ADHESIVES IN TRANSPORT

6th April 2006

Society of Chemical Industry
15 Belgrave Square London

www.uksaa.org/

Programme

10.00	Registration and Coffee.
10.30	Effects of chromic acid anodising of aluminium on the adhesion and durability of bonded joints Xiaorong Zhou, UMIST.
11.05	From crash integrity to bonding rear view mirrors: the future of automotive adhesives John Hill, Ford Motor Company.
11.40	Removal of silicone contamination on aftermarket windscreens in automotive applications. Steve Tellwright, Autoglass.
12.15	The Radshape experience in manufacture/bonding of aluminium structures Keith Chadwick and John Harper, Radshape Sheet Metal Ltd.
12.50	Lunch
14.30	Bonding in Commercial Aircraft Structures Ben Hawtin, Airbus UK.
15.05	Fuel tank sealants in aerospace applications. Steve Shaw, DSTL and Phil Duke, QinetiQ Ltd.
15.40	Adhesive bonding of friction materials John Bishopp, Star Adhesion Limited.
16.15	Discussion, Close and Coffee.

This one-day symposium is one of an on going series organised by the Society for Adhesion and Adhesives.

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The next symposium is due to be held at the SCI on Thursday 7th December 2006, entitled "Avoiding Failure with Adhesives and Sealants".

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Effects of Chromic Acid Anodizing of Aluminium on the Adhesion and Durability of Bonded Joints

X. Zhou

Corrosion and Protection Centre, School of Materials, The University of Manchester

Abstract: Anodic film growth on aluminium in chromic acid under different conditions has been examined, with various parameters, including overall film thickness, barrier layer thickness, pore and cell diameters determined precisely. Further, the selected anodizing conditions allow formation of film with either normally or inversely funnelled pore morphologies. An anodic film with funnelled-type pores, developed under the optimized anodizing process, is well penetrated by adhesive. However, the film with inversely-funnelled type pores is not significantly penetrated by adhesive. The former shows improved initial bond strength and durability. It is also found that transition regions evidently exist between the anodic film and the bulk adhesive. Such regions exhibit a variation in electron transparency compared with that found within the bulk adhesive. After immersion in water, bonded samples supporting anodic films with normally funnelled type pores reveal a locus of failure within the adhesive i.e. cohesive mode. However, for the samples supporting anodic films with inversely funnelled type pores, the locus of failure passes closely to the adhesive/anodic film interface. Aluminium species, resulting from the outward transport of the hydrating alumina film material during immersion in water, were observed within the polymer.

From Crash Integrity to Bonding Rear-View Mirrors: The Future of Automotive Adhesives

Dr. John Hill, Adhesives Technical Specialist

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Abstract

Adhesives are used extensively in the manufacture of current automotive vehicles. From cosmetic trim parts through to safety critical items such as the front windscreen, a variety of adhesives are used to bond them. There is a vast choice of adhesives available, and the selection for any particular task is dependent upon a multitude of criteria ranging from material properties through to ease of processing. Continuing efforts to reduce the specific weight of a vehicle have resulted in the employment of alternative materials to sheet steel. Aluminum, thermosetting composites, thermoplastics and magnesium parts are all becoming more widespread. The introduction of such mixed material combinations necessitates the use of adhesives to attach them to adjacent parts.

The most demanding applications for an adhesive are in the body structure where they are subjected to high impulse loads and a corrosive environment. In recent years, most automotive manufacturers have started to use adhesives in the body structure to improve stiffness and fatigue durability. The next major frontier for adhesives is in the management of energy during a crash event. Numerous studies on simple box beam assemblies have highlighted the need for highly toughened adhesives and have shown the potential benefit they can offer in terms of energy dissipation.

This presentation will initially provide a brief overview of how adhesives are used on today's automotive vehicles and where they are likely to be used in the near-term. The presentation will then move into the subject of adhesives for crash energy management with an overview of some of the aspects that need to be considered when using adhesives in such applications. The presentation will conclude by summarizing where are the areas for growth and areas that require further work with regards to using adhesives for energy management.

Surface Cleaning of a Laminated Glass Windscreen to Improve Adhesion

Steve Tellwright

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Some laminated glass windscreens used in the automotive aftermarket windscreen replacement industry have been identified as having a thin film of silicone like residue on the ceramic ink band on the internal face of the windscreen, which leads to a significant amount of quality issues during windscreen fitment. Secondary Ion Mass Spectrometry, X-Ray Photoelectron Spectroscopy and Atomic Force Microscopy have been used to confirm the source and the type of contamination present. The source has been confirmed as a de-airing hose that is used during the windscreen manufacturing process.

The hose deposits a non-homogenous silicone line, four to five millimeters wide, on the ceramic ink surface around the circumference of the windscreen and is not removed by the windscreen producer at the end of the manufacturing process. Contact angle measurements highlight that the residue causes the surface of the ceramic ink to have a very low surface free energy and adhesion tests have shown that the residue forms a weak boundary layer on the ceramic ink which does cause interfacial bond detachment. Complete detachment of the windscreen has never been experienced due to the large bond line width but there have been unacceptable levels of small areas of detachment leading to water ingress.

The windscreen replacement industry currently uses chemical cleaning, supplied by the adhesive manufacturer's, to clean the windscreen before bonding and the effectiveness of this on the silicone residue was studied. The contact angle and adhesion tests results show that chemical cleaning is an unreliable method of removing the silicone residue from the windscreen as low surface energies and areas of interfacial failure continued to be experienced. Flame cleaning was proposed as a more reliable cleaning method if the duration of the treatment could be short enough to prevent damage to the ceramic ink surface and more importantly the PVB interlayer. The results show that flame cleaning the ceramic ink surface produces a high

energy surface resulting in adhesive bonds that have sufficient strength for windscreen installation. The adhesion test results also show that there were no instances of adhesion failure between the primer and the ceramic ink surface of the glass and only cohesive failure within adhesive. However, it is recognized that this process is only suitable for use at the end of the manufacturing stage and is not appropriate for use in the field when a windscreen is about to be fitted.

More recently, a second method of removal, abrasion using a specific grade of Scotchbrite pad, has been identified as a possible solution. This method is much more suitable for the installation companies to undertake during the windscreen fitment process as it is quick, simple and cheap to use. The process involves rubbing the pad over the silicon contamination two or three times around the whole circumference of the windscreen. The results indicate that abrasion is not as reliable as the flame removal method but it does give about an 80% success rate.

SAA Spring Seminar – 'Adhesives in Transport' – 6th April 2006

Presented by John Harper – Product Development Engineer – Bonding

Introduction

John Harper is a time Served Sheet metalworker with a background in Vehicle repair. Employed by Radshape since 1995 and until 1999 had no knowledge of Bonded Chassis. John was involved at the onset of the Morgan Aero 8 Chassis and has developed his knowledge extensively over the last 7 years. He has overseen the introduction of the Aero 8 build and the Gibbs Aquada Amphibious vehicle chassis from concept stage into production and has been responsible for the development and training of the team to ensure continuity of knowledge. His lectures on 'The Radshape Experience' are renowned for being humorous with a down to earth approach.

Background

Based in Aston in Birmingham, Radshape was formed in 1967 by 3 Sheet Metalworkers who were made redundant. It is a privately owned company by 3 Shareholders. Formerly known as Radiator Shapings due to the first work was forming radiators into bay windows of houses. The company has developed over nearly 40 years by being people focussed in niche markets. The strength of the company is in utilising the knowledge of the entire workforce. With a workforce of 55 and a turnover of £3.5m the company can boast a Customer base of Bentley, Morgan, LDV, Prodrive and BAE in its portfolio.

Radshape has seen significant changes in its 40 years no more so than in the last 9. The company was based in Kings Heath in Birmingham for 30 of its 40 years and saw an opportunity with Morgan Motor Cars to develop the business and move to bigger and better facility, hence the move to its present home in Aston, Birmingham. It also saw the opportunity to develop the culture of 'Continuous Improvement' within the Company.

The Facility

In 1999, with the development of Morgan as a key Customer Radshape embarked on 'The Radshape Experience' combining the knowledge of the workforce, a 28,000 sq feet facility and a new product opportunity, the driver behind all of this was 'Continuous Improvement'.

Training the Team in Continuous Improvement Techniques was vital to take the business forward, before we could ever hope to achieve the 'Experience'

Over a 2 year period the facility underwent a complete transformation and no area of the business was untouched it was titled 'The Road to a Brighter Future'.

Bonded Structures – The Beginning

Radshape already manufactured many parts for Morgan but in 1998/9 with the concept of Aero 8, Morgan approached the company to manufacture a Bonded Chassis. Radshape had already recognised the opportunity and with Morgan started a dream which ultimately came to reality.

Radshape's knowledge of Bonded Structures was minimal however we saw this as an opportunity to invest in our futures. A dedicated Team was formed spearheaded by John Harper; problems were seen as challenges, we were committed, however we need advice and assistance.

We approached many Technical Partners who were specialist in their field, our knowledge bank grew; soon we were making a prototype.

Bonded Structures – 1st Morgan Prototype & Production

Made from Alcan Material PT coated, manufactured in sheet material supplied from Germany our first prototypes were built in an uncontrolled area on 2 dustbins. We sought Morgan's assistance to get the first chassis cured and then as more prototypes were manufactured we assessed our facility.

We invested in our own Oven and a Zwick Tensile Test Machine – we had complete control of the process. Our processes became robust and consistent , traceability of chassis was of paramount importance , build instructions were compiled , test coupons lap and shear were conducted and all findings held in a History Book – extensive training was given to all the Team. Our build jigs and Cell was designed and manufactured by our own employees – we took complete ownership.

Invitation to the Geneva Motor Show was the icing on the cake

Bonded Structures – Chapter 2

Radshape was approached to be involved with another project by Gibbs Technologies. It was highly confidential and Radshape was initially contracted to do 7 chassis – it was the Gibb's amphibious vehicle – the Aquada.

We were becoming a Company that people recognised for Bonded Chassis; we could demonstrate that we had the controls and disciplines to meet our Customer requirements

Different to the Morgan chassis, the Aquada was predominantly extrusion based whereas the Morgan was sheet based, anodised Pre Treatment, the adhesive was the same but required different disciplines in handling.

Fixtures were designed and manufactured, knowledge of Pre Treatment was attained, extrusion supply identified, machining knowledge was gained, we trained the Team in different aspects.7 prototypes became 57.

It brought greater challenges to the Company which were overcome, it was progress for Radshape

The Aquada was launched on Wednesday 3 September 2003 on the Thames

Richard Branson broke the record for the fastest channel crossing in an amphibious vehicle

Bonded Cell Visitors

The Duke of Kent visited in February 2002 during a tour to view the Brightware Radshape was manufacturing for the Queen's Bentley a gift given by Bentley for the Golden Jubilee celebrations

In June 2004 we held the West Midlands Entrepreneur Seminar attended by Gordon Brown, Richard Branson, Stelios (Easy Jet) and John Snow – US Secretary of State.

The Future

We need to keep ahead of our competitors, quality, cost and delivery is a given, we need to continually place our head above the parapet and offer our Customers/prospective Customers more than our competitors offer

We are proud our chassis sits under the bonnets of Morgan Aero 8 and the Aquada.

We are proud of what we have achieved but that is history, we have set our foundations and we wish to continue to develop our expertise in bonded structures and ultimately expand our Customer base in various sectors of Transport.

Keith Chadwick
Managing Director
Radshape Sheetmetal Limited
April 2006

Society for Adhesion and Adhesives – Bonding in Transport
6th April, 2006.

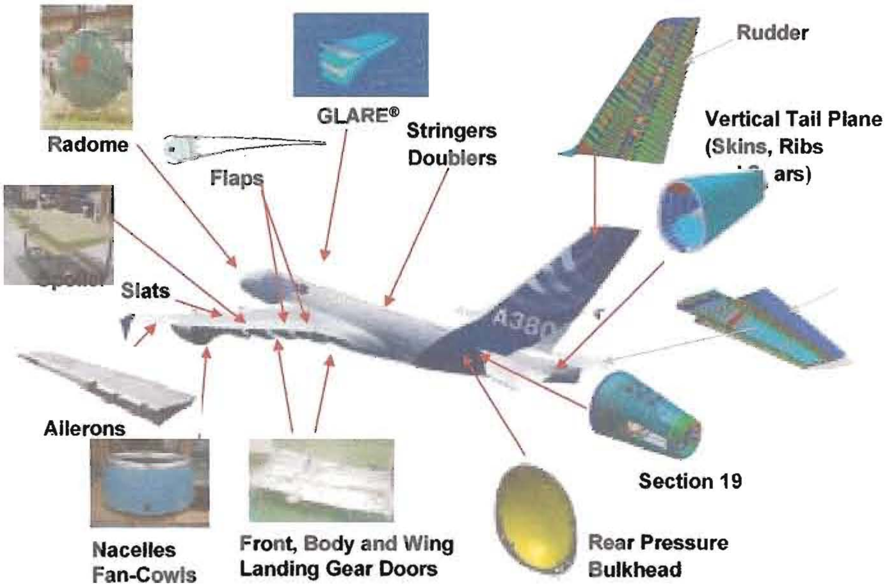
Bonding in Commercial Aircraft Structures

Benjamin C. Hawtin, Airbus

The commercial aircraft industry has made use of adhesive bonding for many years. Composite honeycomb structures have been used since the very first Airbus Aircraft, the A300, and the amount of composite structure as well as bonded metallic structure has increased steadily over the past 37 years.

The latest Airbus aircraft, the A380 makes extensive use of structural bonding for numerous components, as shown in figure 1, below:

Figure 1: Structural adhesive bonding applications in A380



Adhesive bonding offers many advantages to aircraft structures, particularly:

Low weight assembly process:
- no notch factors
- joining of shells with low thickness
- no fasteners needed (or reduced fastener count)

High fatigue resistance:
- efficiently distributed load-transfer
- exceptional design feature: crack stopping function

High grade of geometric complexity acceptable
High tolerance of bond-line thickness acceptable
Assembly without or with small amount of sealant
Low corrosion due to flat un-notched surfaces versatility
- metal/metal, composite/composite, metal/composite bonding
- multifunctionality (one adhesive for bonding & shimming & sealing)

Smooth surface on the outside of shell structure

Environmentally compliant materials and processes for the adhesive bonding of both composite and metallic structure have been developed and used extensively within the industry. The key to achieving good quality bonded structure lies in the surface preparation prior to bonding.

For composite structures a number of surface preparation methods are used within the industry. These methods include application of specific peel-plies, manual abrasion, grit blasting and the use of laser for surface cleaning. Research into semi-automated processes including plasma treatment and corona discharge looks promising for future applications, particularly for inert thermoplastic materials such as PEEK, PPS and PEKK.

For many years Chromic Acid Anodising (CAA) has been the standard pre-treatment for aluminium alloys used within the industry. This process produces a good surface finish for both corrosion protection and adhesive bonding applications however alternative processes are being developed as the industry strives to move away from chromated products.

In order to make full use of the advantages that adhesive bonding can offer to Aircraft structures, robust bonded repair methods are required. The key to achieving this is the development of surface preparation techniques that can be applied in the field combined with viable quality control processes including NDT of bondline.

As aircraft design evolves to make more use of advanced materials and with the constant strive to reduce the cost and weight of aircraft structures, adhesive bonding becoming a more and more attractive alternative to mechanical fastened structures.

The industry is carrying out numerous research activities aiming to develop and introduce new adhesive bonding processes and applications with the objective to introduce viable 'in-field' bonded repair techniques in the future. To achieve this, surface tolerant adhesives, robust surface preparation methods and improved quality control and inspection techniques must be developed. With cost and weight being the primary drivers for the industry, adhesive bonding offers both metallic and composite structures with a step-change in performance at reduced cost.

Fuel tank sealants in aerospace applications

J Day[1], P Doran[2], P W Duke[3], S J Shaw[4]

[1]retired [2]deceased [3]QinetiQ, Farnborough, Hants [4]Dstl, Porton Down, Salisbury, Wilts

For reasons primarily associated with both weight considerations and fuel capacity, modern aircraft are usually designed to carry fuel in integral tanks rather than bags, with elastomeric sealants generally employed to seal mating surfaces, mechanical joints etc. This is in complete contrast to motor vehicles, where fuel is carried in a self-contained distinct structure separate to the main structure of the vehicle. Unfortunately, experience with many aircraft types has shown that the integral tank approach to fuel carriage can result in substantial fuel leakage problems.

Although several types of elastomer composition have been considered and used for applications requiring resistance to hydrocarbon based fuels, those based on polysulphides are currently employed in most fuel tank sealing applications. More recent sealant systems, based on for example polythioethers have been developed. Although these sealant types have a sound reputation for resisting aviation fuels, the continuing fuel leakage problem has necessitated a detailed consideration of this troublesome issue.

In considering the question of fuel leakage, it is important to recognise that the environment in which the sealant is required to operate is an extremely harsh one. For example, in addition to the obvious presence of aviation fuel, other potential degradants will include water and icing inhibitors contained within the fuel, the effects of which will be superimposed on temperature extremes and dynamic fatigue loading. Under such extreme conditions, failures associated with either degradation of the bulk sealant and/or the sealant/substrate interface have been observed in practice.

In an attempt to generate a greater understanding of the effects of these principal fuel tank fluids, research carried out in DERA and, more recently, QinetiQ has been carried out to assess the extent to which each of these fluids is absorbed by typical fuel tank sealant materials, together with their effects on bulk sealant properties. Four types of sealant were investigated, two being polysulphide formulations, the third a modified polysulphide and the fourth a polythioether.

Results from these studies have revealed the varying extent to which fuel, water and FSII are absorbed by the sealant systems studied. As would perhaps be expected, only limited amounts of aviation fuel are absorbed by the four sealant types investigated, with the polythioether showing the highest levels of uptake. Much higher absorption levels occur with both water and FSII. With the latter, although absorption at levels in the region of 60% are observed, it is important to recognise that sealant materials in aircraft fuel tanks will not experience neat FSII. In reality the icing inhibitor will combine with water to produce, at maximum, a 60/40 FSII/water mixture. Work has shown that such a combination exhibits relatively low fluid uptake values.

Further work has been carried out to assess the extent to which fluid uptake has a degrading effect on bulk sealant properties. Fluids utilised were fuel, water and a 60/40 FSII/water mixture. As would perhaps be expected, the fluid based on a 60/40 FSII/water mixture demonstrated the most damaging effects.

Bonding of Friction Materials

John Bishopp: Star Adhesion Limited

For the SAA Seminar: Adhesives in Transport
Thursday 6th April 2006

Introduction

Although it is an 'old science, the bonding of friction materials is still an important undertaking in the production of key components for the transport industry: particularly in automotive applications. The purpose of this paper, therefore, is to outline why and where adhesives for the bonding of friction-materials are used, the chemistries of the current ranges of adhesives, how they are used and to show how they are evaluated in the laboratory and in the bonding shop.

Friction Materials

Fiction materials are composite materials possessing high coefficients of friction. They are, now, most usually produced by dough-moulding techniques and comprise: fibre- or fibre-and-metal-filled polymeric materials. This polymeric material generally being a phenolic novolac or a nitrile rubber-phenolic novolac binder

Friction materials are attached to metallic backing 'plates' using rivets or an adhesive bonding process. In use, they are mechanically or hydraulically brought into contact with other moving parts. Contact induces frictional forces at the interface which can be used to impart or translate drive or effect braking. In brake linings they slow or stop a vehicle by converting kinetic energy to heat. In transmissions they transfer kinetic energy from a rotating crankshaft to the vehicle's wheels

Why Bond?

A bonded component is more efficient than its riveted equivalent, and has a longer life potential, because:

- Costs have been calculated as up to 40% lower when bonding instead of riveting
- The area over which frictional forces can act is increased up to 12% by eliminating the rivet holes in the lining material
- The lining material can be selected purely for its frictional properties without any need to compromise to cope with the bearing loads exerted by the rivets
- Friction materials are now often supplied in flexible rolls. Sufficient bearing strength for riveting applications requires a wire mesh backing to be used. Industry now prefers an adhesive-coated, unreinforced material
- At least 90% of the lining thickness can be used without risk of scoring caused by exposed rivets
- Rivet holes in the lining material collect abrasive dust that can cause metal scoring even if rivets are not exposed; there is obviously no need for these holes when the lining is bonded

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e-mail: john.bishopp@btinternet.com

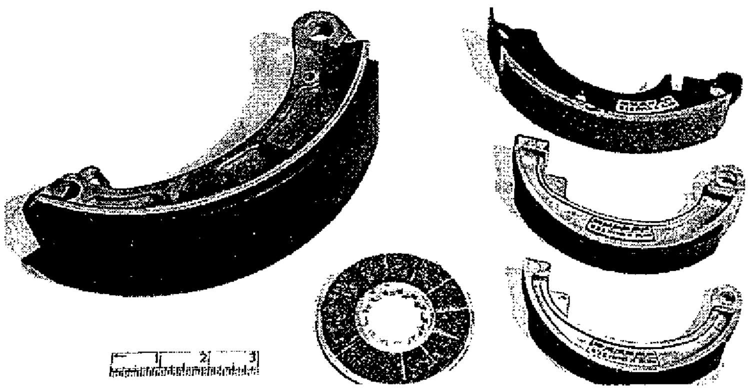
- Improved service temperature requirements for heavy truck brakes has driven the move to adhesive bonding from riveting

- In the manufacture of disc brakes and electro-magnetic braking systems, injection-moulding techniques are now often used to apply the friction material, directly to the backing plate; to enhance the performance, this steel plate has been coated with a structural adhesive; friction material and adhesive are then co-cured

Bonded Friction Materials: Applications

In this paper an examination will be made of the use of synthetic adhesives to produce components which can range from washing machine drive cones and moped and bicycle brake shoes, through general automobile clutches, friction drives and brakes [both drum and disc], to the braking systems for funicular railways and colliery lift gears.

The technology dates back to 1940, when Aero Research Limited launched its first resole phenolic structural adhesive, which was used to bond clutch plates in the Cromwell and Churchill tanks. Then, in 1948, Redux 64 [an acetal modified resole phenolic] was launched as a general purpose friction-bonding adhesive for use in the manufacture of drum brakes, disk brakes, clutches and drive-plates.



Motor Cycle clutch and a selection of Redux-bonded car brake shoes [Sodiema, Paris]

The range of applications has not altered to the present day; if anything the scope of the market has increased to include braking devices for industrial machinery and machine tools with rotating components. This increase is also partly driven by the fact that the old, stronger, asbestos-containing friction materials have been replaced by systems containing more 'user-friendly' fibres, which proved to give much weaker materials!

The applications can be split into those components which exhibit a zero radius of curvature, for example: disc brakes [automotive and rail transport], clutches and drive units; and those where a significant radius of curvature is present, for example: drum brakes.

Adhesive Chemistries

All adhesives for bonding friction materials are solution-based systems; the initial adhesives were either phenolic resoles in solution or they were solutions of acetal-modified [polyvinyl formal or polyvinyl butyral] phenolic resoles. This is still true today, particularly where components exhibiting a zero radius of curvature are to be bonded or where low viscosity/solids content adhesives are to be used: particularly as a primer both for **both** adherends; to protect the surface pretreatment of the steel prior to bonding and to as a dust suppressant by sealing the lining surfaces.

In the mid-1960s the industry led a demand for nitrile-phenolic adhesives [solutions of phenolic novolac resins modified with acrylonitrile-butadiene elastomers], as it saw this class of adhesives as offering a more flexible approach: ease of rheology variation; a greater variety of cure cycle options; better performance when tackling simple, single-curvature bonding applications.

Although several variants on the basic nitrile phenolic adhesive formulation have been evaluated and, indeed are, on the market: unfilled; black-filled, silica-filled; with and without vulcanising agents, the industry is still served today with acetal-phenolic and nitrile-phenolic adhesives.

Component Bonding

Surface Preparation: As for all structural adhesive bonding, the correct surface preparation is vital. As most of the metallic substrates encountered are mild steel, surface abrasion is still the favoured method using automated grit-blasting equipment or wheel abraders; degreasing and cleaning away collected dust take place both before and after pretreatment. Aluminium substrates, for example: in bicycle brakes, receive the same pretreatment – not chemical; the 'shot' used is fused silica or alumina rather than the chilled iron that is used on mild steel.

The other surface pretreatment favoured is to carry out a surface conversion in baths containing specially formulated mixtures of phosphoric acid, phosphate salts and oxidisers and accelerators. This is the so-called 'phosphating' process which not only etches the mild steel surface but also lays down a complex coating of iron oxides and phosphates which is claimed to give a high degree of corrosion resistance to the bonded component. Although the chemical make-up of the bath has to be constantly monitored and adjusted, this process, by many, is taken as being a more economical and also continuous.

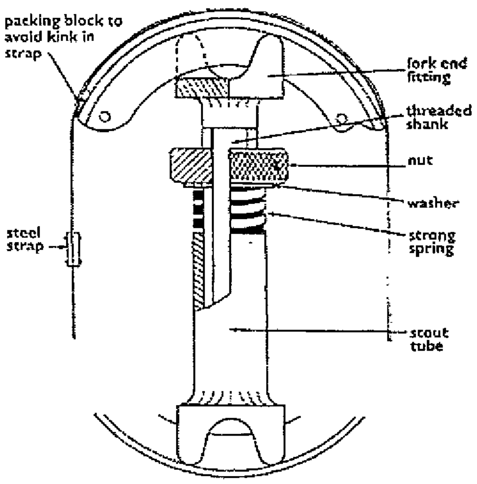
Irrespective of the method used, to obtain maximum corrosion resistance, the final step is often to dip-coat the metal substrate in a dilute solution of the adhesive to be used.

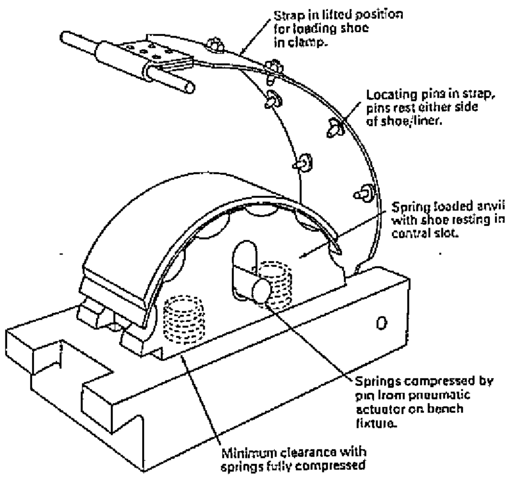
Adhesive Application: Apart from, for example, integrally-moulded disc brakes, the adhesive is invariably applied to the friction material. Its method of application will depend as much on the rheology of the adhesive as on any other considerations. Typically, roller coating, spray coating, silk screen printing and extruder methods are used.

Although spray- and roller-coating can be accomplished using adhesive systems with a fairly wide range of solution viscosities, silk screen printing requires a highly controlled viscosity and adhesives are generally formulated specifically for this application method; spray-coating is the quickest method to apply adhesive to the friction material, but it is somewhat wasteful and a little 'messy'.

This is also true for extruder coating where relatively low viscosity systems of high thixotropic, have been developed. This is considered the easiest method of application. A number of different applied patterns can be achieved; the machine is adaptable for a wide variety of lining sizes; it is not wasteful, being able to apply a controlled amount of adhesive: very important for the achievement of consistent results.

Adhesive Bonding: For components having significant radii of curvature, ring and expander and anvil bonding are the main methods of clamping the assembled component for bonding; pressures in excess of 3.5 MPa are required. Conventional static or conveyor ovens are used to cure the components in the ring and expander jig; the cure temperature is set at 150° to 160°C and the transport time is in the region of 30 to 60 minutes. The anvil contains its own heating element which can heat the glueline to about 200 to 220°C; permitting very fast cures.



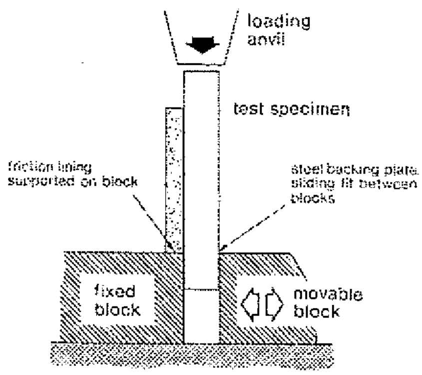


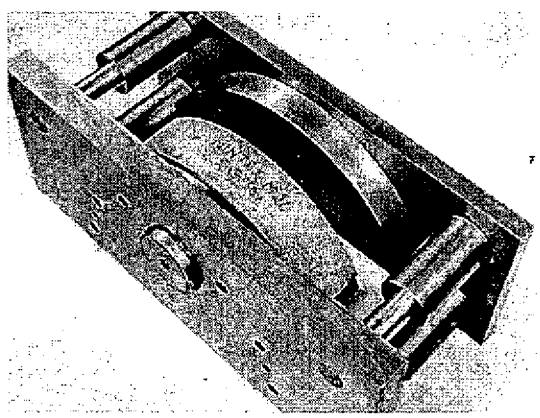
Schematics of methods of component clamping for bonding
Ring and Expander **Anvil**

For flat components conventional press clamping and curing can be used; for any components too large for these methods, plates and clamps are used to apply pressure. Curing is then accomplished in conventional temperature controlled static or tunnel ovens: usually controlled at about 150°C.

Mechanical Performance

Apart from end-user in-house fit-for-use testing as, for example, dynamometer performance, adhesives for bonding friction material usually go through three sets of tests: conventional lap-shear testing on aluminium or steel adherends, a friction material to steel 'push off' shear test and a brake show shear test. Since, particularly automobile brakes can run at around 100°C and can 'peak' at 300° to 400°C, much of this testing is at elevated temperatures.





Lining 'Push-Off' Shear Test **Brake Shoe Shear Test**

These tests tend to be used for product development, data generation, quality control, customer acceptance and in-line product monitoring.

The Table, below, gives a snap-shot of the levels of strengths obtainable and the differences seen from one chemistry to another; as a comparison, the shear strength of a typical riveted brake shoe is shown.

		PVF-Resole	PVB Resole	Nitrile Phenolic: + Vulc. Agents	Nitrile Phenolic: No Vulc. Agents
Lap Shear in MPa at:	-5°C	15.4	21.7	25.4	
	22°C	15.6	21.8	24.4	10.7
	100°C	12.5	17.3	15.8	4.3
	200°C	8.3	10.2	6.7	2.2
	250°C	6.5	7.8	3.7	
	300°C	5.2	6.3		
'Push-Off' Shear in Tonnes load at:	22°C			1.8	
	200°C			0.2	
Brake Shoe' Shear in Tonnes load at:	22°C			4.9	
	200°C			2.2	
	300°C			0.7	
Riveted Shoe at:	**22°C**			**0.4**	

Mechanical Performance of various Friction Bonding Adhesives

Conclusion

Although the bonding of friction materials, for various applications, is a 60+ years old technology, the industry itself is still open to novel approaches. Formulators could do better than to address the main problem associated with these adhesives: namely the use of solvents.

Novel systems utilising water-based technologies, or novel chemistries, which can eradicate the need for solvents at all, would be welcomed by the industry: providing, of course, that they are cost effective!