FORGEWAY

GLUE WITH HIGH IQ

The Fundamentals of Adhesives

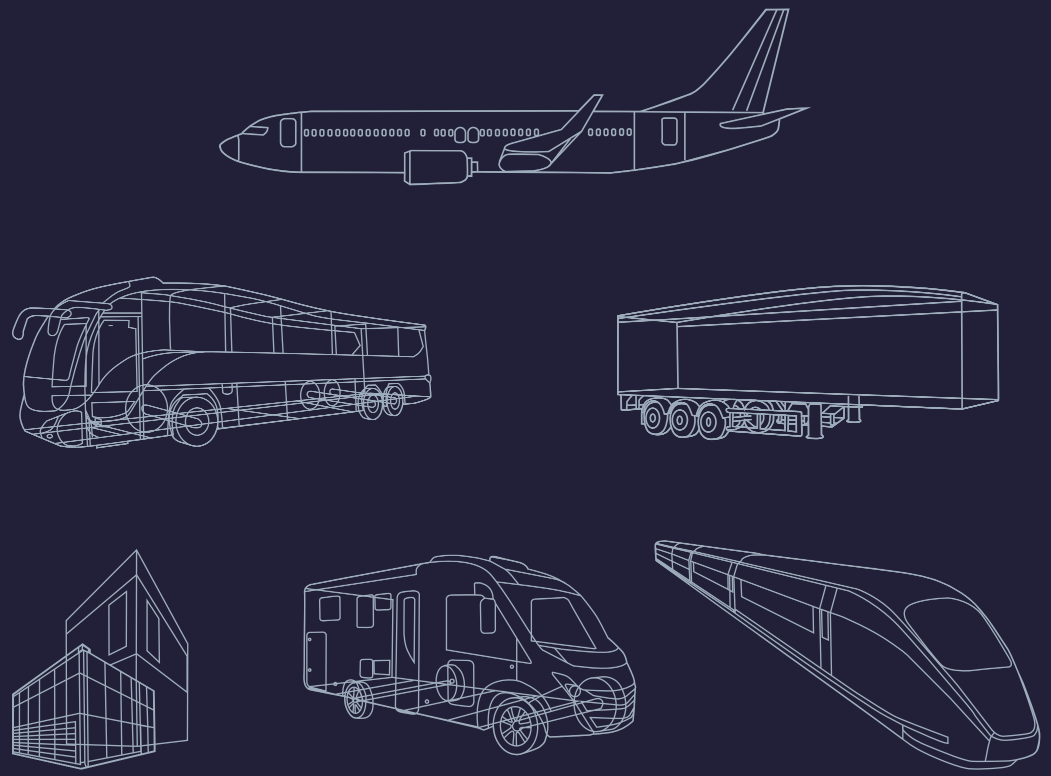
Third edition **2021**

Preface

This book has not been written by academics, it has been written by Forgeway's in-house R&D team, with first hand knowledge and experience working with customers to solve problems in the field.

This book has not been produced as a guide on what we can do for our customers, nor does it detail all the products we can provide for our customers. It has been written to provide a comprehensive and practical guide for engineers.

Our aim was to create something you could call an engineer's best friend, packed with useful information and informative diagrams to clearly explain the theories and science around adhesives and bonding.



Introduction

The content and insight within these pages is a compilation of 25 years of knowledge; developing and manufacturing adhesives for industries including transportation and solid surface. Forgeway's adhesive knowledge is extensive, from colour matched adhesives for worktop ranges, to formulating and producing adhesives for aero engine fan track liners that can withstand bird ingestion testing. Forgeway have collaborated with leading manufacturers in jet engines, solid surfaces, flooring for transportation and more.

Forgeway was established in 1994 after recognising a gap in the market. With the increasing need for vehicles to be lighter, safer and faster to build, it was evident that adhesives would be more likely to play a greater role in the future of manufacturing. There would be a need to support manufacturers wanting to make the change from mechanical fixings.

The adhesive industry was very much dominated by large companies with very little flexibility in what they could provide to their customers. It was evident that the bigger companies would not provide the personalised support needed to push the boundaries of what could be achieved with the use of adhesives. All of the products that Forgeway have developed and produced are in response to customer and industry feedback. We work with our customers to solve industry problems, because of this, there is a story behind each product and it's development pathway.

There have been some excellent books written that cover adhesives and bonding that go into great detail as to the science behind adhesives and bonding, but these are aimed more at academics than people working in the manufacturing industries. This book is a visual and practical resource for people wanting to know more about the uses of adhesives and how it affects the process of design in manufacturing.

Contents

Contents of tables and figures

01. The Forgeway Way

The Forgeway Way

You are reading this book because you have been sent it by one of the team who contributed to its contents, you requested a copy, or you have been given a copy because somebody else knows you need it. You will find the material contained in this book interesting and hopefully extremely useful if you use adhesives, own products which are manufactured using adhesives or would like to use adhesives but do not know where to start.

The team behind this book have taken science from the ivory tower of academia and put it within reach of every one of us and made it applicable to what we see all around us. We know that there is very little in the way of facilities or governing bodies that teach courses in adhesives and bonding. Universities and colleges tend not to teach the practical skills of adhesive application and as a result, we've often had requests for a more practical guide to help train operators.

The global adhesives market was estimated to be US$53 billion in 2019 and is estimated to reach US$85.7 billion by 2030. This growth, whilst there is huge opportunity there are challenges that must be faced or the consequences will be dire not only for man but for the environment and the world at large.

In this book and if ever you meet one of our team face to face or virtually, we use the power of questioning to provoke meaningful discussion so that you can actually answer your own question or problems. Our aim is to provide the question marks not the exclamation marks.

Most people continue reading through this book because they have a problem and they are looking for an answer. In most situations the book and the information contained within it will give an inkling or a clue and it will need further testing, measuring and evaluation to ascertain a full solution and the cause of any problem.

Your Problem

We will list below a few questions that often you the reader answer in your head but would recoil from writing down the answer. What we would say "hold on, help is very close".

1. Is it causing death or injury?
2. Has this issue been identified by artificial intelligence or predictive intelligence?
3. Who else is aware of this problem – police, health and safety, the authorities, media, the customer?
4. Will this be your biggest warranty claim ever?
5. Are your competitors aware?
6. What have you typed into Google to find an answer already?
7. Will this effect net profit by over 10%
8. Will it turn a square red on your risk matrix?
9. Will this impact your sustainability strategy?
10. Will this affect your company share price?

The questioning could go on, in fact there are probably over 100 more that could be asked right here and now. We want you to survive and thrive to see how the Forgeway 7 step process can work to help any company who is manufacturing products that need to be joined or coalesce together, last a lifetime, including recycling, recovery and responsible and safe disposal some 50 years later.

The Forgeway Way

There is a step by step methodology behind how we work and each step must not be confused, bypassed or viewed on its own. The following is what lies behind a tenacious quest to find the reason why something is behaving the way that it is.

The steps are as follows: -

Listen intently to the customer as they articulate their problem and ask for evidence of the problem. Understand why this is an issue for the customer and the whole stakeholder group. Monetising or putting a cost on the problem is critical right from the outset.

Identify the problem and confirm that this is indeed an issue and is having a significant impact from mortality to monetary and if not addressed will escalate.

Identify the root cause of the problem including simulated repetition or mirroring of the issue through accelerated testing and simulation.

A holistic view including the interdependence of other substrates, materials, environmental and geo-political factors are considered and what effect these have on a recommended solution.

Design and develop a solution to the problem including small scale production which is then tested through various accelerated programs to demonstrate the effectiveness of the solution.

The final solution can be scaled up in production from 0.100Kg to 1000Kg.

The tested and measured scaled production can either be passed to a third party for manufacture or we would pass it to our manufacturing sister organisation.

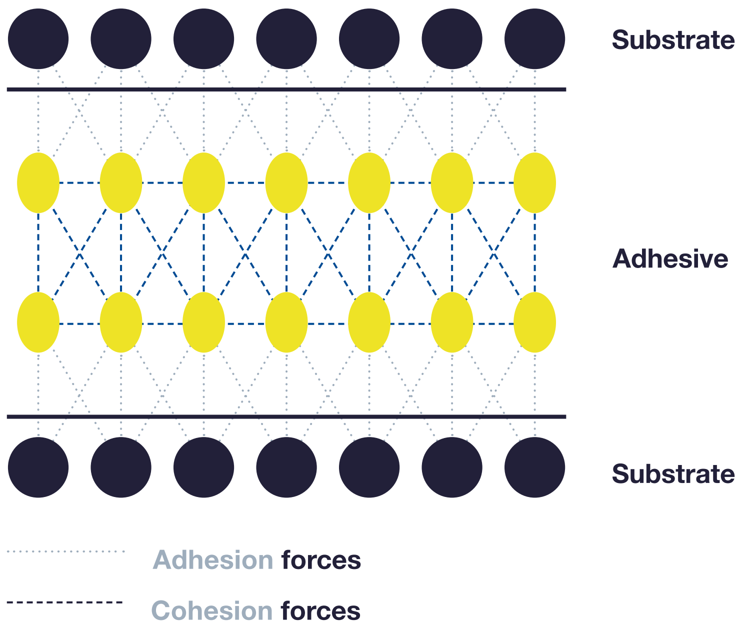
02. What is an adhesive and what is bonding?

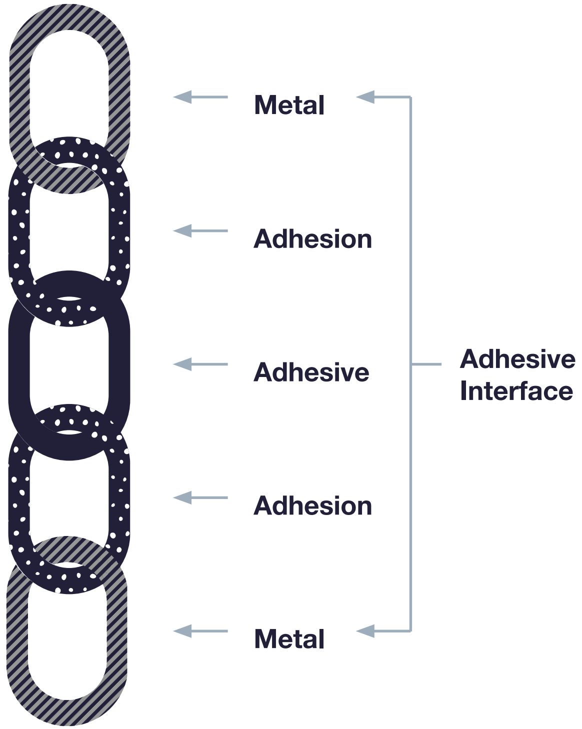
What is an adhesive and what is bonding?

An adhesive is a substance capable of holding dissimilar or similar materials together by surface attachment.

Adhesives are polymer-based materials that can be used to join a wide variety of different surfaces together without the need to create discontinuities in the substrate materials, e.g. rivets, screws and bolts.

Adhesion and cohesion





Adhesion

The phenomenon of adhesion is caused by molecular interactions between the substrate surface and the adhesive. If no molecular interaction occurs between the substrate and the adhesive, then no bond will form.

Cohesion

Cohesion is defined as the internal strength of an adhesive as a result of a variety of chemical interactions within the adhesive (polymer matrix).

Diagram showing adhesive failure

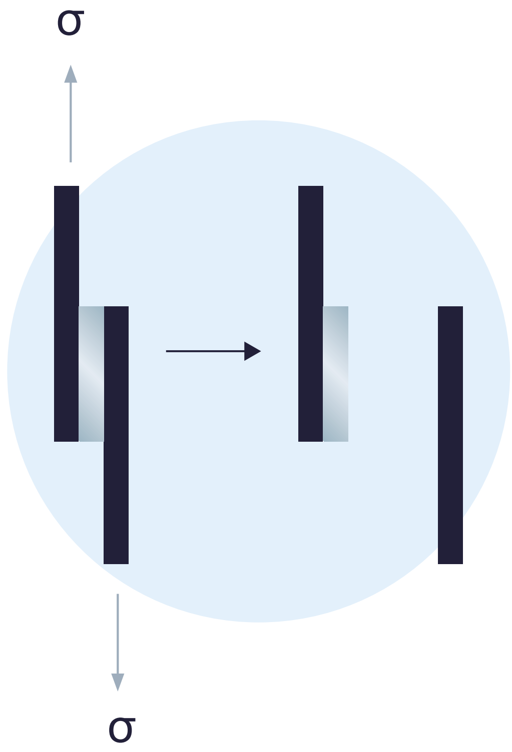
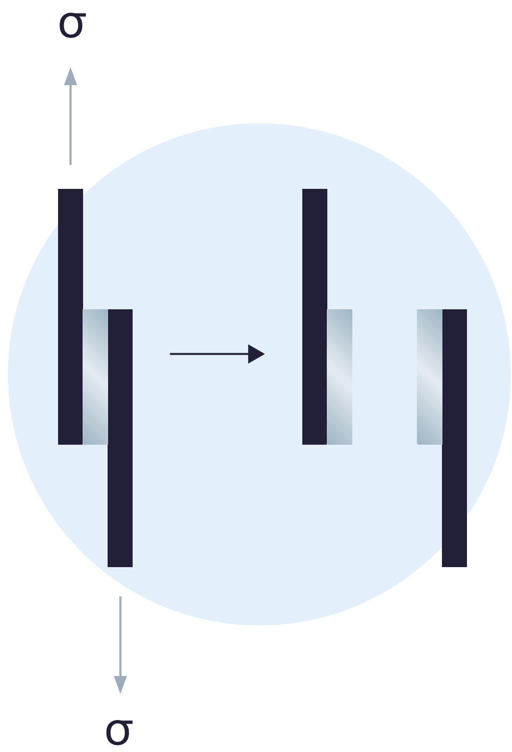


Diagram showing cohesive failure



Both adhesion and cohesion play their part in maximising the strength of a bond. In the same way that a chain is only as strong as its weakest link, the weakest link in a bonded joint determines what loads the joint can be subjected to.

03. Advantages and disadvantages of adhesive bonding

Adhesive bonding

Advantages

- Ability to join dissimilar substrates / materials together; of different geometries, sizes and compositions
- Provides flexibility of a joint
- Sealing properties (filling gaps and voids) to maintain a watertight bond
- Can provide electrical or thermal conductivity or insulative properties
- Good fatigue resistance
- Reduces the corrosion rate
- Good vibration damping properties
- Uniform distribution of stress over the bond area
- Eliminates damage to the structure of the material
- Reduction of noise

Disadvantages

- Requires careful substrate surface preparation
- Long mixing and curing times may be required
- Importance of correct joint design
- Difficult disassembly of adhesively joined parts
- Service temperature and environment limitation
- May change properties during service life

Stresses are absorbed through the substrate and adhesive, minimising the impact through the substrate and joint. The bonded joint remains flexible to allow for movement and reduces noise.

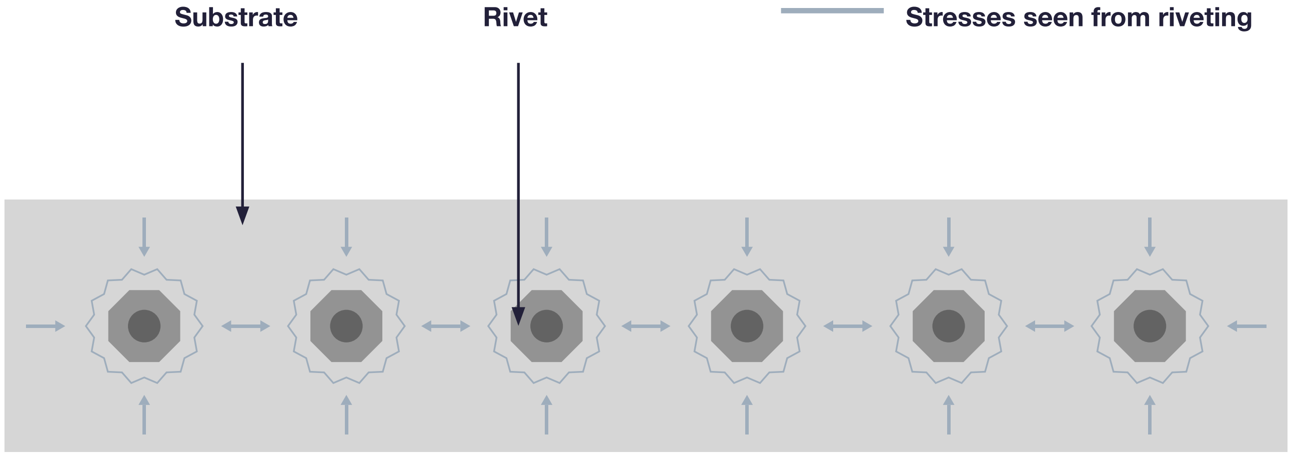
Riveting

Advantages

- Cheap
- Increases production output due to easy assembly
- Available in different materials and different strengths
- Easy inspection and maintenance

Disadvantages

- Requires a lot of people to complete a riveting process
- Increases weight
- Not aesthetically pleasing
- Contributes to corrosion
- Noisy
- Substrate has a tendency to stretch around the joint area; increasing movement and vibration



Stresses are concentrated through the riveted area on the substrate. As the joint starts to move, the impact is increased around the joint area; causing the substrate to wear around the rivets. The substrate then has increased movement around the riveted area; giving rise to noise and vibration.

04. Types of adhesive

Types of adhesive

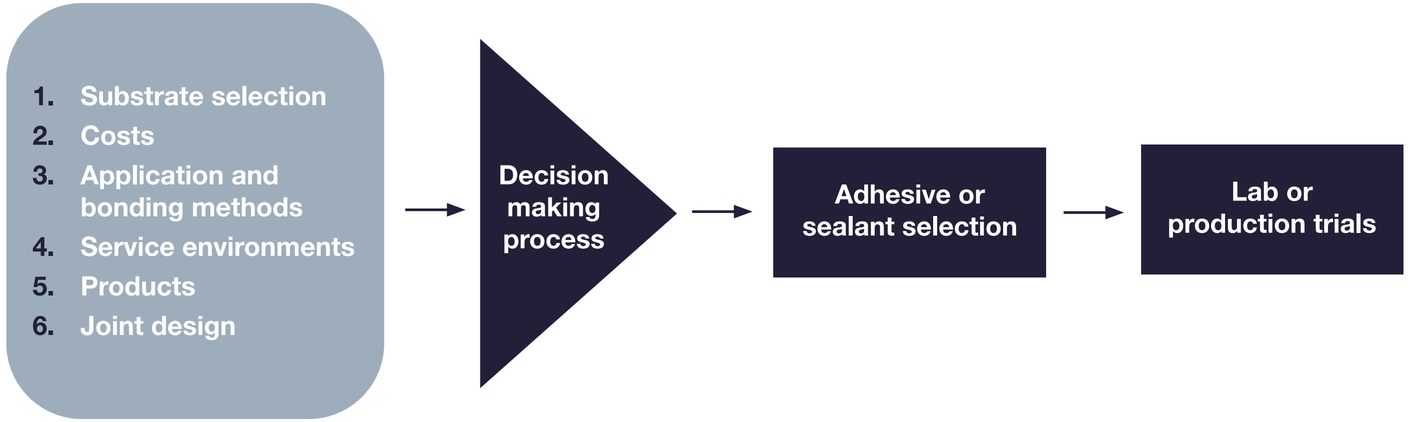
This chapter will focus upon adhesive selection and the most common types of adhesives used within industry. There are many adhesives and sealants on the market today, however we will only concentrate on a small selection. These are detailed below:

- **Adhesive selection**
- **MS polymer**
- **Epoxy adhesives**
- **Polyurethane adhesives**
- **Methacrylate adhesives**
- **Silicones**
- **Pressure Sensitive Adhesives (PSA)**
- **Hot melt adhesives**
- **Parquet adhesives**
- **Conductive and non-conductive adhesives**
- **Anaerobic adhesives**
- **Cyanoacrylate adhesives**

Adhesive selection

Adhesive selection **involves the following considerations:**

1. **Substrates:** What are you trying to bond? Are the surfaces the same or dissimilar, porous or smooth? Are you covering a large area?
2. **Cost associated with manufacturing:** Are the adhesive properties compatible with processing time requirements?
3. **Application restrictions:** How do you intend to apply the adhesive?
4. **Ease of inspection after bonding:** Can the bonded area be easily serviced or checked?
5. **Use requirements:** How does the bonded piece get used? How much strength is required? What kind of environments might it see? Will it experience temperature extremes and / or high humidity?
6. **Joint design:** What type of stress will the joint see in service?



MS polymer

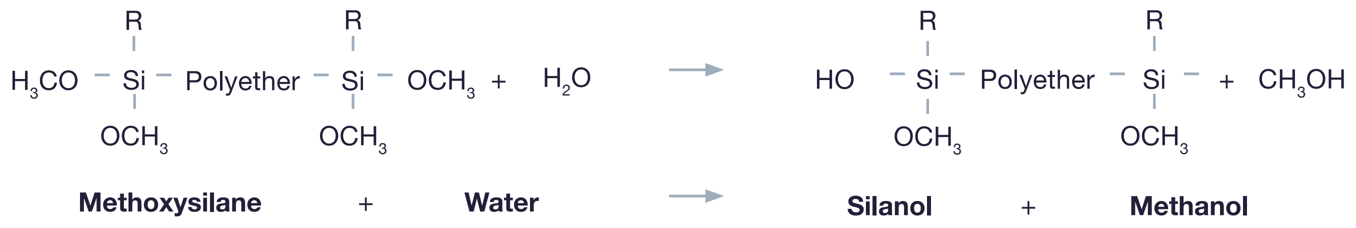
MS polymers are seen to combine all of the ‘best bits’ of a one component polyurethane and silicone. This is due to modified silane chemistry having a high weathering resistance (silicone technology) and high performance properties (polyurethane technology).

They can be supplied in a one component foil pack, cartridge or in a two component cartridge. The difference in the two are the speeds in which they cure and the performance that they offer in a given amount of time. One component MS adhesives are much slower to cure than two component as they require moisture from the air to penetrate the adhesive to cure and gain their initial to final strength. Whereas, two component MS adhesives are much more rapid on through cure and strength initially, due to their included water component.

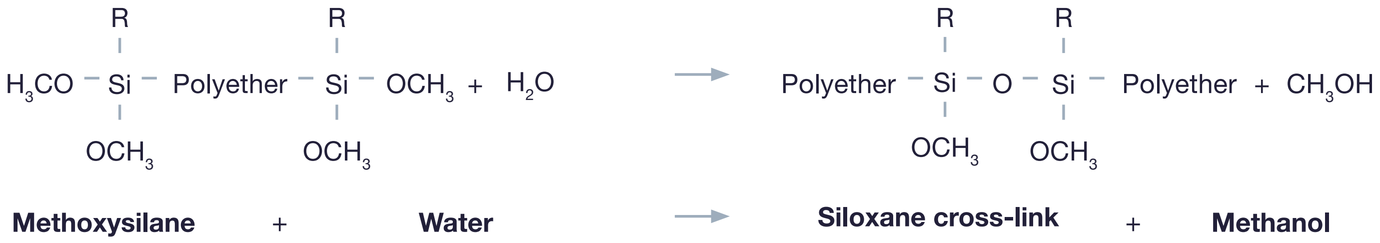
Chemistry

MS polymers react with moisture in the air to form a fully cross-linked solid from a fluid paste.

Step 1



Step 2



See page 163 for CASE STUDY on 1K vs. 2K

Advantages

- Weather resistant
- Durable
- Stain resistant
- Good adhesion to many substrates
- Low odour
- Environmentally friendly
- Good shelf life
- Can be over-painted
- Can be used to join dissimilar materials
- Less dependent on temperature changes – stays fluid for ease to ‘gun out’

Disadvantages

- Time to cure (one component) – through cure is dependent on area of adhesive and accessible moisture
- Removal / disassembly of the joint for repairs
- Involves some surface preparation to obtain and maintain good adhesion

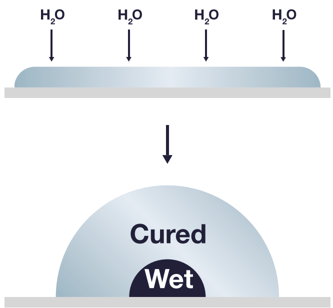
Where can MS polymer typically be seen?

The application of MS polymer is vast and there are many industries which require a tough, flexible bond:

- Bus and coach
- Truck body
- Trains and trams
- Aerospace
- Caravans and motorhomes
- Construction

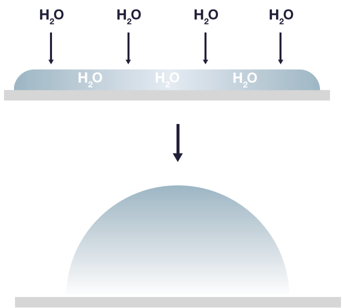
Curing mechanism

1K moisture curing



Curing from outside in

2K moisture curing



Curing through all gradients

Epoxy adhesives

Epoxies are also known as structural adhesives; due to their high stress loading capability. They are generally used to bond heavy duty materials over long service periods.

There are three types of epoxy resins chemically manufactured and used in industry:

1. **Bisphenol A -** Bisphenol A is cheaper, less viscous and has a good chemical resistance.

2. **Bisphenol F -** Bisphenol F is more viscous than Bisphenol A, has a better chemical resistance and is generally more expensive.

3. **Novalac -** Novalacs are very similar to Bisphenol F type epoxies; they are much more viscous, (almost solid) and have a better functionality and higher resistance to a greater number of chemicals.

The grade of epoxy used in a reaction will determine the overall properties of the structural adhesive.

Epoxies can be supplied in one component or two component systems. Two component systems are epoxies which require a hardener to fully cross-link and cure. One component epoxy systems use a latent amine which requires elevated temperatures to initiate the curing process.

Chemistry

Epoxies can be reacted with a variety of curing agents / hardeners to form an insoluble cured cross-linked network. The type of curing agent chosen will depend on the overall properties of the end product.

Types of curing agent:

- Amine – most common
- Anhydride
- Imidazole
- Acids
- Alcohols
- Mercaptans

The most common of these are amines, in which the below reaction can be seen:

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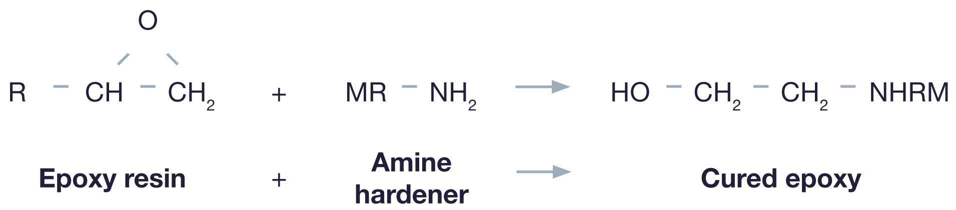


The speed of cure will rely on the epoxy equivalent weight of the epoxy and the number of active hydrogen's associated with the amine.

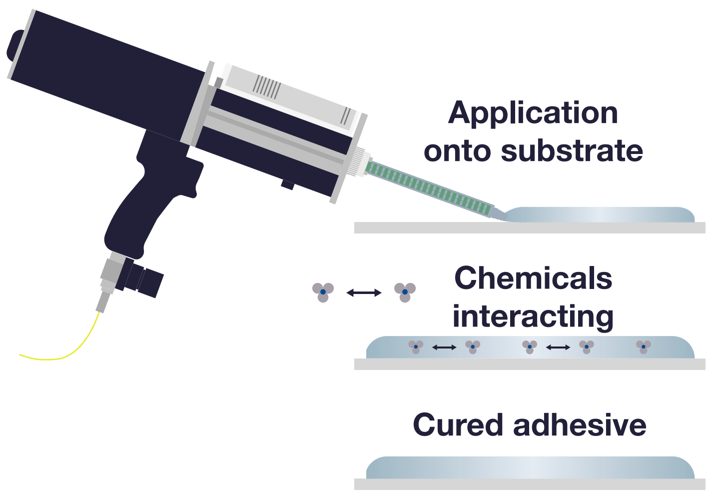
Advantages

- Good chemical resistance
- Low shrinkage
- Absorbs mechanical and thermal stresses
- Cheaper than some other methods of structural bonding
- High fatigue resistance
- Can be used to join dissimilar materials together with little surface preparation

Disadvantages

- Possibility of poor heat resistance
- Can be brittle
- Hard to break bonds once cured – making repairs difficult
- Can produce a high exothermic temperature when curing

Curing mechanism



Where are they used?

- Floorings
- Paints and emulsions
- Light weight void fillers
- Aerospace
- Truck and body

Polyurethane adhesives

Polyurethanes are made from reacting an alcohol with two or more reactive –OH groups (diols, triols, polyols) with an isocyanate, containing more than one reactive isocyanate group per molecule (diisocyanate, polyisocyanate).

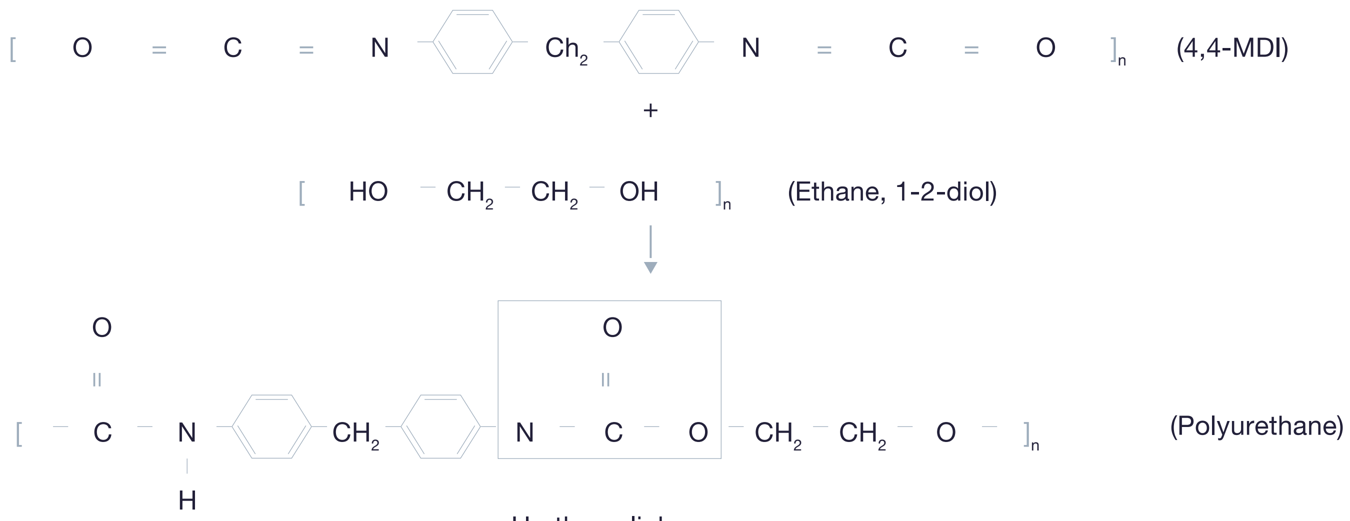
Polyurethanes can be manufactured as a one component adhesive or a two component adhesive. Just like MS polymers, the two component **polyurethane** will have a quicker cure time and higher strength initially compared to the one component **polyurethane**. The two component adhesive will be split out into the polyols and isocyanate groups and will react when mixed together. The one component polyurethanes are isocyanate terminated prepolymers that cure when reacted with moisture.

There are two main polyisocyanate groups which are key to industry:

- TDI – low density, flexible polyurethanes
- MDI – higher density, ridged polyurethanes

The structure, relative functional groups and weight of the overall **polyurethane,** influence the properties and final use of the product.

Chemistry



The more reactive groups which are associated with the isocyanate or polyol, the more ridged the polymer becomes when cured.

See page 163 for CASE STUDY on 1K vs. 2K

Advantages

- High durability at a relatively low cost
- High abrasion resistance
- Can be recycled
- Lower levels of VOC's than some solvented compounds

Where can they be seen?

- Paints and emulsions
- Solvent based coatings
- Construction insulation – ridged foam
- Automotive furniture – moulded foam
- Mattresses and cushions – flexible foams
- Transportation – flexible adhesive

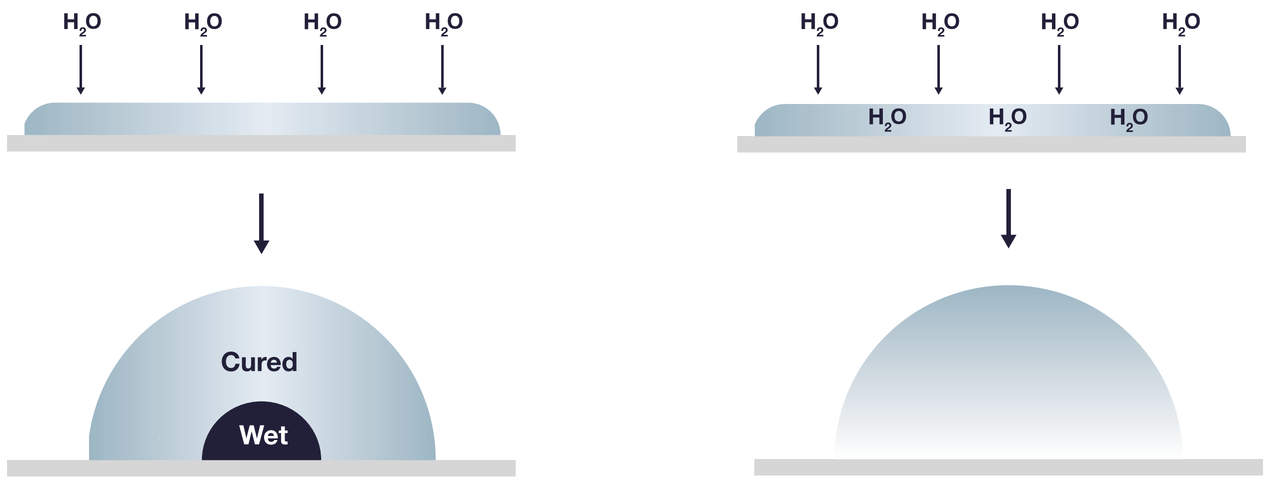
Disadvantages

- Puddles / marks over time
- More elastic than most polymers, therefore shows wear over time
- Can stain other substrates
- Poor UV resistance, leading to chalking, cracking and colour loss
- Tend to require primers in order to achieve a strong bond between substrates

Curing mechanism

1K moisture curing

2K moisture curing



Curing from outside in

Curing through all gradients

Methacrylate adhesives

Methyl Methacrylate Adhesives (MMA) are commonly used for structural applications, meaning they are required to withstand high loads of a variety of stresses for extended periods of time.

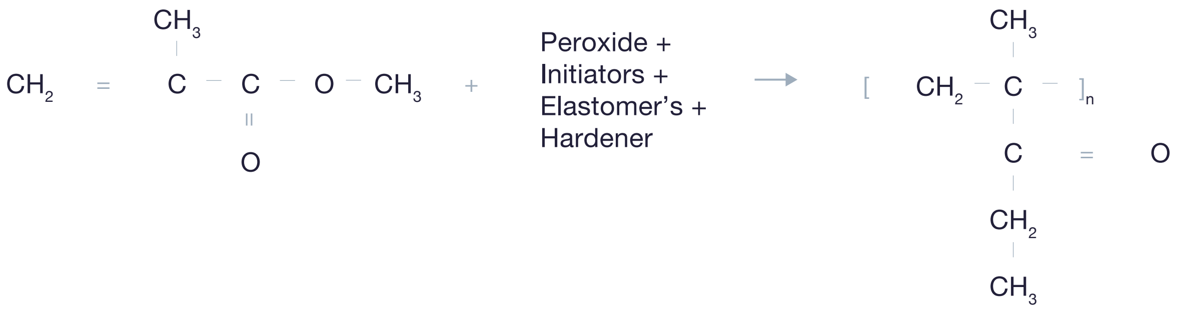
There are two fundamental types of **methyl methacrylate** adhesives:

1. **Chemically curing-** is supplied as a two component product. One of the two sides will contain the adhesive proportion with the accelerators and initiators, the other side will contain the hardener / curing component. When mixed together the curing agent will propagate free radicals in the initiator; which starts the process of cross-linking and thus curing.

2. **UV curing methacrylate -** is supplied as a one component product, it can be applied and left until curing is required. Photoinitiators within the product are activated by UV light which produce the free radicals needed to enable cross-linking to take place.

Chemistry

A two component reaction will follow the below reaction path:



MMA **PMMA**

Advantages

- Good UV resistance
- Good hydrolysis resistance
- Excellent adhesion build up
- Good solvent resistance
- Good temperature use range
- Easy application
- Excellent shear strength
- Good service life
- Able to join dissimilar materials
- Good shock dampener
- Can be applied to many substrates with little or no surface preparation

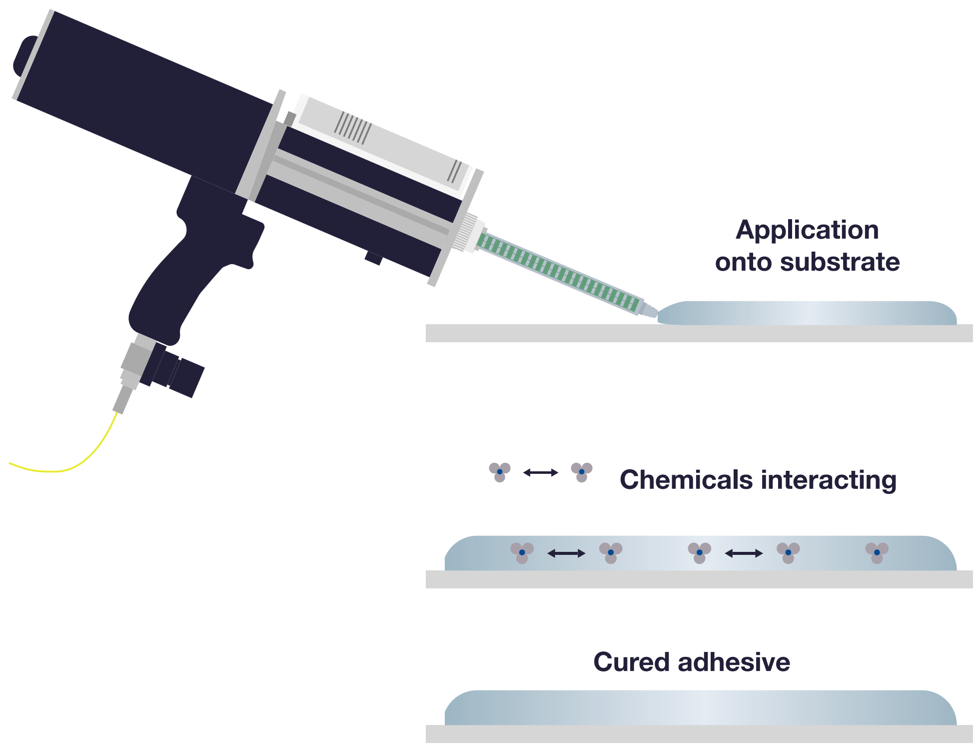
Disadvantages

- Poor creep resistance
- Can suffer from air inhibition, resulting in insufficient cure
- Strong smell from vapours when curing
- Produces high exothermic temperatures when curing

Where can they be seen?

- Transportation industry
- Decorative surfaces
- Aerospace

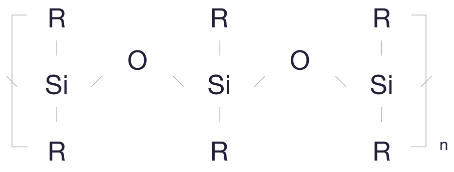
Curing mechanism



Silicones

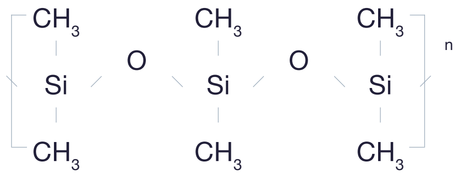
Silicones are synthetic polymers which are made up of a silicon-oxygen backbone.

Simple structure



R = variable organic group

Most common structure



The silicon-oxygen bond in the molecule gives it its thermal stability. The 'R' groups on the simple structure can be altered by substituting different organic groups. Doing so can allow you to optimise specific properties of the silicone.

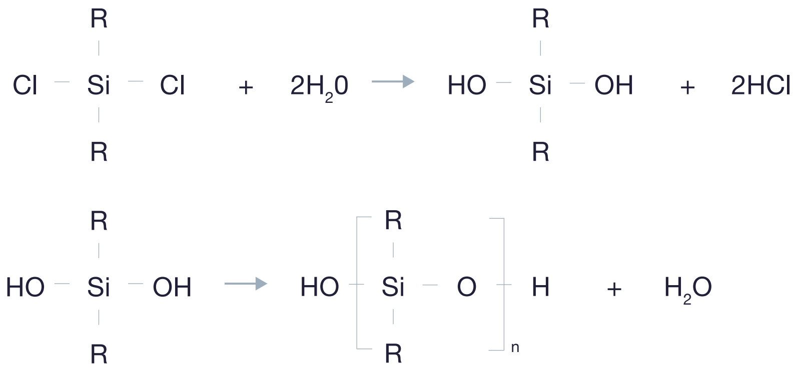
Chemistry

Manufacturing from pure silicon requires a three step process:

1. Synthesising chlorosilanes
2. Hydrolysing chlorosilanes
3. Condensation polymerisation

1. $Si + 2CH_3Cl \rightarrow (CH_3)_2SiCl_2$

2.



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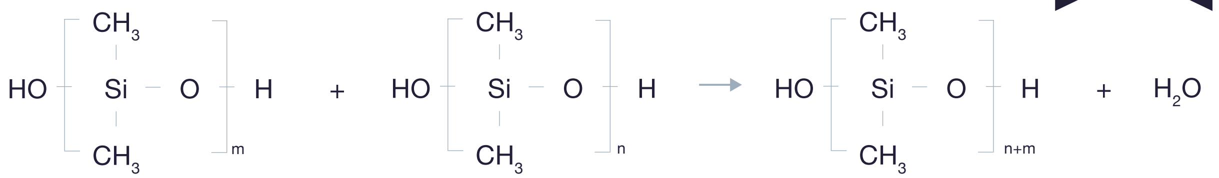
See page 163 for CASE STUDY on 1K vs. 2K

3.



Advantages

- Excellent chemical resistance
- Excellent solvent resistance
- Wide temperature range ~ +73°C to +260°C (+163.4ºF to +500ºF)
- Good oxidization resistance
- Good adherence to low and high energy surfaces

Disadvantages

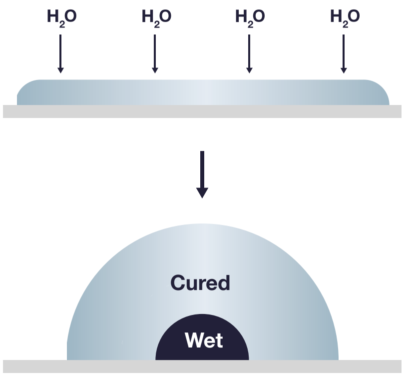
- High cost
- Lack of aggressive behaviour
- Stains easily – bleed out due to low molecular weight
- Poor over-paintability characteristics
- Poor mechanical properties
- Smell

Where can they be seen?

- Silicone fluids and gels
- Automotive – protection of electronics
- Cooking equipment
- Medical applications – dressings, medical tubes and orthopaedic products
- Windows and façades

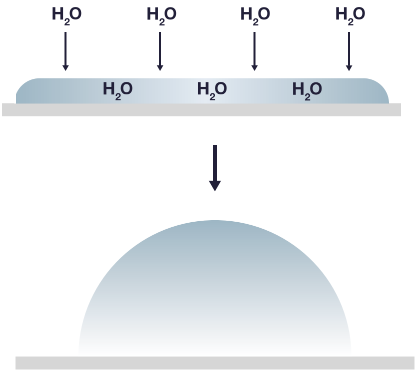
Curing mechanism

1K moisture curing



Curing from outside in

2K moisture curing



Curing through all gradients

Pressure Sensitive Adhesives (PSA)

PSAs are non-curing adhesives and are required to maintain a continuous high tack under pressure. The bonds are made by inducing contact between the adhesive and the substrate and applying pressure. If inadequate pressure is applied during processing, the adhesive may bubble or de-laminate from the substrate.

Pressure sensitive adhesives can be found in two forms:

1. Contact adhesive - Is a tackified product which is usually a flowable liquid supplied in a solvent carrier. Once applied to a substrate, the solvent flashes off to reach a permanent aggressive tack.

2. Tape - Tapes on the other hand are solid tackified adhesives which are supplied on a carrier; a film, fibre or fabric. Tapes can be supplied single-sided or double-sided, with the same liners on both sides or different. A beneficial property of double-sided tape with different liners is that you can choose a different adhesive type on either side if the substrates are dissimilar.

Chemistry

There is no real reaction chemistry involved in PSAs, the bonding forces (covalent bonds) are made when sufficient pressure is applied to the adhesive and the substrate to allow the adhesive to 'grab on' to the substrate allowing adhesion to occur.

Advantages

- Instant fixture is made
- Thin controllable bond line
- Flexible
- Simple application (tapes)
- Can be used as a temporary hold during processing

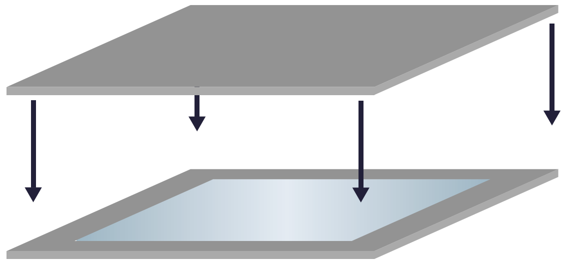
Disadvantages

- Low bond strength
- Poor temperature resistance
- Poor load bearing capabilities – undergoes creep when subjected to high loads
- Can be hard to handle (liquid applications)

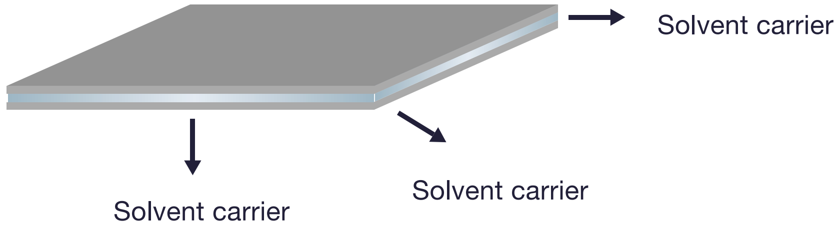
Where can they be seen?

- Labels
- Tapes – duct, masking, double sided, single sided, electrical
- Medical dressings
- Postage stamps
- Graphic films

Application of PSA onto substrate



Apply pressure onto another substrate



Permanent tackified fixture

Hot melt adhesives

Hot melt adhesives are an example of a thermoplastic material. A thermoplastic material is one which does not cure or set when under heated conditions. At room temperature they are solid materials and melt when they are heated. They form cohesive bonds when they cool down and solidify onto the selected substrate. These types of adhesives can be reheated at any stage once in their solid form for removal or maintenance of the bond, deeming them a reversible reaction.

Hot melts can also be found in a flowable state if they are dissolved in a solvent or water. The bond is then formed when the solvent evaporates from the adhesive, causing it to harden.

Chemistry

There is no complete reaction chemistry involved in the process of hot melt adhesives. Good adhesion is formed through strong covalent bonds when the adhesive is cooled down and hardened. The covalent bonds maintain adhesion with the substrate until it is reheated.

Advantages

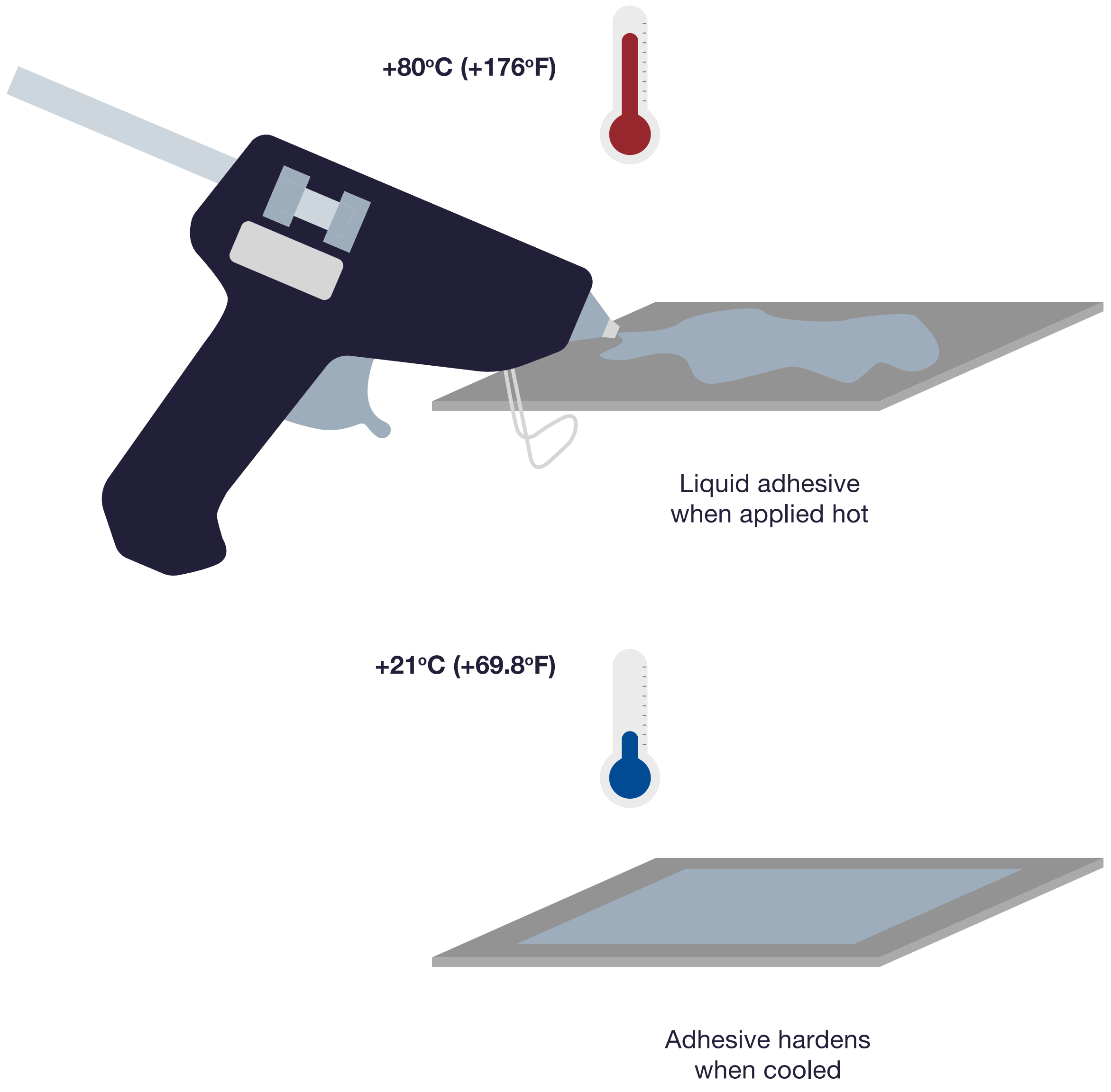
- Can be solvent free (in solid form)
- High production processes due to rapid setting times
- Wide range of adhesion
- Bonds are made quickly without a drying process
- Low cost
- Easy to use

Disadvantages

- Limited in performance
- Poor corrosion resistance
- Poor water resistance
- Subjected to creep under elevated temperatures or stress

Where can they be seen?

- Packaging
- Labels
- Manufacture of shoes
- Textiles
- Crafting
- Manufacture of furniture
- Electronics



See page 163 for CASE STUDY on 1K vs. 2K

Parquet adhesives

Parquet adhesives can be made from MS polymers or polyurethanes, using the chemistries referred to earlier in the corresponding technologies (pages 14 - 15 and pages 18 - 19).

Parquet adhesives are predominantly used in the assembly of hard floorings. The adhesive used is generally required to have the following properties:

1. Ease of extrusion
2. Rheological properties – free standing, ease of tooling up
3. Adhesion to a variety of wood types, concrete, ceramic and subflooring
4. Long term elasticity
5. Long term stability

Changing the properties of the adhesive can lead to three different subcategories of parquet adhesives:

1. Elastic
2. Hard elastic
3. Hard

Adhesive selection is based upon application of the parquet adhesive and what service conditions it is expected to see during its lifetime. Hard elastic adhesives are becoming more popular in the industry, as they do not wear as quickly as hard adhesives.

Chemistry

Based on the modified silane polymer chemistry and polyurethanes: see these sections for more information (pages 14 - 15 and pages 18 - 19).

Advantages

- Adhesive selection gives a variety of parquet applications
- Can be solvent and isocyanate free
- Easy to use

Disadvantages

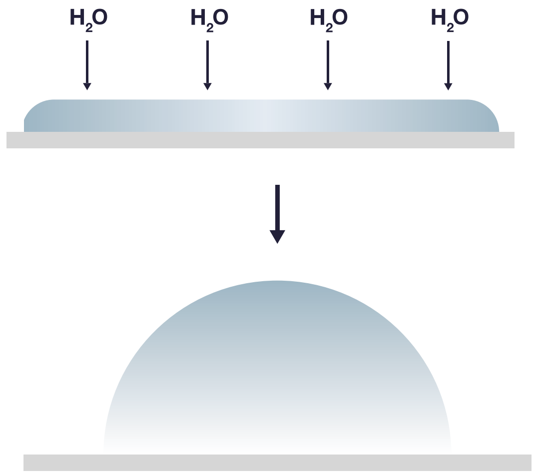
- Application is limited
- Flooring must be cleaned prior to use

Where can they be seen?

- Ceramic tiles
- Wood flooring
- Decking

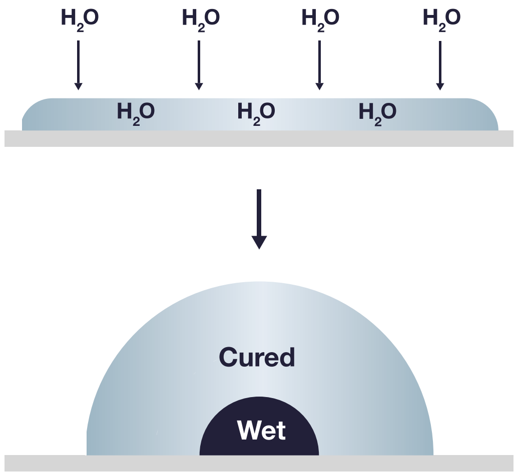
Curing mechanism

1K moisture curing



Curing from outside in

2K moisture curing



Curing through all gradients

Conductive and non-conductive adhesives

Electrically conductive adhesives are a method of bonding electrical components in an environmentally friendly manner; due to their lead and solvent free compositions.

There are two types of **conductive adhesives:**

1. Isotropic – electrically conductive in all directions when bonded. They are highly filled systems and can replace soldering techniques in circuit boards.

2. Anisotropic – when compressed they are only conductive in one direction (Z plane). They contain low levels of conductive filler.

Adhesives can be made **electrically conductive** with the use of metallic or **conductive** carbon particles. The conductivity of an adhesive can be altered depending on the ratio of filler / polymer. However, increasing the conductivity by increasing the total **conductive** filler can see detrimental effects on the adhesive properties. Therefore, finding the right balance is key!

Chemistry

Based on the chemistries of MS polymers and epoxies.

Advantages

- Reduced cost – process steps are reduced
- Environmentally friendly - no toxic components i.e. lead or solvents
- Low curing temperatures
- Good fatigue resistance
- Compatibility with a range of materials

Disadvantages

- Insufficient knowledge on performance capabilities
- Electrical performance during service life
- Compliance with company specifications

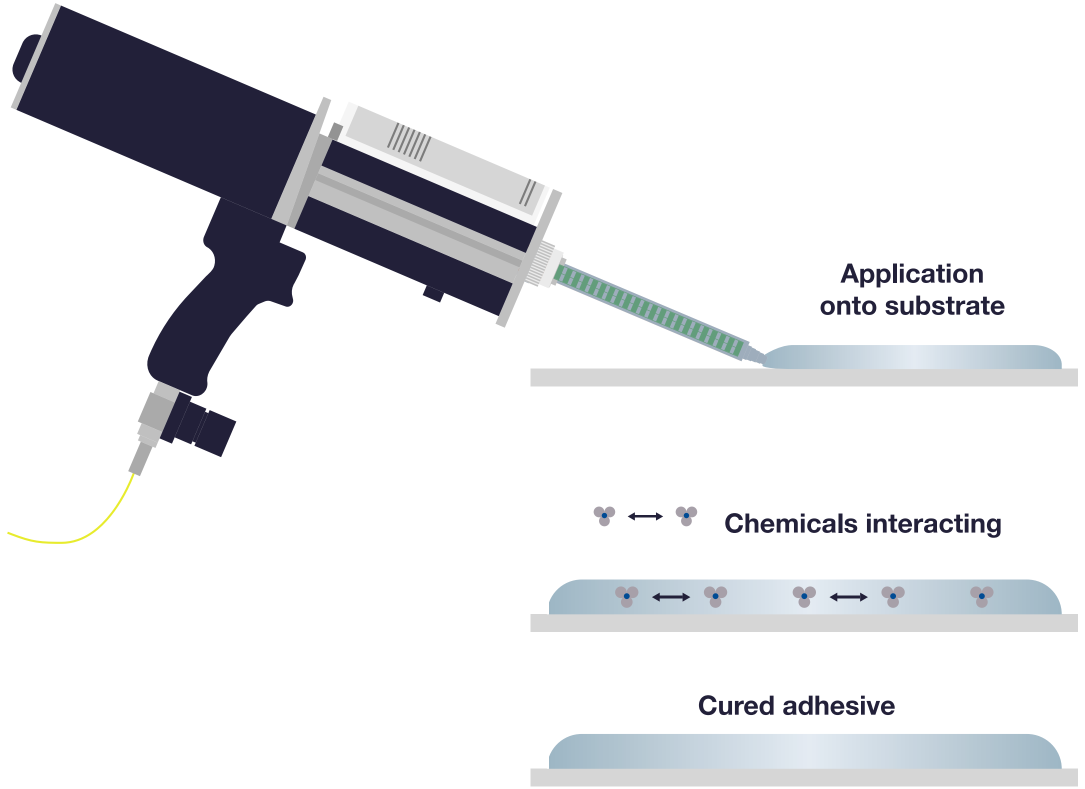
Where can conductive adhesives be seen?

- Electronics
- Solar cells
- Medical instruments
- Aerospace
- Automotive components

Non-conductive adhesives

Do what they say on the tin; do not allow electricity pass through them. These adhesive chemistries relate to MS polymer, epoxy, polyurethanes and some methacrylate adhesives; systems which are filled with standard fillers.

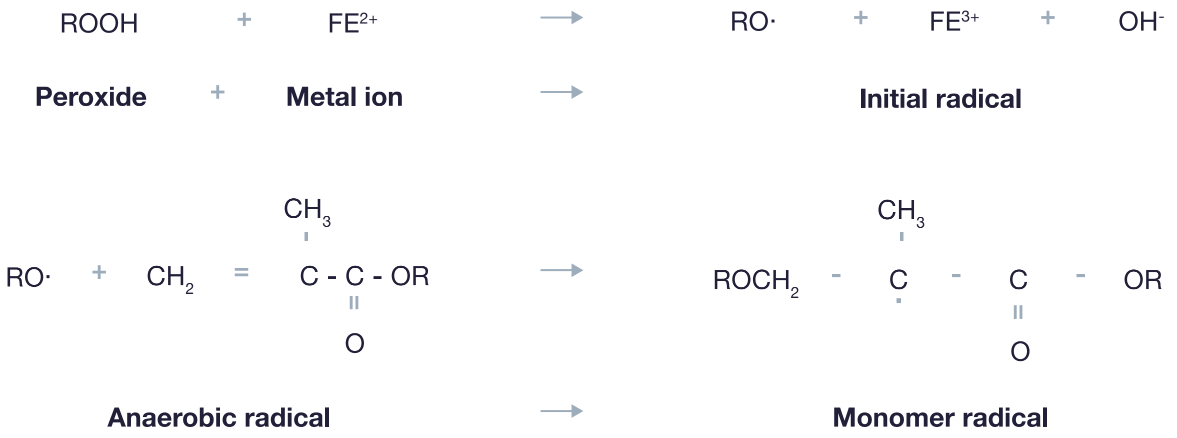
Curing mechanism



Anaerobic adhesives

Anaerobic adhesives are single component materials which cure in the absence of oxygen and in the presence of metal ions (iron or steel). As long as the adhesive is in contact with the air, the adhesive will not cure. When the adhesive becomes completely deprived of oxygen, the curing process begins rapidly.

Chemistry



Advantages

- Stability and consistency of performance
- No need to prime inactive metals
- Improved product reliability
- Superior product output
- Light weight
- Enhanced finished product
- Fast curing times
- Easy to apply
- Reduces corrosion risk
- Reduces fastener fatigue
- Removes the need for other fastening devices

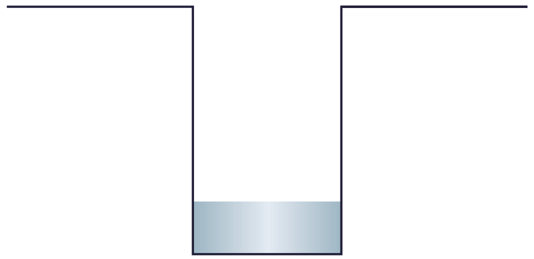
Disadvantages

- Brittle
- Limited gap filling
- Cure rate is surface dependent
- Can cause stress cracking on some thermoplastics
- Expensive

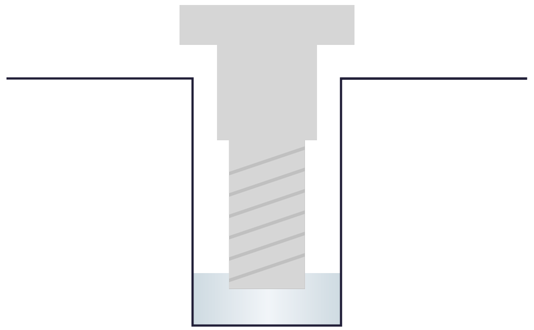
Where can they be seen?

- Thread locking
- Challenging applications to fill spaces and surface irregularities
- Mechanically connected assemblies
- Thread sealants
- Retaining materials; used to repair joints which were previously joined by a press fit
- Pipe sealants
- Gasketing; improving stress distribution

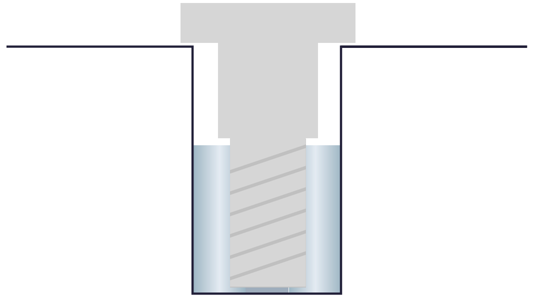
Curing mechanism



Adhesive liquid in the presence of oxygen



Rivet applied in the presence of oxygen
Adhesive remains liquid

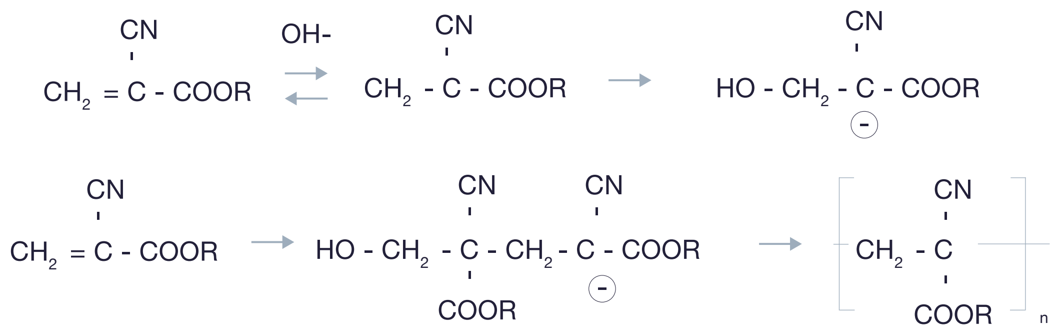


Oxygen removed, adhesive cures in the presence of metal ions

Cyanoacrylate adhesives

Cyanoacrylate adhesives are more commonly known as super glues / instant glues. They are single component, solvent free products which cure quickly when confined between two surfaces at room temperature.

Chemistry



R: Methyl, ethyl, alkyl groups ($-CH_3$, $-C_2H_5$, etc.)

Advantages

- Instant bonding
- Curing at room temperature
- One component, catalyst free
- High bonding strength
- High electric insulation capacity
- High chemical resistance
- Requires small volumes

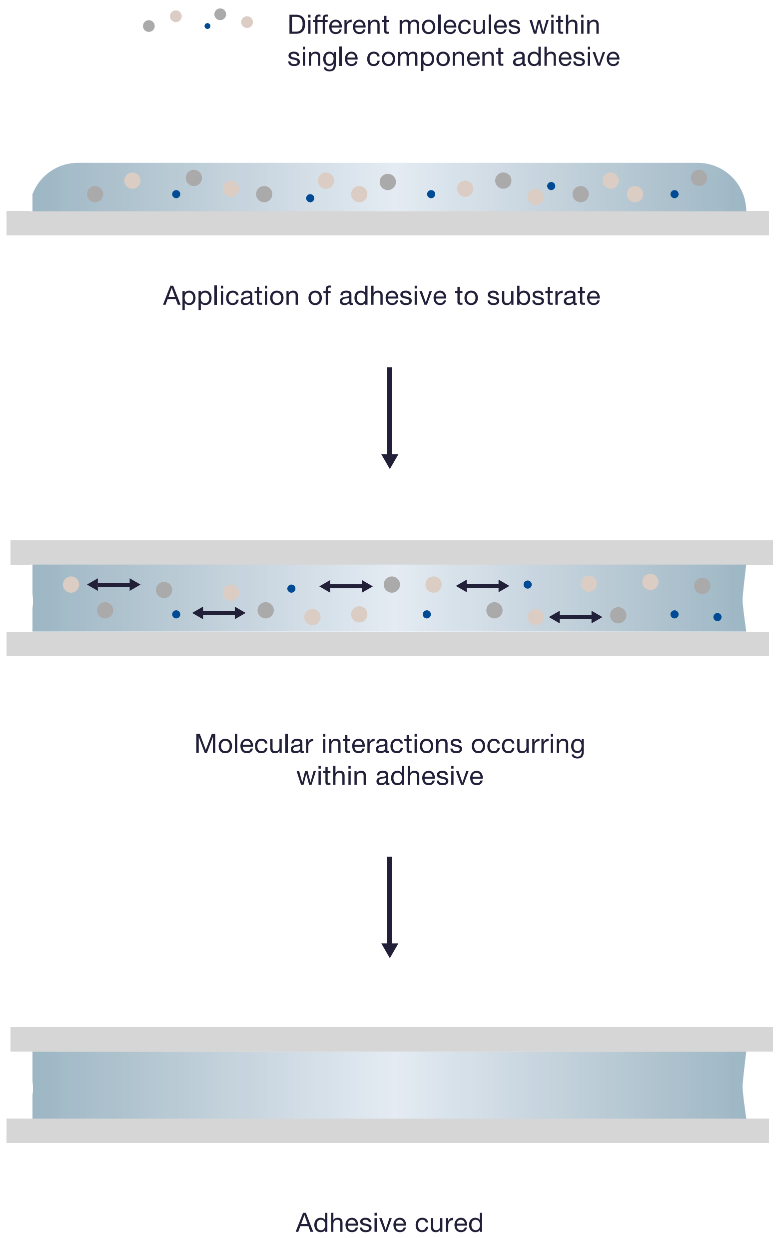
Disadvantages

- Low heat resistance
- Low impact resistance
- Low elasticity
- Only applicable in small applications
- Unsuitable for bonding large surface areas
- Irritating odour and causes blooming
- Care required when handling due to adhesive bonding well with skin
- Requires caution in storage

Where can they be seen?

- Electrical instruments
- Automotive
- Precision instruments
- Musical instruments
- Medical instruments

Curing mechanism



05. Substrate types and preparation methods

Preparation of substrates

What is surface preparation?

Surface preparation is used to:

- **Remove or prevent formation of a weak layer on the substrate surface**
- **To maximise the number of molecular interactions between the adhesive and substrate**
- **To optimize the initial joint strength of the formed molecular interactions**
- **To create a specific microstructure on the surface substrate**

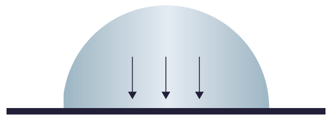
Knowing your substrate plays a key role in the engineering of joint design. There are many factors which influence the way a substrate must be prepared before bonding occurs, these are:

1. **Surface energy**
2. **Protective films or coatings attached to the substrate**
3. **Type of substrate – metals or non-metals**

Surface energy

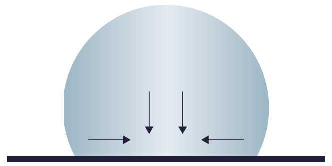
The **surface energy / surface tension** of a substrate determines how readily an adhesive can ‘wet out’ on the surface. Typically, adhesion will be at its best when the **surface energy** of the substrate is higher than that of the adhesive. It is poor when the substrate **surface energy** is lower than the adhesive.

Metal Surfaces
(High Surface Energy)



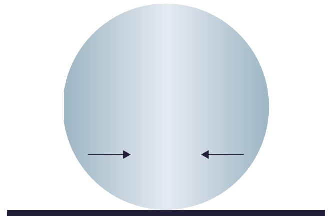
mJ/m²	Surfaces
1103	Copper
840	Aluminium
753	Zinc
526	Tin
458	Lead
700-1100	Stainless steel
250-500	Glass porcelain

High Surface Energy Plastics (HSE)



mJ/m²	Surfaces
50	Kapton® industrial film
47	Phenolic
46	Nylon
45	Alkyd enamel
43	Polyester
43	Epoxy paint
43	Polyurethane paint
42	ABD
42	Polycarbonate
39	PVC rigid
38	Noryl® resin
38	Acrylic

Low Surface Energy Plastics (LSE)



mJ/m²	Surfaces
37	PVA
36	Polystyrene
36	Acetal
33	EVA
31	Polyethylene
29	Polypropylene
28	Tedlar® polyvinyl fluoride film
18	PTFE
18*	Powder coated paints
*	Waxes used in powder coat paints create a low surface energy.

Figure 1 - Highlights some materials with their associated **surface energies.**

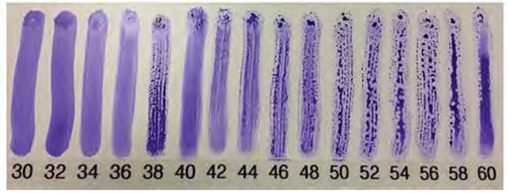
Effect of temperature on surface tension

Surface tension of adhesives and substrates are affected by temperature. As temperature increases, **surface tension** decreases; reducing the molecular interactions on a substrate surface.

Testing for surface energy – Dynes Pens

When analysing new substrates for bonding applications or changing from mechanical fixings to bonding, it is good practise to measure the surface energy of the substrate. This is especially important on painted, pre-primed or coated surfaces.

Dyne Test Pens are a cost effective, quick and easy method to measure surface wetting or surface energy. Sometimes known as corona test pens or sherman pens the Dyne Test Pen is a simple method of determining the surface energy of most polymer based materials.



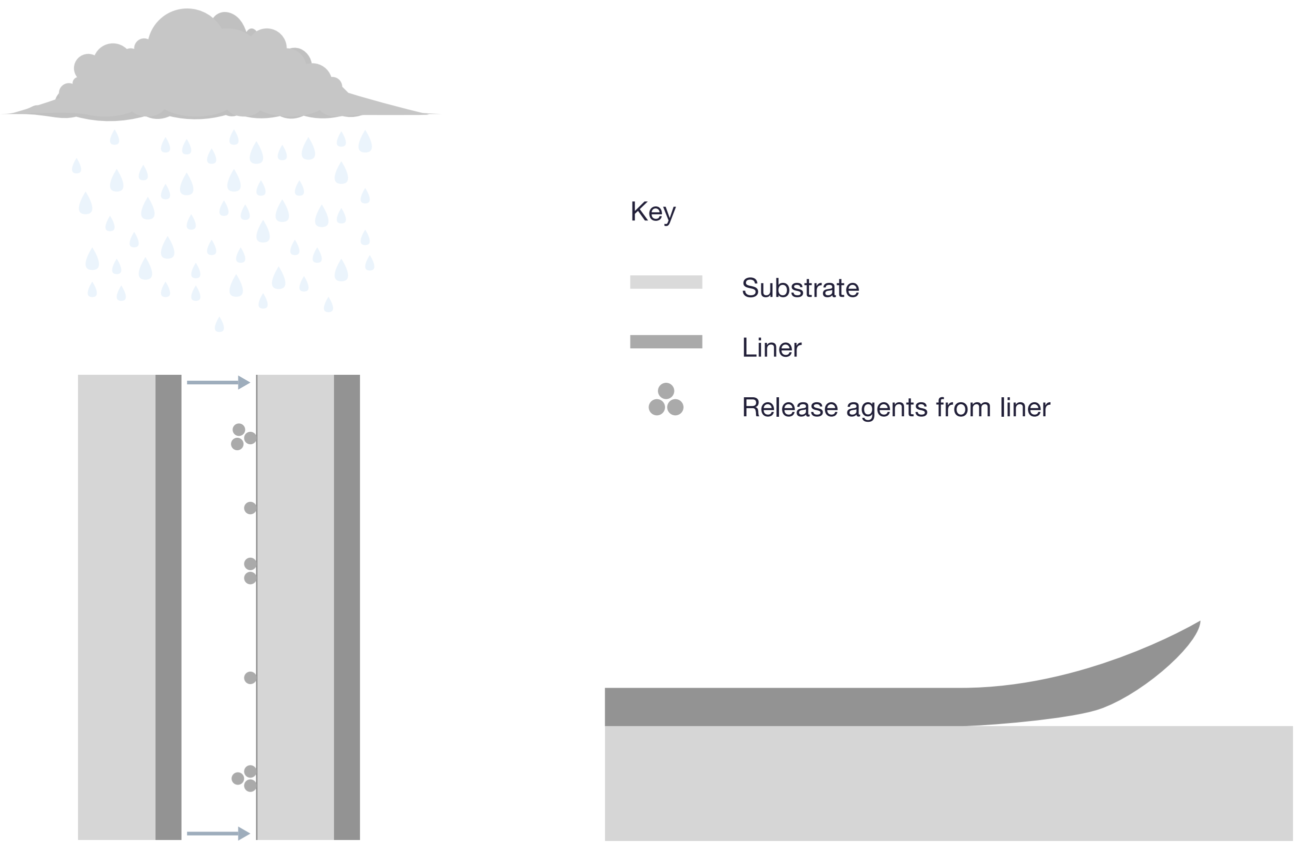
Dyne Test Pens are equipped with a valve tip applicator and do not suffer the inherent disadvantages of the “Magic Marker” or “Felt Tip Pen” type.

To use simply draw the Dyne Test pen across the material surface, the liquid will either form a continuous film on the surface or draw back into droplets. If the Dyne test fluid remains as a film for 3 seconds or more then the material will have a minimum surface energy (Dyne level) in mN/m of that ink value. Should the Dyne test liquid draw back into droplets in less than 1 second then the surface energy (Dyne level) of the substrate is lower than that of the liquid value. The exact surface energy (Dyne level) can be determined by applying a range of increasing or decreasing values of Dyne test pens.

Dyne Test Pens are available in a range of values from 30 to 72 Dynes/cm (mN/m) and are supplied in disposable pens. The test fluid contained within the pens is to ISO 8296 with additional high visibility dye for easy readings.

Protective films / coatings

Adhesion can be hindered if the substrate is processed with protective films or mould release agents. Additives found in release liners and mould release agents migrate onto substrate surfaces. These additives lower the overall surface tension of the substrate (even if the substrate usually has a high surface energy). You should always check if the substrate you are using has been manufactured with liners before bonding. This is to ensure that correct cleaning processes are put into place to remove the outer surface layer. The below graphic shows the transference of the release agents from the protective liner onto another substrate when wet. The release agents are now a contamination on the other substrate and will only be removed with appropriate cleaning.



See page 159 for CASE STUDY on Sealant Yellowing

Type of substrate

As you can see from *Figure 1,* a substrate's composition affects the surface energy. This is not the only consideration which affects substrate selection, metals generally contain a layer of oxides and gases which can easily be removed. Whereas non-metals can contain surface moisture and migrating additives (plasticizers, pigments etc.), which are more difficult to control due to the material constantly changing throughout its service life.

Difficult substrates

- **Powder coated metals**

The treatment of powder coating reduces a metal's chance of corrosion and degradation, but also reduces the surface tension; deeming it less desirable for adhesive bonding.

The process of powder coating uses a free-flowing powder to coat the surface of a metal substrate through an electrostatic charge it is then baked until a hard exterior is formed. Powder coating is used over liquid paints due to characteristic to form a hard 'skin', for its non-drip and non-sag properties and for even coat weights.

There are very few problems associated with powder coated substrates. However, in some cases, powder coat powders can be applied to substrates with uneven coat weights (a thicker build up in some areas and a thinner layer in others), causing intermittent adhesion to occur. Not only this, if only one side of a metal is to be coated, over-spray can occur on the reverse side of the metal; also causing intermittent adhesion over the areas where the over-spray has formed.

- **EPDM rubbers**

EPDM rubbers are notoriously hard to bond to, due to their high composition in butadiene and styrene. Not only do these two compounds reduce the surface tension, they can cause yellowing and de-bonding of the adhesive as a result of styrene leeching out of the rubber.

- **Porous substrates**

A substrate which is porous in nature has a reduced surface area for bonding. When bonding an adhesive to a porous substrate, it is likely that there will be air entrapment or moisture underneath the adhesive if the correct precautions are not taken. With an insufficient surface area and air pushing against the adhesive, it is almost certain that the adhesive will de-bond, showing thin film adhesion or adhesive failure.

See page 153 for CASE STUDY on Environmental Stress Cracking

- **Amorphous thermoplastics**

Stress cracking can occur on amorphous plastic materials when subjected to two different environments:

- In contact with solvents; breaking down the structure of the plastics causing cracks to form.
- Environmental stress corrosion cracking; repeated tensile stress stretching the thermoplastic inducing cracks.

The plastics which are more susceptible to stress cracking are:

- Polycarbonates
- Polymethyl methacrylates (PMMA)
- Polystyrene
- Acrylics
- Styrene-acrylonitrile
- Polysulfone
- ABS
- Polyphenylene oxide

What affects stress cracking?

- Time
- Temperature
- Solvents
- Plastic type
- Adhesive type
- Force applied
- Environment
- Surface preparation methods

Ways to prevent stress cracking:

- Use adhesives which are free from solvents
- When joining materials together, avoid stretching or deforming the plastic as this can generate stress from the outside
- Post bake plastic parts to reduce internal stresses
- When using solvent based adhesives, ensure that the curing time is fast to minimize the length of time the solvents are in contact with the plastic
- Do not over apply solvent based adhesives to plastic materials
- Do not leave adhesive residues of the edges of joints
- When using UV curable adhesives, ensure the adhesive is cured immediately after application
- Anaerobic adhesive should not be used to join amorphous thermoplastics
- Prepare thermoplastic surface with the use of abrasion and cleaning with IPA

All substrates must be treated accordingly before use with adhesives or sealants. There are many ways to modify a substrates surface to increase the bonding sites made, these are:

Surface treatment

1. **Degreasing:** this is an extremely important step before bonding. At this stage, a degreasing solvent can be used to remove surface contaminants such as dirt and dust which are held on the surface loosely. There are two common methods of degreasing, the first is vapour degreasing or degreasing repeatedly. The second is cleaned and dried completely.

1. **Degreasing**

Degreasing methods frequently use different types of solvents.

What is a solvent?

A liquid that serves as a medium for a reaction to take place. Solvents can be used for two purposes:

- Dissolving reactants
- Acting as acids or bases

Solvents

Polar

Protic

Capable of making strong hydrogen bonds, as they contain a hydrogen bonded with an electronegative atom. Solvents of this type include:

- Water
- Ethanol
- Methanol
- Ammonia
- Acetic acid
- Isopropanol (IPA)

Aprotic

Contain no hydrogen atoms bonded to electronegative atoms and are therefore not capable of hydrogen bonding. Solvents of this type include:

- Acetone
- Acetonitrile
- Ethyl acetate
- Dimethylformamide

Non-Polar

Not capable of making strong hydrogen bonds. Solvents of this type include:

- Pentane
- Hexane
- Toluene
- Chloroform
- Dichloromethane

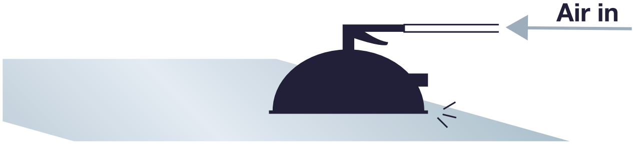
Types of solvents:

Ensure all edges, corners, crevices and hard to reach areas are cleaned appropriately as these areas are often overlooked.

All surfaces should be dry, as well as cleaned before adhesive application. Insufficient drying of areas can cause water entrapment in the form of condensation at low temperatures, humidity at high temperatures and can results in ice layers when temperatures drop to subzero.

2. **Abrasion:** mechanical abrasion removes heavy, loose surface deposits such as dirt and oxide layers which are associated with the substrate surface. Abrading the surface is not just a cleaning mechanism, it also increases the bonding area for improved wet-ability of the adhesive. There are a few methods of abrasion techniques, some of which include: sandblasting, wire-brushing and abrasive pads (sandpaper, emery cloth or ScotchBrite).

3. **Chemical treatment:** chemical treatment methods have been completely optimised for specific substrates and their applications. The reason for chemically treating a substrate is to change the physical and chemical properties of the substrate surface to improve adhesion (metal substrates are typical substrates of chemical treatment). Some examples of these are:



2. **Abrasion**

- **Chromic acid etching –** uses a solution of sulphuric acid, sodium dichromate and water to produce an oxide layer on the surface. This creates a larger surface area and a higher surface energy for ease of bonding.
- **Sulphuric acid anodising –** substrate is immersed in a solution of sulphuric acid and water whilst an electric current is put through it. An oxide layer is formed on the substrate surface to increase the surface area and surface energy for ease of bonding.
- **Phosphoric acid anodising –** once one of the most widely used surface treatment processes in aerospace. Substrates are submerged in a 9-12% by weight solution of phosphoric acid at +19°C to +25°C (+66.2°F to +77°F) with a direct current running through it at 9-16V. A stable coating is formed on the substrate to increase the available bonding sites.
- **Chromic acid anodising –** is similar to that of phosphoric acid anodising, whereby the substrate is subjected to a direct current of a specific voltage. The only difference being the solution; chromic acid. A strong layer of metal oxide is left on the substrate, which is a suitable bonding environment.

4. **Physical methods:** changes a surfaces reactivity and modifies it for better adhesion. There are three physical methods which are more commonly used among specific substrates.

- **Flame treatment –** the substrates surface is exposed to a gas flame for a few seconds which oxidises the surface and thereby increases the surface energy.
- **Corona discharge –** generated by ionizing the air between two closely spaced electrodes. They react with the substrate surfaces to form free radicals which then in turn react with oxygen in the atmosphere. This process increases the substrates surface energy and allows the adhesive to wet the surface easier. This method is popular for polyolefin type materials.
- **Plasma treatment –** differs from corona and flame treatments as it is carried out under a partial vacuum. Activated gas plasma creates highly excited ions that react with the substrate surface to increase bonding sites and improve stability. This method is more often used with plastic substrates.

Key

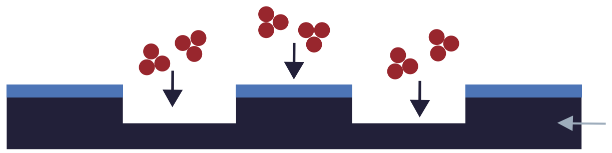
Etching mask

Substrate

Positive and negative ions reacting with radicals to form and electric potential

Before plasma treatment:

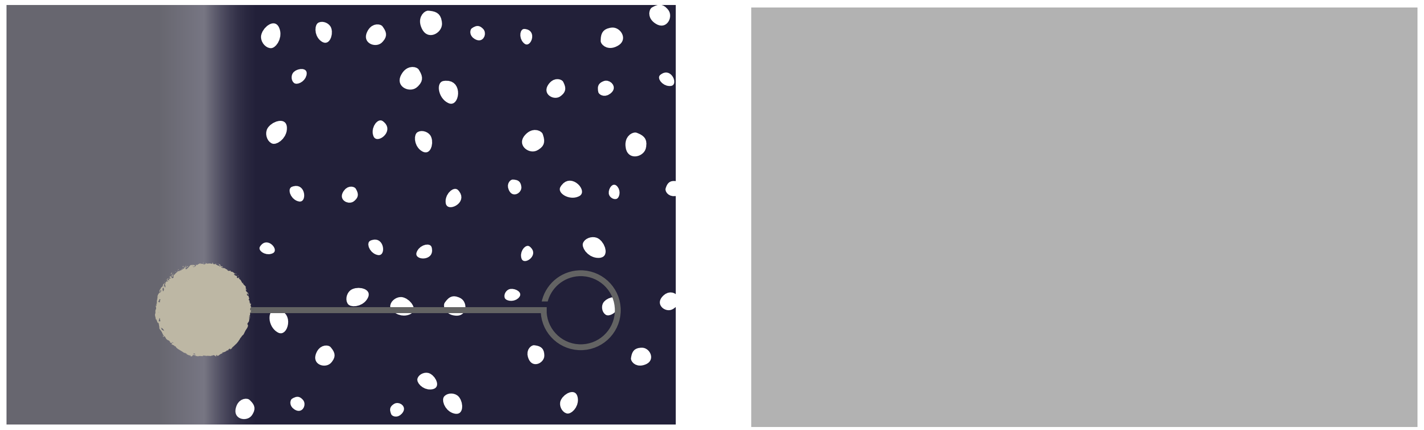
After plasma treatment:



4. Plasma Treatment

5. **Primers can be used for three key improvements to a substrate:**

- To create a 'new' substrate surface for the adhesive to bond to.



Porous substrate → **Consolidated surface**

- To increase the surface energy of the substrate (aid wetting).
- To consolidate porous materials and aid adhesion.

What is a primer?

A primer is an material which changes the characteristics of a surface so that an adhesive will adhere more efficiently. It is important to note that not all primers obtain the same level of adhesion on all substrates. It is imperative that the correct primer is chosen for the right application. They can be made from a multitude of materials (solvents or aqueous solutions), which can determine its suitability for application in certain areas.

For example, aqueous primers would not be used on areas which are susceptible to rust. Solvent based primers should not be used if there are health and safety hazards.
Evaluating the success rate of treated substrates

There are four ways to test your substrate to ensure that treatment has been successful:

1. **Destructive test -** mechanical strength tests (tensile or shear) can be used to evaluate the mode of failure of a bonded joint. If the joint fails cohesively, the treatment has been successful. An adhesively failed joint means the surface preparation has not been achieved and needs to be re-evaluated.

2. **Non-destructive test** - a film of deionised water is sprayed or coated onto the substrate. A consistent film shows good treatment with no contaminants, a broken film shows there are contaminants on the surface and pre-treatment was not successful. This test is not a quantitative test and may be subjective to the person analysing the surface.

3. **Contact angle test -** measuring the contact angle between the surface and a reference material liquid. The larger the contact angle, the more 'wet-able' the surface.

4. **UV light detection test -** the surface is coated in a fluorescent oil and examined under UV light for contaminants.

Why failures occur

It is important to be aware of de-lamination or de-bonding to substrates and why they might occur. In many instances, failures in the field can very rarely be replicated in the laboratory.

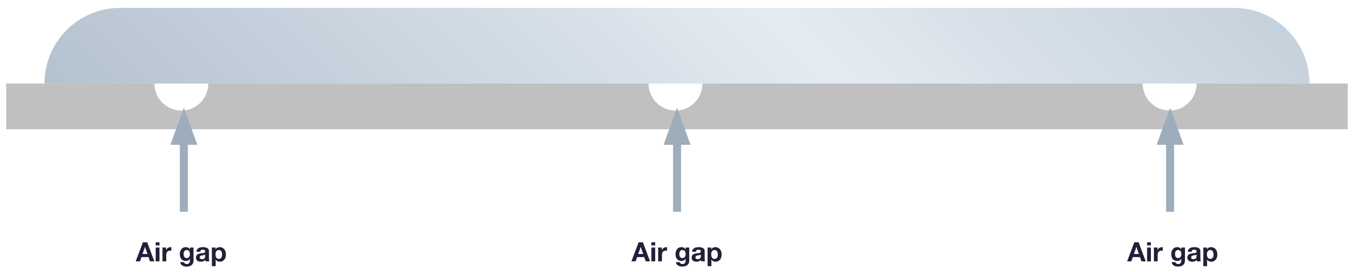
This has been highly related to processing in manufacture or not following the correct procedures.

Key causes:

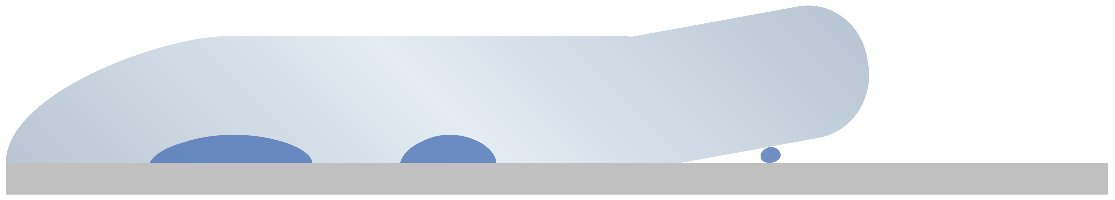
Contamination on a substrate - The substrate has not been thoroughly cleaned / prepared before bonding. The intermolecular forces which are made between the substrate and adhesive have not been made. This is due to the fact that the bonding forces have been made with the contaminant instead and therefore the adhesive will fail.

Flash off times - Solvents used for cleaning have not been given their required flash off time. The substrate which is affected most in this case is GRP (porous substrates). This is due to the fibrous composition of the material which the solvent 'soaks' into. More time is required for the solvent to evaporate out of the GRP compared to other substrates. De-bonding occurs when the flash off times are not considered; when the adhesive is bonded, the solvent continues to evaporate into the adhesive which stops the bonds obtaining full adhesion with the substrate.

Air gaps - Air in sealed joints which have been bonded incorrectly can cause leaks and ultimately de-lamination.



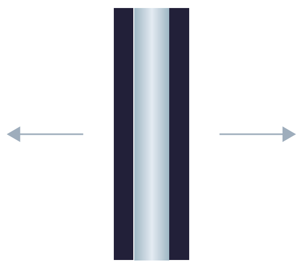
Trapping water / solvents - Pooling of water / solvents at an adhesive interface can cause softening of the adhesive and break-down at the adhesive - adherend interface. Cleaning solvents should be used at a minimal level as this can cause swelling and loss in strength properties of the adhesive.



06. Joint design

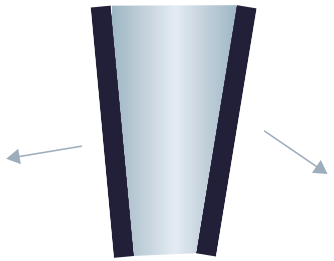
Stresses seen in joint design

Tensile
Stress exerted equally over the entire joint.



Shear
Stress exerted over the adhesive bond; materials are being forced to slide over one another.

Cleavage
Stress is concentrated over one edge. The stress is felt on the entire bond.



Peel
Stress is concentrated on a thin bond line with only one surface being flexible.

Rules to consider

Keep the stress on the bond line to a minimum

- Whenever possible, design the joint so the adhesive is stressed in shear / tensile
- Distribute stress as uniformly as possible - Balance the load!

Why is joint design important?

- To analyse the potential stresses the adhesive and adherend will see in its service life
- To analyse crash testing and how an adhesive behaves upon impact energy
- To ensure the most suitable adhesive is used for the right application
- To ensure that failure is of a 0% occurrence
- To reduce any slip between the adhesive and adherend
- Detailing out weight saving and cost implications

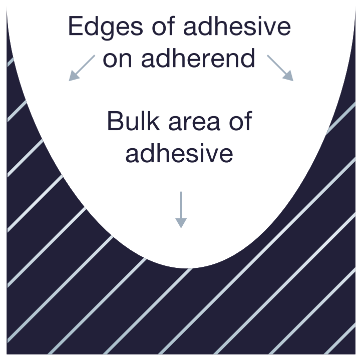
How a joint is designed can determine what properties are required in an adhesive for the application; flexibility, strength, rheology and maximum available bonding time. Generally, an adhesive is classified as a structural adhesive if it has a shear strength of 5-7 MPa. However, if the joint is designed correctly, an adhesive with 2-4 MPa acts as a structural adhesive from the distribution of load(s).

Failure in joint design

Failures can always occur in joints, however predicting them before they happen is of utmost importance and allows the engineer to re-design if necessary. There are three methods which can calculate the stresses and failures seen in a shear joint:

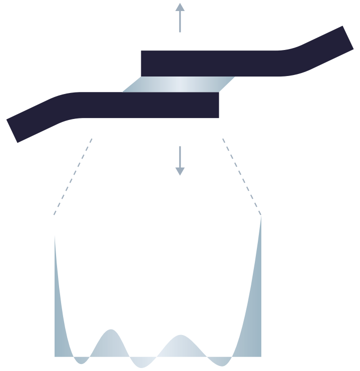
1. Finite Elements Method (FEM) – used to analyse more complex joints and calculates the stress numerically.
2. Volkersens analysis – considers the adherends to be elastic and introduces stress across the whole lap shear joint. The substrates are in pure tension and the adhesive is in pure shear stress.
3. Goland and Reissner analysis – considers the adherend bending which can introduce peel stresses within the adhesive.

Volkersens Analysis



Stress distribution on an overlap shear joint

Goland and Reissner Analysis

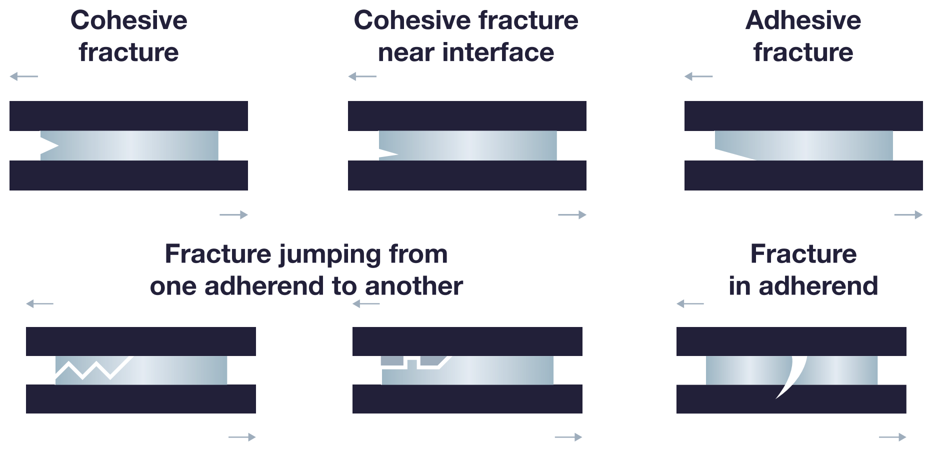


Peel stress distribution

Fracture failures in joint design

It can be difficult to monitor or calculate failures seen from fractures in adhesive or adherend. Thus it is extremely important to ensure the adhesive and adherend are compatible and suitable for the intended application.

There may be six fractures which could occur when a joint is subjected to shear:



The thickness of the adherend can have an impact on the way the joint can fail. This is due to the distribution of stress exhibited over the adhesive. As adherend thickness increases, the mode of **failure** begins to change. Low adherend thickness tends to stress the adhesive in shear; due to the adherend bending. As adherend thickness increases, peel forces are exerted over the adhesive, ultimately resulting in **failure**.

Fatigue and creep resistance
Joints which are used for high impacts or high loads should be analysed for creep and fatigue performance, to ensure that the full load requirements can be maintained under the stress load, temperature and humidity.
To reduce the creep or fatigue of an adhesive in a joint, the adhesive must be kept in an elastic state. Creep deformation occurs when an adhesive is subjected to constant loads over a long time period. This is worsened when temperature and humidity are introduced.

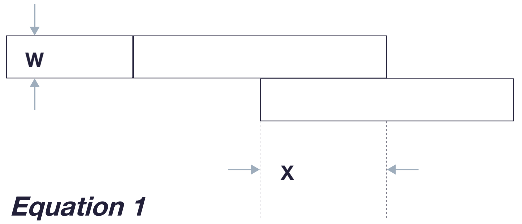
Determining the adhesive overlap

When designing an overlap joint, there are a couple of factors that need to be taken into account to maintain even distribution:

1. A ductile adhesive will deform plastically as the load increases on the joint. The adhesive will distribute the stress evenly until failure occurs. Increasing the overlap will distribute the stress further for a longer period of time until the failure finally occurs.
2. Using a brittle adhesive means the stress will not be distributed as well and is concentrated on the edges of the overlap joint; failure will be seen at a faster rate. Increasing the overlap in this case will not change how the stress is distributed, and will therefore not affect the failure.

An overlap joint can be calculated through characteristics of the substrates for intended use (not taking into account the adhesive properties):

A lap joint should generally be designed so the length of overlap is three times greater than the thickness of the thinner joint member. See below for an example:



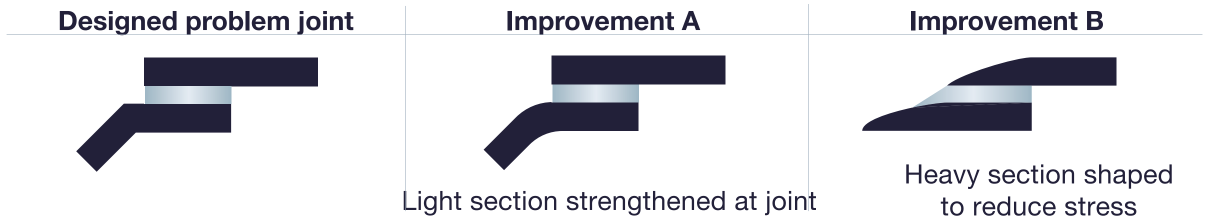
$$X = \frac{TW}{CL}$$

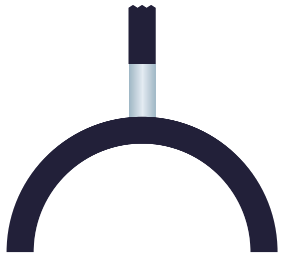
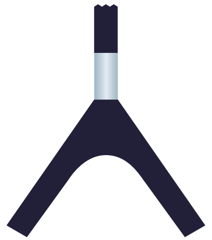
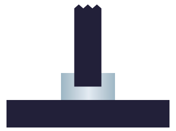
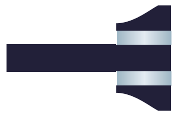
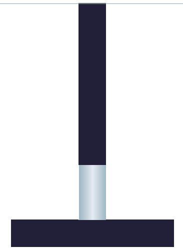
Equation 1

X = Length of overlap
T = Tensile strength of weakest member
W = Thickness of weakest member
C = Joint integrity factor = 0.8
L = Overlap shear strength of adhesive

Designing your joint
It is important that the maximum strength of the adhesive is optimised in a joint. The concentration of stress should be distributed evenly across the bonded area to avoid weakened areas or even failure.

Joint design improvements
You can use simple design improvements to ensure that you achieve even stress distribution.



Designed problem joint	Improvement A	Improvement B
	 Members thickened at joint	 Scarf joint to increase bond area
	 Light section strengthen at the joint	 Light section reinforced at the joint
	 One member re-designed to reduce stress	 Other member re-designed to spread stress
	 Add fillet for stress distribution	

Safest joints for absorbing energy

In the automotive industry, all joints are designed to ensure that any impact **energy** a joint may see will be transformed into deformation **energy**. In the event of an accident, adhesives behave as being crash resistant and contribute towards keeping passengers safe.

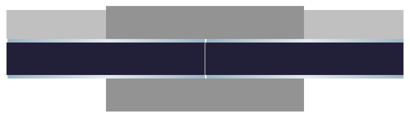
The below joints are those which are engineered using structural techniques and can withstand maximum impact without deformation.

Key

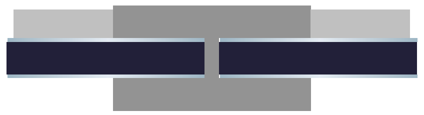
 Structural support

 Substrate

Typical flat joining methods

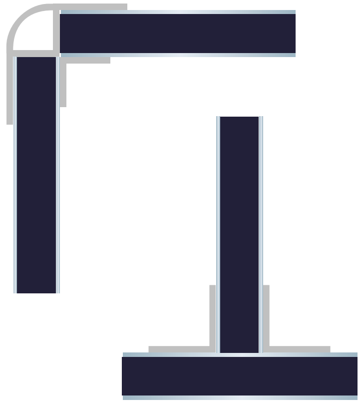


Bonded face supported butt joint



Bonded butt joint using ‘H’ section extrusion

Typical corner joints



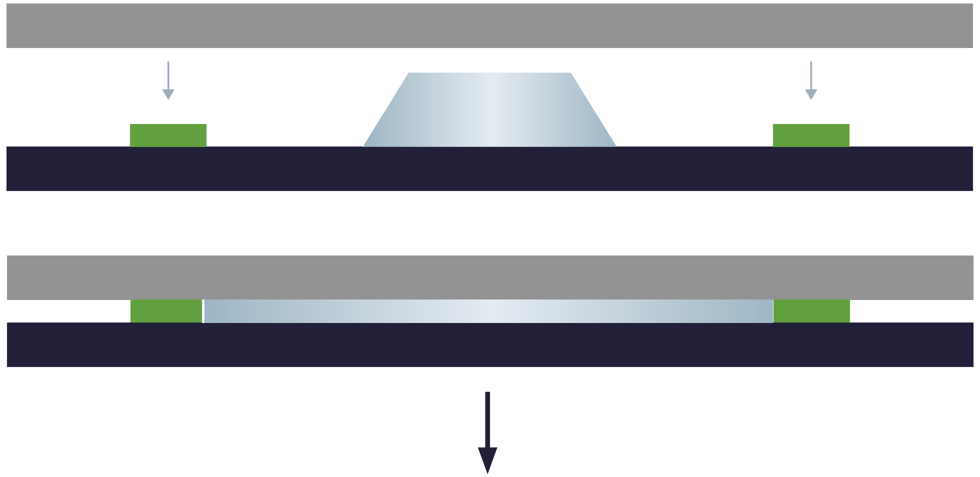
Typical T - joints

Designing extrusions to maximise process efficiency

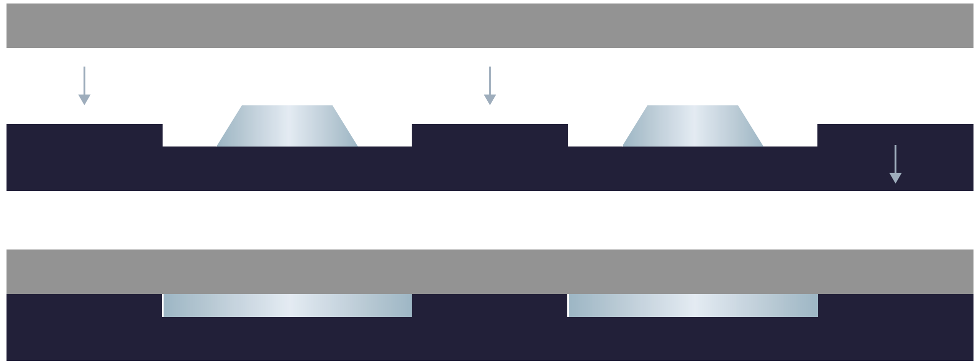
Designing your **extrusions / substrates** around bond-line thickness not only saves time on processing, but reduces the risk of operational error and over application of adhesive.

The next set of images show design improvements of two different extrusion types to maximise the joint capacity.

Design 1



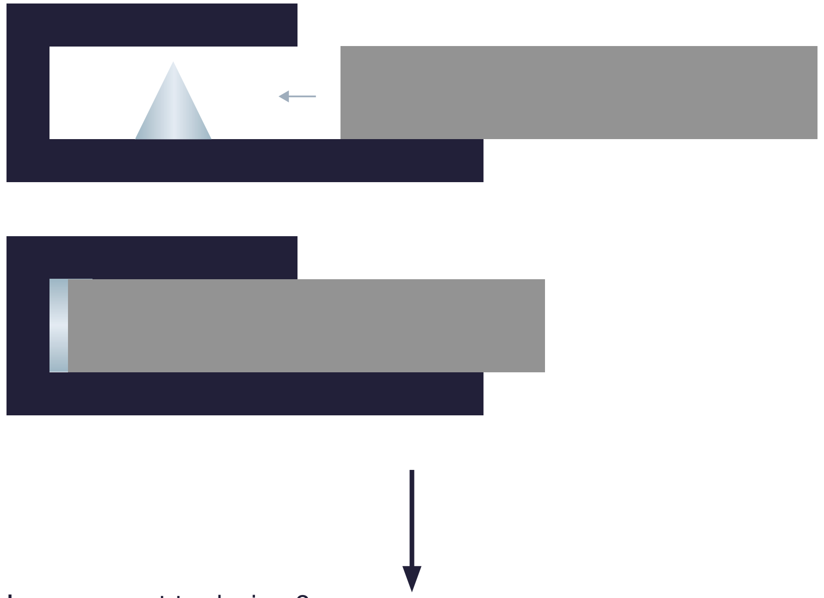
Improvement to design 1



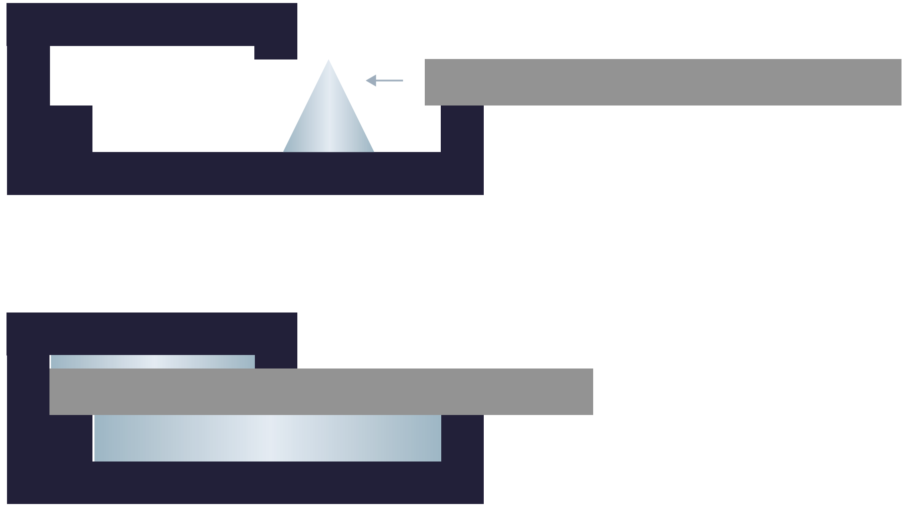
Key

- Spacer
- Adhesive
- Substrate 1
- Substrate 2

Design 2



Improvement to design 2



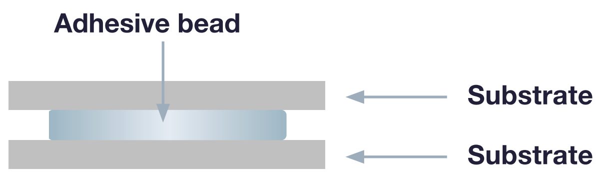
Key

- Adhesive
- Substrate 1
- Substrate 2

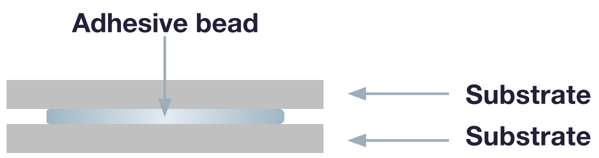
Bondline thickness

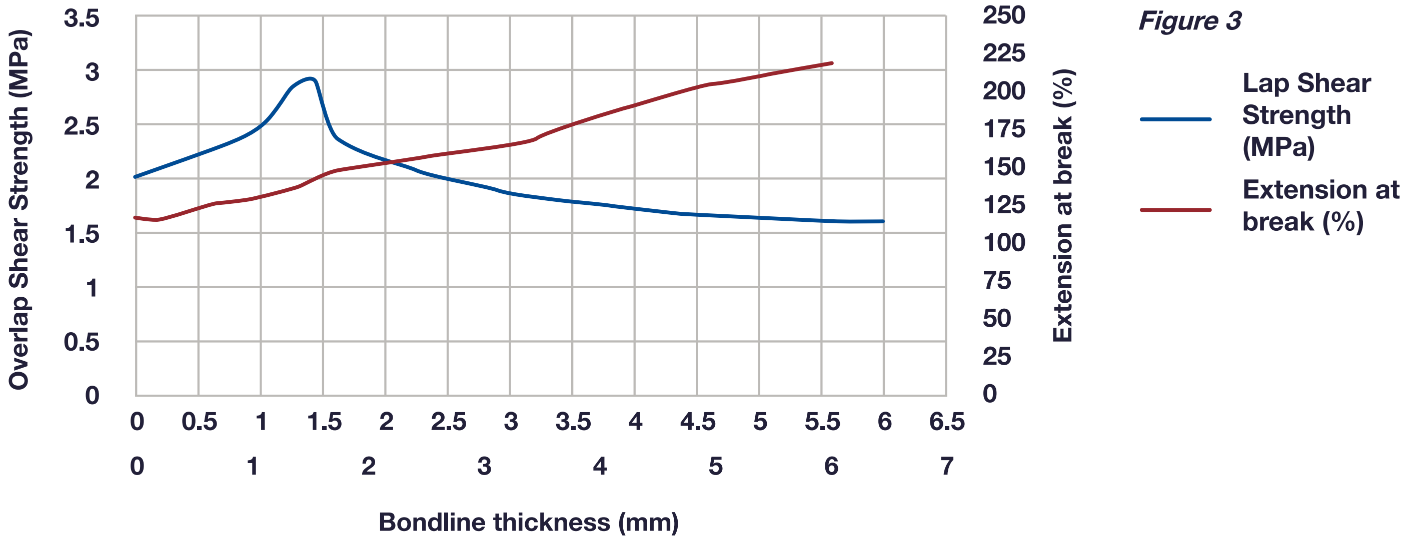
For vehicle manufacturers it is critical that joints are designed with a specific bondline thickness in mind to achieve a balance between strength and flexibility. Typically an optimum thickness for general applications is between 1mm and 2mm. However for an application such as glass bonding, where the substrate is very rigid and often toughened, a bondline thickness of 4mm is normally required to place the stress on the adhesive rather than the glass which could crack under stress.

Thick bondline



Thin bondline





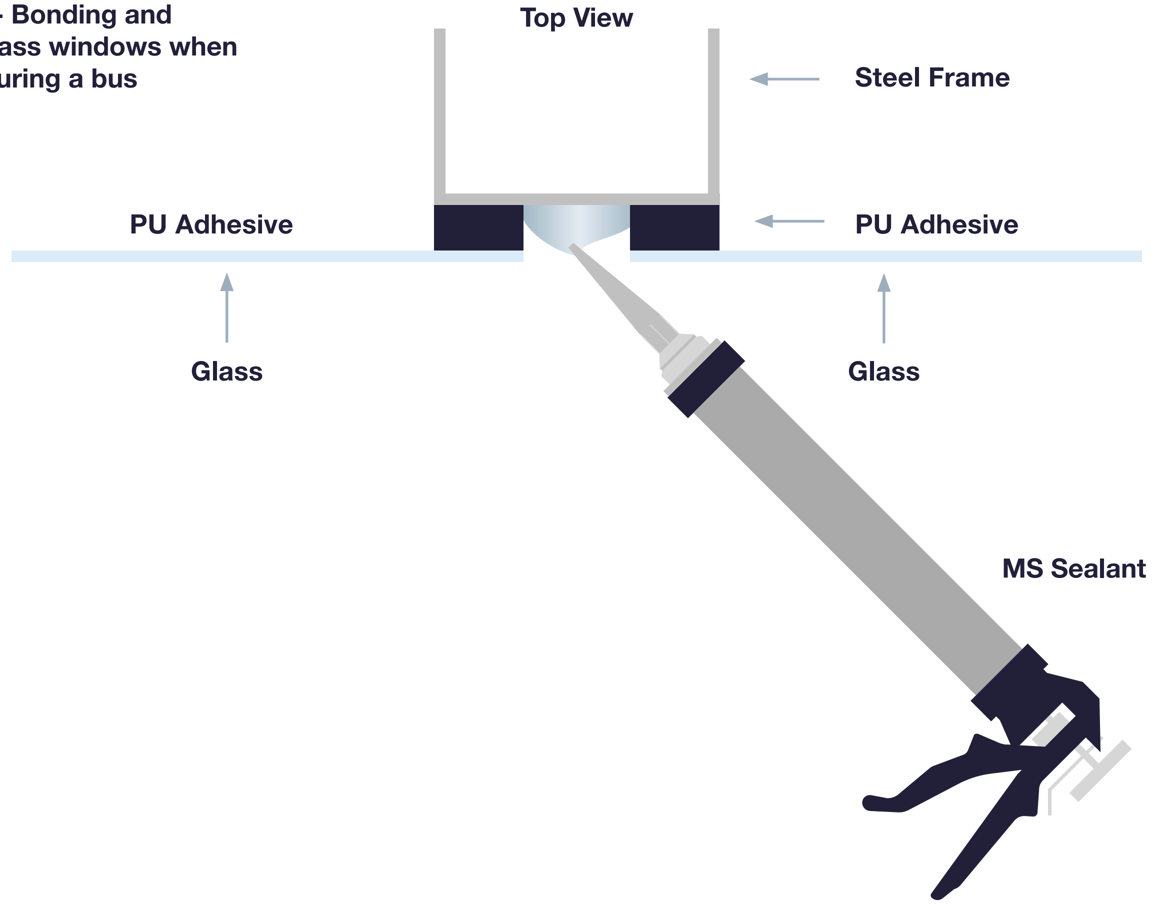
The above graph shows typical effect of bondline thickness on shear strength and extension.

MS Polymer compatibility with Polyurethane

If you are designing joints incorporating MS polymer and polyurethane adhesives, it is important to know some MS Polymers will not cure in their normal way when in close presence to a Polyurethane adhesive. This is not always the case, but something to consider when selecting the right adhesive for your application. Where possible it would be good practise to use the same adhesive chemistry if MS polymer and / or Polyurethane adhesives are being considered for a design.

A way to avoid this risk would be to wait for the PU to cure before applying the MS, if your process would allow for this.

Example - Bonding and sealing glass windows when manufacturing a bus

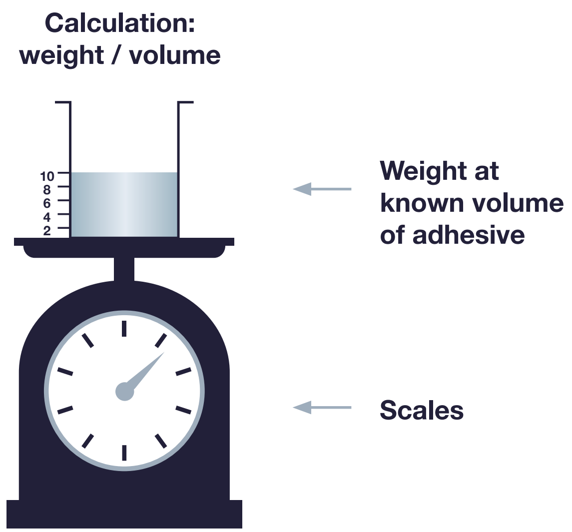


07. Test methods

Characteristic testing

Density
FGY001

Can be achieved by filling an adhesive into a container of a known volume and weighed. The weight is divided by the volume size to give density in g/ml.



Extrudability
FGY013

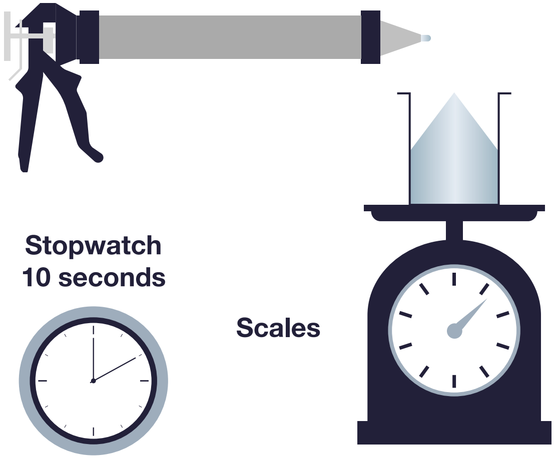
The rate of extrusion is determined by the volume of adhesive which is expelled through a 6mm aperture nozzle from a foil or cartridge over a 10 second period.

The weight of the expelled adhesive is measured. After this, a calculation can be done to achieve the extrusion rate (typically in g/s or g/min).

Both extrusion and rheology work together to determine the viscosity of materials.

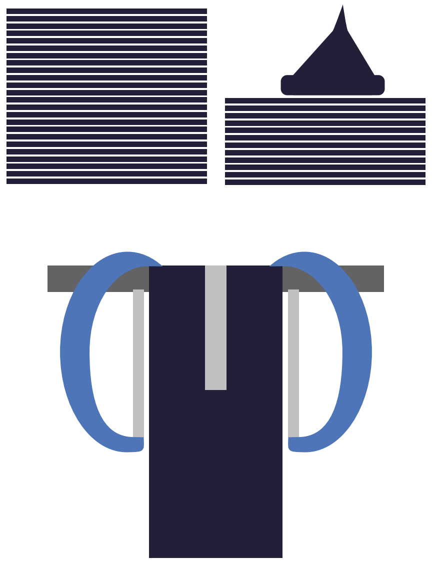
Calculation:

$$\frac{\text{Weight of matter (g)}}{\text{Time (s)}}$$



Slump test / green strength
FGY026

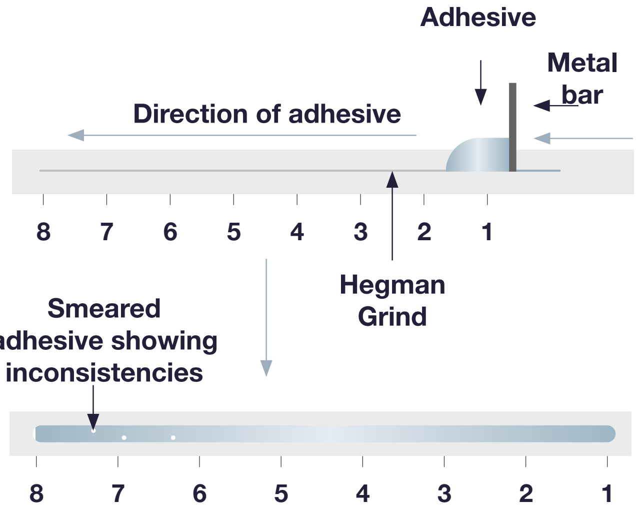
This test determines the overall green strength of a product when wet. Adhesive is applied to weight tabs and pushed onto a vertical block. The amount of weighted tabs an adhesive can hold, without drop / movement of the tabs, is described as the green strength.



Consistency – Hegman Grind
FGY003

Used to gauge the fineness of grind of adhesives, pigments and coating materials.

Adhesive is applied to Hegman Grind Block and smeared using the metal bar. An accepted level of grind is seven.

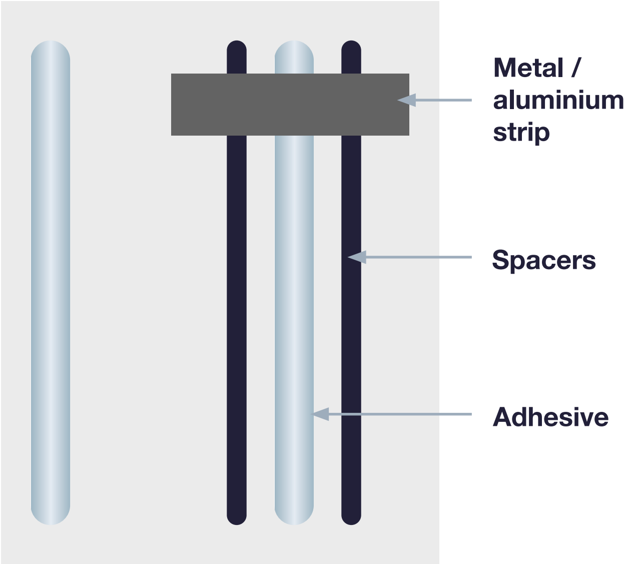


Max available bonding time

FGY031

The time taken to ascertain the 'open time' of an adhesive.

A known volume of adhesive is gunned out onto a hard surface in bead like formation. The time is recorded at the start. Strips of aluminium are applied to the adhesive and removed at time intervals. You will notice the adhesive bonds to the aluminium strip, leaving a coated area. (This shows the adhesive is still workable). The maximum bonding time is determined at the time when no adhesive transfers onto an aluminium strip.

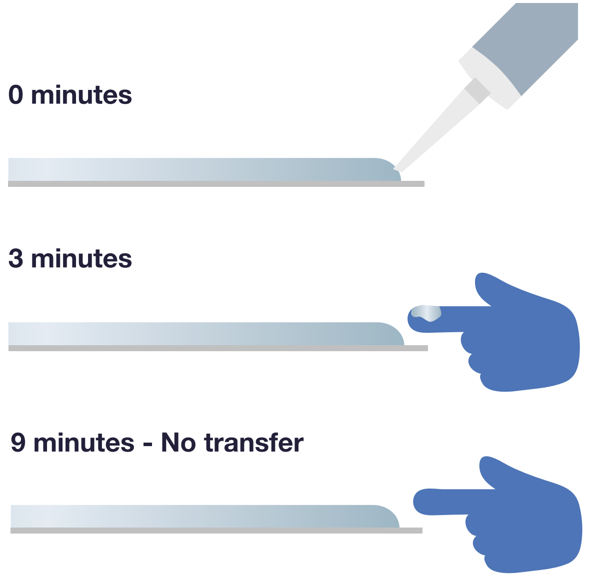


Tack free time

FGY005

This test is used to measure the time at which a moisture curing adhesive forms an active skin.

A plaque of wet adhesive is spread out on a hard surface so that the top of the adhesive is smooth and even. The time is recorded when the adhesive is spread until the time the adhesive becomes transfer free. A gloved finger is used to press on the top of the adhesive at pre-defined intervals until the transfer free time is determined.



Rheology (cone and plate)

FGY004

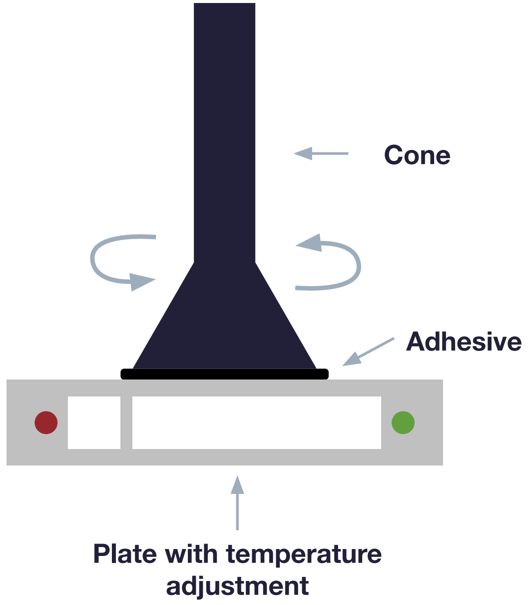
For the determination of the viscosity of adhesives, pigments and coating materials.

Approximately 1g of adhesive is applied to the plate. The cone is lowered on top of the adhesive and any excess is wiped away. The speed of shear thinning the material can be chosen to determine the adhesive rheology.

A flow curve of the adhesives rheology properties is generated, showing the relationship between shear stress and shear strain at a pre-defined temperature.

Forgeway measures viscosity at 0.6 S-1, @ +23.5oC (+74.3oF).

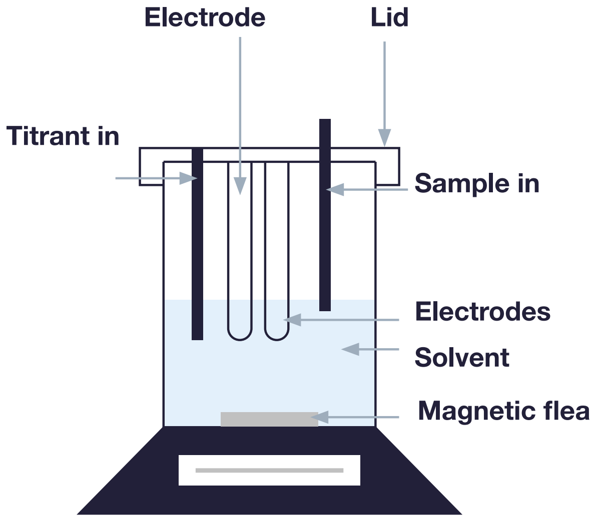
Varying temperatures can be used for further assessment of materials.



Karl Fischer titration

FGY011

This is a critical QC test during and after production, where by the amount of water is calculated in the adhesive (ppm). There are tolerance levels that certain products must achieve in order to pass the relevant testing.

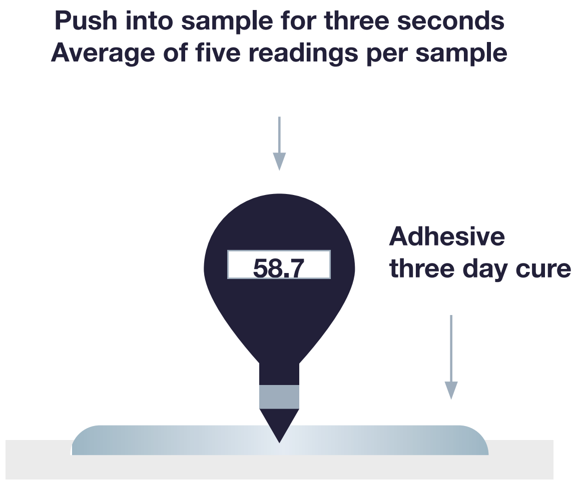


Shore A / D hardness
DIN ISO 7619-1

This test determines the hardness of an adhesive when it has achieved a full cure.

An adhesive is cured with a 6mm depth for three days at ambient temperature. After this a durometer is used to assess the hardness. An average of five readings are taken to achieve the results.

The two common scales of hardness are shore A and D:
- **Shore A -** used for softer materials
- **Shore D -** used for harder materials



Ribbon bead adhesion testing
DIN 54457

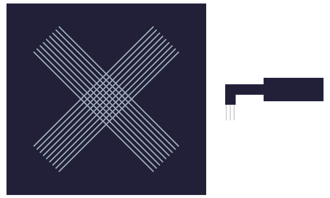
Sometimes also known as Cut & Peel Testing tests the compatibility of the adhesive to a specific substrate. This enables us to provide the right solution for difficult substrates and how we ensure the best methods of bonding are carried out.

A bead of adhesive is applied to a substrate using the intended surface preparations. Once cured, the bead of adhesive is cut at a 90° angle to the substrate. The cut should be deep enough to scribe the substrate so that the peel stresses are concentrated at the bond interface.

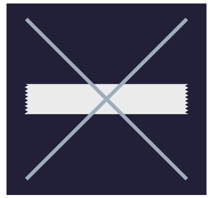
After each cut, the bead should be pried back to force the adhesive bead to fail either at the interface or cohesively within the bulk of material. A minimum of 10 cuts should be performed on each tested adhesive bead.

Over-paintability
ASTM D3359

The ability to over-paint a product can be tested two ways. The first being a cross hatch test and the second is an X-cut tape test. Both tests can be carried out when the adhesive and paint have cured completely.



Cross hatch test

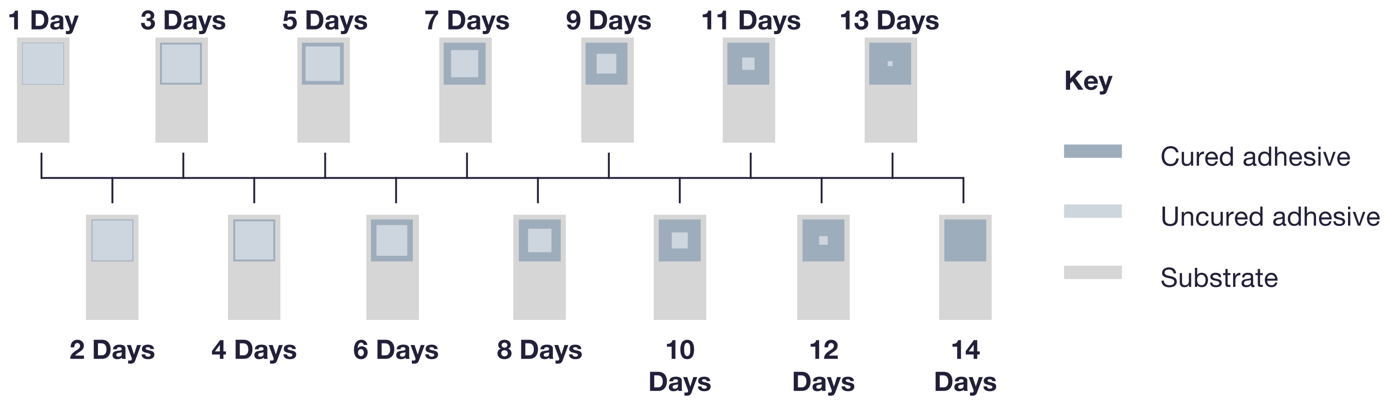


X-cut tape test

Through cure rate
FGY012

The time taken for an adhesive to fully through cure at a known bond-line thickness and surface area.

Typically this is measured on a day to day basis using overlap shear test pieces. The amount of cured adhesive is measured using a micrometer.

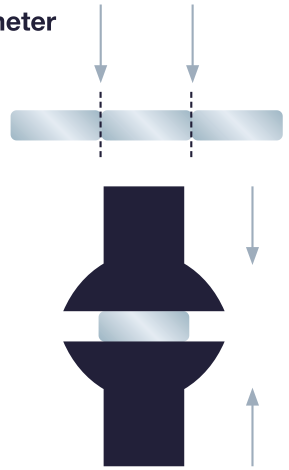


Mechanical testing

Compressive strength
ASTM D3410

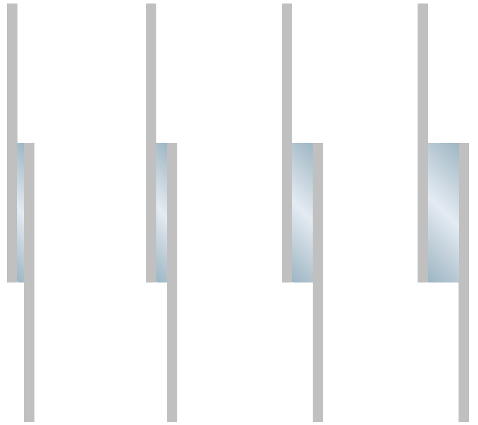
Test method for determining the behaviour of materials under compressive load. It is conducted by loading the test specimen between two plates and applying a force by moving the crossheads together. The following can be calculated; elastic limit, proportional limit, yield point, yield strength and compressive strength.

Cured epoxy 10mm diameter
Cut to 20mm pieces

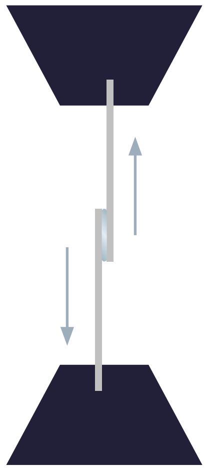


Effect of bond-line thickness
FGY041

Bond-line thickness is tested to assess the level of strength and elasticity when increasing or decreasing a bond thickness. This is to ensure that the optimum level of adhesive is used in ‘real life’ circumstances.



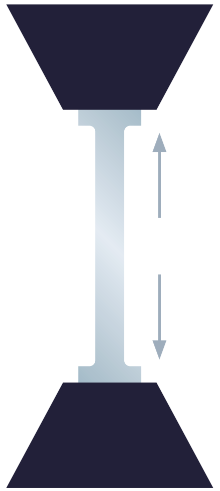
0.5mm 1mm 2mm 3mm



Pulled in tensometer

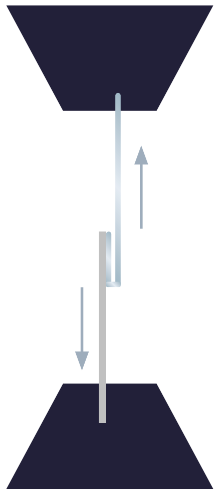
Tensile testing (dumb-bell)
ASTM D412-16

Testing the resistance of a material under tension. This test shows the elasticity of the product as well as the overall tensile strength.



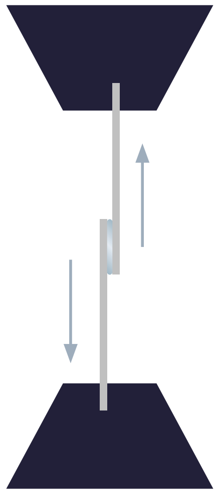
180 degree peel
ISO 8510-2

To determine the peel strength of an adhesive bond with one flexible adherend and one ridged adherend.



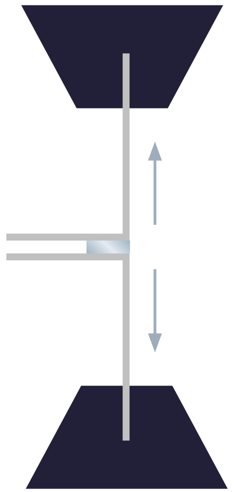
Overlap shear testing
ASTM D1002

Testing the mode of failure and optimum strength of the adhesive; can be manipulated to specific substrate testing for specific customer bond design.



T-Peel
ASTM D1876

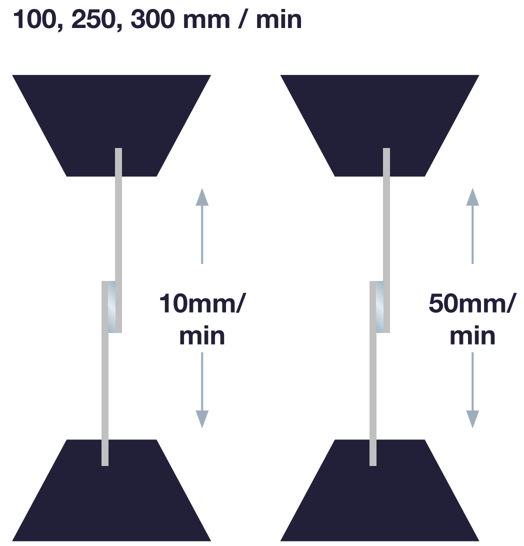
To determine the relative peel resistance of an adhesive bond between two flexible adherends (substrate has to have the ability to bend to 90° without breaking or cracking).



Analysis of jaw separation

FGY040

The jaw separation speed, measured in MPa (megapascal), is the speed at which the adhesive is pulled apart. The effects of higher jaw separation speeds have less effect on the peak loading (load at break) during testing of adhesives with higher elasticity. This is because, the elasticity in the adhesive absorbs the shock. If the joints are subject to rapidly moving forces or shock loadings, it is often important to simulate these shock loadings with the maximum jaw separation speed. However, to obtain the most consistent mechanical properties of an adhesive or sealant, a slow jaw separation speed is beneficial. The peak load at break will be lower than that achieved with high separation speeds. The joint design will need to take this into consideration to ensure that the joints will not fail in service.



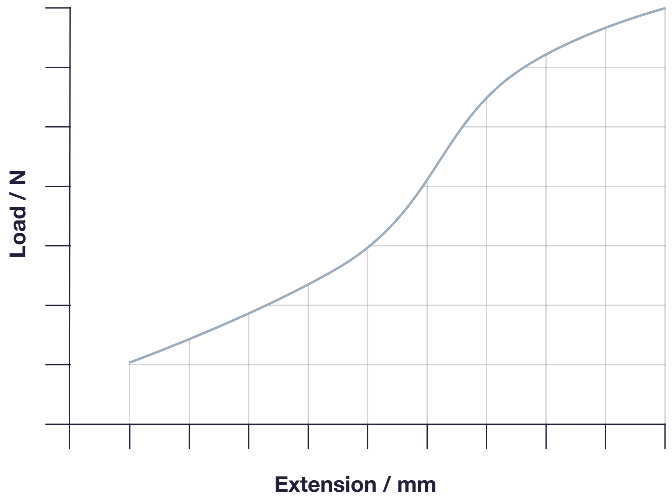
Determination of modulus

ASTM D52504

Calculating modulus from dumb-bell tensile testing.
100% E modulus

$$\textbf{E mod} = \frac{F \times Lo}{AL \times A}$$

F = Force at break
Lo = Original length of test piece
AL = Change in length
A = Cross sectional area



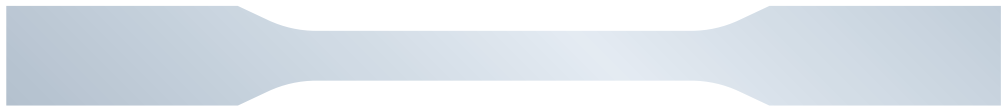
See page 153 for CASE STUDY on Environmental Stress Cracking

Environmental Stress Cracking (ESC)

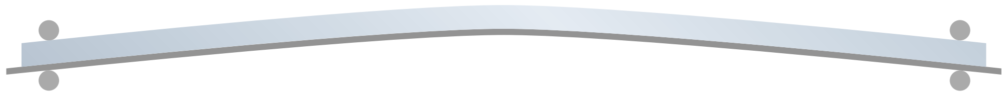
ISO 22088-3

Tensile tests are performed on the tensometer, which has the prescribed steadily increasing speed and load of the specimen according to EN 10002 standard (initial speed 10 mm / min, initial force 50 N). During the test the parameters (tensile strength, F max, F elongation, elongation length, elasticity modulus, etc.) are measured, which shows the loads of individual materials with the applied media according to the ISO 22088-3 standard.

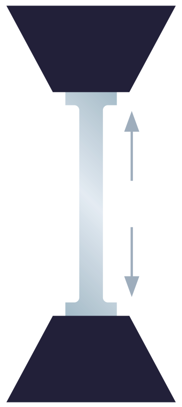
ESC is most likely to occur when a combination of factors are all present. These are; sensitive plastic such as ABS or PMMA, plastic under stress/tension, often a mechanical fixing and finally an adhesive that chemically attacks the plastic.



Plastic dumb-bell



Clamping dumb-bell at a radius of 418mm



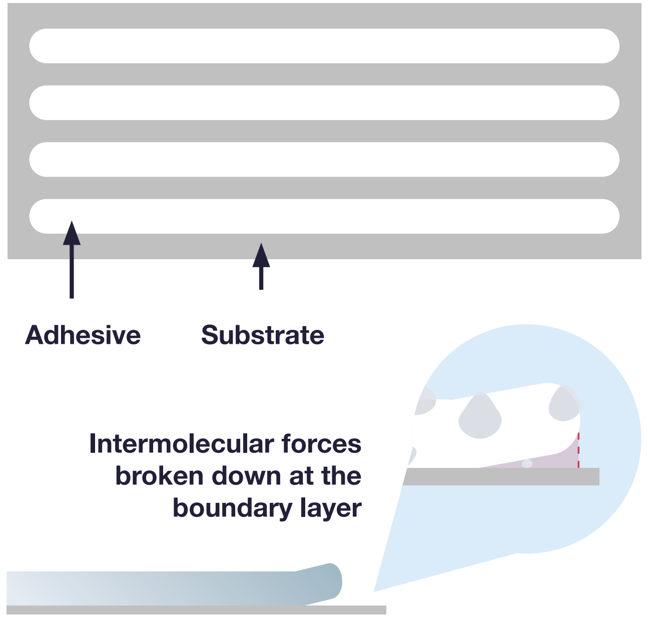
Tensile testing of plastic dumb-bell

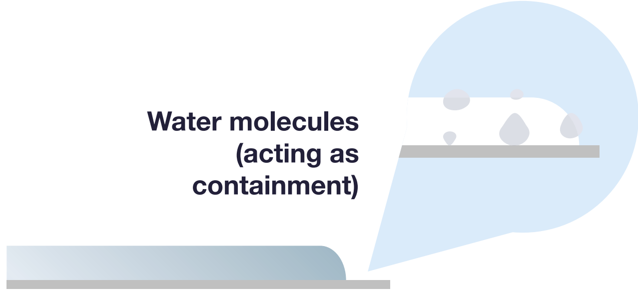
See page 169 for CASE STUDY on Cataplasma

Environmental testing

Durability
FGY042

1. Artificial high heat and humidity testing (+70°C/+158°F @ 90% relative humidity). Determines the adhesion, colour and bond strength of an adhesive in given time periods.
2. Cataplasma – JNS 30.03.35. Determines the adhesion compatibility between substrate and adhesives in the harshest environments.

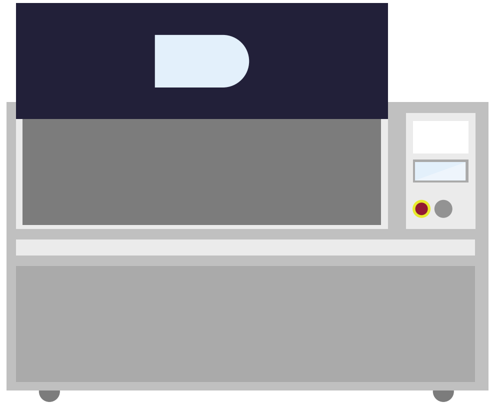




Salt spray
ASTM B117

Is a test which not only determines how fast a sample corrodes, it can also determine regression in processing, design flaws, change in pH of a sample and highlight areas in a test specimen which are more at risk from corrosion.

Samples are usually put into a fogging chamber made up of 5% NaCl solution. Samples are checked 2-3 times a day depending upon the sample being tested.

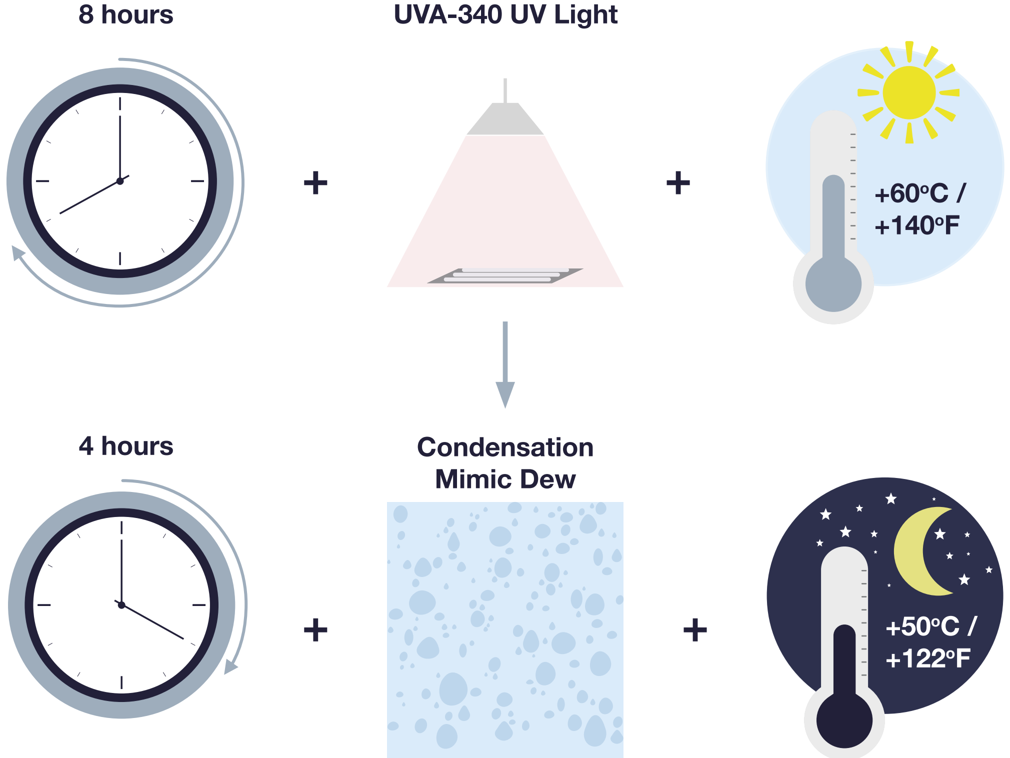


QUV & outdoor weathering
ASTM G154

Artificial weathering system which determines the maximum exposure of high heat, UV and moisture, before substrate degradation occurs.

Samples tested for outdoor weathering are tested using the same time period as those put into QUV. Both outdoor weathering and QUV can give a quantitative ranking system in order of most-least change of sample. Both are also used in conjunction to each other to try and determine a correlation factor to hours in QUV to change in natural outdoor weather.

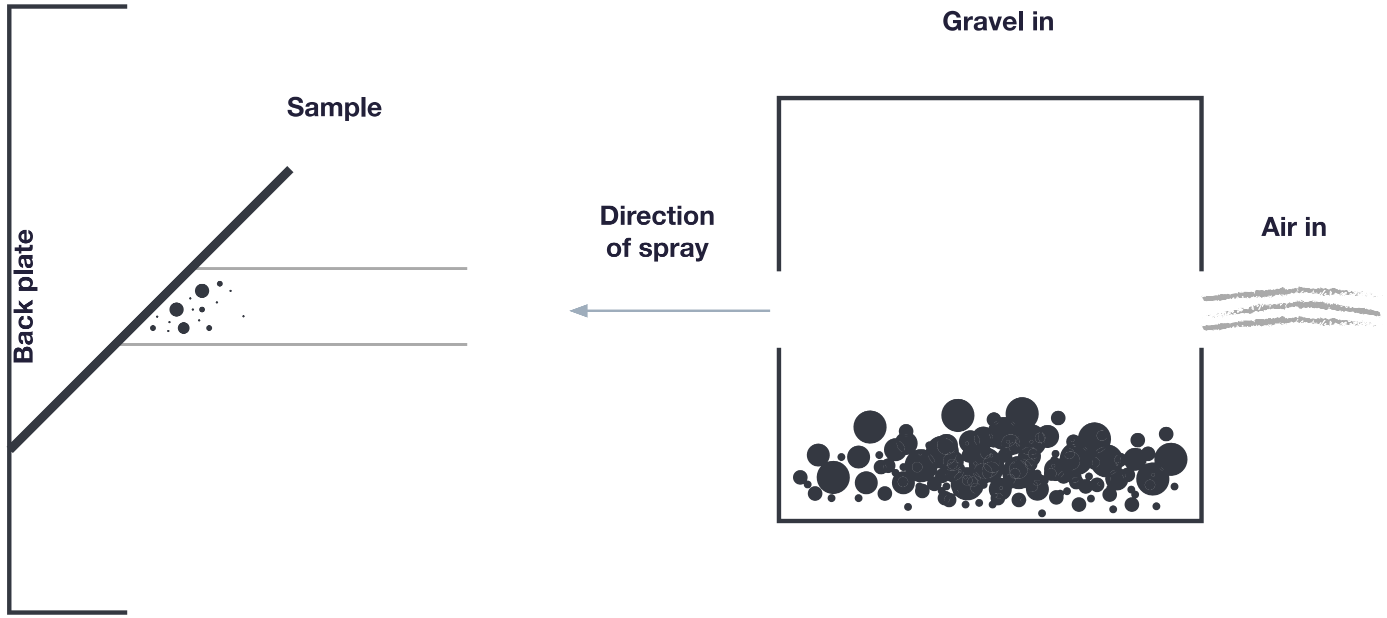
Artificial ageing system 12 hour full cycle consisting of:



Abrasion resistance using a gravelometer
ASTM D3170

Determines the resistance of a coating or material when hit with abrasive flying objects, i.e. stones, gravel and de-icing materials.

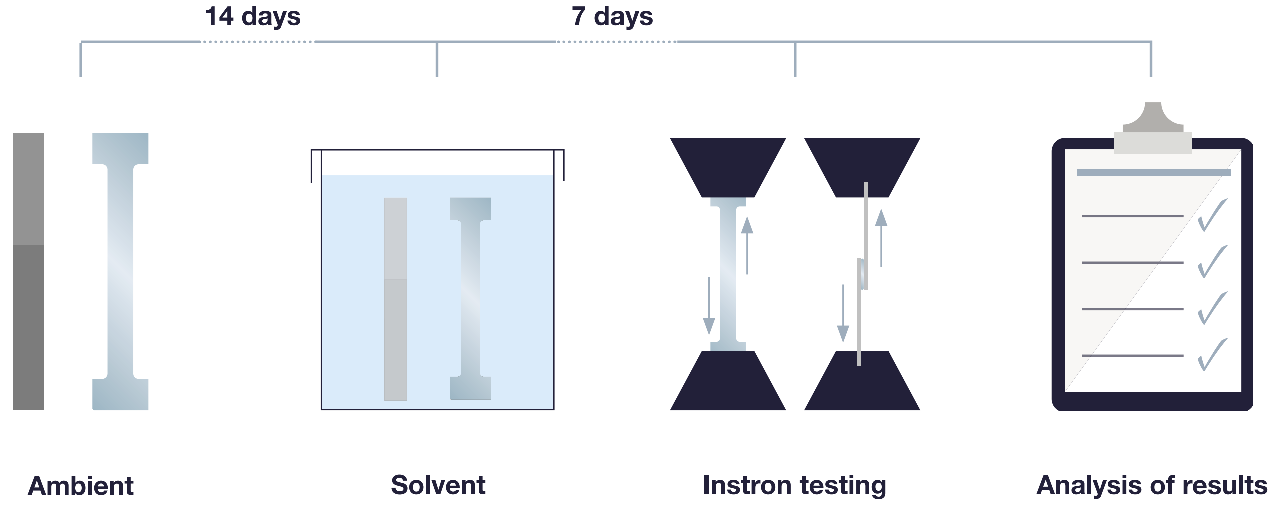
A measured amount of gravel is vibrated out of a hopper and down a feed chute under partial vacuum. The gravel media is sucked down into the gun assembly and is fired at the test specimen by means of air blast. After the gravel media hits the target it falls into a gravel box below. The sample is then analysed to determine the level of resistance.



Chemical resistance
ASTM D896-04

Chemical resistance is used to test the performance characteristics of an adhesive / adhesive bond when subjected to solvents or cleaning solutions which an adhesive may see during its service life.

Test specimens can be made up as a lap shear configuration, as ribbon bead testing for adhesion purposes, or dumb-bell formation. Test pieces are immersed in the solvents for 7 days and tested as per test configuration once it has dried out of solution.



08. Durability

See page 169 for CASE STUDY on Cataplasma

What is durability?

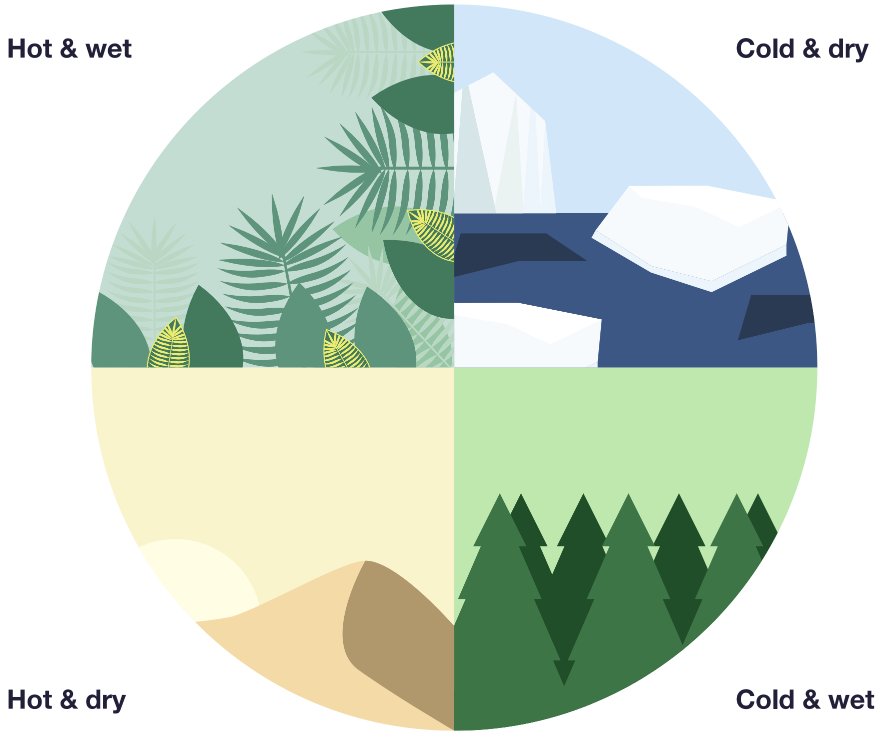
Durability is the ability to withstand wear, pressure or damage, allowing a long continuous life without breakdown or damage.

Why is durability important?

The more durable a product is, the less likely it is that it will need to be repaired or replaced; offering excellent reliability. The environment will also benefit from durable products as raw materials and energy will not be wasted in the process of repair or replacement and therefore energy is saved.

There are 6 key areas which must always be evaluated when developing / testing adhesives:

1. High heat and humidity testing
2. Cataplasma
3. QUV & outdoor weathering
4. Corrosion and erosion
5. Anti-fungal
6. Dirt pick-up



See page 152 for CASE STUDY on glazing test

1. High heat and humidity testing ISO 9142

Artificial heat and humidity testing determines the performance properties of both the adhesive and adherend in the harshest environments.

The test piece should be prepared considering the environment in which it is expected to see throughout its service life. The temperatures should be ±20oC (±68oF) more or less than the expected conditions.

1000 hours in these conditions will detect (if any) failures on the adhesive and the substrate in which it is bonded to.

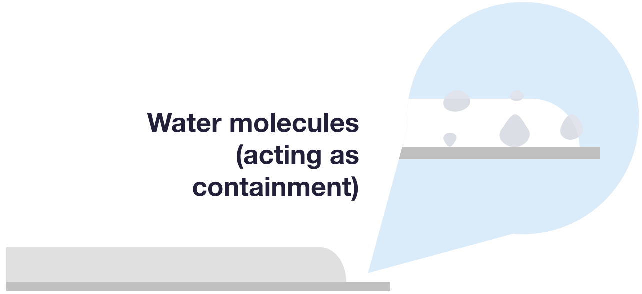
This test is extremely important as it could give early indications on product performance and durability when in service.

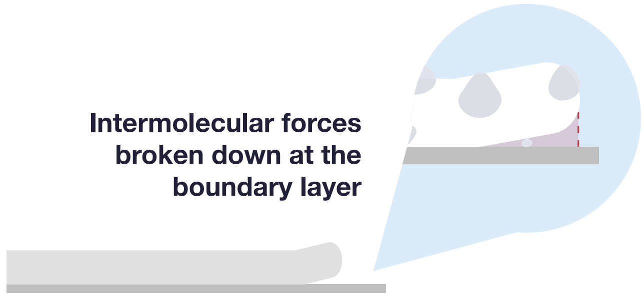
When an adhesive bonds with a substrate, strong intermolecular forces are created at bonding sites. This core of bonding sites from adhesive to adherend is known as the boundary layer; and is the key in maintaining utmost adhesion throughout its service life.

When a bonded adhesive is subjected to high heat and high moisture environments, the boundary layer can begin to break down. In this case, water starts to act as a contaminant within the adhesive-adherend layer. The water molecules interact with intermolecular forces within the weak boundary layer and slowly begin to de-bond the adhesive. This is more prominent on metal surfaces, where, covalent bonds are made from the polarity of the water and the available bonding sites from the metal. Failure must not occur within 10,000 hours for a glazing adhesive and not within 5,000 hours for a panel bonding adhesive.

How is breakdown of the boundary layer prevented?

Antioxidants within the adhesive stop the breakdown at the boundary layer so the forces between the adhesive and adherend remain strong and intact.



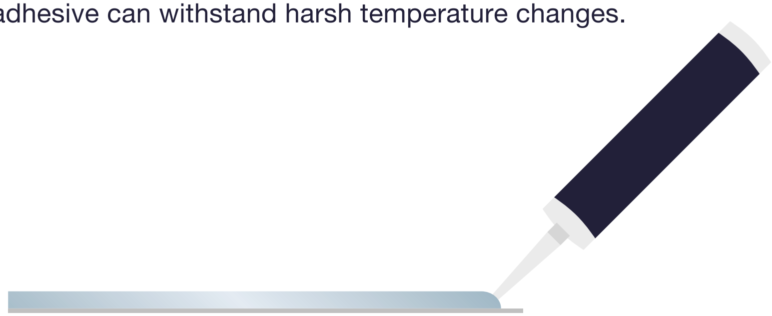


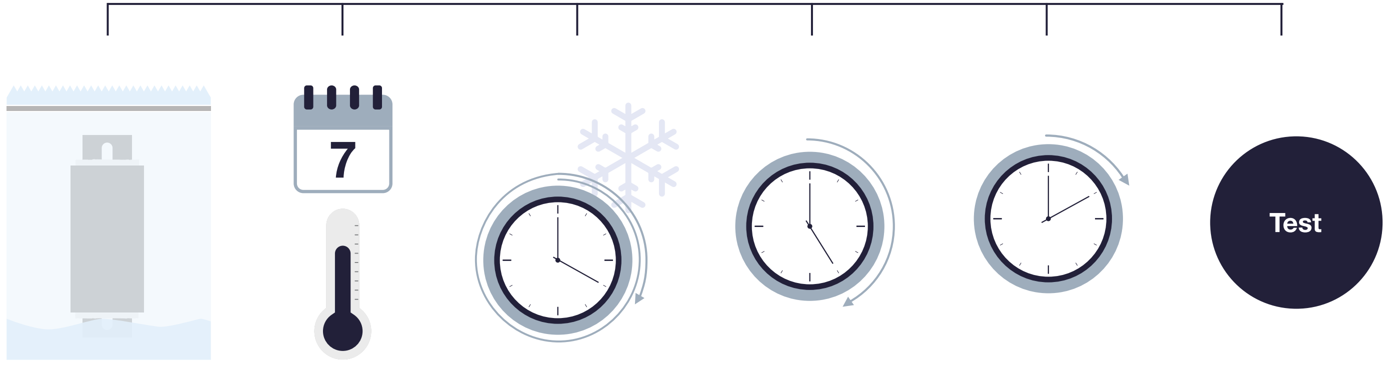
See page 169 for CASE STUDY on Cataplasma

2. Cataplasma JNS 30.03.35.

This test is designed to assess the compatibility of adhesive and substrate after extreme temperature changes. Test pieces are wrapped in cotton wool then wrapped in tin foil. Specimens are added to a sealable bag with deionised water (volume equals 10 times the weight of the cotton wool around the test pieces). The sealed bags (containing all constituents mentioned above) are left in a +70°C (+158ºF) oven for 7 days then put into a freezer of -14°C (+6.8ºF) for 16 hours. The test is completed when the substrates have been unwrapped and allowed to thaw for 2 hours.

The rapid extreme temperature changes determines if adhesion is possible and if the adhesive can withstand harsh temperature changes.





Adhesive on substrate (Wrapped in cotton wool and tin foil sealed in a plastic bag)

7 days at +70ºC (+158ºF)

16 hours at -14ºC (+6.8ºF)

5 hours thaw

2 hours rest

Full cohesion to substrates after full cataplasma cycle

See page 173 for CASE STUDY on Water Ingress

3. QUV and outdoor weathering

There are two common types of QUV test methods which use two different forms of light:

1. **ASTM G154 –** Fluorescent light (UVA and UVB). Photodegradation occurs, because UV light has a shorter wavelength than visible light and can penetrate polymers more deeply. This method of accelerated weathering is best suited for surface finishes, coatings and polymers.
2. **ASTM G155 –** Xenon arc UV. Photodegradation occurs, because long UV and visible light penetrate shallow areas and deeper areas within the sample. This method of acceleration is best suited for colour change of samples over time.

Deterioration of samples in QUV can show the following changes to the naked eye:

- Change in colour
- Loss of gloss
- Chalking (white precipitate starts to migrate towards to the surface of the polymer).

After prolonged exposure, the following changes are visible:

- Cracking
- Blistering
- Embrittlement (the adhesive can no longer withstand its original shape or form; can completely turn to chalk).

There are some colours which are more susceptible to UV degradation than others, for example; red, orange and blue etc. Pigments used to colour adhesives contain an aromatic ring structure which makes them more susceptible to UV degradation. This is because structures like aromatic rings absorb UV waves more readily, which causes the aromatic ring to break down. In real life, this is visible as chalking and fading of colour.

Most weathering damage is caused by three overriding factors:

1. **Light –** Short wave UV is the most common cause of polymer degradation. Material degradation caused by light is dependent upon the materials sensitivity (this can change from material to material).
2. **High temperatures –** Temperature is not a primary factor which causes material degradation, however, it affects the secondary reactions of a materials by-products.
3. **Moisture –** Dew, rain and high humidity are the main causes of moisture damage. Dew is the reason why objects outdoors remain wet for prolonged periods of time, which allows for high moisture absorption. Rain can be also very damaging as it can cause thermal shock on materials subjected to high heat environments.

Bond failure and water ingress with 2500 hours of QUV = 208 cycles

Withstands 536 cycles with no change / breakdown to samples = 6432 hours of QUV

4. Corrosion and Erosion ASTM B117

See page 156 for CASE STUDY on Filiform Corrosion

See page 176 for CASE STUDY on Galvanic Corrosion

Corrosion

Definition of corrosion: degradation or destruction of metals and alloys in an environment, by the process of electrochemical or chemical process.

Corrosion affects all aspects of industry; automotive, construction, transportation, production, marine and manufacturing to name a few. A recent study by NACE International found corrosion costs $2.5 trillion globally, contributing to 3.4% of gross domestic product.

How are adhesives affected?

Oxides associated with the corrosion reaction can break down the boundary layer at the adhesive-adherend interface, and in turn begin to deteriorate the forces within the adhesive itself. The adhesive can begin to soften, de-laminate and lose its strength properties.

How can corrosion be prevented?

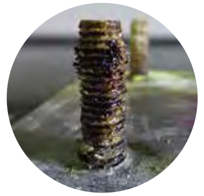
Using metals that are more resistant to corrosion; aluminium, stainless steel, chrome etc.

Protective coatings – paints and powder coatings reduce oxidation on the metal surface.

1. **Design modification –** avoiding crevices which trap dust, as this can attract water ultimately leading to corrosion.
2. **Anodic and cathodic protection –** the use of less reactive or more reactive coatings which inhibit oxidisation on the bulk metal material.

There are four main types of corrosion:

1. **Uniform corrosion:** whereby the surface layer of metal / alloy will rust due to environmental factors. This type of corrosion is most common amongst ferrous metals and alloys which are uncoated.



2. **Galvanic corrosion:** this type of corrosion is driven by corrosion potentials of dissimilar metals when in an electrolytic solution (water). The lowest corrosion potential metal becomes the anode and the highest becomes the cathode.

3. **Electrolytic corrosion:** similar to galvanic corrosion, the only difference being that the corrosion does not have to take place in an electrolytic solution. There has to be an external source of electromotive (EMF), this could be from a battery or electric generator etc.

4. **Filiform corrosion ASTM-D2803 & crevice corrosion:** formed through ion gradients which generate anodic and cathodic areas on the metal.

Erosion

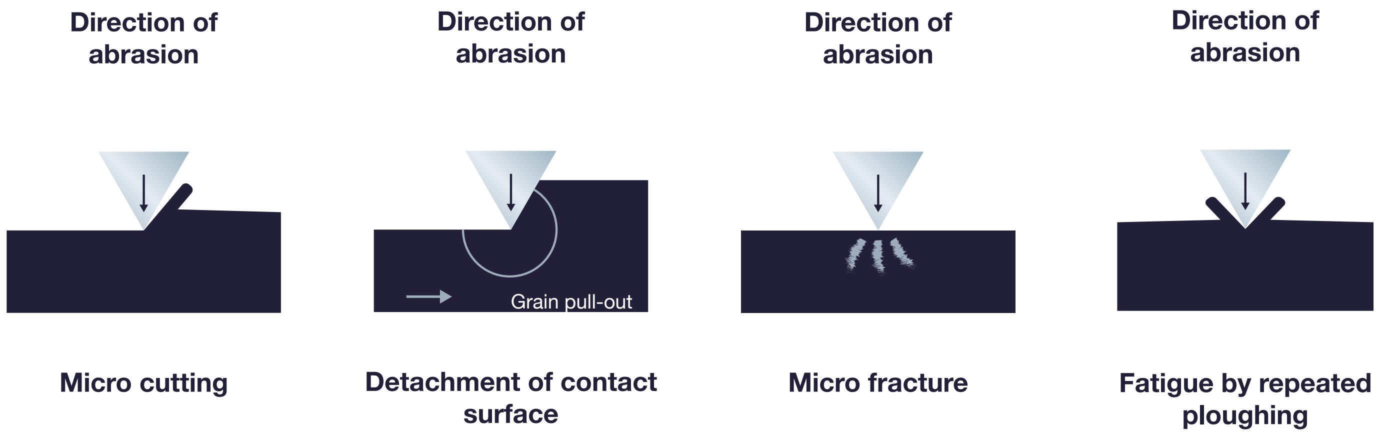
There are two types of particulate erosion:

1. **Foreign body erosion**

Foreign body erosion is mostly associated with the automotive industry. The underside of a vehicle can be damaged through the impact of stones, causing crevices and chips. This type of erosion can be more damaging when it's cold due to the rate of foreign bodies increasing; salt (grit) and anti-freezing agents.

2. **Airborne particulate erosion**

Airborne particulate erosion is largely present in the rail industry, whereby small particles in the air (made up from dust or particle emissions from rail vehicles) act as an abrasive - material is slowly lost from the impact on both contacting surfaces. The rate of erosion is therefore highly dependent on the speed and position of particulate and contact surface. There are six types of wear known to this erosion**; however, abrasive** erosion (the main type) is the most damaging. The below diagram shows the effect on abrasive wear.



The resistance to airborne particulate erosion on adhesives is largely reliant on the hardness properties. If the hardness is increased, the impact on erosion is reduced.

See page 165 for CASE STUDY on Mould Growth on Sealants

5. Anti-fungal

What is mould?

Mould is a naturally occurring microscopic organism that is a vital part of nature's recycling system. It destroys whatever it grows on as it feeds on and digests it. Mould can spread either by extension of tiny root hairs called hyphae, or it produces spores (tiny seeds) which can be carried by air or water.

Mould generally requires the following to grow:

- Any organic material
- Synthetic materials such as adhesives
- Pastes and paints
- Moisture
- Oxygen
- Warm temperatures

What does it do to your adhesive / sealant?

It has been found that, products containing anti-fungal properties will still allow mould growth if:

- Standing water is left on the sealed joint
- There is little / no air flow through a high moisture environment
- The sealed joint is not regularly cleaned

As mould starts to grow around your sealed joint, it starts to feed off of the materials in which the adhesive is made; fillers, polymer, pigments etc. As this happens, your sealant will slowly lose colour, start to de-bond from its joining substrates and have a foul odour.

Preventing the spread of mould

There are five key points that should be taken into consideration:

1. Identify where the problem areas are – where does water pool? Are there areas where the joint is not sealed sufficiently?
2. Dry off the wet / damp areas – remove standing water or condensation.
3. Prevent high humidity conditions – ensure there is sufficient ventilation for the size of the room. Make sure air is circulated effectively.
4. Repair damaged areas – incorrectly applied sealant should be re-done. If there are any areas which water can migrate into, mould will form from underneath the joint.
5. Clean the sealant regularly – ensure the sealed area is cleaned thoroughly at least weekly; this will eliminate any surface spores which are ready to grow.

6. Dirt pick-up

When your adhesive gets dirty and particulates start to migrate into the adhesive, it can no longer be cleaned free of contamination.

What factors should be taken into consideration when tooling up your sealant?

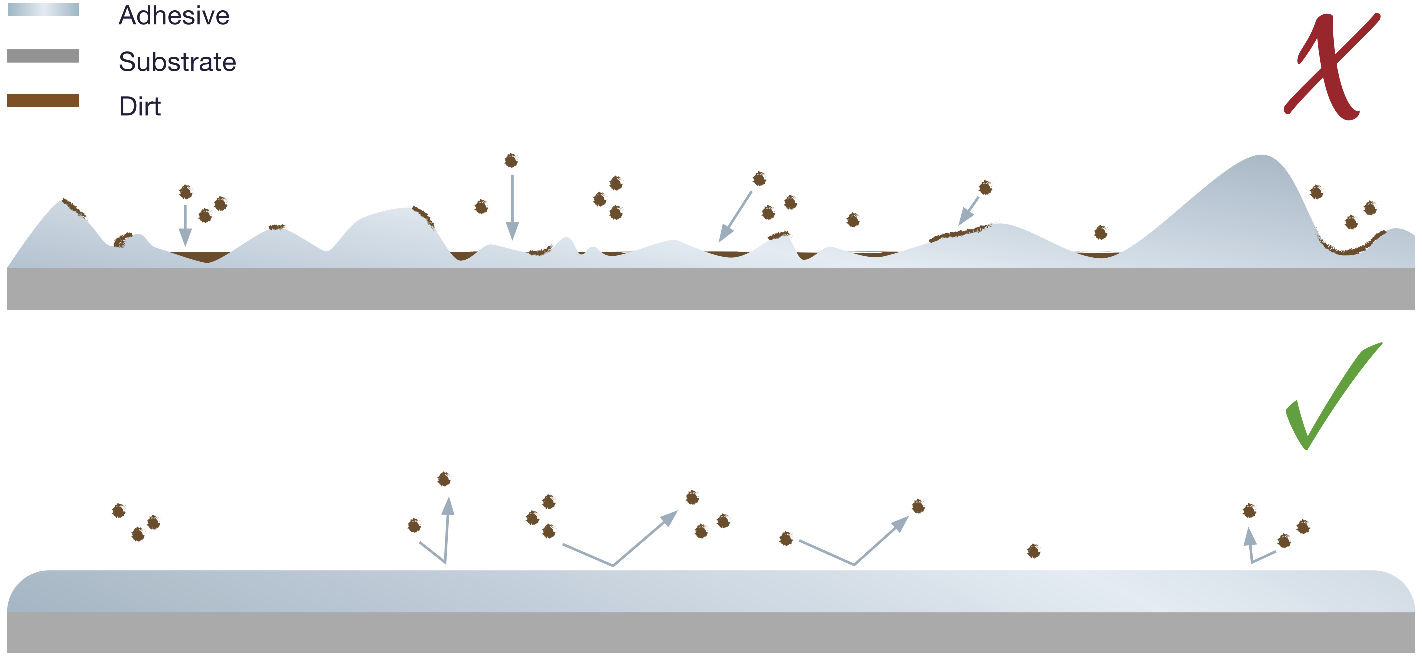
Firstly, no peaks or crevices should be seen on the surface of the sealant. This is because dirt particulates have a tendency to 'hook on' or sink into uneven areas. A smooth surface allows dirt and foreign objects to slide over it without affecting the sealant and causing degradation. This also enables cleaning to be achieved more easily.

Secondly, tackiness plays a big role in how much dirt sticks to it. The less tacky your sealant is, the less dirt that will migrate into your sealant.

Therefore, a few design and processing solutions may see your sealant cleaner than ever.

Key

- Adhesive
- Substrate
- Dirt



09. Analysis methods

Fourier Transform Infrared Spectroscopy (FTIR)

What is FTIR?

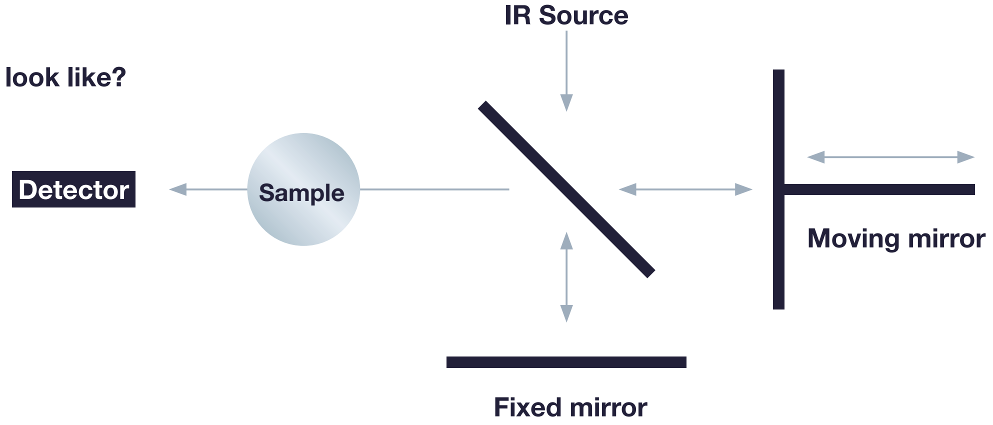
Infrared spectroscopy is an important technique in organic chemistry. It is an easy way to identify the presence of certain functional groups in a molecule. The unique absorption properties of functional groups are used to confirm the identity of a compound. You can also detect the presence of specific impurities within a sample.

- A source generates light across the spectrum of interest e.g. 4000 - 500cm-1.
- A light splitter separates the source radiation into its different wavelengths.
- The light is directed through the sample.
- The sample absorbs light according to its chemical properties.
- A detector collects the radiation that passes through the sample and compares its energy to that going through the reference.

A = ECL **A** = Absorbance **E** = Molar absorptivity **C** = Concentration **L** = Length

Equation 2

What does FTIR look like?



A light beam is divided into two separate light paths to a beam splitter. Half of the radiation is reflected and the rest is transmitted. Transmitted light travels to a fixed mirror and the reflected light to a moving mirror. The light from both fixed and moving mirrors are combined at the beam-splitter, it travels through the sample and hits the surface of the detector.

Why is FTIR important?
It is used for many reasons which are important to both qualifying a product, identifying failure modes of a product / part and for the identification of contaminants.

Gel Permeation Chromatography (GPC)

What is GPC?

GPC is one of the most powerful and versatile analytical techniques available for understanding and predicting the performance of a polymer. It is used to calculate the complete weight distribution of a polymer, determining four important parameters:

1. Number average molecular weight
2. Weight average molecular weight
3. Z weight average molecular weight
4. Molecular weight distribution

The values obtained determine the following physical properties:

- Tensile strength
- Adhesive strength
- Elastomer relaxation
- Flex life
- Cure time
- Brittleness
- Elastic modulus
- Melt viscosity
- Impact strength
- Hardness
- Toughness
- Softening temperature
- Draw-ability
- Tear strength
- Adhesive tack
- Stress crack resistance
- Coefficient of friction

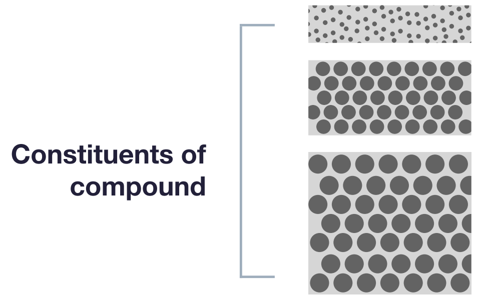
How does it work?

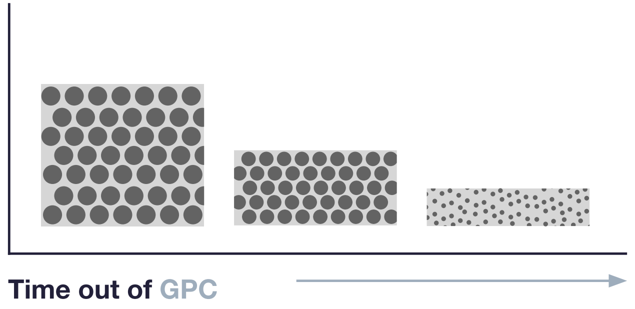
The polymer is dissolved in an appropriate solution for the polymer type. The polymer solution is then injected in a mobile phase (flowing solvent) which then flows through millions of porous, rigid particles (stationary phase). The pore sizes of the stationary phase are of varying sizes and control the time at which each particle passes through the system (retention time).

The higher average molecular weight of the molecules elute first out of the column; the lower molecular weights remain in the column for longer.

Limitations

- There are a limited number of peaks that can be resolved from the column in a short period of time.
- GPC requires at 10% difference in molecular weight for a reasonable number of peaks to occur.
- With regards to polymer analysis, most of the polymer chains will be too close to show anything but broad peaks.
- The instrument is very sensitive and requires filtration of the material being analysed to prevent dust particles blocking the instrument.





Dynamic Mechanical Analysis (DMA)

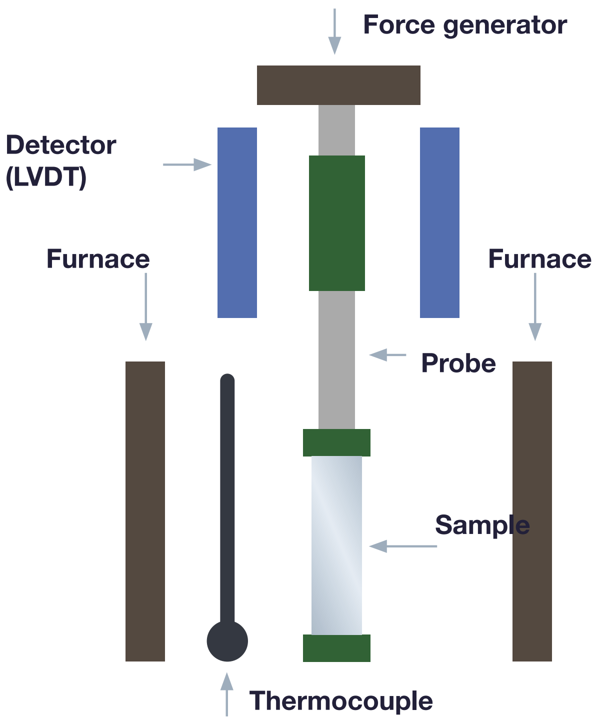
What is DMA?

DMA is used to characterise materials properties as a function of temperature, time, frequency, stress, atmosphere or a combination of all parameters. Its key analysis strength is the determination of a materials glass transition temperature (Tg – the state at which a material turns from a hard material to a soft one). Results are usually given graphically as a function of tan delta vs. temperature. The DMA technique is more sensitive than thermal mechanical analysis for detecting transitions, which is why it is more favourable to use for Tg analysis.

How does it work?

Applies an oscillatory force at a set frequency to a sample and reports changes in stiffness and damping (damping is a measure of the dissipated energy in a material under cyclic load).

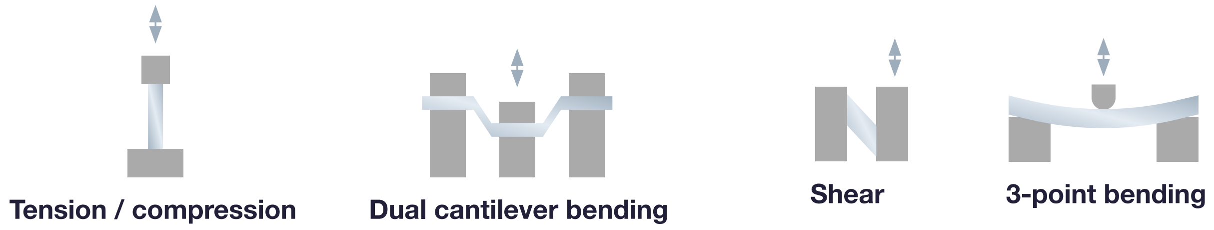
Applies a sinusoidal deformation to a sample of known geometry. The sample can be subjected by a controlled stress or controlled strain. For a known stress, the sample will then deform a certain amount. How much it deforms is related to its stiffness.



Limitations

- There are a few draw backs with this kind of analysis, relating to the sample size, obtaining an accurate measure and misalignment of results when using different machines

Deformation modes



Differential Thermal Analysis (DTA)

What is DTA?

DTA measures the difference in temperature between a known reference and a sample as temperature changes.

The analysis provides data on the following:

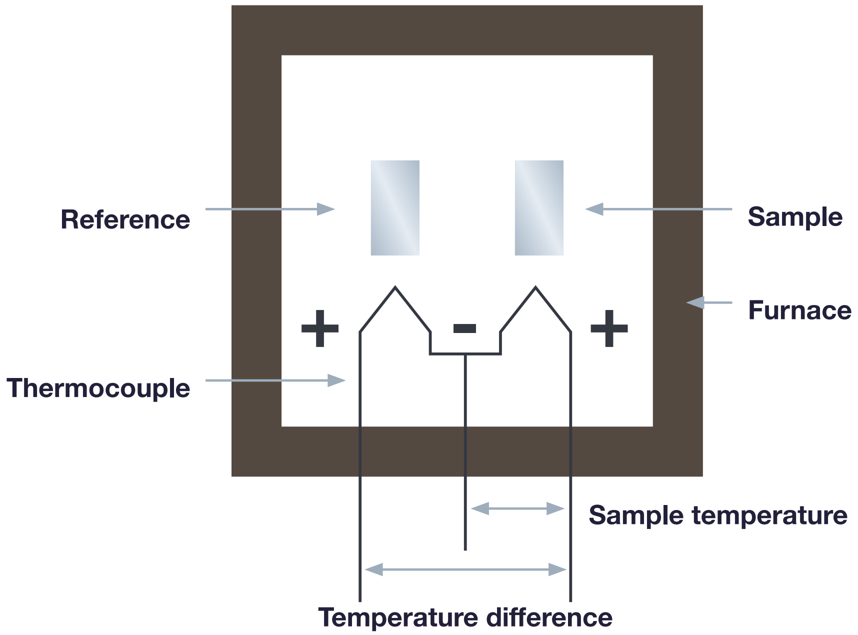
- Glass transition temperature (Tg)
- Crystallization
- Melting point
- Sublimation
- Enthalpy change

How does it work?

An inert reference material is used to compare temperature differences of the sample under analysis through temperature changes / thermal cycles.

Applications

- Used for identification purposes of materials; polymers, cement, minerals etc.
- Pharmaceutical industry
- Food industry
- Environmental studies
- Dating fossils / archaeological materials



Limitations

- Temperature change is not 100% accurate, recorded results could be up to +2oC - +3°C (+3.6oF - +5.4oF) out
- Small changes in temperature cannot be detected
- Heat variations between the sample and the reference sample makes the analysis method less sensitive

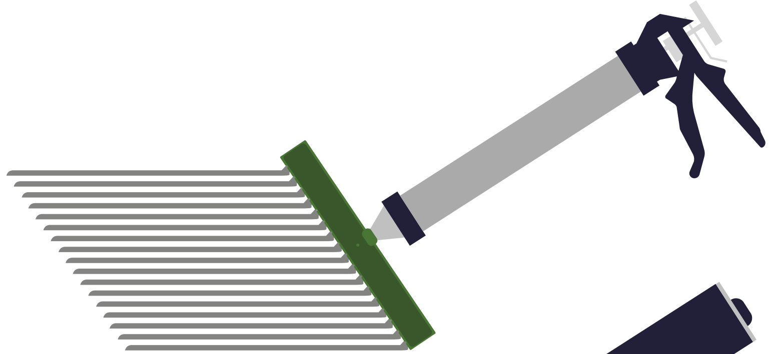
10. Applying adhesives

Applying adhesives

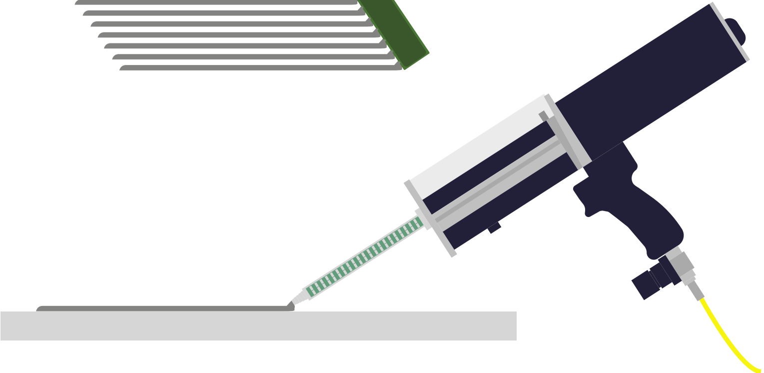
Rules to consider:

1. Surface is prepared and contaminant free
2. Apply in straight beads along the substrate intended for application of adhesive
3. DO NOT apply in ‘S’ beads (this can cause water entrapment)
4. DO NOT over apply adhesive (more is not better)
5. Spacing of beads on a large surface area is important - this encourages through cure
6. Determine joints depth; use spacers to achieve desired thickness of adhesive

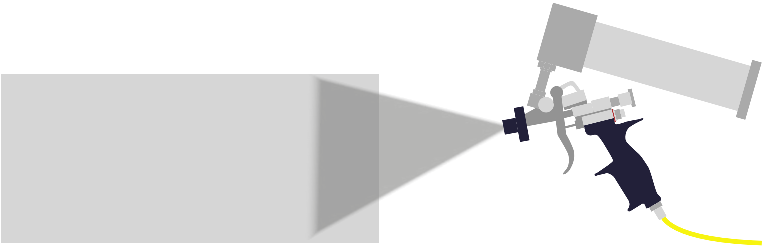
Application of multibead applicator (300mm / 150mm)



Application of two component adhesive

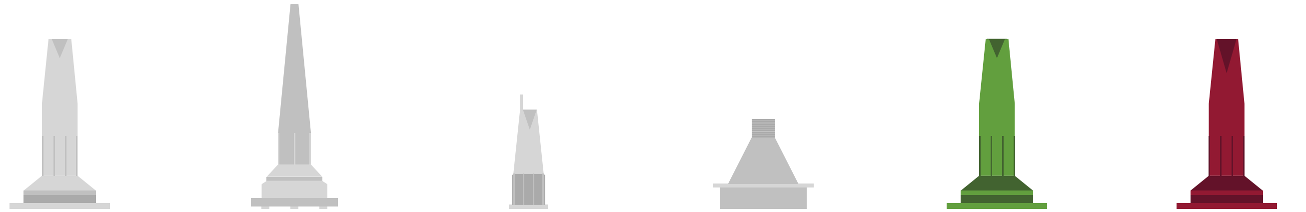


Spray application of low viscosity adhesives



Nozzles selector guide

Foils

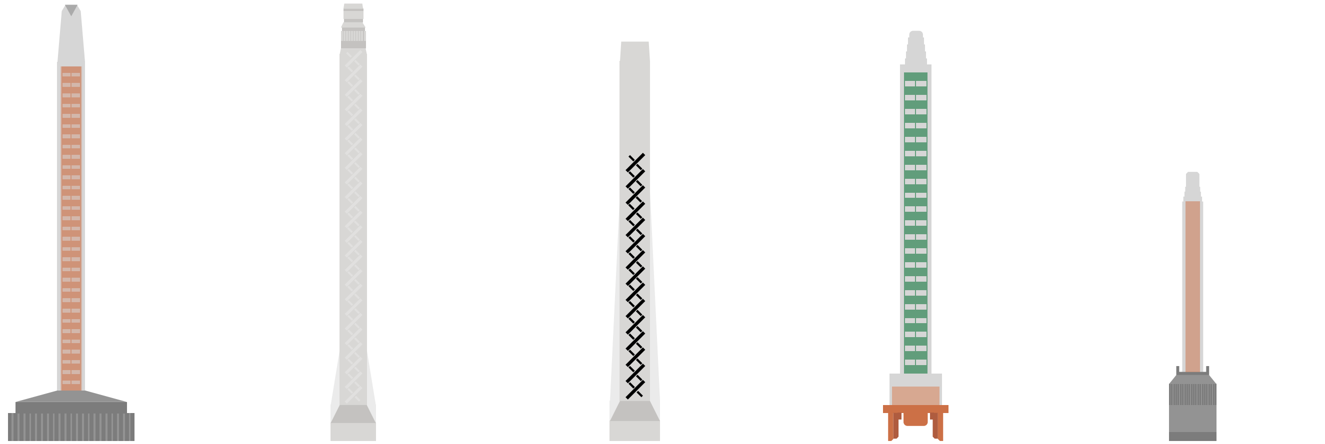


8 x 8 V-cut nozzle | Standard nozzle- not pre-cut | Stepped nozzle | Self piercing foil applicator head | 8 x 8 V-cut nozzle (Panel bonding) | 10 x 12 V-cut nozzle (Glazing)

Cartridges

Standard nozzle (not pre-cut) | V-cut nozzle | Nozzle with cap | Stepped nozzle

2 Component



Dual component static mixing nozzle | Dual component static mixing nozzle | Dual component static mixing nozzle | 10:1 Static mixing nozzle (490ml) | 10:1 Static mixing nozzle (50ml)

Storage of adhesives

The storage and application temperatures of adhesive is critical and impacts the cure speed of the product.

The ideal storage temperature conditions are between +15°C (+59oF) and +25°C (+77oF), although most adhesives can be stored between +5°C (+41oF) and +25°C (+77oF).

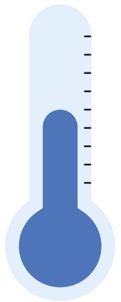
You should always consult the technical data sheets to determine the ideal storage conditions.

Most one component epoxy and methyl methacrylate adhesives will need to be stored in the fridge to inhibit premature curing inside the cartridge.

Consideration should be given to autumn and spring time temperatures; warm days and cold nights can be deceiving. With the heating turned off, your adhesive may not have through-cured as much as you expect.

Note: substrates should be kept at ideal temperature conditions also as this can impact cure speed.

1

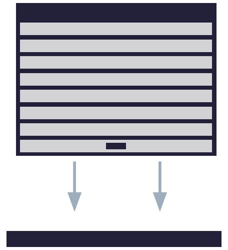


For optimum performance, the substrate and the adhesive should be between +15°C (+59oF)and +25°C (+77oF). If over or under this range, the product may display different characteristics.

2

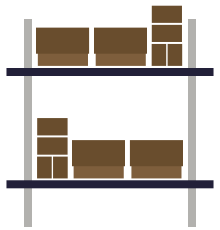
Store in a warm / heated environment.

3



Keep roller-shutter doors down to avoid too much heat escaping.

4



Keep it raised off the floor. Even a pallet height can make all the difference!

5

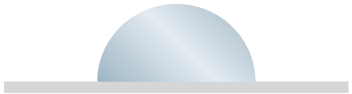
Keep the heating on overnight.

6

Use foil pack / cartridge warmers.

Usage guide

Sealing

Yield per cartridge / 600ml Foil	
 Bead diameter (mm)	 Linear meters
3	40
4	23
6	10.2
8	5.7

Bonding

Yield per cartridge / 600ml Foil	
 Bead width x thickness (mm) (Bond area)	 Linear meters
12 x 2	12.0 / 25.0
20 x 2	7.2 / 15.0
50 x 2	2.9 / 6.0

Equation 3

$$X = \frac{V}{\pi r^2}$$

KEY

V Volume of sealant (mm3)

r Radius of sealant's circular profile (mm)

X Linear mm per cartridge

11. Cure and handling times

Cure and handling times

The cure time or handling times of adhesives and sealants can be described in various ways. The terms used are usually associated with the adhesive type and the mechanism of cure.

- Pot life / working life / working time / gel time - A term used for two-part adhesives with a specific mix ratio. Pot life is used to state when the two parts of the adhesive are mixed together and are no longer usable. The pot life of two component adhesives can be shortened if the temperature is increased and the volume of adhesive is increased. Conversely, the pot life can be lengthened if the temperature is decreased.

- **Fixture time -** A term used for very fast setting adhesives such as, cyanoacrylates or UV curable adhesives. It is the time taken for the adhesive to be set firm; the adherends are no longer moveable.

- **On-part life -** A term used to describe contact adhesives. Once the contact adhesive has been applied, there is a limited time in which the adhesive loses its reactivity and can no longer be bonded.

- **Handling time -** The time taken after joint assembly in which the clamps can be removed. The adhesive has built up enough strength to hold itself in position.

- **Working strength -** The time taken for the adhesive to reach enough strength to be put into light operation.

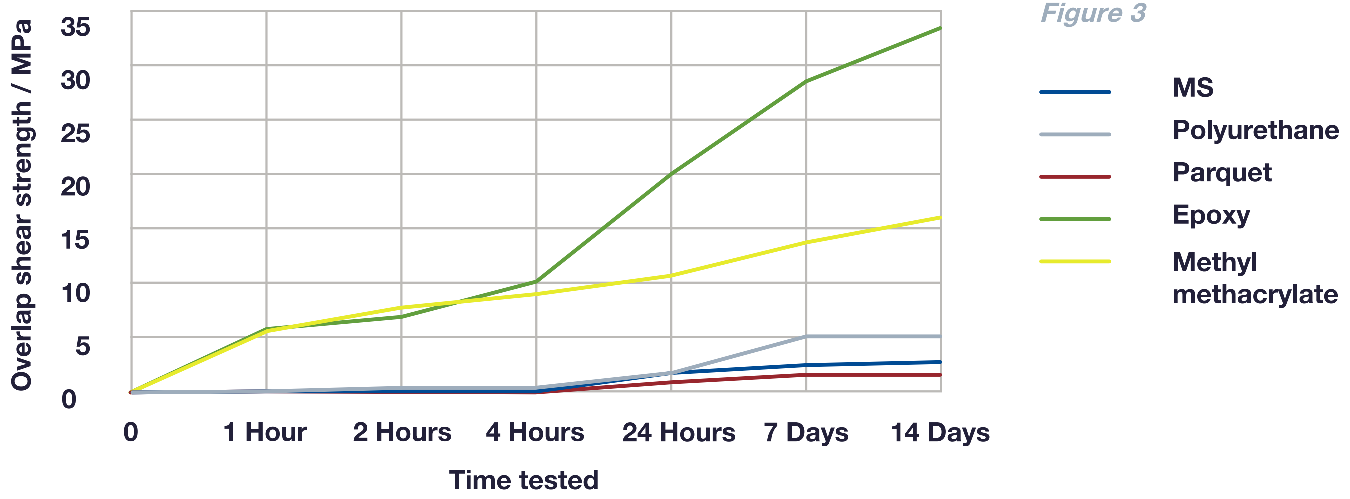


Figure 3

The above graph shows the 14 day overlap shear strength of various adhesives types.

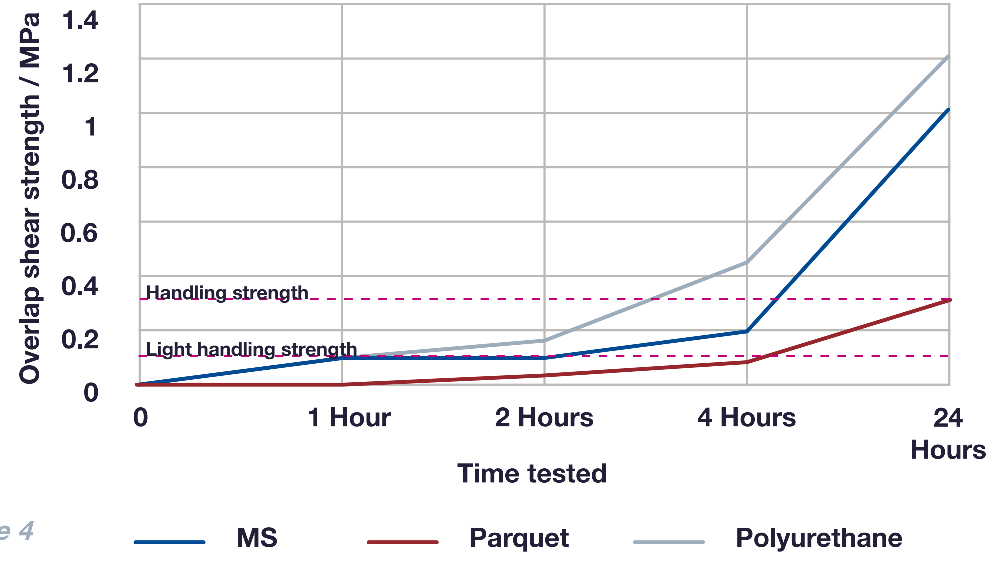


Figure 4

The above graph shows the handling times of one-part moisture curing adhesives.

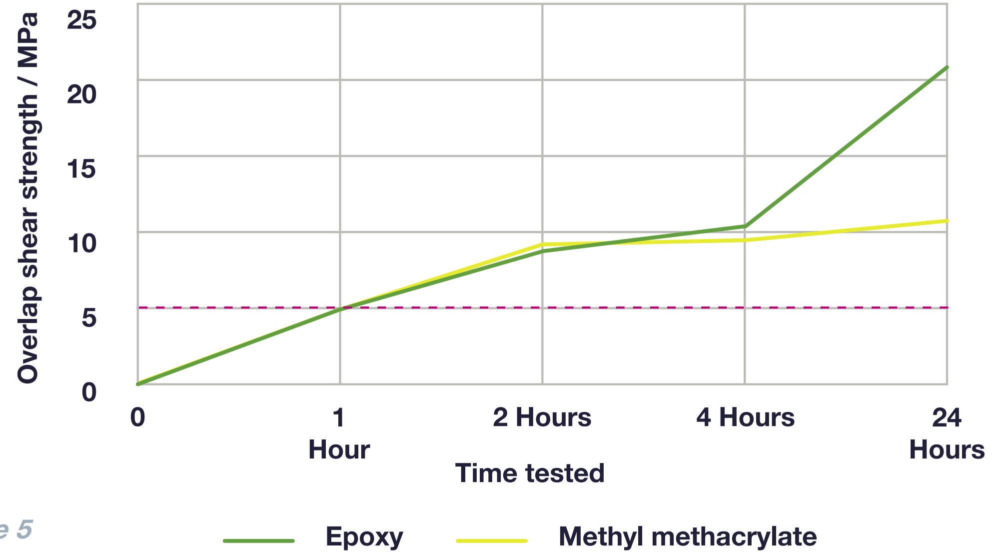


Figure 5

The above graph shows the fixture time of two part chemically curing structural adhesives.

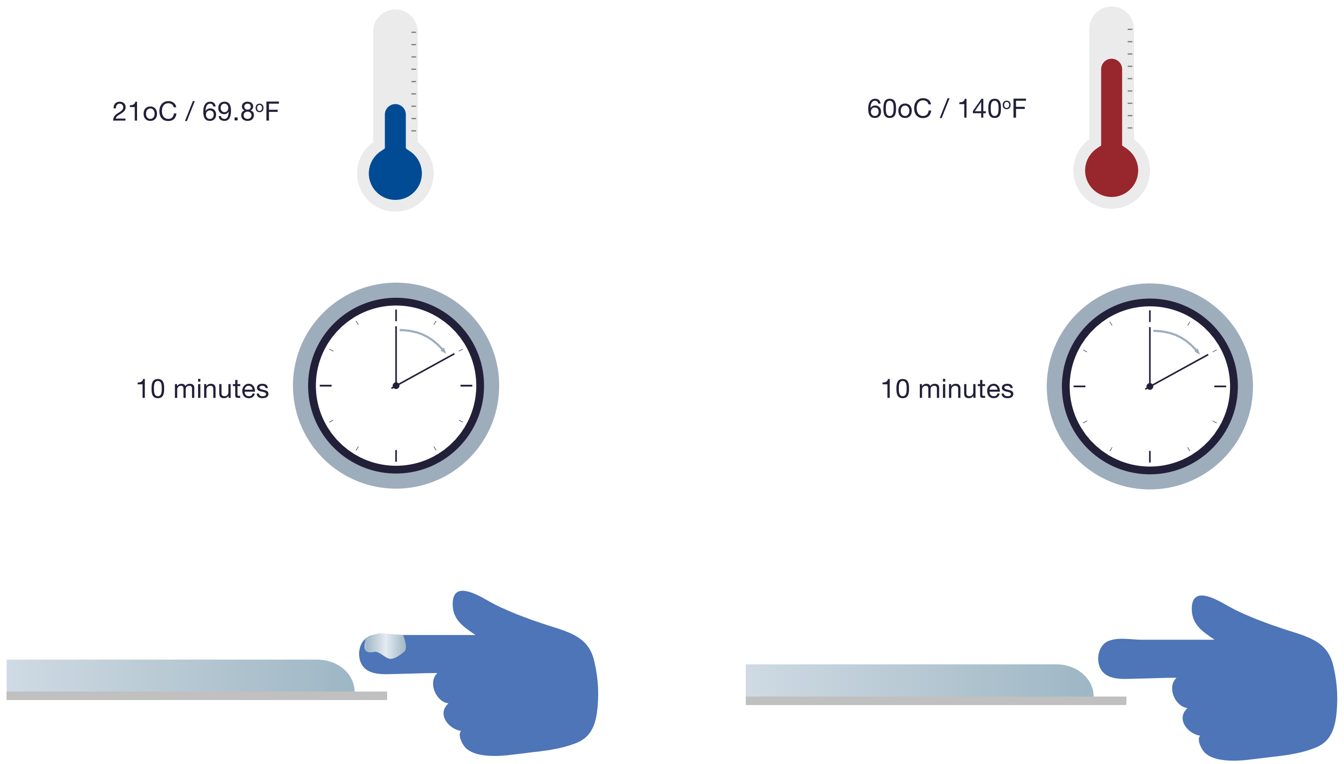
12. Factors affecting cure speed

What affects cure speed

There are several factors that need to be considered when determining how long it will take for an adhesive to fully through cure. These factors will differ depending on the chemistry of adhesive, but generally they are all affected by the following:

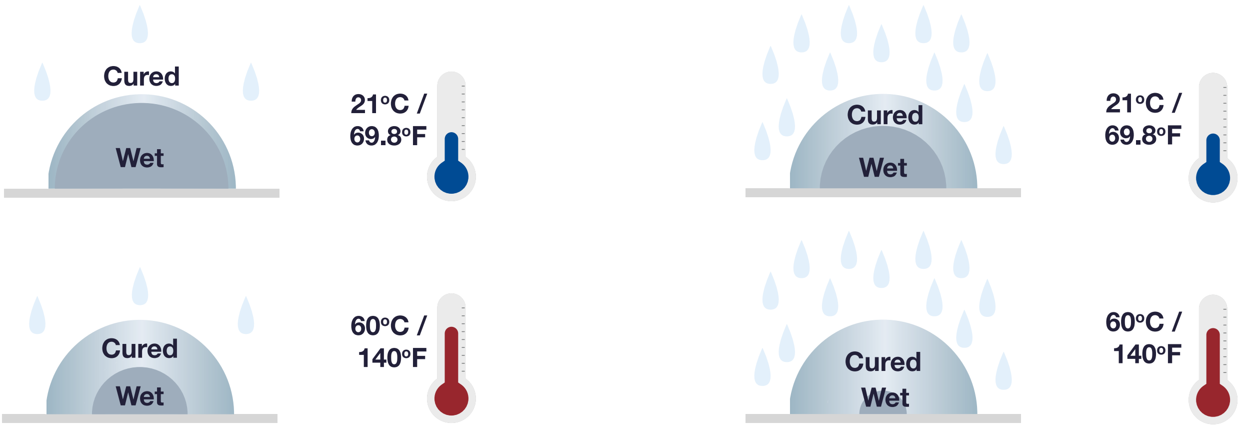
1. **Temperature**

In all chemical reactions, **temperature** speeds up the rate of reaction. This is because the collision rate / the speed at which interactions are made are increased, so everything happens at a faster rate. The same is true when we consider the **speed of cure** or through cure of adhesives, **temperature** increases the rate of through cure, but also decreases both the tack free time and maximum available bonding time of adhesives as the reaction is sped up.



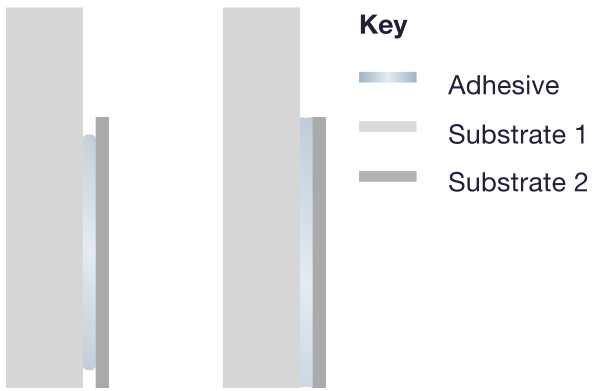
2. **Humidity**

For any adhesive system which uses moisture to cure, the relative moisture in the environment will determine how fast an adhesive will cure. A higher percentage of humidity in the air will increase the rate of cure and conversely a low percentage of humidity will decrease the rate of cure. When considering an increase in temperature and humidity, the rate of reaction will be increased further and therefore reducing the tack free time and maximum available bonding time at a higher rate. The opposite is true for low temperature and low humidity levels.



3. **Area of coverage**

When considering moisture curing adhesives, the larger the volume of adhesive in an area the slower the cure rate will become. As we have seen from previous chapters, moisture curing adhesive cure from the outside in. Therefore, the larger the volume of adhesive the longer it will take for the moisture to penetrate through the cured outside adhesive material and into the uncured middle. For chemically curing adhesives, a larger volume of adhesive means a faster reaction rate and therefore a faster curing time. This is because in mass, the chemical reaction gets hotter quicker. As we have just learnt, heat speeds up the rate of reaction. It is also important to ensure that the bonded area is completely covered; leaving no gaps / un-bonded areas which could give rise to water entrapment and corrosion.



4. Excess adhesive

Excess adhesive is another factor which decreases the time to cure. Going back to moisture curing adhesives, cure speed and shear strength are directly related. The less through cure achieved, the lower the shear strength. The more through cure achieved, the higher the shear strength. The below graph illustrates the 24-hour cure of MS polymers with and without excess adhesive. It is clear to see that the removal of excess increases the through cure and directly increases the shear strength.

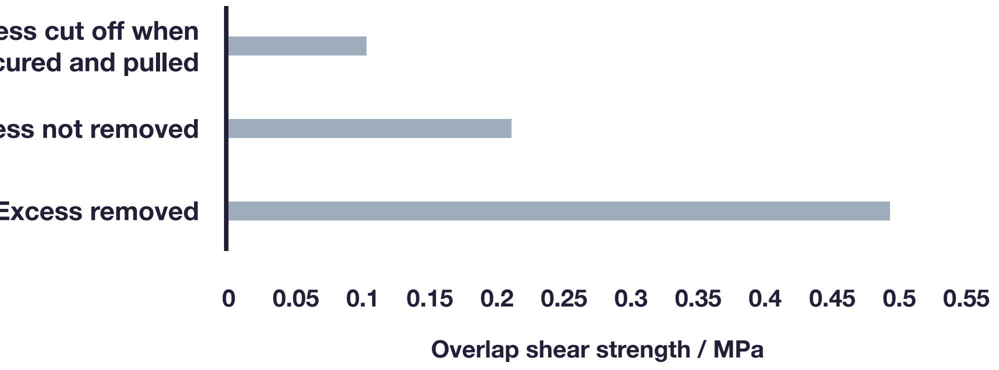


Figure 6

The graphs on the opposite page show how the maximum available bonding time is affected when temperature is increased. At ambient temperature (+23°C / +73.4°F) you can see that MS polymer has a maximum available bonding time of 27 minutes and 2K MS polymer of 20 minutes. When temperatures are elevated to +30°C (+86°F) the maximum available bonding time is reduced to 11 and 6 minutes respectively.

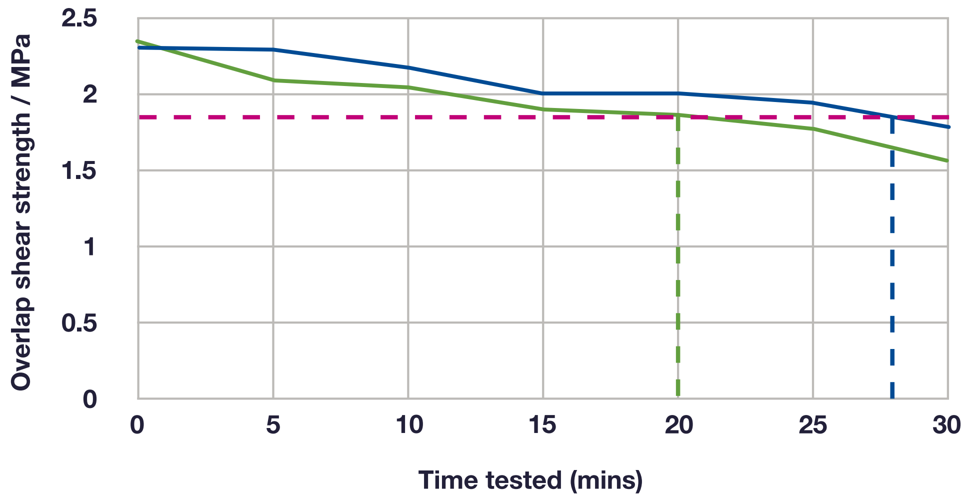


Figure 7

Ambient MS Polymer

Ambient 2K MS Polymer

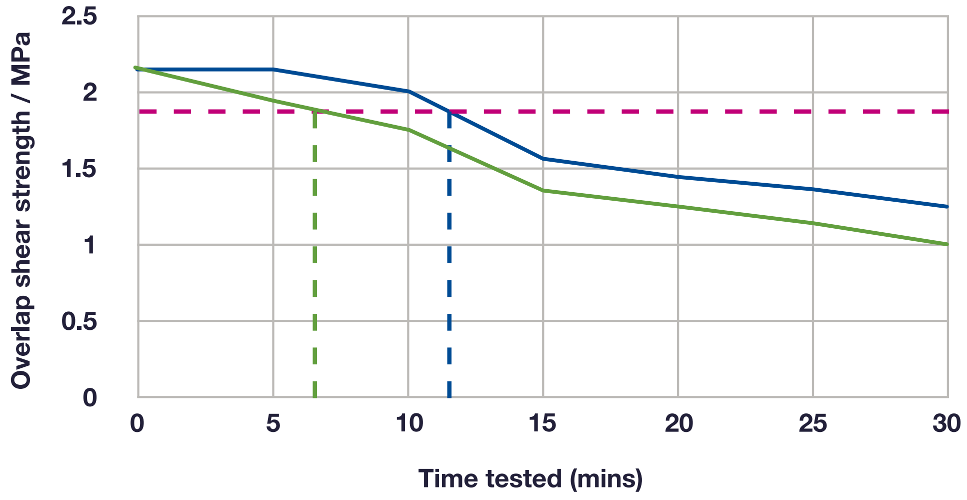


Figure 8

30°C / +86°F MS Polymer

30°C / +86°F 2K MS Polymer

13. Adhesive properties

Effect on different chemicals

It is important to be aware that when removing excess adhesives or cleaning adhesive joint areas that solvents are not allowed to pool / puddle. It can have a negative impact on both adhesives performance and properties. The below graph shows how the adherence on the adhesive is affected in an overlap shear formation when submersed in fluids.

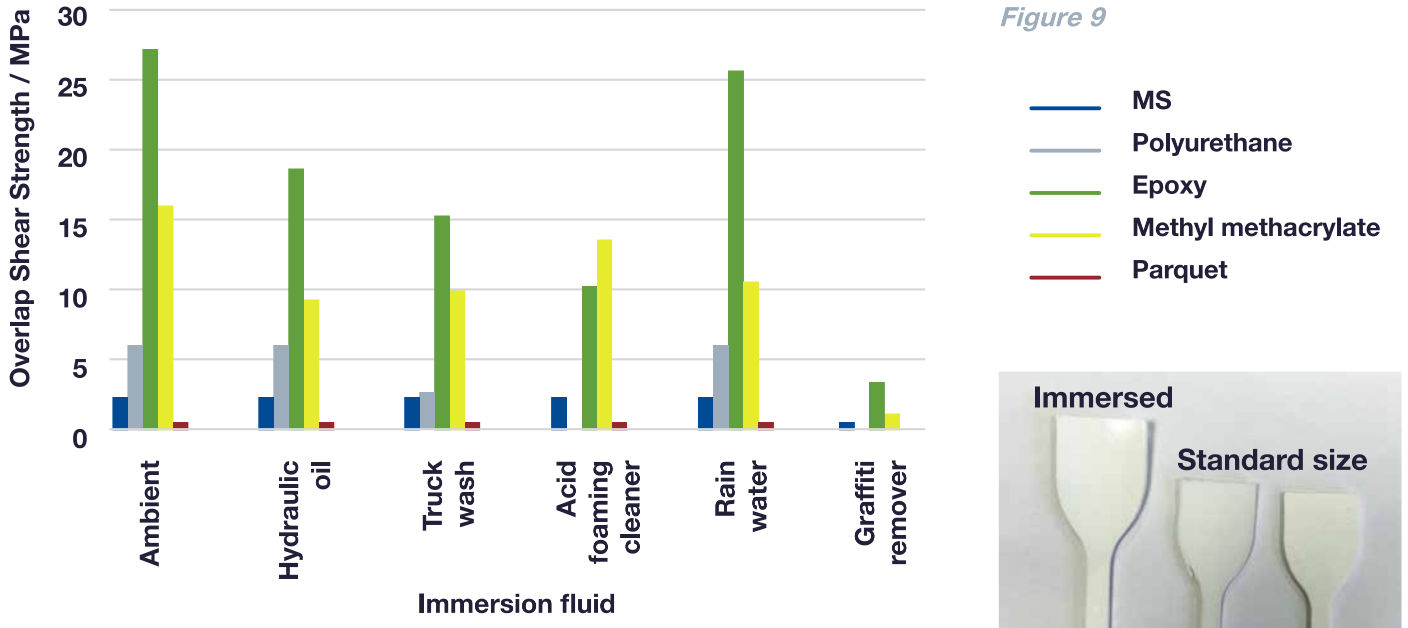


Figure 9

See page 172 for CASE STUDY on Fire Resistance

Effect on temperature

Different adhesives have different temperature resistance ranges. Generally, epoxies have poor temperature resistance, however if they are fire retardant, their temperature properties can be significantly higher. Polyurethanes tend to have quite poor temperature resistance, whereas both MS polymer and parquet remain consistent throughout varying temperature ranges.

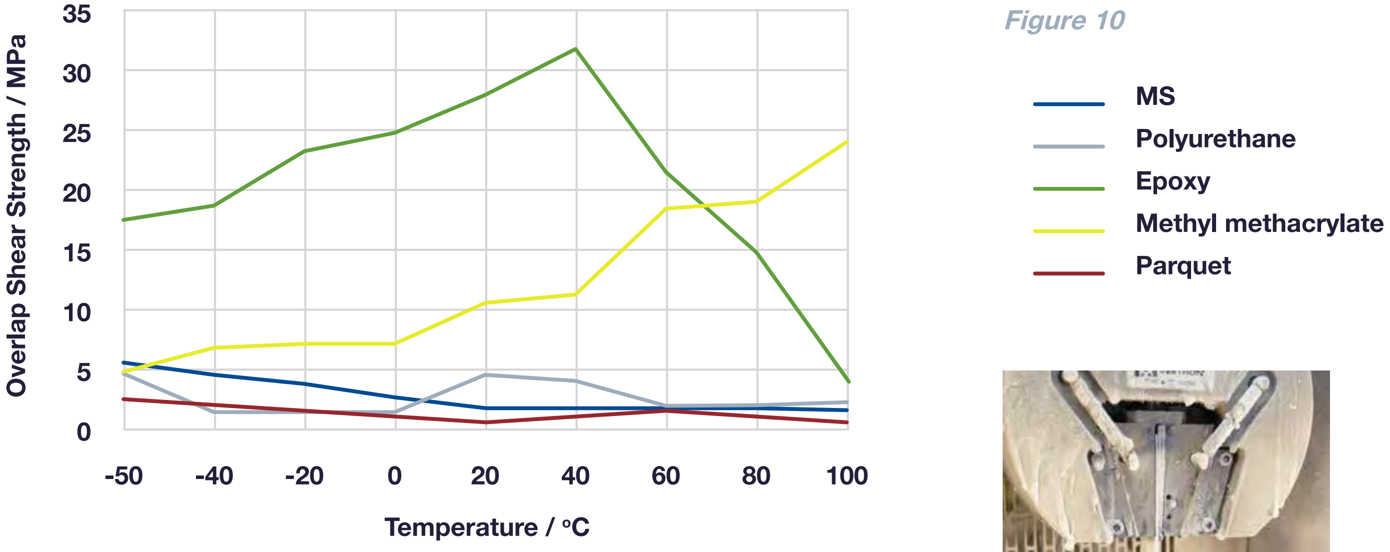


Figure 10

14. Understanding when things go wrong

Understanding when things go wrong

Analysing why failure may have occurred plays a big part in understanding application requirements and preparation methods.

Most failures in the field are put down to poor surface preparation methods and not taking into account the surfaces being bonded. Other failure modes may be due to insufficient time given during the cross-linking process.

Wet cohesive failure

The joint has cohesively failed, but has not fully through cured. The bond should be left for longer to fully through-cure.

Thin film cohesive

Adhesive left on substrates with a thin micro layer of adhesive on other substrate. This can be due to contamination on the substrate. Alternatively, this can be due to the fact that the adhesive has not fully cross linked and bonded to the substrate surface. It can take up to 21 days to fully cross link.

Tunnel effect failure

Adhesive failure through the middle of a bead of adhesive, where the outer layer of adhesive remains cohesively bonded. This can occur on low surface energy plastics and indicates that strength is building on the bond.

Island effect failure

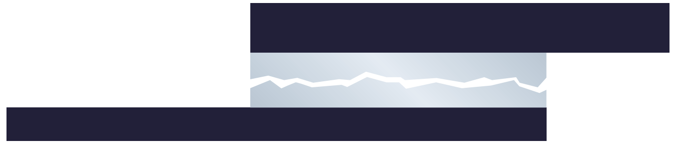
Adhesive failure on the outside edges of the cured bead and cohesive failure on the larger middle proportion of the bead. The cause of this is bad application. Apply adhesives with the nozzle forcing adhesive onto the substrate, rather than being gently laid.

Adhesive failure

This type of failure occurs when the surface energy of the substrate and adhesive are incompatible, e.g. the substrate has a low surface energy or poor surface preparation has taken place i.e. contamination on the substrates surface.

Adhesive / cohesive failure

Partial cohesion and partial adhesion can be related to inconsistencies in the substrate (varying surface energy throughout the substrate), or insufficient surface preparation of the substrate. Therefore intermittent bonding may be seen.



Cohesive failure

When the forces between the substrate and the adhesive (bond interface) are much stronger than the forces within the bulk material (adhesive), the adhesive breaks, leaving two bonded substrates.

Substrate failure

In this case, the substrate is weaker than the bulk material (adhesive) and therefore the substrate breaks before the adhesive.

See page 172 for CASE STUDY on Fire Resistance

Asking the right questions

Before using any substrate in assembly, it is critical that the following three factors are given consideration, and to ask yourself the following questions:

1. **Look**
Does the substrate look right? Is the substrate the same as previously used? Are there any inconsistencies throughout the substrate surface? Is the colour the same throughout?

2. **Feel**
Does the adherend feel different on any areas? Does the substrate feel different to normal? Is it greasy?

3. **Smell**
Is the substrate emitting a strong odour?
Does it smell different to normal?

All of the above questions should be asked before bonding. This is to ensure the correct measures are given before applying adhesive, i.e. surface preparation and changing material / part.

Many substrates have varying compositions at different times of manufacture. There are some types of substrates which always give variability during testing, these are:

- **Plastics** (ABS, PMMA, Polypropylene) - any plastic part which is manufactured with release liners, mould release agents and pigments, all contribute to an inconsistent surface for bonding and in turn reduce the surface energy.

- **GRP / FRP** (Glass Reinforced Plastics / Fibre Reinforced Plastics) - The percentage of components vary per supplier. The major factor which causes issues for manufactures is the amount of polyester resin and peroxides which are used to cure the resin. The higher the peroxide / polyester resin levels, the more difficult it becomes to bond. This is due to free / unreacted molecules of both substances which leech out of the GRP. Another factor is fire retardant additives. These additives cause the GRP to have a reduction in surface energy, making it difficult to obtain adhesion of the adhesive.

- **Painted surfaces** - the adhesive is will only ever be as good as the surface it is bonding to. Loose or flaky paint which has not bonded to the surface sufficiently will have detrimental impacts on the adhesive; de-bonding / de-lamination and increases the substrates chance to corrode.

- **E-coat** - possesses the same problems as painted surfaces; the E-coat can become brittle or flaky and start to peel away from the metal surface it is bonding to. Ultimately causing de-bonding of the adhesive from the substrate and giving rise to corrosion.

- **Galvanised steel** - As previously described, poor coating preparation leading to the galvanised coating peeling off; giving rise to de-bonding and corrosion on the metal surface.

- **Grades of stainless steel and aluminium** - some alloys are produced with high compositions of silicon or molybdenum which can reduce the surface energy of the metal. You should always check which grade of stainless steel or aluminium you are using before bonding, as additional surface preparation may be needed.

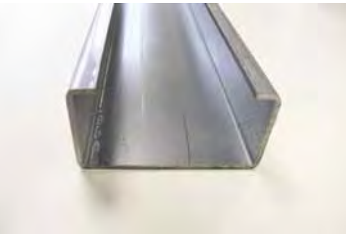
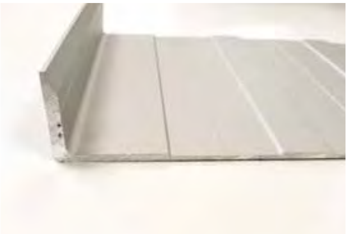
- **Recycled materials** - rigid polyurethanes and composite plastic can be made using recycled materials. Although this is great for the environment, they are not so good for bonding; the surface energy can be extremely low and will need further surface preparation methods.

There are two other factors to be aware of before bonding:

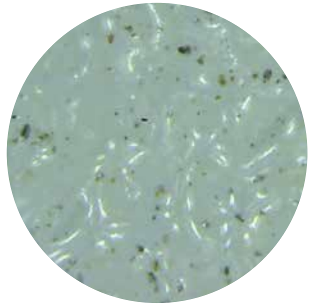
1. Silicon contamination - When adherends are cut using mechanical cutting saw, cutting solutions (containing high silicon content) can pollute the substrate surface. Cutting solutions can leave a greasy residue on the substrate surface and therefore reduces the overall surface energy.

2. Recycled solvents - Solvents which are recycled are reused in some manufacturing sites. These recycled solvents can sometimes be contaminated with silicon from paint plants, mould release agents and various cutting solutions. Further decrease substrate surface energy and reducing adhesion.

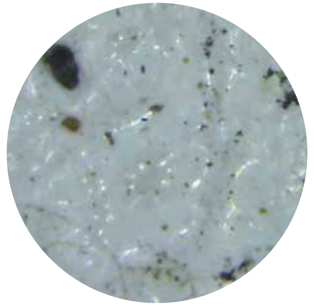
Substrates

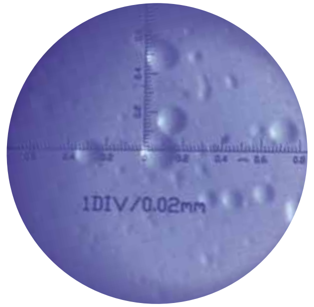

The below images are microscopic photos, taken from substrates which have been problematic in the field.



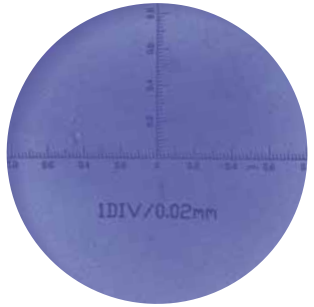
Loose powder coat on surface



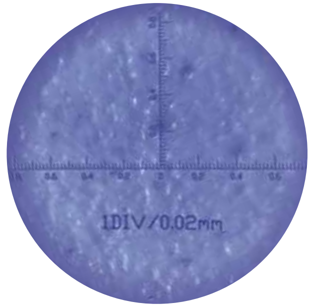
Loose powder coat transferred onto adhesive



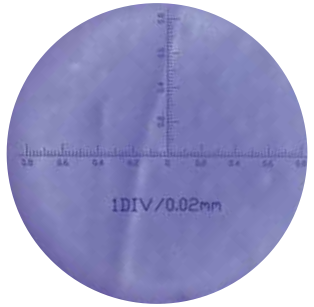
Pitted powder coat



Non-pitted Powder coat



Fire retardant GRP



Cleaned fire retardant GRP

Substrates to watch out for

GRP

The two GRP's above are manufactured from the same supplier, they are reportedly made to the same product specification. After careful analysis and testing it was found that the GRP gave variability in results. This was associated with higher levels of un-reacted products such as peroxides and polyester resins. To ensure your product does not de-bond / de-laminate from variable GRP's, ensure that you use reputable suppliers and the materials are consistent.

Powder coat

The above photos are two different powder coats, the photo on the left is fully consolidated with powder coat and the photo on the right shows an over sprayed area on the edge of the substrate; giving rise to intermittent bonding.

As well as issues with overspray, powder coat powders can contain silicon or teflon products, which increases the abrasion and UV resistance of the overall substrate but also reduces the surface energy; giving rise to adhesive failure when bonding.

15. When adhesives aren’t the right option

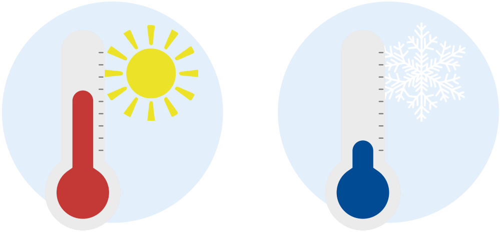
When adhesives aren’t the right option

In some applications, other methods of bonding may be chosen instead of adhesives. The reasons for this are given below:

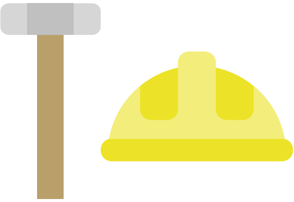
- **Insufficient surface area -** the bonding area is too small for an adhesive to be used, i.e. width or length.

- **Areas of high contamination -** The most important factor which allows an adhesive to maintain an excellent bond is surface preparation. If long methods of surface preparation would be needed to overcome contamination of a substrate / material in order for an adhesive to adhere cohesively. The cost and time implications may outweigh the benefits of weight saving and even weight distribution.

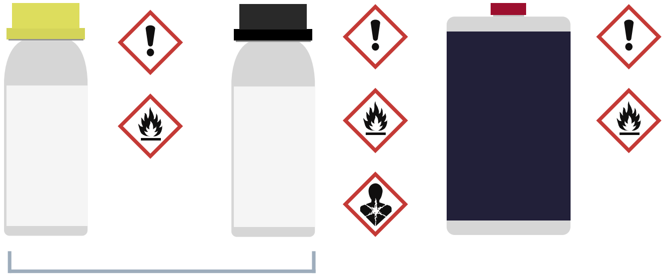
- **Extreme temperature changes -** this can be applied to both manufacturing / assembly of the product and in the field. Some adhesives cannot withstand extreme temperature changes, this may cause the adhesive to fail at a quicker rate, resulting in high repair costs and time.



- **Removal or disassembly -** adhesives can be hard to remove. If any repair work is required, it can be tough and time consuming to remove the adhesive and access the problem area.

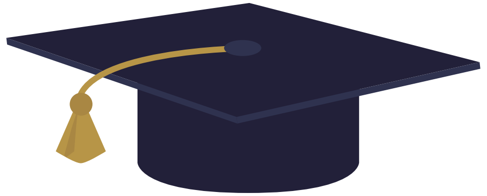


- **Safety of operatives -** working with an adhesive that has a heavy chemical influence can have hazardous effects on operatives. This has to be accounted for before using the adhesive and safety data sheets must be referred to.



- **Chemical corrosion -** some applications are simply not designed for an adhesive. For example, swimming pools. Fully saturated, high chlorine environments are not suitable for adhesive purposes.

- **Training -** operatives need to be trained on how to apply, how much to apply, if PPE is required, handling times and surface preparation before full integration of adhesives.



- **Handling times -** curing time can be an issue in production areas which require quick turnaround. Using moisture curing adhesives can lengthen these processes.

16. How to read a Safety Data Sheet (SDS)

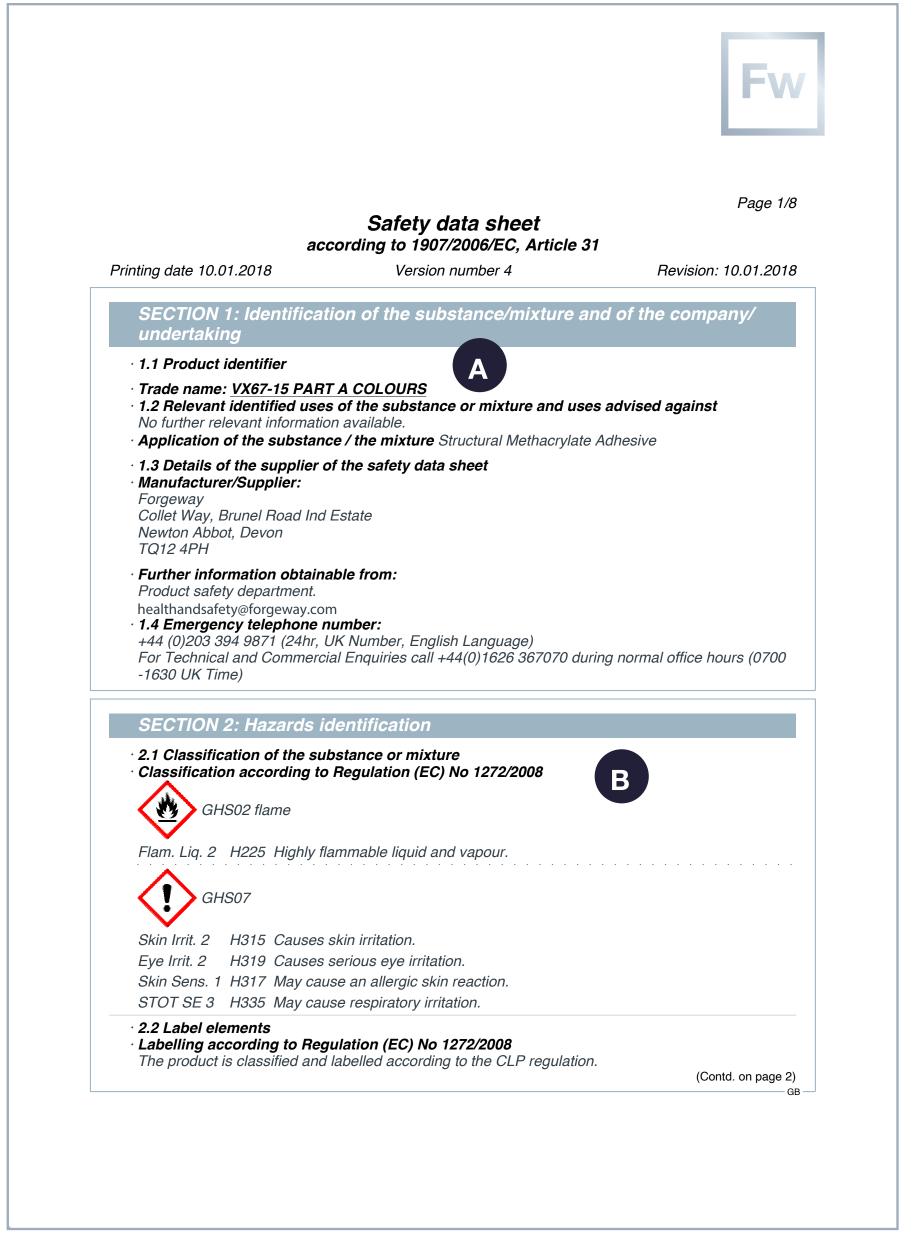
How to read a Safety Data Sheet (SDS)

Safety Data Sheets (SDS) are an important requirement of the OSHA Hazard Communication Standard. **SDS** are essential documents that are used to inform employees, students, and the general public about how materials can be safely handled, used, and stored. Using clear and straightforward language, each **Forgeway Ltd** SDS provides all the relevant safety and hazard information in a consistent, useful, and easy-to-read two-page format. Forgeway Ltd **SDS** follow the Globally Harmonized System of Classification and Labelling of Chemicals (GHS).

The 16 sections are divided into four major areas, each designed to answer a specific question.

What is the material and what do I need to know immediately in an emergency? Sections 1–3.

- **A.** Ensure that both the name on the **SDS** and product are the same before proceeding to use the product. Many chemicals have similar names, but very different properties.
- **B.** The most important section! Provides an overview of the potential physical and health hazard risks associated with using the material.



Fw

Page 1/8

Safety data sheet
according to 1907/2006/EC, Article 31

Printing date 10.01.2018 Version number 4 Revision: 10.01.2018

SECTION 1: Identification of the substance/mixture and of the company/undertaking

A

· **1.1 Product identifier**
· **Trade name: VX67-15 PART A COLOURS**
· **1.2 Relevant identified uses of the substance or mixture and uses advised against**
No further relevant information available.
· **Application of the substance / the mixture** Structural Methacrylate Adhesive
· **1.3 Details of the supplier of the safety data sheet**
· **Manufacturer/Supplier:**
Forgeway
Collet Way, Brunel Road Ind Estate
Newton Abbot, Devon
TQ12 4PH
· **Further information obtainable from:**
Product safety department.
healthandsafety@forgeway.com
· **1.4 Emergency telephone number:**
+44 (0)203 394 9871 (24hr, UK Number, English Language)
For Technical and Commercial Enquiries call +44(0)1626 367070 during normal office hours (0700 -1630 UK Time)

SECTION 2: Hazards identification

B

· **2.1 Classification of the substance or mixture**
· **Classification according to Regulation (EC) No 1272/2008**

GHS02 flame

Flam. Liq. 2 H225 Highly flammable liquid and vapour.

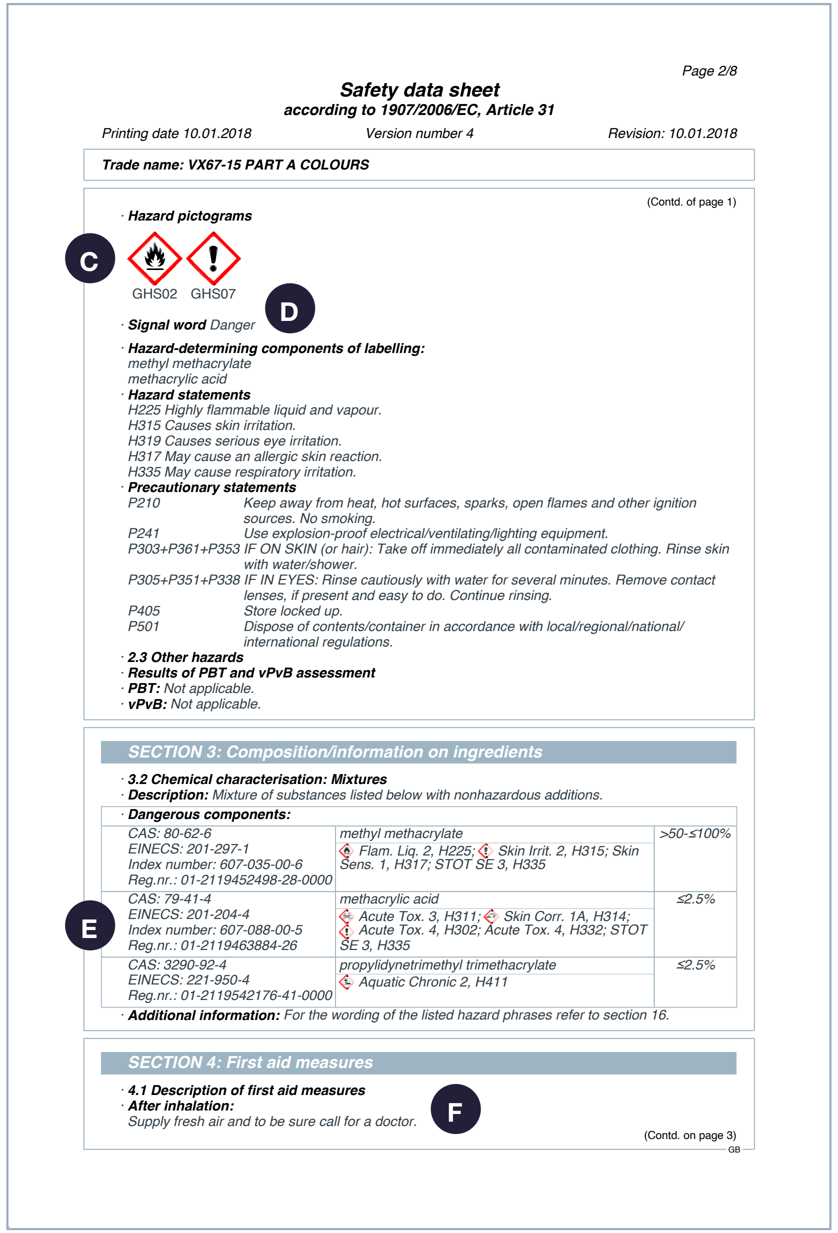
GHS07

Skin Irrit. 2 H315 Causes skin irritation.
Eye Irrit. 2 H319 Causes serious eye irritation.
Skin Sens. 1 H317 May cause an allergic skin reaction.
STOT SE 3 H335 May cause respiratory irritation.

· **2.2 Label elements**
· **Labelling according to Regulation (EC) No 1272/2008**
The product is classified and labelled according to the CLP regulation.

(Contd. on page 2)

GB



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Safety data sheet
according to 1907/2006/EC, Article 31

Printing date 10.01.2018 Version number 4 Revision: 10.01.2018

Trade name: VX67-15 PART A COLOURS

(Contd. of page 1)

· **Hazard pictograms**

C

GHS02 GHS07

D

· **Signal word** Danger
· **Hazard-determining components of labelling:**
methyl methacrylate
methacrylic acid
· **Hazard statements**
H225 Highly flammable liquid and vapour.
H315 Causes skin irritation.
H319 Causes serious eye irritation.
H317 May cause an allergic skin reaction.
H335 May cause respiratory irritation.
· **Precautionary statements**
P210 Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.
P241 Use explosion-proof electrical/ventilating/lighting equipment.
P303+P361+P353 IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.
P305+P351+P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P405 Store locked up.
P501 Dispose of contents/container in accordance with local/regional/national/international regulations.
· **2.3 Other hazards**
· **Results of PBT and vPvB assessment**
· **PBT:** Not applicable.
· **vPvB:** Not applicable.

SECTION 3: Composition/information on ingredients

· **3.2 Chemical characterisation: Mixtures**
· **Description:** Mixture of substances listed below with nonhazardous additions.

· **Dangerous components:**

E

CAS: 80-62-6 EINECS: 201-297-1 Index number: 607-035-00-6 Reg.nr.: 01-2119452498-28-0000	methyl methacrylate Flam. Liq. 2, H225; Skin Irrit. 2, H315; Skin Sens. 1, H317; STOT SE 3, H335	>50-≤100%
CAS: 79-41-4 EINECS: 201-204-4 Index number: 607-088-00-5 Reg.nr.: 01-2119463884-26	methacrylic acid Acute Tox. 3, H311; Skin Corr. 1A, H314; Acute Tox. 4, H302; Acute Tox. 4, H332; STOT SE 3, H335	≤2.5%
CAS: 3290-92-4 EINECS: 221-950-4 Reg.nr.: 01-2119542176-41-0000	propylidynetrimethyl trimethacrylate Aquatic Chronic 2, H411	≤2.5%

· **Additional information:** For the wording of the listed hazard phrases refer to section 16.

SECTION 4: First aid measures

· **4.1 Description of first aid measures**
· **After inhalation:**
Supply fresh air and to be sure call for a doctor.

F

(Contd. on page 3)

GB

- **C.** Nine hazard pictograms, exist in the GHS classification scheme to call attention to physical and health hazards (page 79).
- **D.** Signal words, indicating the relative risk associated with the material. **Danger** substances and mixtures with most severe hazards. **Warning** substances and mixtures with less serious hazards.
- **E.** Formula compositions; corresponding to D. Note: CAS numbers do not need to be supplied, only the associated hazard pictogram.
- **F.** Seek medical attention. These first aid measures are only meant for immediate first aid and should always be followed up with professional medical care.

G. This section is written for the fire fighter. The correct extinguisher is documented along with any other relevant product information.

H. How to clean up a spill. Always remove unprotected personnel from area, contain the spill with sand or absorbent materials - stated on **SDS**.

I. This section details out (if any) specific storage requirements.

Page 3/8

Safety data sheet
according to 1907/2006/EC, Article 31

Printing date 10.01.2018 | Version number 4 | Revision: 10.01.2018

Trade name: VX67-15 PART A COLOURS

(Contd. of page 2)

In case of unconsciousness place patient stably in side position for transportation.
· **After skin contact:** Immediately wash with water and soap and rinse thoroughly.
· **After eye contact:**
Rinse opened eye for several minutes under running water. If symptoms persist, consult a doctor.
· **After swallowing:** If symptoms persist consult doctor.
· **4.2 Most important symptoms and effects, both acute and delayed**
No further relevant information available.
· **4.3 Indication of any immediate medical attention and special treatment needed**
No further relevant information available.

SECTION 5: Firefighting measures

G

· **5.1 Extinguishing media**
· **Suitable extinguishing agents:**
CO2, powder or water spray. Fight larger fires with water spray or alcohol resistant foam.
· **For safety reasons unsuitable extinguishing agents:** Water with full jet
· **5.2 Special hazards arising from the substance or mixture**
No further relevant information available.
· **5.3 Advice for firefighters**
· **Protective equipment:** No special measures required.

SECTION 6: Accidental release measures

· **6.1 Personal precautions, protective equipment and emergency procedures**
Wear protective equipment. Keep unprotected persons away.
· **6.2 Environmental precautions:** Do not allow to enter sewers/ surface or ground water.
· **6.3 Methods and material for containment and cleaning up:**
Absorb with liquid-binding material (sand, diatomite, acid binders, universal binders, sawdust).
Ensure adequate ventilation.
· **6.4 Reference to other sections**
See Section 7 for information on safe handling.
See Section 8 for information on personal protection equipment.
See Section 13 for disposal information.

H

SECTION 7: Handling and storage

· **7.1 Precautions for safe handling** No special precautions are necessary if used correctly.
· **Information about fire - and explosion protection:**
Keep ignition sources away - Do not smoke.
Protect against electrostatic charges.
· **7.2 Conditions for safe storage, including any incompatibilities**
· **Storage:**
· **Requirements to be met by storerooms and receptacles:** Store in a cool location.
· **Information about storage in one common storage facility:** Not required.
· **Further information about storage conditions:**
Keep container tightly sealed.
Store in cool, dry conditions in well sealed receptacles.
· **7.3 Specific end use(s)** No further relevant information available.

I

SECTION 8: Exposure controls/personal protection

· **Additional information about design of technical facilities:** No further data; see item 7.

(Contd. on page 4)

GB

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Safety data sheet
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· **8.1 Control parameters**

· **Ingredients with limit values that require monitoring at the workplace:**	
80-62-6 methyl methacrylate	
WEL	Short-term value: 416 mg/m³, 100 ppm Long-term value: 208 mg/m³, 50 ppm
79-41-4 methacrylic acid	
WEL	Short-term value: 143 mg/m³, 40 ppm Long-term value: 72 mg/m³, 20 ppm

· **Additional information:** The lists valid during the making were used as basis.

· **8.2 Exposure controls**
· **Personal protective equipment:**
· **General protective and hygienic measures:**
Keep away from foodstuffs, beverages and feed.
Immediately remove all soiled and contaminated clothing
Wash hands before breaks and at the end of work.
Avoid contact with the eyes and skin.

J

· **Respiratory protection:**
In case of brief exposure or low pollution use respiratory filter device. In case of intensive or longer exposure use self-contained respiratory protective device.
· **Protection of hands:**

Protective gloves

The glove material has to be impermeable and resistant to the product/ the substance/ the preparation.
Due to missing tests no recommendation to the glove material can be given for the product/ the preparation/ the chemical mixture.
Selection of the glove material on consideration of the penetration times, rates of diffusion and the degradation
· **Material of gloves**
The selection of the suitable gloves does not only depend on the material, but also on further marks of quality and varies from manufacturer to manufacturer. As the product is a preparation of several substances, the resistance of the glove material can not be calculated in advance and has therefore to be checked prior to the application.
· **Penetration time of glove material**
The exact break through time has to be found out by the manufacturer of the protective gloves and has to be observed.
· **Eye protection:**

Tightly sealed goggles

SECTION 9: Physical and chemical properties

· **9.1 Information on basic physical and chemical properties**
· **General Information**
· **Appearance:**

Form:	Liquid
Colour:	According to product specification
· **Odour:**	Pungent
· **Odour threshold:**	Not determined.

K

(Contd. on page 5)

GB

J. Details the protective equipment that should be worn when handling the product. Any special measures will be documented in the section e.g. breathing equipment, ventilation or face masks.

K. Clear, concise, and useful physical and chemical properties help you learn more about the product in use.

L. Describes the conditions or reactions to be avoided. Also provides some indication about anticipated shelf life.

M. Used to give the product a toxicological classification.

N. Oral (ORL), inhalation (IHL), and skin absorption (SKN) toxicity data on test animals is included.

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· **pH-value:**	Not determined.
· **Change in condition**	
Melting point/freezing point:	Undetermined.
Initial boiling point and boiling range:	Undetermined.
· **Flash point:**	10 °C
· **Flammability (solid, gas):**	Not applicable.
· **Ignition temperature:**	430 °C
· **Decomposition temperature:**	Not determined.
· **Auto-ignition temperature:**	Product is not selfigniting.
· **Explosive properties:**	Product is not explosive. However, formation of explosive air/vapour mixtures are possible.
· **Explosion limits:**	
Lower:	2.1 Vol %
Upper:	12.5 Vol %
· **Vapour pressure at 20 °C:**	47 hPa
· **Density at 20 °C:**	1.04 g/cm³
· **Relative density**	Not determined.
· **Vapour density**	Not determined.
· **Evaporation rate**	Not determined.
· **Solubility in / Miscibility with water:**	Not miscible or difficult to mix.
· **Partition coefficient: n-octanol/water:**	Not determined.
· **Viscosity:**	
Dynamic:	Not determined.
Kinematic:	Not determined.
· **Solvent content:**	
VOC (EC)	0.00 %
· **9.2 Other information**	No further relevant information available.

SECTION 10: Stability and reactivity

· **10.1 Reactivity** No further relevant information available.
· **10.2 Chemical stability**
· **Thermal decomposition / conditions to be avoided:**
No decomposition if used according to specifications.
· **10.3 Possibility of hazardous reactions** No dangerous reactions known.
· **10.4 Conditions to avoid** No further relevant information available.
· **10.5 Incompatible materials:** No further relevant information available.
· **10.6 Hazardous decomposition products:** No dangerous decomposition products known.

L

SECTION 11: Toxicological information

· **11.1 Information on toxicological effects**
· **Acute toxicity** Based on available data, the classification criteria are not met.

M

· **LD/LC50 values relevant for classification:**

80-62-6 methyl methacrylate		
Oral	LD50	7,872 mg/kg (rat)

N

(Contd. on page 6)

GB

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Dermal	LD50	>5,000 mg/kg (rabbit)
Inhalative	LC50/4 h	78,000 mg/l (rat)
	EC50/48 h	69 mg/l (daphnia)

· **Primary irritant effect:**
· **Skin corrosion/irritation**
Causes skin irritation.
· **Serious eye damage/irritation**
Causes serious eye irritation.
· **Respiratory or skin sensitisation**
May cause an allergic skin reaction.
· **CMR effects (carcinogenity, mutagenicity and toxicity for reproduction)**
· **Germ cell mutagenicity** Based on available data, the classification criteria are not met.
· **Carcinogenicity** Based on available data, the classification criteria are not met.
· **Reproductive toxicity** Based on available data, the classification criteria are not met.
· **STOT-single exposure**
May cause respiratory irritation.
· **STOT-repeated exposure** Based on available data, the classification criteria are not met.
· **Aspiration hazard** Based on available data, the classification criteria are not met.

SECTION 12: Ecological information

· **12.1 Toxicity**
· **Aquatic toxicity:**

80-62-6 methyl methacrylate		
Inhalative	LC50/96 h	283 mg/l (fish)
	EC50/72 h	>110 mg/l (algae)

O

· **12.2 Persistence and degradability** No further relevant information available.
· **12.3 Bioaccumulative potential** No further relevant information available.
· **12.4 Mobility in soil** No further relevant information available.
· **Additional ecological information:**
· **General notes:**
Water hazard class 1 (German Regulation) (Self-assessment): slightly hazardous for water
Do not allow undiluted product or large quantities of it to reach ground water, water course or sewage system.
· **12.5 Results of PBT and vPvB assessment**
· **PBT:** Not applicable.
· **vPvB:** Not applicable.
· **12.6 Other adverse effects** No further relevant information available.

SECTION 13: Disposal considerations

P

· **13.1 Waste treatment methods**
· **Recommendation**
Must not be disposed together with household garbage. Do not allow product to reach sewage system.
· **Uncleaned packaging:**
· **Recommendation:** Disposal must be made according to official regulations.

SECTION 14: Transport information

Q

· **14.1 UN-Number**
· **ADR, IMDG, IATA** UN1133

(Contd. on page 7)

GB

O. Ecological impact if large amounts (e.g. tank, car) of the chemical spill near a river or lake.

P. Suggested disposal methods for laboratory quantities of chemicals.

Q. Department of Transportation shipping information is included.

R. Regulatory information used by regulatory compliance personnel.

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Trade name: VX67-15 PART A COLOURS

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· **14.2 UN proper shipping name**	
· **ADR**	1133 ADHESIVES
· **IMDG, IATA**	ADHESIVES
· **14.3 Transport hazard class(es)**	
· **ADR, IMDG, IATA**	
	
· **Class**	3 Flammable liquids.
· **Label**	3
· **14.4 Packing group**	
· **ADR, IMDG, IATA**	II
· **14.5 Environmental hazards:**	Not applicable.
· **14.6 Special precautions for user**	Warning: Flammable liquids.
· **Danger code (Kemler):**	33
· **EMS Number:**	F-E,S-D
· **Stowage Category**	B
· **14.7 Transport in bulk according to Annex II of Marpol and the IBC Code**	Not applicable.
· **Transport/Additional information:**	
· **ADR**	
· **Limited quantities (LQ)**	5L
· **Excepted quantities (EQ)**	Code: E2 Maximum net quantity per inner packaging: 30 ml Maximum net quantity per outer packaging: 500 ml
· **Transport category**	2
· **Tunnel restriction code**	D/E
· **IMDG**	
· **Limited quantities (LQ)**	5L
· **Excepted quantities (EQ)**	Code: E2 Maximum net quantity per inner packaging: 30 ml Maximum net quantity per outer packaging: 500 ml
· **UN "Model Regulation":**	UN 1133 ADHESIVES, 3, II

SECTION 15: Regulatory information

· **15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture**

R

· **Directive 2012/18/EU**
· **Named dangerous substances - ANNEX I** None of the ingredients is listed.
· **Seveso category** P5c FLAMMABLE LIQUIDS
· **Qualifying quantity (tonnes) for the application of lower-tier requirements** 5,000 t
· **Qualifying quantity (tonnes) for the application of upper-tier requirements** 50,000 t
· **REGULATION (EC) No 1907/2006 ANNEX XVII** Conditions of restriction: 3
· **15.2 Chemical safety assessment:** A Chemical Safety Assessment has not been carried out.

GB

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SECTION 16: Other information

This information is based on our present knowledge. However, this shall not constitute a guarantee for any specific product features and shall not establish a legally valid contractual relationship.

S

· **Relevant phrases**
H225 Highly flammable liquid and vapour.
H302 Harmful if swallowed.
H311 Toxic in contact with skin.
H314 Causes severe skin burns and eye damage.
H315 Causes skin irritation.
H317 May cause an allergic skin reaction.
H332 Harmful if inhaled.
H335 May cause respiratory irritation.
H411 Toxic to aquatic life with long lasting effects.

· **Department issuing SDS:** Product safety department.
· **Contact:** Forgeway Ltd
· **Abbreviations and acronyms:**
ADR: Accord européen sur le transport des marchandises dangereuses par Route (European Agreement concerning the International Carriage of Dangerous Goods by Road)
IMDG: International Maritime Code for Dangerous Goods
IATA: International Air Transport Association
GHS: Globally Harmonised System of Classification and Labelling of Chemicals
EINECS: European Inventory of Existing Commercial Chemical Substances
ELINCS: European List of Notified Chemical Substances
CAS: Chemical Abstracts Service (division of the American Chemical Society)
VOC: Volatile Organic Compounds (USA, EU)
LC50: Lethal concentration, 50 percent
LD50: Lethal dose, 50 percent
PBT: Persistent, Bioaccumulative and Toxic
vPvB: very Persistent and very Bioaccumulative
Flam. Liq. 2: Flammable liquids – Category 2
Acute Tox. 4: Acute toxicity – Category 4
Acute Tox. 3: Acute toxicity – Category 3
Skin Corr. 1A: Skin corrosion/irritation – Category 1A
Skin Irrit. 2: Skin corrosion/irritation – Category 2
Eye Irrit. 2: Serious eye damage/eye irritation – Category 2
Skin Sens. 1: Skin sensitisation – Category 1
STOT SE 3: Specific target organ toxicity (single exposure) – Category 3
Aquatic Chronic 2: Hazardous to the aquatic environment - long-term aquatic hazard – Category 2

GB

S. Forgeway Ltd has an ongoing program to update its **SDS**. As professional chemists, we try our best to provide the most accurate and useful safety information.

Call Forgeway Ltd on **+44 1626 367070** if you have any questions. We can help!

17. Health and Safety Information

Health and safety information

PPE information

You will find the symbols and hazards shown below in safety data documents. Please take time to find out what they mean and ensure you follow the correct advice.

Table 1

	Wear eye / face protection
	Safety shoes must be worn
	Respiratory equipment must be worn
	Wear protective gloves
	Wear hearing protection

Hazard information

Take time to find out what these hazard symbols mean and ensure you follow the correct advice.

Table 2

LABEL	HAZARD	ACTION
	May explode if exposed to fire, heat, shock, friction.	Avoid ignition sources (sparks, flames, heat)
	Flammable if exposed to ignition sources, sparks, heat. Some substances with this symbol may give off flammable gases in contact with water.	Avoid ignition sources (sparks, flames, heat)
	Can burn even without air, or can intensify fire in combustion materials.	Avoid ignition sources (sparks, flames, heat)
	Contains gas under pressure. Gas released may be very cold. Gas container may explode if heated.	Do not heat containers. Avoid contact with eyes.
	Corrosive material which may cause skin burns and eye damage. May corrode metals.	Avoid contact with skin and eyes. Do not breathe vapours or sprays. Wear protective clothing. Keep away from metals.
	Toxic materials which may cause life-threatening effects even in small amounts and with short exposure.	Do not swallow the material, allow it to come into contact with skin or breathe it.
	May cause serious and prolonged health effects on short or long term exposure.	Do not swallow the material, allow it to come into contact with skin or breathe it.
	Toxic to aquatic organisms and may cause long lasting effects in the environment.	Avoid release into the environment.
	Serious health hazard. May be fatal if swallowed and enters airways. May cause damage to organs. May cause allergy or asthma symptoms or breathing difficulties if inhaled.	Do not breathe dust / fume / gas / mist / vapours / spray. Wash thoroughly after handling.

For more information please visit: echa.europa.eu

18. Case Studies

Glazing Test

Many vehicle manufacturers and their engineering departments are often frustrated and challenged when it comes to translating values for shear peel and tensile forces provided by technical data sheets into what this really means for them when designing and manufacturing vehicles.

There are many test standards and engineering norms which are applicable to the automotive industry but few of these directly relate to the manufacture of buses coaches trains and trams. Type approval for whole vehicles was an attempt to rectify this but it only broadly covers the real needs that exist. For adhesives it is common for manufacturers to state drive away times and windscreen glazing air bag requirements but these are not applicable and transferable for bus and coach glazing

The weight, size and angles of bonding are so different in bus manufacture approval is often obtained by testing once the vehicles are completed and full durability track tested. Joint design and bondline thickness play a major part in successfully bonding any construction but it is critical in glazing due to the flexibility required and the rigidity of glass windows.

A major UK bus manufacturer was approached by an operator who had recently ordered over 100 double deck buses which were a lot larger than previous models and they wanted maximise passenger numbers and achieve a modern look. Direct bonding glass was the only option for them. The ongoing security and safety of window glazing was of paramount importance to them and so we were approached to come up with a method whereby each window could be periodically checked and signed off as secure

We manufactured an aluminium bridge frame that would span the distance from the cant roof rail to the vertical side frame pillar and secured the Formoa® portable test pulling system complete with electronic gauge and Bluetooth phone connection to record the values obtained. A heavy duty vacuum suction cup was secured to the glass window and this was coupled to the pulling device. A force of over 2000Kgs was applied to the window. This has now become a standard periodic test for the customer to assure them that all windows are secure.

Environmental Stress Cracking (ESC)

Are you using the correct adhesive? Did you know that you could be unintentionally weakening your plastic? ***Selecting the wrong adhesive could lead to an issue called environmental stress cracking, sometimes referred to as the 'Plastic Killer'***

Environmental stress cracking (ESC) is defined as the premature embrittlement and subsequent formation of cracks in plastics as a result of both being under stress and in contact with a chemical agent. Environmental stress cracking is a significant problem, accounting for '25% of all plastic failure in commercial usage'[1].

In ESC a chemical agent does not cause direct molecular degradation or chemical attack, but instead permeates into the molecular structure of the plastic and weakens the forces between the polymer chains, resulting in molecular disentanglement. In short, the plastic will become severely weakened and as a result will develop cracks and become structurally compromised.

An example of environmental stress cracking on polycarbonate can be seen below. The polycarbonate sample at the top has been placed under stress for over 7 hours with no chemical agent applied, it shows no visual signs of cracking. However, the polycarbonate on the bottom was once again placed under strain, but when a chemical agent commonly found in adhesives and paints was applied to this surface, cracks developed within 10 minutes and the test piece snapped. The test piece in the middle was exposed to the same chemical agent but was not placed under any stress and no cracks were observed. This shows that you need both a form of strain and a chemical agent to cause environmental stress cracking.

At Forgeway® we have carefully designed and tested an adhesive which will be suited for your most sensitive of applications. So, if you have plastic under strain and want to use an adhesive choose **Formoa® 206i.**

Stress Cracking is seen widely in the RV market as plastic is used extensively and is often placed under strain during every day life.

[1]: J. A. Jansen, "Environmental stress cracking: the plastic killer," Advanced Materials and Processes, vol. 162, no. 6, pp. 50–53, 2004.

Bus and Coach Industry

What happened?

A European adhesive manufacturer supplying the domestic furnishings & horticultural markets attempted to enter the transportation adhesive industry.

The customer was sold the benefits of this alternative product but the adhesive suffered complete failure when subjected to accelerated weathering.

ASTM G154 is a normal test standard used in adhesive weather tests. Products must withstand rigorous cycling to be used in bus/truck manufacture.

Photo reveals the competitor's product completely failing – resulting in bond failure & serious water ingress.

Commercial Vehicle Industry

What happened?

A key player in the low floor, high volume 3.5 tonne vehicle market dominated their industry - the vehicles were bonded with **Formoa®**.

But then a new player entered the industry & selected an alternative European adhesive.

Failure occurred after a few months.

The active relationship between the adhesive & substrates was mismatched & the adhesive was too rigid causing roof & chassis failure.

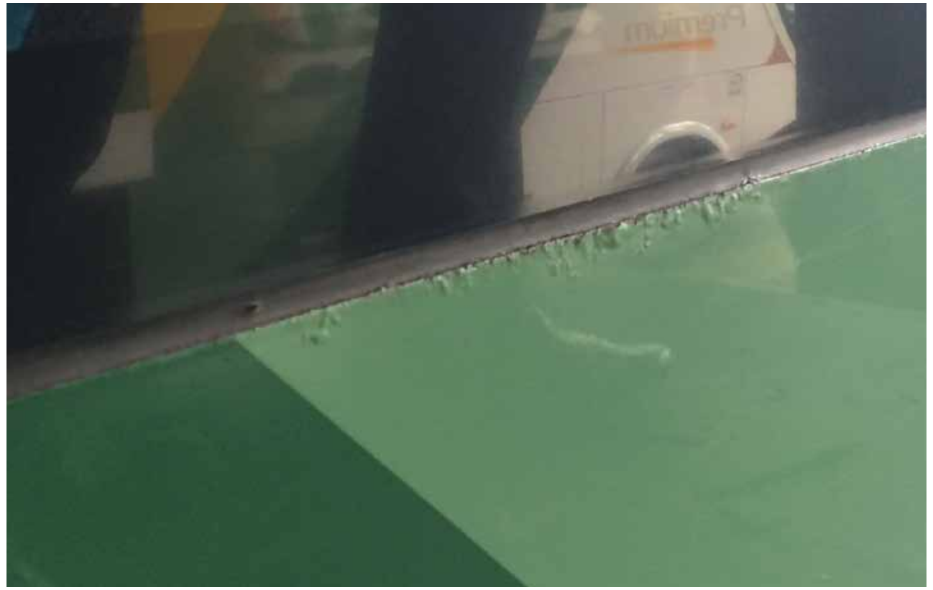
Filiform Corrosion

Painting is time consuming, particularly to a high standard; hence, ensuring that all your effort is not wasted is important to any business. An unwanted consequence of painting on metals is the risk of filiform corrosion. This forms as bulges underneath paintwork and can lead to blistering and staining. It is a particular concern around windows and painted joints that are exposed to the elements and is unsightly to the customers. Forgeway® have a new range of anti-corrosive adhesives that are specifically designed to stop this from happening.

Corrosion is a common issue across many industries, with an estimated global cost of $2.5 trillion in 2013. Factors like humidity, temperature, pH and the presence of salt will cause and accelerate corrosion. Filiform corrosion occurs when water gets beneath a coating due to a defect in the paintwork. This can range from a scratches, dents or microscopic tears that develop in the paint as it dries around edges and corners. These defects allow water to carry in oxygen and salt, which trigger corrosion. The metal will react with oxygen and spread along tendrils under the coating, which eventually result in swelling under the paint. These develop into bubbles on the bodywork of the painted object.

In response to this, Forgeway® has developed a unique range of adhesives to tackle this problem. It imparts a layer protection around the adhesive, protecting it from filiform corrosion. Our unique product range, such as **Formoa® 055 AC** combined **Formoa® Surface Activator AC**, is designed to secure your windows, as well as protect the paintwork around them. Therefore, providing your customers with lasting confidence in your work.

In coastal areas or regions which have prolonged periods of salted roads, filiform corrosion can become manifest within months.



Bus and Coach Industry

Success Story

A manufacturer switched to a cheaper adhesive/sealant supplier to meet aggressive cost targets & meet the demands of a French client - vehicles can be stocked for Spring deliveries for 3-4 months.

This move resulted in staining on the vehicle sides & repainting was required at a huge cost due to poor quality bonded glazing & backfill materials.

Formoa® 066 and 069 were trialled & left for 4 months outside – no staining was visible & the adhesive retained its gloss.

Commercial Vehicle Industry

Success Story

A commercial vehicle body builder took the jump from a traditionally mechanically fixed 3.5T Luton van to a fully bonded design - using **Formoa® 017FE**.

The strength of the new design was proven before the vehicle was even used - on pre-delivery it hit a low bridge! The impact was severe enough to bend the chassis but the body remained intact.

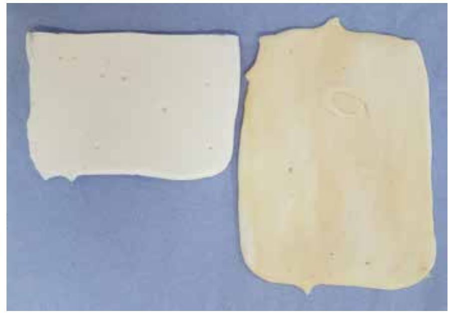
Sealant Yellowing

There is nothing worse than paying for something you did not want. Like buying a white sealant for it to quickly turn yellow. This is both unsightly and unwanted, regardless of the excuse. Here at Forgeway®, we put our customers' needs before anything else so that you stick with us.

Environmental conditions are the most common cause of yellowing. These include factors like intense sunlight, changes in humidity or elevated temperatures. UV light given out by the Sun is absorbed by chemicals within the sealant, causing them to degrade and turn yellow. As they break down, they release free radicals, which are highly reactive and will continue to react within the sealant, unless dealt with. This can lead to further yellowing, chalking, adhesive failure and cracking.

To prevent this from happening, we include UV absorbers as our first line of defence. This class of chemicals are specifically designed to block UV light in the same way as sun cream. Even if free radicals are generated, our sealants contain a mixture of highly effective radical scavengers that act as a second layer of defence. They work by reacting with the radicals to neutralise them before they can do any damage.

To confirm their effectiveness, we use environmental testing equipment to ASTM G154 standard, which exposes the sealants to strong UV light lamps, changes in humidity and temperature. This is confirmed with real world testing once we are happy with the products performance. Therefore, our **Formoa®** range will not yellow for years to come, even when exposed to the harshest condition. Whether that is inside or out, sun or rain, **Formoa®** stays white and continues to shine.



Bus and Coach Industry

What happened?

A bus manufacturer adopted a competitor’s low flexibility adhesive system.

This caused stress, strain & torsional forces to be directly transferred to the chassis, resulting in twisting of the chassis.

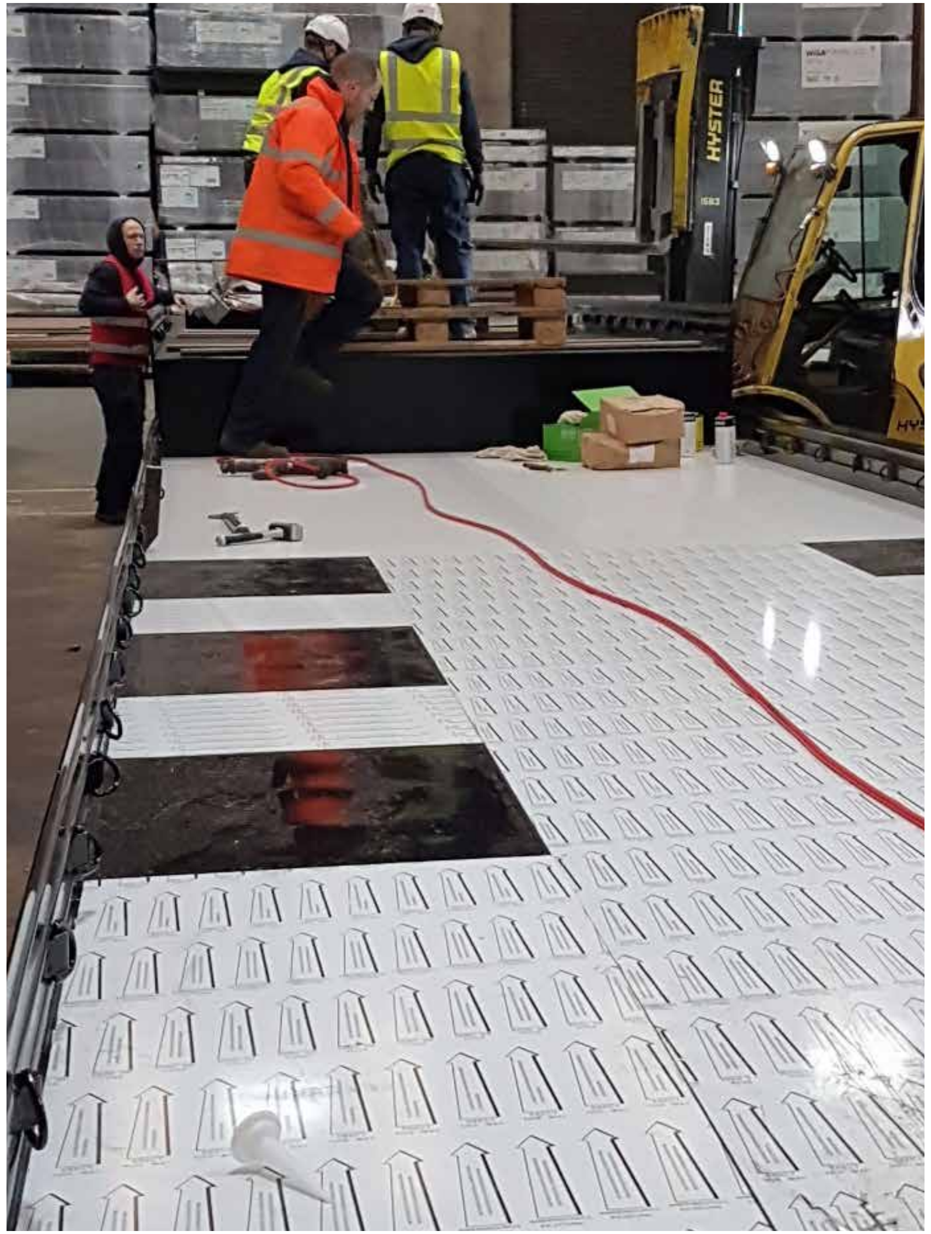
Over $9000 per chassis cost to weld in additional strengthening bracing.

Commercial Vehicle Industry

Success Story

A manufacturer needed an adhesive to bond a composite floor to a trailer chassis.

We supplied **Formoa 017FE®** - resulting in a saving of over 400 kilos per vehicle!



Sealant Colour Matching

Mother Nature really knew what she was doing with her colour pallet. Our planets ecosystem is a rich tapestry made up of wonderfully blended colours – we enjoy stunning light blue skies, rich green rainforest's, golden sanded desserts, deep blue seas and magnificent vanilla skied sunsets.

Within our environment all manner of creatures are using vivid colours to set themselves apart. Some use colour to defend themselves, some to show off their vibrancy to attract the best partners to grow the strongest offspring.

Here at Forgeway we also know what we are doing with our colour pallet, and we can offer a powerful kaleidoscope of colours to our customers.

For us at Forgeway matching colour is a source of pride, we match all of our adhesives to common standard colours within the European RAL standardisation reference system, and have the ability to match bespoke colours to suit your business needs whatever they maybe. This is made possible as we utilise CIE L*a*b* technology.

The CIE L*a*b* scale is successfully used across many sectors of industries with great confidence in its reliability. The scale communicates colour values based on 'opponent colour theory' – each value is based on pairs of opposite colours which amalgamate to form the visually perceived colour. The L scale measures white vs black, the a scale red vs green & the b scale yellow vs blue.

Not only does the use of the CIE L*a*b* scale ensure the correct colour is produced it also protects against metamerism. This is the visual effect caused by observing colour in different lights i.e. a colour can look different inside a building under common 'yellow light' bulbs, compared to when it is taken outside into natural day light. The CIE L*a*b* data shows a colour match to be true.

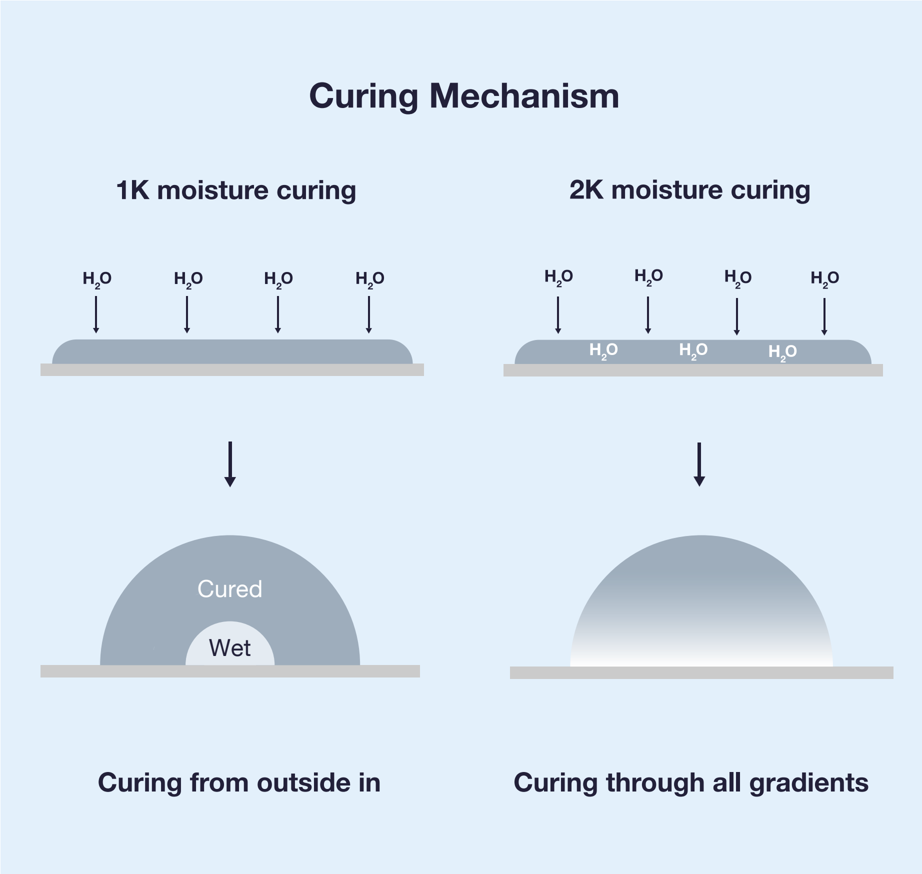
If you are interested in creating or enhancing your application colours to stand out from the crowd, be instantly recognisable, and show off your business vibrancy, Forgeway are on hand.

For more information on Forgeway products, or any of our high performance adhesives, sealants and coatings, give us a call.

1K vs. 2K

Adhesives are designed for specific tasks. Though a glue might work on something it was not designed for, it does not mean you should settle for second best. As a result, there are a whole range of adhesive that can be roughly broken down into two main types. These are 1k or 2k adhesives, which refers to the number of components it contains.

Simplicity is the name of game with 1k adhesives. Prime, point and pull the trigger, these adhesives are so simple that children literally use them. There are two main curing mechanisms for 1k adhesives, which are triggered by ambiently exposing them to the atmosphere. First being that the adhesive reacts with moisture in the air; the second being the evaporation of a solvent triggering the curing mechanism. The result is the formation of a "skin" on the surface as the glue as it cures from the outside inwards. There are many advantages to 1k adhesive, which includes their ease the use and storage, easy process to manage and less waste cartridges.



2k adhesives are all about precision. Precise and predictable, those glues are based on specific mixing ratios of two components. This give the adhesive a reliable cure time that you can set your watch to. As the two components interact in the mixing nozzle, an initiator will trigger a chain reaction that propagates through the adhesive, resulting in a snap cure. This ensures that the adhesive has the best chance of curing, regardless of its environment.

At Forgeway® we never stand still and are continuously seeking to perfect our products. Therefore, why not combine the best parts of 1k and 2k adhesives to take advantage of both their properties. Introducing **Formoa® 2k**, fusing the practicality of 1k with the precision 2k. It allows for the easy application of 1k systems with quick reliable cure times of a 2k adhesive. Forgeway®, presenting you with the best of both worlds.

Primerless bonding: Glazing

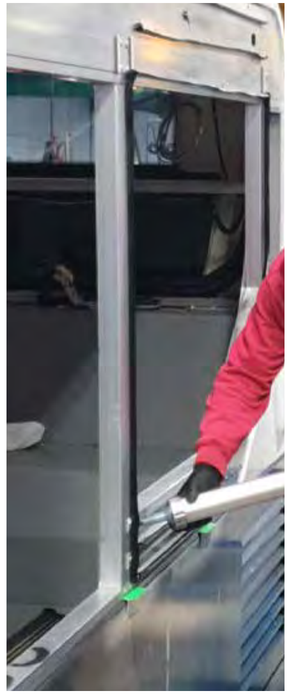
Found in every continent of the world – bonding windows in people movers and road transportation – tens of thousands of vehicles, travelling more than 10 million miles per week, carrying more than 1 billion passengers per year.

The Formoa® Gb range of adhesives are continuing to gain a reputation for successful bonding in transportation applications. A truly primerless adhesive bonding system that reduces build and total vehicle costs. For over 20 years Forgeway® have led the market in producing primerless adhesives for bonding. Originally developed and launched in 2001, the Formoa® Gb range has continued to maintain the critical balance between a simple process, end strength and long term durability.

The process is simply clean and bond. Easy to extrude at ambient temperatures with fast strength build up and cure. The high tack non-sagging formulations can support the largest of glass units found in modern vehicle manufacturing. Formoa® glass bonding products can be used to bond many new generation “glass alternatives” giving huge potential in riot and custodial vehicles to increase protection and reduce weight. The lower shear modulus of the Formoa® Gb product family ensures that any stress and strain are absorbed into the polymer matrix rather than transferred to the bond interface.

Never a company to stand still, and knowing there must be a solution to the lengthy and exacting processes associated with typical polyurethane technology glass bonding systems, Formoa® Screen Extra 2 was developed. Formoa® Screen Extra 2 is a fast curing glass bonding adhesive suitable for bonding and backfilling and meets the requirements of FMVSS212 2 hour drive away time/ double airbag test and the 1 hour NCAP. It provides the ultimate solution for both OEM’s and the aftermarket who desire excellent mechanical properties with a simple process and fast cure times.

All the Formoa® Gb range allows manufacturers to simplify their processes; for one customer switching to Formoa® meant 16 man hours per vehicle saved. Find out how much you could save.



Mould Growth on Sealants

Have you been a victim of mould? If yes, then you know how frustrating it can be to eliminate this relentless horror. These attacks are usually identified as black spots on the surface of the material. However, they can come in many other colours such as brown, yellow, red or even pink.

Mould is a type of fungus that can survive in a wide range of conditions. However, there are a few key requirements for mould growth such as mould spores, food, appropriate temperatures and moisture.

Unfortunately, most moulds grow well under temperatures we prefer to live in. But mould truly thrives under warmer conditions, such as that of the tropics or your bathroom However, even temperatures close to freezing such as in a refrigerated lorry, are not enough to stop the growth of mould.

All moulds require moisture for growth and will quickly grow when the humidity approaches 70%. If the temperature, moisture and mould spores are optimal then mould will feed on any substance that contains carbon atoms. This could include the oils from your skin, left behind when you touch a surface, soaps, wood and of course sealants. Mould can secrete digestive juices that breakdown sealants into usable food. If this is allowed to occur, the mould will quickly multiply and grow into the sealant and the distinctive spots of mould will be observed.

Sealants in bathrooms are particularly affected because they have low thermal conductivity and are therefore the warmest parts of a tiled surface. This means moulds can flourish in bathrooms as they have ideal warmth, moisture/ humidity and food e.g. from shampoos and oils. However, mould is not just confined to the bathroom, it can also prove problematic for refrigerated trucks, this is particularly concerning as some of these trucks are carrying products for human consumption.

Moulds may be unsightly and smelly, but there are far more serious concerns than that. Actively growing moulds are feeding on the material they are living on, thus impairing the structural integrity of the material. Even more concerning than this is the potential health implications that moulds can have on human health including allergies, respiratory infections and asthma attacks.

So, if you are concerned about mould growth, we have a solution for you. Through extensive research and development, we at Forgeway have developed a Formoa® Antimicrobial formula which can combat not only mould, but even bacteria and other fungi. Through extensive testing our Formoa® AM product has shown to provide significant reduction in microbe growth and longevity, ensuring the sealant will remain both structurally and aesthetically pleasing for years to come.

ABS Bonding

ABS is a high-performance plastic commonly used for automotive body-parts, dashboards and decorative interior panelling. The demand to seal and bond ABS components is ever increasing as the automotive industry wish to take full advantage of the versatile plastic, combined with the benefits adhesives offer - Fast operation times, easy application procedures, maintain ABS strength & integrity by avoiding destructive riveting, professional finishing, and reduced weight of the vehicle meaning greater fuel efficiency.

Unfortunately for many adhesives bonding ABS is a major problem, here at Forgeway® we love a challenge and see problems as opportunities. To overcoming such formidable challenges, we seek to fully understand the problem. ABS bonding is a layered problem which needs to be unravelled to find the solution.

ABS is ABS right? Wrong!

Our knowledge of ABS means we understand that any two given ABS's are rarely the same.

ABS is available in various compositions depending on the desired nature of the finished product, and these compositions have various surface energies.

In 1963, Lego changed the plastic their bricks were made from to ABS. The only downside was that, unlike cellulose acetate, ABS is opaque, so transparent Lego parts can't be made from it. In these cases, a polycarbonate plastic is now used instead.

The surface energy of ABS determines the ease at which the adhesive can interact with the bonding area. The lower the surface energy the harder it is to bond. ABS can have low to very low surface energy depending its composition.

Some ABS adhesives overcome the low surface energy by essentially melting its surface, such solvent based adhesives describe this as a chemical weld. Whilst the principle is good the practice is far from it. This bond formation is closer to chemical attack which breaks down the ABS leaving it vulnerable to environmental stress cracking – early life failure.

With the problems facing vehicle manufacturers in full view, Forgeway® adhesives are developed to meet the challenges head on, and to pass the most stringent of examinations before being taken to the market - Glues with high IQ's is more than just a moto.

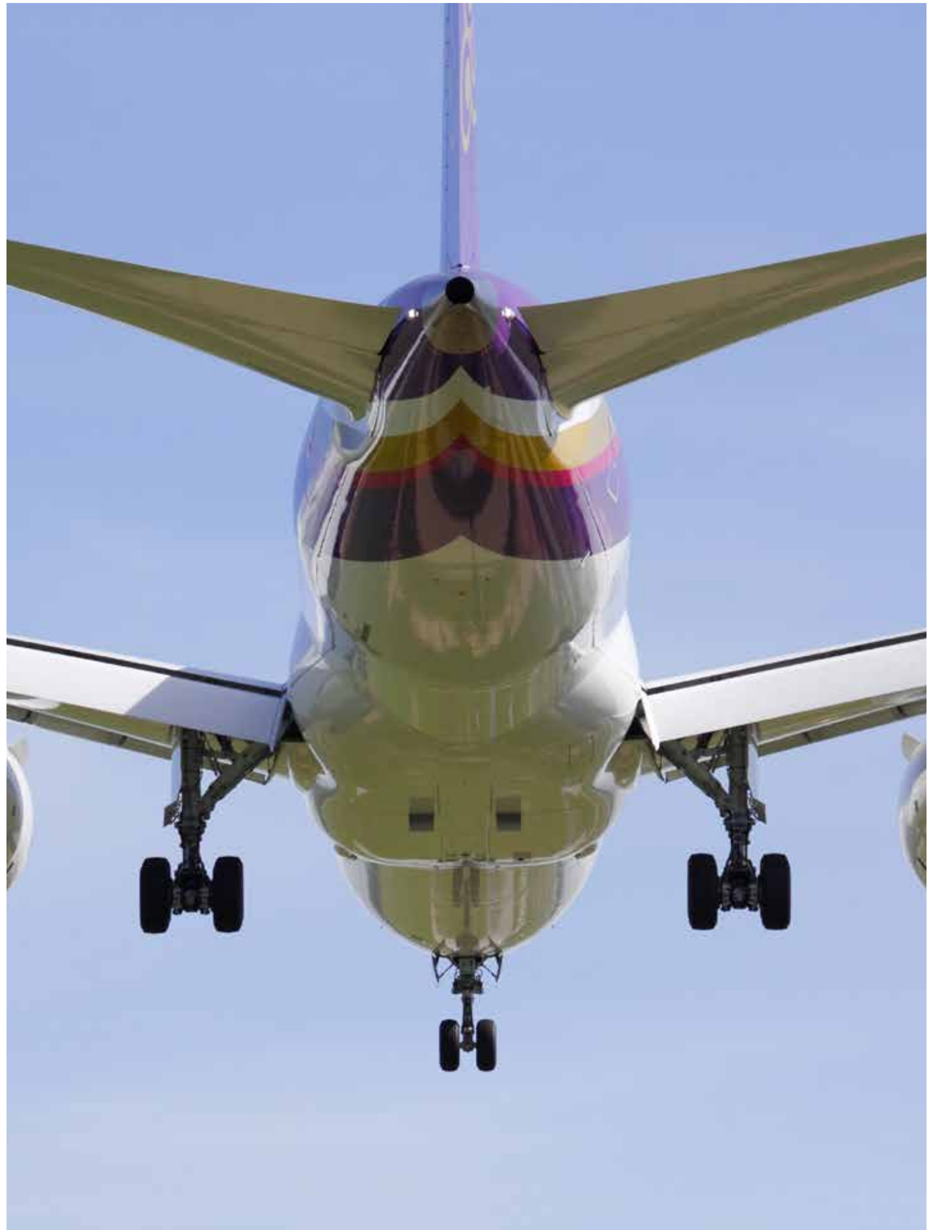
Formoa® 063 is the lean fighting fit 6-pack of ABS adhesives. It can also be used in conjunction with **Formoa® Surface Activator +** for the lowest surface energy ABS's, providing vehicle manufacturers with a non-destructive ABS bonding solution ensuring high quality & maximum performance over the lifetime of the vehicle.

Aviation Industry

Success Story

Aerok® 8250 is a fire-retardant structural adhesive that can withstand extreme temperatures.

Composite fuselage developments have resulted in higher cabin operating temperatures - putting greater demands on adhesive specifications.



Construction Industry

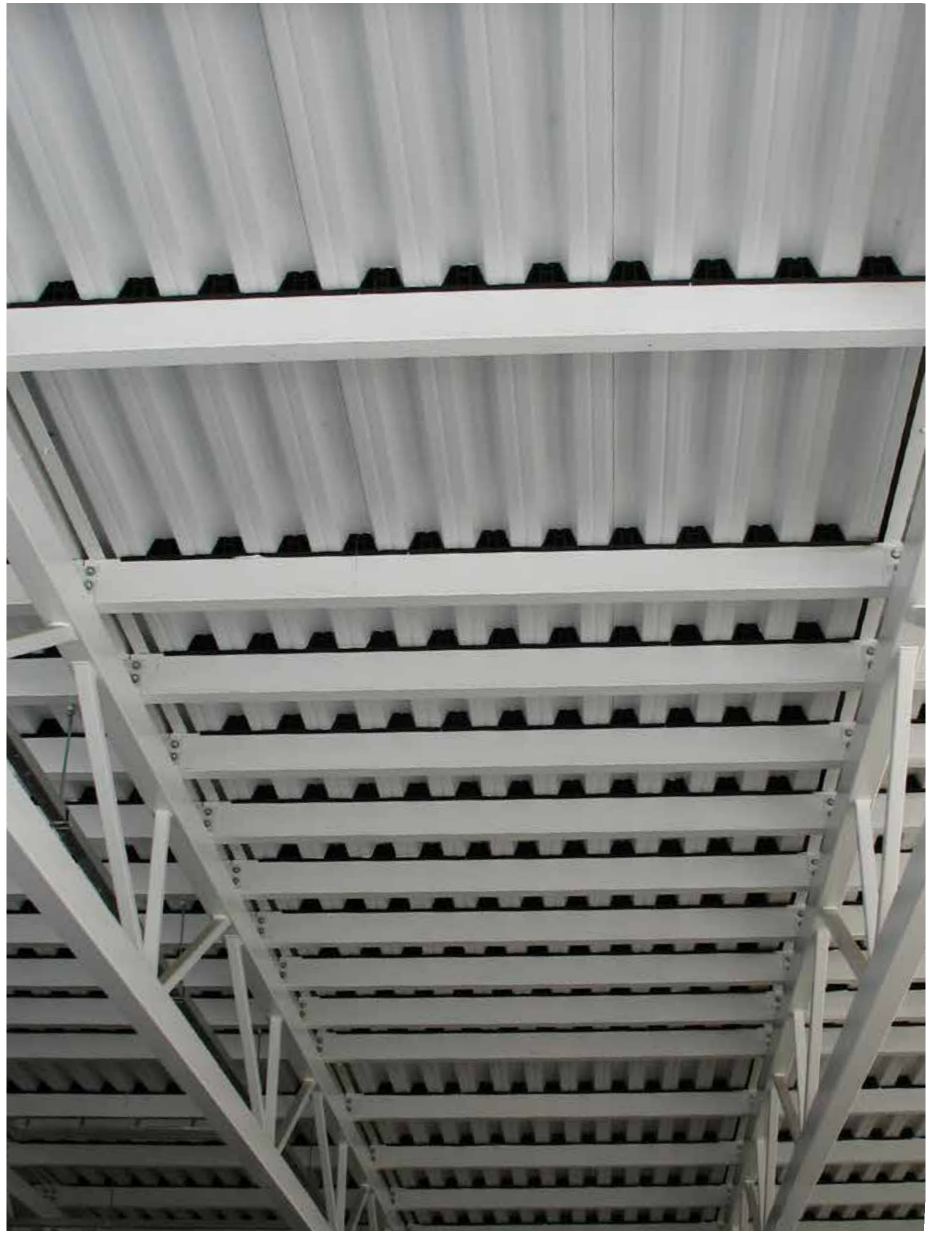
Success Story

A modular car park manufacturer working with major companies like Sainsbury's & Chiltern Railways, constructed prestigious modular car park systems.

Impressive three-storey steel structures were built containing bonded composite panels.

Formoa® 066 was tested & approved for bonding of these composite & steel sections.

Formoa® enabled increased output.



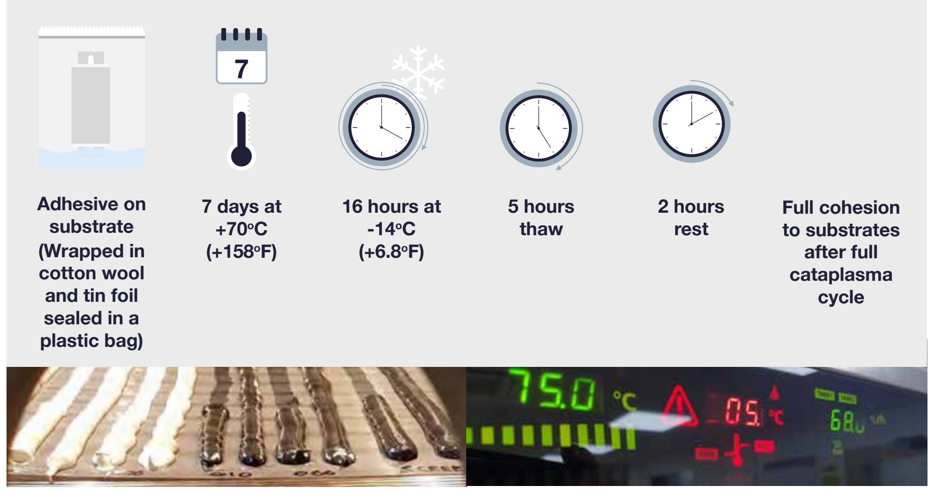
Cataplasma

Motorhome enthusiasts love nothing more than experiencing nature in the comfort of their luxury vehicles. Traveling across continents is now easier than ever - an adventure from the north of Scotland to the south of Spain is a dream turned reality with a motorhome.

That dream however can turn into a nightmare if cataplasma conditioning has not been taken into consideration!

Over the course of the adventure the motorhome will experience a wide range of weather conditions, from the heavy rainfall in Scotland, near freezing temperatures in the French Alps to the glorious Mediterranean heat in Spain – And its these drastic changes in conditions which Forgeway® has identified as the root cause of failure in inferior products, were debonding is seen time and again. These drastic changes in conditions are referred to as Cataplasma conditions, and they are of growing concern to global motorhome manufactures who demand the highest performance from every aspect of their vehicles.

At Forgeway® we put the needs of the customer first to ensure the quality of our products, meaning that they are fit for purpose and beyond, which is why we run adhesion durability testing as standard on all our adhesives. The Forgeway® adhesives used for the most critical bonding are also Cataplasma tested – This testing really pushes the adhesive performance to the extreme.



The Forgeway® Cataplasma test method bonds the adhesive to the substrate under ambient conditions until fully cured, then really ups the ante. The test specimen is then kept at a high temperature with the most severe humidity - This temperature & humidity combination aggressively attacks the bonding interface between the adhesive and substrate. Formoa® glides through this stage of the testing, where inferior products lose the battle readily breaking down their adhesive bond. And as if the hot wet cycle was not enough, the adhesive bond is then thermally shocked by being subjected to below freezing temperatures for a further 24h – literally being taken from Scotland to Spain and back again!

It is important to understand the specifics of cataplasma testing. Cataplasma is an overall term and there are between 3 and 5 different methods of testing for specific environments. It should also be noted that it is almost impossible to create a test method for every eventuality or combination of eventualities.

Commercial Vehicle Industry

What happened?

A safety floor manufacturer required a new adhesive for bonding their floor system.

They were persuaded to trial an alternative adhesive supplier.

Application conditions resulted in the adhesive “sweating” & complete bond failure - all passengers would have died.

Construction Industry

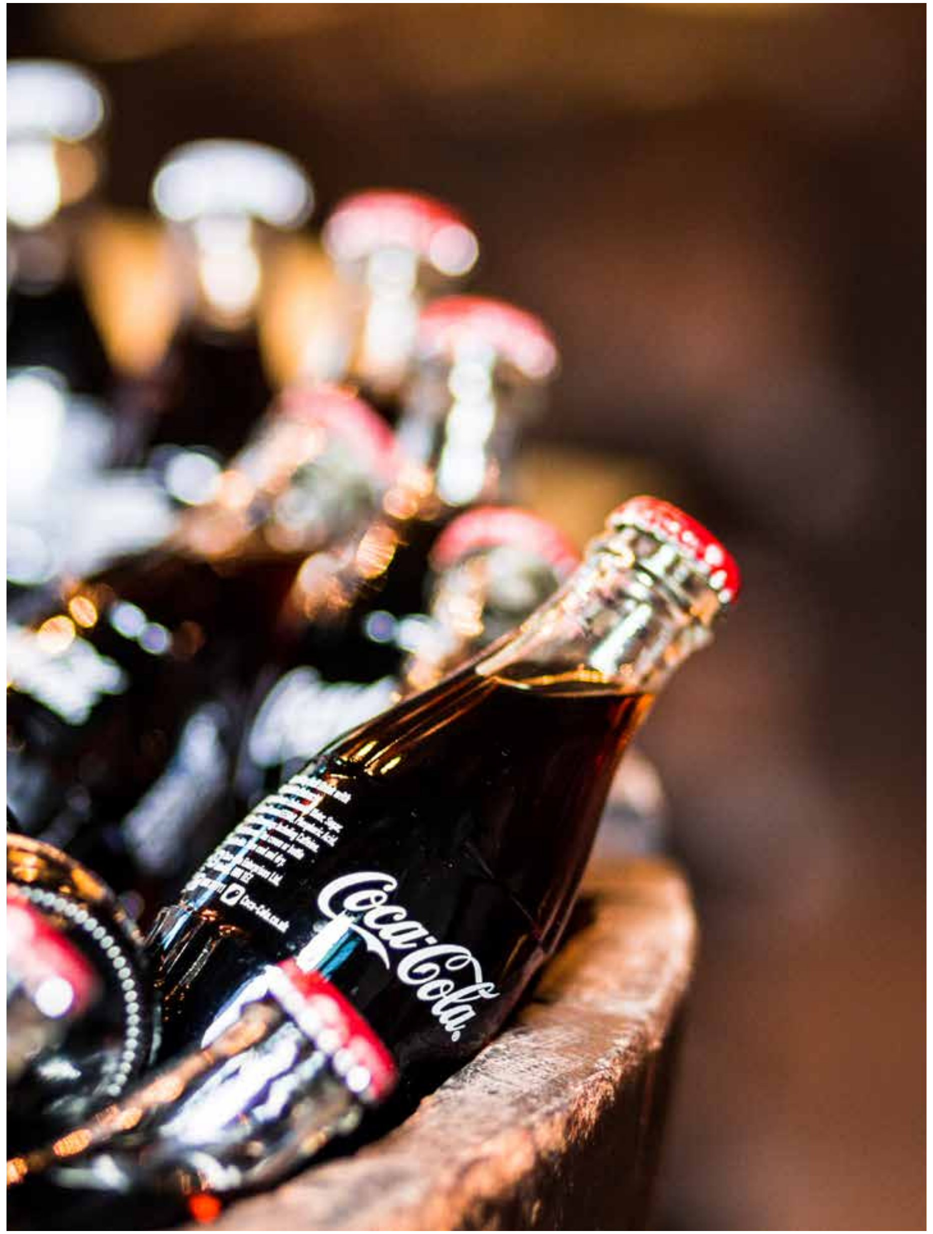
Success Story

A leading manufacturer of filtration systems required a white fast cure adhesive, drinking water compatible - BS 6920.

It also needed to withstand high impact & abrasion, as well as ultrasonic vibration.

The solution…we developed **Poxrok® 2118**.

Most UK drink manufacturers’ ingredients would have flowed past **Poxrok®**.



Fire Resistance

Sudden & unexpected outbreaks of fire can occur naturally, through mechanical faults, poor practices, and unfortunately they can be started deliberately by reckless individuals. Such fire outbreaks have devastating effects wherever they occur, be it in the environment, our homes or in our vehicles. The worst case scenarios gravely leading to loss of life.

Preventing such disasters is taken very seriously at Forgeway®, and is at the forefront of our thoughts when developing adhesives and sealants for use where potential fire situations are a very real threat.

We recognise the major threats of fire as the flammability of materials, the spread of smoke, and the emission of toxins to the surrounding environment (FST fire smoke toxicity).

By formulating with base raw materials which do not burn **Forgeway® FR** adhesives & sealants cannot be used to start fires and do not propagate any fires which have occurred. Our FR adhesives are also formulated without toxic components to eliminate the release of harmful substances in to the environment.

Forgeway® also have FR adhesives which use the fire to their advantage! These adhesives have two defensive reactions when the heat begins to rise – they swell filling all voids surrounding the bonded area preventing smoke passing from one compartment to the next, and they form a ceramic char protective barrier which quenches the spread of the fire beyond the joint.

Forgeway® FR adhesives meet the strict internationally recognised standards across many sectors, EN45545-2 (European railway standard for fire safety), AS/NZS 1530.3 (Australian & New Zealand Standard fire test on building materials), BS 476 (British Standard fire test on building materials and structures), FAR/JAR 25.853/ CS 25.853 (a) and ABD0031 (Airworthiness standards).

The **Forgeway® FR** adhesives are available in several application technologies to match both your manufacturing demands and in-service performance requirements. **Formoa® FR**, **Pyrok® 803**, **Pyrok® 805** and others – For more information on Forgeway fire safe products, or any of our high performance adhesives, sealants and coatings, give us a call.

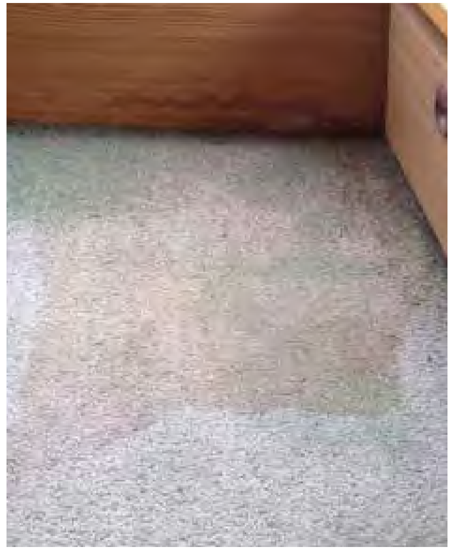
Water Ingress

Water ingress…This term has plagued vehicle manufacturers for a long time and repercussions from its effects come at a heavy price. Body leaks, delamination of panels or flooring, mould growth plus numerous other negative effects, are all potential warranty issues that await if joint design and adhesive choice are not carefully considered.

The concept of waterproofing a vehicle is simple, however it is evident that in critical sections where reliance on a permanently sealed joint is essential, the adhesive / sealant used does not stand up to the task. Enter **Formoa®** – our range of adhesives and sealants that can stand test of time.

Major recreational vehicle manufacturers are now seeing the benefit of using **Formoa®** for the service life of their vehicles. Typical warranty cover for vehicle body integrity is 3-5 years regarding issues connected with water ingress, and the **Formoa®** range will comfortably deal with environmental exposure over that period. We have evidence of vehicles bonded with **Formoa®** that are over 20 years old and still in full service.

The secret behind the success is our fanatical attention to detail about knowing how our products will perform under extreme environmental conditions. For an adhesive or sealant to be effective for many years, it must chemically interact with the substrate and remain anchored together after exposure to many environmental factors; for example, high temperatures, high humidity, contact with water, other chemicals such as cleaning solutions and UV light. Should the chemical interaction between the adhesive or sealant breakdown, this is likely to then lead to water ingress and other issues. So, it is vital that the adhesive or sealant can cope with these extreme factors when in service. Our products are tested with these harsh environmental conditions in mind. A key example is the Forgeway® cataplasma test, where the adhesive bond is subjected to a thermal shock cycle – sustained high heat and humidity exposure and then immediately transferred to extreme cold.



Adhesive durability is one of the hallmarks of the Forgeway® design lab requirements and no product is released without this being fully verified. An excellent all-rounder for recreational vehicle manufacturers, where a product can be used for both structural bonding and sealing, is **Formoa® 063**. This product has been put through its paces to ensure that it will perform under extreme conditions and will not let you down.

Aviation Industry

What happened?

In November 2010 Qantas flight 32 suffered an uncontained failure in one of its four engines. The failure occurred 4 minutes after taking off from Singapore.

Forgeway had worked extensively on the development of specialist structural void filler for the attrition liner and had supplied materials for a number of the test, development and first production engines.

An alternative material was selected for mainstream production.

Following this near catastrophe the customers investigation and development team reached out to discuss the superior performance characteristics of the Aerok material originally selected.

Aviation Ovens

An aviation oven manufacturer was struggling to find an adhesive to bond stainless steel to a PEI core. The stainless steel side of the panel would be the inside of the casing of an aircraft oven. In such an application, the adhesive is required to withstand a huge increase in temperature and a very fast pace. For example whilst sat on the runway the inside of the oven could be at a minus temperature and then required to heat up to over 300 degrees Celsius very quickly.

The manufacturer had tried all products offered by all of the prominent global adhesive companies with every product tested causing bond failure.

Forgeway® supplied Aerok® 7001P for the lamination of the stainless steel and the PEI core and Aerok® 7205 as the void filler. Both products passed all testing and maintained performance even at a constant temperature of 350 degrees Celsius!

Galvanic Corrosion

What Is Galvanic Corrosion?

Galvanic corrosion (also known as dissimilar metal corrosion) is a type of corrosion which occurs when two dissimilar metals are brought together. For galvanic corrosion to occur the metals must be connected in two ways:

1. They must be in electrical contact with one another, this could be either via direct physical contact or through another material which is conducting, such as an adhesive.
2. There must also be ionic contact, ions must be able to flow between the two metals. For this to occur an electrolyte such as water is required.

The two metals don’t have to be immersed in water for galvanic corrosion to occur. Just a continuous film of electrolyte/water that coats both metals is all that is needed for galvanic corrosion to occur, this is especially common in areas of high humidity.

Choosing the Correct Metals

The chart to the right shows the Galvanic series, this chart can be used as a general guide for choosing the correct metals. To minimize the amount of corrosion it is always best to choose metals which are close together on the galvanic series. If two metals are chosen which are far apart on the chart then galvanic corrosion is more likely to occur, with the corrosion targeted at the least noble metal.

Direction of Attack (↑)

Electric Current / Movement of Ions (↓)

Least Noble / Anode

Magnesium
Magnesium Alloys
Zinc (hot-dip, die cast, or plated)
Aluminium 1100, 3003, 3004, 5052, 6053
Tin (plated)
Lead
Steel 1010
Iron (cast)
Stainless steel 410 (active)
Copper (plated, cast, or wrought)
Nickel (plated)
Chromium (plated)
Stainless steel 301, 304, 310 (active)
Tungsten
Brass
Nickel-silver (18% Ni)
Stainless steel 316L (active)
Bronze 220
Copper 110
Red Brass
Stainless steel 347 (active)
Copper-nickel 715
Admiralty brass
Stainless Steel 202 (active)
Bronze, phosphor
Monel 400
Stainless steel 201 (active)
Stainless steel 321 (active)
Stainless steel 316 (active)
Stainless steel 309 (active)
Silicone Bronze 655
Stainless steel 301, 304, 321 (passive)
Stainless steel 201, 286 (passive)
Stainless steel 316L (passive)
Stainless steel 202 (passive)
Titanium
Gold, Platinum
Graphite

Most Noble / Cathode

The Anodic Index is a more useful tool in determining whether galvanic corrosion is likely. Table 1 gives the anodic index of various metals. By subtracting the anodic index of the metals, you can determine the relative voltage of the pair of metals.

Preventing Galvanic Corrosion

The first line of defence should be to choose materials which are close in the galvanic series and have the required anodic index for that environment.

However, if there is no other choice than to use two dissimilar metals, then the following precautions should be implemented:

Break the electrical connection by insulating the two metals from each other.

Applying coatings to both materials.

Separating the two materials by inserting a suitably sized spacer.

Installing a sacrificial anode that is anodic to both metals.

Using corrosion inhibitors

Table 1: Anodic Index of Various Metals.

Metal	Index (Volts)
Gold, solid and plated, Gold-platinum alloy	0.00
Rhodium plated on silver plated copper	0.05
Silver, solid or plated; monel metal. High nickel-copper alloys	0.15
Nickel, sold or plated, titanium and alloys, monel	0.30
Copper, solid or plated; low brasses or bronzes; silver solder; nickel-chromium alloys	0.35
Brass and bronzes	0.40
High brasses and bronzes	0.45
18% chromium type corrosion resistant steels	0.50
Chromium plates; tin plated; 12% chromium type corrosion-resistant steels	0.60
Tin-plate; tin-lead solder	0.65
Lead, solid or plated; high lead alloys	0.70
Aluminium, wrought alloys of the 2000 series	0.75
Iron, wrought, gray or malleable, plain carbon and low alloy steels	0.85
Aluminium, wrought alloys other than 2000 Series aluminium, cast alloys of the silicon type	0.90
Aluminium, cast alloys other than silicon type, cadmium, plated and chromate	0.95
Hot-dip-zinc plate; galvanized steel	1.20
Zinc, wrought; zinc-base die-casting alloys; zinc plated	1.25
Magnesium & magnesium-base alloys,cast or wrought	1.75
Beryllium	1.85

Environment of Metals		Difference in Anodic Index which can be tolerated (Volts)
Normal Environment	Storage in warehouses or non-temperature and humidity-controlled environments	<0.25
Controlled Environment	Temperature and humidity are controlled	<0.50
Harsh Environment	High humidity and salt environments	<0.15

An Example of Poor Metal Choice:

The images below show an example of galvanic corrosion observed on a coach that was no more than three years old.

The corroded metal was **Zintec mild steel**, which is mild steel that has been electrically coated with a thin layer of zinc. Using the tables above we can see that it will have an anodic index of approximately **1.20-1.25 volts.** This steel was both welded and bonded with a **non-insulating** adhesive to **chromic steel** which has an anodic index of **0.60 volts.** For the conditions, this coach might experience such as humid/wet and salty environments the difference in anodic potential should be **less than 0.15 volts.** However, calculating the anodic difference between these two metals we find it to be **0.60-0.65 volts.** Therefore, it is not surprising that significant corrosion was observed in just three years.

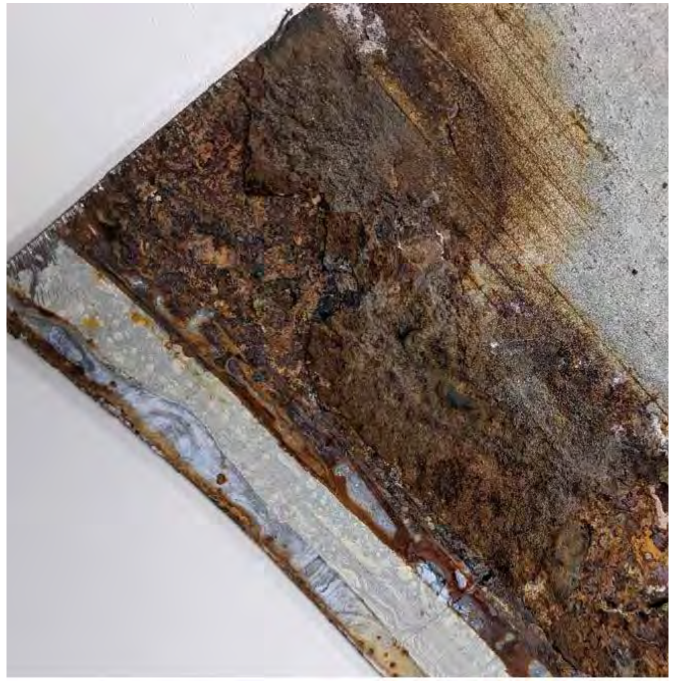


Figure 1: Zintec mild steel showing galvanic corrosion

Figure 2: Galvanic corrosion observed around the adhesive bond. The adhesive was not insulating enough and allowed the two dissimilar metals to transfer charge, causing galvanic corrosion.

Glossary of terms

Abrasion	The method of wearing down (scratching, roughening etc.) a material to increase the surface area
Active layer	The outer most layer on a surface which has been treated to form highly reactive groups on the surface
Additive migration	The movement of plasticizers and pigments from the bulk material to the surface of the material
Adhesion	The phenomenon of two materials sticking together permanently
Adhesive failure	A failure occurring at the adhesive-substrate interface
Adhesive interface	The layer of bonding forces between the adhesive and bonding material
Adhesive	Known as a glue, cement or paste which bind two materials together
Adhesive / cohesive failure	Intermittent failure at the adhesive-substrate interface
Alcohol	A colourless volatile flammable liquid
Anisotropic	Defined as a material having a different value when measured in different directions
Application	The method at which a process is carried out
Aqueous solution	A solution which uses water as the solvent
Area of coverage	The amount of adhesive applied to a certain area
Bond	A substance used to bind something together
Brittle	A hard material which is easily broken
Chemical compatibility	The stability of a compound when it has undergone a reaction
Cleavage stress	The force exerted over one edge of a substrate
Cohesion	A permanent bond made between two materials
Cohesive failure	A failure occurring within the bulk of adhesive
Compressive load	The capacity of a material to withstand loads tending to reduce the size
Condensation reaction	A chemical reaction which produces water as a by-product
Conductivity	The degree at which a material allows electricity or heat to pass through it
Consistency	The determination of the physical nature of a substance
Contaminant	A polluting substance which makes another substance impure
Corrosion	Degradation of a substance through a natural process
Covalent bond	A bond involving the sharing of electrons
Creep	The time dependent deformation of a material under constant load
Cross-linking	A bond(s) made between two compounds (polymers)
Cure speed	The time taken at which an adhesive hardens
De-bonding	A mode of failure whereby a material detaches from another
De-lamination	A mode of failure whereby a material detaches from another
Deformation energy	Refers to any changes in the shape or size of an object to an applied force
Density	The quantity of mass per unit volume of a substance
Disassembly	To take apart or remove something from a structure
Dissimilar materials	Substances made of different materials

Double sided tape	A pressure sensitive tape with adhesive on both sides
Ductile adhesive	An adhesive able to flex without losing toughness
Elasticity	The ability of a material to resume to its shape after being stretched or compressed
Endothermic	A reaction which uses up heat
Environment	The surrounding conditions of a person or place
Epoxy Adhesive	Structural adhesive made from an epoxy polymer
Erosion	The natural weathering of a substance
Evaporate	The process in which a liquid becomes a vapour
Excess adhesive	Over application of adhesive to a certain area
Exothermic	A reaction which releases heat
Extrusion	**1.** A process used to expel a liquid from a closed system **2.** A process used to cut a material of a fixed cross-sectional area
Fatigue	The process in which a substance weakens over repeated stress
Fibrous	A substance which consists of / made up of fibres
Flash off time	The time taken for a solvent based material to evaporate from a material
FTIR	Fourier Transform Infrared Spectroscopy
Fungicide	A chemical that destroys fungus
Gaseous layer	A surface layer which is made up of varying gases
Green strength	The mechanical strength of a material after pressing
Handling strength	The mechanical strength of a material after a determined amount of time
High ratio	With respect to cartridge gun; the gun dispenses more adhesive per force of the user
High viscosity	A material containing more friction and a lower flow rate
Intermolecular forces	The forces of attraction or repulsion between neighbouring molecules
Isocyanate	A salt or ester of isocyanic acid
Isotropic	Defined as a material having the same value when measured in different directions
Joint	A connection made between two materials
Karl Fischer	A machine used to calculate the amount of water in a substance
Low ratio	With respect to a cartridge gun; the gun dispenses less adhesive per force of the user
Low viscosity	A material containing less friction and a higher flow rate
Maximum available bonding time	The time taken for an adhesive to no longer have an active skin to bond
Mechanical stress	Expresses the internal forces of an adhesive
Microscopic organism	An organism that cannot be seen with the naked eye and only consists of one cell
MMA	Methyl methacrylate
Modulus	A constant factor or ratio
Moisture	A small quantity of water (or other liquid) found within a solid or on a surface
Molecular interactions	The forces of attraction or repulsion between molecules

Molecule	A group of atoms bonded together
MPa	Megapascal
MS Adhesive	Modified silane adhesive made from polyether
Non-porous	A substance which does not allow air or liquid to pass through it
One-component	An adhesive which is made up of a single part
Organic group	A functional group of a compound which determines its characteristics
Overlap joint	At joint in which the two materials overlap
Over-paintability	The ability of substance to be painted
Oxidation	The loss of electrons from a compound
Oxide layer	A thin layer or coating of a compound containing more than one chemical compound
Oxygen radical	A highly reactive species containing an unpaired electron
Peel stress	The force exerted over an adhesive on one flexible adherend
Porous	A permeable substance which allows air and water to pass through it
ppm	Parts per million
Pre-treatment	The treatment of a substrate with a chemical before use
Primer	A paint or coating which you add to a material's surface to increase bonding sites
Spacer	An object used to hold a space open; to obtain a desired width of joint
Spores	A single celled reproductive organism which can multiply asexually

Stability	The state a which a material stable
Structural adhesive	A material used to transfer loads between adherends
Substrate failure	The breaking of a material
Substrate	A material used in assembly manufacture
Surface energy	The sum of molecular forces which are made on a material's surface
Synthesis	The production of compounds from a chemical reaction
Synthetic	A chemical made material; not naturally made
Tack free time	The time taken for an adhesive to become touch dry
Tack	The property of an adhesive which allows it to adhere to a surface
Tensile stress	Equal opposite forces applied to a material at a constant rate
Thermal stability	The ability for a substance to not change at a molecular level
Thermal stress	The stress exerted over a material through an increase or decrease in temperature
Two-component	An adhesive which is made up two parts
UV	Ultra-violet
Viscosity	The state of a substance being determined by the friction forces within it
VOC	Volatile organic compound

Measures and conversions

Length

12 inches	1 foot
3 feet	1 yard
220 yards	1 furlong
5,280 feet	1 SM
10 mm	1 cm
10 cm	1 dm
10 dm	1 m
10 m	1 da
1000 m	1km
1 inch	2.54 cm
0.3937 inch	1 cm
1 SM	1.6093 km
0.6214 SM	1 km
1 NM	1.852 km
0.54 NM	1 km

Area

144 inch^2	1 foot^2
9 feet^2	1 yard^2
4840 yards^2	1 acre
640 acres	1 mile^2
100 mm^2	1 cm^2
100 cm^2	1 dm^2
10 000 cm^2	1 m^2
100 m^2	1 dam^2
100 dam^2	1 ha
10 000 dam^2	1 km^2
1 inch^2	6.4516 cm^2
0.155 inch^2	1 cm^2
1 acre	0.4047 ha
2.471 acres	1 ha
1 SM^2	2.59 km^2
0.3861 SM^2	1 km^2

Weight

437.5 grains	1 ounce
480 grains	1 try (fine) ounce
16 drams	1 ounce
16 ounces	1 pound
14 pounds	1 stone
112 pounds	1 long hundredweight
1 long hundredweight	50.8023 kilograms
1 kilogram	1000 grams
2000 pounds	1 short ton
2240 pounds	1 long ton

Volume

1728 inches^3	1 foot^3
27 feet^3	1 yard^3
1000 mm^3	1 cm^3
1000 cm^3	1 dm^3
1000 dm^3	1 m^3
1 inch^3	16.387 cm^3
0.061 inch^3	1 cm^3
1 yard^3	0.7645 m^3
1.308 yard^3	1 m^3

°F	-40	-31	-22	-13	-4	5	14	23	32	41	50	59	68	77	86	95	104
°C	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40

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Notes

Disclaimer

The Fundamentals of Adhesives is not an academic study. It is a compilation of 25 years of practical experience in developing and manufacturing adhesives and supporting those who use adhesives in their manufacturing.

You should always request a consultation if you are unsure of any aspect of adhesive application.

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