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Adhesives, syntactics and laminating resins for aerospace repair and maintenance applications from Ciba Specialty Chemicals

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Abstract

Ciba Specialty Chemicals, Performance Polymers Division, has been a leading supplier of materials to the aerospace industry for the fabrication, repair and assembly of interior and exterior aircraft components for many years. Araldite®, Epibond® and Epocast® epoxy adhesives, syntactics and laminating resins in addition to Uralane®, polyurethane adhesives have long been associated with quality, reliability and innovative chemistry. The majority of these systems are qualified to aircraft manufacturer's specifications and are included as approved repair materials in structural repair manuals and service bulletins. Many of the adhesives, syntactics and laminating resins are self-extinguishing and exhibit the low flame, smoke and toxicity (FST) characteristics required to comply with industry legislation such as FAR (Federal Aviation Regulation) 25.853 which governs the requirements for materials used in aircraft interior applications. The aim of this paper is to review a number of newly developed Ciba materials for repair and maintenance with a specific emphasis on technical performance and novel methods of application which can increase cost effectiveness and reduce labour when compared to conventional methods.

Keywords: A. Novel adhesive; A. Polyurethane; B. Composites; B. Plastics; Araldite®

1. Introduction

Ciba Specialty Chemicals, Performance Polymers Division, has been a leading supplier of materials to the aerospace industry for the fabrication, repair and assembly of interior and exterior aircraft components for many years.

Araldite® Epibond® and Epocast® epoxy adhesives, syntactics and laminating resins in addition to Uralane®, polyurethane adhesives have long been associated with quality, reliability and innovative chemistry.

The majority of these systems are qualified to aircraft manufacturer's specifications and are included as approved repair materials in structural repair manuals and service bulletins. Many of the adhesives, syntactics and laminating resins are self-extinguishing and exhibit the low flame, smoke and toxicity (FST) characteristics required to comply with industry legislation such as FAR (Federal Aviation Regulation) 25.853 which governs the requirements for materials used in aircraft interior applications.

The aim of this paper is to review a number of newly developed Ciba materials for repair and maintenance with a specific emphasis on technical performance and novel methods of application which can increase cost effectiveness and reduce labour when compared to conventional methods. Actual case histories will be presented.

2. Adhesive systems for repair applications

Adhesive failure of a bonded part can be due to several factors. Environmental bond line attack, incorrect application of the adhesive, i.e. a deviation from the recommended mixing ratios or poor attention to surface preparation of the substrate to be bonded. Repairing aircraft in the fastest time possible is a major priority at many repair and maintenance facilities. Consequently, repair technicians require a versatile, fast-setting adhesive for quick repairs. Epibond® 1559A/B epoxy adhesive has been formulated with these criteria in mind. This grey, thixotropic adhesive has been developed to achieve a handling strength after 1 h at room temperature (25°C).

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It can be used for bonding a variety of substrates, such as, metals, honeycomb core laminates and thermoplastics as well as dissimilar substrates. Epibond® 1559A/B is ideal for insert potting applications in fiberglass skin/Nomex® honeycomb parts such as bulkheads and also for edge filling on fibreglass skin/metal honeycomb parts such as floor panels.

2.1. Adhesive case history number 1 [1]

Miami's Commodore Aviation is a FAA Class IV repair station Amongst other repair applications, it handles the repair and replacement of interior aircraft sections, such as floor panels for Boeing 757's. Commodore cuts a fibreglass/epoxy skin/Nomex® honeycomb core panel to the required size for each application. Once cut to size, tabbed inserts required to attach flooring to the aircraft are bonded into the panels (Fig. 1). Epibond® 1559A/B is used to fill pre-drilled holes around the insets (Fig. 2). The material is supplied in dual-barrel Accumix® cartridges. This package allows the adhesive components to be automatically blended in the cartridge nozzle and dispensed, allowing for a fast and clean application. After use, the replaceable nozzle is disposed of and the cartridge can be re-sealed allowing for the adhesive to be retained for future use. Other advantages are as follows:

(1) *Decreased chemical exposure*. The worker's exposure to chemicals is less than with conventional adhesive packaging.
(2) *Improved performance reliability*.

- The Accumix® helical nozzle ensures that the adhesive components are thoroughly mixed which is vital in forming strong durable bonds.
- By mixing the adhesive components in a nozzle, air entrapment is minimised. This can often be a problem when conventional mixing methods are employed.

Epibond® 1559A/B is self-extinguishing to comply with FAR 25.853 and OSU (Ohio State University) requirements when used in conjunction with other low combustible composite components and therefore, can be used to fabricate or repair aircraft interior parts. This quick setting adhesive system's cured properties include a tensile lap shear strength of 13.8 MPa on aluminium/aluminium substrates after 24 h at 25°C.

Fig. 1. Once cut to size, tabbed inserts required to attach flooring to the aircraft are bonded into the panels.

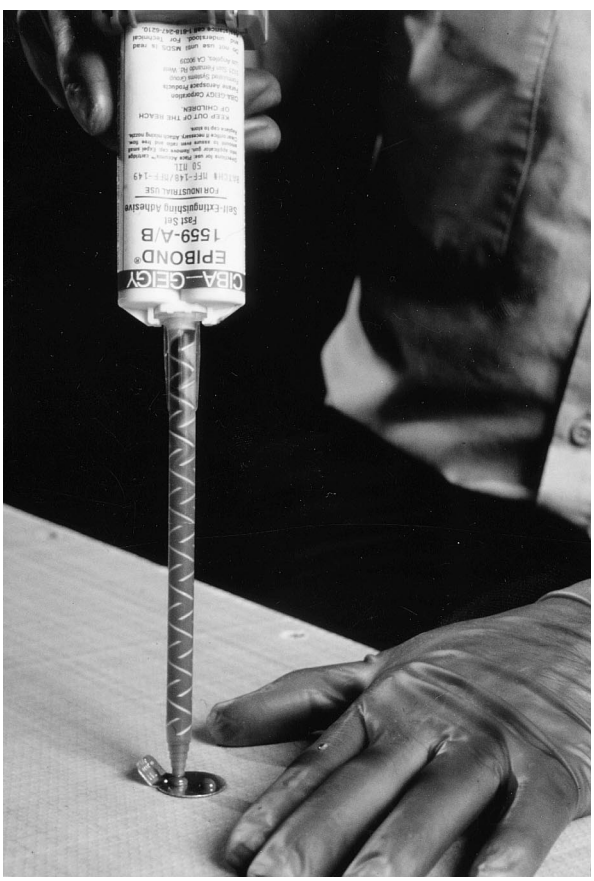

Fig. 2. Epibond® 1559A/B is used to fill pre-drilled holes around the insets.

Table 1
The variation of tensile lap shear performance of Uralane® 5774A/B with temperature on aluminium and polycarbonate

Substrate	Test temperature (°C)	Tensile lap shear strength (MPa)
Etched 2024-T3 Aluminium	− 40	33.2
	25	16.0
	82	8.6
Polycarbonate	− 40	13.8
	25	10.5
	82	5.2

Epibond® 1559A/B epoxy is specified on Airbus Service Information Letter 53-035, Appendix 4, and is qualified to a number of specifications, including Sikorsky SS-8640.

Today, interior aircraft components are fabricated with high performance thermoplastics in order to meet a variety of required properties. These thermoplastics have excellent thermal stability, chemical resistance and FST properties. These characteristics are as a result of a rigid polymer network which affords materials with high glass transition temperatures (T_g). However, there are some disadvantages, thermoplastics are chemically inert and as a result, will not react with conventional adhesive systems to produce tough, durable bonds. Therefore, Ciba Specialty Chemicals has developed an easy to handle, room-temperature curing adhesive that can bond to a variety of thermoplastic substrates. Uralane® 5774A/B is a two component polyurethane adhesive. The reaction of the polyol with the isocyanate component produces an isocyanate terminated urethane prepolymer which is then reacted with an amine curing agent affording a crosslinked polymer matrix. This polymer matrix combined with a number of additives and fillers produces an adhesive with excellent performance characteristics.

Uralane® 5774A/B demonstrates good FST properties and is formulated as a fast-setting adhesive with a work life of 15–25 min and can be handled after only 4 h, in order to meet the requirements of the aerospace repair and maintenance sector. Due to the convenient 2:1 by volume mixing ratio, the material is also available in dual-barrel Accumix® cartridges as well as working packs. On application, the adhesive has a paste-like consistency and demonstrates good slump resistance on vertical surfaces. Uralane® 5774A/B provides good surface wetting characteristics and can therefore be applied to most thermoplastic substrates with minimal substrate surface preparation. Often surface abrasion of a thermoplastic substrate is required in order to ensure a durable adhesive bond. This can result in the release of plastic particulates to the surrounding air. This situation can be eliminated by using a surface wipe with isopropyl alcohol (IPA) which is a sufficient surface pre-treatment for Uralane® 5774A/B.

The cured adhesive produces tough, impact-resistant bonds on thermoplastic and metallic substrates. The variation of tensile lap shear performance with temperature on aluminium and polycarbonate are shown in Table 1 [2].

In the past, polyurethane adhesives have been scrutinised as a result of their proneness to hydrolytic degradation under extreme environmental conditions. Table 2, compares the tensile lap shear performance of non-aged bonded samples against aged samples on a variety of substrates after 14 days exposure at 48°C, 95% relative humidity.

As can be seen from the results, Uralane® 5774A/B performs well in this testing environment. In many cases, the tensile lap shear strength improved on ageing, thus indicating that Uralane® 5774A/B will remain stable in the most aggressive environments that an aircraft interior is likely to offer.

Uralane® 5774A/B also exhibits excellent T-peel strengths on a variety of substrates as shown in Table 3.

Table 2
The tensile lap shear performance of non-aged bonded samples against aged samples of Uralane® 5774A/B on a variety of substrates after 14 days exposure at 48°C, 95% relative humidity [3]

Substrate	Chemical description	Aged (MPa)	Non-aged (MPa)
Etched 2024-T3 Aluminium	—	14.7	16.0
Stainless steel	—	12.9	9.5
Lexan®	Polycarbonate	10.8	10.5
Declar-T®	Polyetherketoneketone	8.6	6.0
Ultem® 2100	Polyetherimide	6.6	6.0
Plexiglas®	Polymethylmethacrylate	6.9	5.0
ABS	Acrylonitrile–butadiene–styrene	6.6	5.6
Radel® 7700	Polyphenylsulphone	7.8	6.5
Kydex® 6565	Acrylic / PVC alloy	6.6	6.2
PEEK	Polyetheretherketone	7.8	7.8
Aeroplex®	Polyethersulphone	5.0	9.1

Table 3
T-peel performance of Uralane® 5774A/B on a variety of substrates [4]

Substrate	T-Peel Strength (N/mm)
Etched 2024-T3 Aluminium	10.0
Stainless Steel	5.9
Lexan®	6.6
Declar-T®	4.6
Ultem® 2100	5.3

2.2. Adhesive case history number 2 [5]

Miami's Professional Modification Services (PMS) undertakes the repair and maintenance of Boeing and McDonnell Douglas Aircraft. Uralane® 5774A/B's excellent thermoplastic bonding characteristics makes it the ideal adhesive for the repair of parts such as a cracked thermoplastic cockpit panel from a Boeing 727 aircraft.

A PMS technician begins by applying a bead of adhesive from an Accumix® cartridge into the crack (Fig. 3). Additional adhesive is dispensed around the panel's surface and then a fibreglass doubler is placed over the area surrounding the crack (Fig. 4). For reinforcement, several more beads of adhesive are then dispensed over the top of the fibreglass (Fig. 5) and the resin is spread across the cloth with a squeegee to ensure that the cloth is thoroughly wet-out (Fig. 6).

The panel is then placed under a heat lamp for 10 min in order to promote a fast cure. The repaired cockpit panel is then sanded and finally painted prior to reinstalled into the aircraft (Fig. 7).

Uralane® 5774A/B is qualified on a number of specifications, including Boeing BMS 5-105, Type 5, Airbus Industrie AIMS 10-04-001-01 and Douglas DPM 5892.

2.3. Newly developed polyurethane adhesives

Ciba Specialty Chemicals has recently introduced two new polyurethane adhesives to it's range of aerospace adhesives. Uralane® 5776A/B is an easy to apply adhesive that has been designed to be flexible over a wide temperature range. This polyurethane adhesive performs well in vibrating environments and has good damping properties. It is a room temperature curing adhesive that is particularly suitable for bonding larger parts due to it's work life of 35-45 minutes at room temperature.

Uralane® 5779A/B is a self-extinguishing adhesive that can withstand exposure to temperatures of up to 71°C. It has excellent stability under UV light and humidity. This makes it an ideal adhesive for sealant or caulking applications instead of traditional silicone sealants which tend to discolour on ageing. The adhesive is available in white, beige or grey colours in order to match thermoplastic decorative films used on luggage bins, wall / ceiling panels and galleys. The material is qualified to Boeing BMS 5-105, Type 6, Rev K.

3. Syntactic systems for repair applications

A syntactic adhesive is formulated by the incorporation of hollow microspheres into a liquid resin component. For example, this could be an epoxy resin or an amine

Fig. 3. A PMS technician begins by applying a bead of adhesive from an Accumix® cartridge into the crack.

Fig. 4. Additional adhesive is dispensed around the panel's surface and then a fibreglass doubler is placed over the area surrounding the crack.

Fig. 5. For reinforcement, several more beads of adhesive are then dispensed over the top of the fibreglass.

hardener. The microspheres can be made from a variety of materials, for example, glass, epoxy, phenolic or acrylic and are added in combination with other additives to form a moldable, light-weight 'putty' adhesive system.

Generally, damage to honeycomb structures occurs as a result of delamination between the laminate and honeycomb structure or damage to the basic structure as a result of an impact. Depending on the type of damage present, a number of repair actions can be taken. Firstly, the damaged area can be simply filled with a foam or syntactic type material. Secondly, the sandwich skin and honeycomb can be removed from the damaged area. After this, the hole can be filled will a syntactic foam and a new skin constructed over the top of the area to complete the repair. Finally, the damaged skin and honeycomb is removed as for the second type of repair, however, in this case, a new piece of honeycomb is cut to size in order to replace the damaged honeycomb. The new honeycomb is then bonded into place by means of a fast setting paste adhesive or syntactic although a core splicing adhesive is more common. Again, a new skin is constructed over the top of the area and the core splicing

Fig. 6. Resin is spread across the cloth with a squeegee to ensure that the cloth is thoroughly wet-out.

Fig. 7. After curing, the repaired cockpit panel is then sanded and finally painted prior to being reinstalled into the aircraft.

adhesive is either cured before or co-cured with the composite structure. This type of repair often allows for original compressive properties of the structure to be obtained without significantly increasing the weight of the structure.

3.1. Eposert® syntactic insert technology [6]

An advanced concept in syntactic compounds used to repair and reinforce damaged composite structures has been designed by Ciba.

Eposert®, pre-formed epoxy inserts feature a number of performance and handling benefits that can significantly increase productivity and finished part quality.

3.2. Improved quality

Eposert® inserts allow repair and maintenance technicians to produce higher quality composite structures due to the fact that these inserts are formed with a minimal void content which can often be as a result of mixing a resin and hardener component together. Therefore,

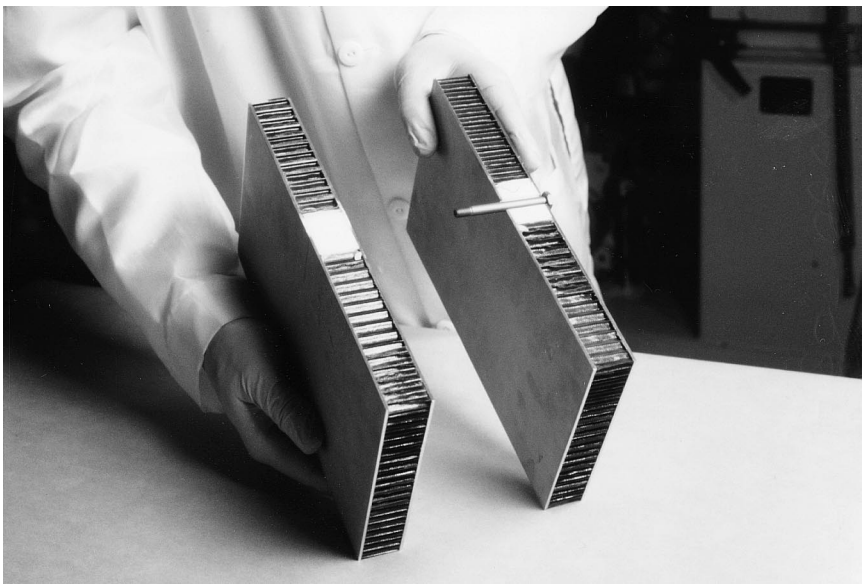

Fig. 8. Eposert® syntactics produce repaired parts with improved integral strength, optimised compressive properties, greater reinforced area and part to part consistency.

Eposert® syntactics produce repaired parts with improved integral strength, optimised compressive properties, greater reinforced area and part to part consistency (Fig. 8). The amount of material required to effectively reinforce a structure is also significantly reduced and hence the overall weight of the repaired component is reduced.

3.3. Handling advantages

Due to the fact that Eposert® syntactic inserts are precured, operator exposure to reactive materials is minimised during the repair process. The fact that reactive materials are eliminated, allows these inserts to be placed under different transportation classifications as opposed to conventional syntactic paste materials. Material waste is also reduced during a repair operation in terms of the amount of material used and in terms of the virtually unlimited shelf life of these inserts.

3.4. Increased productivity

Eposert® insert technology can reduce the time required to repair a damaged section of honeycomb by up to 95% when compared to conventional syntactic repair techniques. This is because the ready to use inserts eliminate time consuming steps such as weighing, mixing, gelling and curing cycles which are normally required.

3.5. Repair procedure with Eposert® syntactic inserts

The first step to repairing an area of honeycomb with an Eposert® syntactic insert, is to simply remove a circular section of the damaged core (Fig. 9). Then one of two methods can be employed to bond the preformed insert into the honeycomb. With the first method, a piece of expanding core splice tape adhesive is cut to the required size and wrapped around the Eposert® syntactic. After the release film is removed, the insert can be installed in the honeycomb cavity (Fig. 10). Alternatively, the honeycomb core can be reinforced by applying a paste syntactic such as Ciba's Epocast 1614-ATF or CG 1305 around the insert until the surrounding honeycomb cavities are completely filled (Fig. 11). When all the areas of the honeycomb have been reinforced, fabrication of the composite structure can be completed (Fig. 12). The adhesive materials used around the Eposert syntactic® will co-cure with the honeycomb composite part. Secondary drilling and boring operations can then be performed.

3.6. Eposert® syntactic inserts performance characteristics

Eposert® epoxy inserts can be fabricated from a variety of Ciba's syntactic systems in order to meet the specific requirements of a repair project. For example, Ciba has manufactured inserts from its one-component Epocast 927 syntactic system to give an Eposert® insert with temperature resistance to 205°C and a compressive strength of 135 MPa at room temperature.

Readily available inserts are currently manufactured from two syntactic systems, CG 1305 and Epocast® 1614. The CG 1305 Eposert® epoxy insert is a 0.90 g/cm^3 density, self-extinguishing syntactic compound which exhibits a room temperature compressive strength of 60 MPa and compressive modulus of 3200 MPa. The

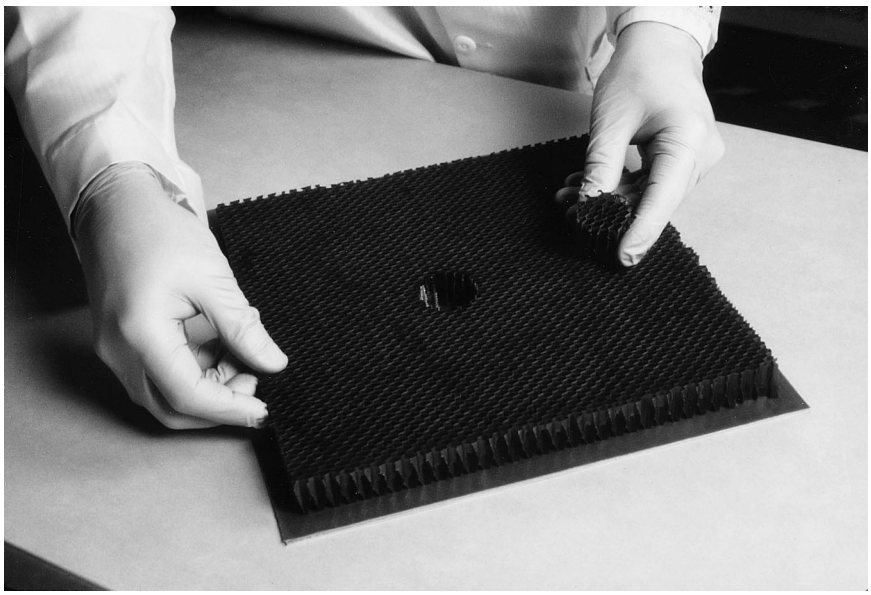

Fig. 9. The first step to repairing an area of honeycomb with an Eposerts® syntactic insert, is to simply remove a circular section of the damaged core.

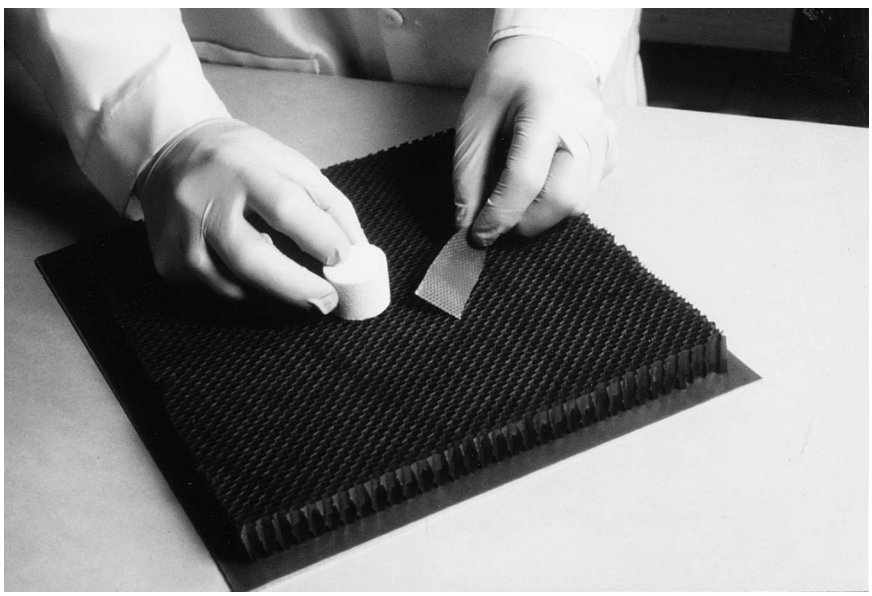

Fig. 10. A piece of expanding core splice tape adhesive is cut to the required size and wrapped around the Eposert® syntactic. After the release film is removed, the insert can be installed in the honeycomb cavity.

Epocast® 1614 epoxy insert is a 0.75 g/cm^3 density, self-extinguishing syntactic compound that can be used in parts that must perform up to 175°C. The Epocast® 1614 insert features a room temperature compressive strength of 115 MPa.

Eposert® syntactic inserts are currently available in 3.175 cm and 3.81 cm diameter cylindrical shapes measuring from 0.952 to 10.67 cm high. However, Ciba can also produce inserts in custom diameters, lengths and configurations in order to meet specific repair project requirements as shown below (Fig. 13).

3.7. Newly developed syntactic systems

Ciba Specialty Chemicals has recently introduced two new syntactic systems to it's current range. Epocast® 1631A/B and Epocast® 1632A/B are pumpable, self-extinguishing, medium density systems (0.7 g/cm^3) available in 200 cm Accumix® cartridges for ease of application. Both these materials have been formulated for edge filling, core splicing and insert potting applications. Epocast® 1631A/B has a working life of 16 minutes at 25°C and Epocast 1632A/B has a working life of 4 min at 25°C. These rapid

Fig. 11. Alternatively, the honeycomb core can be reinforced by applying a paste syntactic such as Ciba's Epocast® 1614-ATF or CG 1305 around the insert until the surrounding honeycomb cavities are completely filled.

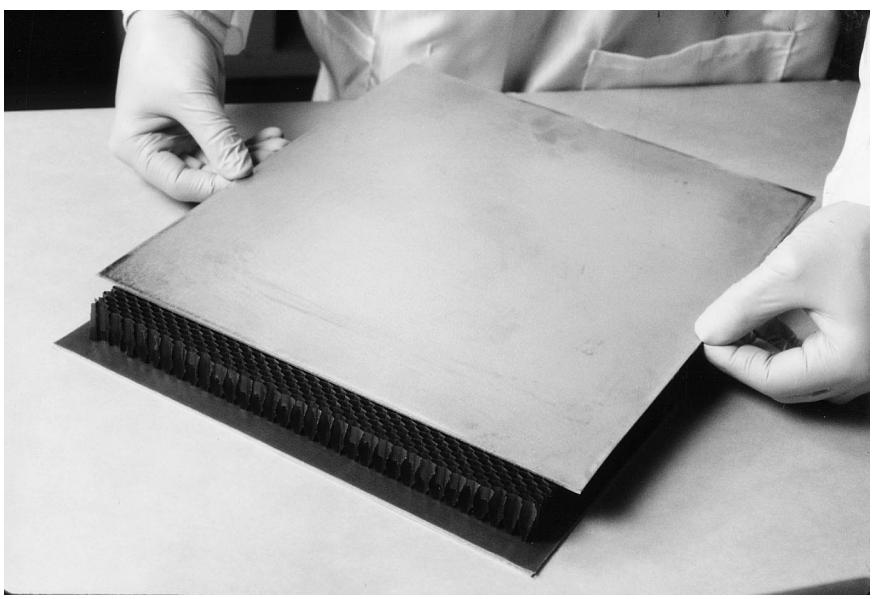

Fig. 12. When all the areas of the honeycomb have been reinforced, fabrication of the composite structure can be completed.

materials are ideal for repair and maintenance applications when rapid fabrication is a primary consideration.

Epocast® 1631A/B and Epocast® 1632A/B meet the requirements of BMS 5-28, Type 30, Class 1 and BMS 5-28, Type 30, Class 2, respectively.

4. Laminating resins for repair applications

Damage to aircraft composite components usually involves delamination between plies, destruction of a material due to an impact or it may be a combination of the two. Before a repair is undertaken, the manufacturer"s structural repair manual is consulted. This will determine whether the damage is within repairable limits and will provide information such as processing instructions and approved materials that should be used. Examples are as follows [7]:

- Fabric type (class and style).
- Number of plies needed for the repair, orientation of fibre warp and fill.

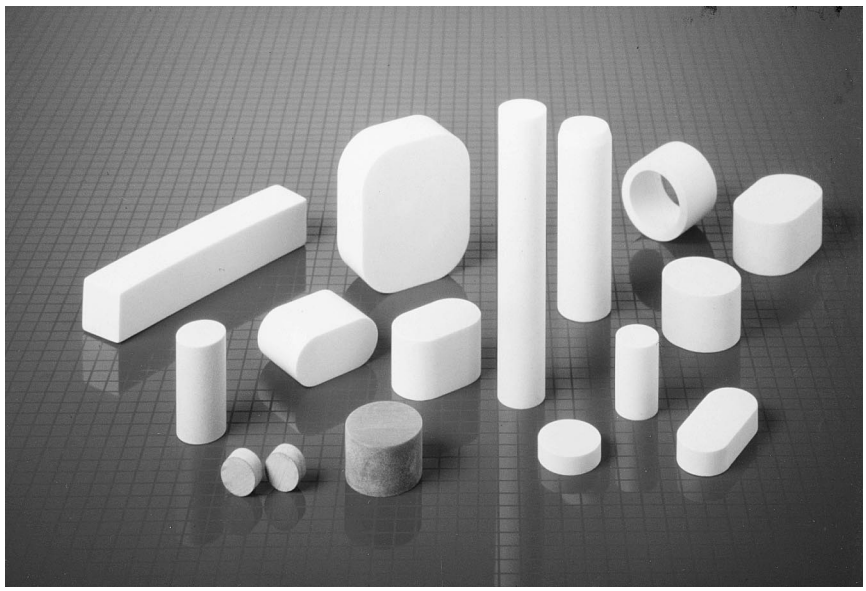

Fig. 13. Ciba produces inserts in custom diameters, lengths and configurations in order to meet specific repair project requirements from a range of syntactic systems.

- Stacking sequence of the plies.
- Laminating resin and hardener system to be used.
- Core type, ribbon type and core-splicing adhesive/potting compound to be used.

4.1. Laminating resin case history [8]

In addition to handling repair and maintenance operations on its own fleet of aircraft, Qantas Airlines in Australia also undertakes "C" and "D" checks for other airlines in the Pacific Rim region. Typically, Qantas composite shops repair damage to aircraft which is a result of routine "day-to-day" operations. Composite components frequently repaired by Qantas include radomes, wing to body fairings, flight control surfaces, cabin components and cargo bay lining panels.

Ciba's Epocast® 50A epoxy resin with 9449 hardener has been used by Qantas to repair delamination damage to fibreglass/phenolic carpet riser panels on Boeing 737 aircraft. This laminating system is qualified to Boeing specification BMS 8-201, Type 2 and has been developed to provide the handling characteristics required to fabricate repairs quickly and effectively.

The Boeing 737 aircraft in the Qantas fleet are designed with carpet covered fibreglass/phenolic panels that are installed to form an aesthetic joint between the sidewall and the floor of the passenger compartment. These vented panels also form part of the air recirculation system. As a result of passenger "wear and tear", the bottom edge of the panels can crack, particularly in sections where they are clipped to the side wall.

Fig. 14. After removing damage and solvent wiping the panel, several fibreglass plies are cut to fit the repair area.

Fig. 15. The Epocast® 50A resin and 9449 hardener are mixed thoroughly and brushed onto the clean panel surface. Dry fibreglass plies are then positioned into the wet resin and the laminating system is pulled through the cloth with the aid of a squeegee which also helps in removing trapped air beneath the cloth.

Fig. 16. If required, additional adhesive is poured onto the fibreglass and again spread with a brush or a squeegee.

The Epocast® 50A/9449 laminating system has a 25–40 min working life and cures at room temperature. Once cured, this repair adhesive has a room temperature tensile lap shear strength of 22.1 MPa on aluminium and a flexural strength of 310 MPa. Two further hardener systems are available, namely, 946 and 9816. These give a useable life of 15–20 and 90–180 min, respectively. Thus, by selecting the appropriate hardener, the useable life of the system and the cure speed can be varied to suit the conditions, i.e. the size of the area to be repaired. The Epocast® 50A/9449 laminating resin is also self-extinguishing making it particularly suitable for interior cabin repairs.

For the repair process, a Qantas technician begins by removing any cracked or delaminated areas and then wiping with a solvent to give a clean surface for bonding. Several fibreglass plies are then cut to fit the repair area (Fig. 14). Next, the Epocast® 50A resin and 9449 hardener are mixed thoroughly and brushed onto the clean panel surface. Dry fibreglass plies are then positioned into the wet resin and the laminating system is pulled through the cloth with the aid of a squeegee which also helps in removing trapped air beneath the cloth (Fig. 15). If required, additional adhesive is poured onto the fibreglass and again spread with a brush or a squeegee (Fig. 16). When the laminate is complete, the structure is vacuum bagged using a layer of release film and a breather cloth (Fig. 17). A vacuum is then applied and the repaired part is allowed to cure overnight at room temperature. After the curing cycle is complete, the panel is covered with carpet and reinstalled into the aircraft (Fig. 18).

4.2. Epocast® 52A/B high temperature resistant laminating resin [9]

In order to respond to the increasing need for fast, effective field repairs on the ever increasing number of composite structures used on today's aircraft, Ciba has developed Epocast® 52A/B. This product has been formulated to provide repair and maintenance technicians with ease of handling and excellent high-temperature performance of up to 175°C. This laminating material is particularly suitable for use with either graphite or fibreglass fabrics and features an easy to handle mixed viscosity of less than 0.4 Pa s at room temperature and a 60 min

Fig. 17. When the laminate is complete, the structure is vacuum bagged using a layer of release film and a breather cloth. The part is then allowed to cure overnight.

Fig. 18. After the curing cycle is complete, the panel is covered with carpet and reinstalled into the aircraft.

Table 4
Typical properties of Epocast® 52A/B high-temperature-resistant laminating resin

Property	Epocast® 52A/B
Mixed colour (visual)	Blue
Mix ratio, pbw / pbv	100:41/2:1
Density, g/cm^3 (ASTM D-792)	1.1
Viscosity, Pa s at 25°C (ASTM D-2393)	0.3–0.4
Work life at 25°C, Mins (ASTM D-1338)	60
Cure cycle	3 h at 65°C or 2 h at 93°C
Compressive interlaminar shear, MPa (ASTM D-2733)	
At − 54°C	48.3
At 25°C	51.7
Tensile strength, MPa (ASTM D-638)	
At − 54°C	241.4
At 71°C	131.0
Long beam flexural strength, MPa (Mil std. 401)	
At 25°C	2.3
At 71°C	2.1
Flatwise tensile strength, MPa (Mil std. 401)	
At 25°C	3.8

working life. Hence this laminating adhesive provides good cloth wetting properties and after an elevated cure cycle, produces composites with a high shear modulus, good hot/wet properties and excellent damage resistance from moisture and aircraft fluids. Epocast® 52A/B has recently been approved for Boeing specification BMS 8-301, Class 1, Grade 2. Typical properties are outlined in Table 4.

5. Conclusion

Ciba Specialty Chemicals, Performance Polymers Division can offer a number of repair and maintenance solutions for a customer. Not only is there an extensive range of adhesives, syntactics and laminating resins available, but also technical support advice on material selection, fabrication and material application techniques.

Acknowledgements

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[Flightline is a technical newsletter on aircraft paste adhesives and syntactics from the aerospace products group of the Ciba Specialty Chemicals Corporation.]