SP Systems

Composite Engineering Materials

Guide to Filling & Fairing

Contents

Introduction

Most craft of whatever size or construction material have required filling and fairing compounds at some time either in their life or in their development and design. Production grp hulls which emerge from their moulds with a smooth gel coat finish owe their fairness and quality of finish to the skill of the builders original shape or 'plug' from which the mould was formed.

The same high standard of finish can also be seen in 'one-off' composite racing sailboats. These craft mostly use epoxy rather than polyester resin in their construction and are built over a male plug. All one-off racing sailboats use lightweight epoxy filler mixers and specialized high performance paint schemes to obtain the necessary high standard of finish.

Recently we have seen an increase in the number of craft, both mono and multihulls, which use wood as the principal core material in their construction, particularly cedar strip and end-grain balsa. These hulls rely on extensive filling and fairing to give a surface finish which can match that of moulded grp hulls.

Steel boatbuilders also use epoxy filler to fair their hulls once the shaped steel plates have been welded together. Filler will take out any slight curvature imperfections and hide the welding lines before a final paint system is applied.

Filling and fairing is a very labour intensive operation but an essential one necessary to ensure that the hull offers the least resistance to movement through the water. Nowhere is efficient filling and fairing more important than on underwater appendages - the keel and rudder, where not only section shape can be controlled by application of filler, but surface finish, fairness and smoothness can be perfected for noticeable performance gains.

This guide covers the range of products which are available from SP Systems used in filling and fairing procedures and outlines the standard procedures which are necessary in order to achieve the best quality finish on wood, composite, ferrocement and metal surfaces.

Review of Principal Products Required

Resin System

A resin system of some type, usually epoxy or polyester, forms the basis of every filler, together with a mixture of inert filler ingredients. Through the action of a catalyst, in the case of polyester, the resin is caused to polymerize to a hard plastic. With epoxy based products, the resin reacts with a specialised hardener and together they 'crosslink' and polymerise to form an outwardly similar looking hard plastic material.

For marine use especially, epoxy resin based fillers are far superior to those based on polyester resin as they are inherently more water-resistant, shrink less during curing, are more adhesive and have a higher degree of toughness and strength. Although epoxy-based fillers cost more they are the only type recommended for boat hulls.

Although the epoxy resin and hardener can be supplied with filler additions pre-mixed into one or both components as a 'formulated' filler (as in the case of SP S'Fill 400 Lightweight Epoxy filler), most professional users working on a large scale prefer to create their own mix by using a liquid epoxy resin system and low density filler 'powders'. This gives the user considerably more control over application and working properties over a wide range of working conditions. The user can vary the quantity of filler added to create 'thick' or 'thin' mixes. The resin system will have a number (usually at least 2) of different hardeners, each of which will offer different levels of reactivity when mixed with the resin component. This approach is referred to as the "recipe" method.

The following SP Systems epoxy resins and the respective hardeners can be used:

Epoxy Resin	Hardener (described in terms of speed of reactivity)
Ampreg 26	Fast, Slow
Ampreg 20	Fast, Standard, Slow
Ampreg 22	Fast, Extra Slow
SP 320	Fast, Slow
Spabond 120	Fast, Slow
SP 106	Fast, Slow

All of the above resin systems have roughly the same working properties (pot-life, gel time etc.) when used with their fast hardeners. The gel times of the above systems using the fast hardener range from about 10-15 minutes. However, the term 'slow' for a hardener is only relative, such that the gel time for one system's slow hardener may be much longer than another system's slow hardener (e.g. SP 106 slow - 17 minutes: Ampreg 26 slow - 230 minutes). The reader is advised to consult the data sheets of the products and note the 'gel times' of the proposed hardener and resin mixes, as this will give a relative index of working time of the final resin/hardener/filler mixes.

Choice of Hardener

Appropriate selection of hardener can give mixes with different degrees of reactivity or speed. Final choice of resin system and speed of hardener will largely depend both on size of mix required and working temperature. Often, it is possible to use the same resin system that is being used to build the component. This saves the inconvenience of buying a second system but it may not be the most cost-effective approach, as another system maybe cheaper.

Table 1 is offered as a guide and is applicable to using Spabond 120, SP 106, SP 320 and Ampreg 20, Ampreg 22, Ampreg 26 with their respective hardeners,
(F = Fast, Std = Standard, SL = Slow, XS = Extra Slow):

TABLE 1

Appropriate Hardener to Use in Different Temperature Ranges and for Different Filler Mix Sizes for the SP Epoxy Systems Recommended

Filler Mix*	10°-15°C	16°-21°C	22°-27°C	28°C+
Up to 200cc	Ampreg 22 F Ampreg 20 F SP 320 F Spabond 120 F SP 106F	Ampreg 26 F Ampreg 22 F Ampreg 20 F SP 320F Spabond 120 F SP 106F	Ampreg 26 F Ampreg 22 F Ampreg 20 F SP 320 SL Spabond 120F SP 106F	Ampreg 20 Std Spabond 120 SL SP 106 SL
200cc - 500cc	Ampreg 26 F Ampreg 22 F Ampreg 20 F SP 320 S Spabond 120 F SP 106 S	Ampreg 26 SL Ampreg 22 XS Ampreg 20 Std SP 320 SL Spabond 120 SL SP 106 SL	Ampreg 26 SL Ampreg 22 XS Ampreg 20 Std SP 320 SL Spabond 120 SL SP 106 XS	Ampreg 26 SL Ampreg 22 XS Ampreg 20 SL SP 320 SL Spabond 120 SL SP 106 XS
500 cc +	Ampreg 26 SL Ampreg 22 XS Ampreg 20 Std SP 320 SL Spabond 120 SL SP 106 SL	Ampreg 26 SL Ampreg 22 XS Ampreg 20 Std SP 320 SL Spabond 120 SL SP 106 XS	Ampreg 26 SL Ampreg 22 XS Ampreg 20 SL Spabond 120 SL SP 106 XS	Ampreg 26 SL Ampreg 22 XS Ampreg 20 SL

*Volume approximate (Resin/hardener/fillers)

Filler Ingredients

Whereas the resin system will control the working characteristics, mechanical and chemical properties of a filler, the filler ingredients will dictate how easy the filler will be to apply and finally sand down to provide a fair smooth finish.

The 'hollow sphere' type of filler is the only type which will create a filler mix with the two desirable characteristics of being both lightweight and relatively easy to sand. This type of filler can also be used for structural adhesive purposes, especially for low density fillet bonding. However, the glue mix created is relatively weak and therefore it should be restricted to certain types of wood bonding.

Hollow spheres are often described as "microspheres" and are very effective at reducing the density of the mix by displacing resin. As the microspheres have a hard, resin resistant 'shell' the resin does not penetrate the 'interior' of the bubble. Although the user is free to add whatever filler proportion serves his particular needs, there is a maximum practical additive level for each type of filler powder. There must always be sufficient resin present to coat each microsphere and bond one microsphere to the next, effectively creating a type of 'foam'. The greater the proportion of the filler ingredient added, the lower the density of the filler mix will become.

If too much filler powder is added to the resin (beyond the point where all microspheres are effectively coated), the mix will become 'dry' and 'pasty', and difficult to work. It also may not bond well to the surface to which it is being applied.

The two principal types of hollow bubble filler are phenolic microballoons and glass bubbles. Tables 2 and 3 outline their principal physical properties and compare the characteristics of the filler mixes created.

TABLE 2 - Physical Properties of the Principal Filler Ingredients Used for Filling and Fairing

'Hollow Sphere' Filler	Particle Density	Bulk Density Compacted*	Composition	Particle Size	Appearance
SP Microballoons	0.25 g/cc	0.10 g/cc	Phenolic resin	50 Microns	Reddish Brown Powder
SP Glass Bubbles	0.20 g/cc	0.15 g/cc	Up to 70% Silicon dioxide plus other oxides	40-80 Microns average	Free-flowing white powder

*The bulk density figures for each filler type were calculated from volume and weight figures. The volume figure for each filler was obtained by applying hand pressure to a smooth flat disc laid on the filler surface within an SP Systems 0.5 litre plastic measuring cup until no further compaction could be achieved. The filler volume was read from the side of the container and the contents weighed.

TABLE 3 - Comparative Properties of Fairing Mixes Created from Different 'Hollow Sphere' Ingredients

Property	Ranking Order		1	2
Density	1 = Lightest	2 = Heaviest	Phenolic Microballoons	Glass Bubbles
Physical hardness	1 = Softest	2 = Hardest	Phenolic Microballoons	Glass Bubbles
Ease of sanding of filler mix	1 = Easiest	2 = Most difficult	Phenolic Microballoons	Glass Bubbles
Water resistance of mix	1 = Highest	2 = Lowest	Glass Bubbles	Phenolic Microballoons
Cost to create low density filler mixes	1 = Cheapest	2 = Most expensive	Glass Bubbles	Phenolic Microballoons

Preparation Guidline for Filling on Different Substrates

Wood

Wood is an absorbent material and therefore the best possible adhesion is obtained by first pre-coating with an unfilled solvent-free epoxy resin and hardener mix. The filler mix can then be applied either after first leaving the surface to cure and then sanding to obtain a good key, or whilst the initial unfilled epoxy coating is still wet or tacky. Deep indentations or screw holes may be filled without pre-coating.

Polyester GRP

a) Fibrous Laminate Surface without Gel Coat

Pre-coat with clear, unfilled solvent-free epoxy resin mix first and treat as for bare wood. Polyester grp should be well cured otherwise the epoxy cure will be inhibited and there will be poor adhesion to the surface.

b) Polyester Gelcoat Surface

Wet sand with 150 - 180 grit paper then solvent wipe with a fast evaporating epoxy solvent (e.g. SP Solvent A) to obtain a good key. The polyester should be well-cured.

Polyester Filler or Epoxy Filler

A previously filled surface should be well abraded with 40 - 80 grit production paper and wiped with fast evaporating solvent (e.g. SP Solvent A) before commencing any further filling. The polyester should be well-cured if epoxy filler is to be used.

Epoxy FRP

This may or may not have used nylon peel ply incorporated into the last laminate layer. If it had, then tear away the peel ply and simply apply the filler. If no peel ply was used then sand the surface thoroughly with 80 grit production paper and clean with SP Solvent A (Fast Epoxy Solvent) or other fast evaporating solvent such as clean acetone.

Metal

a) Sand-blasted

For the best possible adhesion, first wipe with Solvent A then pre-coat with a thin unfilled solvent-free epoxy resin mix. Then apply filler mix whilst this coating is still tacky.

b) Primed

Metal primers should ideally be epoxy based and be well sanded, followed by a wipe with fast evaporating solvent to give the epoxy filler a good key.

Ferro-Cement

First check that no metal reinforcement is standing level or proud of the surface. Clean off laitance and preferably wash with dilute hydrochloric acid. Brush off and dry, then treat surface as for bare wood.

Combination Quantities of Resin & Filler Ingredients

Where the 'recipe' method of creating an epoxy filler mix has been selected, the following information contains guidelines for making the mix to a fairing consistency. The relative quantities suggested may be varied by the user to create thinner, thicker or more thixotropic mixes to suit individual application needs.

Mixes of lower density can be created for other applications e.g. to create a low density 'syntactic' foam for filling rather than fairing purposes. Here the mix may have a higher filler loading to allow application by trowel in specific areas. As a specific example a Microballoon mix for this purpose can be made with a density of 0.5 g/cc rather than one nearer 0.6 g/cc used for fairing. Fairing mixes are required to be more mobile because of the greater area to be covered and to suit the tools and application equipment used.

Note the inclusion of colloidal silica to the mix in every case. Although added in relatively small volume compared to the primary filler ingredient, colloidal silica serves the very useful function of giving additional non-sag properties to the mix. This is a particularly desirable for vertical or sloping surfaces where some 'sagging' in a filler mix may be expected whilst the filler is still in a workable state, before sufficient hardening has taken place. The following material weights (Table 4) will create one litre of low density epoxy filler.

TABLE 4

Primary Filler	Primary Filler Weight	Colloidal Silica Weight	Resin + Hardener Weight	Total Filler mix Weight	Approx Density of Mix
SP Microballoons	125g	11g	450g	~580g	0.6g/cc
SP Glass Bubbles	125g	13g	330g	~470g	0.5g/cc

One litre of filler, if spread evenly, will produce an average 1mm thickness over an area of 1m^2. Generally, for filling and fairing on rough surfaces, sufficient quantities of resin system and fillers should be ordered to allow for an average thickness of 2mm (2 litres of filler mix per sq.m). This will allow for uneven surfaces and losses through sanding.

Ordering Resin System and Fillers

The following information will be useful when ordering suitable epoxy resin system and filler ingredients to create fairing mixes using SP Microballoons. The quantities indicated in Table 5 will produce a low density filler mix sufficient to cover the area shown to an average thickness of 1.0mm.

TABLE 5

Area to be Faired (m^2)	Wt of Epoxy Resin & Hardener (kg)	Weight of Microballoons (kg)	Weight of Colloidal Silica (kg)
5	2.2	0.67	0.06
10	4.4	1.33	0.11
20	8.8	2.66	0.22
30	13.2	3.99	0.33
40	17.6	5.32	0.44
50	22.0	6.65	0.55

Measuring out Epoxy Resin and Hardener by Weight

The weight method of measuring relative amounts of epoxy resin and hardener is the most accurate method of combining the components in exactly the right ratio. Volume methods using graduated cups may be sufficiently accurate for epoxy systems with simple mix ratios such as 2:1 or 3:1 resin-to-hardener ratios. Metering resin and hardener using SP minipumps (1 litre packs) or Maxipumps (larger packs) may be appropriate for small volumes found in some adhesive applications but is too laborious for the volumes generally used for creating fairing mixes.

Measuring by weight is easily achieved using simple, inexpensive electronic scales. Those of either 2 kg or 5 kg capacity which have an accuracy of $\pm$ 2% are most suitable. The following (Table 6) indicates the mix ratios of resin : hardener by weight of the SP epoxy systems which are commonly used to create filler mixes.

TABLE 6 - Mix Ratio of resin : hardener by Weight

Epoxy System	Resin	Hardener (parts by weight)
Ampreg 26	100	33.3
Ampreg 22	100	28
Ampreg 20	100	25
SP 320	100	33.3
Spabond 120	100	44
SP 106	100	18

Using Epoxy Filler in Fairing

Procedures

This section is divided into:

a) **Overall Fairing -** the removal of high spots in order to create a fair shape which blends perfectly into the overall shape.

b) **Localized Fairing -** making small areas such as fastening holes or local voids smooth to the touch and undetectable.

Preparing the Mix

Select an appropriate epoxy resin system and hardener speed to suit the application (see Table 1). Measure out sufficient quantities of materials to make a suitable quantity of filler which can be spread over the work area and made smooth well within the working time that the hardener will allow. Ideally start with small volumes until some idea of working time is gained. In order to prevent early gelling of the resin and hardener before the application is finished, reduce mix volumes if ambient temperature levels rise or a faster hardener is used.

Mix components thoroughly. Always mix resin and hardener thoroughly first before adding filler ingredients. Choose a suitable vessel such as a smooth-sided plastic tub in which to mix the filler. Once mixed, transfer the filler mix to a board and spread thinly (maybe up to 10 mm thick) to help dissipate the heat of the resin/ hardener chemical reaction and so lengthen the working time of the mix.

Application

a) Overall Fairing

Using a plasterers 'hawk' to hold a suitable volume of filler, transfer a manageable amount to the surface using a flexible metal applicator and apply in thin layers to avoid air pockets. For fairing large areas of 3-5m^2 at a time on boat hulls use a plastic fairing batten (a length of plastic drain pipe is sometimes used) held by two people. Aim at a slight overfill. Apply no more than 3-4 mm at a time.

On very unfair hulls the 'notched applicator' technique is useful whereby the initial filler application is by a batten with a 'notched' or serrated edge, which gives a furrowed surface to the filler. Once hardened the surface is sanded using long sanding boards which will take off the tops of the 'ridges' on the high areas and leave them intact on the low areas of the surface. This technique ensures that the minimum of filler is used and sanding time is shortened because only 50% of the normal filler quantity is removed with every sanding stroke.

Once fair the hollow areas and 'furrows' are filled level to the original epoxy surface, it is useful to use a slightly colour-tinted mix for the second filler application to differentiate it from the first when subsequently sanding.

b) Localized Fairing

Apply the filler with a spatula or metal straight edge. A higher loading of primary filler is often used together with colloidal silica, to create a stiffer filler mix for this type of filling.

Curing

All epoxy filler mixes will sand most easily when fully cured because a fully-cured polymerised epoxy will not soften as a result of the heat-generating abrasive action.

Since most filler mixes are sanded before being fully cured, a coarser grade of paper will be necessary in order to avoid 'clogging'. Warm conditions with, ideally, low humidity help the epoxy components to cure most effectively.

Working with Cured Epoxy Filler

Preliminary Fairing

The aim of fairing is to remove excess filler in a controlled manner in order to ensure a visually 'perfect' surface. A variety of tools and cutting edges may be used in the initial stages to remove the worst lumps of filler to create a surface on which abrasive paper will be most effective.

The following (Table 7) outlines some of the tools which may be used.

TABLE 7

Surface	Tool	Working Mode
Coarse lumps & bumps	'Surform' Cabinet scraper	Multiple blade Single blade
	Angle grinder	Abrasive sanding pad and disc
Smooth filler	Stiff or flexible board Electric or air powered random orbital sander	Abrasive paper sheet or abrasive disc

Using Abrasive Papers in Fairing and Finishing

Two basic types of abrasive paper are usually used. For more coarse sanding the paper used is aluminium oxide 'production' paper obtained by the metre from a roll. This can be cut to convenient length to use on boards or mechanical sanders. The other type is wet or dry silicon carbide paper which can be used either wet (with water as the 'lubricant'), or dry and is always used for final finishing of coatings. The abrasive paper is usually cut and used on a rubber palm-held sanding pad.

The following (Table 8) is a guide to the abrasive grades used at the different stages of fairing.

TABLE 8 - Grade and Type of Abrasive Paper

Surface	Type of Sanding	Production Paper Grade	Wet-or-Dry Grade
Epoxy filler or wood	General rough fairing	40 - 60	Not used
	Fine fairing	80 - 100	Rarely used
	Finishing (wood only)	120 - 180	180 - 220
Polyester gelcoat	Surface preparation	120 - 180	180
High-build epoxy surfacer/ undercoat SP Hibuild 302	Fine surface fairing	80 - 120	120 - 180
Polyurethane undercoats	Very fine surface fairing	180	180 - 220
	Keying for finish coats	Not used	280 - 320
Polyurethane finish coats	Very fine surface fairing and keying	Not used	280 - 320

Note: The lower the 'grade' number the larger the grit particle and the lowest density of cutting particles.

Fine Fairing and Finishing

Once the main fairing has been completed, leaving a sanded, fair, smooth surface, the next stage is to use a type of coating system which is characterised by its high loading of fine filler ingredients. These high build, undercoat/surfacer type of products are more common in the automotive industry but are becoming increasingly used as part of the fairing process in the marine industry.

SP Hibuild 302 has the ideal characteristics for application over sanded filler to serve as an intermediate stage before the finishing coats of a paint system. Although solvent based, Hibuild 302 has a very high solids content, consisting of resin solids and easily sanded fillers. This serves to both minimize shrinkage on cure and fill the sanding marks and other imperfections such as small air pockets on the filler surface, which normal undercoats cannot mask. Quick-drying characteristics lead to rapid overcoating and early sanding. Additional fillers may also be added to increase the solids content and facilitate easy sanding if required.

Hibuild 302 may be applied by brush, roller or conventional spray and is available in both white and light grey. It is common when fairing yacht hulls to use both colours alternately in order to identify high and low spots.

Hibuild 302 is usually sanded dry, at least initially, then overcoated with a paint undercoat, usually a two-pack polyurethane. This product is best sanded wet with fine abrasive to leave a surface which is sufficiently well prepared to take a gloss paint finish.

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SP Systems therefore strongly recommend that representative test panels and component sections are built and tested by the user in order to define the best process and materials to use for the desired component. This should be done under conditions as close as possible to those that will be used on the final component.

SP Systems' guides are being continuously reviewed and updated. Please ensure that you have the current version before using the product, by contacting SP Systems' Marketing Services and quoting the revision number in the bottom left-hand corner of this page.

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