USING PHASE TWO™ EPOXY RESIN

W. Kern Hendricks
System Three Resins
Seattle, Washington

INTRODUCTION

Phase Two is an epoxy resin system especially designed for building composite boat hulls with foam, balsa or honeycomb cores. It achieves an optimum balance of mechanical and toughness properties by utilizing two-phase morphology. A paper presented at the 1986 annual meeting of the Society of Plastics Industry titled *Two Phase Epoxy Systems for Composite Cored Boat Construction* will furnish the interested reader with a detailed discussion of the concepts behind the development of Phase Two. Tables 1 & 2 of that paper give the physical testing data for the "neat" resin along with laminate test data. It is not necessary, however to understand the concepts behind Phase Two in order to properly use it. Rest assured that it is a highly tested epoxy system for wet lay-up work and is far superior to polyester, vinyl ester or other epoxy laminating resins existing today. Like other high performance resins, Phase Two requires a mild post heat cure prior to placing the part in service.

MEASURING AND MIXING PHASE TWO

Although the chemistry and morphology behind Phase Two is exceedingly complex, it is as simple to use as any other laminating resin. It is measured and mixed exactly like other epoxy systems. Phase Two is used at 10 parts of resin to 4 parts of converter BY VOLUME or 3 parts of resin to 1 part of converter BY WEIGHT (33phr). The "pot life" is 105 minutes at 77°F allowing ample time to carefully measure and thoroughly mix the resin and converter even when using large batches. The Phase Two measuring system is a fast, low cost way to prepare and measure quart to gallon batches. Generally, only the amount that will be used within 30-40 minutes should be mixed. This is because Phase Two will increase in viscosity prior to gellation. This viscosity increase will make it more difficult to wet out the fabric being used. When spread out Phase Two has sufficient open time to allow vacuum bagging large parts. Once mixed, Phase Two is used just like any other wet lay-up resin. It should never be sprayed, however. In shops with several workers the possibility of measuring and mixing errors is greatly reduced when one person is assigned the task of doing this job.

Phase Two is clear when first mixed. As it begins to cure it will start to turn opaque as the second phase forms. Thick sections appear creamy white when fully cured. This opacity is difficult to see in high fiber to resin ratio laminates.

Most polyester/vinyl ester resin mold release systems work well with Phase Two. System Three Resins has tested a number of release systems and finds that the best results have been obtained when using PVA (polyvinyl alcohol) parting films. This film releases from the waxed or coated mold and can then be removed with water from the part. Phase Two has outstanding fracture resistance and may stick tenaciously to materials that will release parts made from the ester resins or even other epoxy systems. The prudent builder will test his mold release system with small Phase Two laminates prior to committing an entire mold. Cured Phase Two will not stick to polyethylene, Saran, Teflon or similar plastic films. It will stick moderately well to several of the fluorocarbon and paste wax release systems.

Phase Two is designed to be used "as is" for large vacuum bagged hulls. The open mold time is about 4 hours at 70°F. Thin film set time is about 6 hours at that temperature. Quicker set times are possible with the addition of Phase Two Accelerator. Set times as short as two hours are possible. However, these come at the expense of a great reduction of pot life. Phase Two should not be used below 50°F. Use accelerator when the temperature is below 60°F.

PHASE TWO ACCELERATOR

Pot life and cure times may be controlled with Phase Two Accelerator. The builder should only use this accelerator if ambient temperatures are low or the part is small so that long pot life is unimportant. Indiscriminate use of Phase Two Accelerator will not get the boat launched faster and may cause pot life and wet-out problems as this is a very powerful accelerator. Phase Two has a normal pot life of 105 minutes at 77°F and a thin film set time of about 6 hours. As little as 2 percent accelerator will cut the thin film set time in half. However, the pot life will be cut by 80 percent. Fast set times always come at great expense to pot life in accelerated systems.

The Phase Two curing reaction is exothermic – that is, heat is produced when the product cures. The amount of heat produced is proportionate to the mass of the mixed resin/converter and independent of any accelerator used. Adding accelerator has the effect of shortening the time period in which the heat is produced. The net effect is to raise the temperature of a gelling accelerated mass much higher than an equal mass without accelerator. If too much accelerator is used, Phase Two may foam in the pot and char during gellation.

Using Phase Two Accelerator is quite simple. Resin and converter are measured and mixed. The appropriate amount of accelerator based on the mixed volume is added using the syringe provided in the accelerator kit. This mixed in well and used immediately. Mixed Phase Two is greenish yellow. It will immediately turn an iridescent yellow green when the accelerator is mixed in. Phase Two Accelerator is water-soluble. Spills should be cleaned up with water. Do not wipe the syringe with solvent, as this will remove the markings.

The data below will serve as a guide for accelerating Phase Two. While these data apply to 100 grams of mixed mass at 77°F, different amounts at other temperatures may be approximated as follows: Every 18°F change in temperature will halve the gel time for higher temperatures and double it for lower temperatures. Amounts of material one quart and above held in the pot will have gel times 30 to 40 percent lower than those shown below. For example, one quart at 60°F would have a gel time of about 40 minutes with 20cc of accelerator added. Never use accelerator at a level higher than 30cc per quart of mixed Phase Two resin and converter.

Phase Two Accelerator

Accelerator Amount				
CC/Quart	Percent	Gel Time	Set Time	Open Time
0	0	105	360	270
5	.66	86	300	215
10	1.32	62	250	180
15	1.99	50	215	150
20	2.65	28	185	125
25	3.31	24	160	105
30	3.98	22	140	90

Time in minutes. Percent figures are by weight. The density of Phase Two Accelerator is 1.4gm/cc (11.7 #/gallon)

BUILDING THE HULLS

This section is not meant to be a treatise on building composite cored boat hulls. There are many excellent books on that subject. There are some points that should be mentioned with respect to both male and female molding with Phase Two.

In male molding the core material is usually laid onto the mold. The outer skin is then applied. The hull is removed from the mold and the inner skin applied. Phase Two achieves maximum strength only after a post cure (described below). A cored boat hull with only one skin attached is not structurally strong. If this method is used, Phase Two should be post cured prior to removal of the hull from the mold. If this is impossible then the hull should sit on he mold for at least a week so that Phase Two has achieved maximum physical properties for room temperature cures. Even then the builder should exercise extreme caution when turning the boat. Great care must also be taken when post curing a hull that sits only in a cradle.

A variation of male molding is to skin the mold with Masonite, apply mold release, laminate the inner skin, attach the core material and then laminate the outer skin. Female molding is very similar to this except that the mold is concave. In either case the entire hull is laminated prior to removing it from the mold. The skin next to the mold is laminated first and may be allowed to cure prior to attaching the core. When done this way, peel ply should be used as the last layer and removed after the skin has hardened leaving a good bonding surface. The core is bedded in thickened Phase Two epoxy and vacuum bagged until the Phase Two has set. Both milled glass fibers and Cab-O-Sil have been successfully used to thicken Phase Two for this bonding layer. Make sure that there is sufficient thickened material present to get a good bond between the cured glass laminate and the core. After the core is bonded the scrim is removed and the second skin is laminated onto the core.

It is possible to laminate the mold skin and vacuum bag the core before the mold skin hardens. This is a tricky operation requiring large and well-coordinated crew if the hull is at all large. About the only advantage to this method is that slightly less resin is used in the bonding layer.

With either method thought must be given to how the boat will be post-cured. Core materials are good heat insulators. Less actual heating time will be spent if laminates are heated directly rather than trying to drive heat through the core to the laminate. The female mold method is probably the easier to post cure, as the mold itself becomes the heat retainer.

One-off boats need some fairing prior to finishing. For this reason they almost never use gelcoat. System Three epoxy is less expensive and works much easier than Phase Two to make a fairing compound. These compounds are not structural and do not need the physical properties of Phase Two. In fact, there is no reason to use Phase Two for anything other than the skin laminates for the hull, deck, bulkheads, ring frames, and other structural laminates.

Composite-cored laminates usually fail in testing because of initial delamination between the core and skins. Foam core laminates fail most often as a result of core shear at the interface. Balsa core laminates fail because of simple delamination at the interface. Either material will show much less strength if the skin is poorly bonded to the core. Poor interfacial bond strengths are usually the result of resin starvation at the bond line. Be sure to get enough resin between the skin laminate and core to assure a good bond. Vacuum bagging is necessary to make sure there is enough pressure for good contact.

Another troublesome area for some builders is achieving the proper resin/glass ration. While a heavy and weaker boat will result if the laminate is overly resin rich; a lighter and weaker boat will just as surely result if the laminate is overly resin poor. While most fabrics have ideal fiber volume ratios for maximum strength in laminates, the acceptable range is quite large with these fabrics and Phase Two epoxy. A 50/50 weight fiberglass laminate is acceptable for most applications. This might drop to 40/60 (resin/glass) in ultra high tech racing multihulls. Whatever ratio is sought, it should be approached from a resin rich standpoint. That is, excess resin should be squeegeed out of the laminate. It is poor form to make a laminate by mixing an amount of resin equal to the final ratio sought and then trying to spread it out evenly. A weak laminate with starved areas and dry fibers will result. Error on the side of having a little too much resin in the laminate rather than too little.

VACUUM BAGGING

Most one-off boat hulls only use vacuum bagging to attach the core to the skin laminate. While it is possible to bag the skins to increase the fiber volume ration; the results are only marginally better than doing a careful wet lay-up job. Either way the bagging procedure is about the same.

Vacuum bagging takes advantage of the fact that we reside at the bottom of an ocean of air that exerts an absolute pressure of about 15 pounds per square inch (psi) at the earth's surface. If air is removed from a closed vessel then the atmosphere will exert pressure on the vessel. Furthermore, the pressure exerted is equalized in all directions so that the vessel can be under a lot of "squeezing" force without having it distort in the process. If, for example, one square foot of laminate with core stuck on with a Phase Two bedding compound (uncured, of course) were put in an envelope and enough air evacuated so that an attached gauge read 5psi of vacuum; the laminate/core would be squeezed together with over 700 pounds of force. Despite this huge squeezing force, the envelope is under no net force as the pressure on all sides is equalized and cancels out.

The requirements for vacuum bagging are two: To have an airtight envelope and to be able to evacuate enough air to achieve sufficient squeezing force. Fortunately, both are easy and inexpensive to do. One side of the envelope or bag already exists. It is the mold and skin laminate. All that is required to complete the bag is to seal the other side. Polyethylene sheeting (4mil thickness) works well. The sheeting is laid over the core and sealed to the mold closing the bag. Some type of air bleeder should be used on top of the core under the bag so that the suction hose can evacuate air from distant parts of the bag. Common packaging "bubble pack" works very well with cores. Skin laminate bagging requires peel ply and bleeder cloth. Many different materials can be used to seal the bag. A putty-like material that comes in rolls works well. So do rubber based caulking sealants. Be sure to put the sealant on the mold – not the laminate.

The second requirement is a pump to remove air from the sealed bag. The best device is a high volume, low vacuum pump rather than high vacuum, low volume pump. Not much vacuum is required – 5psi is plenty. However, there may be some leaks in the bag and the high volume pump will over-whelm these leaks sealing the bag. An old industrial vacuum cleaner (the type with the pot on wheels) works beautifully and could easily be used to bag the core on a 60-foot boat. Just stick the hose between the mold and bag, seal it and flip the switch. Plug any holes in the bag with duct tape. Put a little hole in the hose to bleed air into the motor as it runs. This helps it run cooler and more efficiently.

The vacuum should be left on until the Phase Two bonding compound reaches a plastic putty state. Turn it off then and let it cure overnight. Remove the bag. Clean up the sealant, remove the core scrim and proceed with the second skin. If the hull was built in the traditional male mold method, vacuum bagging wasn't necessary as skins can be readily laminated to the core.

CURING PHASE TWO

Phase Two must have a post heat cure to reach maximum physical properties. All that is required is 140°F for two hours. This is the time and temperature needed for the laminate. If the hull is being post cured in a female mold in one session, then more time will be necessary, as the heat will have to driven through the core and mold. Although heat curing may appear frightening at first glance, it is really quite easy to do. Before getting into detail it helps to understand why this post cure is necessary and what is achieved by doing it.

Phase Two is a very high modulus laminating resin system compared to other room temperature cured systems. This high modulus is necessary to achieve stiffness, a very desirable property, in the laminate. On a molecular level, high modulus in the matrix resin comes as a result of the molecular structure being very rigid. That is, the molecules can't move much in relationship to each other. They are highly crosslinked and rigidly held in place. Unfortunately, molecules need to move in relationship to each other so that they can come close enough together to chemically react. In the liquid state this is no problem as they slither over and under each other like so many snakes in a barrel. As the material solidifies the mobility becomes less and less until, finally, the movement is insufficient and the chemical reaction stops. At this point there are plenty of reactive sites left – they just can't get close enough to react. Heat solves this problem.

Heat is nothing more than molecules in motion. As a material is heated it absorbs energy by increasing molecular movement. This is exactly what is necessary to finish off the curing reaction in Phase Two. But there is a further benefit to this heat. The chemical reaction proceeds much faster than at room temperature. But the reaction is not instantaneous and how fast the hull is heated can become important.

Ideally, the hull should be heated so that heating induces a loss in rigidity at the same rate the chemical reaction increases rigidity through crosslinking. That way, the hull never really weakens. It simply cures. If it is heated too quickly the laminates will become rubbery until the crosslinking reaction increases their rigidity. As long as the boat hull is well supported in the mold this is no problem. The male molded hull supported in the cradle could be a problem if the temperature is increased too quickly. At worst slight warpage would occur requiring extra fairing. Usually, however, the chemical reaction is crosslinking the matrix resin faster than the hull can be heated. This is because the volume and mass of the hull is large and takes some time to heat.

Most builders post cure the hull in cooler climates by enclosing it in a tent-like structure. On a male mold several lines can be stretched over the hull. The tent is completed with the addition of tarps. Propane space heaters can be rented from almost any industrial equipment rental store for the day. Don't use kerosene or diesel heaters as these throw off unburnt hydrocarbons, which will coat the hulls and cause future bonding problems. Heaters need oxygen to operate so thought should be given to properly venting them. A couple of big fans in the tent will mix the air to produce uniform heating. Toss a couple of thermometers around in strategic locations and turn on the heat. Try to reach 140°F and hold it there for a couple of hours. As long as you are over 120°F the hulls will be fine although they won't reach the maximum heat deflection temperature possible with Phase Two resin. If you can't reach 140°F then don't paint the hulls any darker then beige. The hulls can be heated all the way to 160°F without damaging the skins. However, some core materials will not take this much heat.

Be very aware that any combustion process can produce deadly carbon monoxide. Never enter the tent or enclosed boat hull without having a person outside to make sure you are all right inside. Other than to occasionally check the thermometers there is absolutely no reason to go inside the tent. This does not mean that no one should be in the area when the hull is cured. Be aware that any heater can cause a fire if improperly used. Always have a person in attendance during the curing process.

Builders post curing hulls in the summer in warmer climates have successfully done so by moving the mold out into the sun and covering with black polyethylene for the day. Anyway it is done is fine.

After the hull reaches the proper temperature and stays there for two hours it may be cooled and removed from the mold. Turn off the heat, remove any tarps and let it cool to room temperature. Once there, it has reached full strength and can be de-molded.

The post curing process may be done anytime after the Phase Two in the laminate solidifies. Waiting even a month poses no problem. Usually it is best to wait several days to give the laminate time to cure about as far as it will at room temperature. Material cured at temperatures too cold for a very short period of time may partially melt prior to crosslinking during heating. The solution is to either wait several days or ramp the temperature up very slowly.

FINISHING THE HULLS

Almost all one-off boats are faired prior to painting. This can be done with System Three rather than Phase Two epoxy. *The Epoxy Book,* published by System Three Resins, provides recipes and tips for fairing. Never use a polyester fairing compound over an epoxy resin. It simply will not properly cure or bond well.

The best paints for epoxy boat hulls are the linear polyurethane painting systems. Properly done the LPU painted hull will be glossier, and last longer than any gelcoated hull. Painting systems are beyond the scope of this paper. The best advice is to select the system and follow the manufacturer's instructions.

SAFETY CONSIDERATIONS

All epoxy resins, including Phase Two, have the potential of becoming strong skin sensitizers. Workers should avoid all contacts with uncured resin or converter. Clothing that fully covers the body should be worn. Always wear disposable gloves when working with or handling Phase Two. Avoid sanding the hull prior to post curing, as it is still quite chemically active. Wear protective clothing and adequate dust masks when sanding any fiberglass hull.

People sensitive to epoxy resins usually develop a reddish rash in the area of contact. Hives may appear since this is generally an allergic reaction. If any worker shows these symptoms then he should be removed from the epoxy use area. Usually, the rash disappears within several days after contact with the epoxy is terminated. If it persists or other symptoms appear then a physician should be consulted immediately. Once sensitized most individuals cannot work around uncured epoxy resins without symptoms reappearing. Some seriously sensitized individuals may not be able to be in the same room with uncured epoxy resins.

Because of the low vapor pressure it is not necessary to wear respirator equipment when working with Phase Two. Dust masks should always be worn when sanding epoxy resins or other materials.

Uncured epoxy resin may be removed from the skin with good waterless hand soap. Solvents should ever be used to remove epoxy resins from the skin as they help drive the material into the skin. Tools may be cleaned with acetone, MEK, lacquer thinner or other suitable solvents providing long sleeve solvent resistant gloves are worn and the cleaning is done in a well ventilated place away from open flames or other sources of ignition.

Consult the Phase Two MSDS sheets for additional safety information.

STORAGE OF PHASE TWO

Phase Two epoxy resin and converter present no special storage or handling problems. Store at room temperature. Although the materials are not especially flammable they should be stored away from heat and open flames. The converter is somewhat sensitive to carbon dioxide. Be sure the container is closed when not in use. If a small "heel" in a larger container is to be stored then it should be transferred to a smaller container to minimize carbon dioxide contamination.

The shelf life of both resin and converter is in excess of two years in unopened containers. Protected from moisture and carbon dioxide the shelf life in opened containers should be more than 18 months.