European Harmonized Training for Adhesive Bonding Technology

EUROPEAN ADHESIVE ENGINEER

MODULE 4.6

DURABILITY- RADIATION AND VACUUM EFFECTS ON ADHESIVE JOINTS

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4.6 Radiation and Vacuum Effects on Adhesives in Bonded Joints

Scope:

- ✓ Suitability to be used in vacuum and space environment
- ✓ Methods of evaluation (simulated vacuum environment)
- ✓ Results of adhesive evaluation

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Suitability to be used in vacuum and space environmets [1], [2]

Significance of space environment effects on adhesive joints

Space environments constitutes a high demand on material properties, and depending on application, materials are exposed to high vacuum, thermal cycling, solar radiation, including high-energy radiation, ultraviolet (UV) radiation, X-ray, particulate radiation (electrons, protons, gamma rays), and atomic oxygen.

Polymers are widely used as space materials, and prominent among these are polybenzimidazole (PBI), polyimide (PI), polyether ether ketone (PEEK), perfluorinated polymers, epoxies and silicones because of their favorable electrical, thermal and mechanical properties.

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Suitability to be used in vacuum and space environmets [1], [2]

The factors causing degradation of polymer materials in space environment are primarily because of intense high-energy radiation, which are ultraviolet (UV), solar flare X-rays, solar wind electrons, and protons trapped in Earth’s magnetic field. Materials selected for space applications should maintain chemical and structural integrity when exposed to the environmental conditions of space.

These materials should have low outgassing rates at normal operating temperatures and the outgassing should consist of a minimum of materials condensable at the temperatures to adjoining surfaces.

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Suitability to be used in vacuum and space environmets [2]

Radiation

The radiation spectrum is classified in two types:

- electromagnetic radiation (UV-rays)
- ionizing radiation (neutron, electron, gamma, X-rays)

Radiation of sufficient energy causes molecular chain scission of polymers used in adhesives and sealants. This results in weakening and embrittlement of the bond. The degradation is worsened when the adhesive is simultaneously exposed to both elevated temperatures and radiation.

Suitability to be used in vacuum and space environmets [2]

Generally, heavily crosslinked, heat-resistant adhesives have been found to resist radiation better than less thermally stable systems. Radiation does not have serious effect on the shear tensile strength of highly crosslinked adhesives. Fibrous reinforcement, fillers, curing agents, and reactive diluents will also affect the radiation resistance of adhesive systems. In epoxy-based adhesives, aromatic curing agents offer greater radiation resistance than aliphatic-type curing agents.

Polyester resins and anaerobic adhesives and sealants have high radiation resistance. Anaerobic adhesives have several years of long term exposure in radiation environments due to their use as thread locking sealants in nuclear reactors and accessory equipment.

Suitability to be used in vacuum and space environmets [2]

Nitrile-phenolic adhesives are more resistant to radiation damage than epoxy based adhesives. Thick adhesive layers retain useful strength better than thin layers in a radiation environment.

10 mils (0,254 mm) is recommended as the minimum adhesive thickness when radiation is an environmental factor.

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Suitability to be used in vacuum and space environmets [1]

Polymers are extensively used as structural materials in Low Earth Orbit (LEO) spacecraft due to their high strength to weight ratio and relatively better mechanical, thermal, electrical, and thermo-optical properties.

Application of polymers at Geosynchronous Earth Orbit (GEO) is still limited. At LEO, use of polymers is very common and typical. Such polymers are polysiloxanes (silicones), epoxies, polyurethanes (PUR), polyesters, acetals, acrylics, polyamides (PA), fluorocarbons, polyimide (PI).

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Suitability to be used in vacuum and space environmets [1]

The main hazards of the natural GEO environment include:

1.) external energetic electrons, photons, protons, alpha particles, neutrinos, neutrons, and all naturally occurring isotopes;

2.) internal-neutrons, gamma rays, and beta particles;

3.) braking radiations (X-rays and gamma rays)

Suitability to be used in vacuum and space environmets [2]

Vacuum and outgassing

Evaporation and sublimation into a vacuum system is defined as outgassing. Almost every material, solid or liquid has a small vapor pressure, and their outgassing becomes important when the vacuum pressure falls below this vapor pressure. In a vacuum system, outgassing has the same effect as a leak.

Adhesives may be composed of low-molecular weight constituents that can be extracted from the bulk when exposed to a vacuum. If these low-molecular weight constituents also have a low vapor pressure, they may migrate out of the bulk on exposure to elevated temperatures with or without the presence of a vacuum.

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Suitability to be used in vacuum and space environmets [2]

This results in an overall weight loss and possible degradation of the adhesive. The ability for an adhesive to withstand long periods of exposure to a vacuum is of primary importance for materials used in space applications or in the fabrication of equipment that requires a vacuum for operation.

The degree of adhesive evaporation is a function of the vapor pressure of its constituents at a given temperature. Loss of low-molecular weight constituents such as plasticizers or diluents could result in hardening and porosity of adhesives.

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Suitability to be used in vacuum and space environmets [2]

Since most structural adhesives are relatively high-molecular weight polymers, exposure to pressures as low as $1,3\times10^{-7}$ Pa is not harmful to the base resin. High temperatures, radiation, or other degrading environments may cause the formation of low-molecular weight fragments, that tend to bleed-out of the adhesive in a vacuum.

Epoxy and polyurethane (PUR) adhesives are not appreciably effected by pressure $1,3\times10^{-7}$ Pa for 7 days at room temperature. However polyurethane adhesives exhibit significant outgassing when aged under $1,3\times10^{-7}$ Pa vacuum at +110°C. Under room temperature conditions a high vacuum does not cause significant weight loss in commercial adhesives.

Suitability to be used in vacuum and space environmets [2]

Effect of $1,3 \times 10^{-5}$ Pa vacuum pressure on commercial adhesives

Adhesive	Weight change [%]	Moisture change [%]
Modified epoxy	- 0,03	+ 0,60
Flexibilized epoxy	- 0,06	+ 0,61
Polyurethane (PUR)	+ 0,01	+ 0,41
Polysulfide (PS)	- 0,23	+ 0,39

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Methods of evaluation [4]

ASTM D1879: Standard Practice for Exposure of Adhesive Specimens to Ionizing Radiation

The purpose of this practice is to define conditions for the exposure of polymeric adhesives in bonded specimens to ionizing radiation prior to determination of radiation-induced changes in physical or chemical properties. It covers the following kinds of radiation:

- gamma or X-ray radiation,
- electron or beta radiation,
- neutron radiation,
- nuclear reactor radiation (neutron and gamma radiation).

Methods of evaluation [4]

The procedures outlined in this practice are designed to standardize the exposure of adhesive-bonded specimens for the purpose of studying the effects of high-energy radiation. This practice covers procedures for the following five types of exposure:

Procedure A—Exposure at ambient conditions.

Procedure B—Exposure at controlled temperature.

Procedure C—Exposure in a vacuum at pressure of 10 Pa or less.

Procedure D—Exposure under mechanical load.

Procedure E—Exposure combining two or more of the variables listed in Procedures A to D.

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Methods of evaluation [4]

Three categories of high-energy radiation are specifically included in this recommended practice. The dose rates listed show the range for a given kind of radiation within which past experience indicates that approximately equal effects will result for equal total exposure:

- Gamma radiation, X-radiation, neutrons: 10^3 - 10^4 Gy/h
- X-radiation: 10^4 - 10^7 Gy/h
- Electrons, beta radiation from radioisotopes: 10^3 - 10^5 Gy/h

Depending upon the type and energy of radiation, **inorganic adherends** may have a shielding effect on the adhesive bond!

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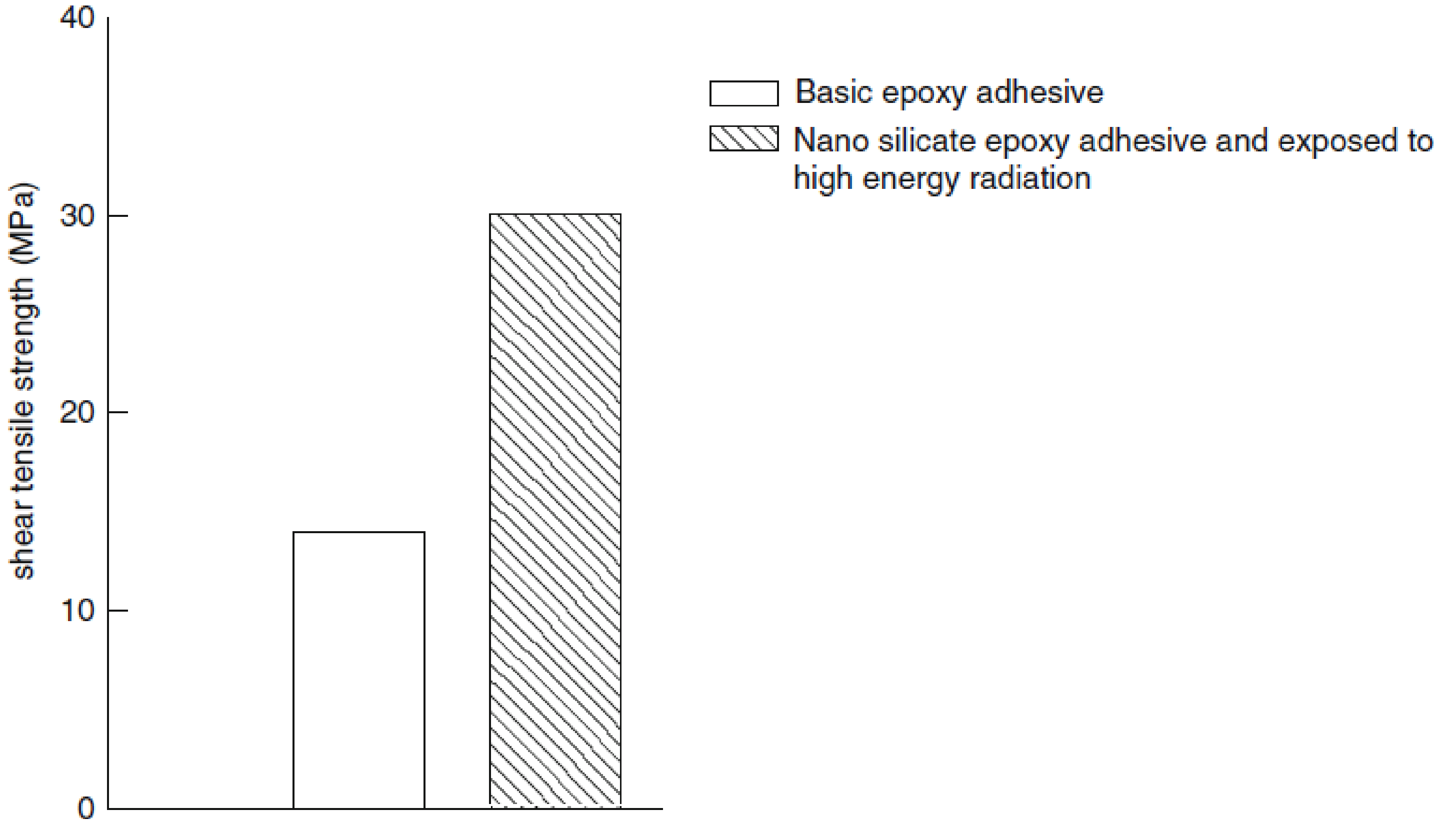
Methods of evaluation [3], [4]

For the effect of irradiation on shear tensile strength, significant changes might be reduction to 80 % - 20 % of initial value.

Significant change in density might be 2 % - 5 % of initial value.

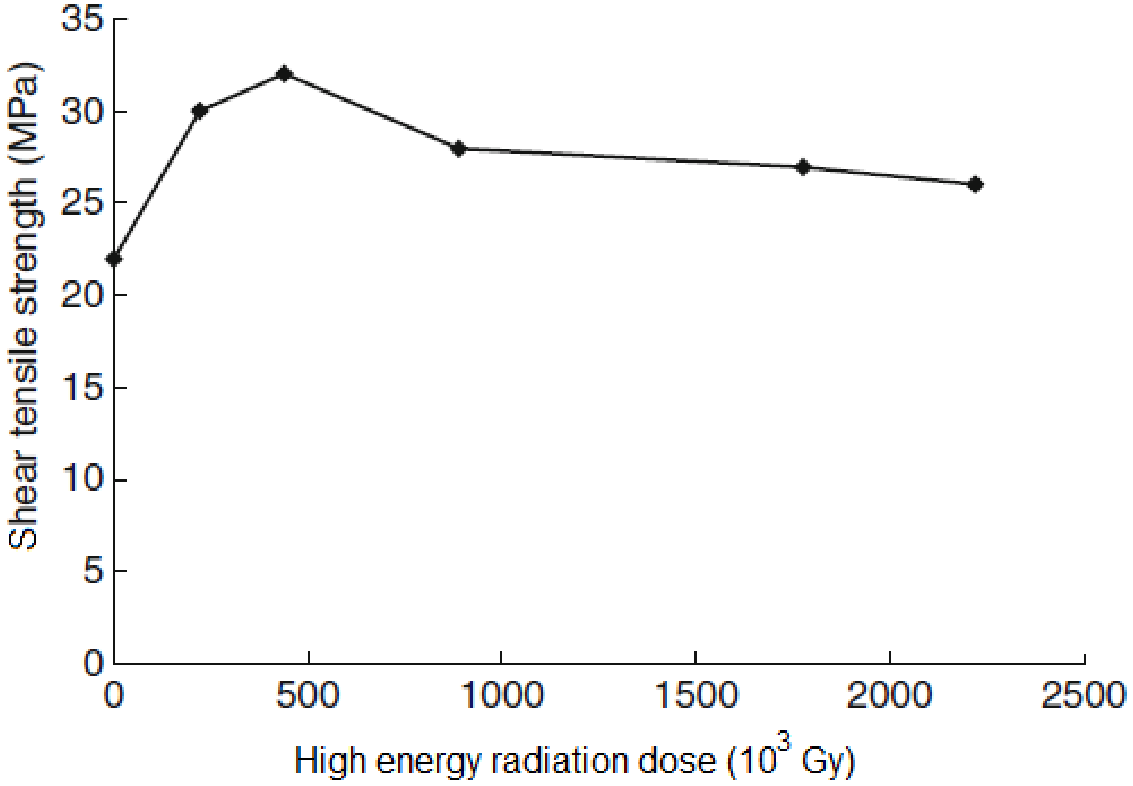
Radiation exposure tests are required for products used in the nuclear industry and applications where radiation is used (medical X-rays and sterilization).

Results of adhesive evaluation [1]



Shear tensile strength increase of nanosilicate epoxy adhesive, exposed 6 h to nuclear reactor radiation

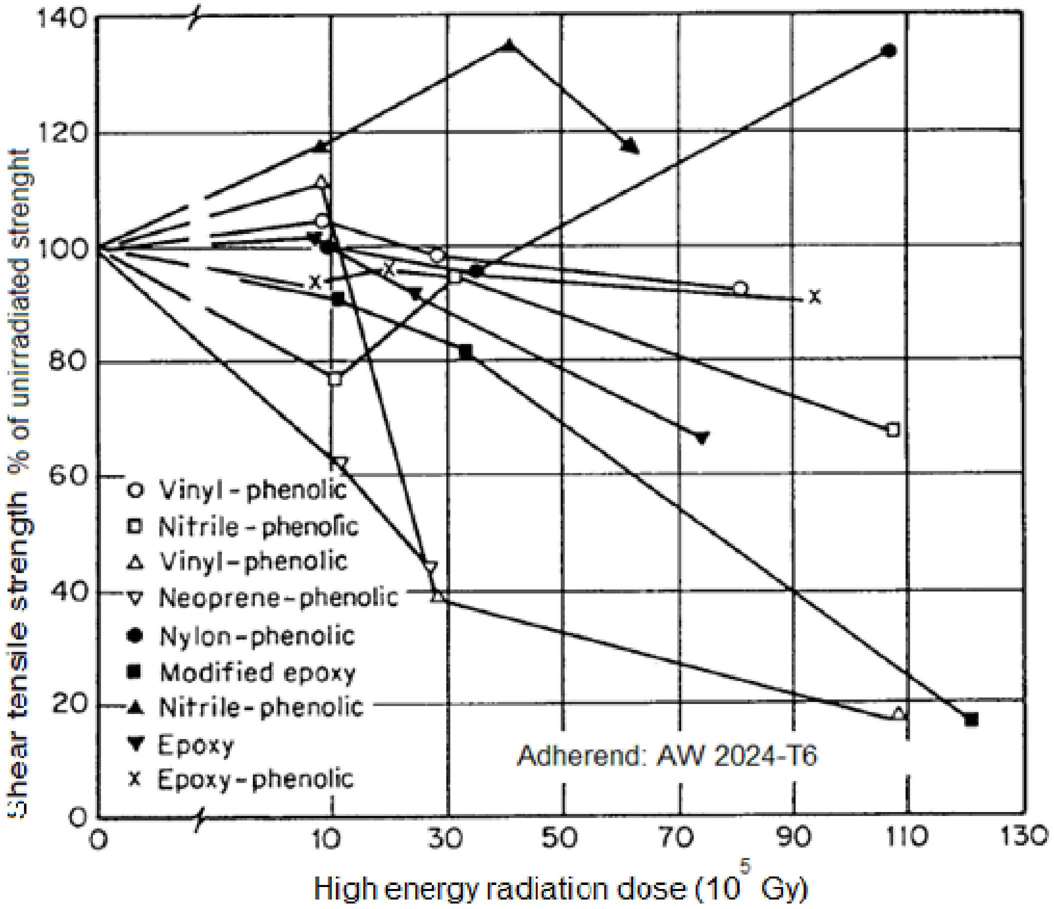
Results of adhesive evaluation [1]



Shear tensile strength of the nanosilicate epoxy adhesive joint exposed to nuclear reactor radiation dose

Results of adhesive evaluation [2]

Percent change in initial shear tensile strength caused by nuclear reactor radiation dose.



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[2]	E.M. Petrie: Handbook of Adhesives and Sealants, McGraw-Hill, 1999
[3]	D.A. Dillard Ed.: Advances in structural adhesive bonding, CRC Press, 2010
[4]	ASTM D1879-06 Standard Practice for Exposure of Adhesive Specimens to Ionizing Radiation

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