AMTS STANDARD WORKSHOP PRACTICE

Bonding and filling using Laminating Epoxy Resin

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1 Technical Terms

Additives: Fillers, pigments, viscosity control agents and surface agents.

Fillers: Solid materials added to a resin mixture to impart or modify certain properties.

Bondline thickness: The thickness of the adhesive at a given point in a bond.

Composite: A material that consists of two or more materials joined to form a matrix.

Cure temperature: The temperature that the adhesive need to reach in order to form covalent bonds.

Curing: A chemical reaction whereby polymer chains interlink, forming a three-dimensional network of covalent bonds.

Micron: A micrometer (m) is one thousandth of a millimetre.

Pot life: The time the adhesive takes to gel and become unusable.

Thixotropy: Resistance to flow on vertical surfaces.

Viscosity: A measure of the resistance of a fluid to flow.

2 Scope

This SWP describes how to alter the characteristics of Laminating Epoxy Resin Systems for use as adhesives, gap filling agents, sealants and castings. It also describes the preparation of materials, mixing of specific additives / fillers and the application of the mixes in a bonding application.

3 Primary References


Composite Materials in Aircraft Structures, Donald H. Middleton.

4 Laminating Epoxy as Adhesive

Adhesives based on two-part epoxies are widely used for adhesive bonding of composite structures. These adhesives provide bonds that are both strong and durable given a range of operating temperatures and relative humidity.

Laminating epoxy resin (e.g. M.G. Scheufler L 285 / H 287) may be used as an adhesive on its own. When modified, however, this improvised adhesive can ensure excellent bonds with numerous advantages over other tailored adhesives. This is achieved with suitable preparation, mixing of certain additives and proper application.

Bond line control is also a crucial factor – refer to SWP 27 on Bond Design for detailed information on design.

4.1 Criteria for selecting an adhesive

The following criteria are important when evaluating an adhesive for use in a certain application. When using laminating epoxies some of these characteristics may be modified. Below a laminating epoxy is evaluated according to these criteria described in SWP 12 on Adhesive Bonding.

1. Maximum operating temperature:
   If a component to be bonded is made using the same epoxy system as the adhesive, the maximum allowable operating temperatures of both are naturally the same. This is a great advantage of using a laminating epoxy as adhesive, and eliminates the risk of joint failure due to exceeding the maximum operating temperature of the adhesive.

2. Elasticity
   Epoxies are usually less elastic than other adhesives. If the components were also made with an epoxy system, the elasticity of part and bond will match and thus eliminate the risk of bond failure when a load is applied.

3. Viscosity
   Carb-o-sil may be readily added to adjust the viscosity of the epoxy adhesive.

4. Shrinkage during curing
   Epoxies shrink less than polyester adhesives after curing. With the addition of any type of filler the little shrinkage is further reduced.

5. Cure temperature:
   The cure temperature of a laminating epoxy adhesive is dependent on that of the resin system being used. Refer to the manufacturer’s datasheets as well as SWP 9 on Curing of Composites for more information.

6. Bond line thickness control:
In order to enhance the crack-filling properties and maintain an optimum bond thickness, fillers may be added to an epoxy adhesive to modify its density.

7. Compatibility:
   When using a laminating epoxy adhesive on an epoxy laminate part, compatibility is ensured and composite manufacturers needn’t be concerned with compatibility.

8. Pot life:
   Different laminating epoxies have different pot lives and the pot life of an adhesive will be dependent on this. Additives will affect the pot life when mixed with an epoxy system. Some metallic additives may shorten the pot life as they react chemically with the mixture. Non-metallic fillers (cotton floss, carb-o-sil and micro-spheres) that “expand” the mixture and thus also the surface exposed to ambient temperature will tend to slightly increase pot life because of this. Composites manufacturers should however not rely on this increase when scheduling production.

9. Cost:
   Using laminating epoxies with additives as adhesives will offer a cost advantage and when the system is used in laminating applications elsewhere in a workshop it will be readily available.

### 4.2 Two component epoxy systems

All epoxies (laminating resin systems as well as bonding epoxies) come in two components called the resin (or part A) and the hardener (part B). They should be mixed strictly according to the correct ratio, supplied in the manufacturer’s data sheet. It is important to know whether the ratio is specified according to weight or volume. Refer to SWP 7 on Mixing of Resins.

The usual low viscosity and poor gap filling properties of a laminating epoxy makes it non-ideal for use as an adhesive on its own. These properties may be altered by the mixing of additives.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Epoxy</th>
<th>Polyester (unsaturated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesion</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Shear strength</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Fatigue resistance</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Strength / stiffness</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Creep resistance</td>
<td>3 – 4</td>
<td>3</td>
</tr>
<tr>
<td>Toughness</td>
<td>1 – 4</td>
<td>1</td>
</tr>
<tr>
<td>Thermal stability</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Electrical resistance</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Water absorption resistance</td>
<td>3</td>
<td>1 – 3</td>
</tr>
<tr>
<td>Solvent resistance</td>
<td>4</td>
<td>1 – 3</td>
</tr>
<tr>
<td>UV resistance</td>
<td>1 – 3</td>
<td>1 – 3</td>
</tr>
</tbody>
</table>
### Table 4.2-1: Comparison between properties of epoxy and polyester systems

<table>
<thead>
<tr>
<th>Property</th>
<th>Epoxy</th>
<th>Polyester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flammability resistance</td>
<td>1 – 3</td>
<td>1 – 3</td>
</tr>
<tr>
<td>Smoke</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Cost</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

(5 = excellent, 1 = poor)

### 4.3 Filler additives (non-metallic)

The properties that normally make laminating epoxies non-ideal as adhesives for bonding composite parts can be improved by adding certain fillers as additives. The same may be done to employ epoxies as gap-filling agents.

With accurate mixing to ensure even consistency, laminating epoxies make strong, durable and highly cost effective bonding adhesives and filling materials.

Fillers can be divided into the following basic categories:

- **Hollow spheres** (e.g. microballoons)
  Decreases density of mixture by increasing the volume of a given weight

- **Short fibres** (e.g. flox)
  Strengthens a resin and prevents starvation when bonding porous components

- **Flow modifiers** (e.g. carb-o-sil, silica)
  Increases the viscosity of a mixture by ‘thickening’ it, also increases thixotropy.

When mixing fillers, the ratios are usually specified by volume. They are, however, only approximate (as the density of resins may differ) and may be adjusted by workers when mixing in order to obtain the desired consistency.

All fillers are mixed after the epoxy and hardener have been thoroughly mixed. The following are commonly used fillers and their effect on a resin when mixed together:

#### 4.3.1 Glass microballoons / -microspheres / -bubbles / Q-cell

Glass microballoons are hollow C glass (chemically resistive) spheres. These are less expensive than phenolic glass balloons discussed below. Epoxy mixes filled with glass microballoons are waterproof, with poor sandability. Phenolic- and glass microballoons may be mixed together as fillers. A mixture of epoxy and glass microballoons is referred to as “micro”.

**Physical characteristics**

- **Appearance:** white powder
- **Density:** ± 200g/litre
- **Particle diameters:** 10 - 300 microns (size more varied than phenolic microballoons)
- **Particle diameters:** 1 - 1000 microns (microspheres)
Applications

- Reduces weight of epoxy for a given volume
- Decreases sandability and increases durability of surface
- Filling voids
- As adhesive between foam blocks, and between foam and glass weaves
- Important: micro should not be applied between glass weave layers, as the structural integrity will be compromised.
- Important: micro is not recommended as structural adhesive (only light duty bonding of timbers and foams, mostly when used as core materials)

Mixing ratios (by volume)

Microballoons may be mixed in different ratios with epoxy to achieve fillers with different properties:

- One part glass microballoons to one part epoxy results in a “slurry” (filling small gaps where a higher viscosity will not “flow away”).
- Two to four parts glass microballoons to one part epoxy is sometimes referred to as “wet micro” and has a consistency similar to that of honey (used as light duty adhesive)
- When increased to about five parts to one the resulting mixture becomes a tight paste, sometimes referred to as “dry micro” (used for non-structural gap filling)

Properties of glass microballoons

- Increases volume of mixture
- Lowers thermal conductivity
- Provides resistance to compressive stress
- Low mechanical strength – good for bonding foam cores and non-structural surface filling.

Application techniques

- With a light spatula
- With putty knives
- Apply in a heap and scrape down with straight aluminium extrusions when filling gaps

4.3.2 Microballoons (phenolic)

Microballoons are microscopic hollow spheres formed from phenolic-based resins. Where waterproofing is not a priority and better sandability is needed, microballoons are a better choice than glass bubbles.

Physical characteristics

- Appearance: dark red powder
- Density: 250g/litre
- Particle diameters: 50 microns (consistent size)

Applications

- Cosmetic fillet joints and fillers in wood construction
- Adhesive in less demanding timber joints

Mixing ratios
• Generally the same as glass microballoons
• May be adjusted to obtain desired consistency

Properties of microballoons
• Increases volume of mixture
• Provides slight resistance to compressive stress.
• Very low mechanical strength – may be used for bonding foam cores, soft timbers and cosmetic surface filling.

Notes on use
• Microballoons should be stored in airtight containers as they easily absorb moisture from surrounding air, which will have an adverse effect when mixed with resin.
• It is important not to use microballoons with poly- or vinylester based resin systems as they will attack and collapse the microscopic spheres (glass microballoons are unaffected)

4.3.3 Cotton flox / cellulose microfibres

A porous bonding surface such as wood easily absorbs laminating epoxy resins, resulting in a resin-starved joint. Cellulose-based (wood, cotton, etc.) microfibers are the most common additives when mixing adhesives for joining wood or glass reinforced plastic. A mixture of cotton microfibers and epoxy is commonly referred to as “flox”.

Applications
• Flox makes an adhesive with excellent gap filling properties.
• To create chamfers

Mixing ratio (by volume)
• By mixing one part microfibers to one part resin a stiff mixture is obtained.
• More resin may be added if a more “runny” mixture is desired (“wet flox”).
• Microfibers may be used on their own to reinforce sharp corners, pre-wet with resin.

Properties of cellulose microfibers
• Absorbs resin and retains it within the bond, improving adhesion.
• Increases the density of the mixture.
• Improves mechanical properties (shear strength).

4.3.4 Glass microfibres

Short glass fibres lend similar properties to a resin as long glass reinforcement fibres would. The random orientation of the fibres, however, lends strength to the matrix in all directions.

4.3.5 Carbon microfibres
Short carbon fibres or carbon flakes lend similar properties to resin as long carbon reinforcement fibres would. The random orientation of the fibres, however, lends strength to the matrix in all directions.

4.3.6 Colloidal silica / carb-o-sil / fused quartz

Colloidal silica (carb-o-sil, fused quartz, -silica or aerosil) is a non-crystalline form of silicon dioxide, made from quartz melted in a high temperature furnace. Carb-o-sil is a filler used to adjust the “sag” properties (referred to as thixotropy) of an epoxy resin. It may also be added to any other mix of epoxy and filler, mainly to alter the flow properties of the combined mixture.

Physical characteristics
- Appearance: white powder
- Density: ± 50g/litre
- Particle diameters: 0.012 microns

Application
- Acts as a lightweight thickener, reducing the flow of epoxy on a vertical surface (thixotropy).
- The fine texture of carb-o-sil makes it suited for filling surface pinholes.
- Sealing of water tanks
- Strong bonding adhesive, less affected by moisture. This bond is slightly more brittle than the cotton flox / epoxy mixture and is less suitable where bonding gaps exceed 5mm.
- Can be combined with most microfibres to form a high-strength, relative low density structural adhesive.

Mixing ratio (by volume)
- Generally carb-o-sil is mixed one to two parts filler to one part resin per volume.
- This ratio may be adjusted to alter the viscosity of the mixture.

Properties of carb-o-sil
- Increases viscosity of resin (more sag-resistant)
- Improves the mechanical properties (shear strength)
- Note: the high silica loading of a mixture will result in greatly decreased sandability.
- Low sandability also translates to durability, which may be desirable in some instances.

4.3.7 Combining fillers

By using a combination of fillers, the properties of the mix can be further manipulated to suit the required application. Typical combinations of fillers used in practise are:

i) Glass microballoons + carb-o-sil
This combination mixture combines the beneficial properties of glass microballoons and carb-o-sil to produce a dry, yet pliable epoxy mixture.

**Fig. 4.3-1: Suggested mixing ratios (by volume) of glass microballoons, carb-o-sil and epoxy.**

ii) **Cotton flox + carb-o-sil**

A combination of flox and carb-o-sil forms an adhesive, certified for bonding of aircraft parts.

**Properties**
- Density: approximately 1.09g/ml

**Fig. 4.3-2: Suggested mixing ratios (by volume) of cotton flox, carb-o-sil and epoxy.**

iii) **Glass microballoons + cotton flox + carb-o-sil**

This mix provides a light duty adhesive with very low weight given its relative strength.

**Fig. 4.3-3: Suggested mixing ratios (by volume) of glass microballoons,**
cotton flox, carb-o-sil and epoxy.

4.4 Metallic fillers

Another type of additive is metallic fillers. These lend the properties of the base metal to the mixture.

4.4.1 Aluminium flakes / powder

Aluminium flakes or powder significantly strengthens a resin whilst still remaining relatively light.

**Important:** Beware of negative effects such as galvanic corrosion which may occur in certain situations when adding metallic fillers.

4.4.2 Steel powder

Steel filings have the same effect as aluminium flakes on a resin, without the weight benefit. Furthermore the ferrite structure of steel will impart magnetic characteristics to part containing a resin mixed with steel powder (and render it visible to radar, in aerospace applications).

4.4.3 Lead powder

By adding lead powder to a resin the weight is greatly increased — this is useful for weight balancing in composite structures.

5 Surface Preparation

A crucial step in bonding is correct surface preparation. As discussed fully in SWP 12 on Adhesive Bonding, surface preparation may consist of the following:

1. Degreasing only
2. Degreasing, abrasion and second degreasing
3. Degreasing and chemical pre-treatment
4. Water break test (simple way to test for a clean surface)

Refer to the abovementioned SWP for details on each.
6 Bonding process

The steps to a successful bonding process resulting in a quality bond using a laminating epoxy resin system, consists of the following:

1. Preparation of the adhesive (correct mixing of resin and additives resulting in consistent mixture)
2. Bonding surface alignment (ensures proper bond line thickness)
3. Surface preparation (as discussed under section 5)
4. Surface priming with epoxy adhesive (low viscosity mix)
5. Application of epoxy adhesive (proper tools)
6. Clamping and removal of excess epoxy adhesive
7. Curing of adhesive joints (refer to SWP 9 on Curing of Composites)

The above steps are discussed in greater detail for both generic and epoxy resin Adhesive Bonding in SWP 12.

7 Quality Control

To ensure the repeatability of a process quality control is crucial. This in turn certifies the quality of the end product. Refer to SWP 12 on Adhesive Bonding for a detailed quality control process.

These steps to determine the quality of an adhesive include:

- Preparing of test specimens
- Visual inspection of bonds