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COMPILATION OF RADIATION DAMAGE TEST DATA

PART IV: Adhesives

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COMPILATION OF RADIATION DAMAGE TEST DATA

PART IV: Adhesives for use in radiation areas

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ABSTRACT

This handbook gives the results of radiation damage tests on various adhesive systems, including thermosetting resins and tapes, intended for use in radiation areas of the CERN high-energy accelerators and particle physics detectors.

Over the years, materials have been proposed by various suppliers or by CERN users. Recently, a selection of adhesives which cure at room temperature have been tested.

The materials were irradiated either in a ^{60}Co source, up to integrated absorbed doses between 200 kGy and a few megagrays, at dose rates of the order of 1 Gy/s, or in a nuclear reactor at dose rates of the order of 50 Gy/s, up to doses of 30 MGy.

The results of the different tests are presented in the form of tables and graphs to show the effect of the absorbed dose on the measured properties (usually the mechanical properties).

RÉSUMÉ

Ce catalogue donne les résultats d'essais sur la résistance aux rayonnements ionisants de systèmes adhésifs, y compris des résines thermodurcissables et des rubans adhésifs, pouvant être utilisés dans des zones de rayonnements ionisants des accélérateurs à haute énergie et des détecteurs de particules du CERN.

Au cours des années, des matériaux ont été proposés par différents fournisseurs et par des utilisateurs CERN. Plus récemment, une sélection d'adhésifs à tester s'est concentrée sur des systèmes qui polymérisent à température ambiante.

Les matériaux ont été irradiés soit en source de ^{60}Co, à des doses comprises entre 200 kGy et quelques mégagrays, à un débit de dose de l'ordre de 1 Gy/s, soit en réacteur nucléaire à un débit de dose de 50 Gy/s, jusqu'à des doses de 30 MGy.

Les résultats sont présentés sous forme de tableaux et de graphiques qui montrent l'effet de la dose absorbée sur les propriétés mesurées (généralement les propriétés mécaniques).

CONTENTS

1 INTRODUCTION

Investigations into the degradation of materials and components which are exposed to ionizing radiation have been carried out in many applications, such as nuclear reactors, fusion reactors, high-energy accelerators, medical and industrial irradiation facilities, space projects, etc. At the European Organization for Nuclear Research (CERN), from the beginning of the high-energy particle accelerators, radiation damage test studies have been centred on organic and inorganic materials [1]–[9]. For several decades, electronic and optical components and devices, as well as other materials that are used in the construction and operation of high-energy accelerators and particle detectors, have been included in the studies.

Apart from electronic and optical devices, the organic materials are the ones most sensitive to radiation. As a consequence of this, a large number of radiation tests have been made on these materials and the results are extensively documented. Design engineers are, however, often faced with the problem of finding the desired information quickly within the available literature. We therefore decided to publish our radiation damage test results on organic materials in the form of catalogues.

The first catalogue, published more than twenty years ago, concerned organic materials used as insulation and sheathing for electric cables [10], a second edition was published in 1989 and concerns halogen-free cable-insulating materials [11].

The second catalogue dealt with thermosetting and thermoplastic resins, the majority being epoxies used for magnet coil insulations [12], the second edition was published in 1998 and concerns the results obtained for thermoset and thermoplastic resins as well as composite materials [13]. A study on high-power and high-voltage insulators has also been conducted [14].

The third catalogue, published in 1982, contained information on miscellaneous materials and components used around high-energy accelerators, such as cable ties, motors, relays, hoses, o-rings, oils, etc, as well as some adhesive tapes [15].

A list of materials presented in the preceding volumes can be found in Appendix 1. The present volume completes the third catalogue and concentrates on adhesive resins and tapes. As in each previous edition, the materials are presented in alphabetical order. In addition, general tables also present approximate radiation levels up to which category adhesives can be used. This catalogue is therefore a useful complement to all the volumes published so far.

In the nineties, a study was conducted to facilitate the selection of organic materials to be used in the cryogenic environment of the LHC [16].

2 SOME BASIC FACTS ABOUT RADIATION EFFECTS ON POLYMERS AND ORGANIC MATERIALS

The main type of chemical bond in a polymer is covalent bonds, which are rather sensitive to ionizing radiation. As a consequence, not only are the physico-chemical properties of polymeric materials affected by radiation, but also their mechanical and other macroscopic properties. Extensive work has been carried out on radiation effects in polymers, mainly for nuclear reactor applications and radiation processing. Many books have also been published. See, for example, Refs. [17]–[25]. Even today, several conferences are held on the subject, some of them organized or sponsored by the International Atomic Energy Agency (IAEA). See, for example, Refs. [26]–[34].

As already discovered by Dole in 1948, [21], one of the most important effects of radiation on molecular weight polymers is the formation of cross-links, i.e. C–C covalent links between the long-chain molecules. A moderate number of such cross-links can often improve the physical properties of polymers, but the materials can become stiff and brittle at very high densities. Conversely, irradiation can break the bonds, leading to scission of the macromolecules. The scission process usually produces deleterious effects, resulting in materials that are soft and weak. In many cases, crosslinking and scission proceed simultaneously. However, depending upon the molecular structure, the presence and the type of some additives, and also the inert or oxidative environment, one effect usually dominates.

Many other radiation effects can occur, including the formation of double bonds and the introduction of low weight molecules in the polymeric network.

When discussing the radiation resistance of polymeric materials, a fundamental distinction must be made as to whether the environment presents oxidizing or non-oxidizing conditions. When oxygen is present, it in fact reacts very rapidly with radicals produced by irradiation. As a result, oxidation chemistry dominates the free-radical reaction pathways and the molecular reaction products: the oxygen reacts with radicals in a chain reaction mechanism that involves radical multiplication. For this reason, the differences in radiation-induced effects on the physical properties of macromolecular materials under oxidizing compared with non-oxidizing conditions are often dramatic.

Moreover, under radiation-oxidation conditions, the extent of radiation-induced degradation of some polymers may be strongly dependent on environmental factors other than just the total absorbed dose. In particular, time/temperature phenomena, including dose-rate effects and post-irradiation effects, can be as important as molecular structural differences for determining the radiation resistance of many polymers. It is generally admitted that if polymers are irradiated below their glass-transistion temperature there is no synergistic effect between radiation and temperature; their degradation is not significantly more pronounced than the one resulting from an irradiation at room temperature and temperature ageing.

More information about the mechanisms of radiation effects induced in polymers may be found in the books cited in Refs. [17]–[25].

The relative radiation resistance of a number of different materials indicates that high temperature resins are extraordinarily resistant to radiation. However, there is no systematic relation between the temperature resistance of a polymer and its radiation resistance [35].

Studies have also been carried out at the other end of the temperature range. At cryogenic temperature the stiffness and brittleness of organic materials are increased, and the plasticity and impact strength are reduced. Irradiation of these materials either at low temperature or at room temperature does not influence their degradation: the mechanical properties of polymer-based materials are more influenced by the test temperature than by the irradiation temperature. A characteristic case is that of materials sensitive to oxido-degradation: the degradation is lower if they are irradiated in a cryogenic fluid rather than in air [6], [16], [36]–[41].

Usually, no important change in flammability is observed with radiation [5].

When studying radiation effects on adhesive systems, it should be noted that the adhesive-adherend interface is not usually sensitive to radiation. As the interface is responsible for the strength of the bonding (the bonding fails at the interface), no degradation will be observed until the polymer starts to degrade. The polymer degradation will then result in a reduction of the deformation at break, and of the modulus at higher absorbed doses. This effect is even more pronounced for soft adhesives such as silicone. This remark with respect to the non-degrading interface is obviously not valid in the case of badly prepared surfaces where pollutants and oxidants may be present [42]–[44].

3 SELECTION AND DESCRIPTION OF THE MATERIALS TESTED

Most of the materials presented in this catalogue were intended to be used for the construction of particle accelerators and detectors at CERN. In particular, many adhesive systems which cure at room temperature[1] have been studied for the detectors to be installed at the Large Hadron Collider (LHC) [29], other ones have been proposed for the accelerator itself [45]–[47]. Most of the materials were supplied by manufacturers involved in submitting offers.

The materials that are dealt with here are: epoxy resins, cyano-acrylates, silicones, photopolymers[2], polyurethanes, and various adhesive tapes.

The list of materials presented in this volume is given at the end of Appendix 1.

Some physical, mechanical, and electrical properties of the materials are summarized in Table 1. These values are only a general indication since they depend on numerous parameters such as the composition and quantity of the base resin, the hardener, the accelerator, the filler, and other additives, as well as on the curing conditions, etc. This table should allow the user to select an adhesive appropriate to its application.

It is clear that when selecting and classifying materials according to their radiation resistance, not all of their properties can be tested, and we had to restrict ourselves to some of the most characteristic and representative ones. For our purposes the mechanical properties were chosen. This choice can be justified by our own experience and that of others [1], [7], [14], [22]–[25]. In general, the mechanical degradation of

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1. Also called Room-Temperature Vulcanizing (RTV) adhesives
2. Also called light-curing adhesives

plastic insulating materials caused by ionizing radiation occurs before the degradation of the electrical properties, whilst the optical properties are usually more radiation-sensitive [48], [49].

4 TEST METHODOLOGY

4.1 Irradiation conditions and dosimetry

The samples were irradiated at different places: the industrial irradiation company IONISOS, the Österreichishes Förschungszentrum Seiberdorf, and the installations of ENEA in Rome.

– At IONISOS in Dagneux (France), a ^{60}Co source was used for absorbed doses of 0.2 MGy, 0.5 MGy, and 1 MGy. The instantaneous dose rate was about 2 to 4 kGy/h, but some irradiations were carried out in steps between 20 and 40 kGy per day, leading to an average dose rate of the order of 1 kGy/h. Radiation coming from a cobalt source is pure gamma rays of 1.17 and 1.25 MeV. 'Red Perspex' dosimeters are used by the irradiation centre on a routine basis. Sometimes, alanine dosimeters [50] were added for our purposes.

– The ASTRA 7 MW pool-reactor at Seibersdorf (Austria), was used in two different ways. Some bulk samples were irradiated in the 'Ebene 1' position of this reactor, in the pool, about 26 cm away from the edge of the reactor core. The neutron dose was less than 5% of the total dose to the samples. The irradiation medium was air and the temperature was kept below 60°C. Doses between 0.5 MGy and 30 MGy were provided at a dose rate of about 200 kGy/h. To minimize the activation of the aluminium plates, the shear samples were irradiated in the switched-off reactor, at dose rates of the order of 10 to 40 kGy/h. In both positions, Faraday cups were used to check the dose rate. Some dosimetry checks were carried out by means of alanine and hydrogen-pressure dosimeters [51]. More details about irradiation conditions and dosimetry in the ASTRA reactor are given in Ref. [52]. This reactor has now been definitively switched off.

– At ENEA, in Italy, two irradiation facilities were used for our purpose: a ^{60}Co source, named Calliope, and a fast neutron source, named Tapiro.

The maximum capability of Calliope, for an installed nominal activity of 3.7×10^{15} Bq, is equal to 27 kGy/h. The apparatus is completed by a dosimeter system, with good characteristics of reproducibility and accuracy, composed of a Fricke dosimeter, a Perspex HX dosimeter, and an alanine-ESR dosimeter [53].

Tapiro is designed to work at a maximum power of 5 kW. It has a cylindrical core of 93.5% U-235, surrounded by a cylindrical copper reflector 30 cm thick. The structure is embedded into a steel envelope, and then placed into a concrete biological protection. Various irradiating channels cross this biological protection. A thermal column completes the experimental apparatus.

Reactor nuclear data are given below:

Neutronic spectrum	Fast
Neutronic maximum flux	$\approx 4 \times 10^{12}$ n/cm^2 sec
Neutronic average flux on the core	$\approx 2.7 \times 10^{12}$ n/cm^2 sec
Neutronic average flux on the reflector	$\approx 1.3 \times 10^{11}$ n/cm^2 sec

Note that 1 Gy = 1 gray = 1 J/kg = 100 rad.

4.2 Mechanical tests

Whenever possible, the tests were carried out according to international norms. However, exceptions had to be made for various practical or technical reasons, e.g. sample size, dose rate during irradiation, etc.

Four types of mechanical tests were performed:

– bending tests on bulk materials,
– tensile tests on bulk materials,
– shear tests on lap-joint samples,
– peel tests on adhesive tapes.

Samples for bending tests (usually 5 to 6 per radiation dose) were cut from 2–6 mm thick moulded plates. Tests were performed on an Instrom testing machine to determine the breaking strength and the deflection at break. The testing method was a three-point loading system using a centre load on the supported sample according to ASTM D790 or the ISO 178 standard. The distance between the two supports was 67.0 mm and the speed of the central point usually 2 mm/min.

Ultimate flexural strength, deformation at break, and modulus of elasticity were calculated from these measurements.

Samples for tensile tests were moulded in a dumb-bell shape according to the ISO R-527 standard (geometry 1). Tests were performed on the same Instrom testing machine. The traction speed was 2 mm/min. The tensile strength and elongation at break were measured and the modulus of elasticity was calculated.

Shear tests were performed with single-lap joint samples. However, instead of using the standard single-lap joint geometry as defined in ASTM D 1002 94, an equivalent symmetric single lap geometry was preferred. The geometry of a sample is shown in Figure 1. However, in some cases, two rectangular plates 10 cm by 1 cm were stuck together with a 1 cm^2 glued area.

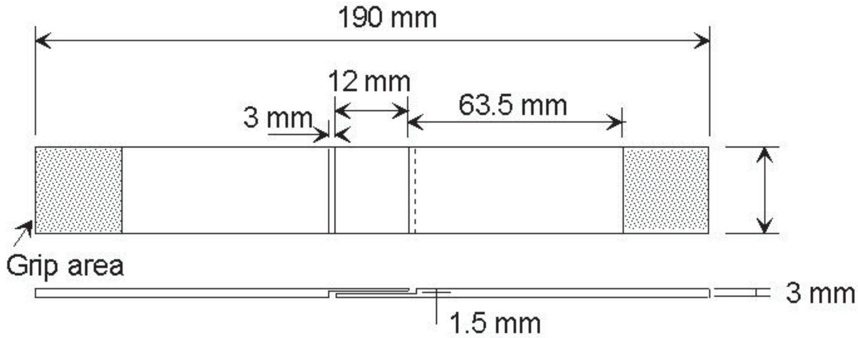

Figure 1: Symmetric single-lap geometry.

Joint tests were performed on a UTS Test-system dynamometer. Tests samples were manufactured in aluminium or fibreglass reinforced epoxy (GFRE) *(Stesalit)*. No pressure was applied during polymerization, but a thickness control device was used in order to obtain 100 ± 30 micron thick adhesive layers. The surfaces of the aluminium samples were sand blasted, but no surface treatment was performed on the GFRE samples. The traction speed was 2 mm/min. Shear strength was measured. In some cases, the equivalent elongation at break and the equivalent modulus of elasticity of the glued zone were also calculated. In order to perform these computations, an equivalent material was defined as illustrated in Figure 2.

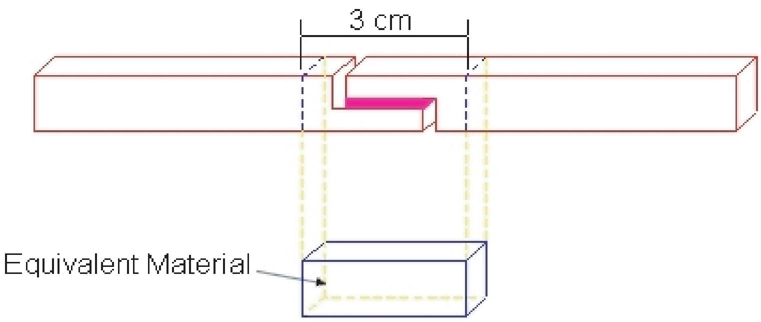

Figure 2: Definition of a material equivalent to a glued zone.

The radiation behaviour of the adhesive tapes was also assessed by means of peel tests: the tapes were glued on an aluminium alloy (6061) plate, previously cleaned with alcohol, and the peel strength was measured with the Instrom machine. However, in some cases, rupture of the tape made it impossible to carry out the peel tests: irradiation had increased the strength of the glue and decreased the resistance of the tape; the assessment of the radiation effects was therefore based on visual inspection and simple manipulations.

5 RADIATION RESISTANCE

5.1 Radiation Index

According to the recommendations of the International Electrotechnical Commission (IEC) [54], the most radiation-sensitive property is chosen as the reference critical property. The properties measured for the present materials are the strength, the deformation at break, and the modulus of elasticity. Our experience has shown that the deformation at break is often the critical property for most of the pure organic materials, whilst the variation of the strength is usually more pronounced for the composite materials. The modulus is generally not a good property to use to assess the degradation of an organic material: it stays constant over a wide dose range and then suddenly drops dramatically with the complete degradation of the polymeric chains [12]–[14]. The end-point criterion is chosen at 50% of the initial value (prior to irradiation) for the strength or for the deformation at break.

The Radiation Index (RI) is defined in IEC 544–4 as the logarithm, base 10 (rounded down to two significant digits) of the absorbed dose in grays at which the critical property reaches the end-point criterion.

5.2 General classification

A general classification of adhesives according to their radiation resistance is given in Table 2. This classification gives an order of magnitude of the maximum dose of usability of the materials; it corresponds to long-term irradiations in the presence of oxygen. Resins and tapes are usually used in different conditions. They are therefore presented separately. More specific results may be found in Refs. [42]–[47].

The results presented in this catalogue confirm the usual classification of adhesives according to their radiation resistance. In particular, cyanoacrylate and silicon adhesives normally degrade at lower doses than epoxy adhesives.

Test samples and preparation as well as irradiation conditions influence the radiation behaviour of an adhesive. The test conditions also influence the test results. Therefore, there is an inherent risk to give a RI without specifying all the conditions, and to rely on this value to assess the radiation behaviour of a given joint in a given condition.

5.3 Discussion of the results

5.3.1 Influence of the type of test

Tests results show that the effects of radiation on bulk materials occur at lower dose than for lap-joints. This can be explained by the two types of failure possible in a lap-joint, in the bulk material, or in the interface. An interface, composed of ionic and physical bonds, is less sensitive to radiation than the adhesive itself.

If the resin shear strength is higher than that of the interface, the joint fails at the interface, but if the interface is stronger than the resin, then the joint fails inside the resin at the rupture strength of the bulk material. In order to verify this hypothesis, one should correlate the tensile and shear strenghts of the resin.

The shear strength S_{st} of a material is related to the tensile strength T_{st} of the same material through a yielding criterion. If the Von Mises criterion is chosen, then

$$S_{st} = \frac{\sqrt{3}}{3} T_{st} \quad .$$

The variation of the shear strength of adhesives and joints is listed and plotted in Appendix 3 as a function of the radiation dose.

It is clearly shown that the hypothesis concerning the relative strengths of the resin and the interface is verified, except for one case. Redux 420 behaves differently than the other adhesives tested: the adhesive's shear strength increases whilst the joint's shear strength strongly decreases when irradiated. Such behaviour can be explained by looking at the dumbbell samples illustrated in Figure 3: the non-irradiated sample is completely flat, whilst the irradiated one is deformed, indicating the relaxation of internal stresses. These internal stresses completely change the situation: internal stresses improve the tensile strength of the resin, but are also detrimental for its shear strength when squeezed between two rigid aluminium adherends.

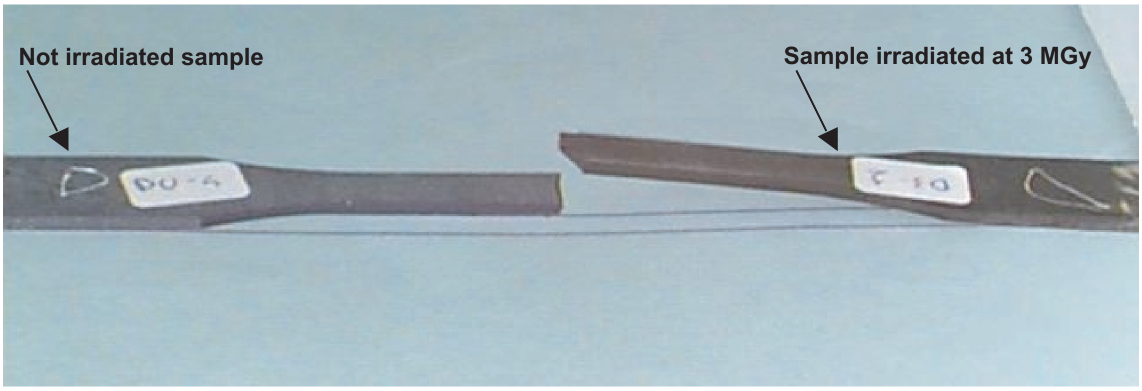

Figure 3: Dumbbell samples of Redux 420 before and after gamma irradiation.

5.3.2 Influence of the support

The performance of the joints can be strongly modified by the surface preparation of the adherends. As an example, the initial shear strength of aluminium joints made with Araldite AW 106 varies from 14.5 MPa when prepared by sand-blasting, up to 21 MPa with the following surface treatment: degreasing with MGL 17.41 ALU for 30 minutes, pickling with a solution of caustic soda 42g/ℓ and gluconate of sodium 14.4 g/ℓ for 1 min at 60°C, a final washing in demineralized water, and drying in an oven at 85°C. However, it is worth noting that joints made with a high performance surface treatment degrade at lower absorbed doses than those made with a lower quality surface treatment. It should also be mentioned that joints made with a less effective support material deteriorate with radiation at higher doses than the other joints. This is the case of the joints manufactured with *Stesalite* compared to the ones made with aluminium.

5.3.3 Influence of the chemical composition and the curing temperature

Differences in the proportions of the resin and the hardener, as well as differences in the polymerization temperature and post-curing processes, usually influence the initial properties of the materials by modifying the initial degree of polymerization of the adhesive. However, radiation induces further reticulation, and after a certain radiation dose the degree of reticulation is normally the same for any composition or curing temperature. This is the reason why differences in composition and curing temperature do not usually modify the properties of the materials irradiated above a certain radiation dose (resin dependant).

6 PRESENTATION OF THE CATALOGUE

The names used in this catalogue are the ones used when the tests were performed. New names (materials, suppliers, etc.) are indicated in the generic pages of Appendix 3.

The lists of the materials presented in this catalogue and in the preceding volumes are given in Appendix 1.

Appendix 2 gives the chemical structures of some commercial products.

Appendix 3 is the alphabetical compilation of data.

For each letter, there is a generic page with the chemical names of the materials, as well as their usual and commercial names (with as many cross-references as possible) and an indication of their radiation resistance obtained with the measured radiation index (RI). (If several tests were carried out on the same material, the given RI refers to the shear test, though the tensile test leads to lower results.) On this generic page, the materials are sorted alphabetically, according to their names.

Under each letter, the individual pages of results are sorted according to the TIS reference number. If several tests have been performed on the same material, the results appear in several pages with the ID No. followed by ′ and ″ as needed. If several compositions of a given material have been tested, the results appear in several pages with the ID No. followed by the letters A, B as needed.

In the individual pages of results, a header gives the TIS reference number, the description of the material, and the name of the supplier (Appendix 5). The results are presented in the form of a table and graph. The mean values (and the standard deviation) of the measured mechanical properties, strength (S), deformation at break (ε), and modulus (M) appear in the table together with the absorbed doses and the corresponding dose rates. (The formulae for the calculation of these properties are given in Appendix 4.2.) The graph presents the evolution of the measured mechanical properties with respect to the absorbed dose. Below the table are given the critical property for the calculation of the radiation index (RI) and its value for the corresponding dose rate.

Appendix 4.1 gives the main abbreviations used in the tables of results, and Appendix 4.2 gives the formulae used for the calculation of the given properties.

Appendix 5 is a list of the suppliers of the materials and/or components who contributed to this catalogue.

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Irradiation conditions, dosimetry and standards

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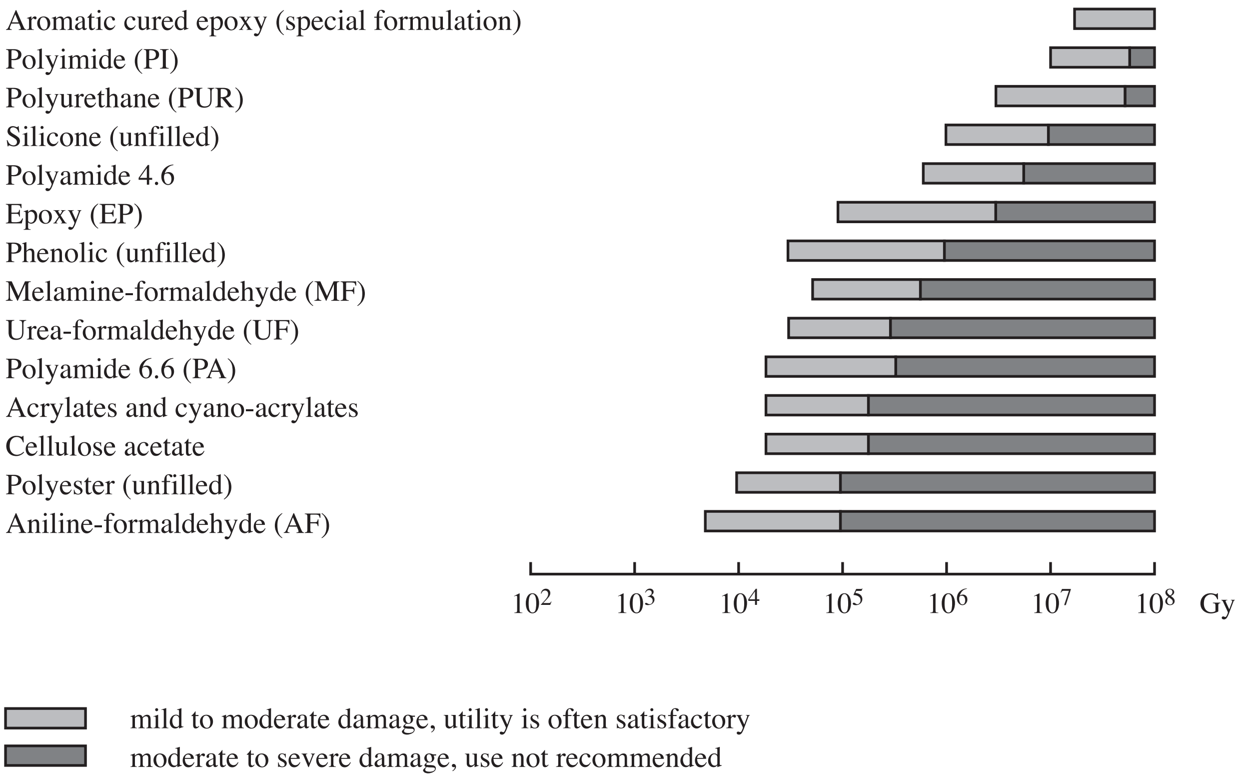
Table 1: General characteristics of classes of adhesives

Type	Characteristics		Limitations
	Advantages	Disadvantages	
Epoxy resins			
Modifiable with • nylon • nitrile • novolac • phenolic resins	• High shear strength • Low shrinkage • Polymerization between room temperature and 170°C depending on the formulation	• Fragile • Low resistance at high temperature	• Temperature <170°C • Hot/humid environments
Polyurethanes			
	• Good shear strength • Hardness • Flexible at low temperatures	• Sensitive to humidity	• Not usable in hot/humid environments in the presence of metals
Acrylics			
Modifiable with rubber materials	• Good shear strength • Hardness • Flexible chemical bounds • Resistant to contaminating materials	• Poor uniformity in the characteristics of large quantity of chemical bounds • Can induce crazing in thermoplastics	• Not many formulations
Polyesters			
	• Good shear strength • Good electrical characteristics	• Fragility • Important shrinkage • Low resistance at high temperature	• Very specific uses
Phenols			
Modifiable with rubbers. Can be used to modify the epoxies	• Good resistance to high temperatures	• May be corrosive • Low electrical properties • Low tensile strength	• Limited use at high temperature (<300°C)
Silicones			
	• Very good resistance to high temperatures	• Low tensile strength	• Limited use at high temperature (<300°C)
Polyimides			
	• Very good resistance to high temperatures • Good electrical characteristics	• Rigid • High polymerization temperature • They may be corrosive	• Limited use at high temperature (up to 300°C)
Cyanoacrylates			
	• Good tensile strength	• Fragile • Low viscosity • Sensitive to humidity and to solvents	• Normally very expensive • Sensitive to radiation
Anaerobic materials			
(Polymerization in absence of oxygen)	• High cohesive resistance	• Low adhesive resistance	• Specific use due to the polymerization process
Thermoplastics			
Large quantity of different materials with different properties	• Low/moderate tensile properties (depending on the material) • Insensitive to humidity	• Become soft at high temperatures	• Only usable for room-temperature applications (below gel point)

Table 2: Classification of adhesives according to their radiation resistance



These appreciations can only serve as a general guideline; environmental conditions such as temperature, humidity, and dose rate, as well as additives influence the radiation behaviour of materials.

APPENDIX 1

List of materials presented in our catalogues

(Trade names in italics)

Volume I: Cable insulating materials (Ref. [10])

Butyl rubber
Chlorostop
Chlorosulfonated polyethylene (CSP)
Cross-linked polyethylene (XLPE)
Desmopan
Ethyl-acrylate rubber (EAR)
Ethylene-propylene diene rubber (EPDM)
Ethylene-propylene rubber (EPR)
Ethylene vinyl acetate (EVA)
Flamtrol
Fluoropolymer
Halar
Hypalon
Hytrel
Kapton
Lupolen
Neoprene
Nordel
Polychloroprene
Polyethylene (PE)
Polyurethane (PUR)
Polyvinyl chloride (PVC)
Pyrofil
Radox
Semiconducting polyethylene
Silicone rubber
Silythene
Stilan
Teflon
Tefzel
Viton
XLPE

Volume I, 2nd edition: Halogen-free cable-insulating materials (Ref. [11])

Acorad
Afumex
Cogegum
Elastollan
Ethyl acrylate rubber (EAR)
Ethylene ethyl acrylate (EEA)
Ethylene-propylene diene monomer rubber (EPDM)
Ethylene-propylene rubber (EPR)
Ethylene-vinyl acetate copolymer (EVA)
Lupolen
Megolon
Polyethylene (PE)
Polyolefin (PO)
Polyurethane (PUR)
Radox
Rheyhalon
Semiconducting PE
Silanpex
Silicone rubber (SiR)
Silythene
Sioplas
Thermoplastic rubber (TPR)
Toxfree
VAC
Vamac
XLPE

Volume II: Thermoplastic and thermosetting resins (Ref. [12])

Araldite B
Araldite D
Araldite F and other *Araldite* resins
Araldite F + epoxy *Novolac*
Birakrit
Cevolit
Crystic
Dobeckan IF
Dobeckot
Epikote
Epoxy resins
Epoxy resins + epoxy Novolac
Etronax
Isoval
Kerimid
Kinel
Makrolon
Novolac
Orlitherm
Phenolic resins
Polycarbonate resins
Polymide resins
Polylite
Polyurethane resins
Resofil
Ryton
Samicanit
Samicatherm
Silicone resins
Veridur
Vetresit
Vetronite

Volume II, 2nd edition: Thermoplastic and thermosetting resins (Ref. [13])

Acetal resin
Adiprene
Araldite B, D, F, MY720
Arenka
Arocy
Bakelite
Bisphenol A epoxies (BPA)
Borolene
Cestidur
Cestilene
Cestitech
CFRP Carbon-fibre-reinforced plastics (composites)
Copolymer polyimide and silicone
Cross-linked styrene copolymer
Crystic
Cyanate-ester
Delrin
Durotenax
Envex
Epikote
Epoxy resins
Phenol-Formaldehyde (PF)
Polyethylene (PE)
Polyester
Polyimide (PI)
Polyoximethylene (POM)
Polyurethane
Samicatherm
Scotchcast
Vetresit

Volume III: Accelerator engineering materials and components (Ref. [15])

Adhesive tape
Aluminium oxide
Araldite
Asbestos cement
Askarel
Buna
Cable insulation
Cable tie
Ceramic
Cerium-doped glass
Connector
Copper wire
Diala C
Diester oil
Electronic components
Epoxy resin
Ethylene-propylene rubber (EPR) and (EPDM)
Ethylene-tetrafluoroethylene copolymer (ETFE)
Fluorinated oil
Fluorinated polymer
Foam
Glass
Glass fibre
Heating element
HF absorber
Hoses
Hostalen
Hypermalloy
Hytrel
Insulated wire
Insulating oil
Insulating sleeve
Insultaing tape
Iron
Joint
Kapton
Kevlar
Kynar
Lighting
Lithium polysilicate
Lubricating oil
Luminous paint
Lupolen
Magnet coil insulation
Magnetic material
Makrolon
Micatherm
Microswitch
Mineral oil
Motor, electric
Mylar
Neoprene
Nitrile-butadiene rubber
Nomex
Noryl
Novolac
Nylon
Oil
Optical fibre
O-ring
Pain
Paper
Particle detector
Pertinax
Plexiglas
Polyacrylate
Polyamide
Polybutylene terephthalate (PBTP)
Polycarbonate
Polychloroprene (Neoprene)
Polyester resin
Polyethylene (PE) and (XLPE)
Polyethylene terephthalate (PETP)
Polyhydantoin
Polyimide
Polyolefin
Polyphenylene oxide (PPO)
Polyphenylene sulfide (PPS)
Polypropylene (PP)
Polysiloxane
Polytetrafluoroethylene (Teflon PTFE)
Polyurethane resin (PUR)
Polyvinyl chloride (PVC)
Polyvinyl toluene
Quartz
Relay
Resin
Resistofol
Rubber
Ryton
Scintillator
Scotchcal
Seal (O-ring)
Silica
Silicon detector
Silicone oil
Silicone rubber
Sleeve
Styrene-butadiene rubber (SBR)
Switch Tape
Teflon (PTFE)
Tefzel
Terminal board
Textile

Thermoplastic resin
Thermosetting resin
Thermoshrinking sheath
Vacuum chamber tube
Vacuum gasket
Vacuum pump accessory
Vacuum seal
Vacuum valve
Valvata
Valve
Vestolene
Viton
Wire
Wood

List of materials presented in this volume
(Trade names in italics)

Adhesive tape	Base polymer	Producer	Reference
Acrylic	Acrylic	GTS France	M 759
Adhesive tapes		3M Muller Tesa Van Roll Isola	see: Tapes, Coroplast, Permacel, Permafix, Scotch-Metal, TesaBand, TesaMetal, TesaPack
Anaerobic adhesive		Lancashire Fittings	see Loctite
Araldite	Epoxy resins	Ciba-Geigy*	M 523, M 722, M 723, M 739, M 740, M 742, M 798, M 799, M 800, M 801, M 802, M 803
Biodur	Epoxy resins	Progressive Products	M 744
Biogard	Epoxy resins	Progressive Products	M 743
Cementit		Merz + Bendeti	M 525
Conductive epoxy resin	Epoxy resin	Epoteck Conductive solder	M 814 see also TRA DUCT M 843
Coroplast	PVC tape	Muller	M 796
Cold Solder	Metallic glue	Rebstar	see Turbometall
Cyanoacrylate	Cyanoacrylate resin		see: Pronto, Cyanolit
Cyanolit	Cyano-acrylate	3M	M 625, M 626, M 627
Epikote	Epoxy resin	Shell Chemie	M 654
Epoxy	Epoxy resins	Bakelite, Ciba-Geigy*, Dolph's, Emerson & Cuming, Epotecny, Hysol, I-Plastic, Isola Br., Magnolia, Norlabs, Progressive Products, Sika, Smooth-On, Tracon, Von Roll Isola	M 695, M 721, M 735, M 736, M 741, M 745, M 749, M 760, M 804, M 810, M 814, M 818 see: Araldite, Biodur, Biogard, Conductive solder, Norcast, Redux, Rutapox, Sikadur, Scotchcast, Stycast, TRA Bond, TRA Duct, Varnish
Katiobond	Photopolymer	Delo	M 737
Loctite	Anaerobic adhesive	Lancashire Fittings	M 650
Norcast	Epoxy resin	Norlabs	M 746
Permacel	PVC tape	Permali	M 797-1
Permafix	Paper tape	Permali	M 797-2

Adhesive tape	Base polymer	Producer	Reference
Polyurethane	Polyurethane (XL polyester)	GTS France	M 758
Pronto	Cyano-acrylate	3M	M 811
Redux	Epoxy resin	Ciba-Geigy*	see Araldite
Rapida	Epoxy resin	Ciba-Geigy*	see Araldite
Rhodorsil	Silicon resin	Shell Aesol AG	see Silicone
Rutapox	Epoxy resin	Bakelite	M 747
Scotchcast	Epoxy resin	3M	M 428
Scotch-Metal	Metallic tape	3M	M 795
Silicon	Silicon resin	Down Corning Peltier Shell Aseol AG	M 762, M 763, M 805, M 812
Sikadur	Epoxy resin	Sika	M 738
Stycast	Epoxy resin	E.& C.	M 748, M 725
Tape	Adhesive tape	Von Roll Isola	M 781-1, M 781-2, M 781-3, M 781-4, M 781-5
TesaBand	Plastic tape	Tesa	M 794-3
TesaMetal	Metallic tape	Tesa	M 794-2
TesaPack	Plastic tape	Tesa	M 794-1
Thermo 2000	Metal-ceramic	Kleiberit	M 476
TRA Bond	Epoxy resin	Tracon	M 807, M 809
TRA Duct	Conductive epoxy resin	Tracon	M 806, M 808
Turbometal	Metal alloy	RebStar	M 614
Voltatex	Epoxy resin	Stollack	M 513, M 455

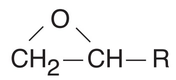
* Now Vantico

APPENDIX 2

Chemical information on some commercial products [25]

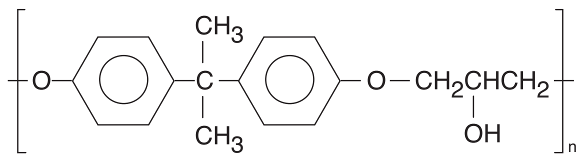
Epoxy adhesives

An epoxy is a polymer, usually a mixture of low molecular weight oligomers, containing, on average, two or more epoxide groups per molecule:

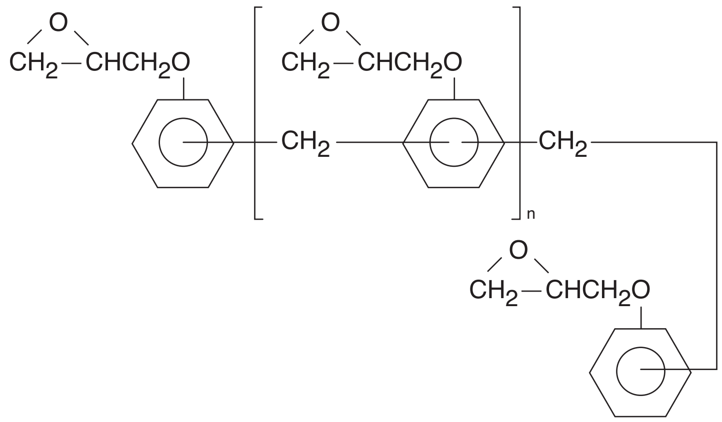


Most commercial epoxy resins are very low molecular weight oligomers and form relatively tough products when crosslinked with a curing agent.

The most common type is a diglycidyl ether of bisphenol A (DGEBA):

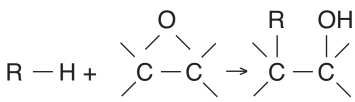


Other glycidyl ethers have a higher epoxy functionality than the difsunctionality of the bisphenol A material. An example is the novolac-epoxy resins:



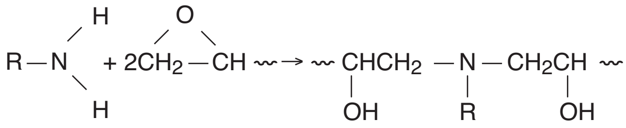
Commercial epoxy resins, of which about 95% are DGEBA, are mixed oligomers characterized by ether epoxide equivalent. Normally they have a molecular weight of up to about 500 u.m.a. and are viscous liquids. Above this molecular weight the polymers are low melting point solids.

Epoxy resins are crosslinked by agents which are able to react with the epoxide groups. This is normally because they have active hydrogen atoms:

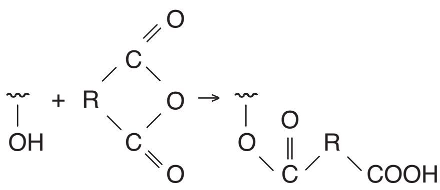


Subsequently, the hydroxyl groups so formed can react further. Since R-H groups may be more than two per molecule, high crosslinked products may be formed.

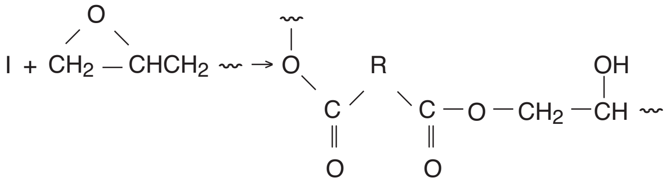
Amines normally give low viscosity mixtures with fast room temperature cures. They are normally used in stoichiometric amounts:

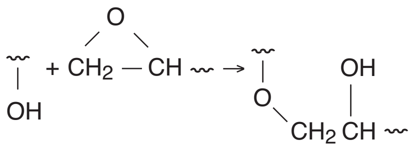


Acid anhydrides are often used to produce cured resins with a higher heat distortion temperature:

1) 

I

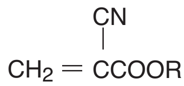
2) 

3) 

Cured epoxy resins are characterized by their toughness, low shrinkage during cure, high adhesion to many substrates, and good chemical resistance, although the properties depend very much on the particular curing system used.

Cyanoacrylate adhesives

A cyanoacrylate is a polymer obtained by curing cyanoacrylate monomers:



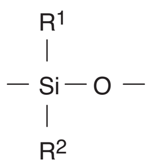
where R is an alkyl group.

Cyanoacrylate adhesives are normally obtained by anionic polymerization in the presence of a mild base, normally water.

Curing occurs especially rapidly when the joint is closed, thus excluding air, which inhibits the polymerization of acrylic monomers.

Silicone adhesives

A silicone resin is a three-dimensional polyorganosiloxane containing the sequence:



where R^1 and/or R^2 are organic groups.

Commercial resins are mostly methylphenylsilxane polymers.

Resins are often classified according to their R/Si ratio, where R represents the amount of both methyl and phenyl groups. In practice ratios of 1.2 to 1.6 are used.

The resins present a very good resistance to high temperature, excellent water repellency, and non-adherent properties.

Photopolymers

Photopolymers are produced by free radical or occasionally ionic, polymerization initiated by the interation of light, usually of ultraviolet length.

Photopolymerization should strictly be termed photoinitiated polymerization, except when absorption of light is necessary for each propagation step. Such polymerizations are rare, but do occur with a monomer of the following type:

$$R_1 - CH = CH - R_2 - CH = CH - R_1$$

Photopolymerization is commercially useful in fast curing applications.

Polyurethanes

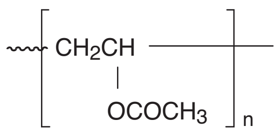
Polyurethanes are polymers containing urethane –NHCOO– groups in the polymeric chain. Crosslinking normally results from reaction with polyols containing more than two hydroxyl groups.

Polyurethanes are among the most versatile polymers: elastomers (PUR), fibres, foams, and adhesives.

Frequently in polyurethanes of commercial interest other functional groups, such as ester, ether, amide, or urea are present in large quantities (even larger than urethane groups).

Polyvinyl acetate

Polyvinyl acetate is produced by free radical polymerization of vinyl acetate. Its molecular structure is as follows:



Homopolymers and a variety of copolymers are widely used commercially as film-forming materials in emulsion paints and adhesives.

APPENDIX 3

Alphabetic compilation of data

(Trade names in italics)

A

Commercial name	Base polymer	Supplier	Reference	R.I.
Acrylic AS 1042	Acrylic	GTS France	M 759	~ 5.0
Adhesive tapes			see Tapes	
Anaerobic adhesive			see *Loctite*	
Araldite 2011	Epoxy resin	Ciba-Geigy	see AW 106	
Araldite 2020	Epoxy resin	Ciba-Geigy	M 802	> 6.5
Araldite AV 138/HV 998 (100/40)	Epoxy resin	Ciba-Geigy	M 798	> 6.5
Araldite AW 106/HV953 U (100/20)	Epoxy resin	Ciba-Geigy	M 740-A	> 6.5
Araldite AW 106/HV953 U (100/30)	Epoxy resin	Ciba-Geigy	M 740-B	> 6.5
Araldite AW 106/HV953 U (100/50)	Epoxy resin	Ciba-Geigy	M 740-C	> 6.5
Araldite AW 106/HV953 U (100/80)*	Epoxy resin	Ciba-Geigy	M 740	~ 6.5
Araldite AY 103/HV951 (100/8)	Epoxy resin	Ciba-Geigy	M 523	6.7
Araldite AY 103/HV951 (100/40)	Epoxy resin	Ciba-Geigy	M 742	~ 5.8
Araldite AZ 15	Epoxy resin	Ciba-Geigy	M 723	> 6.1
Araldite D /HY 951 (100/10)	Epoxy resin	Ciba-Geigy	M 803	> 6.0
Araldite D /HY 991 (100/10)	Epoxy resin	Ciba-Geigy	M 739	> 6.0
Araldite LY 5052	Epoxy resin	Ciba-Geigy	M 801	> 6.5
Araldite Rapid	Epoxy resin	Ciba-Geigy	M 800	~ 6.5
Araldite Redux 420	Epoxy resin	Ciba-Geigy	M 799	~ 6.0
Araldite XD 4447	Epoxy resin	Ciba-Geigy	M 722	> 6.2

* Today named *Araldite* 2011

The Ciba-Geigy products are now commercialized by Vantico, except Redux 420 by Hexcel.

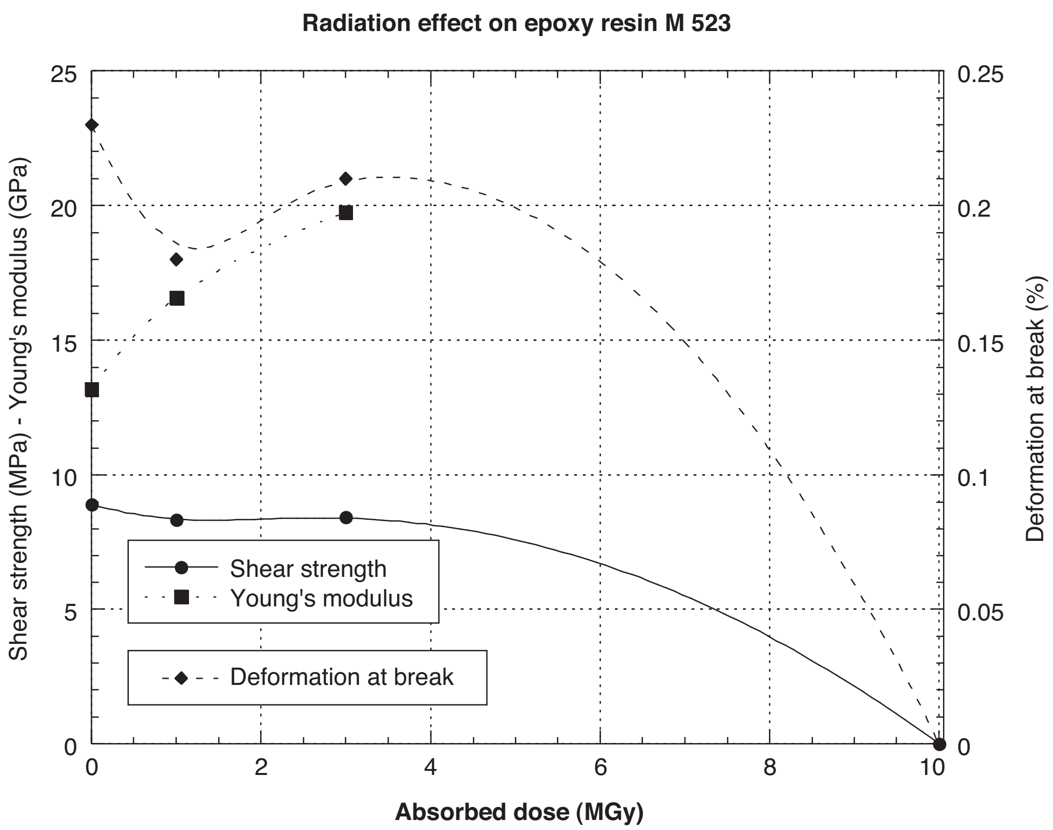
Material: **Epoxy structural adhesive** **ID No. M 523**
Type: **Araldite AY 103/HY 951 (100/8)**

Supplier: **Ciba-Geigy**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60 and Switched-off reactor**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**8.9** ± 0.6	**0.23** ± 0.03	**13.2** ± 6.6
1	**4**	**8.3** ± 0.5	**0.18** ± 0.04	**16.6** ± 1.1
3	**4**	**8.4** ± 0.3	**0.21** ± 0.01	**19.7** ± 1.8
10	**20**	**0.0**	**0.0**	**–**

Critical property = deformation at break
Radiation index (RI) ~ 6.7 at a mean dose rate of 4 kGy/h



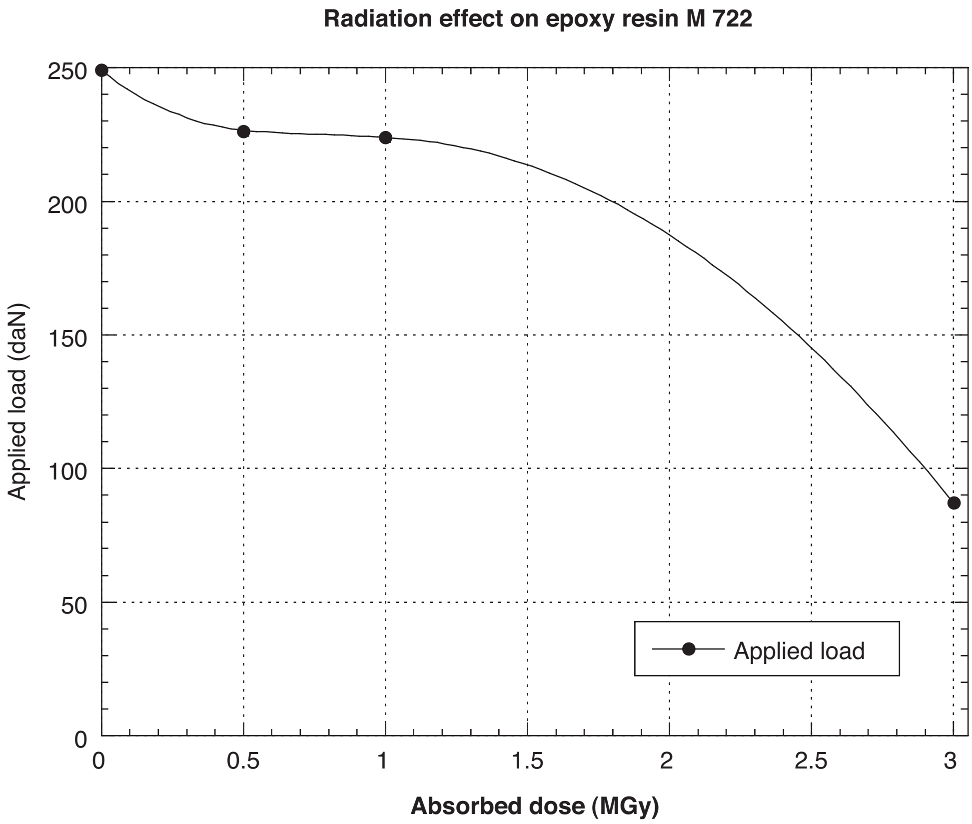
Material: **Structural epoxy adhesive** **ID No. M 722**
Type: **Araldite XD 4447 / 4448**

Supplier: **Ciba-Geigy**

Test method: **Shear test with aluminium samples**
Sample geometry: **Single lap shear samples**
Surface treatment: **Chemical cleaning**
Polymerization temperature: **25°C**
Radiation source: **Switched-off reactor**

Absorbed dose (MGy)	Applied load (daN)
0	**249** ± 14
0.5	**226** ± 20
1	**224** ± 17
3	**87** ± 16

Critical property = applied load
Radiation index (RI) = 6.4



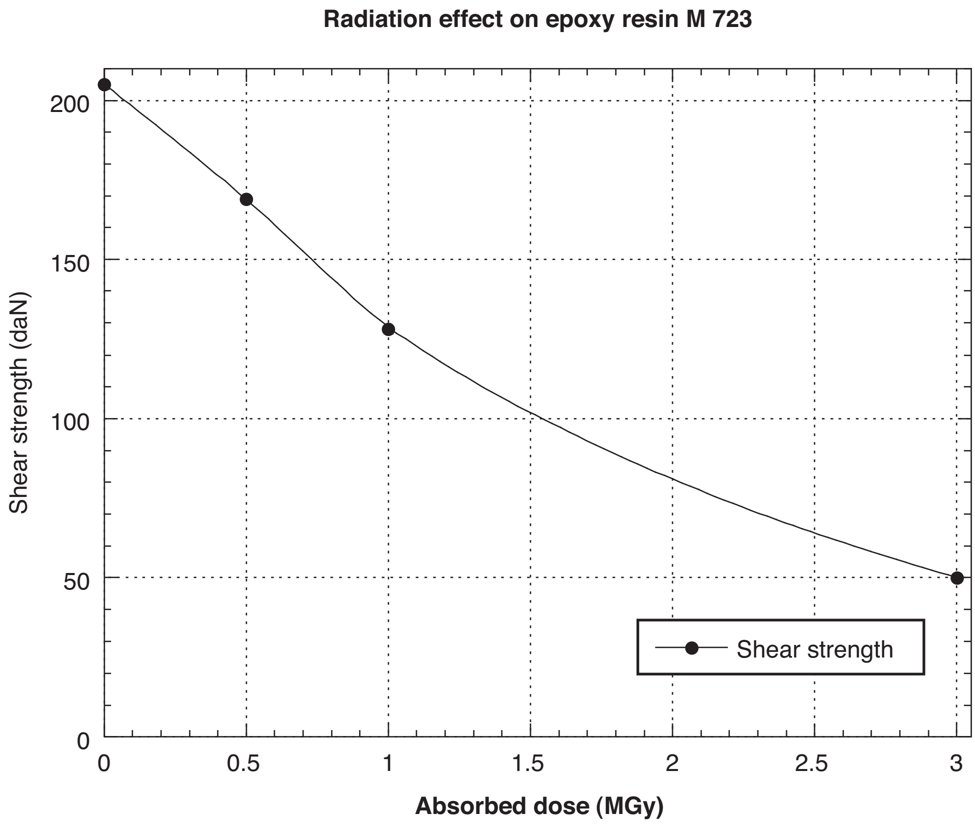
Material: **Epoxy structural adhesive** **ID No. M 723**
Type: **Araldite AZ 15 / HZ 15**

Supplier: **Ciba-Geigy**

Test method: **Shear test with aluminium samples**
Sample geometry: **Single lap shear samples**
Surface treatment: **Chemical cleaning**
Polymerization temperature: **25°C**
Radiation source: **Switched-off reactor**

Absorbed dose (MGy)	**Shear stress (daN)**
0	**205** ± 14
0.5	**169 ±** 5
1	**128** ± 14
3	**50** ± 3

Critical property = only the stress was measured
Radiation index (RI) = 6.1

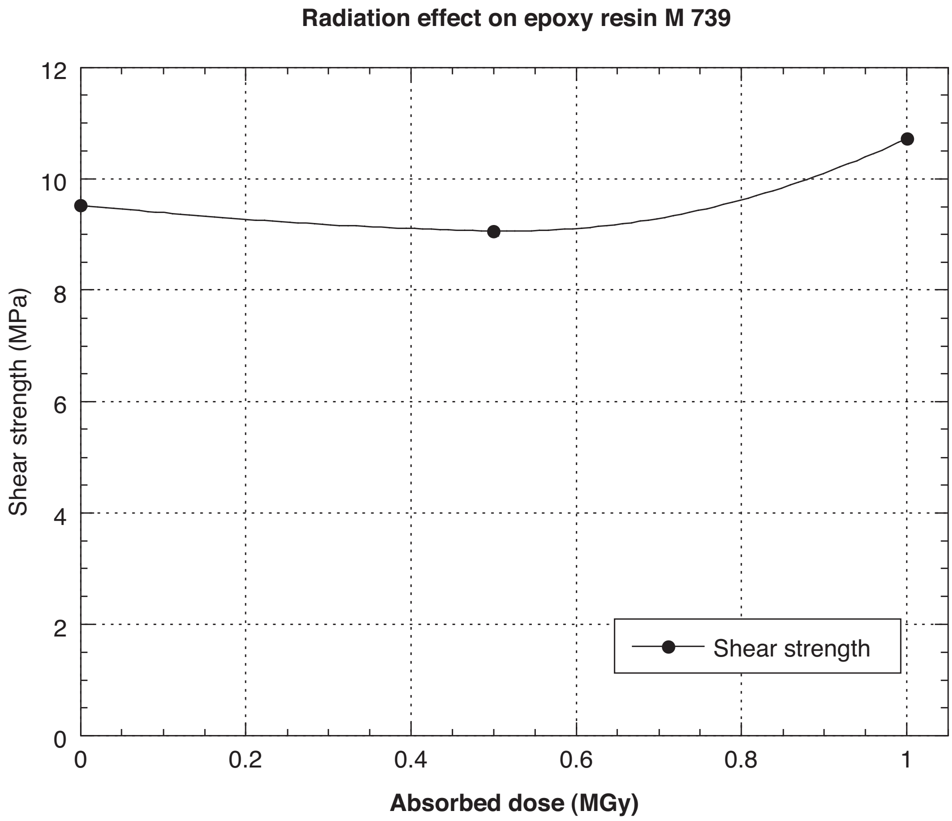


Material:	**Epoxy structural adhesive**	**ID No. M 739**
Type:	**Araldite D/HY 991 (100/10)**	
Supplier:	**Ciba-Geigy**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	**Dose rate (kGy/h)**	**Shear strength (MPa)**
0	**0**	**9.5** ± 2.6
0.5	**4**	**9.1** ± 0.8
1	**4**	**10.7** ± 0.6

Critical property = shear strength
Radiation index (RI) > 6.0 at a mean dose rate of 4 kGy/h



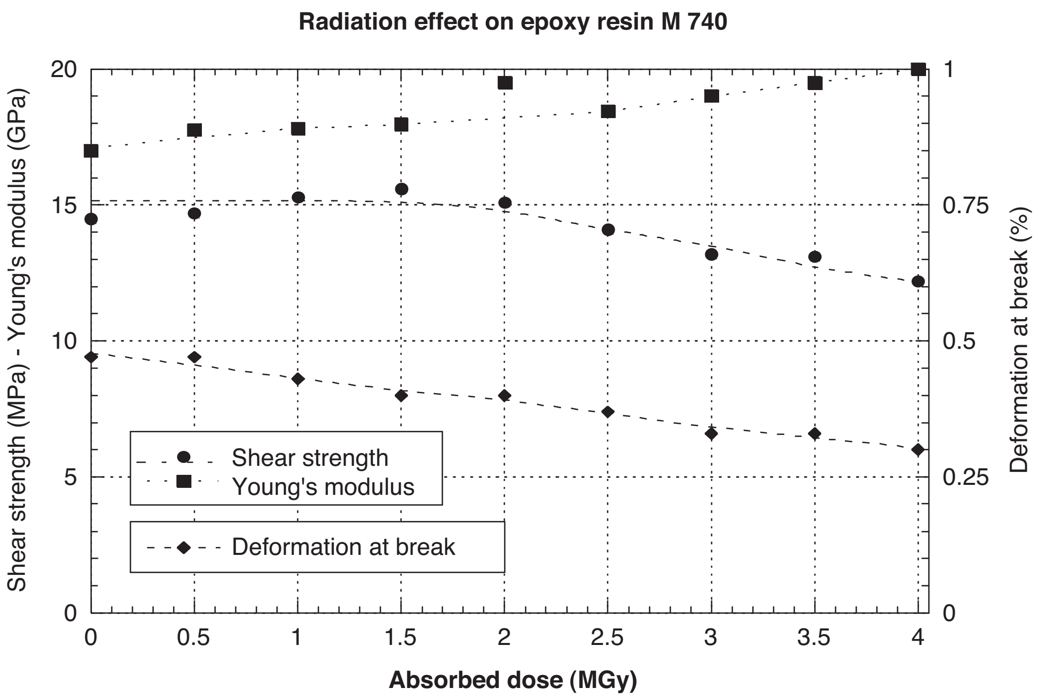
Material: **Epoxy structural adhesive** **ID No. M 740**
Type: **Araldite AW 106/HV953 U (100/80),**
today named: Araldite 2011

Supplier: **Ciba-Geigy**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**14.5** ± 1.1	**0.47** ± 0.13	**17.0** ± 3.1
0.5	**4**	**14.7** ± 0.8	**0.47** ± 0.07	**17.8** ± 1.3
1	**4**	**15.3** ± 0.7	**0.43** ± 0.17	**17.8** ± 2.3
1.5	**4**	**15.6** ± 1.7	**0.40** ± 0.07	**18.0** ± 1.6
2	**4**	**15.1** ± 2.0	**0.40** ± 0.10	**19.5** ± 1.4
2.5	**4**	**14.1** ± 1.5	**0.37** ± 0.07	**18.5** ± 0.9
3	**4**	**13.2** ± 1.4	**0.33** ± 0.17	**19.0** ± 2.1
3.5	**4**	**13.1** ± 0.6	**0.33** ± 0.07	**19.5** ± 2.3
4	**4**	**12.2** ± 0.5	**0.30** ± 0.02	**20.0** ± 1.2

Critical property = deformation at break
Radiation index (RI) > 6.6 at a mean dose rate of 4 kGy/h

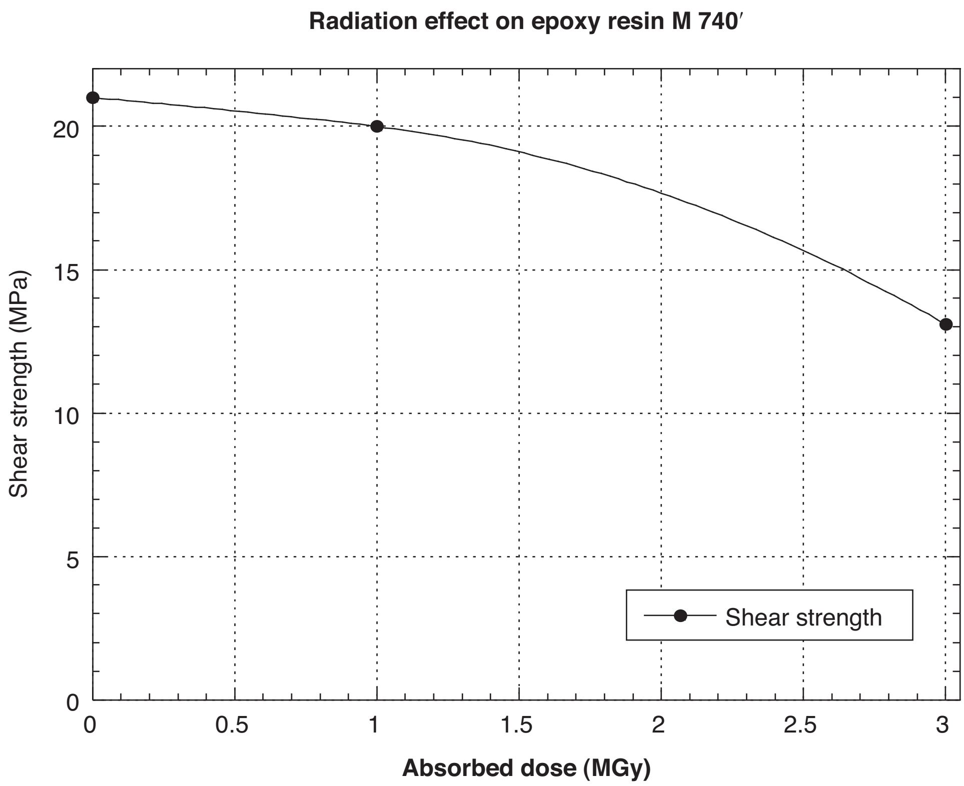


Material:	**Epoxy structural adhesive**	**ID No. M 740′**
Type:	**Araldite AW 106/HV953 U (100/80), today named: Araldite 2011**	
Supplier:	**Ciba-Geigy**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Degreasing MGL 17.41 ALU: 30 minutes; pickling with a solution of caustic soda 42 g/l and sodium gluconate 14.4 g/l: 1 min, 60°C; last washing in demineralized water and drying in oven at 85°C**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	**Dose rate (kGy/h)**	**Shear strength (MPa)**
0	**0**	**21.0** ± 1.2
1	**4**	**20.0** ± 1.2
3	**4**	**13.1** ± 0.4

Critical property = shear strength
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h



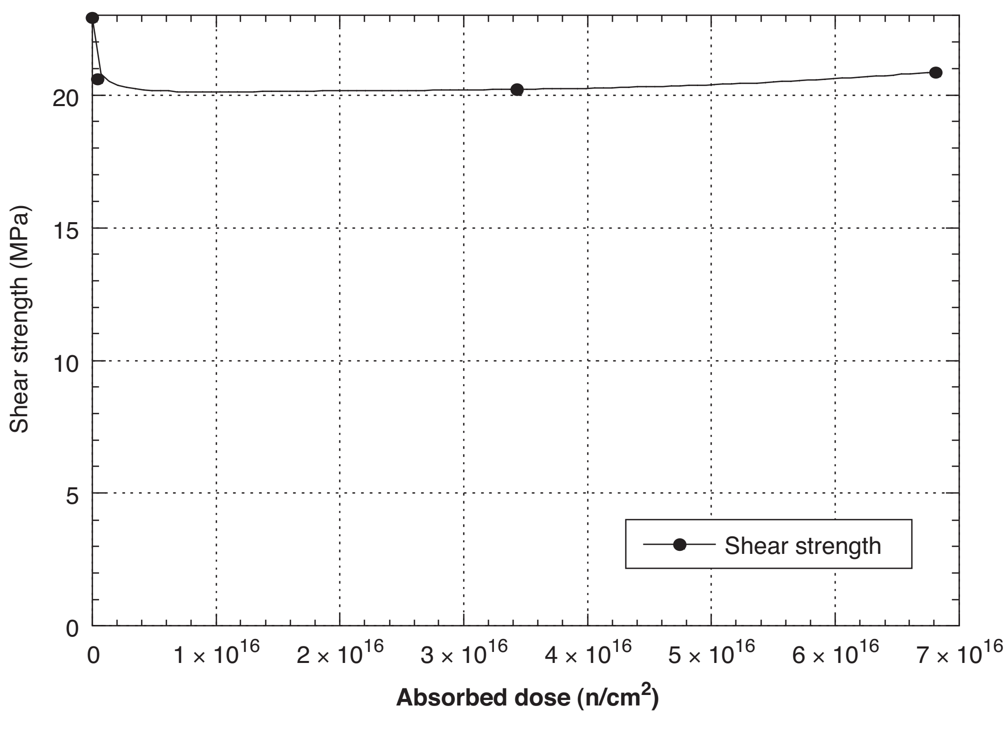
Material:	**Epoxy structural adhesive**	**ID No. M 740″**
Type:	**Araldite AW 106/HV953 U (100/80), today named: Araldite 2011**	
Supplier:	**Ciba-Geigy**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93, but joint surface was reduced to 1 cm^2**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Fast neutrons**

Absorbed dose (n/cm^2)	Shear strength (MPa)
0	**22.9** ± 1.3
4.5×10^{14}	**20.6** ± 1.9
343×10^{14}	**20.2** ± 3.5
681×10^{14}	**20.9** ± 2.0
Note: 681×10^{14} n/cm^2 ~ 1 MGy	

Critical property: shear strength
Radiation index (RI) > 6.0

Radiation effect on epoxy resin M 740″

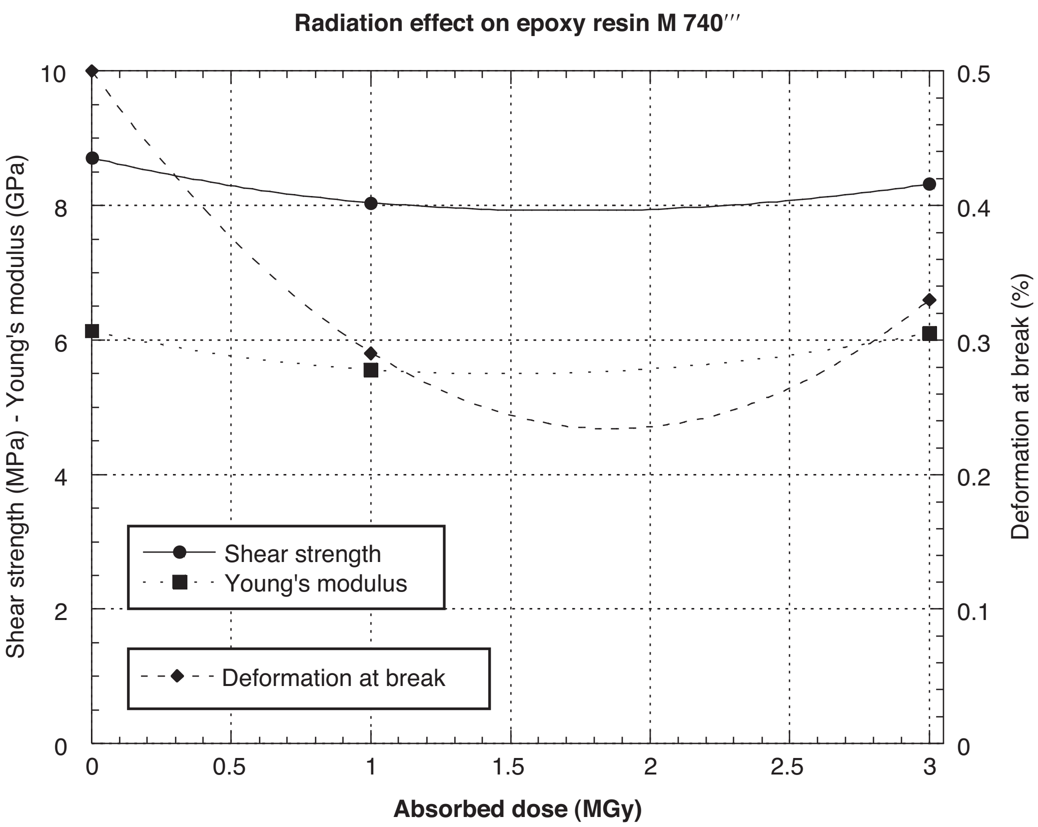


Material:	**Epoxy structural adhesive**	**ID No. M 740‴**
Type:	**Araldite AW 106/HV953 U (100/80), today named: Araldite 2011**	
Supplier:	**Ciba-Geigy**	

Test method:	**Shear test with Stesalite (fibreglass epoxy composite) samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**None**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**8.7** ± 2.8	**0.50** ± 0.13	**6.1** ± 1.0
1	**4**	**8.0** ± 1.3	**0.29** ± 0.10	**5.6** ± 1.4
3	**4**	**8.3** ± 0.8	**0.33** ± 0.09	**6.1** ± 0.3

Critical property = deformation at break
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h



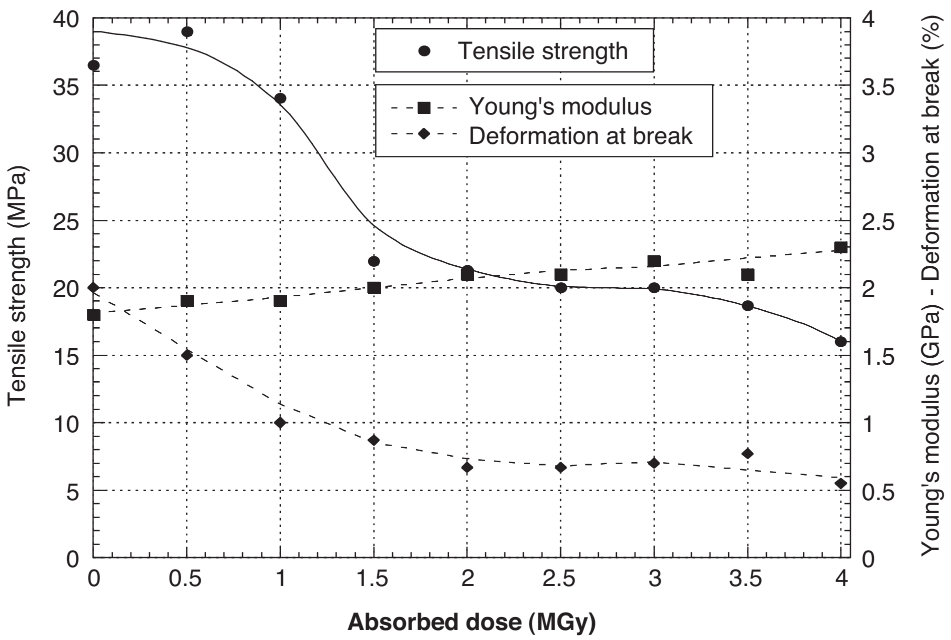
Material:	**Epoxy structural adhesive**	**ID No. M 740''''**
Type:	**Araldite AW 106/HV953 U (100/80),** **today named: Araldite 2011**	
Supplier:	**Ciba-Geigy**	

Test method:	**Tensile test**
Sample geometry:	**ISO R-527 – sample type 1**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Tensile strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**36.5** ± 3.7	**1.8** ± 0.4	**2.0** ± 0.7
0.5	**4**	**39.3** ± 5.5	**1.9** ± 0.2	**1.5** ± 0.6
1	**4**	**34.6** ± 2.5	**1.9** ± 0.4	**1.0** ± 0.7
1.5	**4**	**22.0** ± 4.0	**2.0** ± 0.3	**0.9** ± 0.2
2	**4**	**21.3** ± 2.5	**2.1** ± 0.3	**0.7** ± 0.2
2.5	**4**	**20.0** ± 6.0	**2.1** ± 0.3	**0.7** ± 0.2
3	**4**	**20.0** ± 4.0	**2.2** ± 0.4	**0.7** ± 0.5
3.5	**4**	**18.7** ± 1.5	**2.1** ± 0.2	**0.8** ± 0.1
4	**4**	**16.0** ± 0.0	**2.3** ± 0.4	**0.6** ± 0.3

Critical property = tensile strength
Radiation index (RI) ~ 6.5 at a mean dose rate of 4 kGy/h

Radiation effect on epoxy resin M 740''''



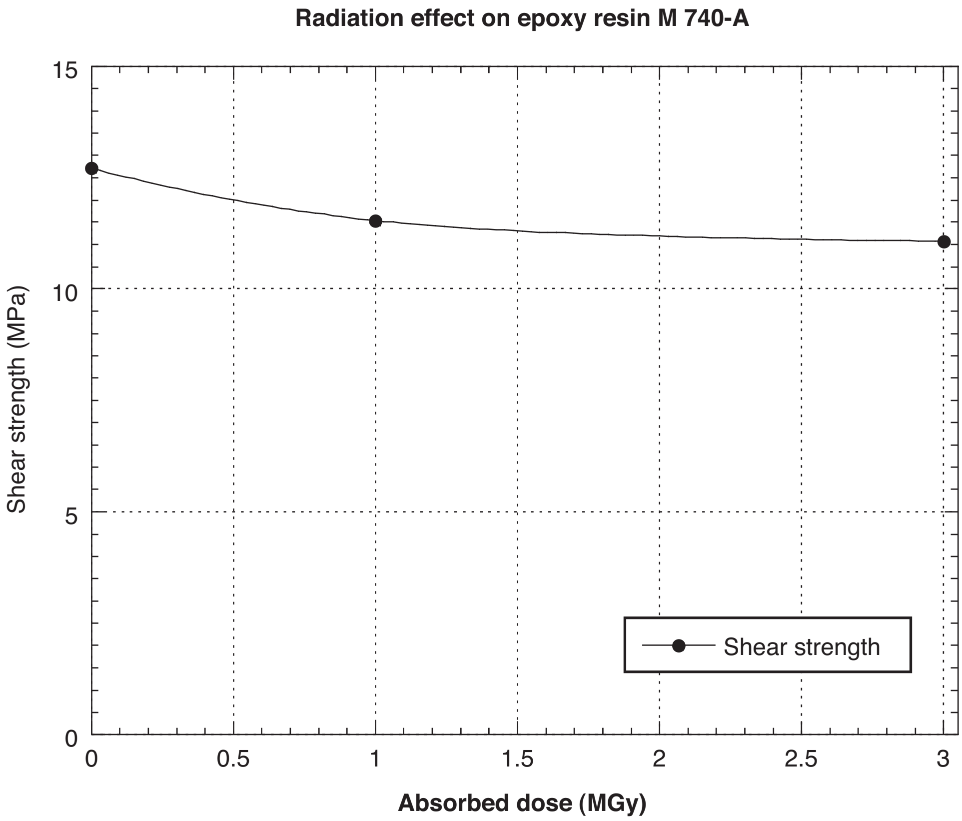
Material: **Epoxy structural adhesive** **ID No. M 740-A**
Type: **Araldite AW 106/HV953 U (100/20)**

Supplier: **Ciba-Geigy**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**12.7** ± 0.7
1	**4**	**11.5** ± 0.9
3	**4**	**11.1** ± 0.5

Critical property = shear strength
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h

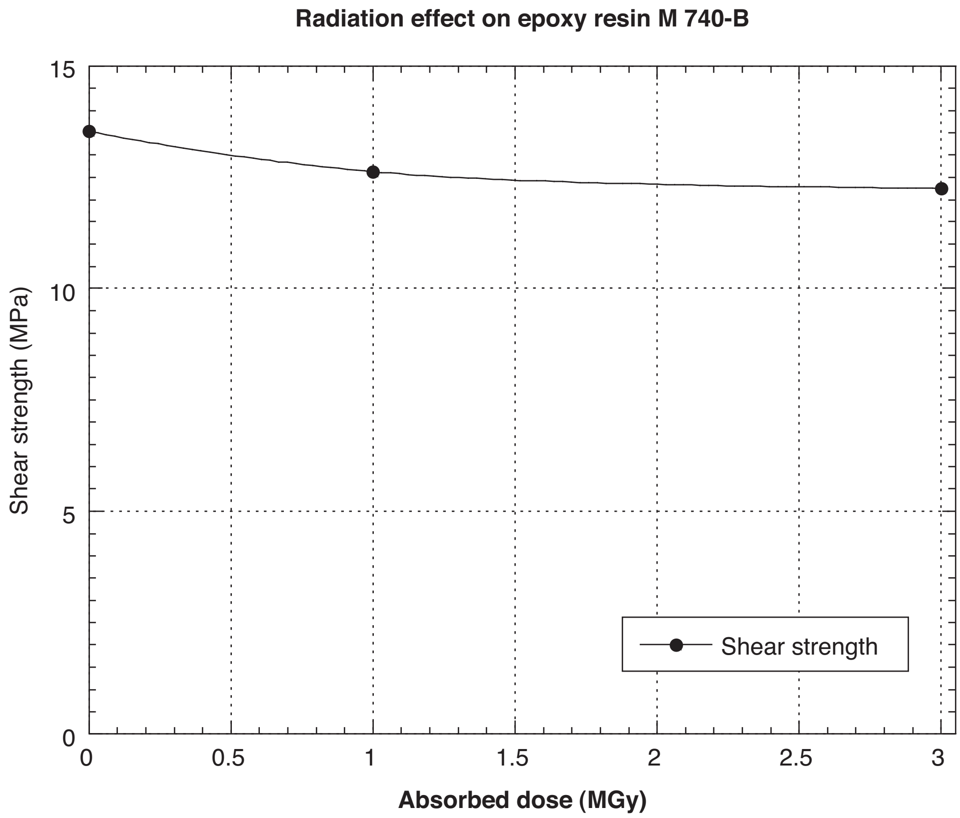


Material:	**Epoxy structural adhesive**	**ID No. M 740-B**
Type:	**Araldite AW 106/HV953 U (100/30)**	
Supplier:	**Ciba-Geigy**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**13.5** ± 0.4
1	**4**	**12.6** ± 0.3
3	**4**	**12.3** ± 0.7

Critical property = shear strength
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h

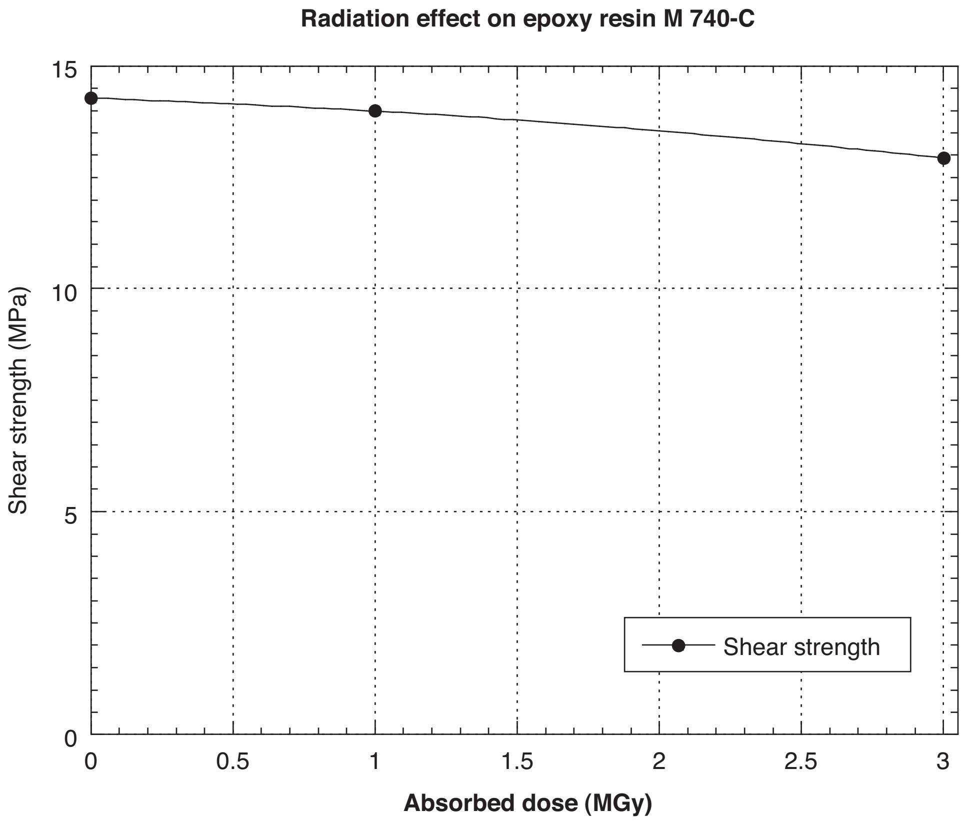


Material:	**Epoxy structural adhesive**	**ID No. M 740-C**
Type:	**Araldite AW 106/HV953 U (100/50)**	
Supplier:	**Ciba-Geigy**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**14.3** ± 1.1
1	**4**	**14** ± 0.9
3	**4**	**12.9** ± 0.7

Critical property = shear strength
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h

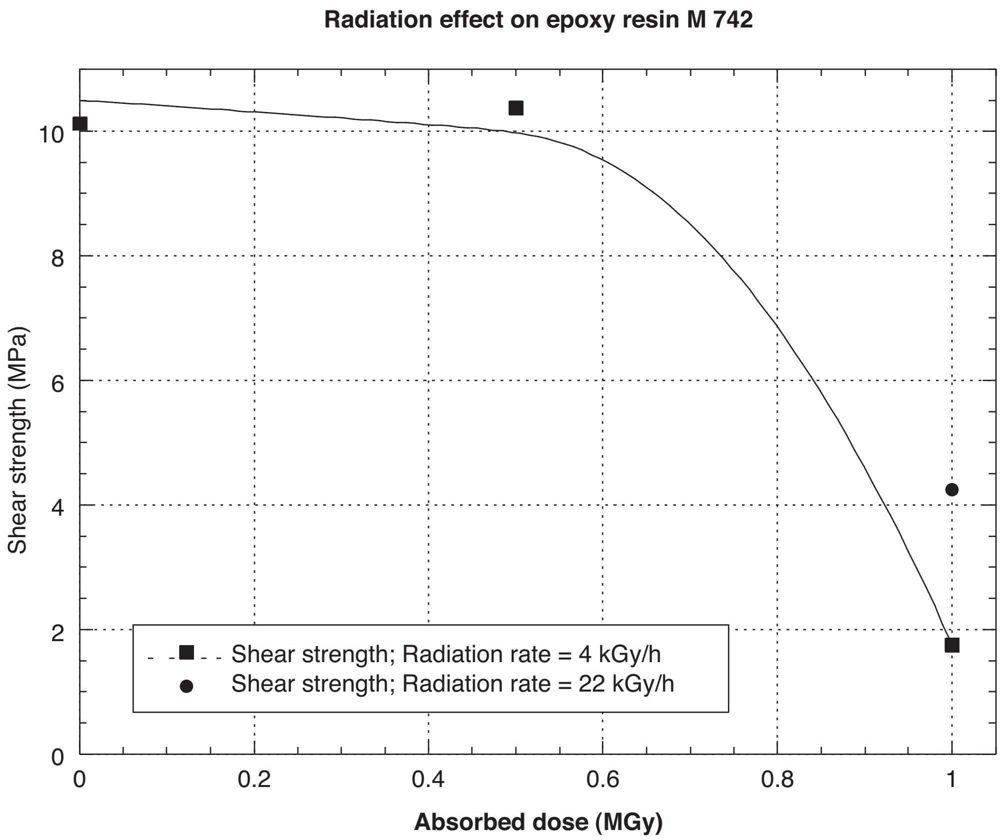


Material:	**Epoxy structural adhesive**	**ID No. M 742**
Type:	**Araldite AY 103/HY 951 (100/40)**	
Supplier:	**Ciba-Geigy**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**10.13** ± 1.1
0.5	**4**	**10.38** ± 0.8
1	**4**	**1.76** ± 0.2
1	**22**	**4.25** ± 0.4

Critical property = shear strength
Radiation index (RI) ~ 5.8 at a mean dose rate of 4 kGy/h
Radiation index (RI) ~ 5.9 at a mean dose rate of 22 kGy/h



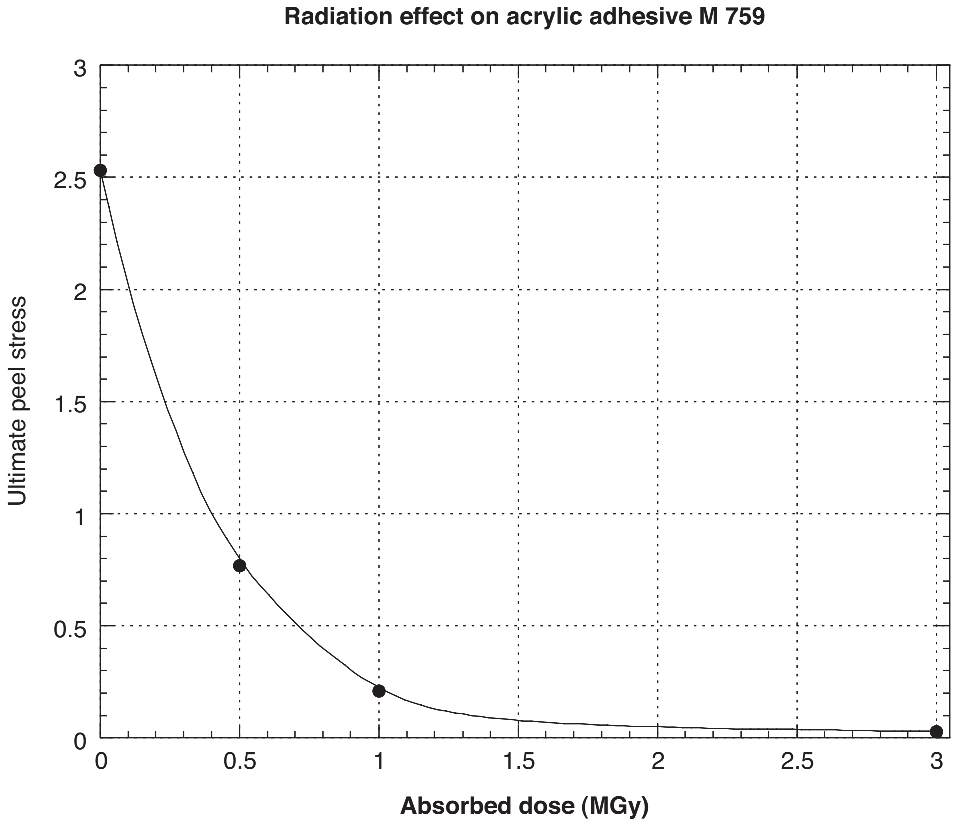
Material: **Acrylic** **ID No. M 759**
Type: **Acrylic AS 1042**

Supplier: **GTS France**

Test method: **Peel test (IPC-650-2.4.9B)**
Description of samples: **Polyimide films (50 μm Kapton) glued on copper (35 μm) with acrylic adhesive**
Polymerization temperature: **25°C**
Radiation source: **Switched-off reactor**

Absorbed dose (MGy)	Dose rate (kG/h)	Ultimate peel stress (N/mm)
0	0	2.53
0.5	1	0.77
1	1	0.21
3	1	0.03

Critical property = ultimate peel stress
Radiation index (RI) ~ 5.0

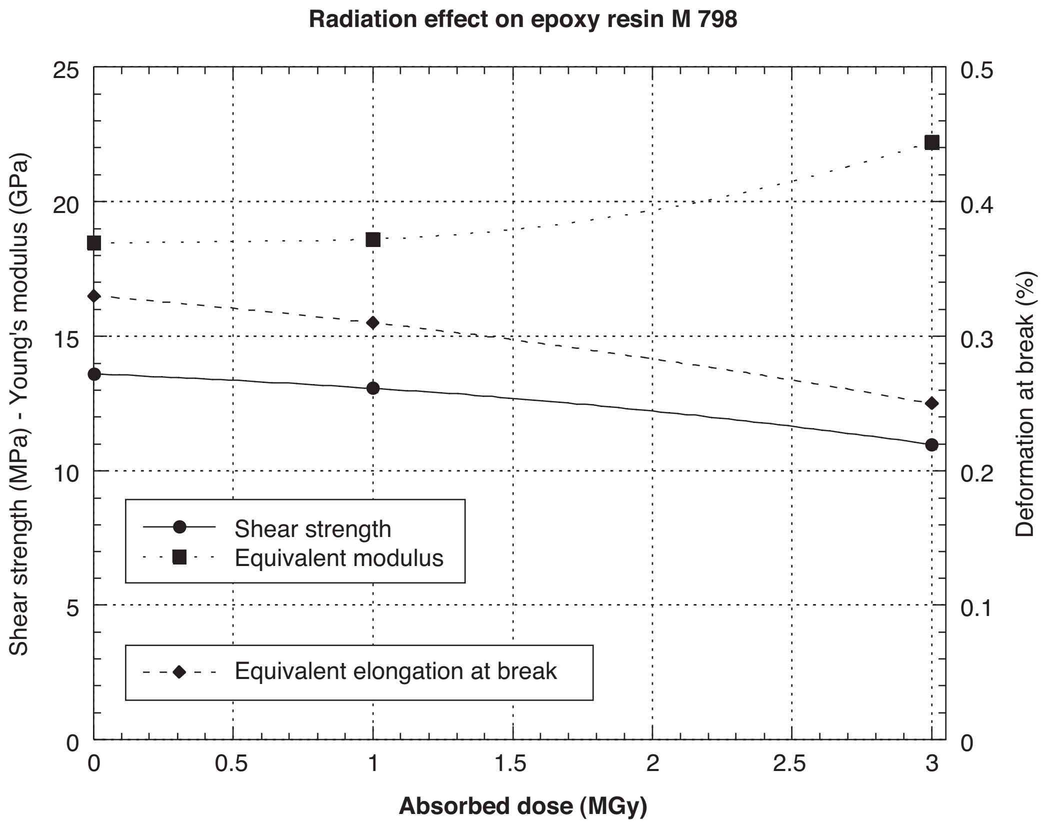


Material:	**Structural epoxy adhesive**	**ID No. M 798**
Type:	**Araldite AV 138/HV 998 (100/40)**	
Supplier:	**Ciba-Geigy**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**13.6** ± 0.3	**0.33** ± 0.02	**18.4** ± 1.2
1	**4**	**13.1** ± 0.5	**0.31** ± 0.04	**18.6** ± 1.2
3	**4**	**11.0** ± 0.4	**0.25** ± 0.03	**22.2** ± 2.3

Critical property = deformation at break
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h

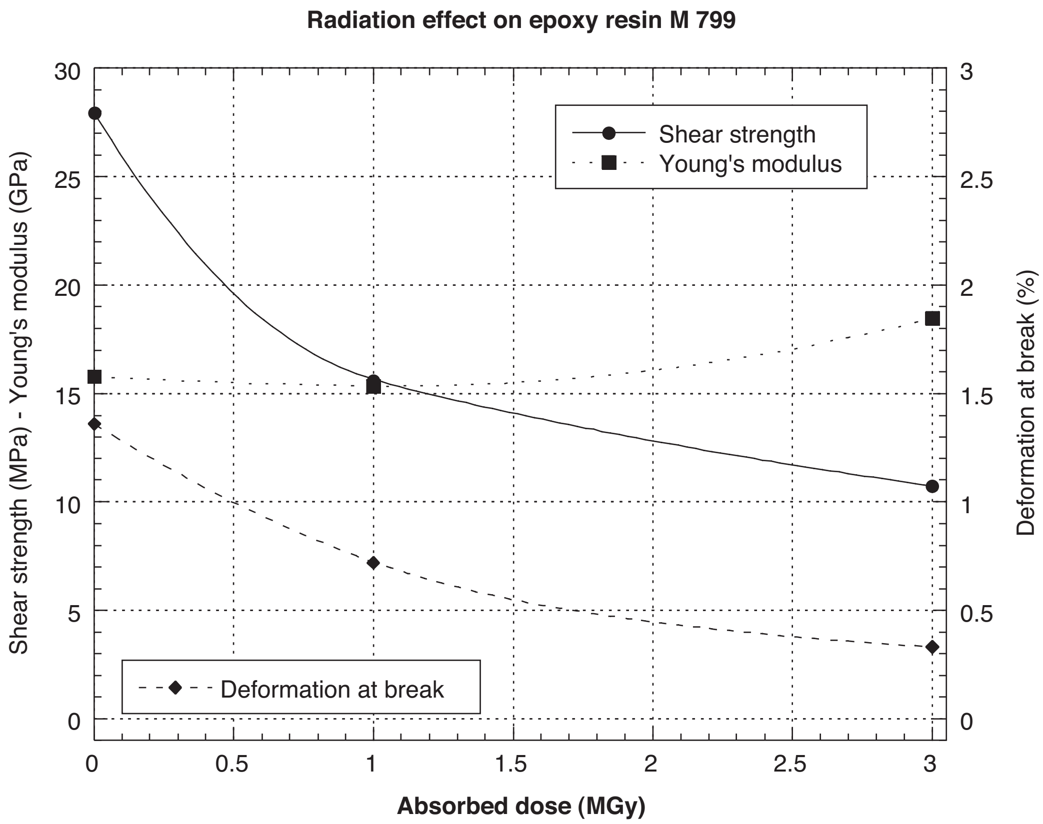


Material:	**Structural epoxy adhesive**	**ID No. M 799**
Type:	**Araldite Redux 420**	
Supplier:	**Ciba-Geigy**	
Remarks:	**Currently supplied by Hexcel**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**27.9** ± 2.4	**1.4** ± 0.2	**15.8** ± 1.0
1	**4**	**15.6** ± 0.7	**0.7** ± 0.1	**15.3** ± 7.1
3	**4**	**10.7** ± 1.3	**0.3** ± 0.1	**18.5** ± 4.7

Critical property = deformation at break
Radiation index (RI) = 6.0 at a mean dose rate of 4 kGy/h

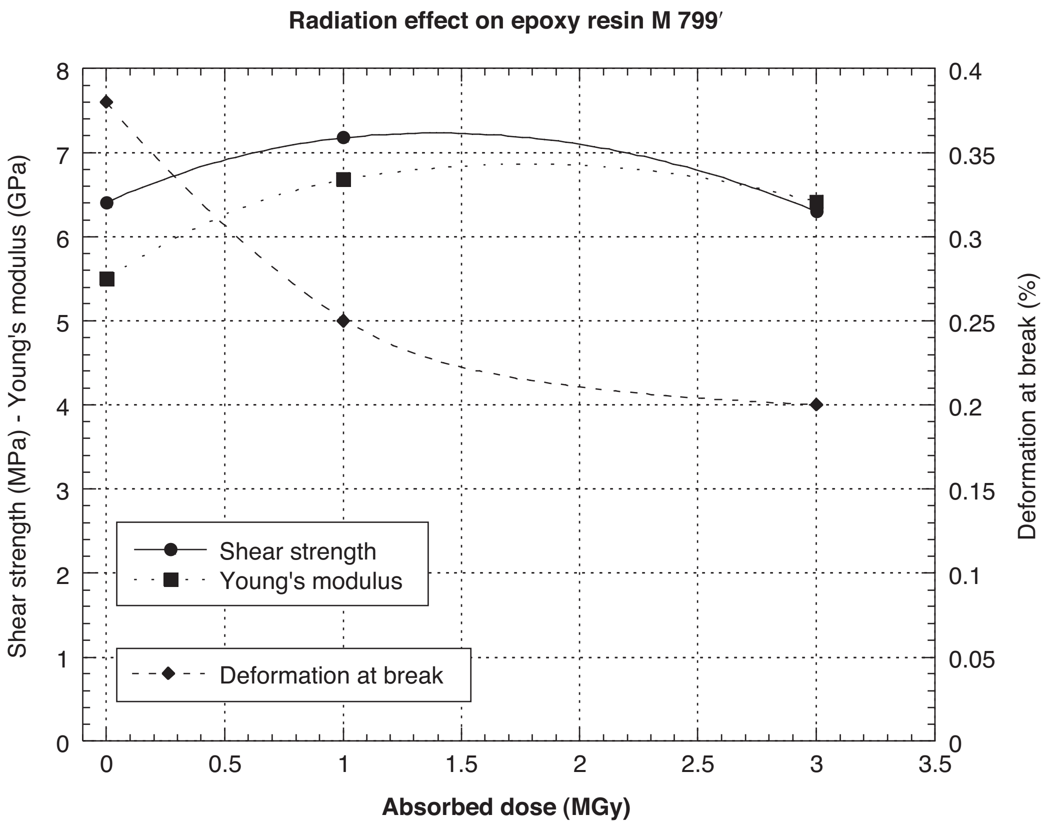


Material:	**Structural epoxy adhesive**	**ID No. M 799′**
Type:	**Araldite Redux 420**	
Supplier:	**Ciba-Geigy**	
Remarks:	**Currently supplied by Hexcel**	

Test method:	**Shear test with Stesalite (fibreglass epoxy composite) samples Equivalent to ASTM D 1876-93**
Sample geometry:	**None**
Surface treatment:	**25°C**
Polymerization temperature:	**Cobalt 60**
Radiation source:	

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**6.4** ± 3.0	**0.38** ± 0.28	**5.5** ± 1.7
1	**4**	**7.2** ± 1.0	**0.25** ± 0.09	**6.7** ± 0.5
3	**4**	**6.3** ± 1.9	**0.20** ± 0.10	**6.4** ± 0.7

Critical property = deformation at break
Radiation index (RI) ~ 6.5 at a mean dose rate of 4 kGy/h



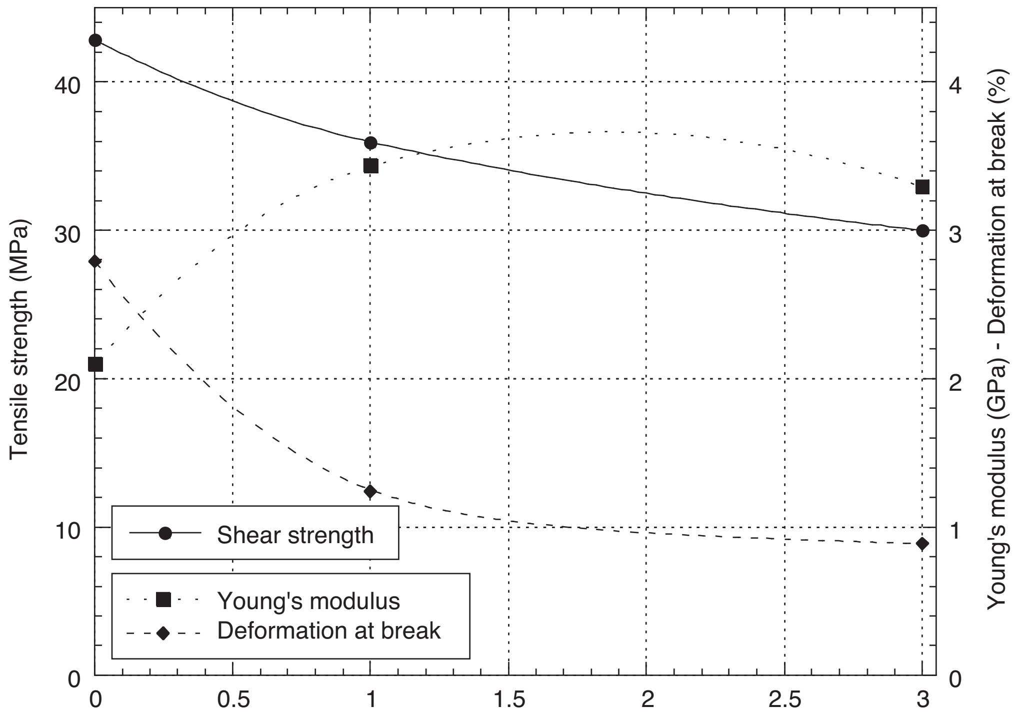
Material:	**Structural epoxy adhesive**	**ID No. M 799″**
Type:	**Araldite Redux 420**	
Supplier:	**Ciba-Geigy**	
Remarks:	**Currently supplied by Hexcel**	

Test method: **Tensile test**
Sample geometry: **ISO R-527 – sample type 1**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Tensile strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**42.8** ± 3.8	**2.79** ± 0.50	**2.1** ± 0.1
1	**4**	**35.9** ± 25.4	**1.24** ± 0.99	**3.4** ± 0.3
3	**4**	**30.0** ± 7.2	**0.89** ± 0.23	**3.3** ± 0.1

Critical property = deformation at break
Radiation index (RI) ~ 5.9 at a mean dose rate of 4 kGy/h

Radiation effect on epoxy resin M 799″



Remarks: samples were dimensionally unstable (radiation-induced deformations)

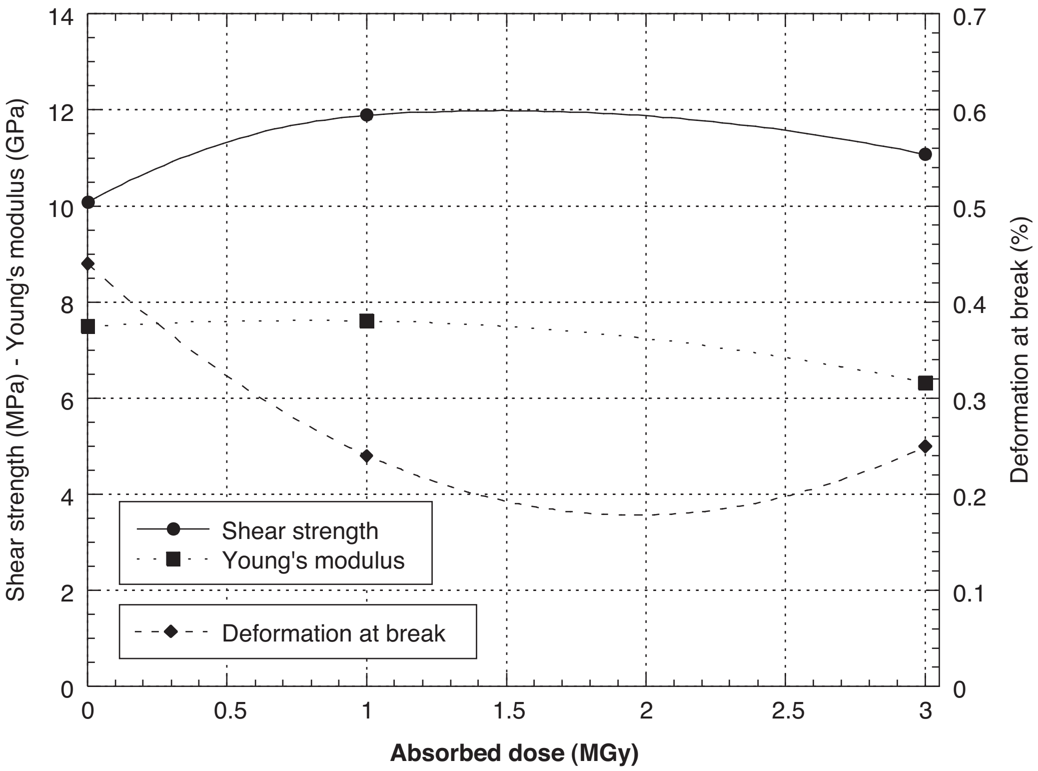
Material:	**Structural epoxy adhesive**	**ID No. M 800**
Type:	**Araldite Rapid**	
Supplier:	**Ciba-Geigy**	

Test method: **Shear test with Stesalite (fibreglass epoxy composite) samples**
Equivalent to ASTM D 1876-93
Sample geometry: **None**
Surface treatment: **25°C**
Polymerization temperature: **Cobalt 60**
Radiation source:

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**10.1** ± 0.6	**0.44** ± 0.12	**7.5** ± 0.4
1	**4**	**11.9** ± 2.3	**0.24** ± 0.06	**7.6** ± 0.4
3	**4**	**11.1** ± 0.9	**0.25** ± 0.05	**6.3** ± 0.7

Critical property = deformation at break
Radiation index (RI) ~ 6.5 at a mean dose rate of 4 kGy/h

Radiation effect on epoxy resin M 800



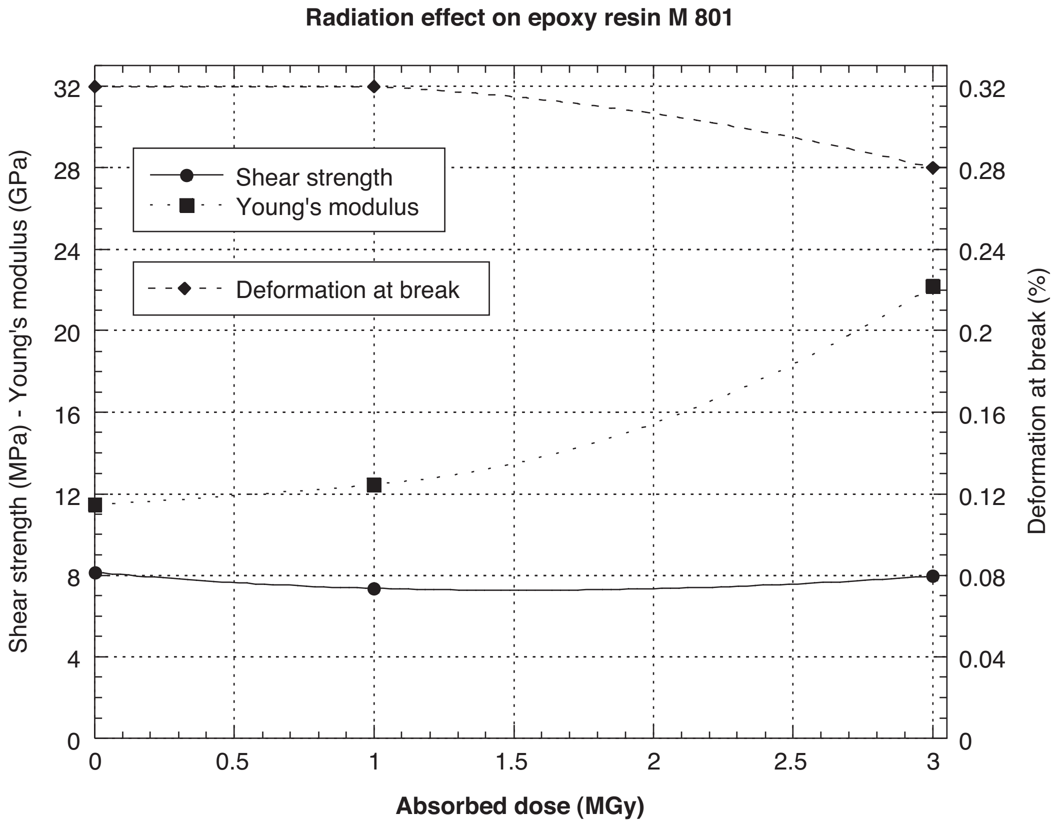
Material: **Structural epoxy adhesive** **ID No. M 801**
Type: **Araldite LY 5052**

Supplier: **Ciba-Geigy**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**8.2** ± 1.1	**0.32** ± 0.04	**11.5** ± 1.2
1	**4**	**7.4** ± 1.4	**0.32** ± 0.06	**12.4** ± 1.8
3	**4**	**8.0** ± 0.3	**0.28** ± 0.04	**22.2** ± 2.7

Critical property = deformation at break
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h



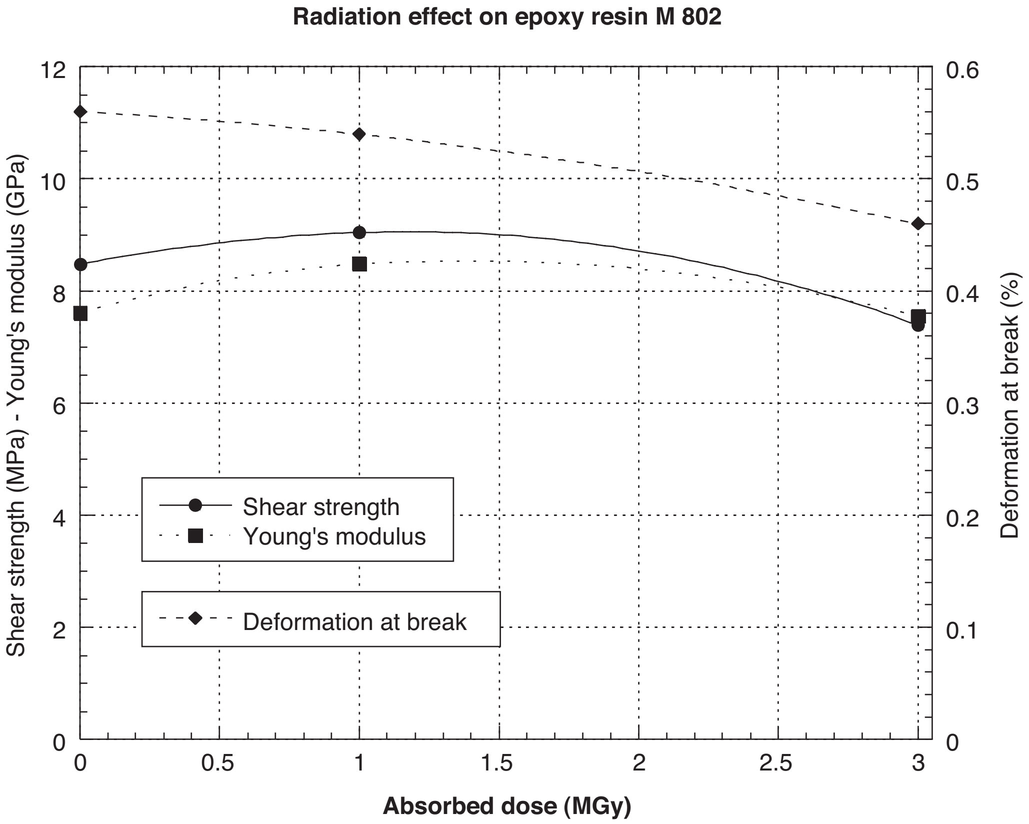
Material: **Structural epoxy adhesive** **ID No. M 802**
Type: **Araldite 2020**

Supplier: **Ciba-Geigy**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**8.5** ± 0.4	**0.56** ± 0.06	**7.6** ± 0.6
1	**4**	**9.1** ± 0.4	**0.54** ± 0.05	**8.5** ± 1.1
3	**4**	**7.4** ± 0.3	**0.46** ± 0.07	**7.5** ± 1.0

Critical property = deformation at break
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h



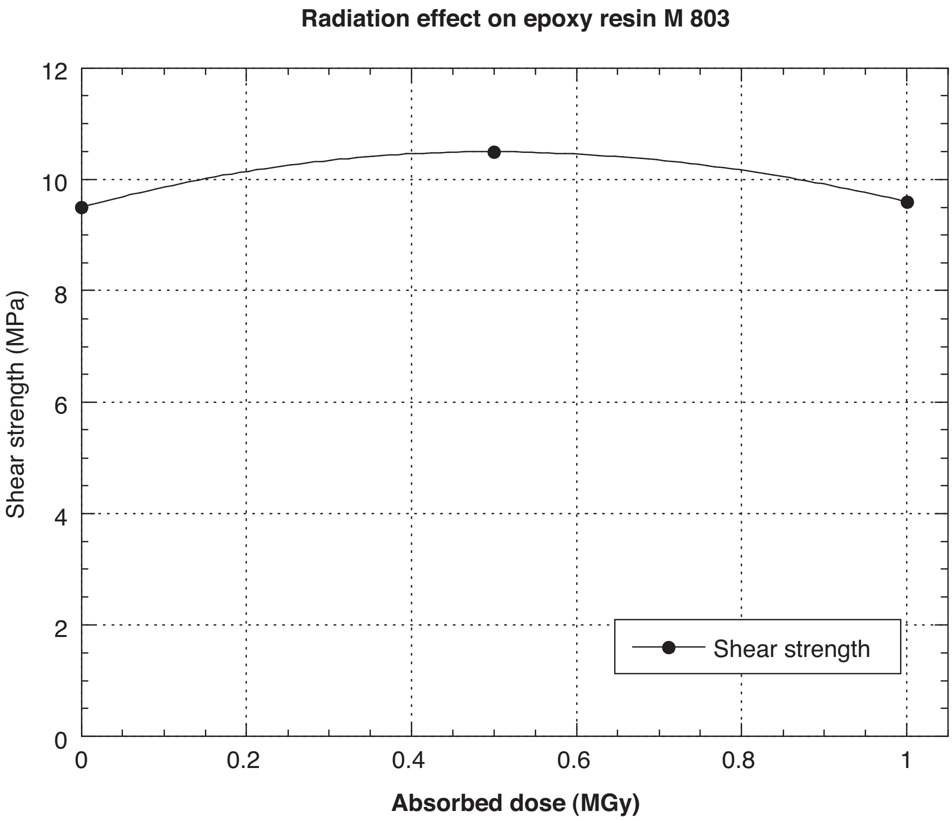
Material: **Epoxy structural adhesive** **ID No. M 803**
Type: **Araldite D/HY 951 (100/10)**

Supplier: **Ciba-Geigy**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**9.5** ± 0.6
0.5	**4**	**10.5** ± 0.7
1	**4**	**9.6** ± 0.2

Critical property = shear strength
Radiation index (RI) > 6.0 at a mean dose rate of 4 kGy/h



APPENDIX 3

Alphabetic compilation of data

(Trade names in italics)

B

Commercial name	Base polymer	Supplier	Reference	R.I.
Biodur 561	Epoxy resin	Progressive Products	M 744	~ 6.3
Biogard 251	Epoxy resin	Progressive Products	M 743	> 6.0

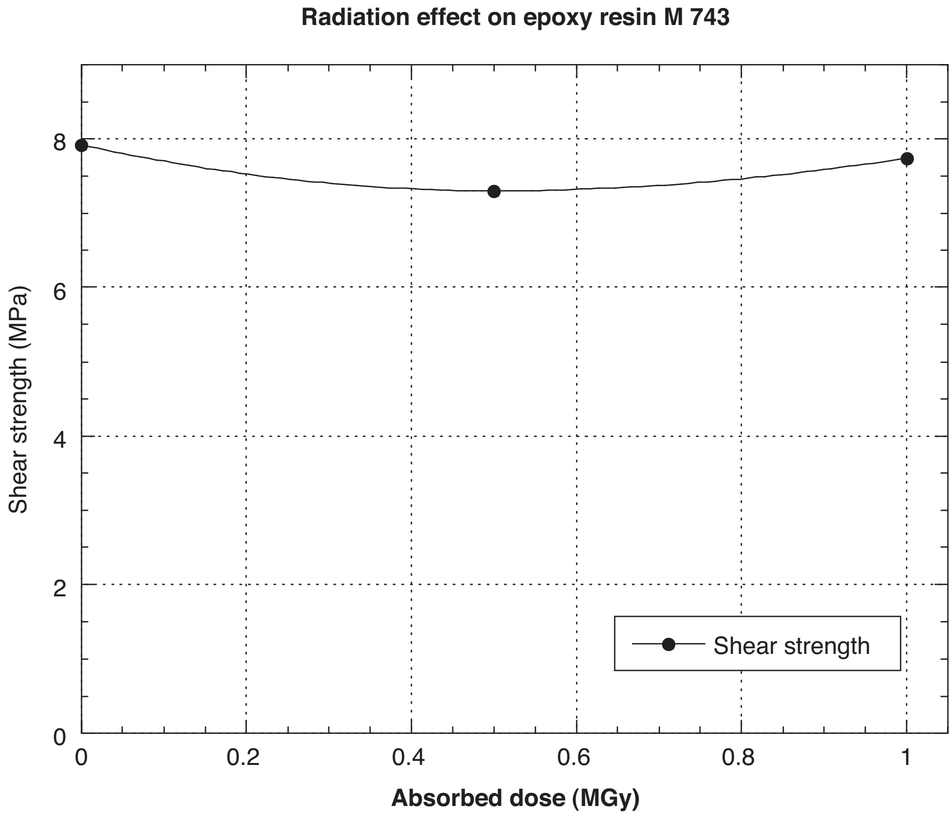
Material: **Epoxy structural adhesive** **ID No. M 743**
Type: **Biogard 251**

Supplier: **Progressive Products**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**7.9** ± 0.3
0.5	**4**	**7.3** ± 0.3
1	**4**	**7.7** ± 0.7

Critical property = shear strength
Radiation index (RI) > 6.0 at a mean dose rate of 4 kGy/h

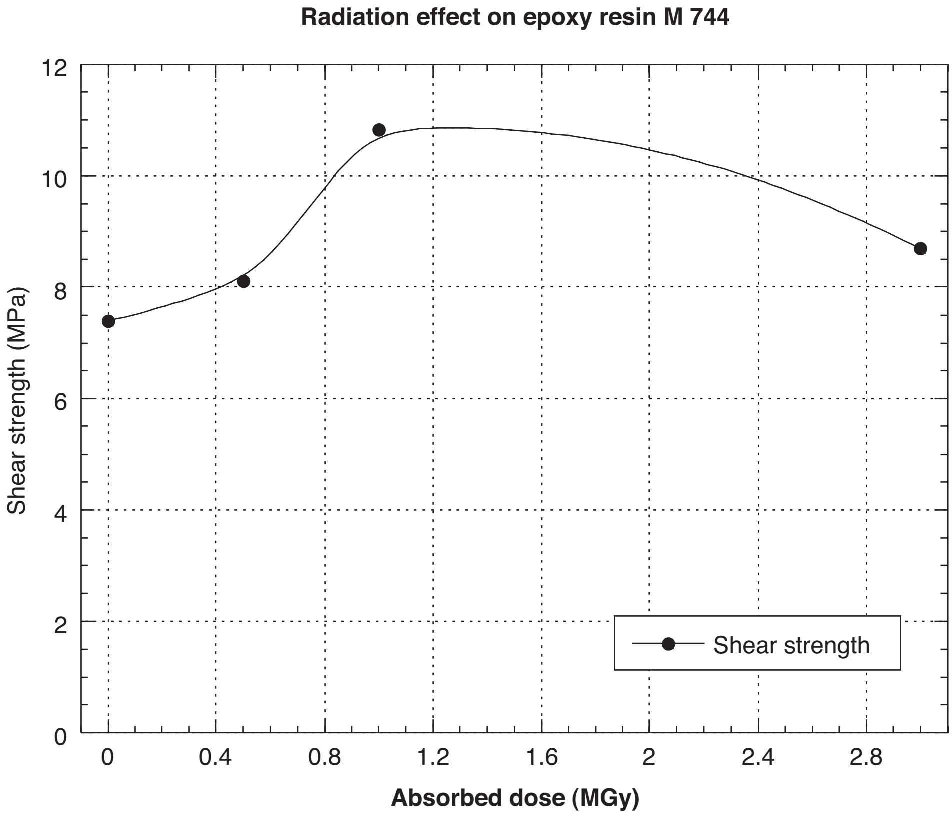


Material:	**Epoxy structural adhesive**	**ID No. M 744**
Type:	**Biodur 561**	
Supplier:	**Progressive Products**	

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**7.4** ± 0.3
0.5	**4**	**8.1** ± 0.2
1	**4**	**10.8** ± 0.5
3	**4**	**8.7** ± 0.7

Critical property = shear strength
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h



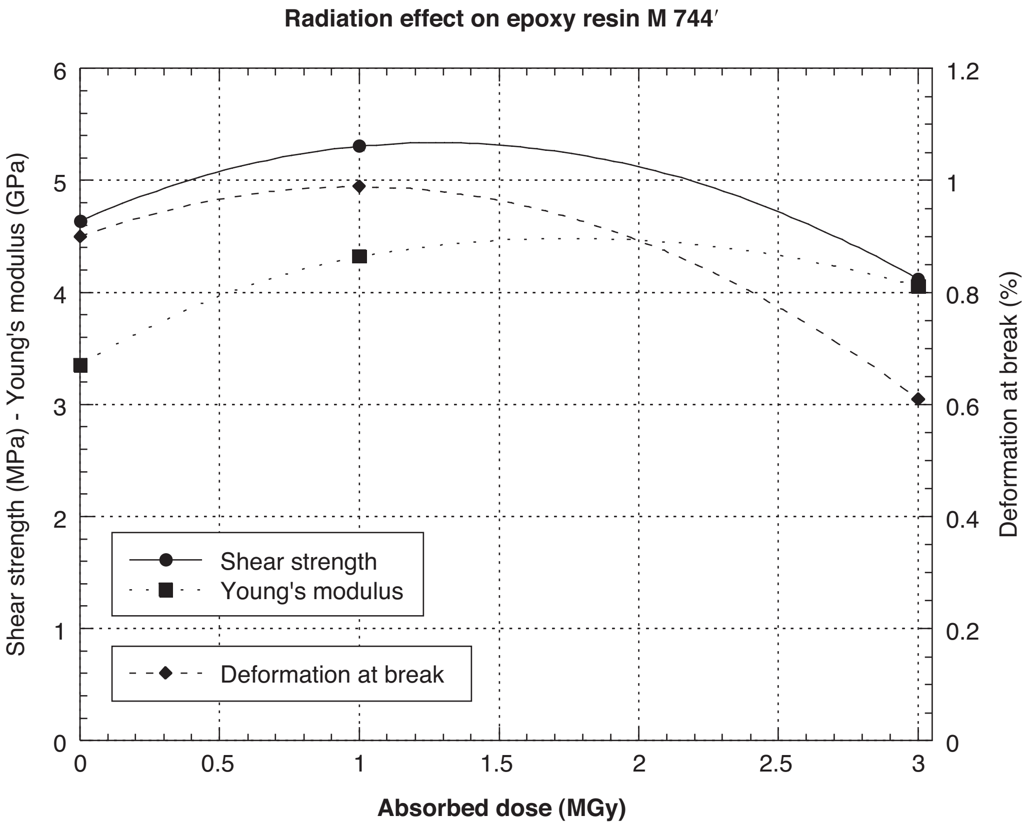
Material: **Epoxy structural adhesive** **ID No. M 744′**
Type: **Biodur 561**

Supplier: **Progressive Products**

Test method: **Shear test with Stesalite (fibreglass epoxy composite) samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **None**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**4.6** ± 1.6	**0.9** ± 0.34	**3.4** ± 0.4
1	**4**	**5.3** ± 1.4	**0.99** ± 0.19	**4.3** ± 0.3
3	**4**	**4.1** ± 0.9	**0.61** ± 0.15	**4.1** ± 0.5

Critical property = deformation at break
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h



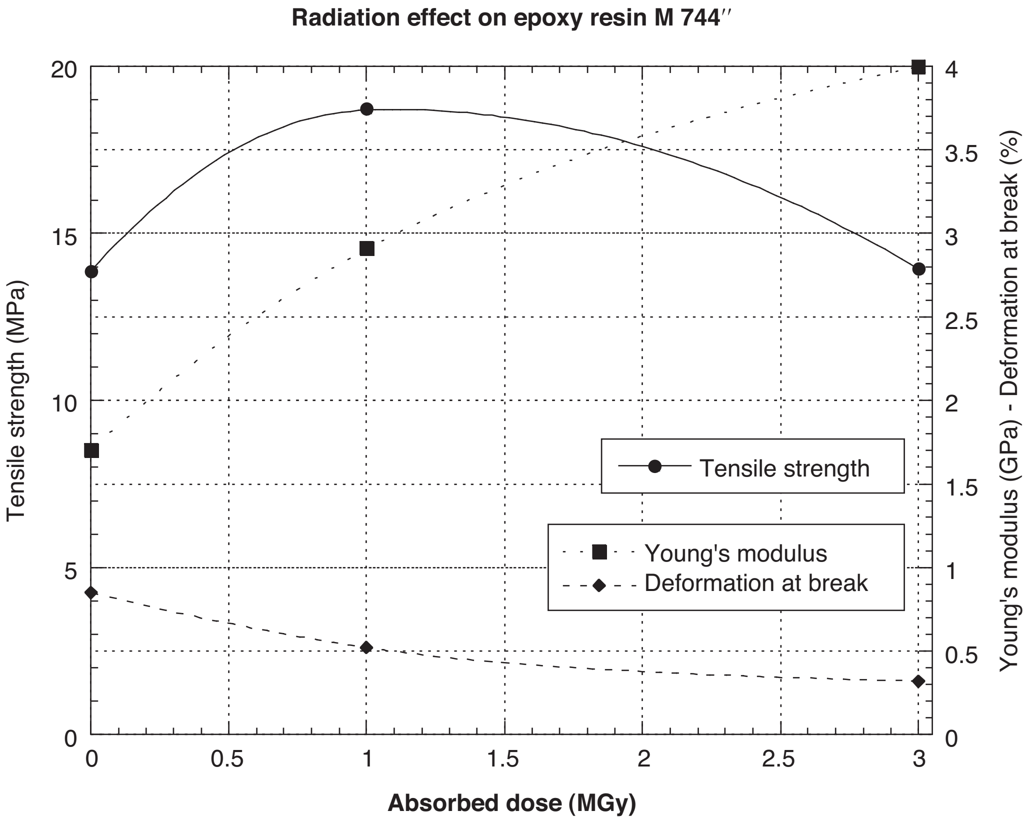
Material: **Epoxy structural adhesive** **ID No. M 744′′**
Type: **Biodur 561**

Supplier: **Progressive Products**

Test method: **Tensile test**
Sample geometry: **ISO R-527 – sample type 1**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Tensile strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**13.9** ± 0.9	**0.85** ± 0.03	**1.7** ± 0.2
1	**4**	**18.7** ± 1.9	**0.52** ± 0.22	**2.9** ± 0.9
3	**4**	**13.9** ± 1.1	**0.32** ± 0.03	**4.0** ± 0.4

Critical property = deformation at break
Radiation index (RI) ~ 6.3 at a mean dose rate of 4 kGy/h



APPENDIX 3

Alphabetic compilation of data

(Trade names in italics)

C

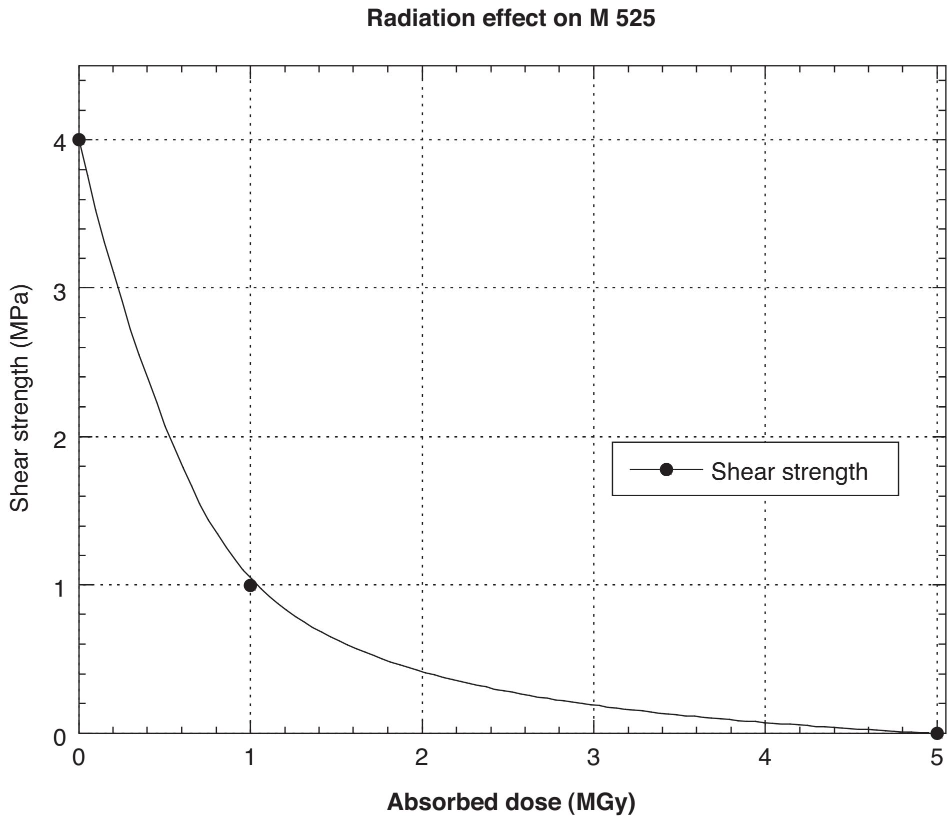
Commercial name	Base polymer	Supplier	Reference	R.I.
CATV 4	Silicone resin	Shell Aesol AG	see *Rhodorsil*	
Cementit		Merz + Bendeti	M 525	< 6.0
Conductive epoxy resin		Muller	see epoxy 417 see *TRA DUCT*	
Conductive solder	Epoxy resin	Von Roll Isola	M 843	> 6.0
Coroplast 302	PVC	Muller	see Tapes	
Cold Solder	Metallic glue	Rebstar	see *Turbometall*	
Cyanoacrylate glue	Cyano-acrylate resin		see *Pronto* see *Cyanolit*	
Cyanolit 102	Cyano-acrylate resin	3M	M 627	~ 4.9
Cyanolit 201	Cyano-acrylate resin	3M	M 625	~ 5.0
Cyanolit 202	Cyano-acrylate resin	3M	M 626	~ 5.1

Material:	**Resin with 10% methyl acetate and ethyl acetate**	**ID No. M 525**
Type:	**Cementite Universal**	
Supplier:	**Merz+Benteli**	

Test method: **Shear test**
Sample geometry: **Single-lap shear samples on aluminium**
Polymerization temperature: **25°C**
Radiation source: **Switched-off reactor**

Absorbed dose (MGy)	Strength (MPa)
0	**4** ± 0.6
1	**1** ± 0.2
5	**0**

Critical property = applied load
Radiation index (RI) < 6.0



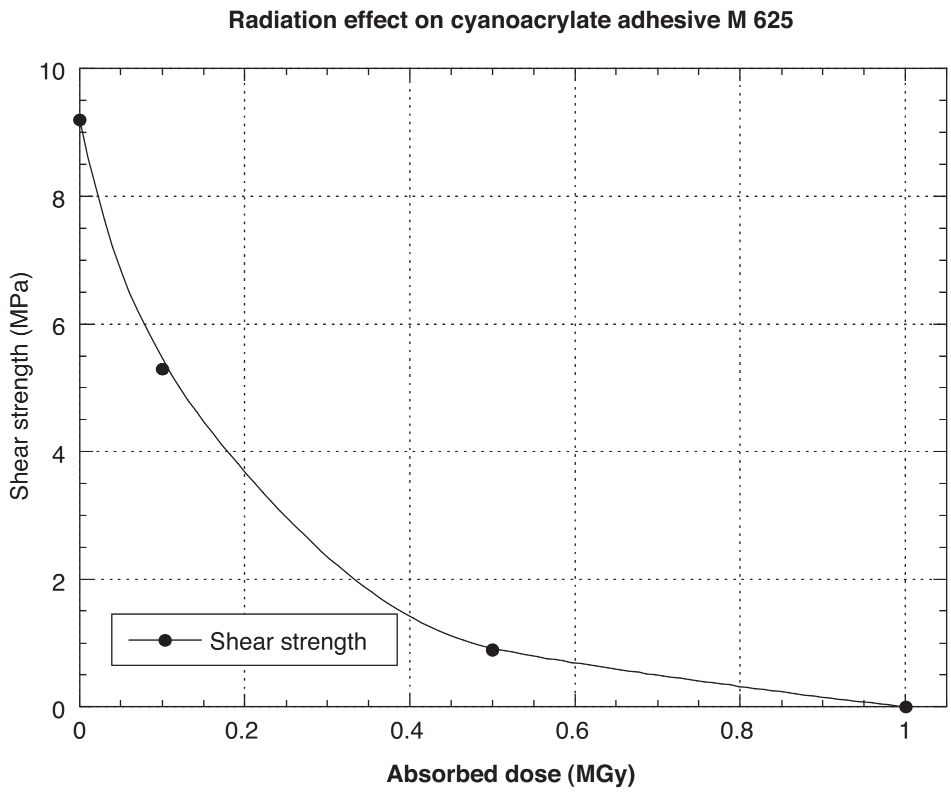
Material: **Cyanoacrylate adhesive** **ID No. M 625**
Type: **Cyanolite 201**

Supplier: **3M**

Test method: **Shear test with aluminium samples**
Sample geometry: **Two plaques (10 × 1) cm were stuck together with a 1 cm^2 surface area**
Surface treatment: **None**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Shear strength (MPa)
0	9.2
0.1	5.3
0.5	0.9
1	0

Critical property = shear strength
Radiation index (RI) ~ 5.0



References: TIS–CFM/MTR/88–026 (1988)

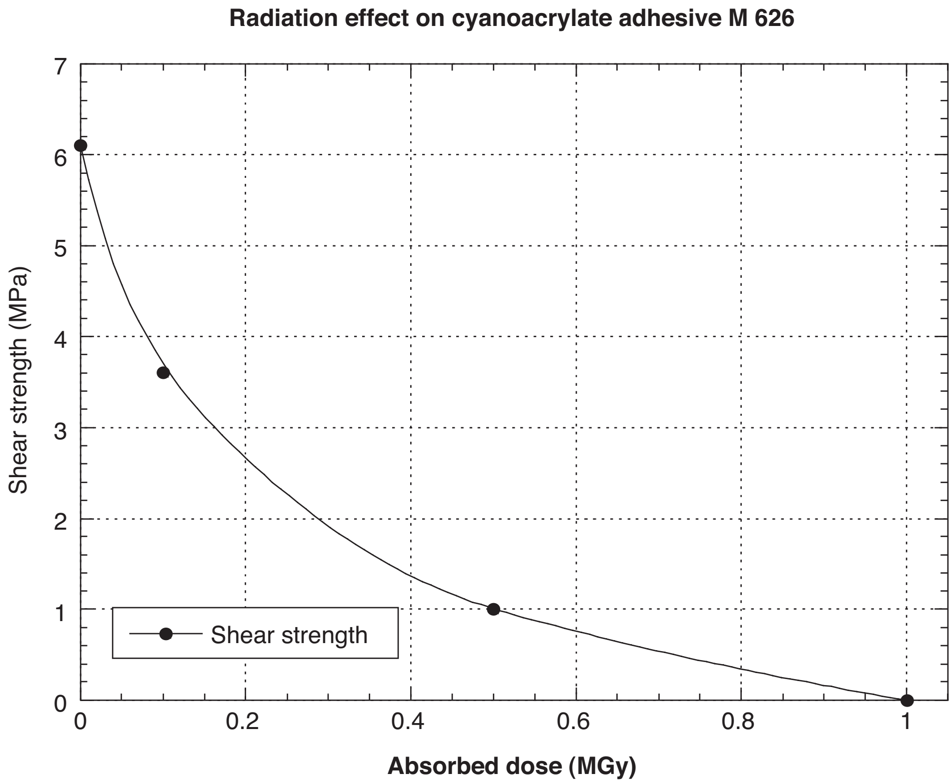
Material: **Cyanoacrylate adhesive** **ID No. M 626**
Type: **Cyanolite 202**

Supplier: **3M**

Test method: **Shear test with aluminium samples**
Sample geometry: **Two plaques (10 × 1) cm were stuck together with a 1 cm^2 surface area**
Surface treatment: **None**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Shear strength (MPa)
0	6.1
0.1	3.6
0.5	1
1	0

Critical property = shear strength
Radiation index (RI) ~ 5.1



References: TIS–CFM/MTR/88–026 (1988)

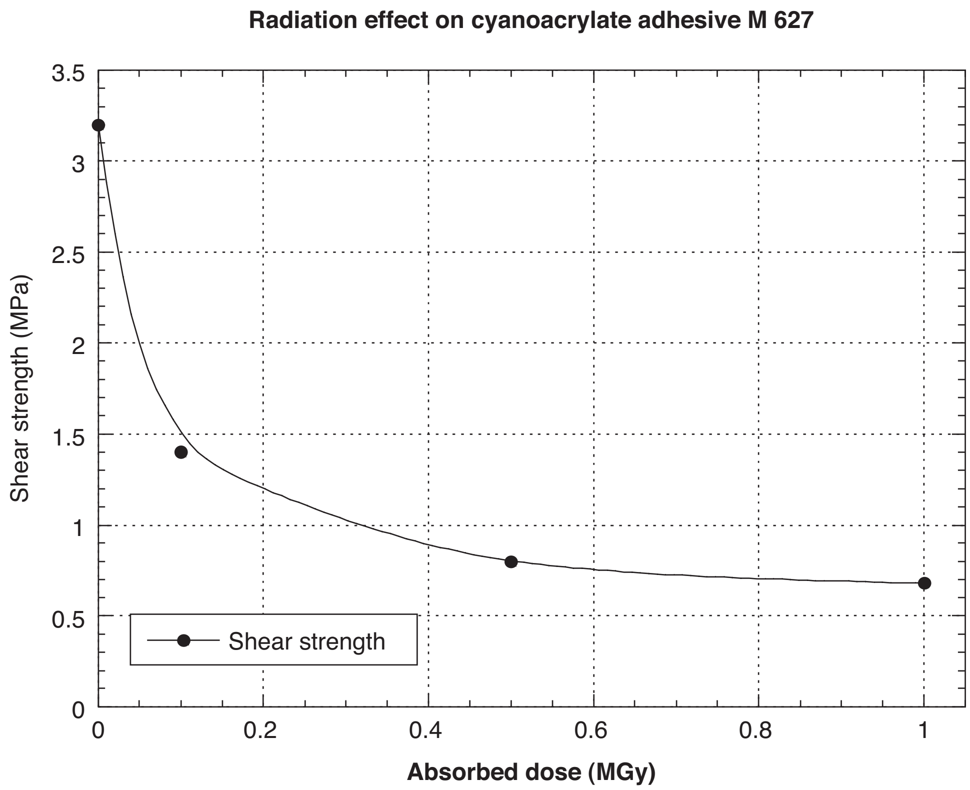
Material: **Cyanoacrylate adhesive** **ID No. M 627**
Type: **Cyanolit 102**

Supplier: **3M**

Test method: **Shear test with aluminium samples**
Sample geometry: **Two plaques (10 × 1) cm were stuck together with a 1 cm^2 surface area**
Surface treatment: **None**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Shear strength (MPa)
0	3.2
0.1	1.4
0.5	0.8
1	0.68

Critical property = shear strength
Radiation index (RI) ~ 4.9



References: TIS–CFM/MTR/88–026 (1988)

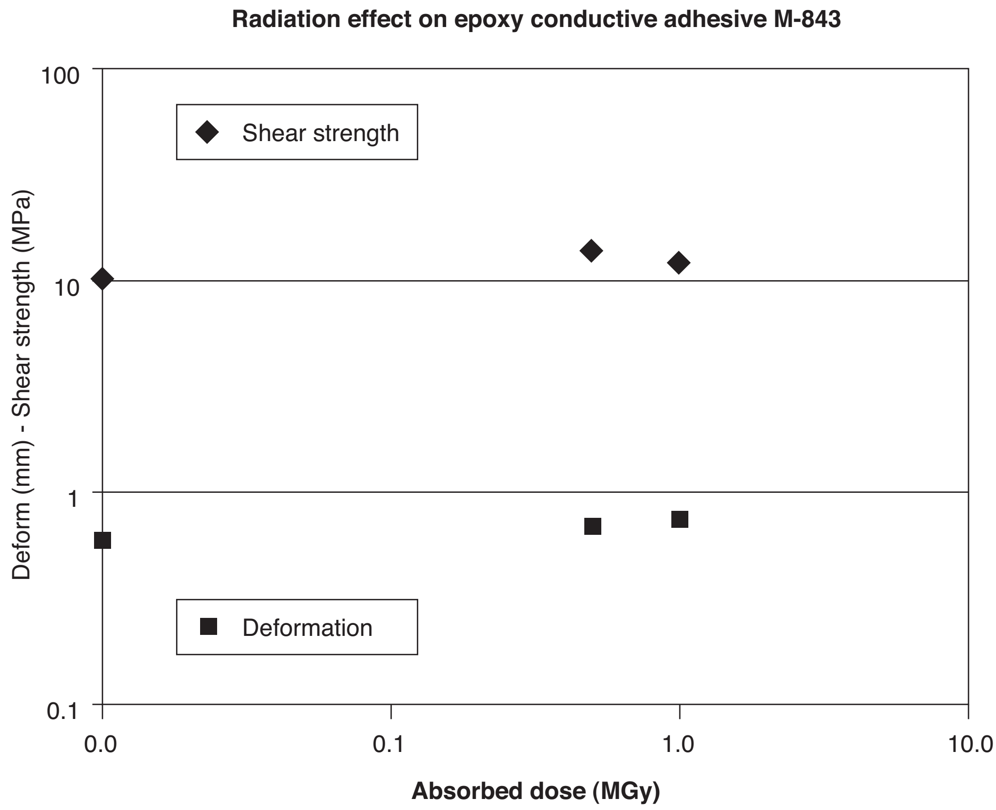
Material: **Conductive adhesive** **ID No. M 843**
Type: **Solder 3025-E**

Supplier: **Von Roll Isola**
Remarks: **Based on epoxy resin**

Test method: **Radiation test based on shear test with aluminium plates**
Sample geometry: **Two plaques (10 × 1) cm were stuck together with a 1 cm^2 surface area**
Surface treatment: **None**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorded dose (MGy)	Dose-rate (kGy/h)	Shear Strength (MPa) ± σ	Deformation (mm) ± σ
0.0	**0**	10.2 ± 1.54	0.60 ± 0.02
0.5	**800**	13.7 ± 0.80	0.69 ± 0.05
1.0	**800**	12.1 ± 0.53	0.75 ± 0.08
3.0			

Radiation Index (RI) > 6



APPENDIX 3

Alphabetic compilation of data

(Trade names in italics)

D

Commercial name	Base polymer	Supplier	Reference	R.I.
DC 3140	Silicone resin	Dow Corning	see silicone	
DC 3145	Silicone resin	Dow Corning	see silicone	

APPENDIX 3

Alphabetic compilation of data

(Trade names in italics)

E

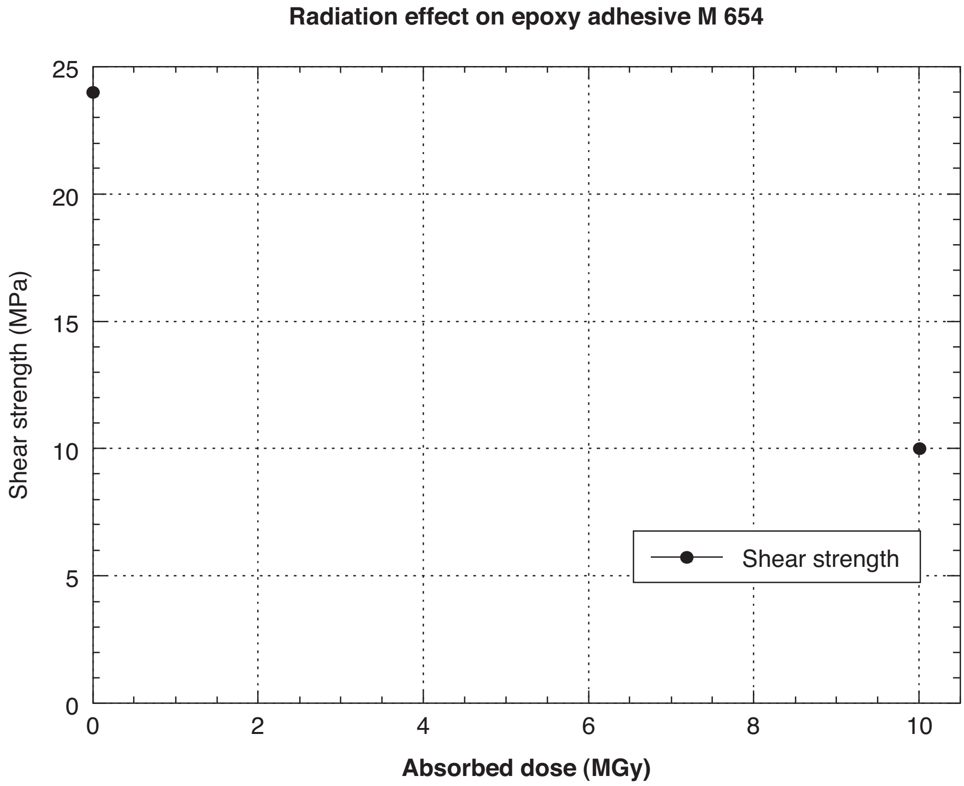
Commercial name	Base polymer	Supplier	Reference	R.I.
Epikote	Epoxy resin	Shell Chemie	M 654	~ 6.8
Epoxy 1056 (50/50)	Epoxy resin	Dolph's	M 741	> 6.5
Epoxy 2014-I/235 (100/25)	Epoxy resin	Magnolia	M 735	> 6.0
Epoxy 2014-I/346 (100/75)	Epoxy resin	Magnolia	M 736	> 6.0
Epoxy 2014-I/459 (100/25)	Epoxy resin	Magnolia	M 749	> 6.0
Epoxy 3025-E	Conductive epoxy resin	Von Roll Isola	M 843	> 6.0
Epoxy 417	Conductive epoxy resin	Epoteck	M 814	> 6.5
Epoxy 9323 B/A	Epoxy resin	3M	M 810	~ 6.4
Epoxy AS 1084	Modified epoxy	GTS France	M 760	~ 5.0
Epoxy E 505 SIT	Epoxy resin	Epotecny	M 721	> 6.0
Epoxy EA 9394	Epoxy resin	Hysol	M 804	> 6.5
Epoxy gluing systems	Epoxy resin Epoxy resin Epoxy resin Epoxy resin Epoxy resin Epoxy resin Epoxy resin Epoxy resin Epoxy resin Epoxy resin Epoxy resin Epoxy resin	Ciba-Geigy Progressive Products Progressive Products Norlabs Ciba-Geigy Bakelite Sika 3M Emerson & Cuming Tracon Tracon Isola Breitenbach	see *Araldite* see *Biodur* see *Biogard* see *Norcast* see *Redux* see *Rutapox* see *Sikadur* see *Scotchcast* see *Stycas* see *TRA BOND* see *TRA DUCT* see *Varnish*	
Epoxy IP25A/10	Epoxy resin	I-Plastic	M 695	> 6.7
Epoxy MT 13	Epoxy resin	Smooth On	M 745	> 6.0
Epoxy, type L	Epoxy resin	R&G	M 818	> 6.2

Material:	**Epoxy adhesive**	**ID No. M 654**
Type:	**Epikote 215 / V 140 (100/85)**	
Supplier:	**Shell Chemie**	

Test method:	**Shear test with stainless steel and Kapton**
Sample geometry:	**Equivalent to ASTM D 1876-93, with a Kapton film inserted**
Polymerization temperature:	**25°C**
Polymerization pressure:	**1 bar**
Radiation source:	**Switched-off reactor**

Absorbed dose (MGy)	**Strength (MPa)**
0	**24** ± 2.0
10	**10** ± 0.5

Critical property = shear strength
Radiation index (RI) ~ 6.8



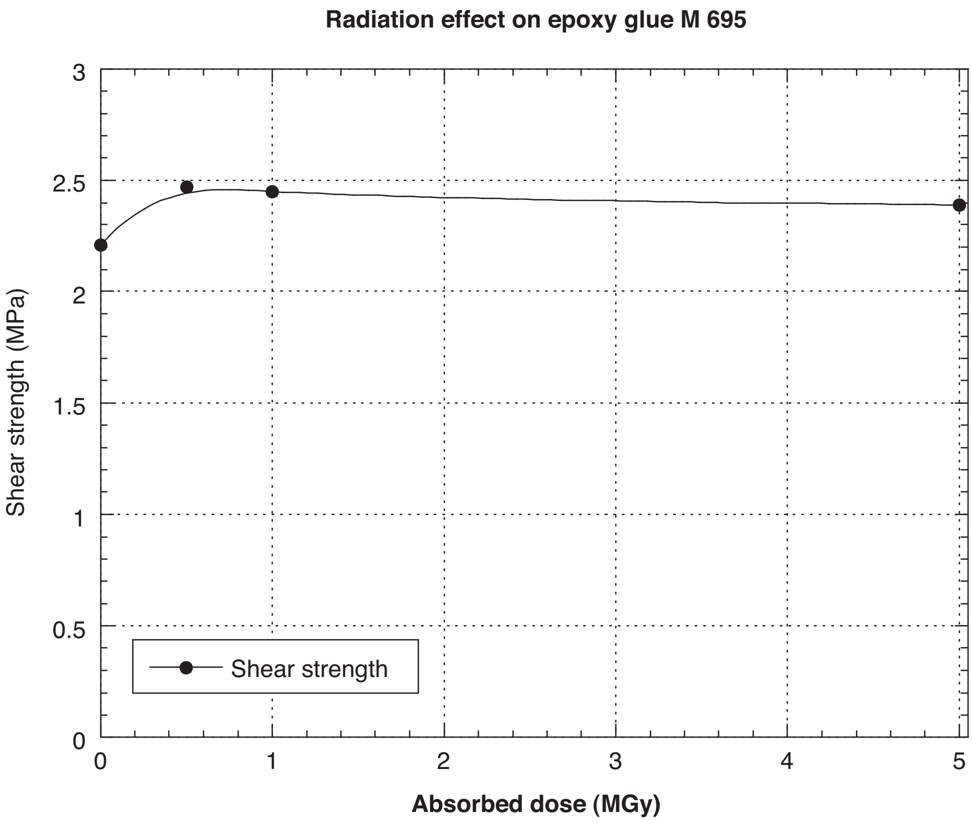
The test was also conducted at 77 K (without irradiation); the resistance of the steel/Kapton joint was unchanged, the resistance of the composite/Kapton joint was reduced by 30% (Ref.: Cornuet, ST/TE/RB/88–165/mc).

Material:	**Epoxy adhesive**	**ID No. M 695**
Type:	**Epoxy IP25A/10**	
Supplier:	**I-Plastic**	

Test method:	**Shear test with aluminium 1000 samples**
Sample geometry:	**Two plates (10 × 1) cm were stuck together with a 1 cm^2 surface area**
Surface treatment:	**None**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60; 2 kGy/h**

Absorbed dose (MGy)	Shear strength (MPa)
0	2.21
0.5	2.47
1	2.45
5	2.39

Critical property = only the shear strength was measured
Radiation index (RI) > 6.7



Material:	**Epoxy glue**	**ID No. M 721**
Type:	**Epoxy E 505 SIT**	
Supplier:	**Epotecny**	

Test method:	**Shear test with Vectra C 130 (liquid crystal polymer) samples**
Sample geometry:	**Two plates (10 × 1) cm were stuck together with a 1 cm^2 surface area**
Surface treatment:	**None**
Polymerization temperature:	**90 min at 60°C**
Radiation source:	**Cobalt 60**

Results: **It was not possible to assess the shear resistance of the glue, because a failure of the system occurred in the Vectra plates, at a force of 700 N.**

The shear strength in the glue joint is above 7 MPa at any tested dose (up to 1 MGy).

The traction/torsion strength in the Vectra plate is about 23 MPa.

Critical property = shear strength

Radiation index (RI) may be around or above 6.0

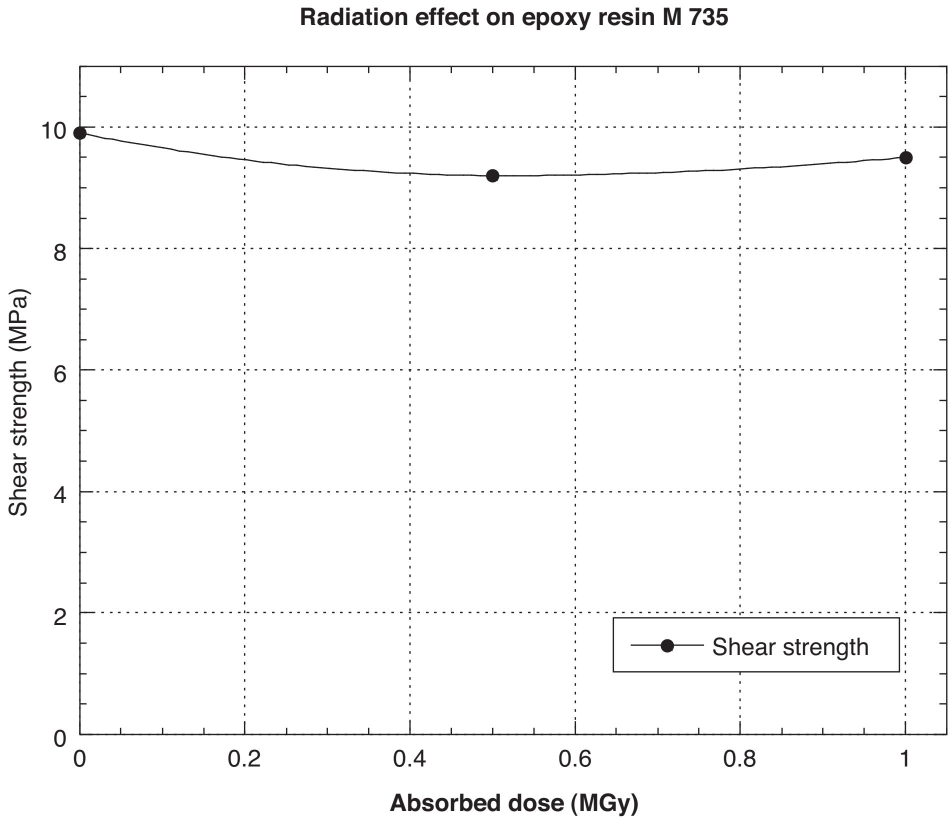
References: TIS–CFM/MTR/88–026 (1988)

Material:	**Structural epoxy adhesive**	**ID No. M 735**
Type:	**Epoxy 2014-I/235 (100/25)**	
Supplier:	**Magnolia**	

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**9.9** ± 1.2
0.5	**4**	**9.2** ± 1.3
1	**4**	**9.5** ± 0.8

Critical property = shear strength
Radiation index (RI) > 6.0 at a mean dose rate of 4 kGy/h



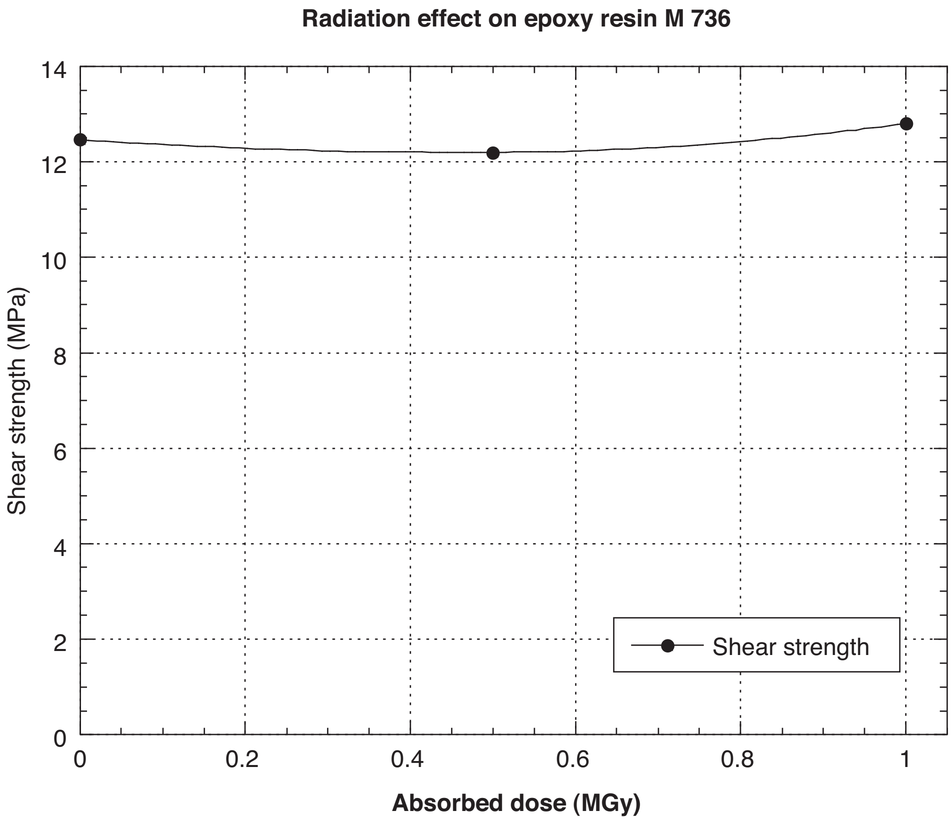
Material: **Structural epoxy adhesive** **ID No. M 736**
Type: **Epoxy 2041-I/346 (100/75)**

Supplier: **Magnolia**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**12.5** ± 1.1
0.5	**4**	**12.2** ± 1.5
1	**4**	**12.8** ± 1.4

Critical property = shear strength
Radiation index (RI) > 6.0 at a mean dose rate of 4 kGy/h



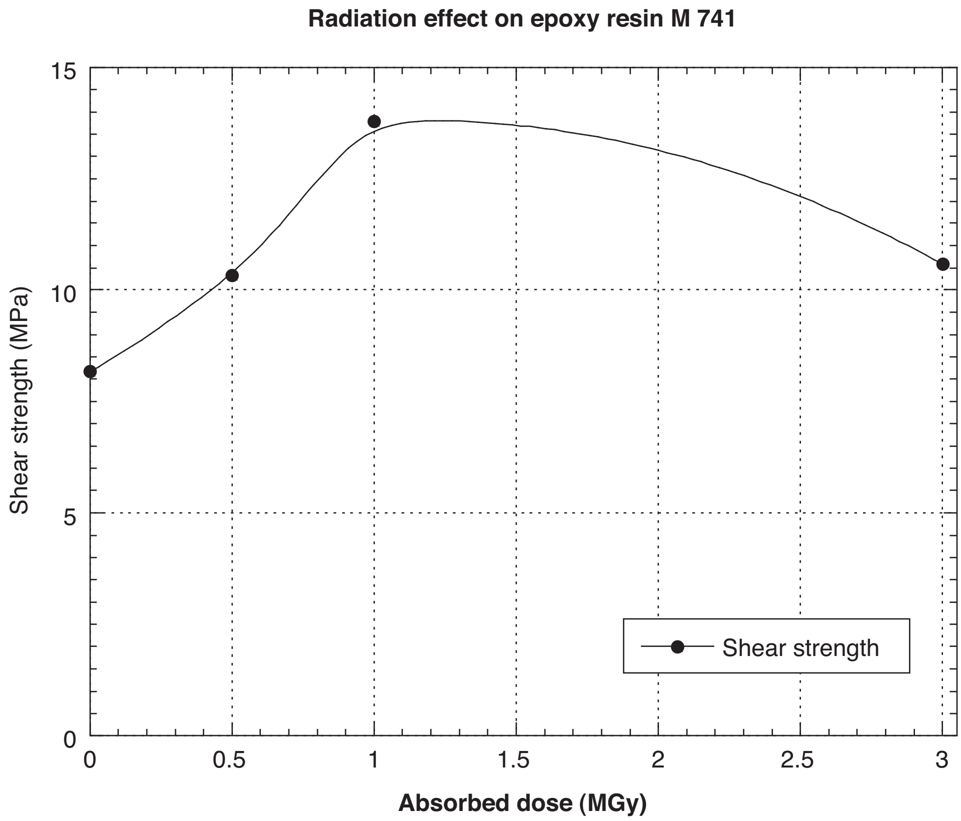
Material: **Epoxy structural adhesive** **ID No. M 741**
Type: **Epoxy 1056**

Supplier: **Dolph's**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**8.2** ± 0.6
0.5	**4**	**10.3** ± 1.0
1	**4**	**13.8** ± 1.0
3	**4**	**10.6** ± 0.6

Critical property = shear strength
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h



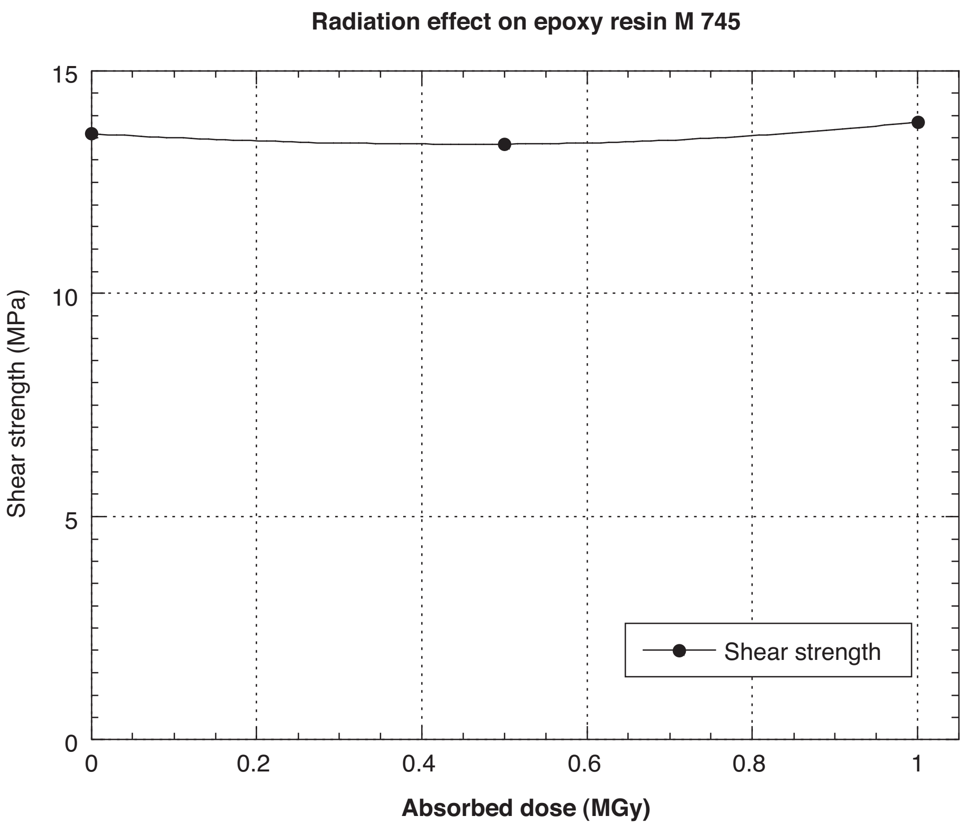
Material: **Epoxy structural adhesive** **ID No. M 745**
Type: **Epoxy MT13**

Supplier: **Smooth on**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**13.6** ± 2.3
0.5	**4**	**13.4** ± 1.3
1	**4**	**13.9** ± 1.9

Critical property = shear strength
Radiation index (RI) > 6.0 at a mean dose rate of 4 kGy/h

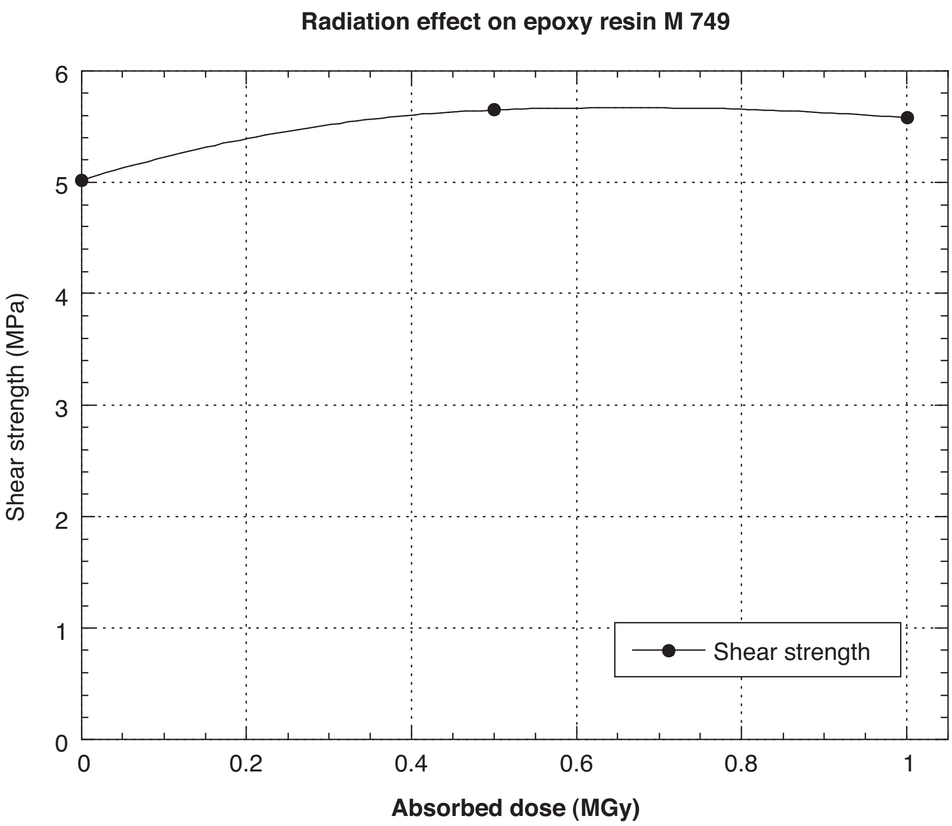


Material:	**Epoxy structural adhesive**	**ID No. M 749**
Type:	**Epoxy 2014-I/459 (100/25)**	
Supplier:	**Magnolia**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**5** ± 0.4
1	**4**	**5.7** ± 0.4
3	**4**	**5.6** ± 0.3

Critical property = shear strength
Radiation index (RI) > 6.0 at a mean dose rate of 4 kGy/h

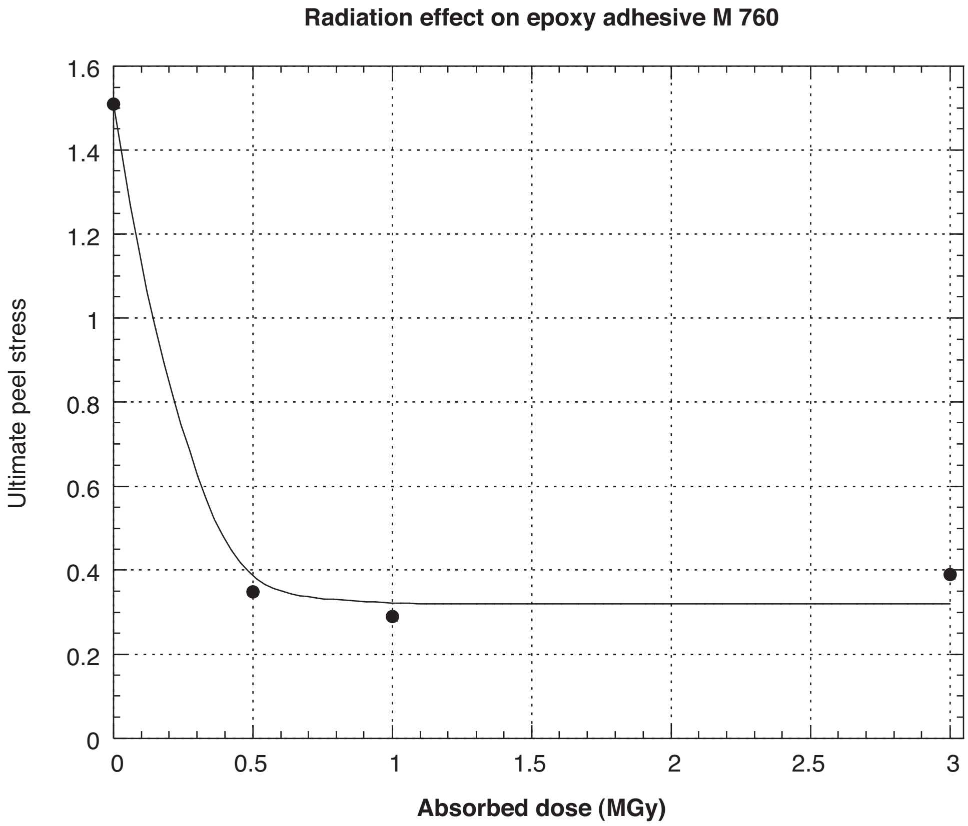


Material:	**Modified epoxy**	**ID No. M 760**
Type:	**Epoxy AS 1084**	
Supplier:	**GTS France**	

Test method:	**Peel test (IPC-650-2.4.9B)**
Description of samples:	**Polyimide films (50 µm Kapton) glued on copper (35 µm) with epoxy adhesive**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kG/h)	Ultimate peel stress (N/mm)
0	0	1.51
0.5	1	0.35
1	1	0.29
3	1	0.39

Critical property = ultimate peel stress
Radiation index (RI) ~ 5.0

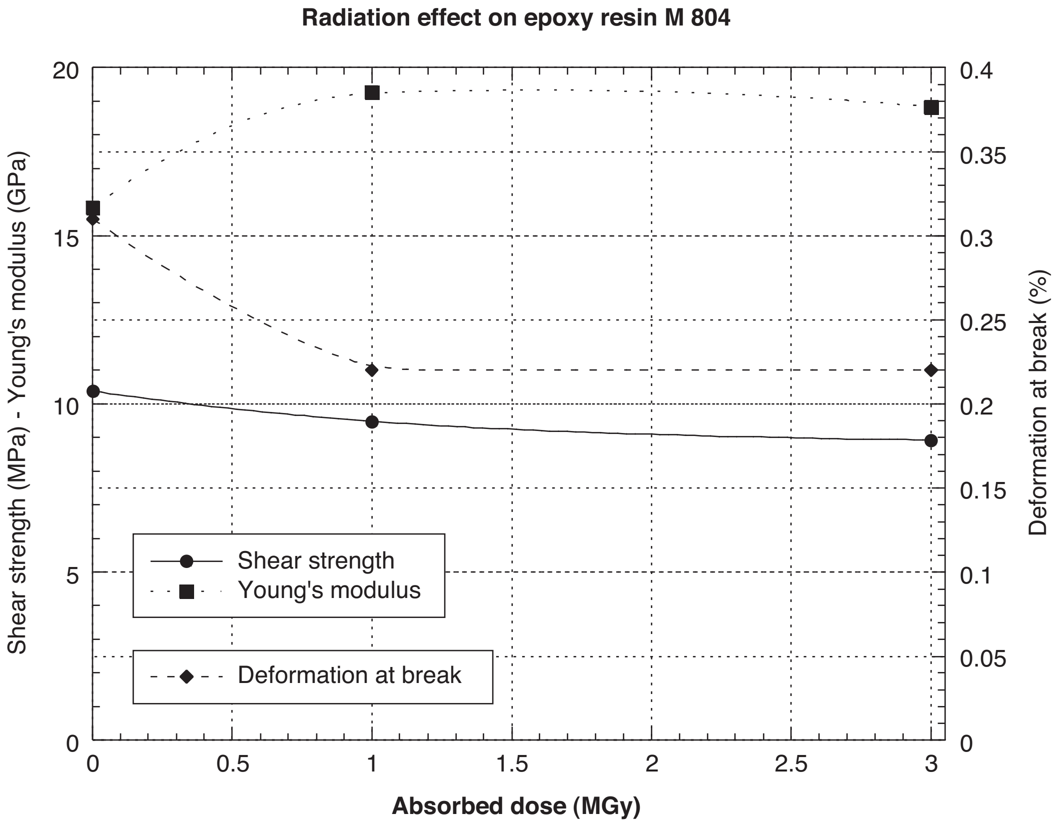


Material:	**Structural epoxy adhesive**	**ID No. M 804**
Type:	**Epoxy EA 9394**	
Supplier:	**Hysol**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**10.4** ± 0.6	**0.31** ± 0.06	**15.8** ± 1.0
1	**4**	**9.5** ± 0.3	**0.22** ± 0.02	**19.3** ± 0.4
3	**4**	**8.9** ± 0.3	**0.22** ± 0.03	**18.8** ± 0.3

Critical property = deformation at break
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h



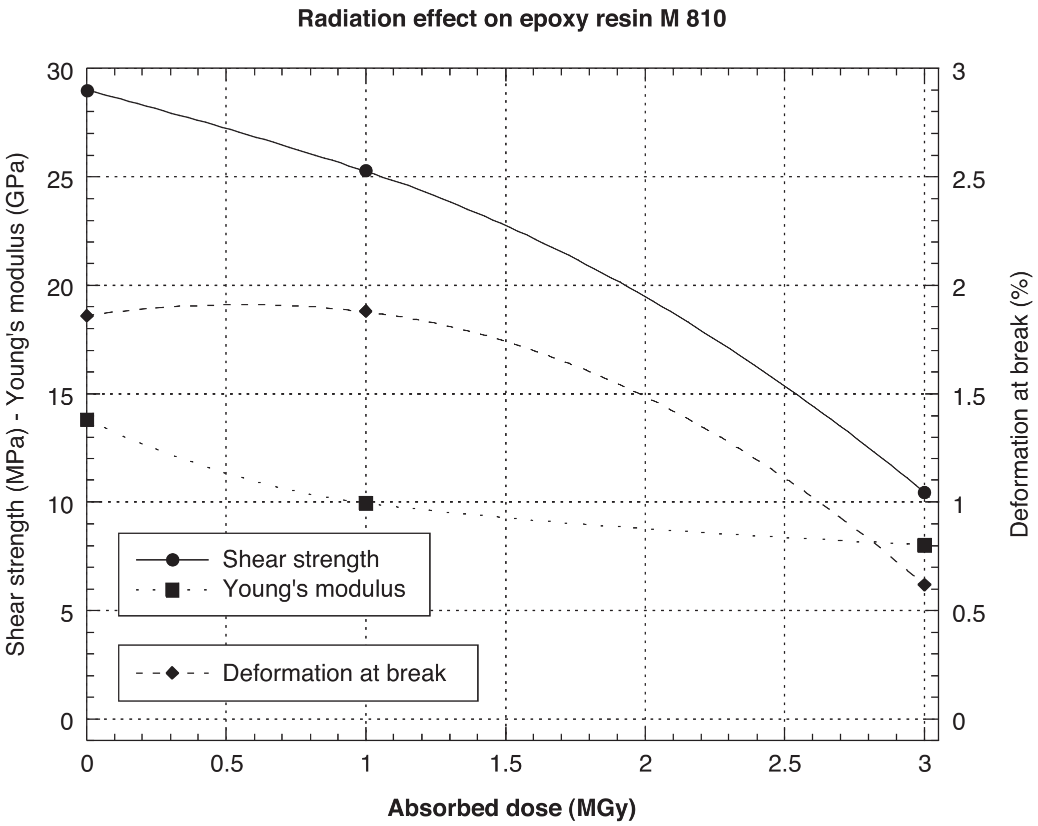
Material: **Structural epoxy adhesive** **ID No. M 810**
Type: **Epoxy 9323 B/A**

Supplier: **3M**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	**Dose rate (kGy/h)**	**Shear strength (MPa)**	**Deformation at break (%)**	**Young's modulus (GPa)**
0	**0**	**29.0** ± 1.2	**1.86** ± 0.11	**13.8** ± 1.5
1	**4**	**25.3** ± 2.2	**1.88** ± 0.16	**10.0** ± 0.9
3	**4**	**10.5** ± 0.9	**0.62** ± 0.08	**8.0** ± 0.6

Critical property = shear strength
Radiation index (RI) ~ 6.4 at a mean dose rate of 4 kGy/h

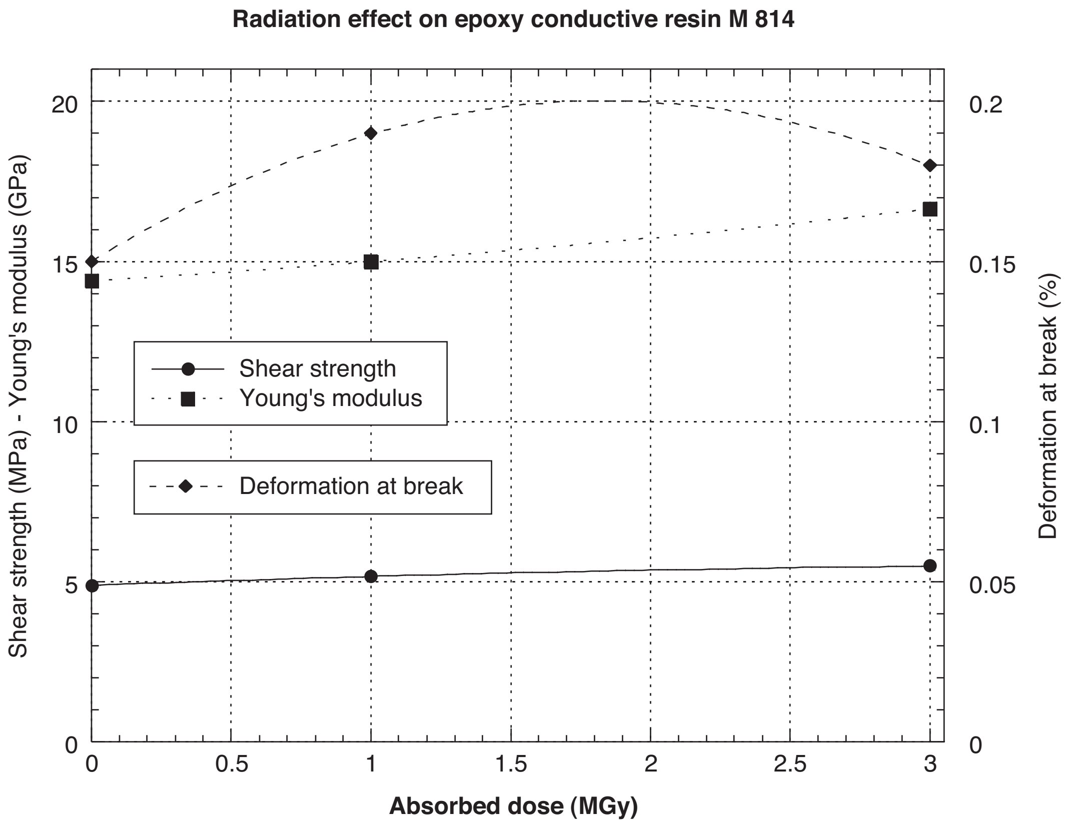


Material:	**Structural epoxy conductive adhesive**	**ID No. M 814**
Type:	**Epoxy 417**	
Supplier:	**Epotek**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**4.9** ± 2.3	**0.15** ± 0.05	**14.4** ± 8.1
1	**4**	**5.2** ± 0.6	**0.19** ± 0.04	**15.0** ± 5.2
3	**4**	**5.5** ± 1.1	**0.18** ± 0.04	**16.7** ± 5.5

Critical property = none
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h

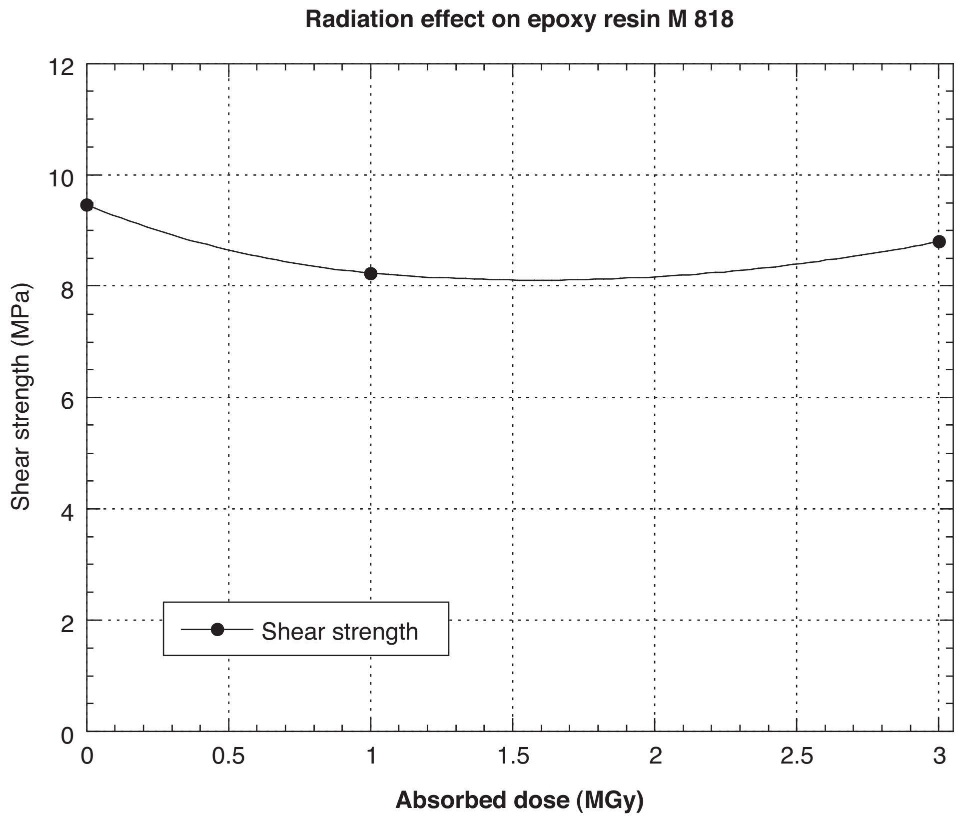


Material:	**Epoxy structural adhesive**	**ID No. M 818**
Type:	**Epoxy, type L**	
Supplier:	**R&G**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	**Dose rate (kGy/h)**	**Shear strength (MPa)**
0	**0**	**9.5** ± 0.6
1	**4**	**8.2** ± 0.5
3	**4**	**8.8** ± 1.3

Critical property = shear strength
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h

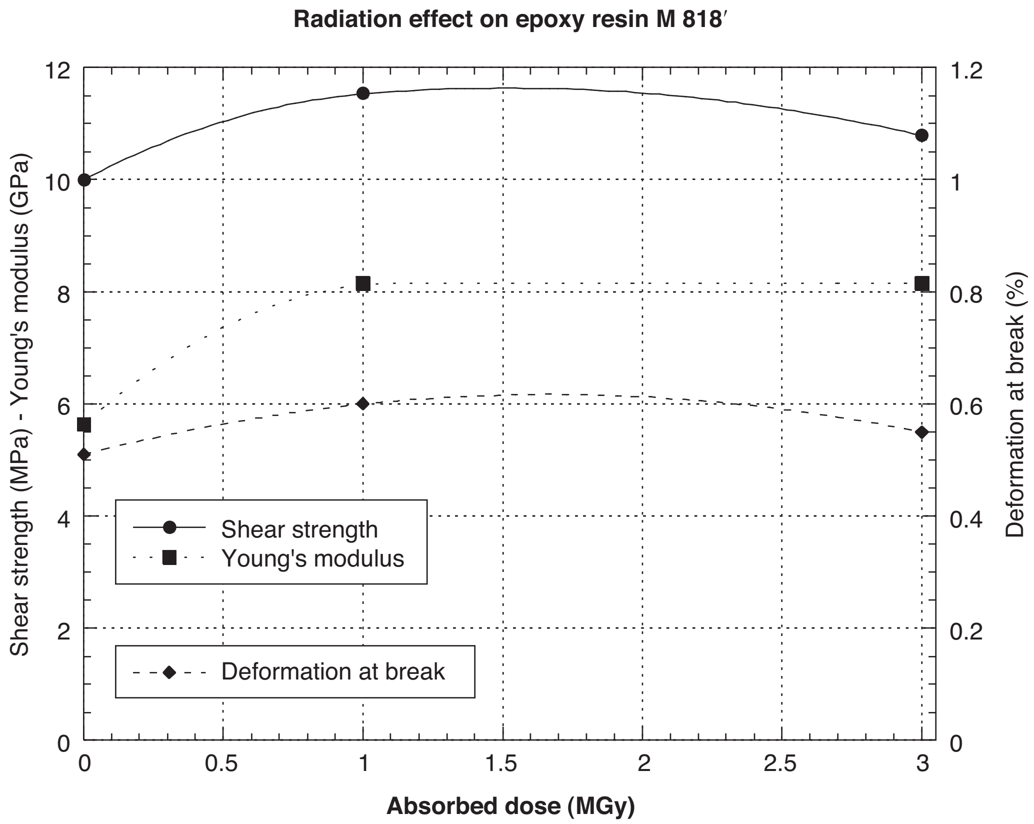


Material:	**Epoxy structural adhesive**	**ID No. M 818′**
Type:	**Epoxy, type L**	
Supplier:	**R&G**	

Test method:	**Shear test with Stesalite (fibreglass epoxy composite) samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**None**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**10.0** ± 0.6	**0.59** ± 0.15	**5.6** ± 3.3
1	**4**	**11.5** ± 0.3	**0.60** ± 0.06	**8.2** ± 0.9
3	**4**	**10.8** ± 0.4	**0.60** ± 0.08	**8.2** ± 1.8

Critical property = shear strength
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h



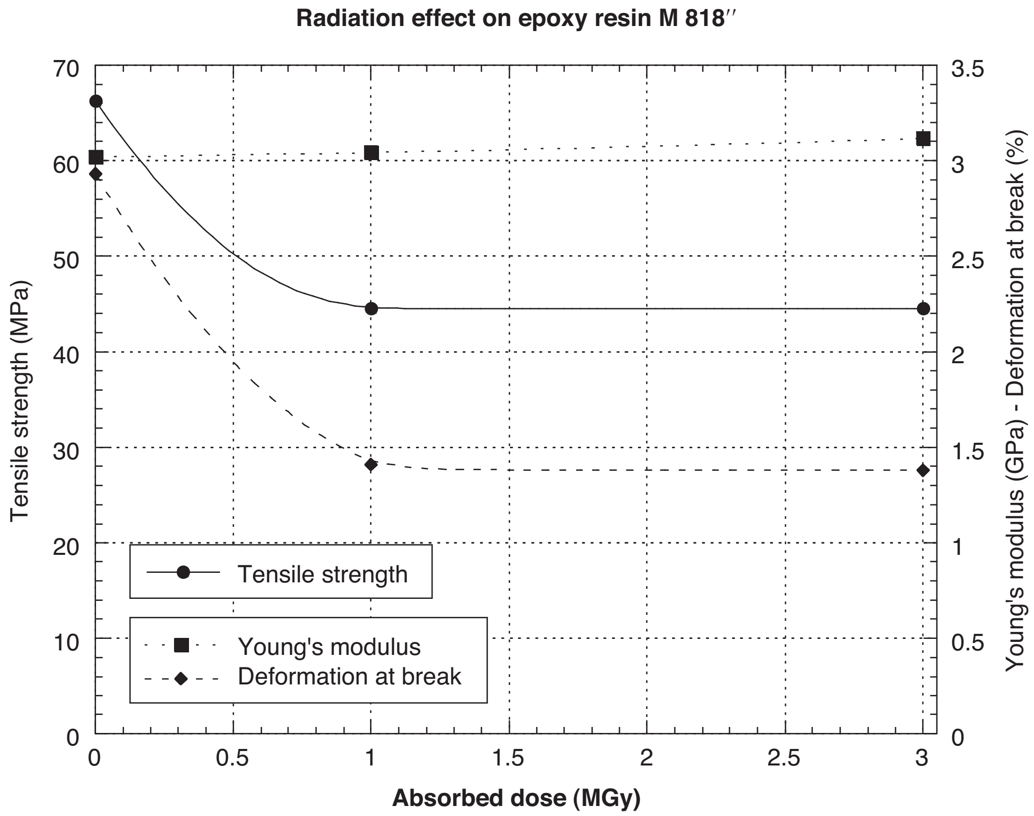
Material: **Epoxy structural adhesive** **ID No. M 818″**
Type: **Epoxy, type L**

Supplier: **R&G**

Test method: **Tensile test**
Sample geometry: **ISO R-527 – sample type 1**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Tensile strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**–**	**66.3** ± 17.2	**2.9** ± 1.4	**3** ± 0.0
1	**4**	**44.5** ± 4.20	**1.4** ± 0.1	**3** ± 0.4
3	**4**	**44.5** ± 10.9	**1.4** ± 0.3	**3** ± 0.3

Critical property = deformation at break
Radiation index (RI) ~ 6.0 at a mean dose rate of 4 kGy/h



APPENDIX 3

Alphabetic compilation of data
(Trade names in italics)

K

Commercial name	Base polymer	Supplier	Reference	R.I.
Katiobond 4553	Photo-polymeric adhesive	Delo	M 737	> 6.5

Material: Photo-polymeric structural adhesive **ID No. M 737**
Type: Katiobond 4553

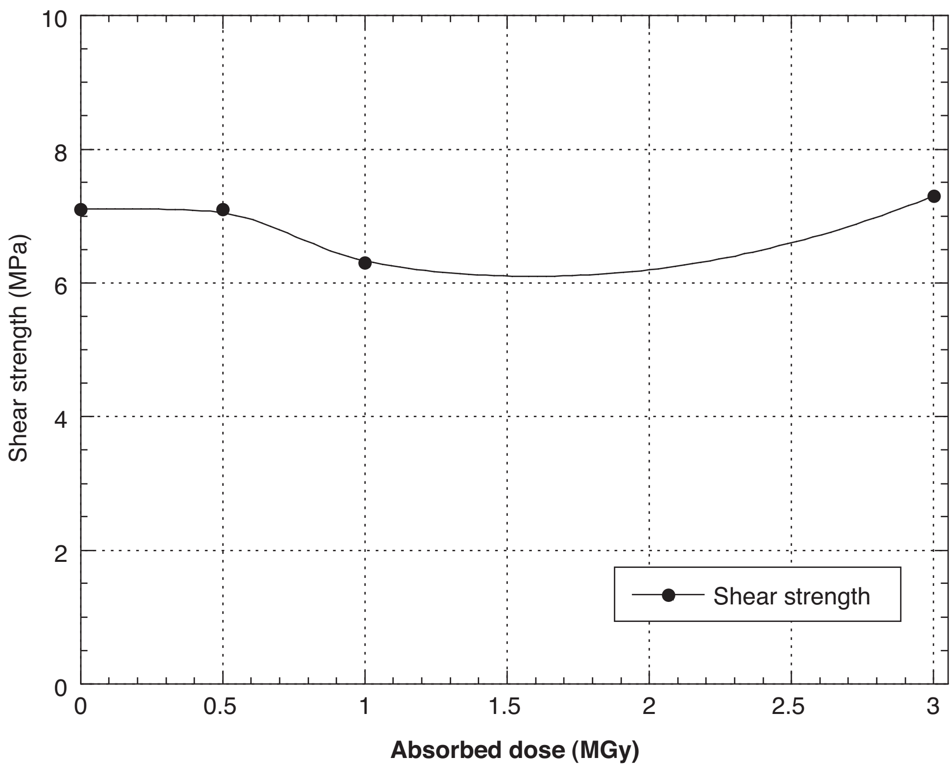
Supplier: Delo

Test method: Shear test with aluminium samples
Sample geometry: Equivalent to ASTM D 1876-93
Surface treatment: Sand blasting
Polymerization temperature: 25°C
Radiation source: Cobalt 60

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**7.1** ± 1.0
0.5	**4**	**7.1** ± 0.3
1	**4**	**6.3** ± 0.4
3	**4**	**7.3** ± 0.5

Critical property = shear strength
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h

Radiation effect on photo-polymeric adhesive M 737



APPENDIX 3

Alphabetic compilation of data

(Trade names in italics)

L

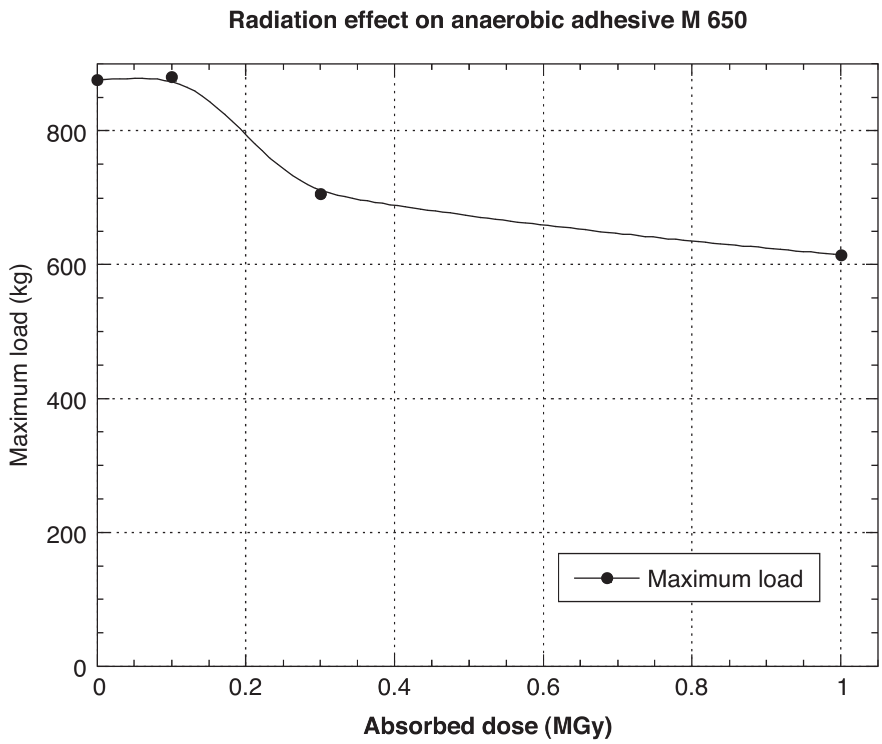
Commercial name	Base polymer	Supplier	Reference	R.I.
Loctite 638	Anaerobic adhesive	Lancashire Fittings	M 650	> 6.0

Material:	**Anaerobic adhesive**	**ID No. M 650**
Type:	**Loctite 638**	
Supplier:	**Lancashire Fittings**	

Test method:	**Two stainless steel tubes were stuck together to form a joint. Tensile tests were carried out on three sets of samples of three joints. The maximum load that each joint would support was recorded and an average of the readings taken for each sample was calculated.**
Sample geometry:	**Stainless steel tubes of about 15 mm in diameter were stuck together to form a lap joint.**
Surface treatment:	**None**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	**Maximum load (kg)**
0	**876**
0.1	**881**
0.3	**706**
1.0	**615**

Critical property = maximum load
Radiation index (RI) > 6.0



APPENDIX 3

Alphabetic compilation of data

(Trade names in italics)

N

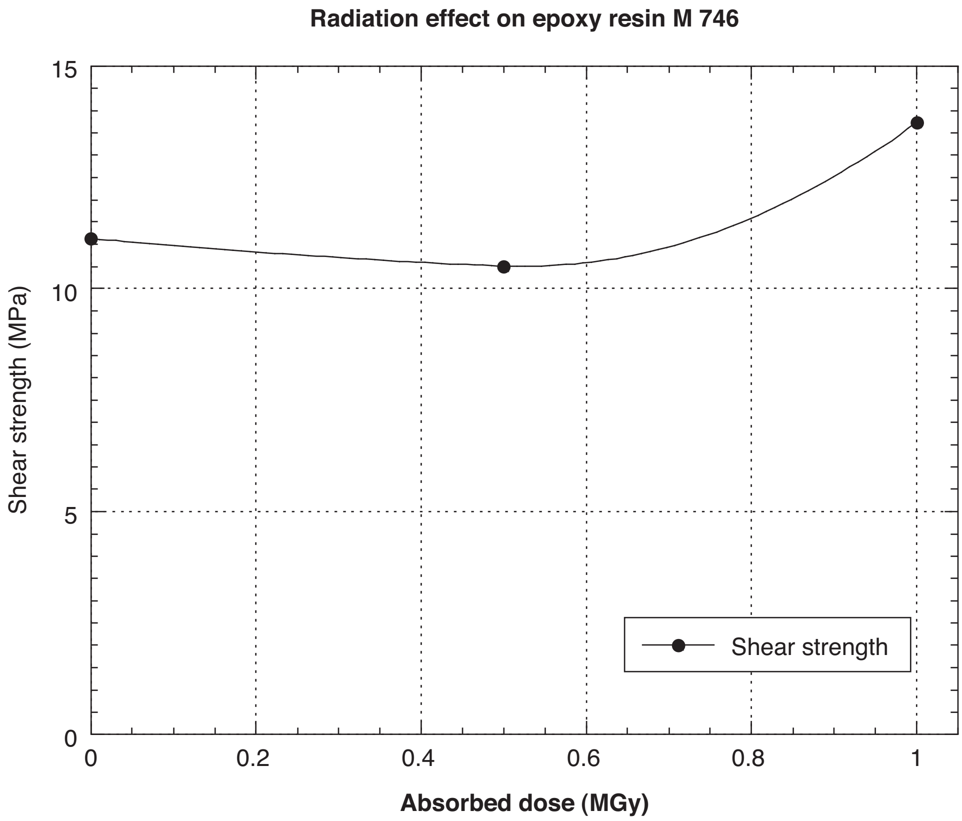
Commercial name	Base polymer	Supplier	Reference	R.I.
Norcast 5124	Epoxy resin	Norlabs	M 746	> 6.0

Material:	**Epoxy structural adhesive**	**ID No. M 746**
Type:	**Norcast 5124**	
Supplier:	**Norlabs**	

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**11.1** ± 2.0
0.5	**4**	**10.5** ± 1.5
1.0	**4**	**13.7** ± 0.8

Critical property = shear strength
Radiation index (RI) > 6.0 at a mean dose rate of 4 kGy/h



APPENDIX 3

Alphabetic compilation of data
(Trade names in italics)

P

Commercial name	Base polymer	Supplier	Reference	R.I.
Permacel P 290	PVC plastic tape	Permali	M 797-1	6.1
Permafix	Paper tape	Permali	M 797-2	4.8
Polyurethane AS 1029	Polyurethane (XL polyester)	GTS France	M 758	~ 6.4
Pronto	Cyanoacrylate adhesive	3M	M 811	~ 5.6

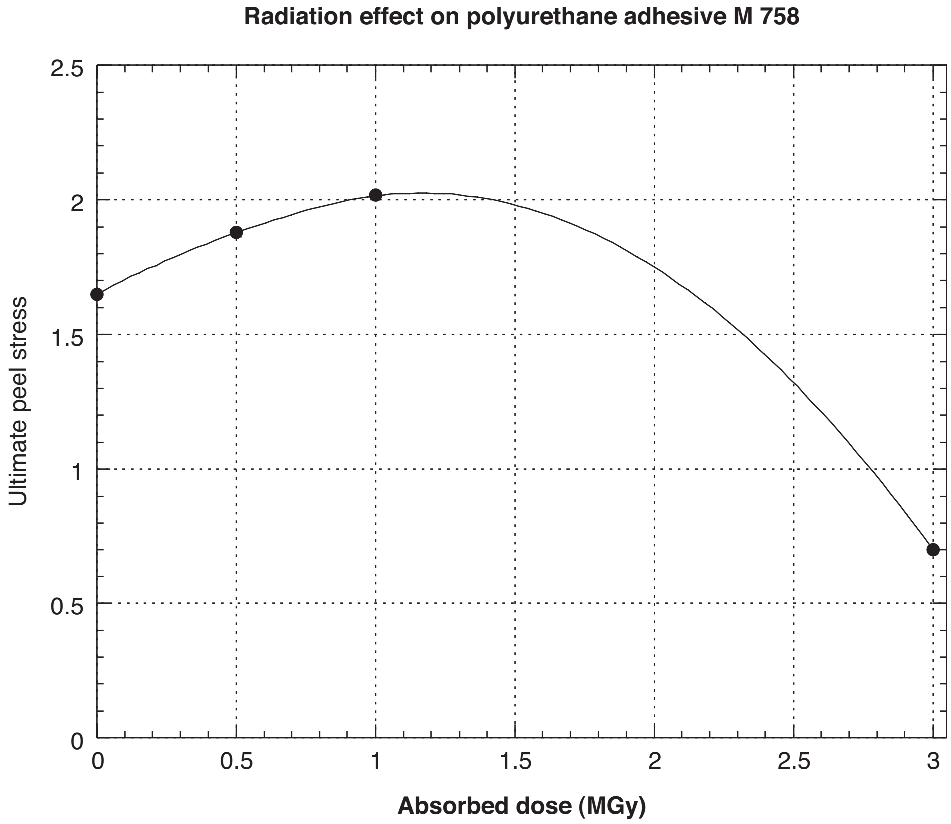
Material: **Polyurethane (XL polyester)** **ID No. M 758**
Type: **Polyurethane AS 1029**

Supplier: **GTS France**

Test method: **Peel test (IPC-650-2.4.9B)**
Description of samples: **Polyimide films (50 µm Kapton) glued on copper (35 µm) with polyurethane adhesive**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kG/h)	Ultimate peel stress (N/mm)
0	0	1.65
0.5	1	1.88
1	1	2.02
3	1	0.70

Critical property = ultimate peeling stress
Radiation index (RI) ~ 6.4



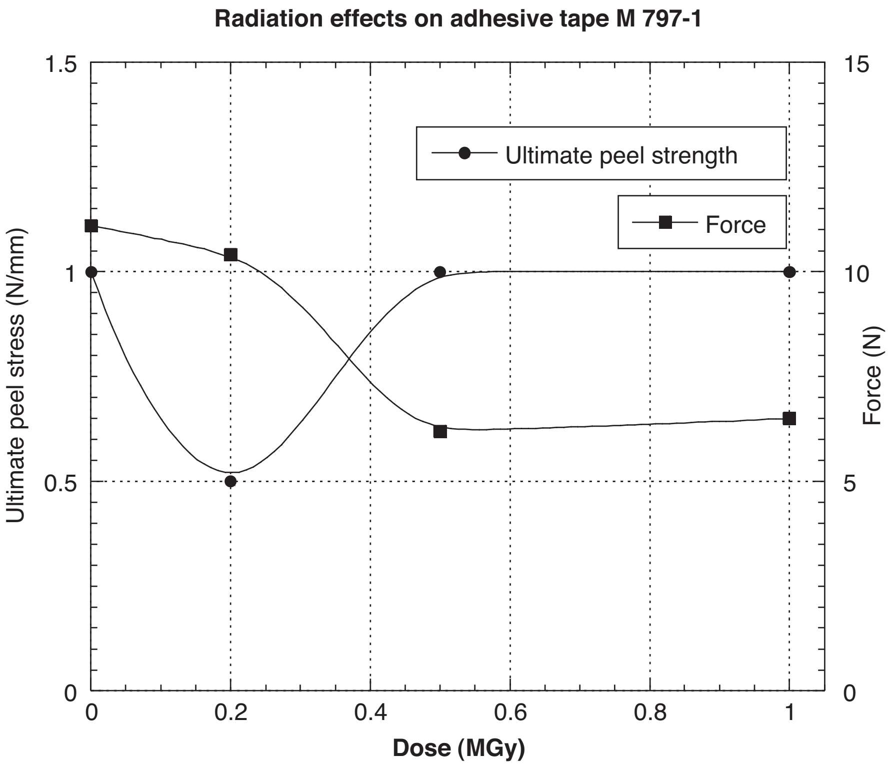
Material: **PVC plastic tape** **ID No. M 797-1**
Type: **Permacel P 290**

Supplier: **Permali**

Test method: **Peel test**
Sample geometry: **The tape was stuck on an aluminium plaque.**
The tape's width was 25 mm
Radiation source: **Cobalt 60; 1 kGy/h**
Remarks: **The peel strength shows the radiation resistance of the glue; the tensile force shows the radiation resistance of the tape itself (the support)**

Absorbed dose (MGy)	Ultimate peel stress (N/mm)	Force (N)
0	1.0	11.1
0.2	0.5	10.4
0.5	1.0	6.2
1	1.0	6.5

Critical property = force
Radiation index (RI) ~ 6.1



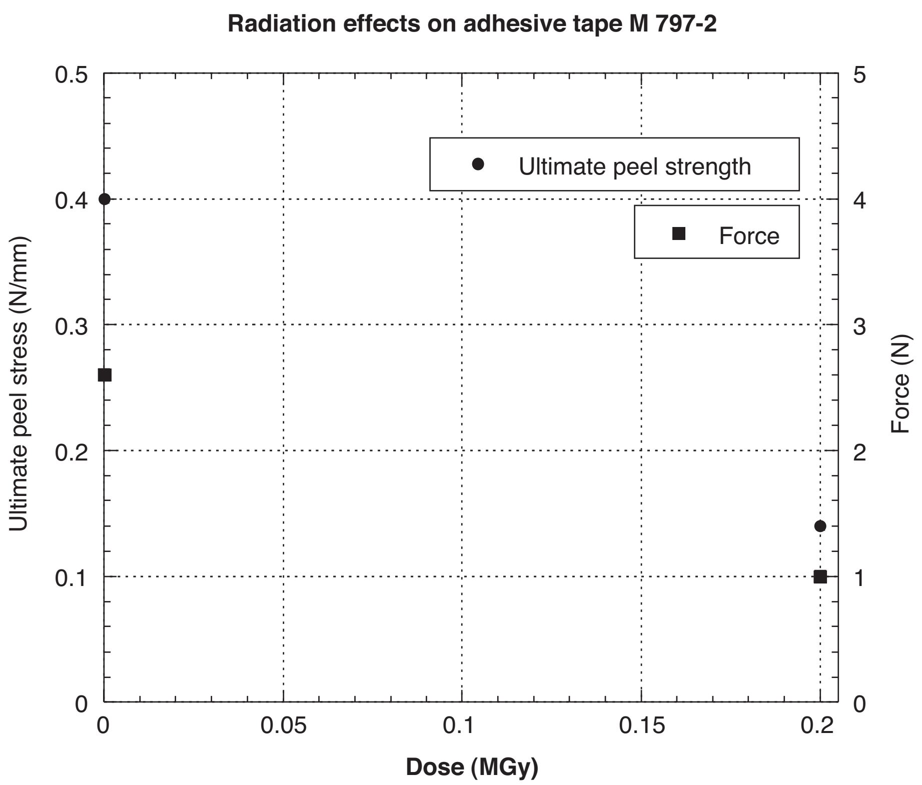
Material: **Adhesive paper tape** **ID No. M 797-2**
Type: **Permafix**

Supplier: **Permali**

Test method: **Peel test**
Sample geometry: **The tape was stuck on an aluminium plaque**
The tape's width was 24.5 mm
Radiation source: **Cobalt 60; 1 kGy/h**
Remarks: **The peel strength shows the radiation resistance of the glue; the tensile force shows the radiation resistance of the tape itself (the support)**

Absorbed dose (MGy)	Ultimate peel stress (N/mm)	Force (N)
0	0.40	2.6
0.2	0.14	1.0
0.5	Stuck	Degraded
1	Stuck	Degraded

Critical property = ultimate peel stress
Radiation index (RI) ~ 4.8



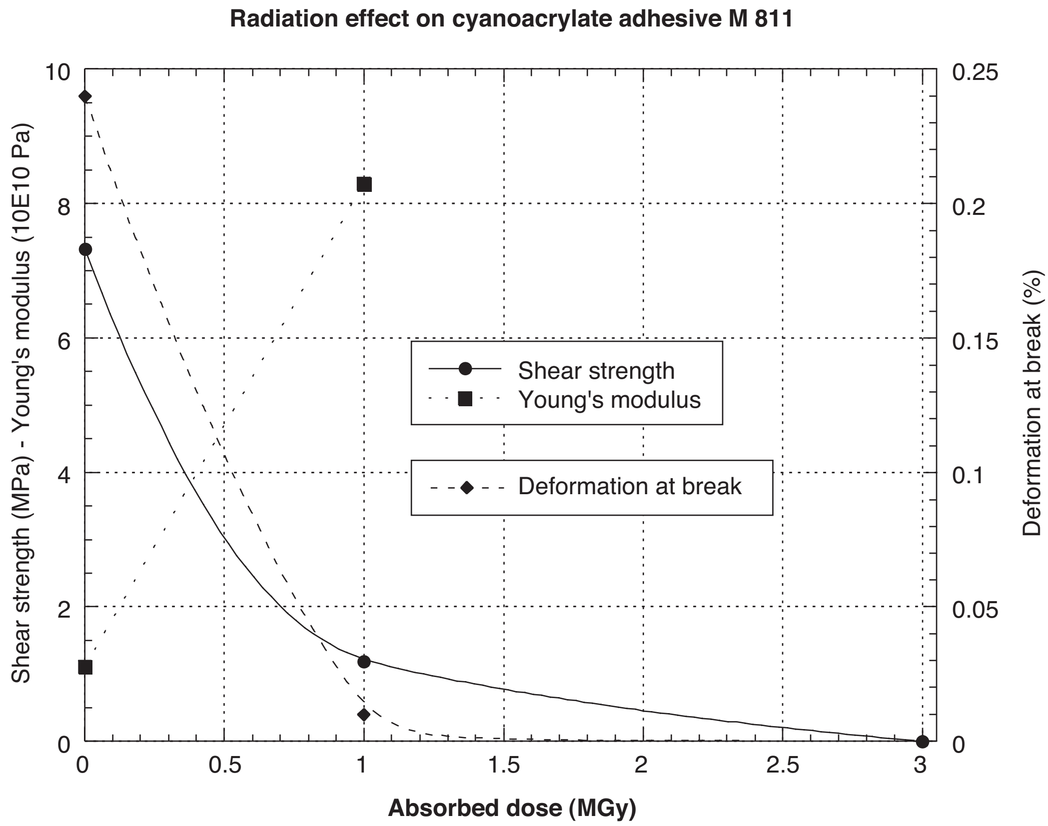
Material: **Cyanoacrylate adhesive** **ID No. M 811**
Type: **Pronto**

Supplier: **3M**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**7.3** ± 1.1	**0.24** ± 0.07	11.2 ± 1.9
1	**4**	**1.2** ± 0.0	**0.01** ± 0.00	83.3 ± 0.0
3	**4**	**0** ± 0.0	**0** ± 0.00	n.a.

Critical property = deformation at break
Radiation index (RI) ~ 5.0 at a mean dose rate of 4 kGy/h



APPENDIX 3

Alphabetic compilation of data
(Trade names in italics)

R

Commercial name	Base polymer	Supplier	Reference	R.I.
Rapida	Epoxy resin	Ciba-Geigy	see Araldite	
Redux 420	Epoxy resin	Ciba-Geigy*	see Araldite	
Rhodorsil CATV 4	Bi-silicone	Shell Aseol AG	M 762	> 6.9
Rhodorsil RTV 851	Mono-silicone	Shell Aseol AG	M 763	> 6.9
Rutapox L20 / *Rutadur* SL (100/34)	Epoxy resin	Bakelite	M 747	~ 6.3

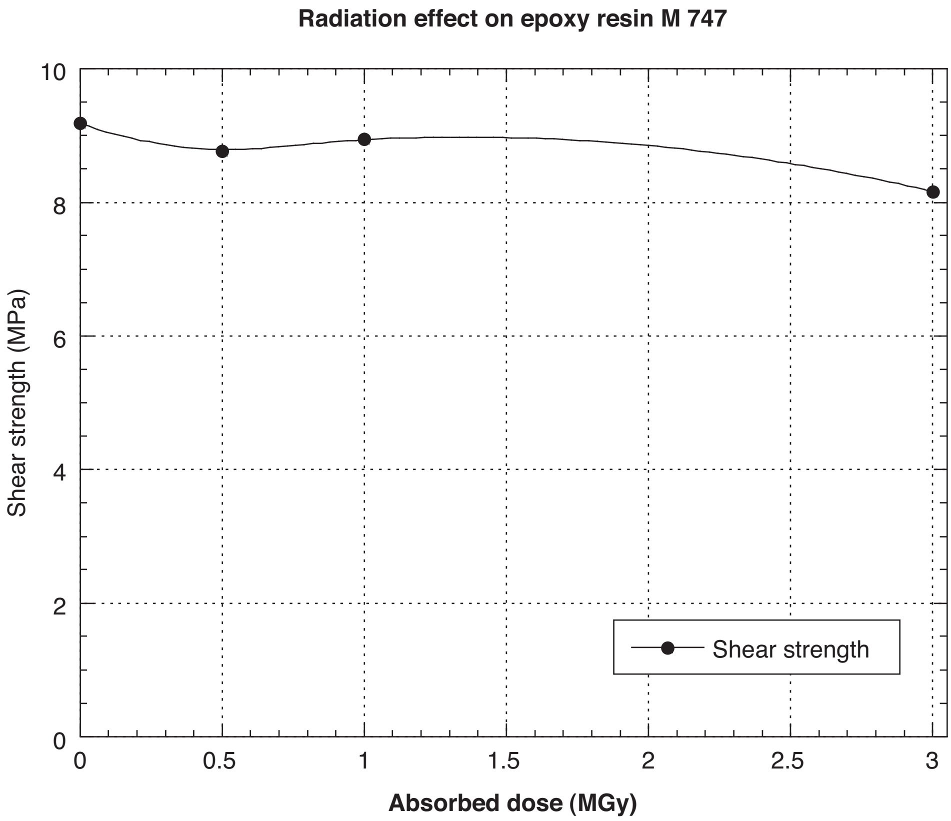
* Currently supplied by Hexcel

Material:	**Epoxy structural adhesive**	**ID No. M 747**
Type:	**Rutapox L20/Rutadur SL (100/34)**	
Supplier:	**Bakelite**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**9.2** ± 0.2
0.5	**4**	**8.8** ± 0.9
1	**4**	**8.9** ± 0.4
3	**4**	**8.2** ± 0.6

Critical property = shear strength
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h



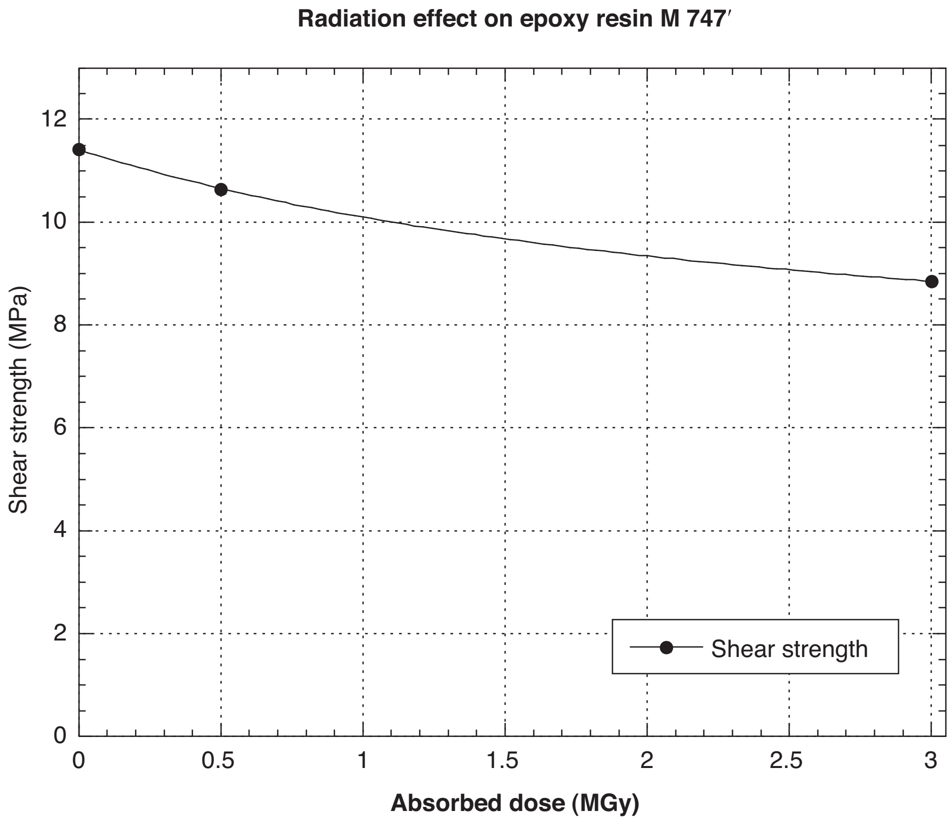
Material: **Epoxy structural adhesive** **ID No. M 747′**
Type: **Rutapox L20/Rutadur SL (100/34)**

Supplier: **Bakelite**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C; post-cured at 60°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**11.4** ± 1.6
1	**4**	**10.7** ± 2.9
3	**4**	**8.9** ± 0.2

Critical property = shear strength
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h



Comment: post-curing improves the initial properties, but not the properties after irradiation

Material: **Epoxy structural adhesive** **ID No. M 747″**
Type: **Rutapox L20/Rutadur SL (100/34)**

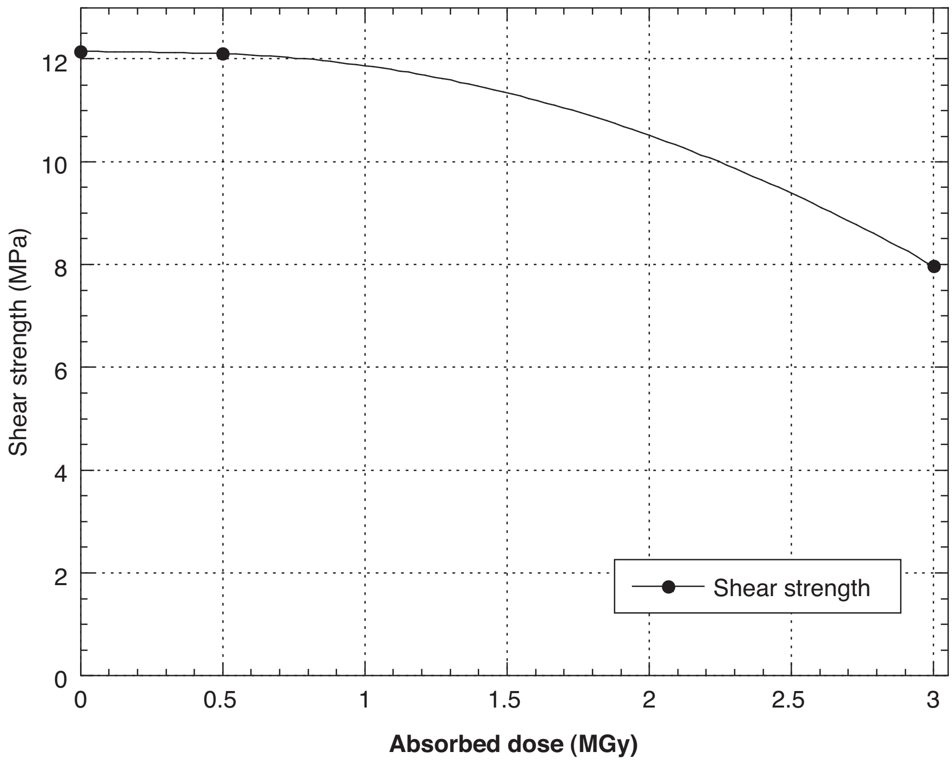
Supplier: **Bakelite**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C; post-cured at 80°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)
0	**0**	**12.2** ± 1.2
1	**4**	**12.1** ± 1.5
3	**4**	**8.0** ± 0.7

Critical property = shear strength
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h

Radiation effect on epoxy resin M 747″



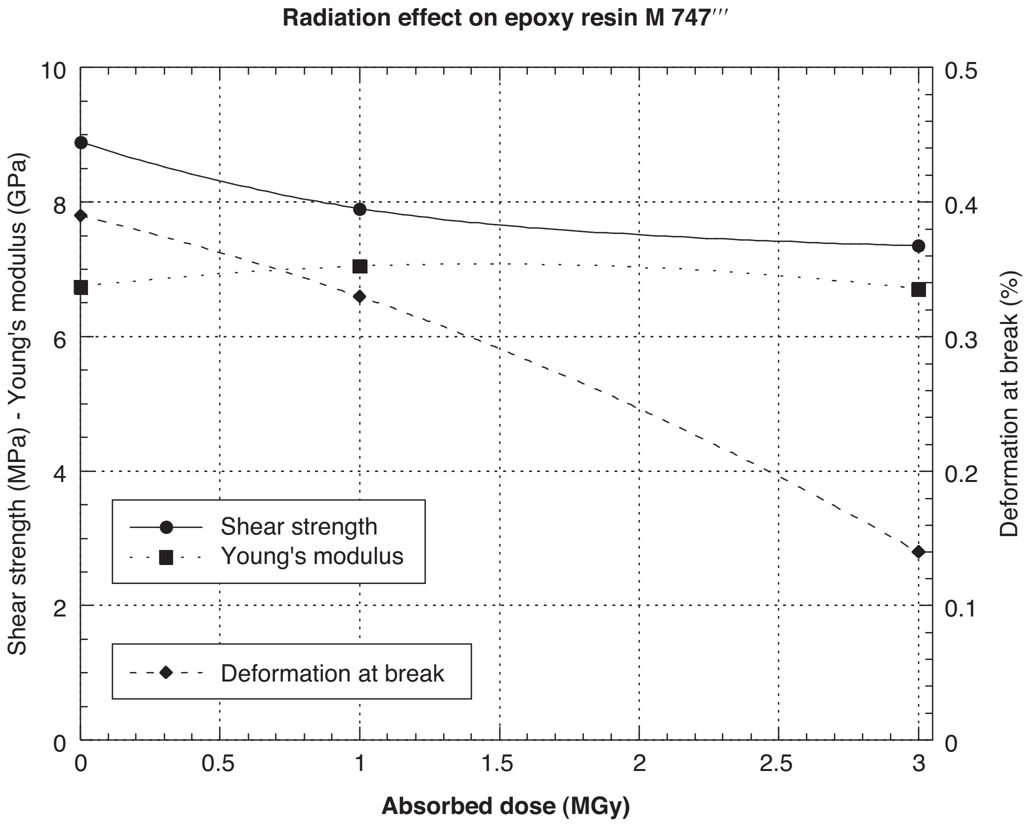
Comment: post-curing improves the initial properties, but not the properties after irradiation

Material:	**Epoxy structural adhesive**	**ID No. M 747‴**
Type:	**Rutapox L20/Rutadur SL (100/34)**	
Supplier:	**Bakelite**	

Test method:	**Shear test with Stesalite (fibreglass epoxy composite) samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**None**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**8.9** ± 1.1	**0.39** ± 0.11	**6.7** ± 1.4
1	**4**	**7.9** ± 1.9	**0.33** ± 0.18	**7.1** ± 1.5
3	**4**	**7.4** ± 1.5	**0.14** ± 0.09	**6.7** ± 0.5

Critical property = deformation at break
Radiation index (RI) ~ 6.3 at a mean dose rate of 4 kGy/h



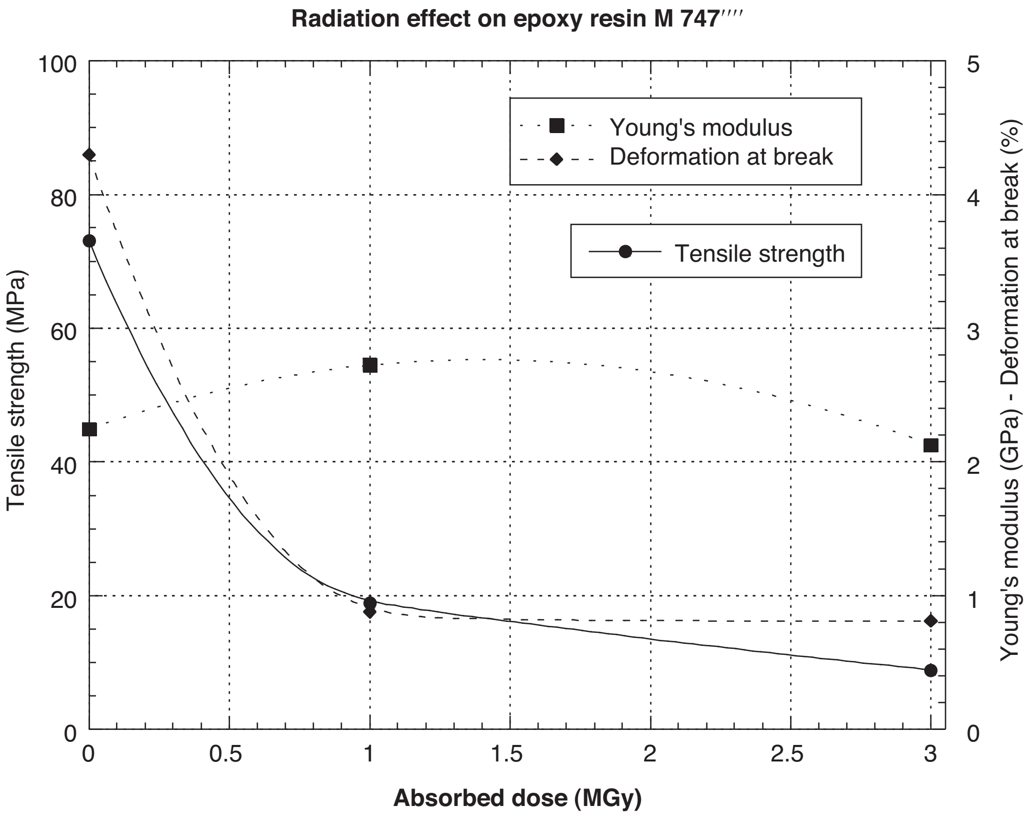
Material: **Epoxy structural adhesive** **ID No. M 747′′′′**
Type: **Rutapox L20/Rutadur SL (100/34)**

Supplier: **Bakelite**

Test method: **Tensile test**
Sample geometry: **ISO R-527 – sample type 1**
Polymerization temperature: **25°C; post-cured at 60°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Tensile strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**73.1** ± 1.1	**4.30** ± 1.51	**2.2** ± 0.2
1	**4**	**19.0** ± 0.2	**0.98** ± 0.23	**2.7** ± 0.5
3	**4**	**8.9** ± 0.8	**0.81** ± 0.69	**2.1** ± 0.4

Critical property = deformation at break
Radiation index (RI) ~ 5.6 at a mean dose rate of 4 kGy/h



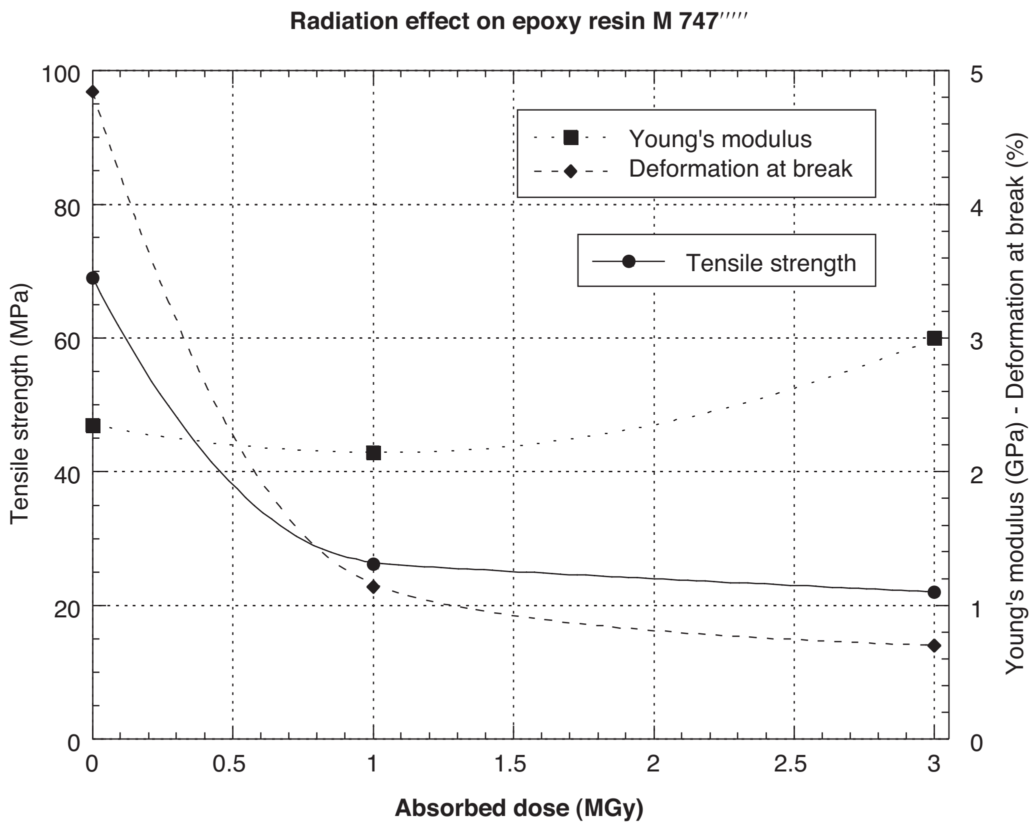
Material: **Epoxy structural adhesive** **ID No. M 747′′′′′**
Type: **Rutapox L20/Rutadur SL (100/34)**

Supplier: **Bakelite**

Test method: **Tensile test**
Sample geometry: **ISO R-527 – sample type 1**
Polymerization temperature: **25°C; post-cured at 80°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Tensile strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**69** ± 2.1	**4.84** ± 0.29	**2.4** ± 2.4
1	**4**	**26.2** ± 4.4	**1.14** ± 0.01	**4.4** ± 2.1
3	**4**	**22** ± 7.3	**0.7** ± 0.05	**7.3** ± 3

Critical property = deformation at break
Radiation index (RI) ~ 5.6 at a mean dose rate of 4 kGy/h

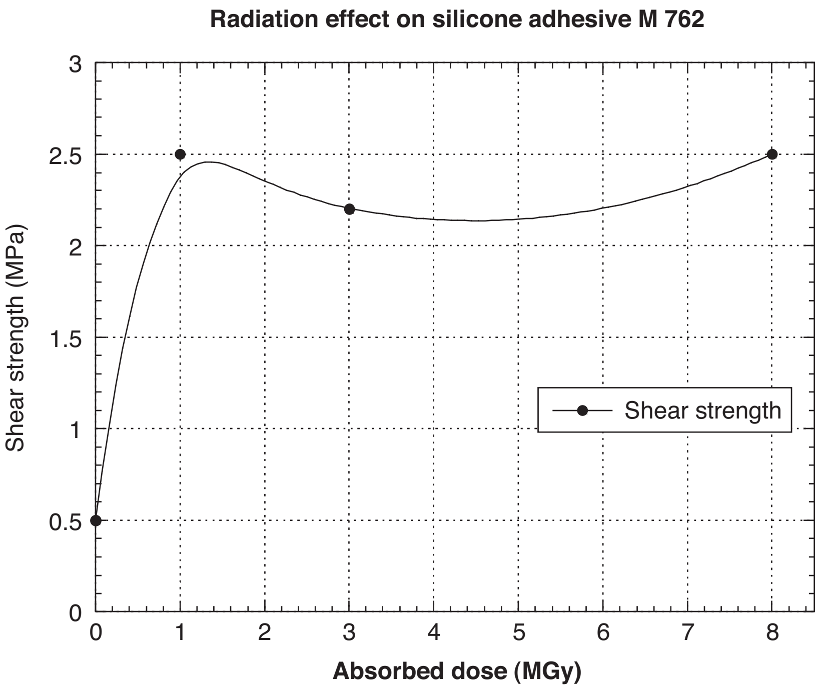


Material:	**One-component silicone glue**	**ID No. M 762**
Type:	**Rhodorsil CAF 4** **(Caoutchouc Auto-vulcanisant à Froid)**	
Supplier:	**Shell Aseol AG**	

Test method:	**Shear test**
Sample geometry:	**Plaques (10 × 3) cm of aluminium 1000 were glued together on a 3 cm^2 surface area**
Surface treatment:	**Sand blasting, cleaning with acetone**
Polymerization conditions:	**25°C, 2.5 N/cm^2 for 24 h**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Strength (MPa)
0	0.5
1	2.5
3	2.2
8	2.5

Critical property = only the shear strength was measured
Radiation index (RI) > 6.9



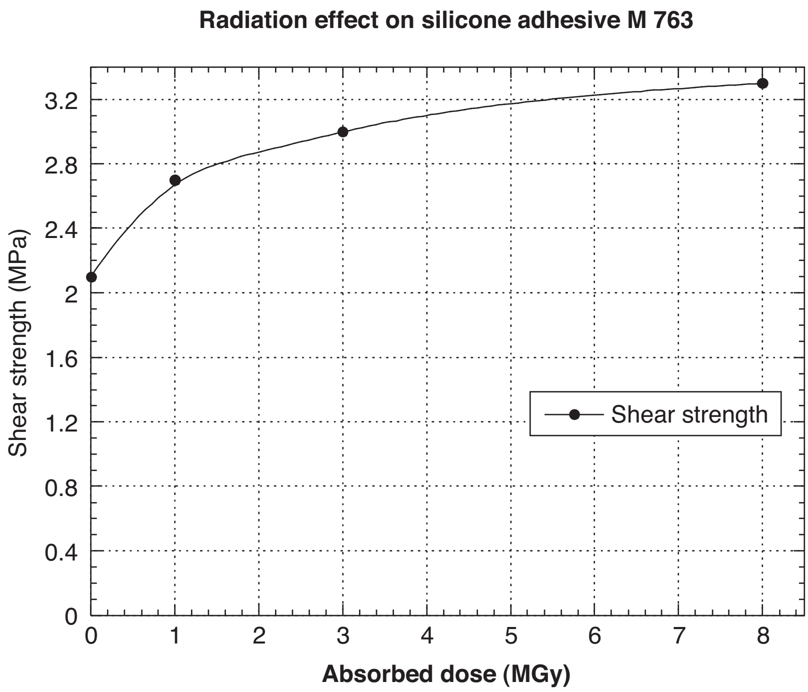
Comment: This joint is rather soft prior to irradiation. It becomes stiffer with radiation. If its flexibility or its resilience were the critical property for a given application, the limit of use would probably be below 1 MGy.

Material:	**Two-component silicone glue**	**ID No. M 763**
Type:	**Rhodorsil RTV 581**	
	(Room-Temperature Vulcanization)	
Supplier:	**Shell Aseol AG**	

Test method:	**Shear test**
Sample geometry:	**Plaques (10 × 3) cm of aluminium 1000 were glued together on a 3 cm^2 surface area**
Surface treatment:	**Sand blasting, cleaning with acetone**
Polymerization conditions:	**25°C, 1.0 N/cm^2 for 24 h**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	**Strength (MPa)**
0	**2.1**
1	**2.7**
3	**3.0**
8	**3.3**

Critical property = only the shear strength was measured
Radiation index (RI) > 6.9



Comment: This joint is rather soft prior to irradiation. It becomes stiffer with radiation. If its flexibility or its resilience were the critical property for a given application, the limit of use would probably be around a few MGy.

APPENDIX 3

Alphabetic compilation of data
(Trade names in italics)

S

Commercial name	Base polymer	Supplier	Reference	R.I.
Scotchcast 265	Epoxy resin	3M	M 498	~ 6.6
Scotch-Metal	Aluminium tape	3M	M 795	~ 5.3
DC 3140	Silicon resin	Dow Corning	M 827	> 5.3
DC 3145	Silicon resin	Dow Corning	M 828	~ 5.3
Silicone CATV 4	Mono-silicone	Shell Aseol AG	see Rhodorsil	
Silicone NEE 01	Silicon resin	Peltier	M 805 = M 829	~ 5.5
Silicone Q1 9226	Silicon resin	Down Corning	M 812	~ 5.6
Silicone RTV 851	Bi-silicone	Shell Aseol AG	see Rhodorsil	
Sikadur 31/N	Epoxy resin	Sika	M 738	> 5.7
Stycast 1266	Epoxy resin	Emerson & Cuming	M 748	~ 6.5
Stycast 2850FT + 24 LV (100/17)	Epoxy resin	Emerson & Cuming	M 725	> 6.5

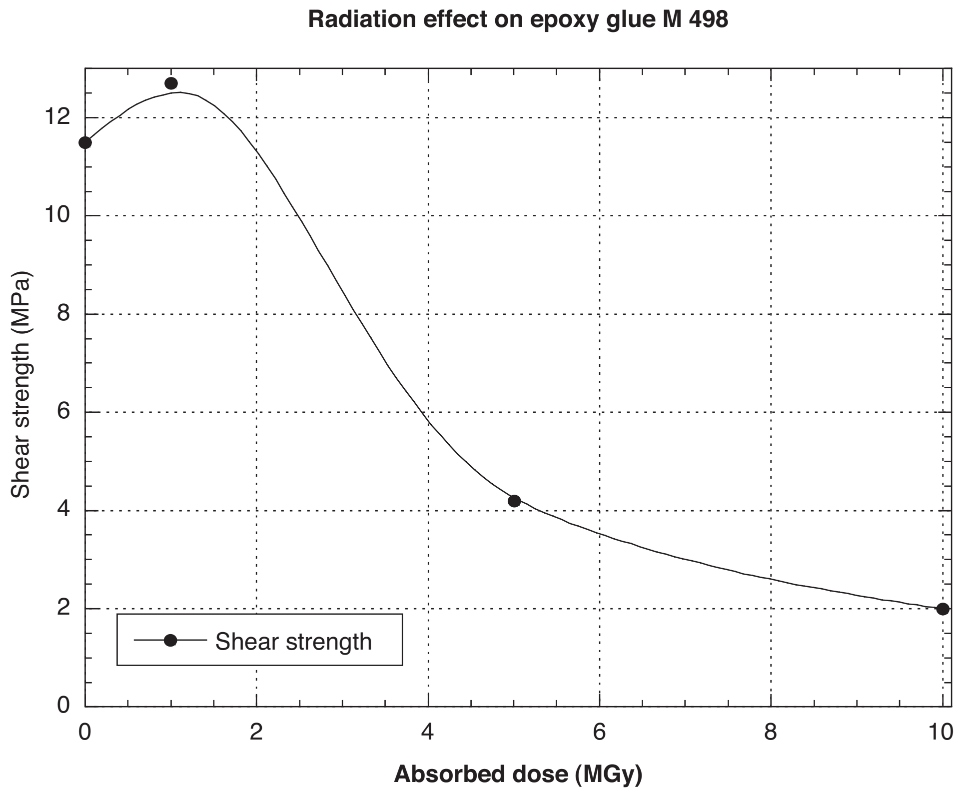
Material: **Epoxy glue** **ID No. M 498**
Type: **Scotchcast 265**

Supplier: **3M**

Test method: **Shear test with aluminium samples**
Sample geometry: **Two plates (10 × 1) cm were stuck together with a 1 cm^2 surface area**
Surface treatment: **None**
Polymerization temperature: **25°C**
Radiation source: **Switched-off reactor**

Absorbed dose (MGy)	**Ultimate strength (MPa)**
0	**11.5**
1	**12.7**
5	**4.2**
10	**2**

Critical property = ultimate strength
Radiation index (RI) ~ 6.6



References: LEP–MA/PB/rh (1986)

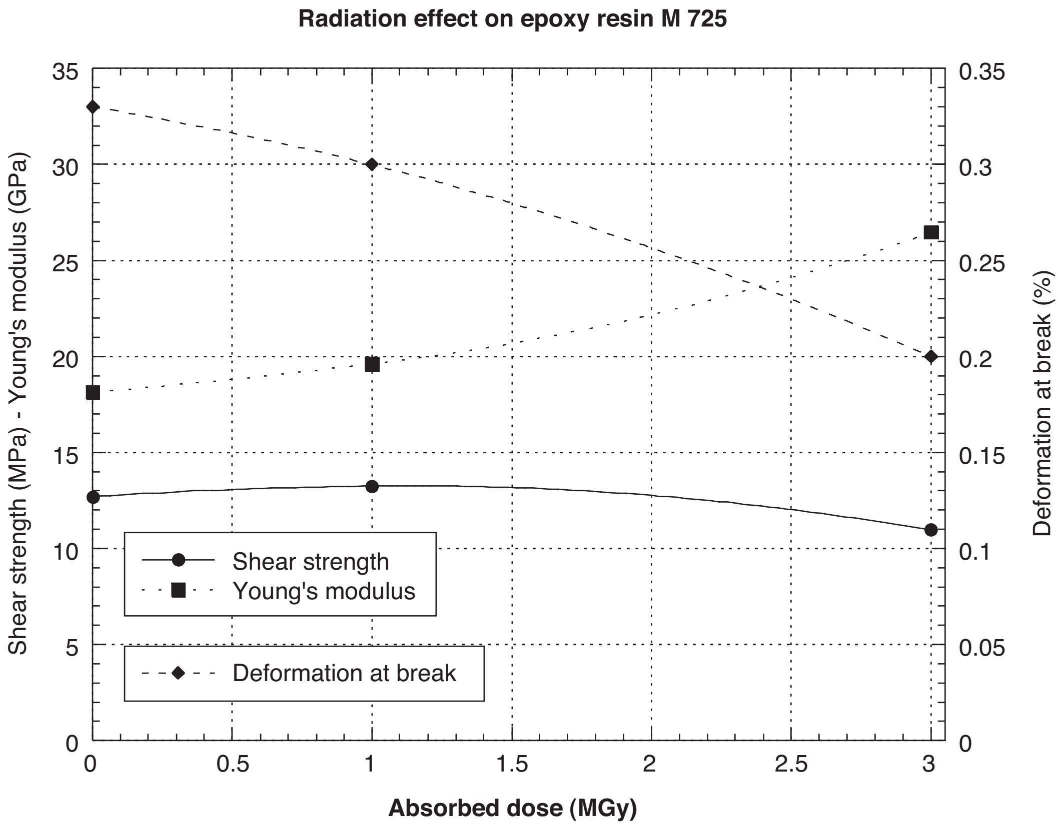
Material: **Structural epoxy adhesive** **ID No. M 725**
Type: **Stycast 2850FT + 24 LV (100/17)**

Supplier: **E&C**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**12.7** ± 0.2	**0.33** ± 0.04	**18.1** ± 2.0
1	**4**	**13.3** ± 0.4	**0.30** ± 0.01	**19.6** ± 2.3
3	**4**	**11.0** ± 0.4	**0.20** ± 0.03	**26.5** ± 2.8

Critical property = deformation at break
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h



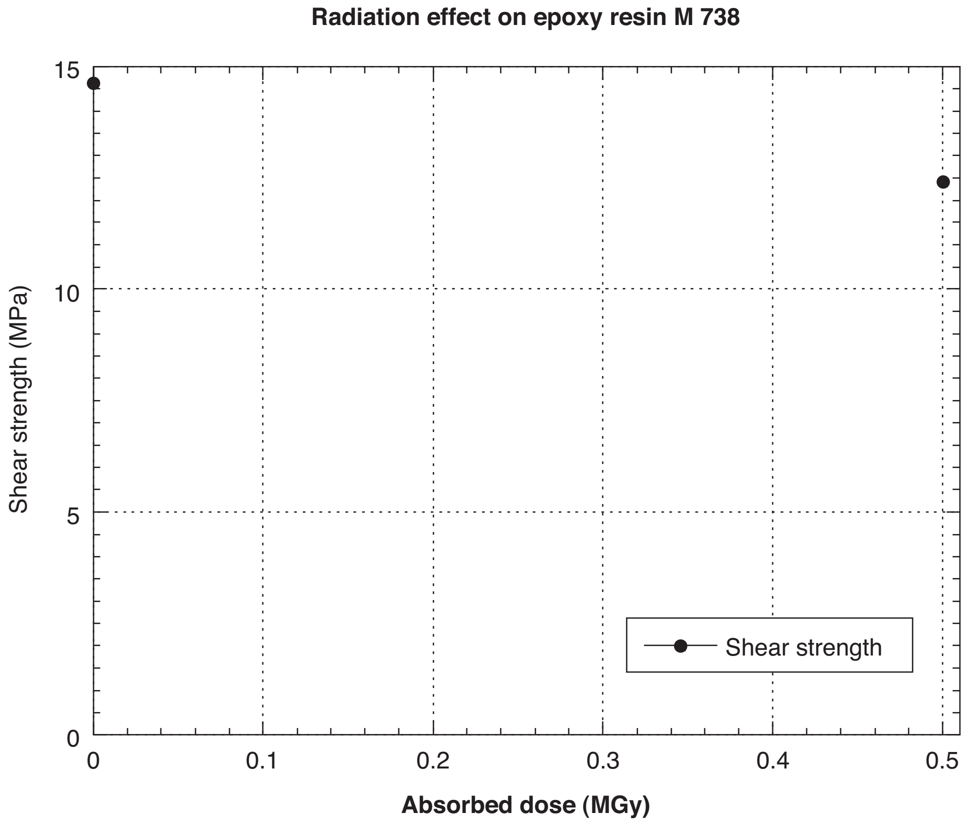
Material: **Epoxy structural adhesive** **ID No. M 738**
Type: **Sikadur 31N**

Supplier: **Sika**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Dose (MGy)	**Dose rate (kGy/h)**	**Shear strength (MPa)**
0	**0**	**14.6** ± 0.7
0.5	**4**	**12.4** ± 0.6

Critical property = shear strength
Radiation index (RI) > 5.7 at a mean dose rate of 4 kGy/h



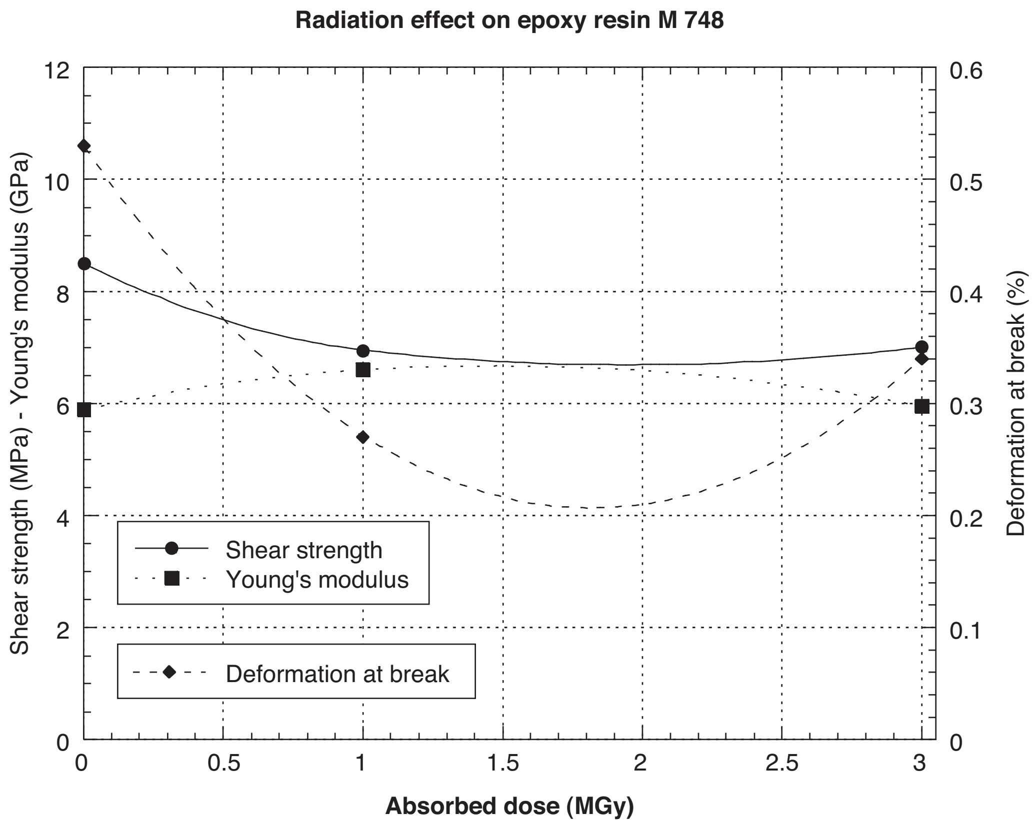
Material: **Epoxy structural adhesive** **ID No. M 748**
Type: **Stycast 1266**

Supplier: **E&C**

Test method: **Shear test with Stesalite (fibreglass epoxy composite) samples**
Equivalent to ASTM D 1876-93
Sample geometry: **None**
Surface treatment: **25°C**
Polymerization temperature: **Cobalt 60**
Radiation source:

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**8.5** ± 2.0	**0.53** ± 0.16	**6.0** ± 1.3
1	**4**	**7.0** ± 1.4	**0.27** ± 0.12	**6.6** ± 2.2
3	**4**	**7.0** ± 2.7	**0.34** ± 0.16	**6.0** ± 0.7

Critical property = deformation at break
Radiation index (RI) ~ 6.5 at a mean dose rate of 4 kGy/h

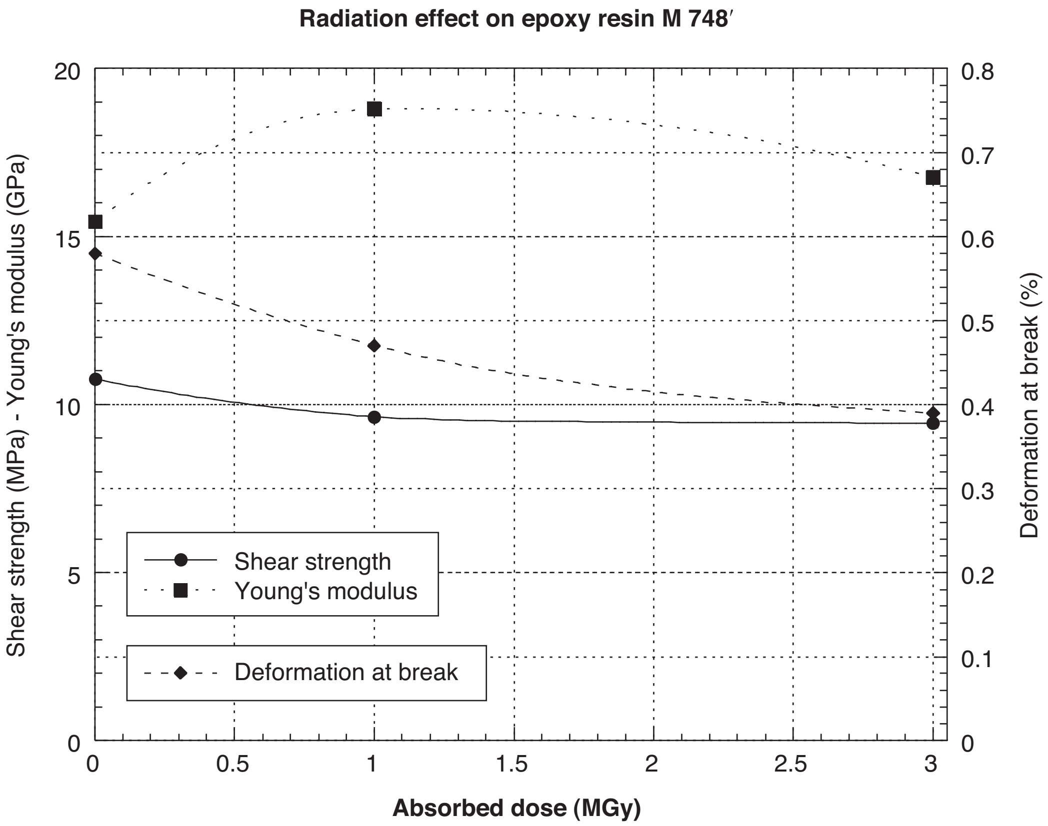


Material:	**Structural epoxy adhesive**	**ID No. M 748′**
Type:	**Stycast 1266**	
Supplier:	**E&C**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**10.8** ± 0.8	**0.58** ± 0.10	**15.5** ± 1.8
1	**4**	**9.6** ± 0.5	**0.47** ± 0.07	**18.8** ± 4.5
3	**4**	**9.5** ± 1.1	**0.39** ± 0.06	**26.8** ± 1.9

Critical property = deformation at break
Radiation index (RI) > 6.5 at a mean dose rate of 4 kGy/h



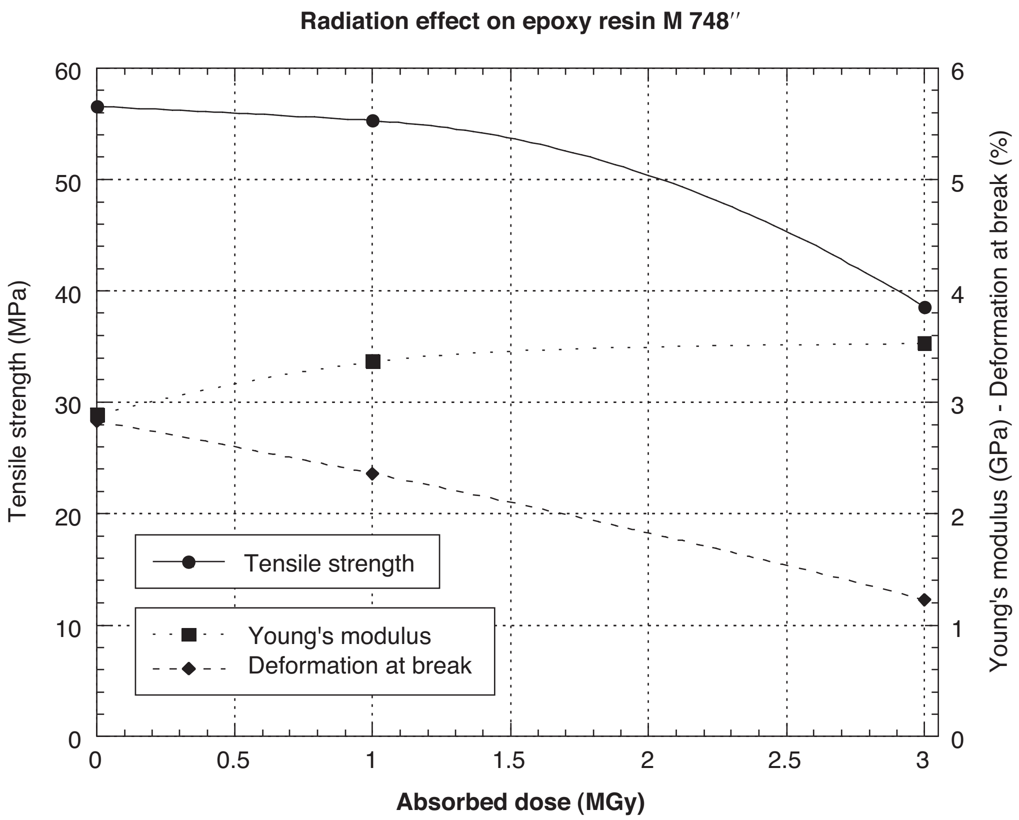
Material: **Epoxy structural adhesive** **ID No. M 748″**
Type: **Stycast 1266**

Supplier: **E&C**

Test method: **Tensile test**
Sample geometry: **ISO R-527 – sample type 1**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Tensile strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**56.6** ± 4.4	**2.83** ± 0.58	**2.9** ± 0.1
1	**4**	**55.3** ± 15.9	**2.36** ± 1.17	**3.4** ± 0.3
3	**4**	**38.6** ± 5.9	**1.23** ± 0.21	**3.5** ± 0.3

Critical property = deformation at break
Radiation index (RI) = 6.4 at a mean dose rate of 4 kGy/h

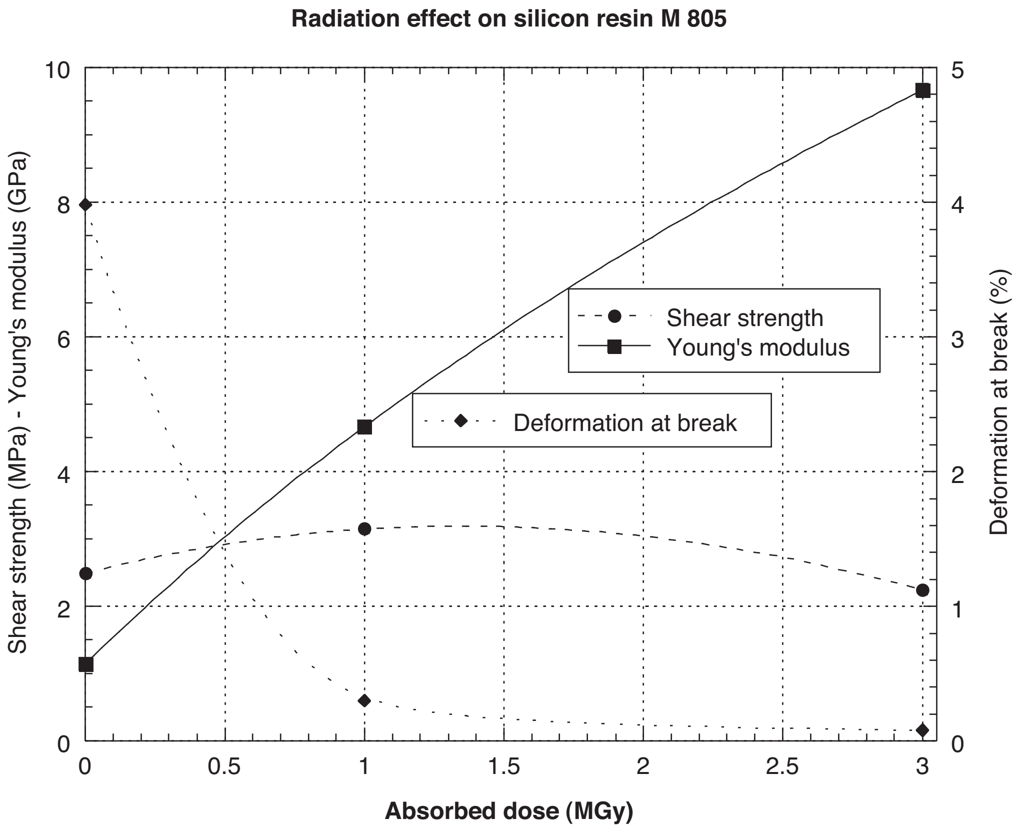


Material:	**Silicon adhesive**	**ID No. M 805**
Type:	**Silicone NEE 01**	
		(= M 829)
Supplier:	**Peltier**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**2.5** ± 0.2	**5.0** ± 0.6	**1.2** ± 0.4
1	**4**	**3.2** ± 0.3	**0.3** ± 0.02	**4.7** ± 1.0
3	**4**	**2.2** ± 0.1	**0.1** ± 0.0	**9.7** ± 3.6

Critical property = deformation at break
Radiation index (RI) ~ 5.5 at a mean dose rate of 4 kGy/h



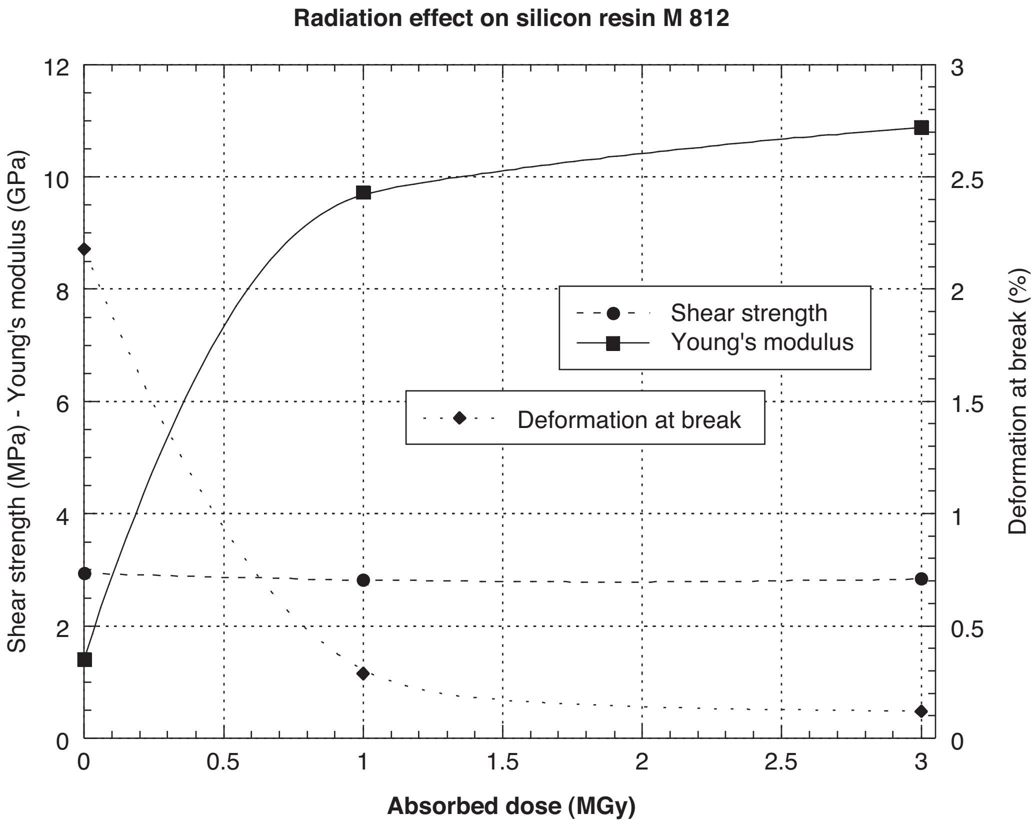
Material: **Silicon adhesive** **ID No. M 812**
Type: **Silicone Q1 9226**

Supplier: **Down Corning**

Test method: **Shear test with aluminium samples**
Sample geometry: **Equivalent to ASTM D 1876-93**
Surface treatment: **Sand blasting**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**2.94** ± 0.53	**2.18** ± 0.39	**1.4** ± 0.4
1	**4**	**2.82** ± 0.73	**0.29** ± 0.21	**9.7** ± 2.8
3	**4**	**2.84** ± 0.44	**0.12** ± 0.04	**10.9** ± 2.4

Critical property = deformation at break
Radiation index (RI) ~ 5.6 at a mean dose rate of 4 kGy/h



Material: **Silicon adhesive** **ID No. M 827**
Type: **Silicone DC 3140**

Supplier: **Dow Corning**

Sample preparation and test method: **Carbon fibre samples were prepared by machining from honeycomb disk, and cleaned using MEK/Kleenex and isopropyl alcohol (dimensions: 0.5 × 25 × 40).**
Araldite 2011 epoxy adhesive produced by Ciba-Geigy was first applied using a paper tape thickness gauge. A Kapton film (9×) was placed between the Araldite and the silicon glue.
Then the aluminium foil 0.15 mm × 25 mm wide was applied and immobilized with tape.
During polymerization the samples were left on a cast iron bench, and a 1N/cm^2 load was applied.

Polymerization temperature: **22°C**

ID	Absorbed dose (MGy)	Max. tensile F Rm (N)	Max. tensile/mm^2 Rm (MPa)	Elongation at failure L Ar (mm)
A1	0	350	0.8	0.9
A2	0	660	1.5	0.7
A3	0.2	540	1.4	0.4
A4	0.2	470	1.1	0.3
A5	0.2	760	1.7	0.5

Critical property = Max. tensile/mm^2
Radiation index (RI) > 5.3

Comments: All samples failed from the silicon glue/ Al interface, except the A2 sample which failed from the silicon glue/Kapton interface.

Material: **Silicon adhesive** **ID No. M 828**
Type: **Silicone DC 3145**

Supplier: **Dow Corning**

Sample preparation and test method: **Carbon fibre samples were prepared by machining from honeycomb disk, and cleaned using MEK/Kleenex and isopropyl alcohol (dimensions: 0.5 × 25 × 40).**
Araldite 2011 epoxy adhesive produced by Ciba-Geigy was first applied using a paper tape thickness gauge. A Kapton film (9×) was placed between the Araldite and the silicon glue.
Then the aluminium foil 0.15 mm × 25 mm wide was applied and immobilized with tape.
During polymerization the samples were left on a cast iron bench, and a 1N/cm^2 load was applied.

Polymerization temperature: **22°C**

ID	Absorbed dose (MGy)	Max. tensile F Rm (N)	Max. tensile/mm^2 Rm (MPa)	Elongation at failure L Ar (mm)
B1	0	700	2.5	1.5
B2	0	1160	3.4	1.4
B3	0.2	330	1.5	0.5
B4	0.2	320	1.6	0.3
B5	0.2	330	1.5	0.4

Critical property = Max. tensile/mm^2
Radiation index (RI) ~ 5.3

Comments: All the samples failed at the silicon glue/Kapton interface.

Material:	**Silicon adhesive**	**ID No. M 829**
Type:	**Silicone NEE 01**	
		(= M 805)
Supplier:	**Peltier**	

Sample preparation and test method:	**Carbon fibre samples were prepared by machining from honeycomb disk, and cleaned using MEK/Kleenex and isopropyl alcohol (dimensions: 0.5 × 25 × 40).** **Araldite 2011 epoxy adhesive produced by Ciba-Geigy was first applied using a paper tape thickness gauge. A Kapton film (9×) was placed between the Araldite and the silicon glue.** **Then the aluminium foil 0.15 mm × 25 mm wide was applied and immobilized with tape.** **During polymerization the samples were left on a cast iron bench, and a 1N/cm^2 load was applied.**
Polymerization temperature:	**22°C**

ID	Absorbed dose (MGy)	Max. tensile F Rm (N)	Max. tensile/mm^2 Rm (MPa)	Elongation at failure L Ar (mm)
C3	0	220	1.0	0.9
C1	0	430	1.9	1.1
C2	0.2	400	2.0	0.7
C4	0.2	690	2.7	1.1

Critical property = Max. tensile/mm^2
Radiation index (RI) > 5.3

Comments: The C3 sample failed by ungluing from the Kapton; all the others failed by ungluing equally from the Kapton and the aluminium

APPENDIX 3

Alphabetic compilation of data
(Trade names in italics)

T

Commercial name	Base polymer	Supplier	Reference	R.I.
Coroplast 302	PVC adhesive tape	3M	M 796	5.7
Permacel P 290	PVC plastic tape	Permali	see Permacel	
Permafix	Paper tape	Permali	see Permafix	
Scotch-Metal	Aluminium tape	3M	M 795	~ 5.3
Tape 4616	Adhesive tape 4616	Von Roll Isola	M 781-1	> 6.3
Tape 4617	Adhesive tape 4617	Von Roll Isola	M 781-2	~ 6.0
Tape 4618	Adhesive tape 4618	Von Roll Isola	M 781-3	< 6.0
Tape 4560	Adhesive tape 4560	Von Roll Isola	M 781-4	~ 6.0
Tape 4562	Adhesive tape 4562	Von Roll Isola	M 781-5	~ 6.1
TesaBand 4651	Plastic tape + cotton	Tesa	M 794-3	~ 5.2
TesaMetal 500	Plastic tape + aluminium	Tesa	M 794-2	~ 5.7
TesaPack 4579	Plastic tape + glass fibres	Tesa	M 794-1	< 5.3
Thermoguss 2000	Metal-ceramic	Kleiberit	M 476	> 7.0
TRA BOND 2115	Epoxy resin	Tracon	M 807	> 6.6
TRA BOND 2151	Epoxy resin	Tracon	M 809	~ 6.6
TRA DUCT 1922	Conductive epoxy resin	Tracon	M 806	~ 6.4
TRA BOND 2115	Conductive epoxy resin	Tracon	M 808	~ 6.6
Turbometall HTR	Metal-ceramic	Rebstar	M 614	~ 7.0

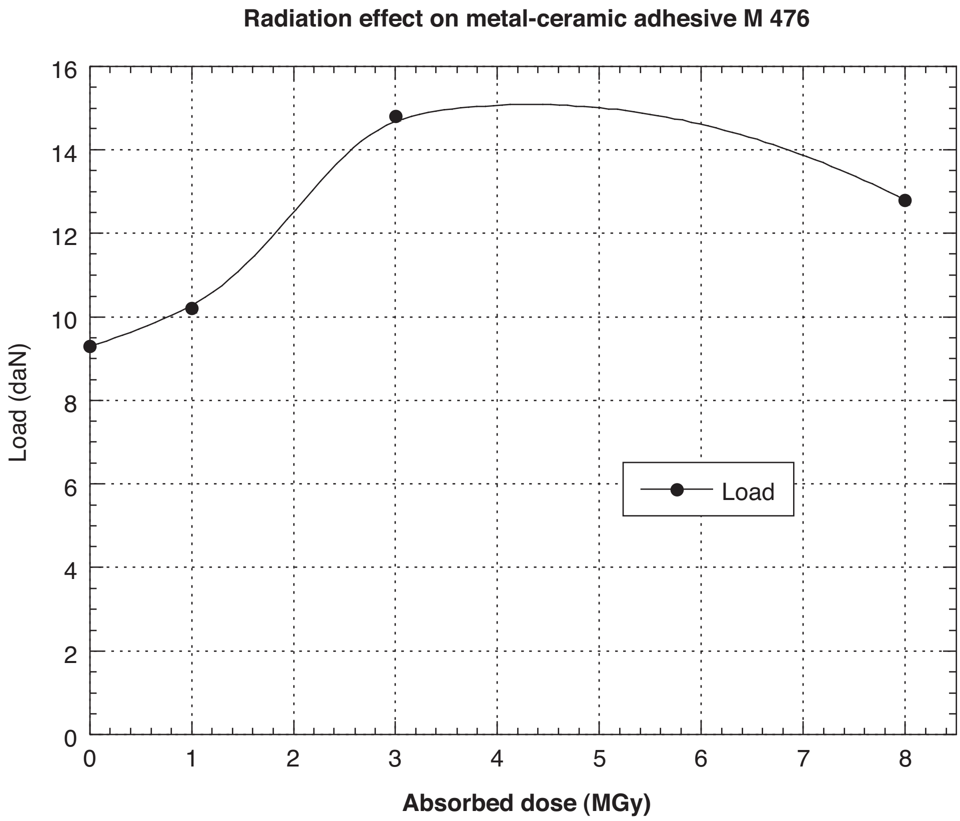
Material: **Metal-ceramic** **ID No. M 476**
Type: **Thermoguss 2000**

Supplier: **Kleiberit**

Test method: **Shear test**
Sample geometry: **A rubber cable glued into a stainless-steel pipe**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60 and switched-off reactor**

Absorbed dose (MGy)	Load (daN)
0	**9.3** ± 0.2
1	**10.2** ± 0.2
3	**14.8** ± 2.0
8	**12.8** ± 0.8

Critical property = load
Radiation index (RI) > 7.00



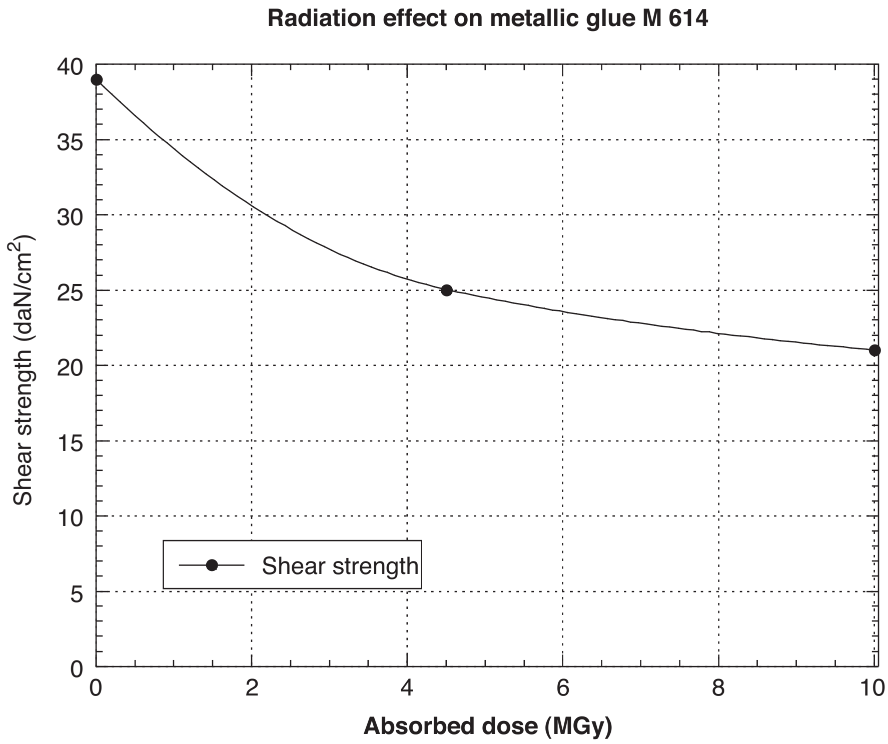
Material: Cold solder (metallic glue) **ID No. M 614**
Type: Turbometall HTR
Multi-purpose 'high-temperature resistant' adhesive

Supplier: Rebstar

Test method: Shear test with aluminium samples
Sample geometry: Two plates (10 × 1) cm were stuck together with a 1 cm^2 surface area
Polymerization temperature: 25°C
Radiation source: Switched-off reactor

Absorbed dose (MGy)	Shear strength (daN/cm^2)
0	39
4.5	25
10	21

Critical property = only the shear strength was measured
Radiation index (RI) ~ 7.00



In addition, plates of various materials (steel, copper, bronze, aluminium and plastic) were stuck together and irradiated at 1 MGy. No apparent degradation of the glue was noticed.

References: TIS–CFM/MTR/88–018 (1988)

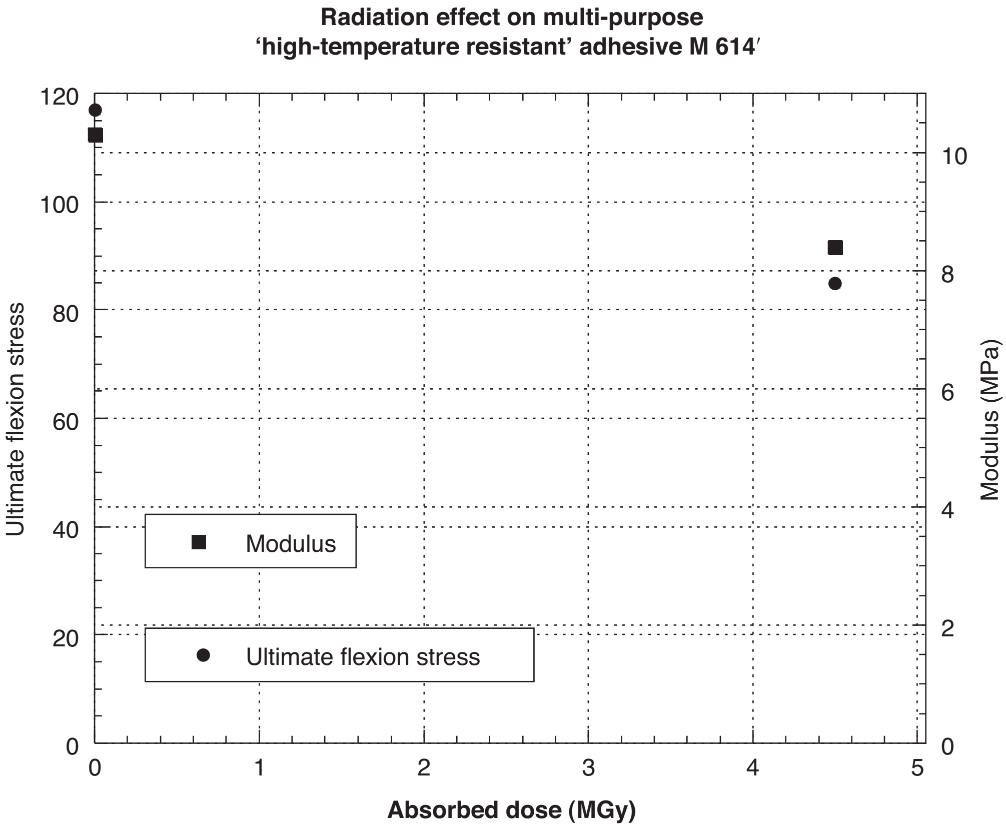
Material: **Cold Solder** **ID No. M 614′**
Type: **Turbometall HTR**
Multi-purpose 'high-temperature resistant' adhesive

Supplier: **Rebstar**

Test method: **Flexion test**
Polymerization temperature: **25°C**
Radiation source: **Switched-off reactor**

Absorbed dose (MGy)	Ultimate flexion stress (MPa)	Modulus (GPa)
0	**117** ± 45	**10.3** ± 1.6
4.5	**85** ± 9	**8.4** ± 1.4

Critical property = ultimate flexural strength
Radiation index (RI) > 6.7



References: TIS–CFM/MTR/88–026 (1988)

Material:	**Adhesive Tape, glass-fibre reinforced**	**ID No. M 781-1**
Type:	**Tape 4616**	
Supplier:	**Von Roll Isola**	

Test method:	**Peel test**
Sample geometry:	**The tape was glued on an aluminium plaque**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60; 1 kGy/h**
Comment:	**The peel strength shows the radiation resistance of the glue; the tensile force shows the radiation resistance of the tape itself (the support)**

The tape was irradiated at 1 and 2 MGy; the adherence of the composite film on the aluminium plaque increased with the absorbed dose; it was impossible to carry out the peel test after irradiation.

Critical property = peel strength
Radiation index (RI) > 6.3

Material:	**Adhesive Tape, glass-fibre reinforced**	**ID No. M 781-2**
Type:	**Tape 4617**	
Supplier:	**Von Roll Isola**	

Test method:	**Peel test**
Sample geometry:	**The tape was glued on an aluminium plaque**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60; 1 kGy/h**
Comment:	**The peel strength shows the radiation resistance of the glue; the tensile force shows the radiation resistance of the tape itself (the support)**

The tape was irradiated at 1 and 2 MGy;
At 1 MGy, the adherence of the composite film on the aluminium plaque increased;
At 2 MGy, the adherence decreased.

Critical property = peel strength
Radiation index (RI) ~ 6.0

Material:	**Adhesive Tape, glass-fibre reinforced**	**ID No. M 781-3**
Type:	**Tape 4618**	
Supplier:	**Von Roll Isola**	

Test method:	**Peel test**
Sample geometry:	**The tape was glued on an aluminium plaque**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60; 1 kGy/h**
Comment:	**The peel strength shows the radiation resistance of the glue; the tensile force shows the radiation resistance of the tape itself (the support)**

The tape was irradiated at 1 and 2 MGy; the adherence of the composite film on the aluminium plaque decreased with the absorbed dose; at 2 MGy, the adherence was completely lost.

Critical property = peel strength
Radiation index (RI) < 6.0

Material: **Adhesive Tape, glass-fibre reinforced** **ID No. M 781-4**
Type: **Tape 4560**

Supplier: **Von Roll Isola**

Test method: **Peel test**
Sample geometry: **The tape was glued on an aluminium plaque**
Polymerization temperature: **25°C**
Radiation source: **Cobalt 60; 1 kGy/h**
Comment: **The peel strength shows the radiation resistance of the glue; the tensile force shows the radiation resistance of the tape itself (the support)**

The tape was irradiated at 1 and 2 MGy; the adherence of the composite film on the aluminium plaque increased with the absorbed dose; it was impossible to carry out the peel test after irradiation.
At 2 MGy, the resistance of the tape decreased.

Critical property = peel strength
Radiation index (RI) = 6.0

Material:	**Adhesive Tape, glass-fibre reinforced**	**ID No. M 781-5**
Type:	**Tape 4562**	
Supplier:	**Von Roll Isola**	

Test method:	**Peel test**
Sample geometry:	**The tape was glued on an aluminium plaque**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60; 1 kGy/h**
Comment:	**The peel strength shows the radiation resistance of the glue; the tensile force shows the radiation resistance of the tape itself (the support)**

The tape was irradiated at 1 and 2 MGy; the adherence of the composite film on the aluminium plaque did not change with the absorbed dose.
At 2 MGy, the tensile strength of the tape decreased slightly.

Critical property = peel strength
Radiation index (RI) = 6.1

Material: **Plastic tape + glass fibres** **ID No. M 794-1**
Type: **TesaPack 4579**

Supplier: **Tesa**

Test method: **Peel test**
Sample geometry: **The tape was glued on aluminium plaques, the tape's width was 26 mm**
Radiation source: **Cobalt 60**
Radiation rate: **The dose rate was 2.3 kGy/h, but the complete irradiations were carried out in steps of 12 to 40 kGy over a period of several days, leading to a real mean dose rate of the order of 1 kGy/h**
Comment: **The peel strength shows the radiation resistance of the glue; the tensile force shows the radiation resistance of the tape itself (the support)**

Absorbed dose (MGy)	Ultimate peel stress (N/mm)	Force (N)
0	0.4	No break
0.2	Degraded	No break
0.5	Degraded	No break
1	Degraded	No break

The matrix of the tape was too brittle to allow testing, but the fibres were of course resistant.

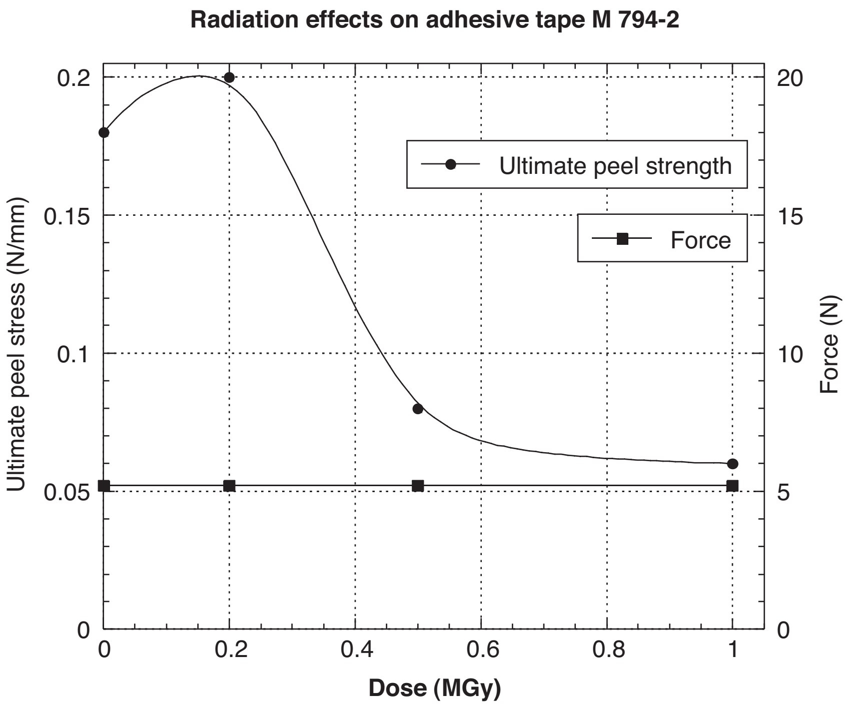
Critical property = ultimate peel stress
Radiation index (RI) < 5.3

Material:	**Plastic tape + aluminium**	**ID No. M 794-2**
Type:	**TesaMetal 500**	
Supplier:	**Tesa**	

Test method:	**Peel test**
Sample geometry:	**The tape was glued on aluminium plaques, the tape's width was 25 mm**
Radiation source:	**Cobalt 60**
Radiation rate:	**The dose rate was 2.3 kGy/h, but the complete irradiations were carried out in steps of 12 to 40 kGy over a period of several days, leading to a real mean dose rate of the order of 1 kGy/h**
Comment:	**The peel strength shows the radiation resistance of the glue; the tensile force shows the radiation resistance of the tape itself (the support)**

Absorbed dose (MGy)	**Ultimate peel stress (N/mm)**	**Force (N)**
0	**0.18**	**5.2**
0.2	**0.20**	**5.2**
0.5	**0.08**	**5.2**
1	**0.06**	**5.2**

Critical property = ultimate peel stress
Radiation index (RI) ~ 5.7



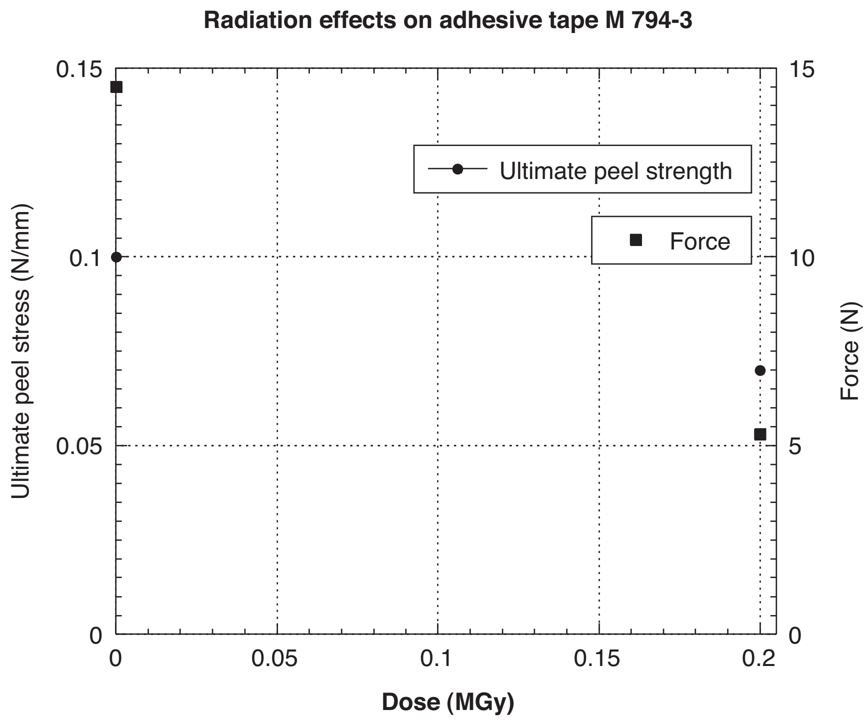
Material: **Plastic tape + cotton** **ID No. M 794-3**
Type: **TesaBand 4651**

Supplier: **Tesa**

Test method: **Peel test**
Sample geometry: **The tape was glued on aluminium plaques, the tape's width was 15 mm**
Radiation source: **Cobalt 60**
Radiation rate: **The dose rate was 2.3 kGy/h, but the complete irradiations were carried out in steps of 12 to 40 kGy over a period of several days, leading to a real mean dose rate of the order of 1 kGy/h**
Comment: **The peel strength shows the radiation resistance of the glue; the tensile force shows the radiation resistance of the tape itself (the support)**

Absorbed dose (MGy)	Ultimate peel stress (N/mm)	Force (N)
0	0.10	14.5
0.2	0.07	5.3
0.5	Stuck	Degraded
1	Stuck	Degraded

Critical property = force
Radiation index (RI) ~ 5.2



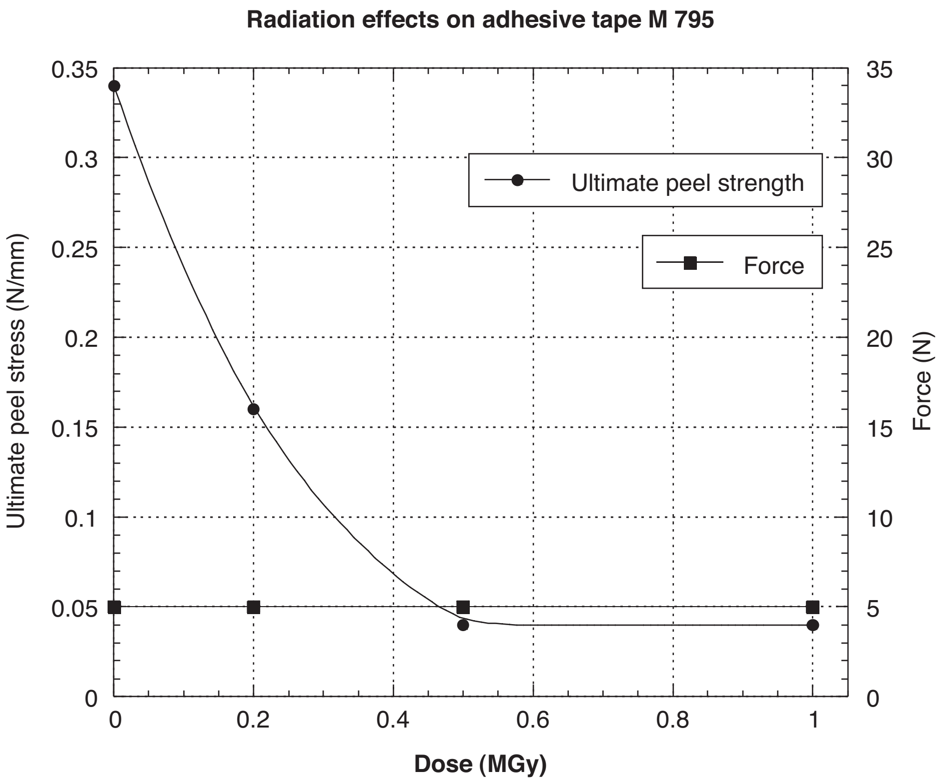
Material: **Metallic adhesive tape** **ID No. M 795**
Type: **Scotch-Metal**

Supplier: **3M**

Test method: **Peel test**
Sample geometry: **The tape was glued on aluminium plaques**
The tape's width was 25 mm
Radiation source: **Cobalt 60; 1 kGy/h**
Remarks: **The peel strength shows the radiation resistance of the glue; the tensile force shows the radiation resistance of the tape itself (the support)**

Absorbed dose (MGy)	Ultimate peel stress (N/mm)	Force (N)
0	0.34	5.0
0.2	0.16	5.0
0.5	0.04	5.0
1.0	0.04	5.0

Critical property = ultimate peel stress
Radiation index (RI) = 5.3



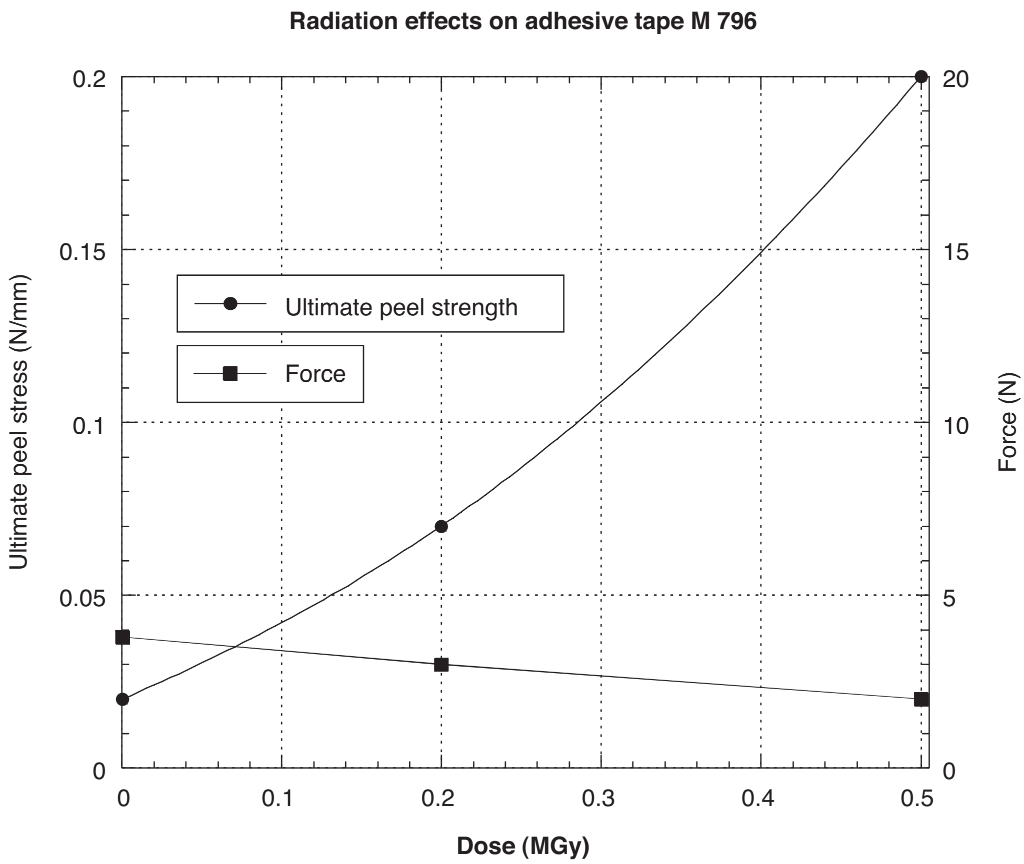
Material: PVC adhesive tape **ID No. M 796**
Type: Tape Coroplast 302

Supplier: Muller

Test method: Peel test
Sample geometry: The tape was glued on aluminium plaques
The tape's width was 10.5 mm
Radiation source: Cobalt 60; 1 kGy/h
Remarks: The peel strength shows the radiation resistance of the glue; the tensile force shows the radiation resistance of the tape itself (the support)

Absorbed dose (MGy)	Ultimate peel stress (N/mm)	Force (N)
0	0.02	3.8
0.2	0.07	3.0
0.5	0.20	2.0
1	Stuck	Degraded

Critical property = force
Radiation index (RI) ~ 5.7

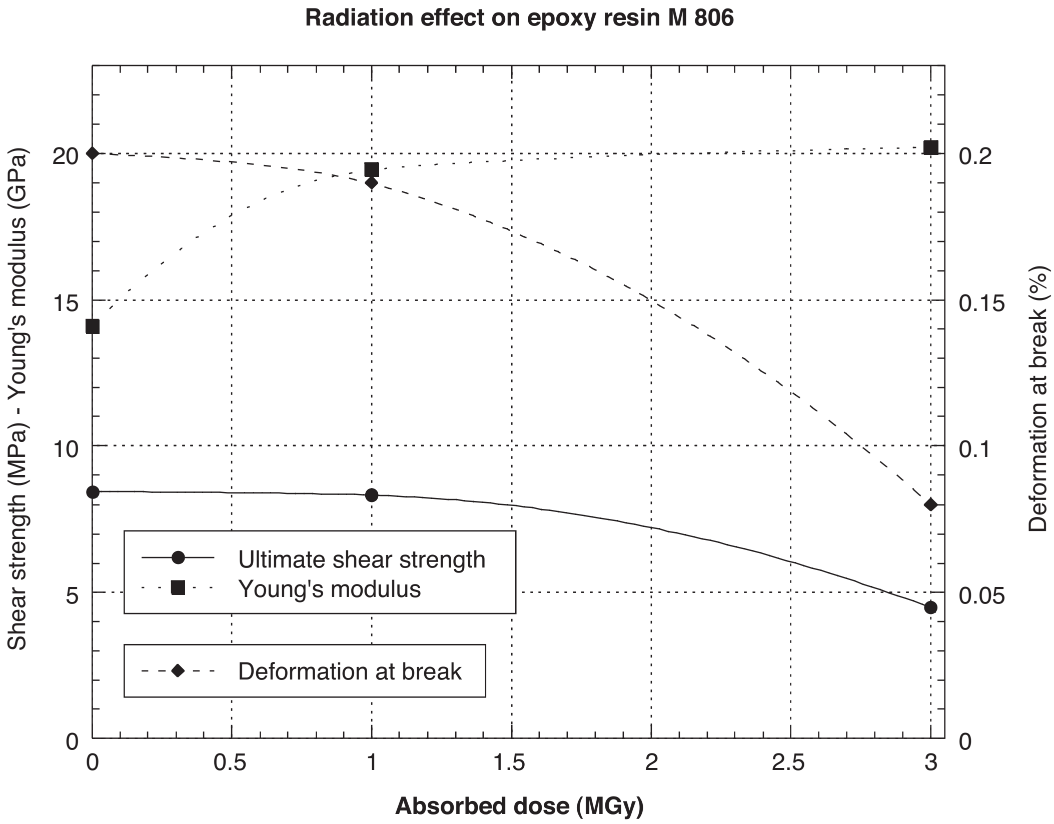


Material:	**Structural epoxy adhesive**	**ID No. M 806**
Type:	**TRA DUCT 1922**	
Supplier:	**Tracon**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Dose (MGy)	**Dose rate (kGy/h)**	**Ultimate shear strength (MPa)**	**Equivalent Deformation at Break (%)**	**Equivalent Modulus (GPa)**
0	**0**	**8.4** ± 0.3	**0.2** ± 0.03	**14.1** ± 2.2
1	**4**	**8.3** ± 0.2	**0.19** ± 0.03	**19.5** ± 2.6
3	**4**	**4.5** ± 0.2	**0.08** ± 0.00	**20.2** ± 1.8

Critical property = deformation at break
Radiation index (RI) ~ 6.4 at a mean dose rate of 4 kGy/h

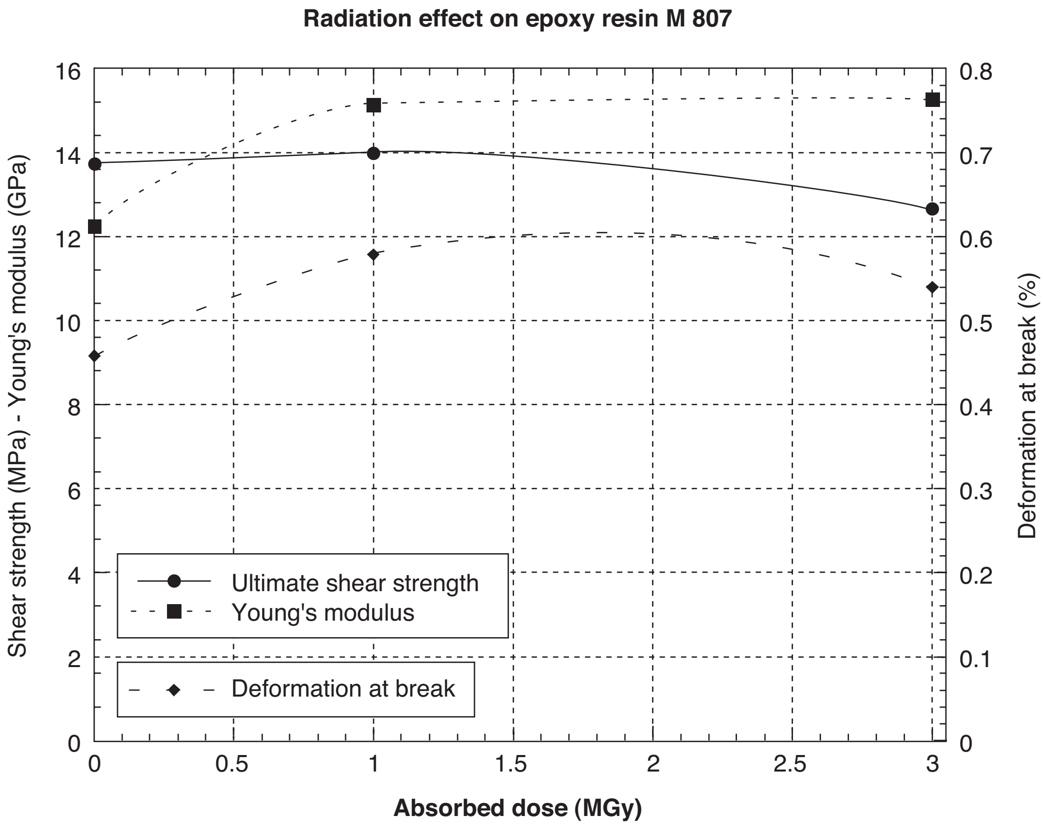


Material:	**Structural epoxy adhesive**	**ID No. M 807**
Type:	**TRA BOND 2115**	
Supplier:	**Tracon**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**13.8** ± 1.5	**0.46** ± 0.06	**12.3** ± 1.0
1	**4**	**14.0** ± 1.2	**0.58** ± 0.07	**15.2** ± 0.6
3	**4**	**12.6** ± 3.3	**0.54** ± 0.09	**15.3** ± 2.7

Critical property = none
Radiation index (RI) > 6.6 at a mean dose rate of 4 kGy/h

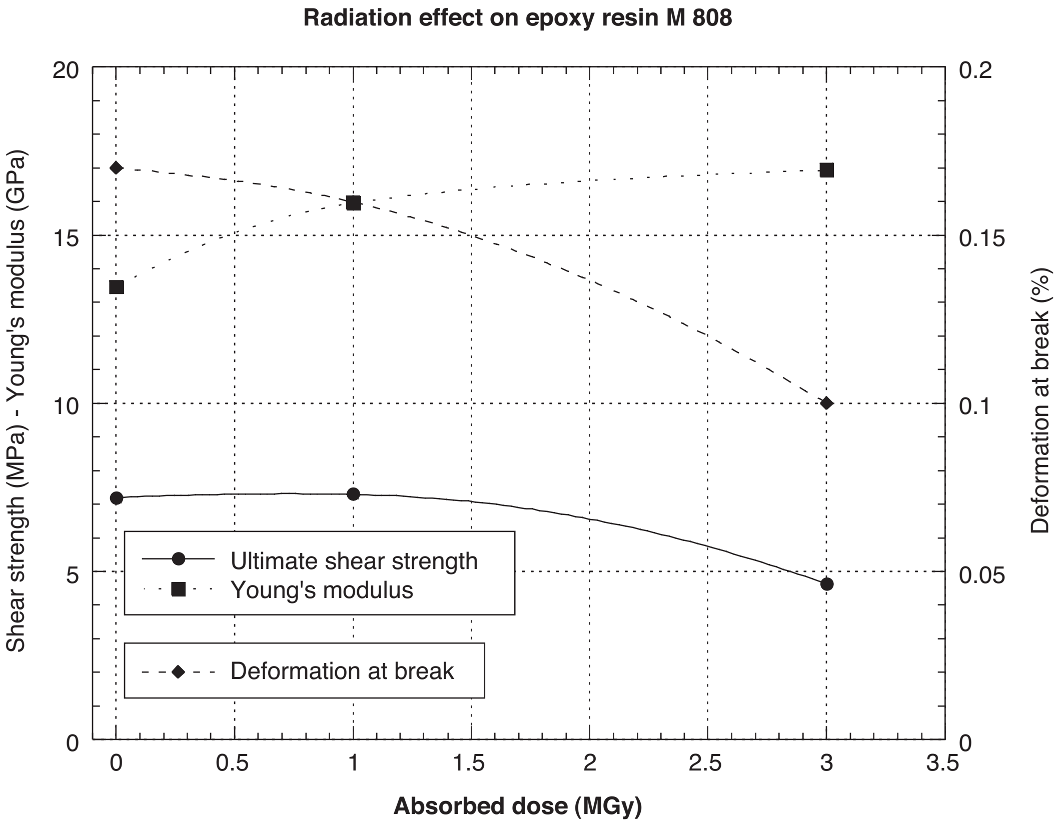


Material:	**Structural epoxy adhesive**	**ID No. M 808**
Type:	**TRA DUCT 2902**	
Supplier:	**Tracon**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Ultimate shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**7.2** ± 0.8	**0.17** ± 0.03	**13.5** ± 2.6
1	**4**	**7.3** ± 0.6	**0.16** ± 0.02	**16.0** ± 1.4
3	**4**	**4.6** ± 0.4	**0.10** ± 0.03	**17.0** ± 1.4

Critical property = deformation at break
Radiation index (RI) ~ 6.6 at a mean dose rate of 4 kGy/h

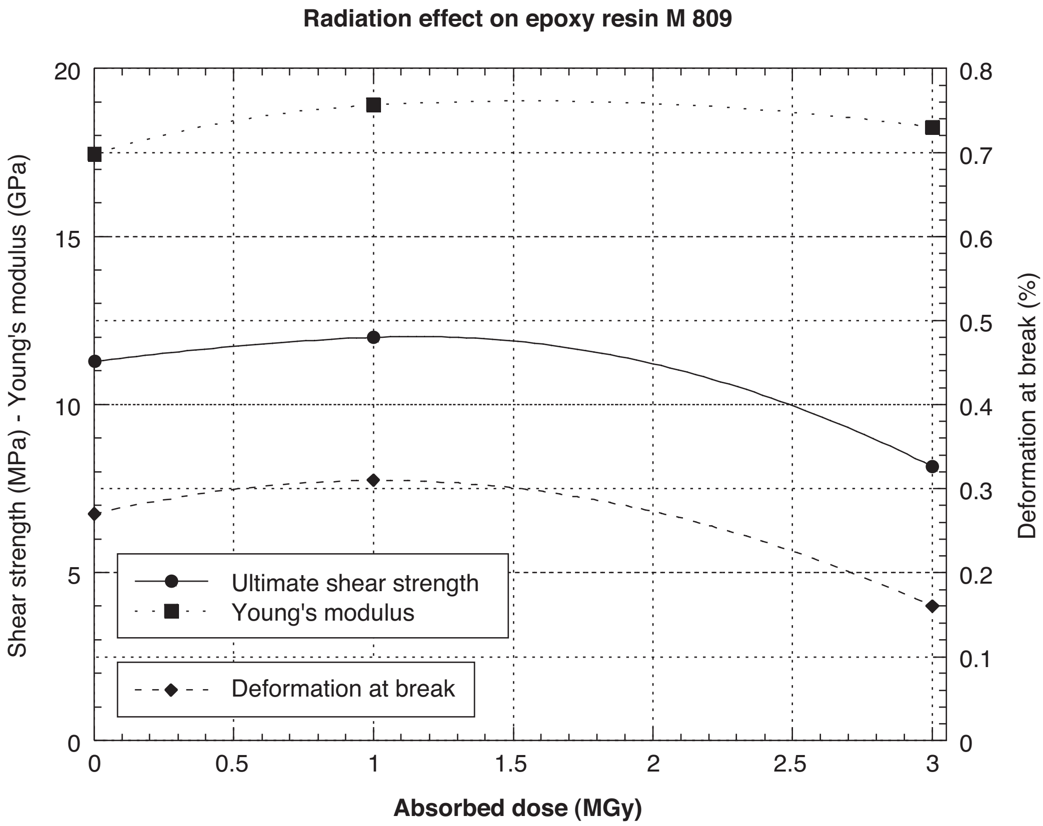


Material:	**Structural epoxy adhesive**	**ID No. M 809**
Type:	**TRA BOND 2151**	
Supplier:	**Tracon**	

Test method:	**Shear test with aluminium samples**
Sample geometry:	**Equivalent to ASTM D 1876-93**
Surface treatment:	**Sand blasting**
Polymerization temperature:	**25°C**
Radiation source:	**Cobalt 60**

Absorbed dose (MGy)	Dose rate (kGy/h)	Ultimate shear strength (MPa)	Deformation at break (%)	Young's modulus (GPa)
0	**0**	**11.3** ± 0.9	**0.27** ± 0.05	**17.5** ± 1.2
1	**4**	**12.0** ± 0.6	**0.31** ± 0.03	**19.0** ± 1.9
3	**4**	**8.2** ± 1.0	**0.16** ± 0.03	**18.3** ± 3.2

Critical property = deformation at break
Radiation index (RI) ~ 6.6 at a mean dose rate of 4 kGy/h



APPENDIX 3

Alphabetic compilation of data

(Trade names in italics)

V

Commercial name	Base polymer	Supplier	Reference	R.I.
Voltatex E 1150		Stollack	M 513	~ 6.8
Voltatex E 1175		Stollack	M 455	~ 6.7

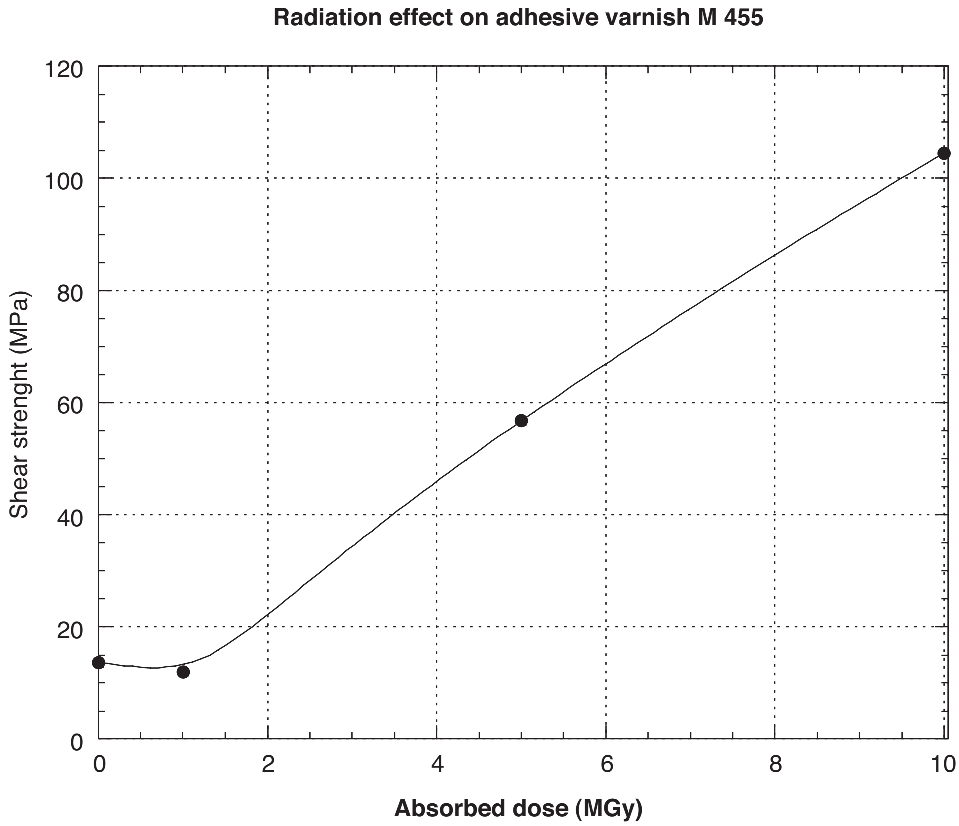
Material: **Adhesive varnish** **ID No. M 455**
Type: **Voltatex E 1175**

Supplier: **Stollack**

Test method: **Shear test**
Sample geometry: **Two plaques (10 × 1) cm were stuck together forming a 1 cm^2 surface.**
Polymerization temperature: **160°C for 1 h**
Radiation source: **Switched-off reactor**

Absorbed dose (MGy)	Strength (MPa)
0	**13.6** ± 4.1
1	**12.0** ± 3.0
5	**56.8** ± 1.4
10	**104.5** ± 0.8

Critical property = only the shear strength was measured
Radiation index (RI) ~ 6.7



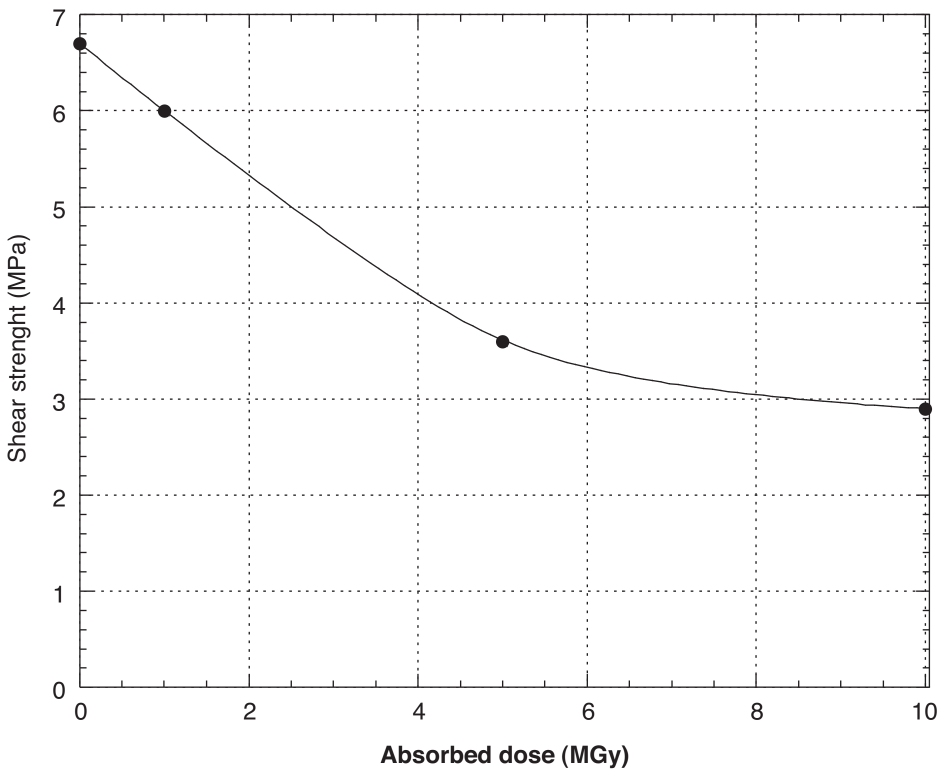
Material:	**Adhesive varnish**	**ID No. M 513**
Type:	**Voltatex E 1150**	
Supplier:	**Stollack**	

Test method:	**Shear test**
Sample geometry:	**Two plaques (10 × 1) cm were stuck together forming a 1 cm^2 surface.**
Polymerization temperature:	**160°C for 1 h**
Radiation source:	**Switched-off reactor**

Absorbed dose (MGy)	Strength (MPa)
0	**6.7** ± 1.3
1	**6.0** ± 1.7
5	**3.6** ± 1.1
10	**2.9** ± 0.7

Critical property = only the shear strength was measured
Radiation index (RI) ~ 6.8

Radiation effect on adhesive varnish M 513



APPENDIX 4.1

List of abbreviations used in the present volume

ASTM	American Society for Testing and Materials
CEI	Commission Electrotechnique Internationale
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LOI	Limit of Oxygen Index (%)
RI	radiation index = logarithm, base 10 (rounded down to two significant digits) of the absorbed dose in grays at which the critical property reaches the end-point criterion (in accordance with IEC 544–4).
TIS	Technical Inspection and Safety Division at CERN
UL	Underwriters' Laboratories
VPI	Vacuum Press Impregnated composite

APPENDIX 4.2

Formulae used for the calculation of the given properties

A	Joint area of the shear samples (mm^2)
B	Breath (width) of the samples (mm)
D	Deflexion interval in linear part of the curve (mm)
D_0	Distance between deflexion transducers during the tests (mm)
Dx	Maximum deflexion during the test (mm)
E	Young's modulus of elasticity = $\frac{P}{T \cdot B} \Big/ \frac{D}{D_0}$ (GPa)
ε	Deformation at break = $\frac{6 \cdot Dx \cdot T}{L^2}$ in the case of flexion test (%)
F_{st}	Flexural strength = $\frac{3 \cdot Px \cdot L}{2B \cdot T^2}$ (MPa)
G	Shear modulus = $\frac{P \cdot Tj}{D \cdot A}$ (GPa)
L	Distance between supports of the flexion test = 67 mm
M	Flexural modulus of elasticity = $\frac{P \cdot L^3}{4 \cdot D \cdot B \cdot T^3}$ (MPa)
P	Load interval in linear part of the curve (N)
Px	Maximum load (N)
S_{st}	Shear strength = $\frac{Px}{A}$; for Von Mises $S_{st} = \frac{T_{st}}{\sqrt{3}}$ (MPa)
T	Thickness of the samples (mm)
Tj	Thickness of the adhesive layer of the shear samples (mm)
T_{st}	Tensile strength = $\frac{Px}{T \cdot B}$ (MPa)

APPENDIX 5

List of suppliers of base materials, transformers, and some users who gave samples to CERN

3M GmbH	Eggstrasse 93, Postfach, CH–8803 Rüschlikon
Ansaldo	8, via Lorenzi, I–16152 Genova
Bakelite	PO Box 120552, Varziner Str., D–47125 Duisburg
Ciba-Geigy	See Vantico
Delo	Ohmstraße 3, D–86899 Landsberg
Dolph's	PO Box 267, 320 New road, Mommouth Jct, NJ 08852, USA
Down Corning	Chaussée de la hulpe 154, B–1170 Brussels, Belgium
E&C	GRACE NV - B 2260 - Westerlo
Epotek	14 Fortune Drive, Billerica, MA 01821, USA
Epotecny	10, impasse Latécoère, F–78140 Vélizy
GTS France	Av de l'Océanie, ZA de Courtaboeuf, F–91968 Les Ulis Cedex
Hysol	2850 Willon Pass Road, Pittsburg, CA. 94565, USA
I-Plastic	Justus-von-Liebig Str 3, D–5300 Bonn
Isola Werke	CH–4226 Breitenbach
Kleiberit	CD 63, F–67116 Reichstett
Lancashire Fiting	Science Village, Claro Road, Harrogate, North Yorkshire, UK
Loctite	http://www.loctite-europe.com/index.htm
Magnolia	5547 Peachtree Ind. Blvd, Chamblee, Georgia 30341, USA
Norlabs	41 Chestnut St. Greenwich, CT 06830, USA
Peltier	Am Moosgraben 25, D–36919 Utting / Ammersee
Progressive Products	4607 Linden PI., Pearland, Texas 77584, USA
Reb-Star	46-48 rue Saint Laurent, F–13002 Marseille
Shell Aseol AG	Steigerhubelstrasse 8, CH–3000 Bern 5
Shell Chemie	CH–8021 Zürich
Sika	Via E. De Amicis 44, I–20123 Milano
Smooth On	1000 Valley Road, Gillette, NJ 07933, USA
Stollack AG	Guntramsdorf, Vienna, Austria
Tesa	Unnastraße, 48, D–20245 Hamburg
Tracon	45 Wiggins Ave., Bedford, MA 01730, USA
UDD-FIM SA	BP 49, F–90101 Delle
Vantico	Klybeckstr. 200, CH–4002 Basel
Von Roll Isola	Theodor Sachs-Str.1, D–86199 Augsburg