A Technical Guide to Epoxy and Polyurethane Coating Systems for Marine Applications

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INTRODUCTION

Sophisticated two part epoxy and polyurethane coating systems are used increasingly by the marine industry in preference to conventional one component products due to their superior mechanical properties and protection against long term environmental degradation.

Both epoxy and polyurethane two part coating systems are of the reaction type whereby the base resin and a hardener are combined just prior to application. This is true of both solvent-free and solvent-based types (see later section). Once applied to the surface, the coating cures either immediately (in solvent-free products) or after the solvents have left the film (in the solvent-based systems).

It is a direct result of this chemical reaction that in aggressive environments these materials can offer significant advantages over one-component coatings which rely on drying or surface oxidation to cure.

This article discusses the relative merits of epoxy and polyurethane systems in their various forms and provides a basic guide to the properties of the two systems.

CHEMISTRY

In order to fully understand the different film properties and applications of each product a basic understanding of their chemistry is worthwhile.

Epoxy Resins

Epoxy resins consist of a linear chain molecule with a reactive epoxy group at each end of the chain. Each particular type of epoxy resin varies in terms of its detailed structure and the length of the chain between the epoxy groups. For example, short chains give liquid resins whereas longer chains give solid epoxy resins.

A variety of agents can be used to cure epoxies but for marine coating applications the main hardeners are amine based. When mixed with the epoxy resin, the amine 'active site' reacts with the epoxy 'active site' and a chemical bond is formed which links the resin and hardener chains together. Once all the amine sites have reacted with the epoxy sites a three dimensional network is achieved.

An important feature of this curing mechanism is that there is a fixed chemical ratio in which the epoxy and amine molecular sites react together: two epoxy active sites to one amine active site. However, due to the inclusion of additives and non-reactive chemicals in either the resin or hardener, and also the inclusion of solvents in solvent-based coatings, the physical mix ratios vary from 1:1 to 5:1 or more. If there is an excess of either component, a full cross-linked network will not be achieved and therefore the mechanical properties of the coating will be degraded. It is for this reason that manufacturers of epoxy systems stress the importance of accurate mixing to the specified ratio.

The actual properties of the final coatings are very much dependent on the type of resin and hardener used. Solid epoxy resins have larger molecules and thereby the distance between cross-linking points is greater, which results in more flexible and resilient films: liquid resins with shorter chains give harder and stronger films due to more dense cross-linking.

Polyurethane Resins

Technically speaking the term epoxy refers to the uncured resin component only (the hardener is usually an amine) whereas polyurethane is the generic term for the cured product which is formed from a chemical reaction between a polyol resin and a polyisocyanate hardener.

When the two components are mixed the hydroxyl groups (-OH) in the resin react with the isocyanate groups (N=C=O) in the hardener and a three dimensional molecular structure is produced.

Only one isocyanate group can react with one hydroxyl group so there is an ideal ratio of hardener molecules to resin molecules which will give optimum mechanical properties. Despite this fact, it is possible to vary this ratio slightly either way in order to modify the mechanical properties of the system. This is because the isocyanate hardener is also capable of cross-linking with itself in the presence of atmospheric moisture.

More hardener than the optimum ratio will produce coatings which are harder, more brittle and have greater resistance to chemical attack. Less hardener will have the opposite effect: the film will be more flexible and its resistance to weathering will decrease.

Therefore it follows that a polyurethane coating can accommodate a degree of variance in the mixing ratio but not without this having some effect on the properties of the final film.

Generally speaking polyurethane systems cure faster than their epoxy counter-parts. They can however, be difficult to use when cured in moist conditions at low temperatures, again because of the affinity of the isocyanate for moisture. This may result in an inadequate cure and premature embrittlement.

■ COATING REQUIREMENTS

The main role of a coating, whether it is used as a primer, intermediate coating or top coat is to protect the substrate to which it is applied and, in some cases, to enhance its appearance. To be considered effective it must give the desired protection level for as long as possible against environmental and mechanical damage. In order to achieve this level of performance good adhesion to the surface and a resistance to moisture and sunlight (ultraviolet) are essential.

Table 1 provides a guide to the relative performance of two component epoxy and polyurethane systems.

Table 1

Property	Epoxy	Polyurethane
Adhesion	Excellent	Good
Water resistance	Excellent	Good
Cure speed	Good	Excellent
Susceptibility to moisture during curing	Little to considerable	Considerable
Gloss retention	Poor	Very good
Abrasion resistance	Good	Excellent

It is apparent that epoxy systems are particularly suitable for use as primer and intermediate coatings because of their good adhesion and water resistance whereas polyurethanes offer very good colour stability and gloss retention and therefore they tend to be used for top coats where a cosmetic finish is required.

Where there is a requirement for good adhesion and water resistance as well as high gloss and colour stability (i.e. non-yellowing) epoxy and polyurethane systems can be used in combination on the same substrate.

The benefits of this combination of materials are clearly illustrated on many of the high performance wooden racing dinghies and cruiser/racers currently racing, where a top quality clear coating is required to enhance the woodwork. Epocoat 301 solvent-based epoxy coating system or SP 320 solvent-free epoxy system can be used as a primer and SP Ultravar 2000 polyurethane is employed as a high gloss topcoat. After several years of exposure to sailing conditions the finish is still clear and bright, and the adhesion of the materials to the wood is sound.

■ SOLVENT BASED AND SOLVENT FREE EPOXY SYSTEMS

Two methods are currently employed to form a film of epoxy on a substrate. The first involves using a liquid resin and a liquid hardener which are mixed together and applied to the substrate. The second method comprises a solution of resin and hardener in a solvent which is designed to evaporate once the material has been applied in a thin film.

A solvent-free or 100% coating is produced by the first method whereas the second is referred to as a solvent-based coating. As it is not possible to manufacture polyurethane resins with low viscosities, all polyurethane resin coatings are solvent-based.

Each system has its advantages and disadvantages, a summary of which is outlined in Table 2.

Table 2

Property	Solvent-Free	Solvent-Based
Max. film thickness (one application)	Unlimited	150 microns
Cure Speed	Comparable	Comparable
Moisture susceptibility during cure	High	Low
Pot Life	Very short	Long
Mixing accuracy	Must be accurate	More tolerant
Water resistance	Very good	Very good
Film Strength	Strong but can be brittle	More flexible
Colour stability	Poor	Fair to good
Film shrinkage on cure	None	Up to 70%

The major advantage of solvent-free systems, such as SP 320 is that a very thick coating can be applied in a single application. It is this feature which gives solvent-free coatings their good gap filling properties.

In comparison, solvent-based systems are normally limited to a wet film thickness of approximately 250 microns because a greater thickness could result in solvent entrapment which prolongs drying and can lead to a semi-cured coating.

However, the thick coating advantage can be more than offset by the disadvantage of the short pot life of solvent-free systems which can pose difficulties if large areas are to be coated. This problem can be overcome by using heated mixing and spraying equipment but the throughput of coating work has to be sufficient to justify the capital expenditure of such equipment. The pot life of solvent-based systems does not present the same problems because the solvents used have a retarding effect on the gel time.

In addition solvent-free epoxy systems can suffer from a surface by-product caused by interaction of the chemicals of the system with water and CO_2 in the air, and which should be removed before overcoating.

Another problem with solvent-free epoxy systems is their potential susceptibility to moisture which can result in a 'blooming' effect on the finished surface. This is caused by the active amine curing agents which are used to achieve a fast thin film cure. These tend to react with water and therefore are should be taken not to apply the system in a damp environment. Solvent-based systems do not suffer to the same degree from this problem as they employ solid resins and pre-reacted hardeners.

The two types of system do not suffer to the same extent from ultraviolet degradation. Generally, solvent-based epoxy systems (e.g. Epocoat 301) exhibit superior light stability and clarity.

■ HANDLING AND SAFETY

As with almost all resin systems, it is important that both polyurethanes and epoxies are used in accordance with the manufacturer's recommendations regarding safety and handling.

All solvents are potentially hazardous if used incorrectly and care should be taken to apply solvent-based systems in a well ventilated area.

Skin irritation is often seen as a particular problem with epoxy systems. However, many manufacturers have minimised this problem by using, as is the case with Epocoat 301 and Hibuild 302, a partially reacted hardener. Barrier cream and/or gloves should be used as a further precaution.

Care should still be taken to avoid skin contact where possible and any material which does come into contact with the skin should be removed as soon as possible using a resin removing cream.