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Qualification of adhesive bonding joints for precision opto-mechanical assemblies

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Abstract

The fixation technology of adhesive bonding is used during assembly and integration of precise opto-mechanical assemblies. Optical components like lenses, gratings, prisms, aperture stops, and slits are aligned into the opto-mechanical systems and fixed at the aligned position using adhesive bonding technology.
Depending on the field of use, the bonding processes and adhesives have to be tested and qualified. In the most cases the test of the mechanical resistance as lap- and shear strength are necessary. For automotive applications thermal environmental tests, humidity tests, and salt spray tests have to be performed on the opto-mechanical assemblies before the mechanical strength will be tested. Also, applications for space use must be tested in a variety of environmental tests, like thermal vacuum tests, humidity-, shock-, vibration-, and radiation tests. These test conditions are defined by ISO standards and special automotive (IATF, TISAX, ISO) and space standards (ECSS).
The paper describes the process chain of the qualification of adhesive bonding connections. The tests and qualification of bonding joints for a prism-grating-prism assembly for space application used in the ESA CO2M-mission will be shown.

Keywords: Adhesive bonding, precise opto-mechanical assemblies, Assembly, Alignment, Qualification

1. Introduction

The qualification of bonding joints is very important for applications, on which a service mode is not possible during lifetime. Any components and sub-systems of earth observation instruments installed on satellites must work for 7 to 12 years in orbit without any maintenance. This requires the selection of special materials, the analysis of several load cases and the qualification and test of the designed systems on component and system level. The qualification and test of bonding joints are key factors to ensure the performance of mechanical-optical systems during storage, launch, and lifetime without failure. The test sequences are established practices in space engineering and defined in the Adhesive Bonding Handbook [1] and the ECSS standard for testing [2].

2. Analysis of load cases

The analysis of the load cases is based on the definition of environmental loads. All single load cases and possible combinations of load cases were analysed to define the highest loads for qualification and tests. Safety factors will be applied to manage tolerances in manufacturing, analysis modelling and variation of material properties. In some cases statistic calculation for defining the number of test samples is used for minimizing the risks of failure assumption and modelling failure propagation.

3. Definition of qualification samples and test sequences and test equipment

The definition of qualification samples is important to have representative samples in geometry, materials, and processes. The test samples should be as similar as possible to the system hardware, but as cheap as possible, because in most cases at least 30 samples, up to 100 samples will be used for test and qualification. All processes, which will be performed to the final hardware, should also be apply during manufacturing of the test samples to cover all possible aspects, influences, and process interactions of the performed manufacturing chain.

4. Qualification of prism-pin adhesive bonding joint for CO2M assembly

As an example of qualification of bonding joints, the structural adhesive bonding of a prism to mechanical mounting pins were chosen. The optical system is a prism-grating-prism-assembly for an optical instrument as part of the ESA CO2M mission. The CO2M mission deals with the carbon dioxide monitoring of emission of greenhouse gases. The two CO2M satellites will each carry a near-infrared and shortwave-infrared spectrometer to measure atmospheric carbon dioxide at high spatial resolution. [3] The opto-mechanical design and integration of the prism-grating-prism (PG+P) assemblies are described in [4].

The design of the test samples is given in figure 2. The sample geometry was designed similar to flight hardware. A glass block made of fused silica is representative for the prism material, the pin is representative for the flight hardware mechanical mounting elements (pins). The size of the gluing pads was designed to cover the highest thermo-mechanical loads of the SWIR2-prism-grating-prism assembly for the CO2M-instrument. The chosen materials met the outgassing requirements of the CO2M mission. By using steel and fused silica there are no significant outgassing issues. The chosen 2 component expoy adhesive is tested and qualified by

outgassing tests. A total mass loss (TML) of 0.77% and a collected volatile condensable materials (CVCM) of 0.04 % were measured by the adhesive manufacturer according to NASA standard 1124 rev.4..

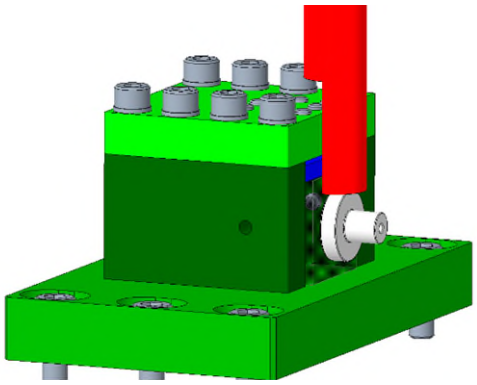

Figure 1. test setup for compressed shear test

The mechanical loads were also analysed for the designed test samples and the test setup. As a result, an averaged shear strength of 11 MPa was calculated and used as success criteria.

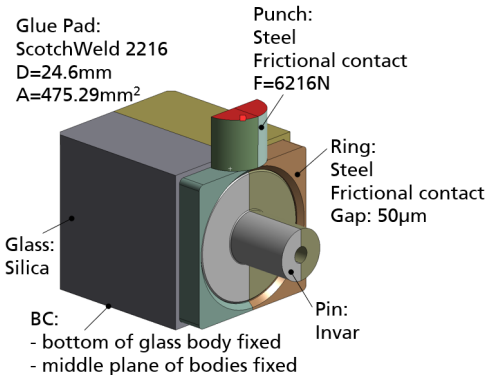

Figure 2. Analysis FE-model of test probes

5. Adhesive qualification test flow

The qualification test flow starts with the sample preparation. This includes surface preparation like grinding (if necessary), cleaning, and surface primer application. The test samples are bonded by the adhesive and cured by representative conditions. The structural adhesive based on two components epoxy is cured for 24 hours at room temperature. Depending on the adhesive, a postcuring of 7 days might be necessary to reach the specified mechanical strength.
After sample preparation, the environmental loads of humidity, thermal cycling and thermal vacuum cycling are applied to the test samples. After all environmental loads were applied, the compression shear testing is performed. Reference samples, which were not exposed to environmental loads, will show the differences in mechanical properties.

6. Adhesive qualification test results

After manufacturing and adhesive bonding of the test samples, all samples have been inspected. The joint partners were correctly positioned after gluing and no significant variation from the average volume and size of glued areas could be detected. The total amount of bubbles or areas, which are not filled with adhesive, were measured and the values were less than the required 20%.

The environmental loads were applied to the test samples. After each execution of an environmental test (humidity test and thermal-vacuum tests) a visual inspection has been performed. Different success criteria were defined and successful proved: no damages, no cracks, no breaks or delamination of the adhesive or the join-partners.

After the compression shear testing the shear strengths were calculated by the maximum shear force (as a result of the destructive test) divided by the nominal contact wetting area of the adhesive. An averaged shear strength of 11 MPa was defined as success criteria and met by all test probes. The absolute values of shear forces have no variation of more than the required 20% before and after environmental tests. The reference samples, which are not exposed to the humidity and thermal vacuum loads, show a higher mechanical strength of 17 MPa. The decrease is induced by humidity loads, which have an influence on the chemical bondings of the adhesive to the surface material of glass and metal.

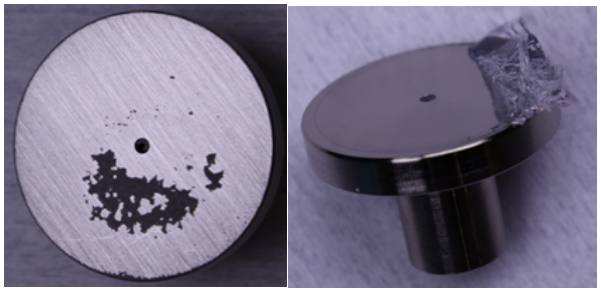

Figure 3. Left: delamination on PIN surface. Fraction within adhesive within small areas. Right: delamination on PIN surface. Fraction within glass cube within small areas.

The qualification was successful, all success criteria were met.

7. Summary

Adhesive bonding joints for fixation of opto-mechanical components were tested for different applications. The process steps of testing are described, starting with the analysis and definition of test loads, the design and manufacturing of the test samples and the environmental loads application and the mechanical testing. The illustrated example of prism-pin test samples show some details in sample design and testing results.

References

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