

ADHESION SCIENCE AND TECHNOLOGY

The Technical Guide for Adhesives

**This brochure is an abstract
of "The Complete Technical
Guide for Adhesives".**

Get the Complete Guide

1.0

ADHESION SCIENCE AND TECHNOLOGY

This guide is designed to help engineers overcome the reservations sometimes held about the use of adhesive bonding.

It includes an overview of bonding techniques and shows how joints may be designed and pre-treated to make the best use of adhesive bonds.

This guide has its roots in the first uses of synthetic structural adhesives: the ARALDITE® brand is known and recognized worldwide in both industry and the home environment.

1.1 INTRODUCTION

A few words about adhesives
Huntsman industrial adhesives
Designing to bond

1.2 ASSESSMENT OF BONDING

Advantages of adhesive bonding
Limitations of adhesive bonding

1.3 DESIGNING A BONDED JOINT

Loading conditions
Basic bonded joints
Basic peel joints
Basic butt joints
Basic cleavage joints
Basic cylindrical butt joints
Practical bonded joints
Reinforced bonded joints
Numerical simulation of joint design
Durability of bonded joints



1.1 INTRODUCTION

A FEW WORDS ABOUT ADHESIVES

Almost all industrial items produced are made up of components which need to be fixed together in some way. Mechanical fasteners such as screws, rivets or spot welds are frequently used, but engineers are increasingly choosing to use adhesive bonding. This assembly technique is well proven and capable of replacing or supplementing mechanical fastenings. Advantages of adhesive bonding include:

- **Outstanding lap shear and peel strength**
- **Reduced component and/or assembly costs**
- **Improved product performance and durability**
- **Greater design freedom**
- **Less finishing operations**

Adhesive bonding is not a new topic; mankind has used adhesives or glues since the dawn of history.

The ancient Egyptians attached veneers to furniture with glue and prehistoric man is even believed to have used basic glues for attaching arrow heads and digging tools. These early glues were all natural substances made from plants, tree resins or animal parts. Nowadays, synthetic resins and polymers are commonly used, enabling much higher performance levels to be reached.

When components are bonded together, the adhesive first thoroughly wets the bonding surfaces, filling the gap between them before hardening to form a bond. Once hardened, the bond can withstand the stresses imposed during use. High-performance adhesives often harden through a chemical reaction and have a strong affinity to joint surfaces. Adhesive bonding is sometimes called chemical joining to differentiate it from mechanical joining.



1.1 INTRODUCTION

HUNTSMAN INDUSTRIAL ADHESIVES

Our industrial adhesives form extremely strong and durable bonds with plastics, metals, glass, rubber and many other materials.

Adhesives have been successfully used for many years in very demanding industrial applications including aerospace, automotive, wind energy, sport and leisure, railways, construction and medical equipment.

Our industrial adhesives form extremely strong and durable bonds with plastics, metals, glass, rubber and many other materials. Designers in just about every industry have found that bonding with Huntsman adhesives can provide the solution to the design challenges created by new materials, new applications and new manufacturing methods.

Our industrial adhesives are easy to use, but to ensure high-performance bonding it is key to closely follow the instructions supplied with our products.

Key instructions for a successful bond

- Resin and hardener components must be carefully measured in the correct ratio (found in our technical datasheets) and thoroughly mixed together.
- Joint surfaces must be degreased and, when necessary, pre-treated.
- Minimum curing temperature and curing time must be observed (data given in the technical datasheets).
- Jigs or other fixtures must be used to prevent the bond surfaces from moving relative to one another during the curing process.
- Though only light pressure is needed, it should be applied as evenly as possible over the whole bond area. Excessive pressure may leave the joint with insufficient adhesive.



At Huntsman we develop adhesives that meet the needs of many industries and we focus on one goal: making our customers' ideas possible.

[▶ Watch the video](#)

DESIGNING TO BOND

In order to get the best performance from an adhesive bond it is important to design the component for a bonded joint, rather than simply trying to bond parts designed for mechanical fastening.

Methods of application of the adhesive and the assembly of the components must always be considered at the design stage. Together, with the curing conditions, these determine the choice of adhesive to be used.

Computer simulation is a technique which is increasingly used for the design of adhesively-bonded structural joints. Simulation offers engineers a reliable evaluation of joint deformation and strength. Comprehensive Material Models are available for the ARALDITE® adhesive range. Based on laboratory material characterization, the Material Models provide a wealth of information on the physical, mechanical and thermal behavior of our products. Material Models include detailed experimental data of adhesive mechanical properties (tensile and fracture properties), adhesion properties (lap shear, peel) and curing phenomenon (glass transition temperature, shrinkage, density, hardness).

Use of ARALDITE® Material Models allows engineers to achieve robust adhesive joint simulation, assisting adhesive selection and joint design, as well as greatly reducing the physical part testing required for the design process.

1.2 ASSESSMENT OF BONDING

ADVANTAGES OF ADHESIVE BONDING

Adhesive bonding can offer reduced stress, greater stiffness, improved aesthetic appearance and lower complexity for parts.

All of these advantages can ultimately translate into economic benefits: simplified design, easier assembly, lighter weight (reduced energy consumption) and extended service life.

FIG.1A STIFFENING EFFECT WITH BONDING

The diagram shows how a joint may be designed to take advantage of the stiffening effect of bonding. Adhesive forms a continuous bond between the joint surfaces.

CONTINUOUS BOND

The stress is uniformly distributed over the entire bond area when a load is applied whereas stress is highly concentrated in a few areas when spot welding or mechanical fasteners are used. Bonded assemblies will therefore typically provide a longer service life under load.

IMPROVED APPEARANCE

Adhesive bonding gives a smooth appearance to parts. There are no protruding fasteners such as screws or rivets, and no spot welds marks.

STIFFER STRUCTURES

The continuity of a bonded assembly will produce stiffer structures. Alternatively, if increased stiffness is not needed, the weight of the structure can be decreased while maintaining the required stiffness. (Figure 1A and 1B)

COMPLEX ASSEMBLIES

Complex assemblies can often not be joined together by any other fastening technique. Composite sandwich structures are a typical example.

FIG.1B STIFFENING EFFECT WITH RIVETING

Rivets and spot welds pin the surfaces together only at specific points. Bonded structures are consequently much stiffer and loading may be increased (by up to 30 - 100%) before buckling occurs.

1.2 ASSESSMENT OF BONDING

ADVANTAGES OF ADHESIVE BONDING

DISSIMILAR MATERIALS

Adhesives can join different materials together – materials that may differ in composition, stiffness, coefficients of thermal expansion, or thickness.

HEAT SENSITIVE MATERIALS

Adhesive bonding does not require high temperatures, making it highly suitable for joining heat-sensitive materials prone to distortion or to a change in properties (e.g. from the heat of brazing or welding processes).

FIG.2A STRESS DISTRIBUTION IN LOADED JOINTS WITH BONDING

The bonded joint shown here is uniformly stressed. A welded joint would also show good stress distribution, but the heat of welding may reduce the metal's properties in the vicinity of the weld, reducing overall strength.

REDUCED CORROSION

The continuous adhesive bond forms a seal. The joint is consequently leak proof and less prone to corrosion.

ELECTRICAL CONDUCTION

Some adhesives are specifically formulated to offer high electrical conductivity. This is particularly useful for electronic applications.

ELECTRICAL INSULATION

The adhesive bond can provide an electrically insulating barrier between components.

VIBRATION DAMPENING

Adhesive bonds have good dampening properties which may be useful for reducing sound transmission or vibration.

REDUCED STRESS CONCENTRATION

A bonded joint may lead to an inherently safer structure, since since reduced stress concentration means that fatigue cracking is less likely to be induced. Fatigue cracks will often propagate more slowly in a bonded structure than in a riveted structure – or even in a solid machined part, because the bond lines will typically stop crack formation. (Figure 2A and 2B)

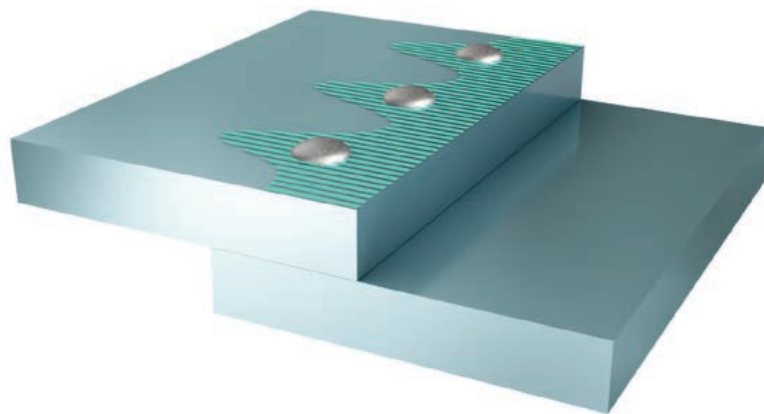


FIG.2B STRESS DISTRIBUTION IN LOADED JOINTS WITH RIVETING

The riveted joint is highly stressed in the vicinity of the rivets. Failure tends to initiate in these areas of peak stress. A similar distribution of stress occurs with spot welds and bolts.

LIMITATIONS OF ADHESIVE BONDING

As with most techniques, adhesive bonding has some limitations which must be considered when designing bonded parts and planning for their production. With sufficient foresight, many of the limitations can be mitigated during the design and planning stage.

TEMPERATURE RESISTANCE

Adhesives are produced from a class of materials known as polymers, plastics or synthetic resins and have some inherent limitations. They are not as strong as metals, but the difference is offset by the increased surface contact area provided by the bonded joints. Bond strength decreases with increasing temperature and the strain properties of the adhesive move from elastic to plastic. This transition is usually in the temperature range of 20 – 220°C (68 - 428°F): the transition temperature depends on the type of adhesive used.

CHEMICAL RESISTANCE

The resistance of bonded joints to the in-service environment is dependent on the properties of the polymer from which the adhesive is made. Possible exposure of the bonded structure to oxidizing agents, solvents, etc., must be kept in mind when selecting the adhesive type to be used.



CURING TIME

With most adhesives, maximum bond strength is not achieved immediately as it is with mechanical fastening or welding. The bonded assembly must be supported while the bond strength is developing. Hybrid joining, whereby mechanical fasteners (e.g. screws or rivets) are used in addition to the adhesive, can overcome the requirement for support during bonding.

SURFACE PREPARATION

The quality of the bond may be adversely affected if the surfaces are not readily wetted by the adhesive during the bonding process (see "Surface preparation and pretreatments" section).

PROCESS CONTROLS

Ensuring consistently good results may necessitate the setting up of unfamiliar process controls. A poorly executed bonding is often impossible to correct.

IN SERVICE REPAIR

Bonded assemblies are usually not easily dismantled for repair.

HEALTH AND SAFETY

High-performance structural adhesives are typically based on chemical products which present some environmental and health risks until they are fully cured. Suitable precautions must therefore be respected during mixing, application and bonding. Information is available for each product on the safety datasheet (SDS).

QUALITY MANAGEMENT

Within the ISO 9000 quality standard, adhesive bonding is required to be treated as a "special process", since bond strength and durability cannot be fully verified by non-destructive testing (NDT).

This means that additional quality standards, such as DIN 2304-1 and DIN 6701 may have to be applied to meet quality management requirements.



LOADING CONDITIONS

It is critical that an assembly which will ultimately be bonded is designed with bonding in mind, rather than simply bonding a design intended for welding or mechanical fastening.

When designing bonded joints the following aspects must be considered:

- Joint geometry
- Adhesive selection
- Adhesive performance properties
- Service conditions
- Stress in the joint
- Manufacturing process

Bonded assemblies may be subjected to tensile, compressive, shear or peel stresses, or a combination thereof (Figure 3). Adhesives are more resilient under shear, compression and tension stresses. They perform less effectively under peel and cleavage loading. A bonded joint needs to be designed so that the loading stresses will be directed along the lines of the adhesive's greatest strengths.

To indicate the typical adhesive performance properties, the Huntsman Advanced Materials technical datasheet will usually report shear strength and peel strength obtained on a range of standard substrates.

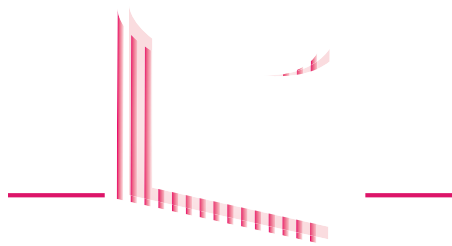


For example, the standard test method for shear (ISO 4587) uses a simple lap joint made from metal sheet, usually an aluminum alloy 25 mm wide with 12.5 mm bonded overlap. The mean breaking stress at room temperature will be in the range 5 to 45 N/mm² depending on the adhesive.

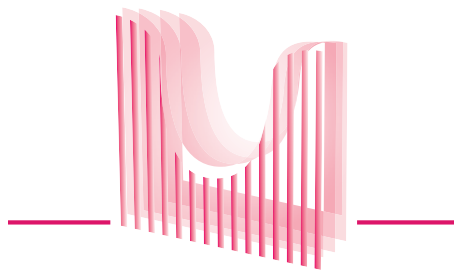
At the top end of this breaking stress range, bonded assemblies made from aluminum alloy up to 1.5 mm thickness will often cause the substrate to yield or break (the lap joint is only one of several different types of bonded assemblies). The breaking load of a lap joint is proportional to its width, but not to its overlap length.

Although the breaking load will increase as overlap length is increased, the mean breaking stress will be reduced. The strength of a joint is a complex function of the stress concentrations set up by the load. In a simple lap joint made from thin metal sheet there are two sorts of stress: shear and peel.

Both the shear and peel stresses vary along the length of the joint, with concentrations at the ends. Alternative joint designs are shown hereafter where these stresses are more evenly distributed. The efficiency gained results in joints of greater strength.

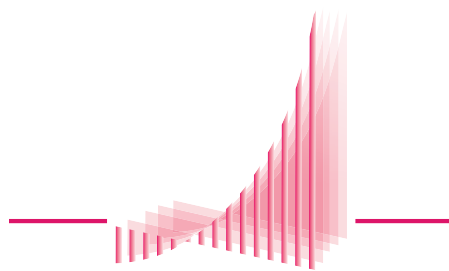


SHEAR



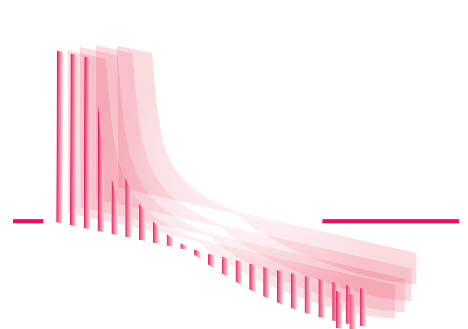
STRESS COMPONENT

CLEAVAGE



STRESS COMPONENT

PEEL STRESS



STRESS COMPONENT



1.3 DESIGNING A BONDED JOINT

BASIC BONDED JOINTS

The basic types of bonded joints are shown in the following diagrams. In practice, a combination of two or more basic types may be used – and the relative dimensions (and areas of bonded surface) of the joints may vary from those shown in the adjoining diagrams.

Tapering of the ends of lap joints or scarf joints serve to distribute the stress more uniformly and reduce stress concentration.

 SIMPLE LAP JOINT

 TAPERED LAP JOINT

 SCARF JOINT

 STEPPED LAP JOINT

 DOUBLE STRAP JOINT / DOUBLE LAP JOINT

 TAPERED DOUBLE STRAP JOINT

BASIC PEEL JOINTS

A peel joint can be designed such that the forces acting on it become compression forces, making a much stronger joint.

+++ BASIC

+++ STRENGTHENED

1.3 DESIGNING A BONDED JOINT

BASIC BUTT JOINTS

By adding a reinforcing plate to this butt joint, the forces run along a much stronger shear joint.

+++ BASIC

+++ STRENGTHENED

BASIC CLEAVAGE JOINTS

Weak cleavage joints can be strengthened through design, in this instance by adding a U-section to the previously bent sheet.

+++ BASIC

+++ STRENGTHENED

BASIC CYLINDRICAL BUTT JOINTS

By sleeving cylindrical butt joints, the forces run along a much stronger shear joint.

+++ BASIC

+++ STRENGTHENED

1.3 DESIGNING A BONDED JOINT

PRACTICAL BONDED JOINTS

Certain metals, especially mild steel, are easily bent or folded to form advantageous joints.

- (A) shows a development from the simple lap joint, (B) a toggled joint.
- (C) shows further developments.
- Closed box structures (D) from formed sheet metal are easily produced using a folding and bonding technique.

A

B

C

D



Multi-layer structures may be built up by adhesive bonding and may also be bonded to other parts.

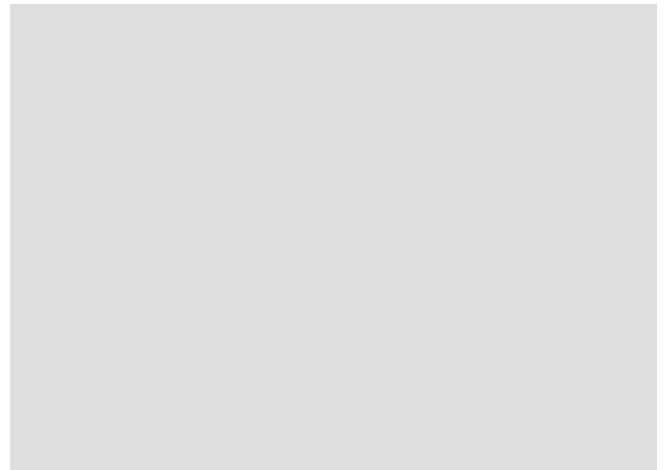
In the adjoining diagram, an edge member is bonded into a sandwich panel. On loading, the stresses will be transferred into the panel. The honeycomb core is itself assembled and bonded to the facing sheets with adhesives.



REINFORCED BONDED JOINTS

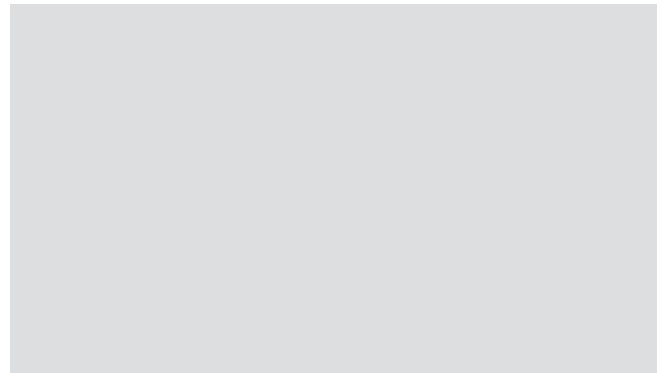
Joints using profiles

Sheets or plates that cannot be bent and folded may be bonded together by means of purpose made profiles. Tapering removes the high stress concentrations caused by abrupt change in section.



Bonded frameworks

Framework structures of square or round tubes, or simple profiles, may utilize plugs or bosses at the joints. Use of these additional pieces greatly increases the area of bonded surface at the joint.



Stiffening of large thin sheets

Large sheets of thin-gauge material may be stabilized by bonding stiffeners made of the same material. The diagram shows a 'top hat' stiffener which was cut away towards the edge of the sheet in order to reduce stress concentrations. The effect is similar to that of the scarf joint.



NUMERICAL SIMULATION OF JOINT DESIGN

Simulation of adhesively-bonded joints is now a common design tool for engineers.

Robust numerical simulation of adhesively-bonded structures relies on detailed Material Models which are based on solid experimental measures. These models should reflect the temperature dependence of the adhesive material.

Material Models are available from Huntsman which provide key experimental data for the range of ARALDITE® adhesives. This aims to help engineers achieve a robust simulation of adhesive joints.

Reliable evaluation of the joint deformation and strength under thermo-mechanical loading is a major challenge in the design of adhesively-bonded structures.

Evaluations must consider the combined effect of design parameters, such as joint configuration and bond line thickness, together with the varying properties of the adhesive material over the process and operating conditions.

Reliability analysis of adhesively-bonded assemblies therefore often necessitates use of complex numerical computation techniques such as finite element analysis (FEA).

TENSILE PROPERTIES

Tensile tests measure the force required to break an adhesive specimen and the extent to which the specimen stretches or elongates up to breaking point. Tensile testing provides the strength, modulus and elongation of the material over a range of temperatures.

POISSON'S RATIO

Poisson's ratio is a measurement of the relationship between how far a material is stretched and how thin it becomes during the stretching process. Poisson's ratio is commonly used in the design of structures to allow engineers to predict dimensional changes of a given material when under load.

FRACTURE TOUGHNESS

A major consideration in the design of adhesively-bonded structures is the possibility of crack growth leading to joint failure, either within the adhesive or at the adhesive-adherend interface. Fracture toughness testing simulates a small flaw in a standardized material specimen (using a pre-crack) and measures the load required to propagate the crack.

LAP SHEAR STRENGTH

Lap shear strength is a measure of how much shear force can be exerted on a lap joint before failure occurs. It is a critical characteristic of any adhesive, as it serves as one of the indicators of bond strength and durability in use.

Key properties that help engineers achieve a robust simulation of adhesive joint can be found in the ARALDITE® Material Models.

PEEL STRENGTH

Peel strength measures how much force is needed when two flexible adherends are bonded and then pulled apart. A T-peel test determines the peel strength of an adhesive by measuring the peeling force of a T-shaped bonded assembly of two flexible adherends.

THERMAL EXPANSION

Linear Thermal Expansion is used to determine the rate at which a material expands as a function of temperature. This test can be used for design purposes and to determine if failure by thermal stress may occur.

GLASS TRANSITION TEMPERATURE

Glass transition temperature is the temperature at which a reversible change in the adhesive occurs as it is heated, characterised by a transition from a rigid glassy state to a flexible elastomeric state. The glass transition temperature (T_g) indicates the temperature range over which an adhesive may be used.

VOLUMETRIC SHRINKAGE

The volumetric shrinkage signifies the contraction of polymeric adhesives which takes place during the hardening step, generally expressed as a percentage. The amount of shrinkage often depends on the temperature attained during the adhesive curing process.

SHORE HARDNESS

Shore hardness is used to determine the relative hardness of softer materials such as adhesives. A durometer measures the penetration of a hardened indenter into the adhesive under a specified force.

CURED DENSITY

Density represents the degree of compactness of an adhesive measured in mass per unit of volume. It is frequently used to follow variations in physical structure or composition of adhesives.

DURABILITY OF BONDED JOINTS

The long-term performance of a bonded joint depends on the properties both of the adhesive and of the materials being joined.

The adhesive may be affected by high temperatures, or by exposure to water or chemicals. The durability of the joint will also depend on the effects of these agents on the materials being joined.

Above all, it will depend on the conditions of the joint surfaces when the bond was made. The best joints are made when the surfaces are absolutely clean and are completely wetted by the adhesive.

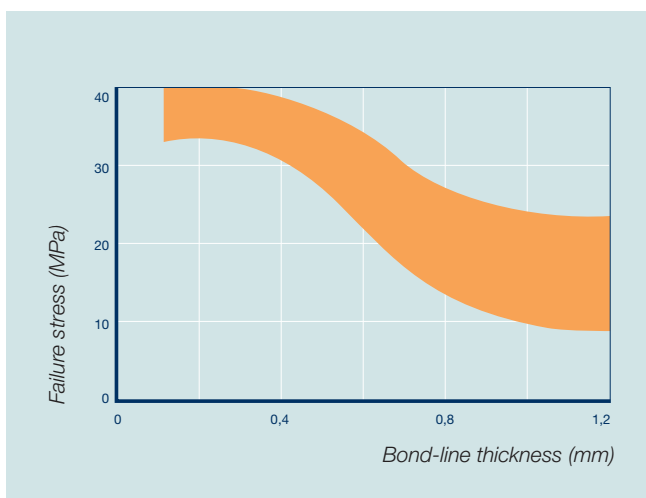
Durability of bonded joints necessitates control of pre-treatment of the surfaces. A poor surface condition usually results in a relatively low initial strength and reduced durability. A thick bond line gives lower initial strength (Figure 4). With most types of reactive adhesives, the application of heat to complete the curing process improves both initial strength and durability.

The user will need to assess the level of control required for these factors in order to produce a bonded joint suitable for the expected service conditions. For many applications, sufficient durability is obtained with easily achievable levels of surface pre-treatment, bond-line thickness control and cure-schedule monitoring.

Shear strength decreases if the bond line is too thick. The effect of increasing bond line thickness in simple lap joints made with cured epoxy adhesives is shown in the diagram (Figure 4). The optimum bond line thickness is in the range 0.1 to 0.5 mm. In very thin bond lines there is risk of incomplete filling of the joint due to contact between high points on the joint surfaces.

The bonded joints may need to resist sustained loads, which are either static or cyclical. Joint designs in which peel stresses are kept to a minimum offer the best durability. Cyclical fatigue testing of simple lap shear joints made with epoxy adhesives will often give failure values of ca 30% of the static breaking load (Figure 5).

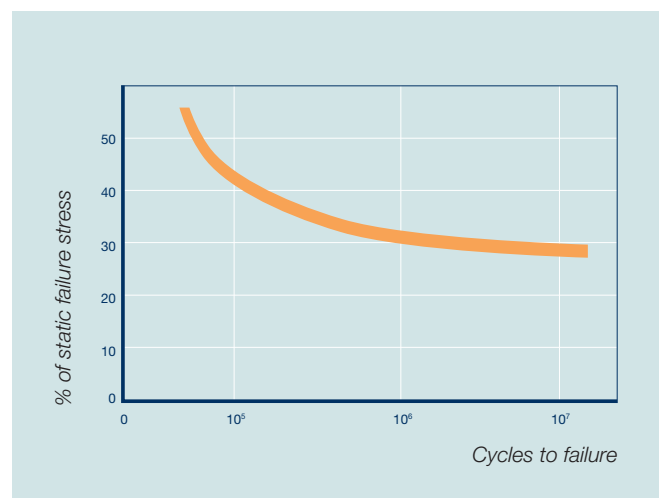
**FIG.4 BOND LINE THICKNESS
VS. SHEAR STRENGTH**



Adhesive strength at the interface is by its nature greater than the cohesive strength within the adhesive. The diagram shows that in this adhesive, the drop in strength occurs in the range 0.4 to 1.0 mm. In thicknesses greater than 1.0 mm, shear strength is approximately constant.

The exact shape of the curve depends on the characteristics of the adhesive. Toughened adhesives will maintain higher values in thicker bond lines, while more rigid adhesives will decline more quickly.

**FIG.5 FATIGUE STRENGTH (TENSILE)
OF LAP JOINTS**



Adhesives are often used in applications where they are subjected to dynamic as well as static stresses. Small, repeated loads can lead to fatigue cracking. Over many load cycles, these cracks may propagate and ultimately lead to joint failure.

Cyclical lap shear testing may be used to determine fatigue resistance of an adhesive joint. A load is applied repeatedly and the number of cycles to failure is recorded. The load can be varied to build a full picture of fatigue performance.

