

# INTRODUCTION TO FORMULATED PRODUCTS



## INTRODUCTION

All of the “formulated products” manufactured by Gurit are classified as thermosetting materials or ‘thermosets’. These materials are supplied in a liquid or semi-liquid form, usually as a “2-part system”. Under the correct conditions, the system undergoes a chemical reaction (known as “curing”) to form a solid material. While the resultant cured material will soften above a certain temperature (its glass transition temperature, or Tg), it will not become liquid and flow again, unlike ‘thermoplastics’ which can be heated up and will reflow in a reversible and repeatable process.

Gurit manufactures a wide range of formulated resin products, based on epoxy, polyurethane and vinylester chemistry. These formulations are unique combinations of chemicals that have been blended together to yield products with characteristics optimised for their intended application. The products have been extensively tested both for their handling and usage characteristics, and for the properties that result from their curing, and this information is presented here.

The characteristics of thermosets mean that they can be formulated into a wide variety of forms, with many different liquid-state properties and cured properties. The products manufactured by Gurit have therefore been grouped under the following headings, broadly relating to their intended application:

- **Laminating Systems** - epoxy based liquids, low viscosity for good wet-out, high strength and stiffness.
- **Gelcoats** - epoxy based thixotropic liquids, opaque, good environmental degradation resistance.
- **Adhesives** - epoxy based semi-liquids and pastes, high strength and durability.
- **Coatings** - epoxy and PU based, solvent-based, and solvent free, clear liquids.
- **Filling and Fairing Compounds** - epoxy based pastes, high adhesive ability and durability.
- **Multi-purpose Systems** - epoxy based. Capable of performing as adhesives, coatings, filling compounds and laminating systems.
- **Custom Formulations** - epoxy systems precisely formulated to customer's specification for handling characteristics and cured properties.

## GURIT FORMULATED PRODUCTS TECHNICAL CHARACTERISTICS

In order to provide easy access to technical data on Gurit formulated products, a standardised reporting format for all data has been used wherever possible. This is based on the use of internationally recognised test methods, where these are appropriate, and Gurit-developed test methods in other cases. To avoid repetition, a description of the significance of each piece of data, and the methods used to derive it, are given in the following article. By standardising on the test methods used in this way, it is now straightforward to make direct comparisons between the different Gurit products, and hence to make the most appropriate selection. In some of the datasheet sections these comparisons have been made even easier by the graphical presentations at the beginning of the section comparing some of the features of the particular group of products. Where test methods or conditions have deviated from those standard tests described here, notes and annotations have been made on the relevant product datasheet.

The datasheets provide all the factual data on a particular formulated product, along with additional information on how to use the product. These data sheets are also supplied with the product when it is ordered. If required in advance of a product, the relevant full SDS (Safety Data Sheet) can be obtained from Gurit.

Each formulated product datasheet contains a brief product description, a list of the availability of the product and its components and then the technical data. The technical data in each datasheet is provided in the following format:

**1. Component Properties** Physical properties of the separate resin and hardener components e.g. viscosity, density etc.

**2. Mixed System Working Properties** Working characteristics of the mixed resin and hardener. e.g. gel time, working time etc. This is presented over a range of different temperatures.

**3. Cured System Properties** Physical and mechanical properties obtained from the cured system, in many cases with more than one cure cycle. e.g. glass transition temperature (T<sub>g</sub>), shrinkage, laminate compressive strength, etc.

Much of this data is also presented in graphical form to make it easier to compare component combinations, look at trends and interpolate between measured datapoints.

### 1. Component Properties

Each product datasheet details some of the physical properties of the separate resin and hardener components. These properties provide important information on the discrete elements of a system, and are particularly relevant when looking at applications such as automated mixing and dispensing.

#### Mix Ratio

Most of the formulated resin products that are produced by Gurit are based on epoxy chemistry. In most cases the reaction of resin and hardener is an addition reaction, which, in its simplest form, means that one molecule of resin needs to react with one molecule of hardener for a complete reaction to occur. This is different to the catalytic cure of, for example, a polyester resin where a 'chain-reaction' is involved. The implication of this for most epoxies is that the ratio of resin to hardener is critical, and deviating from it will result in unreacted resin or hardener, and an inferior end-product.

Most products in the Gurit range are intended to be mixed by accurately weighing out the correct amounts of resin and hardener using appropriate scales. The mix ratio is therefore primarily specified as a mix ratio by weight, and wherever possible this has been made to be an "easy to use" figure. For example, Ampreg 20's mix ratio is 100:25 by weight, which is 4:1, and Ampreg 26 is 100:33.3 by weight, which is 3:1. Other products in the Gurit range are designed to be dispensed and mixed by volume, making them easier to use with dispensing pumps and mixing machines. In these cases, the mix ratio will usually be a convenient volume ratio such as SP106's 100:20 (5:1), and SP320's 100:40 (5:2).

#### Viscosity

The viscosity of a liquid is defined as the measure of its resistance to a shearing action, such as that applied by a brush, laminating roller or the products own self-weight on a vertical surface. It affects many handling properties including ease of fibre wet-out and mixing, degree of flow under vacuum, and drainage on a vertical surface. The viscosity of a mixed resin and hardener system is strongly affected by temperature, with most systems becoming unworkable if the temperature falls below a certain point.

As a resin and hardener react together and begin to cure, the viscosity of the mix will begin to increase, slowly at first and then more rapidly as gelation approaches. The heat generated by the exothermic epoxy reaction will initially tend to reduce the viscosity, but it will also accelerate the cure. If this heat is contained within the mix by keeping the product in bulk, such as in a mixing pot, the time during which the product remains at a workable viscosity



is markedly reduced, particularly in the faster reacting systems. For this reason, once an epoxy is mixed, it should be poured into a shallow tray. This helps the heat of reaction to escape, and prolongs the time during which the product remains useable.

Viscosity can be measured in a number of different ways, with different test methods giving slightly different results. The data given here is all based on measurements from a CAP2000 cone and plate viscometer. This uses a slowly rotating conical disc, which is applied at a constant pressure onto a heated metal base-plate. The liquid being sampled is sandwiched in a thin film between the cone and the plate, and the torque required to revolve the cone is measured and converted to a viscosity. The method can be used to produce isothermal viscosity curves which show how viscosity increases as a material cures at a constant temperature. Non-isothermal curves can also be generated by heating the base-plate. These show how the viscosity of a material, either mixed or as a single component, changes with temperature. All of the resin and hardener products shown here will show an increase in viscosity as the temperature falls, a factor that should be borne in mind when controlling workshop temperatures. The units of measure of viscosity are usually poise (P) or centipoise (cP), where 1 Poise=100cP.

For comparative purposes, indicative viscosities of well known liquids at 20°C are:

Water	15 cP
Sunflower oil	90 cP
Engine oil SAE 15/40	290 cP
PVA adhesive	3,000 cP
Unthinned gloss paint	18,000 cP
Sugar Syrup	57,000 cP



### Thixotropy

Some liquids have a characteristic known as thixotropy whereby their viscosity depends on the *rate* at which they are sheared and, to some degree, the time for which a material is sheared. This means that under high shear rates, such as when

applied with a brush, they act as if they have a low viscosity, but under low shear rates, such as under the product's own weight, they act as if they have a high viscosity. Common products with this behaviour include whipped cream, grease and non-drip paint, which appear to be 'thick' and high in viscosity when they are not being moved. However, when these products are brushed or cut, they act as if they have a low viscosity and do not have the heavy stickiness associated with high viscosity liquids. Among resin systems, this is typical of products such as fillers, gelcoats and some adhesives.

Some resin systems which are low in viscosity can be given this characteristic by the addition of fillers such as colloidal silica powder. However, colloidal silica, being a very low density powder, can be difficult to handle, so pre-thixotroped products, such as Ampreg Pregel can be used to alter the thixotropy of low viscosity resin systems - for example where there is a need to stop a resin system draining from a vertical surface.

### Shelf Life

Since the properties of many resins and hardeners will change slightly with age, they have been allocated a shelf life. Within this shelf life, the properties of an unopened product will remain within the product's original quality control limits. This also assumes storage in accordance with the instructions given in the product datasheet. On each product label this shelf life is expressed in the form of an expiry date. Once

opened and exposed to air, hardeners particularly will begin to degrade and should be used as soon as practicable. To maintain the freshness of the product for as long as possible, it is recommended that when hardener containers are nearly empty, the contents are dispensed into smaller containers so that the headspace of air above the liquid is minimised. It should be noted that, with a few exceptions, products may still be usable after their expiry date, but their properties may have changed beyond those set in the QC specification, and cannot therefore be guaranteed by Gurit. Typical changes that may be noticed are a darkening of colour, an increase in viscosity, an increase in gel times and settlement or separation of fillers and pigments.

### Product Colour

Liquids which are coloured in varying shades of yellow/brown or 'darkness', are often classified using the Gardner colour index. Most of the unpigmented resins and hardeners produced by Gurit can be classified in this way, with the scale being approximately illustrated on the coloured film overleaf. Note that epoxy resins and hardeners may darken on storage, and may also vary slightly in colour from batch to batch. Once cured and exposed to sunlight most epoxies will also yellow slightly. These colour changes do not generally affect their other properties, but should be considered if the clarity and colour of a finished product is important.

### Component Density

The densities of liquid resin and hardener components have been determined using hydrometers to BS 718: M50. Where a product is too high in viscosity for a hydrometer to be used, density has been calculated from weighing a known volumetric quantity.

### Hazard Definition

Most Gurit formulated products have some hazardous properties according to EU regulation on Classification, Labelling and Packaging (EC) No. 1272/2008, also known as Globally Harmonised System (GHS) of classification and labelling. The products may also be classified as dangerous goods for transport according to UN recommendations on the transport of dangerous goods.

This hazard classification system both defines a broad hazard category into which products with similar hazards are grouped, as well as defining in more detail the risks and safety issues associated with the handling and use of each product. The hazardous nature of the product is indicated by red border diamonds on the label of a resin or hardener container. The categories of hazard that can be found on Gurit products are as follows:

Irritant and/or sensitiser	Corrosive	Toxic	Long term adverse effects	Harmful / toxic to the environment

The product label also contains details of the hazards associated with the product and precautions that should be taken whilst using the product. These are listed as Hazard Statements and Precautionary Statements.

Further classification is also allocated to a product to define the nature of the hazard during its transport. This classification uses similar hazard symbols to those for handling, and is indicated by a diamond label on the outer surface of a package in transit.

			
Toxic	Corrosive	Other hazards, such as environmentally hazardous	Dangerous to the environment

Full details concerning the safe handling, use and transport of any hazardous goods are contained in the Safety Data Sheet (SDS) for that product. This is a globally defined document split into 16 sections covering all aspects of product handling, storage and transportation. Every resin and hardener produced by Gurit has an SDS, and you should ensure that you have this document to hand before using the product. If you do not have this document, please contact Gurit.

## 2. Mixed System Working Properties

On each product datasheet, the Working Properties table shows how the mixed resin and hardener will handle in use over a range of ambient temperatures. Many working properties are heavily temperature dependent and so some of this data is also presented as a set of logarithmic graphs. Using these graphs, the working properties at temperatures intermediate to those quoted specifically in the table can be determined.

### Initial Mixed Viscosity

As for the individual components, the Initial Mixed Viscosity has been determined by measurements from a CAP2000 cone and plate viscometer.

### Gel Time - 150g Mix in Water

A 150g resin and hardener mix is placed in a plastic beaker suspended in a water bath at the specified temperature. A Tecam geltimer is used to determine the point at which the viscosity of the liquid has increased to the point where the material is sufficiently solid to provide a back-force, on the plunging 22mm disk, of >0.05N. This test is to BS 3532: 1990, and BS2782 Pt.8 835C.

### Pot life - 500g Mix in Air

A 500g resin and hardener mix is placed in a plastic beaker left in air at the specified temperature. The same Tecam geltimer is used as above. This test gives an indication of the exothermic (heat-emitting) properties of a resin system when confined in bulk, and is useful for both determining how quickly a material needs to be used, as well as providing an indication of how the material will behave in thick sections. Note that because of the greater insulating nature of air compared with water, and the exothermic effects of higher volume mixes, these pot lives are always shorter than the gel-times given above. The only exceptions to this are the solvent-based products which are very low in exotherm, and where the larger mixes provide a greater reservoir of solvent to maintain the fluidity of the product for longer periods.

### Earliest and Latest Time to Apply Vacuum

When a laminating resin and hardener are mixed, they begin to react together. Assuming temperatures remain constant, the viscosity of the mixed system will then begin to increase, with the mixture gradually thickening and becoming less workable as time progresses. If the resin is being used for a laminate that is to be vacuum bagged, the viscosity will eventually become so high that the vacuum bag becomes ineffective at bleeding out excess resin and so cannot consolidate the laminate properly. In the experience

of Gurit this equates to a viscosity of approximately 5000P, and the time taken to reach this viscosity after mixing is given in the datasheets as the 'Latest Time to Apply Vacuum'.

However, it is equally important that the vacuum is not applied too early, since, if the resin is too low in viscosity, excessive bleed out can occur leading to resin-starved laminates. The minimum recommended viscosity for beginning to apply a vacuum to most laminates is 1000P and is quoted in some of the datasheets as the 'Earliest Time to Apply Vacuum'.

The times given in the datasheets are based on measuring the viscosity of a thin layer of the mixed resin system as it cures in a digital CAP2000 cone and plate viscometer. It should be noted that the measurements therefore relate primarily to thin laminates (<1mm) where there is a very low exotherm effect. Thicker laminates may well produce an exotherm effect, raising the laminate's temperature and significantly reducing these times as the data shows. Such temperature changes are best monitored by using thermocouples in the laminate and using the working times quoted for the laminate's actual temperature rather than that of the workshop. All times are measured from when the resin and hardener are first mixed together.



### Demould Time

This is derived from the cure profile of the material and is the earliest time at which a laminate or gelcoat will have sufficient strength to be carefully handled, and removed from a properly release-coated mould. This time is somewhat subjective since the degree of care exercised and the thickness and configuration of the laminate being demoulded will also have a very significant effect on the time at which demoulding can begin. Demould time is measured from when the resin and hardener are first mixed together.

### Clamp Time

This is the time from first mixing after which a resin system used as an adhesive should have reached a degree of cure where the substrates being bonded cannot be easily separated without damage to the adhesive layer or the substrates themselves. The cure will not have advanced to the point where the joint has sufficient mechanical properties to meet the intended in-service loads, but will have sufficient strength to be carefully handled, and removed from a jig or clamp.

### Sag Resistance

This is the maximum thickness of fresh gelcoat, filler or coating material that can be applied to a vertical surface without it slumping or running. Sag resistance may be increased by the addition of Colloidal Silica, although this will also have the effect of making the material more brittle.



### Working Time

This is defined as the time in thin film for a product used as a coating or a gelcoat to reach a viscosity of 5000P. Beyond this viscosity the product will no longer be brushable.

### Tack-Off Time & Latest Overcoating Time

With most Gurit materials used as coatings, a second coat can be applied when the first has 'tacked-off'. This is the point where the material is still tacky but has reached a sufficient degree of cure for it not to be disturbed when a second layer is applied on top. As the first layer of material continues to cure beyond this "tack-off" point, it will reach a point where the tack has disappeared. At this point the exposed surface material

loses its ability to bond due to the formation of an inert surface layer. Overcoating cannot continue after this point unless the first coat is allowed to cure fully and is then sanded to remove this inert layer. This point is known as the Latest Overcoating Time. The time between this and the Tack-Off Time is known as the overcoating window. Attempting to apply second coats outside of the overcoating window, and without sanding, can lead to severe bond problems between the layers. The exact overcoating window is affected by many factors including humidity and temperature.

Although the data presented here will apply in most circumstances, a coating should always be tested by touching lightly with a finger. If the resin comes away on the finger then it is too early to overcoat, if the material is not tacky and a fingerprint cannot be left, then it is too late to overcoat without sanding. These times are measured from when the resin and hardener are first mixed together.

### Earliest Sanding Time

This is the earliest time at which the material can be sanded, once any inert surface layer (commonly known as by-product) has been removed. By-product may form on coatings particularly if they are allowed to cure in low temperatures and high humidities. With SP106 and Handipack, it can be removed by wiping with Solvent C.

### Minimum Application Thickness for Coverage

The minimum thickness for application of a gelcoat or coating in order to achieve sufficient opacity to completely cover a contrasting base colour.

### Suitability for Double Gelling

Many gelcoats have a surface chemistry that means they should not be applied in more than one coat, if inter-coat problems are to be avoided.

### Wet Film Thickness & Dry Film Thickness

With solvent-based systems, the wet-film thickness is the typical coating thickness that can be applied as one layer. When the solvent has evaporated, the dry-film thickness is what remains.

### Solids Content

With solvent-based systems, the solids content is the percentage of a component or mix which comprises non-volatile material. Once the volatile solvent has evaporated, it is the solids element that remains behind to cure into the final film.

## 3. Properties of the Cured System

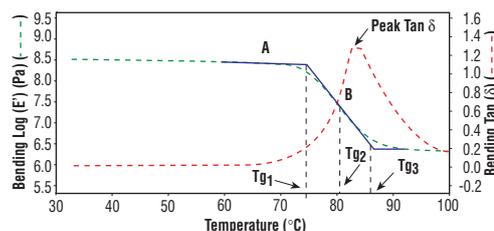
### Physical Properties

One of the most important physical characteristics of all cured formulated products is the way the material behaves when heated. This thermal data is critical to almost every application since it gives an indication of the limiting temperature for use of the material. Although it is ultimately only by testing the products in the loading configuration they will see in service, that an accurate determination can be made as to whether they are suitable for use at a particular temperature, the data presented here can be used as a guide for initial product selection.

### Tg - DMTA (Peak Tan $\delta$ )

The Tg or Glass Transition Temperature of a polymer material, such as cured epoxy, is the temperature at which it changes from a hard and rigid molecular structure into a soft, semi-flexible one. At this point, the polymer structure is still intact, but the cross-links in the matrix are no longer 'locked' in position. In practical terms it signifies the upper use

temperature of the material, above which the material will exhibit significantly reduced mechanical properties.



However, the transition from a rigid state to a flexible state is not an instantaneous one, and so there is a range of temperature over which various properties of the material are undergoing a change. These changes can be measured by a number of different techniques, and one of the most widely used is DMTA (Dynamic Mechanical Thermal Analysis). This technique flexes a small bar of the test material while it is gradually heated. Two properties are then measured: the Bending Modulus (stiffness) ( $E'$ ), and the Loss Tangent ( $\tan \delta$ ). As the material nears its Tg, it loses its stiffness and so  $E'$  drops rapidly, to a new lower level. The Loss Tangent is a measure of the energy that is stored in the polymer's rigid structure arising from the visco-elastic behaviour that most polymers exhibit. This stored energy reaches a sharp peak at the glass transition temperature, and then drops away.

### Tg<sub>1</sub> (DMTA)

While the stiffness (or modulus) of the material drops at the Tg, it is sometimes a gradual change and so defining the exact temperature at which it occurs can be difficult. However, the rate of change of stiffness is important as it determines whether a material just becomes gradually less stiff as it is heated, or whether it suddenly changes. The first transition (Tg<sub>1</sub>) is measured by taking the intersection of the two tangents (A and B) shown in the diagram, and is a good indicator of the onset of significant changes in the stiffness and hence other mechanical properties of the product. Other transition points can also be taken (Tg<sub>2</sub> and Tg<sub>3</sub>), although these are less common.

The peak in the loss tangent curve is usually much more sharply defined, and for this reason is widely quoted when drawing comparisons from one product to another. This figure is quoted in the data tables as Peak Tan  $\delta$ . The equipment used for all the DMTA work is a Rheometric Scientific DMTA Mk III, operating in flexure mode at 1Hz and 3°C/min. ramp.

### Tg Ult. (Ultimate Tg)

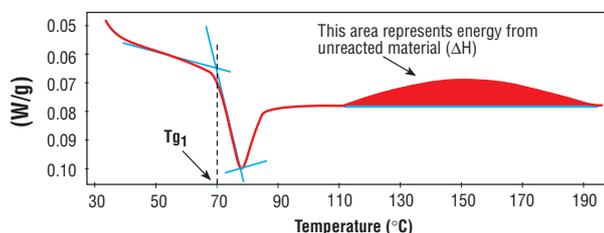
The Tg of a material is strongly related to the degree of cure of the material, and in turn is affected by the temperature and time (energy) of the cure applied. Many slow curing systems will never achieve a full cure however long they are left at ambient temperature, because they will never receive enough energy. An elevated temperature postcure is frequently used to supply enough energy to complete the cross-linking reaction and to push up the Tg, and hence possibly the operating temperature.

With the exception of certain tooling materials and catalytically cured products, as a general rule the Tg<sub>1</sub> achieved during a postcure will increase with increasing postcure temperature but will not exceed the postcure temperature itself. However, this does not mean that any Tg can be obtained if the postcure temperature is simply high enough. The fully cured (and therefore fully cross-linked) molecular structure will have a limit above which the Tg cannot be increased, however much more energy is applied. This is known as the Ultimate Tg, and is achieved by postcuring the material at a temperature

considerably above its normal T<sub>g</sub>, until there is no possibility of the T<sub>g</sub> being increased further. The Ultimate T<sub>g</sub> data presented here is based on the Peak Tan δ achieved after a postcure of 1 hour at 150°C. By comparing the T<sub>g</sub> (Peak Tan δ) achieved after a given postcure with the Ultimate T<sub>g</sub> (Peak Tan δ), an indication can be obtained of how near to the potential T<sub>g</sub> of the system, a particular postcure cycle will get.

### ΔH - DSC

An alternative method of measuring T<sub>g</sub> is through the use of a DSC (Differential Scanning Calorimeter). Using this technique, the heat flow in and out of a small sample of cured polymer can be measured as the sample is heated. At the T<sub>g</sub>, large amounts of energy are absorbed by the sample in order to allow the molecular structure to rearrange. This energy absorption can be plotted, and tangents taken in a similar way to those taken in measuring T<sub>g1</sub>-T<sub>g3</sub> on the DMTA above. DSC T<sub>g</sub> data is never quite the same as that from a DMTA, as the DMTA and DSC measure two different properties (stiffness and heat flow respectively) that are both undergoing changes around the Glass Transition Temperature. However, the results the two techniques produce are broadly in line with each other.



The DSC has a further use, however, in that since it is measuring heat-flow, it can show the residual heat flow from the reaction of any unreacted epoxy left in a sample after a given cure cycle. This is given here as ΔH, and is measured in J/g i.e. the residual energy (Joules) left in a gram of material. In a fully cured material, this residual energy is virtually zero, as all epoxy groups are reacted. The more a material is postcured the closer ΔH will get to zero. The tables show how fast curing systems will tend to get close to zero with an ambient temperature cure, while slower curing systems need elevated postcures to achieve this. As a rough guide, most of Gurit's solvent-free epoxy systems would produce about 400J/g in going from the fully liquid state to the fully cured state. This means that a cured material which exhibited a ΔH of 20 J/g could be considered to have achieved approximately 95% of the theoretical maximum cure.

### HDT - Est

A further indication of the temperature at which a material begins to soften is the HDT (Heat Distortion Temperature). This is usually determined by heating a cast bar of the resin system in an oil bath, and measuring its deflection under an applied flexural load. ISO Standard ISO75-1 covers this.

Although it has been used for a long time, and is still widely quoted today, it is a crude method in comparison to the DMTA which measures the same property (stiffness change), but in a much more controlled way and to a higher degree of accuracy. Empirical testing of a wide range of products at Gurit has determined an approximate correlation between T<sub>g</sub> (Peak Tan δ) and HDT, which has been used here to generate an 'Estimated HDT', by the formula:

$$\text{HDT (Est.) } ^\circ\text{C} = (\text{Tg (Peak Tan } \delta) ^\circ\text{C} - 15^\circ\text{C}) \text{ to an accuracy of } \pm 5^\circ\text{C}$$

### Cured Density

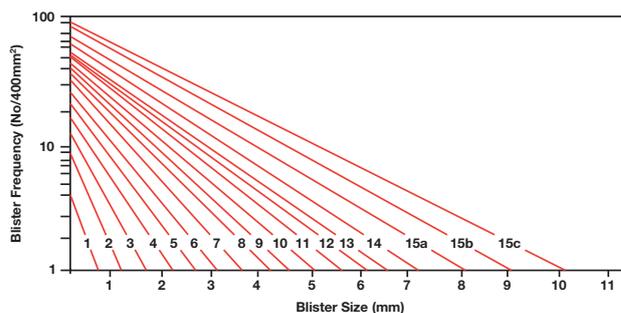
This has been determined by weighing cured samples in air and water.

### Moisture Absorption

Cast samples to BS2782: Part4: Method 430A are fully immersed in distilled water at 35°C, and the weight change is measured after 28 days. This is the required test temperature and time for Lloyds approval of resin systems for marine applications. Moisture absorption of a cast resin on its own can be misleading as it is equally important to know what effect the absorbed moisture has on a laminate's properties. Many hydrolysable resins, such as polyesters, may pick up low quantities of moisture in a casting, but in a laminate that moisture will cause deterioration and damage, and, in extreme cases, osmotic blistering. For this reason this data should always be looked at in conjunction with other wet property retention data.

### Blister Rating

For coatings and gelcoats that may be immersed in water, the blister rating gives an indication of how water-resistant the coating is. The test exposes one side of a coated laminate to a distilled water bath at 50°C for three weeks, in order to accelerate the ageing effects of the water. The number and size of the resultant blisters is graded and a rating assigned from the chart below. A low rating indicates good resistance.



### Linear Shrinkage

An indication of the amount that a liquid product shrinks when transitioning from the liquid state to the fully cured state. It is calculated from the formula:

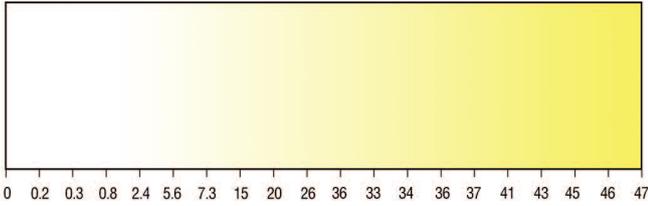
### Barcol Hardness

A measure of the resistance to penetration of a sharp point under a fixed load, applied by a standard Barcol Hardness tester. The higher the number, the harder the material. Barcol hardness can be used as a basic determination of how cured a material is, or as an indication of the wear resistance of a surface.

### Yellowing Index

Most epoxies will gradually turn yellow on exposure to UV light such as that from the sun. The Yellowing Index provides an indication of how rapid and severe this colour change is, so that for applications which require colour stability and clarity, the correct product can be chosen. In the gelcoats section, the comparative graph shows the indices of the epoxy products, and also compares them with a standard isophthalic polyester gelcoat, as this is often used in many UV-exposed applications. The test is carried out by exposing coated panels to a UV/heat/moisture cycle in a QUV accelerated weathering machine. This simulates typical outdoor weather, and provides useful comparisons between products, although these cannot accurately be correlated to a time in real outdoor conditions. A Minolta colour analysis spectrometer is used to measure the change from the unexposed condition, and the following chart provides an indication of what this colour change looks like if

taken from the background white of the page. The test is based on the ASTM D1925 and ASTM E313.



## MECHANICAL PROPERTIES

### Casting Tensile Strength, Modulus & Strain to Failure

Carried out on laminating resins on a casting of the unfilled resin/hardener mix, postcured as specified, and then tested to BS2782: Part 3: Method 320C

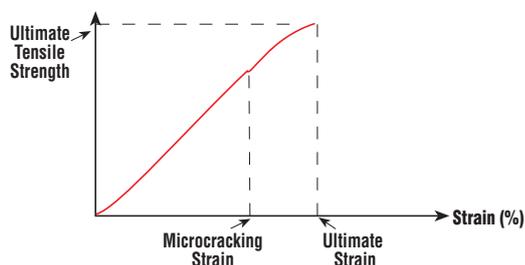
### Glass Laminate Compressive Strength

The compression strength of a laminate is one of the mechanical properties that is dependent on the properties of the resin system, rather than just on the properties of the reinforcing fibres. In compression testing the resin system has to hold the fibres straight as columns, so that they can carry their full loads before they fail themselves. In many designs, the compression strength of a laminate is the limiting factor, since most laminates are weaker in compression than they are in tension. The compression testing here was carried out to a modified ASTM D695. Laminate was 10 plies RE300, (industry style 7781, 8-harness satin glass yarn fabric), vacuum infused at 1 atmosphere.



### Glass Laminate Microcracking Strain

When a laminate is loaded in tension, at some point before ultimate failure occurs, the laminating resin system may begin to crack away from the fibres at 90° to the load applied. Although no fibres have broken at this stage, small fissures will begin to open up in the laminate, and these over time, and particularly under cyclic (fatigue) loading, may spread and cause further damage; they will also increase the rate of moisture pick-up. The strain at which this occurs is known as the microcracking strain, and should be taken as the maximum strain to which a laminate should be allowed to go, under normal service conditions. Many brittle and low-adhesion resin systems, particularly polyesters, have very low microcracking strains, and so although the ultimate strength of the laminate may be high, only a small portion of this strength can really be used in design. The stronger and tougher the resin system, the nearer will the microcracking strain be to the ultimate strain, and as a result, a higher proportion of the laminate's ultimate properties can be used in design. The tensile tests were carried out to ASTM D3039 on the glass laminate described previously, and the microcracking point determined acoustically.



### Glass Laminate ILSS

Inter-Laminar Shear Strength (ILSS) is a measure of the shear strength of a laminate along the plane of a reinforcement layer. It is strongly dependent on the strength and adhesive properties of the resin which stops the laminate layers sliding over each other. The test is carried out to ASTM D2344 on the glass laminate described previously.



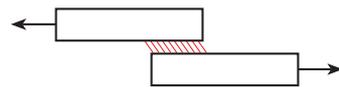
### ILSS Wet Retention

When a laminate is immersed in water, the resin system in the laminate will eventually absorb moisture to an equilibrium level. Since ILSS is a resin-dependent property, it can be used to see what effect the absorbed moisture has had on the

laminate mechanical properties. The ILSS data here is measured after 28 days full immersion in distilled water at 35°C, and is expressed as a percentage of the ILSS before immersion.

### Tensile Strain to Failure on Laminate

For a coating or a gelcoat applied to a laminate, this is the strain at which the gelcoat will crack. In many cases this may limit the strain to a level well below that which the uncoated laminate could be allowed to see before microcracking or ultimate failure occurred.



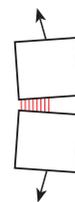
### Lap Shear Strength - Shotblasted Steel

This tests the shear strength of a resin system used as an adhesive by bonding two thick, overlapping steel blocks together and pulling them apart. It is carried out to the British Standard BS5350: Part C5: 1990.

This is one of the most severe shear tests that can be applied to an adhesive, since the steel blocks do not flex at all, and so cannot provide any stress relief to the joint. This is in contrast to the thin aluminium plates often used for adhesive testing, where the flexibility of the aluminium enables artificially high shear strengths to be obtained.

### Lap shear strength wet retention

The lap-shear strength test above is applied to test samples that have been immersed in distilled water at 35°C for 28 days. Expressed as a percentage of the pre-soak value, the retention figure gives an indication of the degradation of the adhesive strength in wet conditions.



### Cleavage Strength

This test pulls apart two steel blocks bonded together, by loading in a mode which will cause cleavage of the adhesive joint. This is a mode in which most adhesives are poor, and is generally avoided in design. However it gives a useful indication of the toughness of an adhesive and its resistance to cracking. The test is carried out to

BS5350: Part C1: 1990, and gives a load in kN at failure for a 25 x 25mm bond area.



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