# PREFACE

## INTRODUCTION

Since the middle of the 17th century, when the industrial revolution began, the process of manufacture has changed dramatically, in methods and materials. At the time, it was state-of-the-art to assemble boats and ships using traditional methods like wood jointing, nailing and screwing. Riveting and welding followed in later years, but today, we are aware of the limitations of these old methods compared to what is currently available. New lightweight materials as well as sandwich structures need smooth, stress concentration free assembly. Today, time, weight, cost, design freedom and reliability are all greatly enhanced by using chemical bonding, sealing and damping products.

### BONDING, SEALING AND DAMPING

Sealants and adhesives share a similar technology. Their functions overlap to a large extent, but as they also have a range of other benefits, the role of elastic bonding is not only to join, but also to waterproof, dampen sound, insulate and prevent galvanic corrosion; all needed to overcome the daily problems in the marine environment. Some products are specifically for bonding as they exhibit high mechanical strength (commonly known as rigid adhesives) and feature variable open time to accommodate everything from quick production rates, to the much slower large structural component assembly. Much of their usefulness in absorbing forces and shock stems from the toughness of the cured bond and this, in turn, is a major factor in the durability and reliability of the bond.

### FLEXIBLE BONDING AND SEALING

Flexible bonding and sealing is distinct from bonding with high modulus adhesives. They are applied in a bondline thickness of some millimetres. These products have the high elastic characteristics of both adhesives and sealants. While it does not have the high mechanical strength of rigid bonding adhesives, it has far greater flexibility, which helps to reduce fatigue in the bonded components.

### FLOORING AND ACOUSTIC DAMPING

Sub decks are not always smooth and level and besides being generally unattractive, they are responsible for the transmission of most of the noise in cabins and compartments.

Modern flooring has elements that improve the marine environment:

- The deck is levelled and smoothed
- The noise level transmitted through it is reduced
- The cosmetic finish improves the appearance
- Various systems can be used that amplify one or more of these.

Sika works closely with suppliers, universities, research institutions, certification societies but primarily with our customers, to maintain the most relevant level of expertise in bonding sealing and damping. We are continuously developing the product range as new methods, materials and designs emerge or are needed. All processes concerning application of our products are fully tested and choreographed to ensure 100% reliability.

This manual explains the processes and describes the procedures necessary to achieve the highest standards. It is therefore essential that the appropriate section is consulted and adhered to for every process undertaken.

From long experience in marine applications, it is highly recommended that Sika (Corporate or local Technical Service) is consulted at the outset of any new projects.

# EXPLANATION OF DIFFERENT FIXING METHODS

## SOME HISTORICAL FACTS

Traditional fixing methods are mechanical fixations. Adhesives have still the nimbus of a low seriousness due to less and / or negative experiences, Adhesive technologies are not accepted voluntary. The bonded result cannot visually be detected. The resulting prudence is also called Icarus effect. From this story from the greek mythology only the crash of Ikarus is known where Daidalos his succeeding father is less known. Nevertheless Daidalos, a blacksmith, is the "historical father" of the bonding technology as the wings he produced to escape from his prison have been feathers bonded with an adhesive (light weight construction).

Nowadays aircrafts like the Boeing 787 Dreamliner are made out of synthetic carbon fibres. Only the bonding technology can be used for joining such substrates. The bonding technology is state of the art in multiple areas including the naval industry.

Sealing on the other hand has been one of the oldest technologies in the shipbuilding. Caulking boats with cotton robs impregnated with bitumen is one of the used technologies. Nowadays modern products replace this demanding working procedure.

The differences between some mechanical fixations and the bonding technologies outline some advantages of each method.

Fig. 1 Ikarus and Daidalos. Painting from Carlo Saraceni 1580-1620

Fig. 2 Boing 787 Dreamliner

## PRINCIPAL DIFFERENCES OF THE FIXING METHODS

| **Production** | Riveting / srewing | Spot weld | Rigid bonding | Elastic bonding |
|---|---|---|---|---|
| Process speed | Fast | Fast | Medium to fast | Medium |
| Substrate preparation | Low | Low | Medium to important | Medium to important |
| Substrate deformation (heatprocess) | Low | High | Low | None |
| Tolerance gapping | Low | Low | Low | Very good |
| Calculation of the bondline | Yes | Yes | Possible | Possible |
| Industrial hygiene | Low | Low | Medium | Medium |
| Noise emission during manufactoring | High to low | Medium | Low | Low |
| Quality control | Easy | Easy | Needs QC | Needs QC |

| **Obtained characteristics** | Riveting / srewing | Spot weld | Rigid bonding | Elastic bonding |
|---|---|---|---|---|
| Joining different materials | Possible / limited | Not possible | Possible | Possible |
| Sealing | Separate operation | Separate operation | Yes | Very good |
| Acoustical improvements | No | No | Limited | Yes |
| Joining of thin substrates | Not recommended | No | Possible | Ideal method |
| Durability | Danger of corrosion | Danger of corrosion | Good | Good |

Adhesive bonding is a modern and highly effective joining technique with a number of innovative performance characteristics, which forms a welcome addition to the standard repertoire of rigid fastening technologies. Through the selective use of these adhesives and careful attention to the specific application techniques associated with them, engineers and designers are now able to design technically sophisticated products that can be manufactured economically.

The use of this bonding technology permits to use all kind of substrates permitting an optimised construction. Just to mention some advantages:

- Freedom of styling (use of GRP / plastics / metals to optimise material cost)
- Weight savings (thinner substrates / plastics)
- Sound reduction (especially with elastic adhesives)
- Corrosion resistance (bonding on anti-corrosive paints, no injury of the anti-corrosive layer)

The highest economic and technical benefit of the bonding technology is based on these multiple advantage which is achieved in a single operation.

The bonding technology is a new tool for engineers and designer to realise modern and innovative solutions in the Marine Industry.

# DIFFERENCE BETWEEN RIGID AND ELASTIC ADHESIVES

Elastic adhesives differ in their functionality to the rigid systems. Rigid (high modulus) adhesives are normally used in thin layers of about some hundred microns. In contrast elastic adhesives are used in a thickness of some millimeters. Therefore the expression of thick layer bonding has been created for such application types.

The function of these systems differs in their way to transmit forces. Rigid adhesives transmit forces directly without noticeable deformation. Elastic adhesives lower the forces by bond line deformation and uniform stress distribution over the whole bonding surface.

Both of these systems have their advantages as well as their limitation. The following article describes the principal characteristics, knowing that this classification is not complete as semi flexible products may be situated somewhere in between.

To show the difference, studies have been done at the University of Munich to demonstrate this difference. Tensile lap shear samples of PMMA (Polymethylmetacrylate, ex. Plexiglas) have been bonded and stressed. By using polarized light, lines of different colours (stress levels) could be visualized.

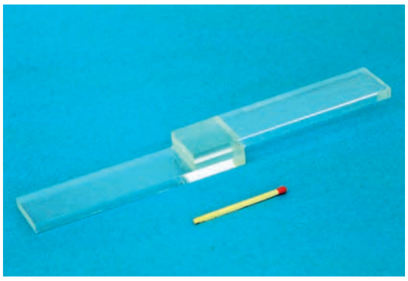


Fig. 3 Test sample. Lap shear test with PMMA substrate bonded with different adhesives. One sample has been screwed

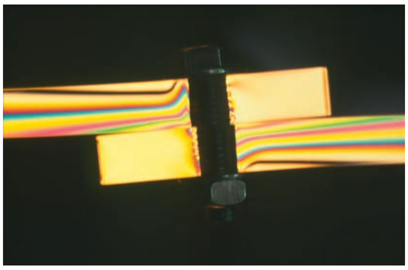


Fig. 4 Screwed sample. The force line indicate a direct transmission of the forces from one part of the sample through the screw to the other part of the sample

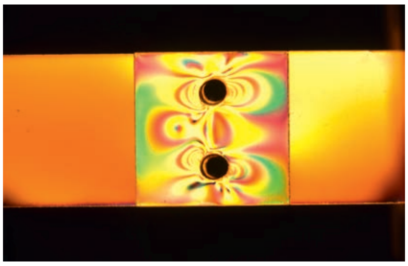


Fig. 5 Same sample plan view. Here stress concentration around the bolts is visible (stress peaks around the screw).

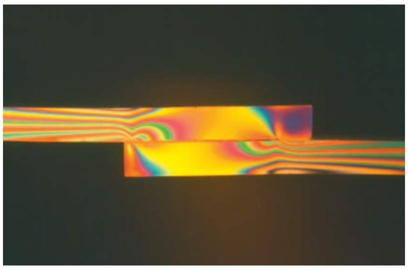


Fig. 6 Thin layer bonded sample with a rigid adhesive. The stress concentration is visible at both ends of the sample.

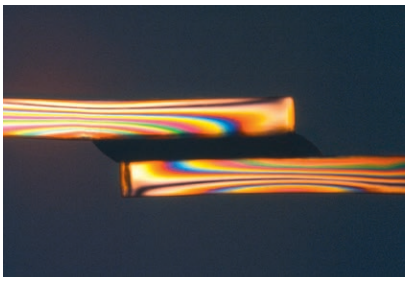


Fig. 7 Thick layer elastic bonded sample. The stress transmission is uniform over the hole bonding area (no stress peaks). The adhesive is not easily visible as it is not transparent.

The uniform stress distribution of the elastic adhesive permits to utilize the whole bonding surface for the force transmission.

Elastic thick layer bonding permits therefore to use thinner substrates, or just to bond directly on painted surfaces for better corrosion resistance, just to mention two of the multiple advantages by using this fixation method.

One of the most contradictory discussion concerns the definition of "Structural bonding" Many authors use this expression in connection with a high strength or modulus of an adhesive. A more practice related definition uses this expression for bonding assemblies which are essential for the functioning to the assembled part. This seams for us a better definition as it will also take in consideration the durability aspects.

Elastic adhesive bonding is a joining technique with a number of innovative performance characteristics, which forms a welcome addition to the standard repertoire of rigid fastening technologies. Through the selective use of these adhesives and attention to the specific application techniques associated with them, engineers and designers are now able to design technically sophisticated products that can be manufactured economically.

Differences between elastic thick layer bonding and rigid thin layer bonding

| General Characteristics | Rigid (high modulus) adhesives | Elastic adhesives |
|---|---|---|
| **Bondline dimension** | Thin adhesive layer, small overlapping | Thick layer of at least 2 mm. Higher force transmission may be achieved by increasing the overlap (bonding area) |
| **Temperatur dependency** | Glass transition temperature has to be observed. If the bonded object is used over this temperature, mechanical resistance drops and may lead to failures | Elastic adhesives have a glass transition temperature at about minus 50 °C. The dependency of the mechanical strength in the normal application range is minim. However the temperature resistance is limited to approx. 90 °C for elastic Polyurethanes and approx. 120 °C for Silicones |
| **Force transmission** | Forces resulted by mechanical stress or differences in thermal expansion coefficient have to be transmitted and result directly from the chosen parameters. In some cases parts may deform during temperature change due to a "Bimetal effect" | Forces applied on an elastic bond line provoke a deformation of the bondline, thus lowering the stress on the substrates |
| **Shock resistance** | Normally the shock resistance of a rigid bond line is not very high, especially in the range of the Glass Transition Temperature. However some special formulations have an excellent choc resistance | The shock resistance of elastic bond lines is excellent. The mechanical resistance increases with the applied speed. Under choc resistance, the mechanical resistance is high |
| **Adhesion on painted substrates** | The paint adhesion on a substrate is about 7N / mm². High modulus adhesive may lead to stress peaks and cause a break between paint and substrate | The modulus of elastic adhesives is lower than the one of the paint. Therefore application on painted substrate is possible. Thereby the corrosion resistance is not impaired |
| **High strength bonding** | Good solution. Rigid adhesives may be combined with mechanical fixation methods | Only possible with larger bonding area |

Differences elastic thick layer bonding / rigid thin layer bonding

| | Rigid thin layer bonding | Elastic thick layer bonding |
|---|---|---|
| **Bonding of different metals** | Perfect in case of metals with low differences in thermal behavior, good for applications where bondline dimension (thickness /surface) is restricted | Good compensation of thermal movements, good protection against galvanic corrosion, good tolerance gapping |
| **Bonding of metals with plastic** | Usable for bonding smaller parts, good for applications where bondline dimension (thickness /surface) is restricted. | Ideal for bonding of GRP with important tolerances, good for shock resistence and acoustical damping |
| **Bonding plastic to plastic** | Normally good technique with low surface preparation, ideal for sandwich construction with low modulus core materials | Less interresting solution. ESC has to be taken in consideration. Ideal for bonding duromers (glass reinforced plastics) with important tolerances |

Fig. 8 Bonded windows on cruise vessel

Fig. 9 GRP parts and windows bonded on high speed ferry

Fig. 10 Luxury megayacht glazing

# BONDING CONSTRUCTION DESIGN

## PRINCIPALS

Joining of two materials means to connect them to a unit which is capable to transmit forces resulting from dynamic, static or other stress during the use of the subject. Normal joint technologies are mechanical joining methods which are known since long times.

Glues however have been reported to be used about 3000 years before JC. Asphalt and natural resins have been used to tighten up ships and clay has been used to build houses.

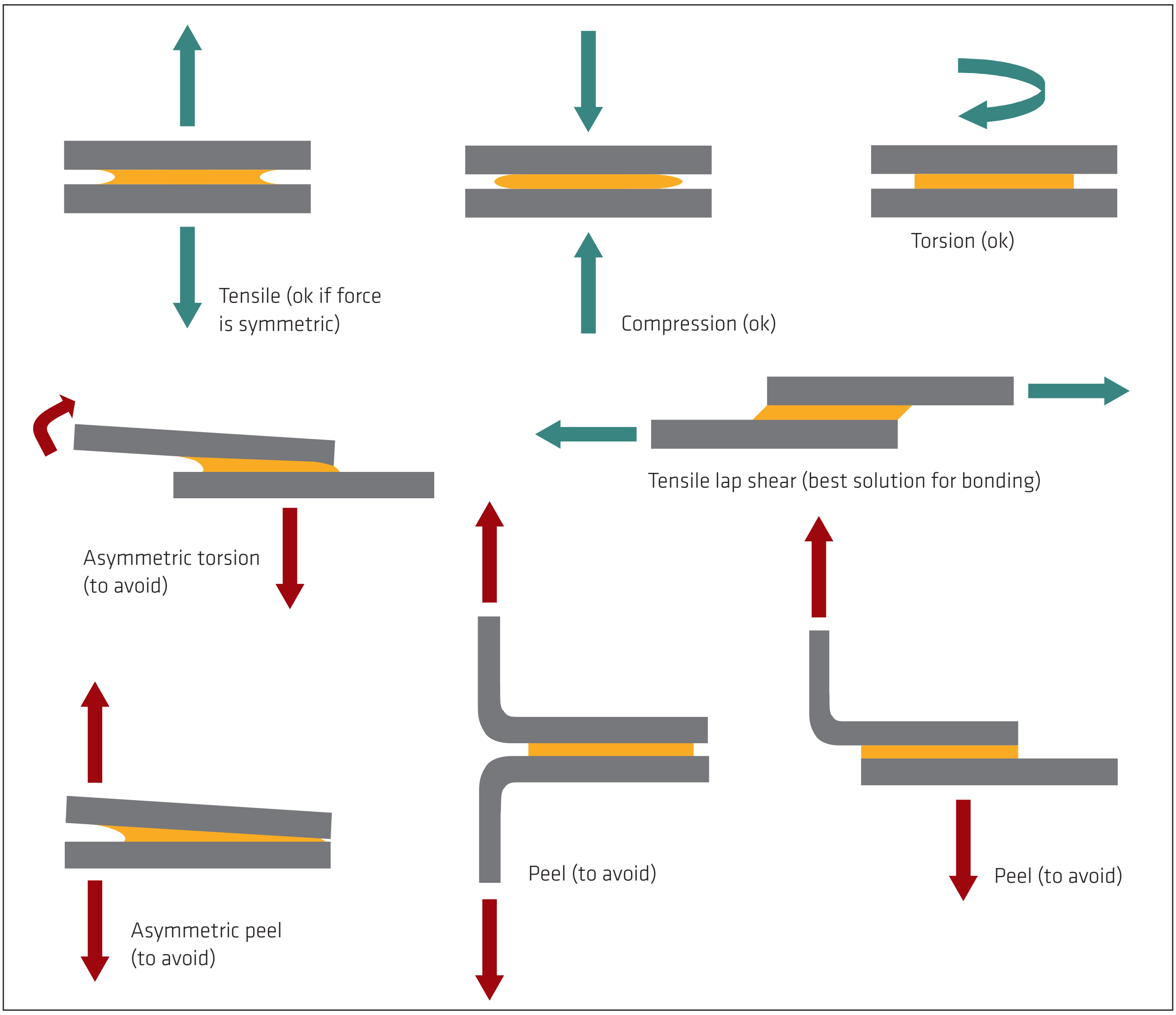
However structural bonding started in the 30ties of this century. One of them is unsaturated polyester which are still in use today. The development of epoxy resins opened up a vast area of bonding applications

Elastic adhesives or sealants started in 1964 in the USA using an elastic adhesive for windscreen bonding. This technology is state of the art in all type of windscreen bonding in all market fields.

In the 80ties elastic bonding was used in busses followed by trains and trams in 1992. Structural bonding in Marine started at the beginning of the 90ties. In the meantime, elastic bonding technology was established in other sectors of the manufacturing industry, such as for containers, refrigerators and washing machines, facades, floors, windows and many applications.

The following chapter will help to understand the bonding technology and how to design an adhesive joining case.

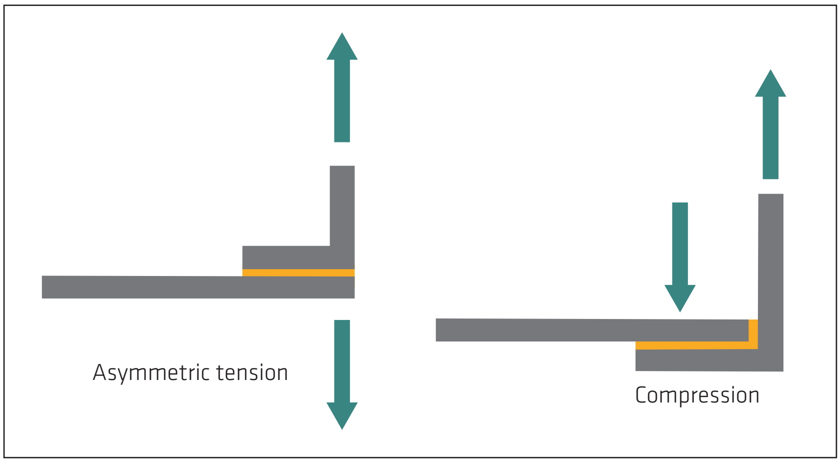
Generally forces which in praxis occur are the following:




The strength of a joint is basically determined by the area of the bond, the inherent strength of the adhesive or the substrate and the stress distribution within the joint. A poorly designed joint can lead to high stress concentrations in the joint itself and / or in the substrates connected, which in turn can lead to premature failure. Good joint design, which takes into account the practicalities of application as well as the geometry of the joint, is essential for a long service life in a demanding Marine environment.

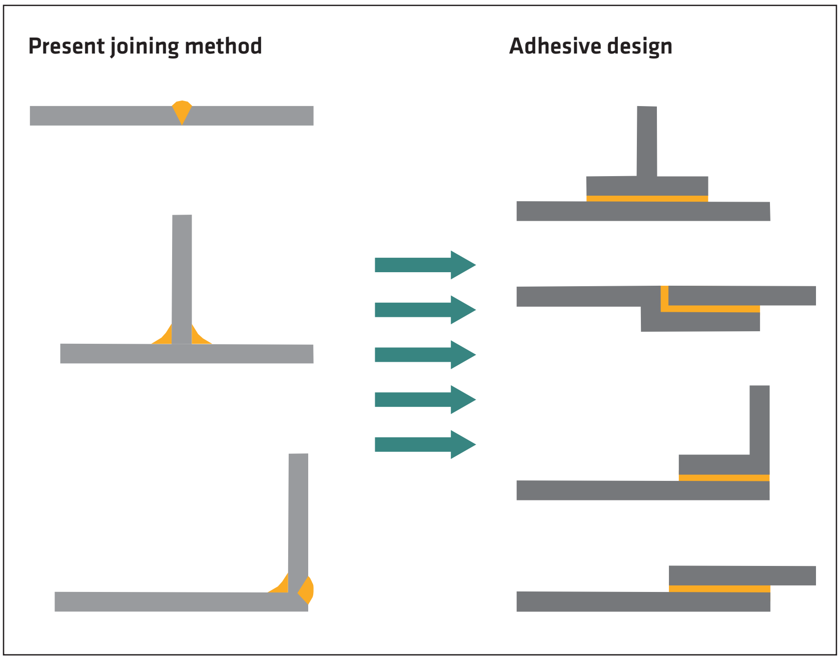
Peel forces are the most difficult to counter and must be avoided by changing the design of the joint.

Here an example: by changing the construction the risk of peel forces could be minimised



Traditional mechanical joint design has to cope with the inherent strength of an adhesive.

The following examples show some of an adhesive alternative to welding.




## CALCULATION OF THE BONDING AREA

The dimensioning of a bond line depends mainly of the forces to be transmitted, and the mechanical resistance of the substrates and adhesives.

One of the most common errors is to calculate the bond line on the bases of the data's in the Product Datasheets. These data's are based on static tests. In praxis a lot of factors have to be considered. Temperature influence, type and frequency of the stress, aging etc. are factors on which the bond line is subjected.

Detailed calculation procedures can be ordered from your local Sika Industry branch or in appropriated literature (Example: "Elastic bonding, the principles of adhesive technology and a guide to its cost effective use in Industry" Verlag Moderne Industrie)

In praxis a rule of thumb can be used as a first approximation. The lap shear strength has to be reduced to 3% of the Product Datasheet value.

**Example:**
Tensile lap shear force needed is 200 kg equal to 2000 Newton.
The Product Datasheet value of a particular adhesive is 2 N / mm$^2$

The calculation value for the applicable tensile lap shear strength is only 3 % of this Product Datasheet value: 2 N / mm$^2$ x 0.03 = 0.06 N / mm$^2$

The required bond surface is therefore: 2000 N / 0.06 N / mm$^2$ = 33'000 mm$^2$ = 330 cm$^2$

Considering a bond line width of 15 mm, the required length of the joint is:
330 cm$^2$ / 1.5 cm = 220 cm or 2.2 m

**Note:**
For exact calculation with the FEM-Methods we recommend to consult the Technical Service Sika Industry


# COST ADVANTAGE OF ELASTIC BONDING

## COST COMPENSATION

Adhesives compared to riveting or spot welding result in an advantage of the mechanical fixations.

However, a cost comparison has to be done taking all factors of the realisation in consideration. As an example spot welding may increase the expenditure of the filling of a surface prior to painting, thus increasing the overall costs.

The following list gives thought-provoking impulse to realise a correct cost comparison.

| Properties | Benefits (manufacturing) |
|---|---|
| Bond / seal simultaneously | Reduction of process steps / No additional sealant costs |
| Compensates for tolerances | Less work to prepare substrate |
| Application at room temperature (no thermal deformation) | Less spatula work / Low energy costs |
| Curing at room temperature | Lower energy costs |
| Bonding different substrates | Optimised choice of materials / lightweight construction / No bimetallic plates necessary |
| No sink marks on thin sheets | Thinner sheets / savings |
| Less tools | Lower investment costs |

| Properties | Benefits (enduser) |
|---|---|
| Not corrosion-prone fixing | Longer life expectancy |
| Reduced maintenance | Lower costs |
| Weight-reduction | Lower fuel consumption |
| No built-in tensions | Increased longevity |
| Design with low cw (drag coeff.) | Lower fuel consumption |
| Application and curing at room temperature | Simple repair |
| Even surfaces | Easy to clean |
| Noise reduction | Increased comfort |
| Freedom of design | Increased brand awareness |