

# **Outgassing Effect on Spacecraft Structure** Materials

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## Abstract

In the vacuum deep space, outgassing has contributed to degrade mechanical performance of composite materials used in satellite. In this paper, four composite materials are used. Three types of epoxy based composite materials are tested: Carbon fiber, glass fiber and kevlar, which are used in satellite structure. The tested materials are manufactured by commercial method (hand lay-up method without autoclave curing). The forth material is polyimide which is a commercial sheet used in thermal multilayer insulator. The aim of this paper is to qualify those commercial manufacture materials to be used as Low Earth Orbit satellite structure. This study proves two important results; the use of hand lay-up Kevlar/epoxy in the satellite manufacture is rejected. While, the commercial Polyimide (Artilon<sup>®</sup>) is confirmed as a new material used in space as a layer in the multilayer insulation at the lower temperature side.

## **Keywords**

Vacuum, Outgassing, Polymers, Glass Fiber, Carbon Fiber, Kevlar, Polyimide Composite Materials

## 1. Introduction

The satellite is exposed to different environmental threats which are not present at the earth surface. These threats are vary by the variation of the satellite altitude. The environmental threats cause many effects such as satellite material degradation and contamination. Vacuum is one of the space environmental threats which create three problems for satellite, (outgassing, cold welding, and heat transfer).

Most of the remote sensing satellite's mission is between 200 - 1000 km. height which called Low Earth Orbit (LEO). The vacuum at LEO is typically  $(1.33 \times 10^{-9} - 1.33 \times 10^{-11})$  mbar outside the satellite and  $(1.33 \times 10^{-6} - 1.33 \times 10^{-7})$  mbar inside satellite. [2]

The outgassing process occurs mostly in polymeric materials which cause loss of dimension stability, structure distortion, surface contamination, and change in properties. Outgassed materials face a sever deterioration in the absorptance and transmittance. [3, 4]

This paper is concerned about the outgassing as sever vacuum effect. It is defined as the release of gaseous species from the sample under high vacuum conditions. [5] The gases escaped out of the satellite materials due to the outgassing process occurred at elevated temperature could form a delicate layer of coating covers the optical sensors lenses or cause an arc in the electronic components.

Selecting the materials for satellite is highly affected by vacuum condition. The materials stability ranking not only depends on the outgassing test results but also at its relative position with the sensitive elements.

Composite and polymeric materials are widely used in space applications. These materials are used in many components in the satellite as structural, thermal and electrical components [3,6].

A commercial manufacturing method is performed and tested throughout this to prove that these materials can be used in space with a law cost manufacturing method.

Vacuum is one of the most important space environment hazards that constrained the material design and selection. In order to qualify these materials for space use we have to follow the American Society for Testing and Materials "ASTM-E595"[9] or the European Corporation for Space Standards "ECSS-Q-ST-70-02C"[11] for the test standard procedures. The mentioned standard test methods are dealing with many types of materials such as organic, polymeric, and inorganic materials These include polymers, elastomers, insulations, fabrics, and composite materials.

The standards are determined the criteria used for the acceptance and rejection of space. Collected Volatile Condensable Material (CVCM), Total Mass Loss (TML), Water Vapor Regained (WVR)., and recovered mass loss (RML) evaluating the mass loss of materials being subjected to  $125^{\circ}$ C at less than 7 x  $10^{-3}$  Pa for 24 h, the values of TML of 1.00 % and CVCM of 0.1% have been used as screening levels for rejection of satellite materials.[7]



Fig. 1. Hand Lay-up Process for Material Fabrication.

## **2. Experimental Work**

#### **2.1. Sample Preparation**

Composite materials with Epoxy based matrix are manufactured using hand lay-up process cured in room temperature without auto-clave facility. This process considered as a commercial material and non-expensive method compared with the auto-clave curing method. [17] Auto-clave method is used to remove humidity from the manufacturing materials. A bidirectional ply used in the sheet fabrication. The laminated composite panels are fabricated by stacking multiple layers fabric. All panels for fabricating test samples used in this study were laminates with the lay-up sequences. The number of plies specified to meet the required materials volume fraction.

The sample materials are made from commercial constituents, theses composite materials are listed as follows:

- 1. High modulus carbon fiber (Thornel<sup>TM</sup> T300-3K)/Epoxy (EpoLam <sup>TM</sup>5014) to simulate the structure material used for manufacturing the honeycomb panel sheets.
- 2. Glass fiber (E-glass DCG)/Epoxy (EpoLam TM5014) to simulate the structure material used for manufacturing fittings and supports.
- 3. Kevlar fiber (DuPont<sup>TM</sup> Kevlar<sup>®</sup> 49)/Epoxy (EpoLam

TM5014) simulate the structure material used for manufacturing fittings and supports and thermal insulator.

4. Polyimide (Artilon) which is used as fittings, supports and thermal insulation material. This material is used in Satellite multilayer insulator (MLI) to protect the satellite from space radiation and thermal effect. The popular polyimide used in space is Kapton®. In this paper, a commercial sheet of polyimide (Artilon<sup>®</sup>) will be tested and verified to be used in space.



Fig. 2. Represent sample cutting tool.



Fig. 3. Sample and collector holders.

The samples are cut from the same sheet prepared with the same process to be applied in space. The samples are formed in small discs with no more than 6 mm in diameter with a minimum weight  $(50 \pm 5)$  mg. the samples were cut using a special tool as in Figure 2.

After the samples formation an (FTIR) Fourier Transform Infra-Red spectroscopy analysis will be performed in order to show the chemical construction of the tested materials.

#### 2.2. Test Facility

The outgassing process has been performed in the "Scientific Aerospace Solutions Laboratory (SASLab)" in

Sapienza University of Rome using the outgassing analyzer. This facility consists of a turbo-molecular pump and a cylindrical vacuum chamber. The vacuum chamber contains a sample holder and collector plates holder as shown in fig.3. These holders were arranged back-to-back and covered with a sealed copper cylinder. The investigated samples were placed in an aluminum boat as shown in fig.4 with a tiny hole in the base. The test followed (ASTM) tolerances because they are stricter than that in (ECSS) standard [8].

The sample boats were wormed up to  $125^{\circ}$ C for 24 hours to enhance the gas escaping from the investigated samples. Whenever the collector plates were kept active cooled by a chiller to force the escaped gasses to condense on the collector plates surface. Before applying the vacuum process both the investigating samples and collector plates are weighted by using the high accuracy (2µg) Mettler Toledo balance to calculate the Total Mass Loss (TML).As shown in fig.3.



Fig. 4. Outgassing Ground Simulator Facility Configuration.



Fig. 5. Sample holders, collectors and microbalance.

#### 2.3. Operation Test Conditions

The operation test conditions are set as mention in ECSS-Q-ST-70-02C [11] and ASTM standard E 595 [9].

| Table 1. | <b>Operation</b> | Test | Conditions. |
|----------|------------------|------|-------------|
|----------|------------------|------|-------------|

|             | Sample     | collector |
|-------------|------------|-----------|
| Temperature | 125 +/-1°C | 25°C±1°C  |
| Pressure    | 10-4 Pa.   | 10-4 Pa.  |

#### 3. Results and Discussions

The outgassing test values represent in four main values

listed in Table.3. The outgassing test is performed at two samples for each material the calculated mean value is considered the important value. Figure 5 is shown the comparison between the mean values for the materials tested parameters and the standard values of the main test parameters TML, CVCM, WVR, and RML. This figure is clarify the relation between each material results and standard values

In the figure the polyimide TML% value is (0.872001%) which is less than the standard value (1%), it means that the polyimide sample proved its ability to withstand the outgassing effect of the space vacuum hazard, accordingly, polyimide qualified as a satellite structure material. In spite of CVCM % is (0.358784%) which is more than the standard value (0.1%) the use of polyimide is allowed because of the location of the material with respect to the sensitive optical elements. WVR% and RML% are lower than the ECSS and ASTM standard values during the test procedures the tested polyimide type was not sufficient thermally stable. Using this type at the positions with low temperature, it is acceptable.

The common two polyimide types used in space are polyimide epoxy and the most popular Kapton® NASA outgassing online database shows in table 2. [16].

 Table 2. Typical Values Listed In NASA Outgassing Database For Tested

 Materials.

| Paramotor     | TMI % range   | CVCM%       | WVR%        |  |  |
|---------------|---------------|-------------|-------------|--|--|
| 1 al allieter | TWIL /0 Tange | range       | range       |  |  |
| polyimide     | 0.86 - 3.38   | 0.05 - 1.39 | 0.14 - 1.12 |  |  |
| CF/Epoxy      | 0.6 - 1.2     | 0.01 - 0.03 | 0.1 - 8.83  |  |  |
| GF/Epoxy      | 1.07 - 3.50   | 0.1 - 1.16  | 0.0 - 0.61  |  |  |
| Kevlar/Epoxy  | 1.86-1.92     | 0.1         | 1.26-132    |  |  |

Figure 5 also shows the relation between the mean values for CF/Epoxy and GF/Epoxy tested parameters and standard values of the main test parameters TML, CVCM, WVR, and RML.

The mean values of TML and RML in both carbon fiber and glass fiber are higher than the standard values in ECSS and ASTM. These values are high because of the highly content of humidity results from the manufacturing method. This high content of humidity does not prevent the use of these materials in space because of the location of the materials with respect to the sensitive elements and the shielding covers.

On other hand, the mean values of CVCM% and WVR% for both carbon fiber and glass fiber are lower than the typical standard values in ECSS and ASTM this can be explained by the absence of the condensation of harmful gases on the optical elements surfaces. NASA outgassing online database as in table 3 [16]

In the same figure, it is clear that the relation between the mean values for Kevlar/Epoxy tested parameters and standard values of the main test parameters TML, CVCM, WVR, and RML. According to the test the TML% value is (7.11 %) which is very high with respect to the typical standard values in ECSS and ASTM (less than 1%). the CVCM% in this study is (0.6256188%) which is very high with respect to the typical standard values in ECSS and ASTM (less than 0.1%).

The Kevlar/Epoxy is commonly used as shield and insulation material because of that is near the elements need to be isolated, this gives the Kevlar outgases a degree of danger more than other materials used away of sensitive elements. Kevlar is a popular material used in satellite, due to the NASA outgassing online database shows in table 2 [16]

The FTIR spectroscopy analyze the material chemical construction and drown a curve with several peaks each peak indicate an individual chemical bond. Shown in Figure 6. this figure will be used to clarify the outgassing test results. The first vertical dashed line indicates the peak at (3378 cm-1) this peak value is repeated at carbon fiber, glass fiber, and Epoxy. It is an indication of the presence of (O-H) bond which changes to H2O under space vacuum and temperature. This peak value does not shown up in the polyimide and Kevlar curves. The second dashed line indicates the peaks at (1026cm-1) this peak is repeated at carbon fiber, glass fiber and epoxy. It is indicating the presence of (C-O) bond. This peak does not appear in polyimide and Kevlar curves. Due to space temperature fluctuation and space vacuum, the water vapor and carbon oxides released. According to ECSS, the water vapor and carbon oxides are not seen as critical gases and not to prevent the use of these materials in space. [5, 11]. Since the FTIR for Kevlar does not show the (H-O) or (C-O) peak so the unknown released gases may be harmful and cause surface contamination. The unknown gases with the high percentage may lead to dimensions instability and properties degradation.



Fig. 6. The Outgassing Test results for polyimide, CF, GF and Kevlar.



Fig. 7. FTIR of the used materials.

| Table 3. | The | Results | of the | Outgassing Test. |
|----------|-----|---------|--------|------------------|
|----------|-----|---------|--------|------------------|

| Material<br>Name | - | S/N | Sample<br>Holder<br>Weight<br>(mg) | collector<br>plate<br>Weight<br>(mg) | Sample<br>Weight<br>(mg) | Sample<br>Weight<br>After test<br>[2 min]<br>(mg) | Collector<br>Plate<br>Weight<br>After test<br>(mg) | Sample<br>Weight<br>After test<br>[24 hr]<br>(mg) | TML %    | CVCM %     | WVR %     | RML %     |
|------------------|---|-----|------------------------------------|--------------------------------------|--------------------------|---|--|---|----------|------------|-----------|-----------|
| CF/<br>EPOXY     | ٨ | A1  | 1317.482                           | 2357.729                             | 73.851                   | 71.607  | 2357.798   | 71.269  | 3.038551 | 0.09343137 | -0.457678 | 3.4962289 |
|                  | A | A2  | 1318.756                           | 2557.481                             | 71.488                   | 69.921  | 2557.533   | 70.278  | 2.191976 | 0.07273948 | 0.4993845 | 1.6925918 |
| GF/<br>EPOXY     | р | B1  | 1361.201                           | 2784.509                             | 93.84                    | 91.629  | 2784.709   | 92.093  | 2.356138 | 0.21312873 | 0.4944587 | 1.8616795 |
|                  | в | B2  | 1348.922                           | 2538.566                             | 89.239                   | 86.945  | 2538.753   | 87.425  | 2.570625 | 0.20954964 | 0.5378814 | 2.0327435 |
| Kevlar/<br>EPOXY | C | C1  | 1884.26                            | 2340.543                             | 44.206                   | 41.025  | 2340.89  | 41.755  | 7.195856 | 0.78496132 | 1.6513595 | 5.5444962 |
|                  | C | C2  | 1880.739                           | 2370.972                             | 46.11                    | 42.863  | 2371.187   | 43.482  | 7.041856 | 0.4662763  | 1.342442  | 5.6994144 |
| Polyimide        | D | D1  | 1303.991                           | 2570.341                             | 88.363                   | 87.399  | 2570.623   | 87.425  | 1.090954 | 0.3191381  | 0.0294241 | 1.0615303 |
|                  | D | D2  | 1303.223                           | 2784.187                             | 84.833                   | 84.279  | 2784.525   | 84.286  | 0.653048 | 0.39842986 | 0.0082515 | 0.6447962 |

## 4. Conclusion

This study shows the effect of outgassing on the composite materials made by a hand lay-up process without auto-clave curing which is low cost commercial method. A comparison between the standard values and the test results values of TML%, CVCM%, WVR and RML are performed. The following points are identified:

1. The Carbon fiber/Epoxy and Glass fiber/Epoxy samples are indicated higher values than standard values but still accepted because of: the materials location in the Satellite are far from the sensitive items, the outgassing constituents are not critically (H2O, COx) according to ECSS [11], the investigated materials are shielded with an insulation materials. These show the possibility of using CF/Epoxy and GF/Epoxy in Satellite manufacturing in spite of the values are little higher than standards.

- 2. The Kevlar/Epoxy result values are very high compared by the standard acceptance values therefore the use of Kevlar/epoxy manufactured by the hand lay-up process without auto-clave curing is rejected to use in satellite structure elements production.
- 3. The Polyimide (Artilon®) Sample test results are confirming that the Polyimide material is accepted in use in space with proper values according to standards. This material is confirmed as a new material used in Satellite

manufacturing materials as a layer in the multilayer insulation at the lower temperature side.

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