductive heating. Observing the temperature and pressure profiles it can be pointed out that the mass release occurred instantly once the material reached the fixed temperature. This confirms the relevance of thermal cycle in promoting the outgassing and ensures that mass loss was fairly complete at the end of the test.

Table 2: Results of thermal outgassing test.

Sample ID	*Weight [g]*			*Variation*	
	Before test	*After test*	*After 2 weeks*	*After test*	*After 2 weeks*
1	27.730	-	27.719	-	-0.039%
2	30.574	30.544	30.559	-0.098%	-0.049%
3	28.196	28.168	28.180	-0.099%	-0.057%

4. CONCLUSIONS

The self-healing ability of EMAA ionomer was investigated in case of hypervelocity impacts, typical condition of space mission employment. SEM micrographs and de-pressurized air flow tests confirmed the self-repairing behavior for studied material.

Thermal outgassing test showed that the ionomer is not significantly affected by outgassing phenomena. Although extensive testing is needed for a space qualification, these tests provide a first basis for a possible future employment of EMAA ionomers as self-healing materials in space applications.

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