Introduction to Boat Building in Composites

This article looks primarily at the Fibre Reinforced Plastic (FRP) technique

Glass reinforced plastics, or GRP as it is commonly called, is the combination of materials most frequently used in the commercial production of small cruising craft, and the cheapest - provided that a sufficient number of hulls are taken off the moulds, because these are expensive pieces of tooling. Unlike the moulds used in laminating timber, they are female in form, having themselves been moulded in GRP from a wooden "plug" . Accordingly they are reinforced on the outside to keep them rigid, with the materials being applied to the inside of the mould. They also require a high standard of surface finish, free of any ripples or blemishes, so that this can be imparted directly to what will become the outside of the boat, without the need for any filling or polishing.

Even without the expense of a suitable mould, solid GRP - as distinct from the foam sandwich described later - has certain other drawbacks. Unlike timber, it is not "user-friendly" and it is also relatively heavy, so it lacks positive buoyancy. It is a poor thermal and sound insulator, and its indifferent panel stiffness has to be corrected in key areas by additional ribs and stringers, adding weight to an already heavy structure. But it is basically simple to produce, and lends itself particularly well to commercial manufacture.

The process consists basically of first coating the mould with a release agent to prevent the new GRP part from sticking to it, followed by a coating of a pigmented, thixotropic resin known as a gelcoat, which will form its outer skin. As soon as this has partially cured - the term used to describe the chemical reaction between the liquid resin and the hardener which is added to it - one or more layers of polyester saturated glass cloth are applied, according to the wall thickness required, being worked firmly on to the mould with a hand roller and left to cure.

Composite construction is often referred to as if it were some new high-tech method of boatbuilding. In fact it is one of the oldest. Back in the bronze age they were stretching animal skins over basketwork frames for their coracles and kayaks, and Cutty Sark was built with wood planking on her iron frames. Nowadays synthetic resins have joined wood as one of the primary groups of materials in small craft construction, with other manufactured substances being added for reinforcement.

REINFORCING MATERIALS

Foremost among these is glass strands in many different forms, ranging from low-cost mats of chopped glass strands which give bulk, and hence stiffness, without adding very much strength, to a variety of woven and knitted fabrics whose filaments are aligned in specific patterns, such as trixial or quadriaxial, with corresponding and predictable strength characteristics. These stitched fabrics have recently made their entry into the South African market and already show substantial savings in time and improved strength . Also uni-directional cloths, where the majority of the fibres run parallel, so as to give maximum longitudinal strength - ideal for the strengthening of 'backbone'ribs on the keel floor.

Most GRP boats are built with a combination of chopped strand mat and woven glass fabric, in which the glass itself can be of two grades: the normal E_Glass, which was originally developed for electrical circuit boards, and the more expensive S-Glass ("S" for structural) which has 25% more strength and 35% better impact resistance.

For top level racing boats, where weight saving is vital, glassfibre is often replaced by an aramid fibre trade-named Kevlar, which is half the weight and three times as strong as glass- and five times the price, and in areas of the greatest stress, such as crossbeams and rigging by carbon fibre which is as strong as light alloy in compression, twice as stiff as Kevlar, and unfortunately no less the than ten times the price of glass. The same materials can of course be equally well applied to hightech wooden boats, sinews of carbon, for example are often used in the construction of wooden wingmasts. For convenience, the term fibre reinforced plastics (FRP) is nowadays used to cover all three types of laminate.

Aside from their high cost, however, these exotics have other drawbacks. Carbon fibre is extremely brittle and vulnerable to impact, and Kevlar is weaker than glass in compressive strength. So they are combined into hybrid cloths, such as Kevlar/carbon and glass/Kevlar, to optimise their mechanical properties. Another state-of-the-art technique is the use of "pre\preg" cloths. These have been passed through a bath of resin and hardener dissolved in a fast evaporating solvent, conveyed through a hot air drying tower, and stored a in fridge ready for use. They are subsequently laid over the mould and vacuum bagged, and the entire hull is cooked in a huge oven until the resin has cured. The cost of such facilities is considerable, but it enables fibre-to-resin ratios to be accurately controlled - essential for minimum weight and maximum strength - and greatly reduces labour costs in laying up.

RESIN TYPES

There is a choice of resins too, on a rising scale of cost and performance, orthophthalic polyester being the cheapest and easiest to use. (Incidentally, it is not the resin that gives a freshly moulded boat its characteristic smell, but the styrene solvent.) Next comes isophthlaic polyester, 50% more expensive, but more resilient and with better resistance to water (see under "Blistering". Then there's vinylester, stronger and more water resistant still, but more than double the price of ortho-polyester. All three behave in the same way chemically, and begin to cure following the addition of a tiny amount (1-2%) of a catalyst to start the polymerisation process. And finally there's epoxy, five times the price of ortho-polyester but far superior in every other respect, notably in its resistance to water degradation as well as in its adhesive strength. Instead of a catalyst, epoxy requires a large proportion of hardener to start the reaction (from 20% to as much as 50%, depending on the particular product) and this hardener forms part of the final polymer. The use of epoxy allows composites to be produced with very high fibre-to-resin ratios making them much stronger and lighter than is possible with the other resins, but it is still too costly to be considered as a universal replacement for them. Somewhere in the middle of the scale of toughness, water resistance and cost is Duroplastics - Durovyn used by a number of commercial boatbuilders and for an anti-osmosis barrier coat between the gelcoat and first chop matt layer.

BLISTERING

The main reason for acceptance of additional cost in a series produced boat is epoxy's good resistance to water penetration and the resultant blistering, which remains the most persistent and aggravating problem of polyester resin construction, affecting possibly as many as one in three of all boats under five years old, and an even higher proportion of older ones. What happens is that unless the hull is either built with epoxy resin, or is thoroughly coated with it near to and below the waterline, the gelcoat absorbs moisture, and an aqueous solution builds up in the small voids which can occur in the laminate unless the strictest precautions have been taken during manufacture - and sometimes even then. As a result, osmotic cells develop under the gelcoat, pressure builds up and blisters form and burst, leaving the skin heavily pockmarked and weakened. Laminates made with Epacryn are actually guaranteed against osmosis for ten years by its manufacturers, which is bound to improve the resale value of the boat, although it does inevitably increase its initial cost by +/- 2%.

SANDWICH CONSTRUCTION

The basic principal of sandwich construction is to separate two load bearing skins with a lightweight core material. In a sandwich panel flexing under load, one skin will be under compression and the other in tension, and it follows that the further apart they are, the stiffer the panel will be. In fact, the stiffness of a laminate is proportional to the cube of its thickness of the panel without adding significantly to its weight. Typically, a 3mm FRP skin on either side of 15mm core creates a much stiffer skin than would 6mm of solid FRP, without being much heavier. Unfortunately the weight advantage of a sandwich diminishes with the size of a boat, because for strength reasons skin thickness cannot be scaled down proportionately, so unless Kevlar/carbon is used, a micro cat can end up heavier than if it had been built of plywood.

Nevertheless this type of construction has a number of other advantages over solid FRP. The first is that instead of a highly finished mould, it is only necessary to use temporary frames covered with closely spaced longitudinal battens as the male former (sometimes refered to as the one-off technique). The sheets of core material are draped or bent over it, and the outer skin applied, filled and faired - quick to say, but in reality involving much tedious trowelling and dusty sanding/fairing for the finish to approach that obtained from a good production mould , often a pot of gold at the end of a rainbow . The hull (or deck component) is then turned over, the framework removed and the inner skin applied, followed by the bulkheads and accommodation items. Conversely, the core material can be applied to the inside of a moulded but thinly skinned FRP shell, or to a 'tortured' ply or laminated wooden hull, followed by the inner skin and interior structure.

As well as stiffness and light weight, and hence positive buoyancy, sandwich laminates provide excellent sound and thermal insulation, helping to avoid condensation in cold climates, and in summer preventing the worst of the sun's heat from soaking through the deck to the interior accommodation. The majority of commercially produced boats with solid FRP hulls incorporate sandwich decks for this reason.

CONSTRUCTION

Looking at the other side of the coin, unless the outer is skin is so heavy as to largely nullify the strength-to-weight advantage of sandwich construction, it is more vulnerable to impact damage, and somewhat more complicated to repair than a solid laminate, especially in the sharply curved areas. As might be expected, the materials themselves cost around 50% more than for solid FRP, although, surprisingly, they are hardly any more expensive than epoxy-saturated plywood and glass cloth. The core and skin must also be reasonably good chemical match to ensure a strong and permanent bond; there have been a number of cases of the core delaminating from the skin, due to flexing of panels subjected to heavy pounding from head seas. And the positioning of all fittings needs, if possible, to be planned well in advance, because hardware can develop high local stress concentrations which must be dispersed throughout the adjoining structure. Whereas the fittings on a plywood deck are simply through-bolted to wooden pads which spread the load, a sandwich deck would crush when bolts were tightened, so the core in the region of each fitting must either be replaced by a plywood insert(doing this after the boat has been built entails cutting away the outer skin and core, bonding in solid blocking and reskinning); or by bonding an FRP plate on to the skin to spread the load.

CORE MATERIALS

Because it lies between one skin in tension and the other in compression, the core is subjected to shearing forces, and its most important property is therefore its shear strength and stiffness. It must also, because it is protected only by a comparatively thin skin , be able to withstand a reasonable amount of compressive loading.

The most widely used core material is PVC foam, which comes in sheets of various densities and thicknesses, and under several trade names such as linear Airex ,cross linked Divinycell and Termanto/Klegecell. It is highly resistant to impact, so it makes a good composite partner for glass/carbon . The result is great structural integrity and an exceptionally high strength and stiffness to weight ratio. PVC foam can readily be bent cold over gently radiused surfaces, or if it is required to follow more to follow more severe curves, softened with a hot air gun or infra-red lamp. For this reason linear PVC foams are unsuitable for decks exposed to the sun. Klegecell however manufactures a high temperature grade to prevent softening of the deck structure.

Balsa is superior to PVC foam in its compressive and shear strengths, and is the price. It is available in the form of small closely spaced squares of the wood, mounted on a light scrim backing of open weave FRP which can be draped over quite acute compound curves, or for single curvature, in panels or narrow strips sandwiched between hardwood veneers. Balsa's drawbacks are that it is at least twice as heavy as foam, and can become heavier still by absorbing large quantities of resin (sometimes called wicking) along its grain during lamination - and water too if the skin should later be punctured, whereas PVC foam with its closed cells is virtually non-absorbent. Despite its great compressive strength, balsa is also vulnerable to impact, so it should not be used under a thin skin in areas where it might get dented, with consequent delamination. Among the other core materials are cedar, heavier than balsa and not available in end grain mats, but much stiffer when used as strip planking. Then there's acrylic foam, strong, stiff and stable, but difficult to form onto curved surfaces; and polyurethane foam, which is more brittle than PVC and liable to deteriorate at the skin interface, causing delamination. But PU foam is also available in aerosol cans as a liquid which expands into a foam for filling large voids such as double skins and small watertight compartments, and in the bows to provide a crumple zone in the event of a collision. However, despite being theoretically unicellular, it can become a waterlogged liability if exposed to prolonged water leakage, and is virtually impossible to remove without cutting open the affected areas.

Finally there are the honeycombs which have originated from the aircraft industry and provide very light, stiff laminates with tremendous strength in compression. But their very small bonding surface area, which is restricted to the very edges of the honeycomb walls requires great care when applying the epoxy resin, to ensure adequate adhesion to the skins. They are made either of aluminium, or from Nomex, which is an aramid paper. Aluminium honeycomb costs no more than PVC foam and is stronger in shear, but it will deform permanently on impact; and since the FRP skins are resilient, delamination follows as it does with balsa cores that have been thumped, and there is always the danger of corrosion in a marine environment. Nomex is the strongest of all the core materials for its weight, completely stable and reasonably resilient, but alas, at three times the price of the others it is mostly confined to the big budget boats.