

THE RESISTANCE OF ADHESIVES

By David Carter

Abstract

The purpose of this paper is to provide information about the factors that will lead to a successful bond using adhesives. This paper is also aimed at the uses of conductive adhesives for EMI shielding.

Back to Basics:

In any adhesive bond, the aim is to get as much surface contact as possible between the two surfaces that are being bonded. The belief that roughening the two surfaces before the adhesive is applied, is not correct. Indeed, the exact opposite is true because the two surfaces should be as smooth and as clean as possible. The best adhesion is achieved by the smoothest surface. Typical lap shear strength of adhesives with various finishes:

Surface Preparation	Joint Strength (Mpa)
Degreased only	5
Degreased and rubbed down with coarse emery paper	13
Degreased and fine grit blasted	14

The most obvious way of making the most intimate contact between the two surfaces is to use a liquid. The mobility of a liquid will enable the molecules to take up the exact shape of the irregularities of the surface. However, the fact that a liquid is being used implies that the joint will have no shear strength. To convert the liquid into a strong layer it must therefore become solid. A very convincing demonstration of this is when rainwater freezes on a car windscreen and sticks the windscreen wipers to the glass.

The mechanism by which the adhesive changes from liquid to solid is often used to classify it. The different types are:

1. Freezing. Here the adhesive is applied molten and is allowed to cool until it solidifies.
2. Evaporation. The adhesive is applied as a solution and a solvent evaporates to leave a solid.
3. Reaction. The adhesive is applied as a mixture, which turns to a solid by the means of a chemical reaction.

Liquid to solid method	Curing type
Freezing	Fish glue is an example
Reaction	Anaerobic reaction
Reaction	Exposure to ultraviolet light
Reaction	Heat curing (epoxies)
Contact	Evostick
Reaction	Activation system (modified acrylics)

An Overview of each curing mechanism:

Anaerobic reaction:

With this single component system, the curing takes place very quickly when the two mating surfaces are put together. The polymerisation process that converts the liquid adhesive to the solid required, is inhibited by the presence of oxygen (from the air) so that when the two surfaces are brought together and air excluded, the polymerisation can proceed and the two surfaces are joined together.

The adhesive will not begin to cure while it is in contact with atmospheric oxygen and because of this pot life is not of any concern.

The most rapid curing of this type of adhesive is achieved when it is in contact with active materials. (See appendix 1 for a list of active materials.) This type of adhesive is often used in thread locking applications.

These adhesives are based on synthetic resins called acrylics. Due to the curing process anaerobic adhesives do not have good gap filling characteristics but have the advantage of relatively rapid curing.

Cyanoacrylates:

Cyanoacrylates use moisture held on the adherand to cure and therefore require close fitting joints to work effectively.

Exposure to ultraviolet light:

Polymerisation is initiated in this type of adhesive by exposure to ultra violet light, the curing time being dependent on the intensity and wavelength of the light source. This type of adhesive is typically used for sealing electronic components and bonding glass to itself or metal. The disadvantage of this type of adhesive is that the UV light must be absorbed by the adhesive at the required intensity which means at least one of the substrates need to be transparent to UV light. The advantage of this type of adhesive is that it can be quickly cured.

Heat curing:

Curing these adhesives depends on a chemical reaction which needs a temperature typically in the range of 70°C to 120°C. At temperatures lower than this, the reaction is slow and so the bonding process will also be slow. Epoxy resins are examples of this type of adhesive and are frequently two pack systems.

The epoxy adhesives can be used for gap filling purposes up to around 25mm.

Moisture curing:

The polymerisation in this case is caused by a condensation reaction with ambient moisture. The cure rate is hence directly related to the relative humidity. There are generally two types of base components, either silicone or polyurethane. Both can cure at room temperature by reacting with the moisture in the atmosphere to initiate cross linking. Because the moisture has to get into the silicone to initiate the curing process and therefore the curing takes place from the outside towards the inner, this action can limit the maximum adhesive thickness applied to a joint.

Because the moisture has to pass from the surface of the silicone into the interior of the material, cure times can be long. (eg one to two hours as well as the thickness of the applied adhesive being limited.)

The resultant joint from this type of adhesive is often very flexible with high elongation properties and can withstand very high temperatures, typically in excess of 200°C.

The main difference between the silicone and polyurethane types is that the silicone type always produce a by product which can be poisonous where as the polyurethane type does not.

It is important with this type of adhesive that the correct storage conditions are followed otherwise a limited pot life will result.

Activation system:

These adhesives cure at room temperature when used with the activator. The activator is often supplied in a separate cartridge and can be either premixed or applied to the surface separately. The major advantage of this type of adhesive is that virtually all type of materials can be bonded with the resultant joint being of a very high shear and tensile strength.

The Components that make up an Adhesive.

Base/Binder:

The main compound that holds the substrates together is called the base or binder. The classification of an adhesive often refers to the base being used, for example an epoxy or cyanoacrylic. The old fashioned 'fish glues' often only had a binder and no other ingredients.

Solvent/ Dispersant:

An evaporation adhesive requires a solvent or dispersant. Whatever is used the setting of the adhesive depends on the liquid part of the mixture evaporating from the freshly applied adhesive to leave the more solid base. The solvents can often be modified to change the fluidity, wetting, setting time and volatility of the adhesive.

Plasticiser:

If the base sets to a glassy and brittle compound then it is likely to crack as the base shrinks due to the solvent evaporating. Plasticisers are often added to the adhesive mixture to combat this effect. The addition of a plasticiser can reduce the overall strength of an adhesive but stress can be more uniformly distributed by using one and hence reduces the possibility of cracking.

Hardener:

When an adhesive changes from a liquid into a solid some form polymerisation usually takes place. This action involves small molecules joining together to form larger ones, or even to form one continuous molecule. The base molecules will react amongst themselves if a hardener is used.

Fillers:

The filler for a conductive adhesive is often a highly conductive metal such as silver in the form of very small particles. With non conductive adhesive, the filler is often a lower cost mineral powder to give the adhesive some bulk. A mineral such as alumina is produced at a much lower cost than a petrochemical produced component.

Fillers can also add other attributes to the adhesive than just adding bulk. For example, thermal expansion can be a problem with heat cured adhesives. The coefficient of expansion within the polymer tends to be far higher than the adherand. This causes a problem when the adhesive cures because as it cools it shrinks more than the adherand which leads to cracking and stress. By careful consideration, a filler with a lower expansion coefficient than the polymer can be added which will match the adherand with the overall effect being a much stronger joint.

Flexibilisers:

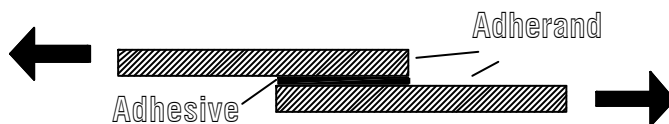
A very successful toughening mechanism for polymers is to add a crack blunting mechanism. This is done by adding rubber particles throughout the relatively rigid polymer. When a crack front is formed, it travels along the polymer until it hits the rubber which has the effect of releasing the strain energy and thus prevents the crack from continuing. Each 'blunting blob' is a site from which a new crack has to initiate if the fracture is to continue.

Types of Load.

The bonded joint with a load acting upon it will have various types of stresses applied. Stress is normally expressed in N/mm^2 .

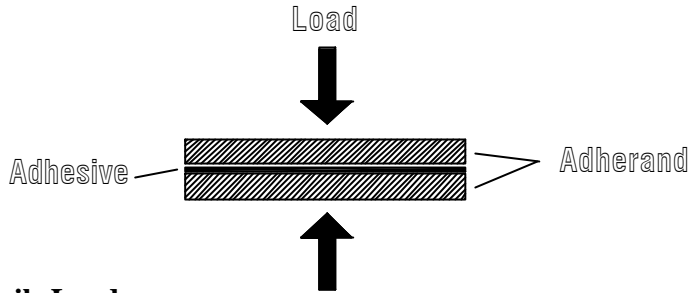
Shear Load:

In this type of load, the stress concentration at the ends of the joint is higher than in the middle. This means that the adhesive at the end must resist a greater amount of stress than the adhesive in the middle of the joint.



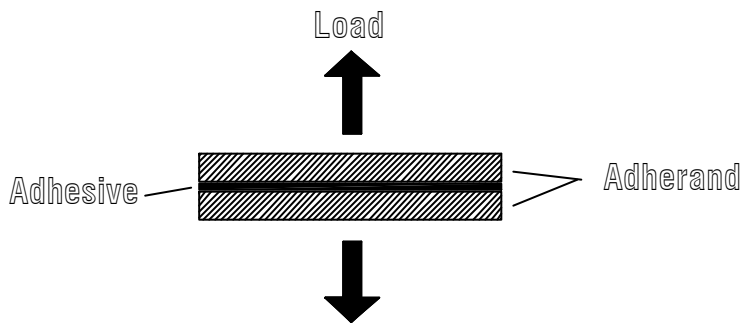
Compressive load.

In a compressive load, the stress distribution over the bondline is very even. This means that every part of the bondline carries the same load. In order to calculate the stresses acting on the adhesive simply, divide the acting forces by the bond area. This type of load is very rare.



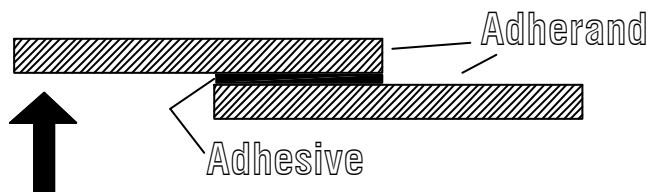
Tensile Load

The tensile load is much the same as a compressive load in that the stress distribution across the bond line is very even.



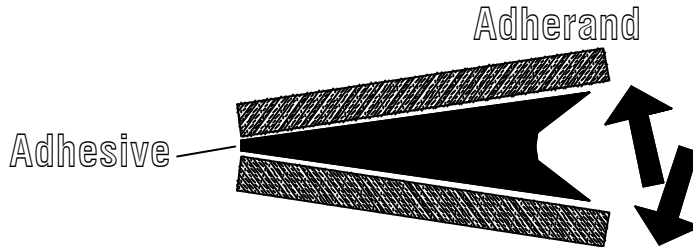
Peel Load

The peel and cleavage loads are similar in that when the load is applied to the joint, the majority of the stress is concentrated at the end where the load is applied.



Cleavage load

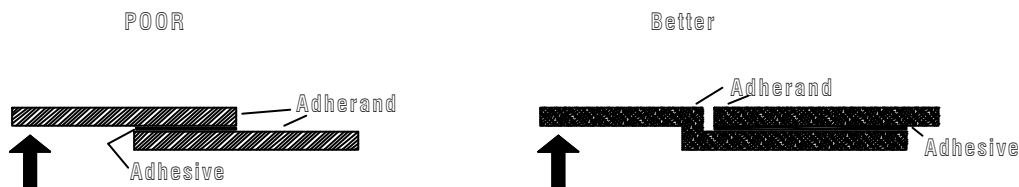
When designing a joint the peel and cleavage types should be avoided where possible.



Joint Design.

The target for the joint designer is to get a uniform distribution of stress across the bond line. One way to achieve this even distribution is to avoid cleavage and peel joint types. A simple way to improve joint performance is increase the bond area. It is often too easy to design a joint with a small surface area. Another common mistake is to simply substitute a welded joint for an adhesive joint. If maximum efficiency is to be realised then the joint to be adhered must be considered at the early stages of conceptual design. Such considerations should involve the properties of the adhesive and adherand, adhesive selection, manufacturing conditions, geometry of the bond and an analysis of the bonded joint stresses.

For example:



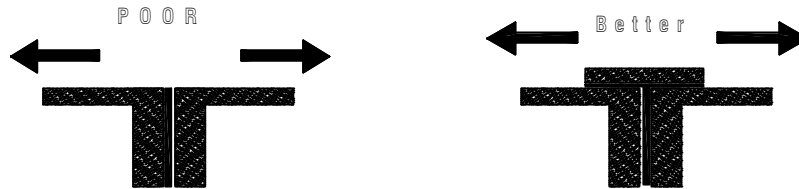
The example on the left shows a joint that is in peel mode. The solution on the right is better because the joint is predominantly under compression.

The relative ability of a joint to withstand certain loads can be summarised by a rule of thumb:

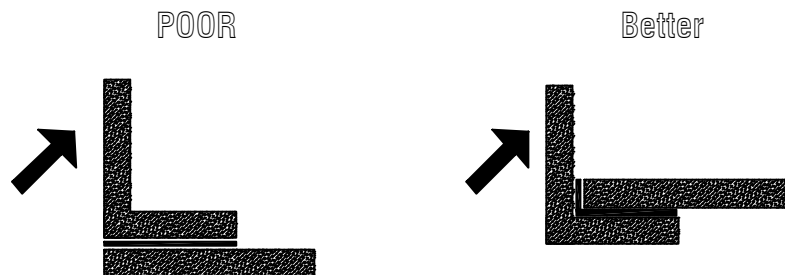
Joint type	Ability to withstand load
Compression	1000
Shear	100
Peel	1

This indicates that a joint under compression is 1000 times stronger than a similar joint under a peel load.

The following figure shows how the strength of a simple joint can be significantly increased. Notice here that it is difficult to design in a compression joint but the addition of the top plate adds a shear type joint which can improve the bond strength by up to a factor of 100.



Another example of a common joint is shown below. The poor joint shows a cleavage type. The same function can still be achieved but the joint is now mainly under compression.



Butt Joints

The simplest of all joint geometries is the butt joint. The main problem with this type of joint is that it is (mostly) in pure tension and it will therefore produce cleavage stress fields at internal flaws. Also, in the straight butt joint, the cross section is constant so the strength of the adhesive, even with minimal flaws, may become the weak point in the joint. This type of joint therefore only makes sense if the adhesive produces a bond which is as strong and tough as the pieces to be joined together.

Lap Joints.

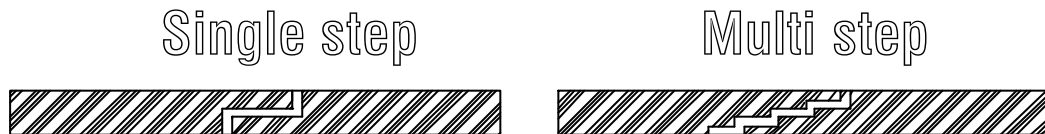
The obvious way to avoid the cleavage and peel stresses on a butt joint is to design a lap joint.

The butt joint can be improved by:

1. Scarf joint. This is similar to a straight butt joint but with a 30 degree taper typically on the joint mating edges. The angle reduces the cleavage component of the load. Accurate machining is required though to achieve the taper.



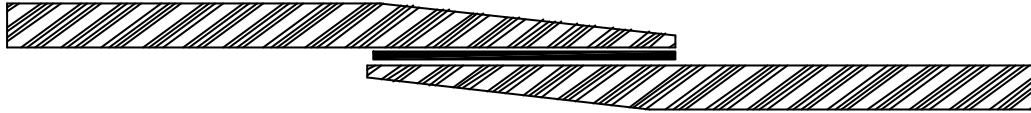
Single and Multi-step joints. The single step has both of the butt edges exposed and is therefore poor under bending conditions. The major benefit is that the simple lap joint alignment with the load is avoided:



Another improvement over the butt joint is to strap it. Here the crack opening in the butt joint is protected by the strapping. The strapping could be achieved by the use of a plastic or metal extruded section. Tape may also offer a more practical solution:



To evenly distribute the stress along the length of a scarf joint, the following shape could also be used:



This technique can drastically reduce stress concentration.

Adhesion and Cohesion:

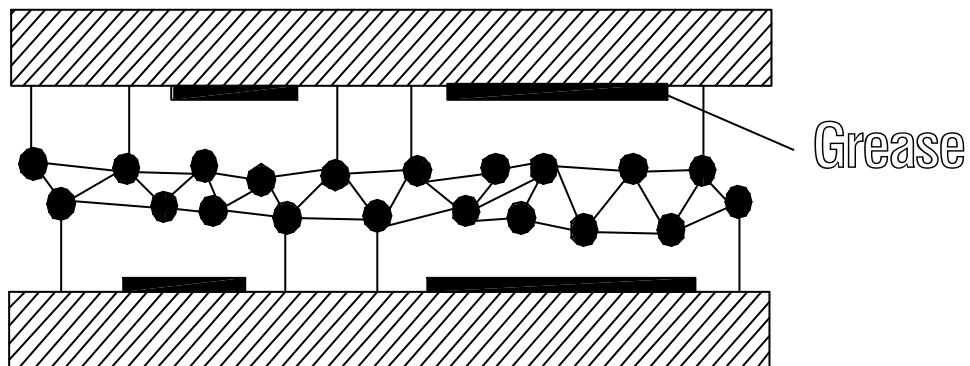
Having designed a joint for maximum strength the next important issue is the surface of the adherand. When an adhesive joint fails, it is either through a failure of cohesion or adhesion.

Adhesion

Adhesion is the bonding force to the substrates to be adhered. It is how well the adhesive bonds to the surface of the adherand. The physical force is attraction and is known as 'Van der Waals' forces. It is these forces that must be in direct intimate contact with the bonding surface to achieve maximum strength. This is why the adhesive must penetrate right into the surface roughness and wet the complete surface. It is when these forces that directly link the bonding surfaces to the adhesive that maximum strength is achieved.

The strength of the adhesive force thus depends on both efficient wetting of the surface and the adhesion properties of the surface. At a given surface tension of the adhesive, wetting depends on the surface energy of the substrate and the viscosity of the adhesive. Wetting can also be reduced if surface contaminants are present.

Adhesion can be improved by degreasing or by abrasion techniques to remove any unwanted surface films. The importance of De-greasing is highlighted on the following figure. See how the grease drastically reduces the contact area and so reduces the adhesion of the adhesive to the substrate:

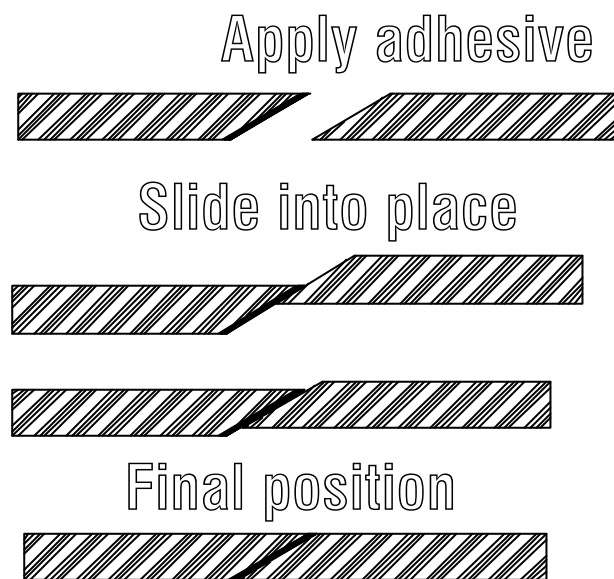


Other methods of improving adhesion include changing the surface activity of the adherand by etching, or by using a primer to build up a new active surface by coating.

No matter how much surface treatment is done, chemical bonding over the whole surface is never achieved. For example, the surfaces of most materials in air are to some extent oxidised material which is itself either not strongly attached to the underlying material or is of low cohesive strength.

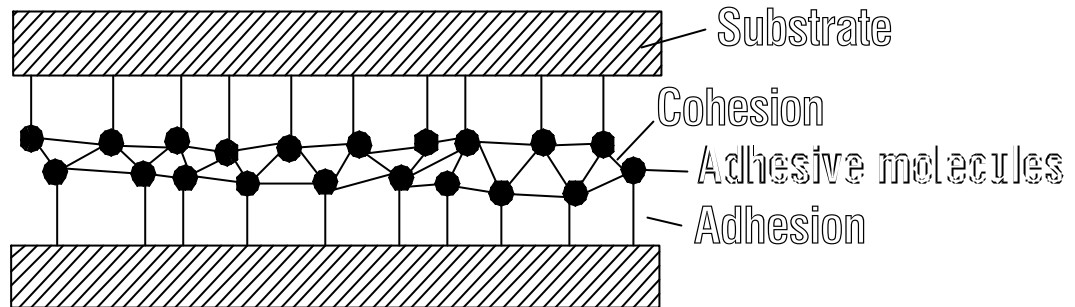
The other problem that prevents total surface contact between the adhesive and the adherand is air, moisture or residual vapour that is trapped between the substrates. This effect can be minimised by the correct surface preparation and the application of adequate pressure during the curing stage. Adhesives that require heat to cure are particularly prone to moisture problems since the adhesive expands and gives off steam during the curing stage (steam is produced only if water is produced). With the above statement in mind it should become clear that an adhesive joint should not be separated and re-made during the curing process if a good strong joint is required.

The correct way to manufacture a joint is to apply the adhesive to one piece of the joint, then slowly and smoothly slide the other substrate over the adhesive in a single movement. This technique should guarantee no air entrapment:



Cohesion:

Cohesion is the bonding within the adhesive and gives it its strength. The forces at play here are, either the intermolecular forces of attraction (Van der Waals) or covalent forces. There is also interlocking of the polymer molecules.



Wetting

The problem in using an adhesive is to arrange that in its liquid state it will wet the surfaces to which it has to adhere. Wettability is best illustrated by the classic adhesion problem of water based adhesives which will not wet greasy surfaces. The reason for this being that hydrogen bonds which hold the water molecules together are stronger than the Van der Waals forces that act between a hydrocarbon grease and the water. The water in this instance forms globules rather than spreading. The coherence of to itself exceeds the forces of adherence to the grease.

The surface of the adherand can be evaluated by a simple water break test. The adherand is applied with several droplets of water. If the water end spreads on the adherand surface then the surface has been cleaned satisfactorily. If however, the spherical form of the droplets is largely retained the surface must be cleaned again as all the grease has not been removed. This test should not be performed on anodic coatings on aluminium or magnesium however. Also, be aware that the hardness of water can vary. In critical applications, special surface tension fluids should be used.

The complete removal of all grease is critical for a successful adhesive joint. Special solvents are available which remove the grease but themselves evaporate to leave no residue.

Grit blasting is a good way of cleaning a large surface area prior to adhesion. The surface roughness of this technique can provide good result providing that not too coarse a grit is used. After grit blasting, grinding and brushing the parts should be still degreased to remove all traces of any residual grease.

Conductive Adhesives.

Tecknit manufacture a range of conductive adhesives to suit most applications. The adhesives are loaded with a conductive filler, typically silver particles, silver glass, Nickel, silver plated copper spheres, silver plated aluminium spheres and Nickel coated graphite spheres are used. These adhesives are used to either form an EMI shield or to assemble a conductive gasket. There are several types of conductive adhesive available, each of which are suited to different applications.

One part Ag filled silicone RTV (part number 72-00002)

This is a pure silver loaded one component RTV. It does not require mixing and cures quickly at room temperature upon exposure to moisture in the air.

Bonding Applications:

Various conductive elastomers, including the silver loaded variants.

(Consil E, A, N, R & II)

Silicone filled with stainless steel gaskets (Teckfelt)

Silicone impregnated woven gasket (Duolastic)

Expanded metal gaskets (Teckspan)

Oriented wire products (Elastomet & Elastofom)

Various types of knitted mesh materials.

Shielded windows to frames

This adhesive can also be used for in place EMI gasketing of shield penetrating components such as connectors or switches.

Two Part Silver (part number 72-00036) and Nickel Filled RTV (72-00035)

This conductive adhesive can also be used as a sealant and provides a strong flexible bond. The main consideration for selecting the correct adhesive should be based on the galvanic coupling of the metallic or conductive materials being used.

Bonding Applications:

Silver based Conductive elastomers, such as Tecknit Consil E, II and R & Metallic materials such as Ag & Au

Nickel based: Conductive elastomers, SC-Consil and metallic materials such as Ni, monel Al, Cu & Sn.

Teckbond –C (part number 72-00192)

This is a silicone rubber base adhesive filled with silver plated copper particles to produce a highly conductive one part adhesive sealant. The system is an RTV moisture cured compound.

Bonding Applications:

Metal to silicone gasket application, such as Tecknit Consil-C. The bond thickness should be less than 0.4mm.

Teckbond –A (part number 72-000236)

Teckbond –A is a conductive system that is silicone based and filled with silver plated aluminium particles. This two part adhesive begins to cure immediately upon addition of the catalyst which is supplied as a separate vial.

Bonding Applications: Metal to silicone gasket application, such as Tecknit Consil-A.

Teckbond –NC (part number 72-00350)

Teckbond –NC is a silicone rubber base filled with Nickel coated graphite particles. The system is an RTV moisture cured compound which is ready to use without mixing or preparation.

Bonding Applications: Metal to silicone gasket application, such as Tecknit Consil-NC. The bond thickness should be less than 0.4mm.

Summary of Tecknit Adhesives:

Parameter	One part RTV	Two part RTV	Two part RTV	Teckbond C	Teckbond A (2 part)	Teckbond NC
Resin	Silicone	Silicone	Silicone	Silicone	Silicone	Silicone
Filler	Ag	Ag/glass	Ni	Ag/Cu	Ag/Al	Ni/C
Colour	Silver-tan	Beige	Dark grey	Grey	Blue	Dark grey
Final condition	Flexible	Flexible	Flexible	Flexible	Flexible	Flexible
Solids	N/A	80%	70%	N/A	85%	N/A
Mix ratio	N/A	49:1	49:1	N/A	49:1	N/A
Volume	1.7in ³	13.6in ³	7.0in ³	2.5in ³	14in ³	1.7in ³
Density	3.06 g/cc	2.03 g/cc	3.95 g/cc	3.8 g/cc	2.0 g/cc	2.6 g/cc
Pot life at 25°C	5 minutes	4 hours	4 hours	15 minutes	4 hours	25 minutes
Shelf life, if unopened	5.5 months	9 months	9 months	9 months	9 months	9 months
Tack free	20 minutes	24 hours	24 hours	2.5 hours	60 minutes	1.5 hours
Full Cure	72 hours	168 hours	168 hours	168 hours	168 hours	168 hours
Volume resistivity	0.01 ohm-cm	0.01 ohm-cm	0.1 ohm-cm	0.04 ohm-cm	0.01 ohm-cm	0.5 ohm-cm
Shear strength	150psi	60 psi	50psi	200 psi	100 psi	100 psi
Peel Strength	2ppi	3ppi	3ppi	2.5ppi	2 ppi	3 ppi
Shrinkage	1%	31%	44%	1%	40%	1%
Temperature	-59 to 204°C	-55 to 150°C	-55 to 150°C	-65 to 182°C	-48 to 65°C	-55 to 200°C
Transportation class	Non flammable	Flammable liquid	Flammable liquid	Flammable	Flammable	Flammable
Part number	72-00002	72-00036	72-00035	72-00192	72-00236	72-00350

Conductive Caulk

In addition to the above adhesives, Tecknit also manufacture a conductive caulk. This caulk is filled with either silver or copper and is formulated to provide at least 100dB of shielding across the entire RF spectrum. This product is often used to improve the joint or seam integrity for all types of electronic enclosures.

The main feature of this product is the ease of which it is applied with conventional caulking guns and dispensing equipment.

In Summary

Will the joint act as a weather proof seal ?

Will water, chemicals or solvents be able to penetrate the bond ?

What sort of forces will the joint be exposed to ?

What type of load will the bond have to carry ?

What properties should the adhesive have: plastic, rigid or elastic ?

Will the bond be exposed to any forces before it is fully cured ?

What is the maximum & minimum temperatures the adhesive will have to endure ? (This should include: storage, shipping and operation.)

Are there any differences in thermal expansion between the adhesive and adherand ?

Additionally with conductive adhesives:

Consider the level of conductivity/shielding required

Consider the galvanic reaction between the adhesive and adherand

Appendix 1

Active and inactive materials table:

Active Materials	Passive Components
Brass	Anodic coatings
Bronze	Aluminium
Copper	Ceramics
Iron	Chromate films
Steel	Glass
	High alloy and stainless steel
	Nickel
	Oxide films
	Plastics
	Silver
	Tin
	Zinc

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