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Michael Eaglen High Modulus

Chairman—Martin Redmayne

Can Bob Curry and Michael Eaglen come up to the stage please and we'll do a little swap over here and have our final 45 minute session on composite applications in the big yacht market. Thank you.

Ok we'll start off with Michael Eaglen—take it away Michael.

Michael Eaglen High Modulus

Today I'm going to talk about the use of composite materials in very large superyachts in the very large motoryacht market, but give a little bit of a picture of where we're using composite materials and where we can be using composite materials and Bob's going to speak a little on the same thing and we'll talk a bit about some of the challenges and classification issues around that.

Many of you will be familiar with composite yachts; composite projects and in some fields it's far from new. Typically the early adopting projects used composites for their high stiffness to weight ratios, high strength to weight ratios; some of the high profile projects are using really pushing the boundaries on the technology they're using and they're great at demonstrating what can be achieved with composite materials. The America's Cup, Formula One projects, are good in some ways but they also demonstrate to some extent the risks that need to be considered in other applications we're very familiar with—more costs and production time driven production boats. Lots of use of composites in these sites and we're all familiar with that. We're also now seeing a lot more use of composite in quite a different field from that; we're seeing aeroplanes, we're seeing bridges, the wind energy market, motor cars, these sorts of things are using composites right down the confidence end of the spectrum. We're quite used to seeing racing boats and racing cars and so on, which are quite risky projects and some risk is acceptable on those. That sort of risk is not acceptable on a superyacht project and I think there's a common misconception amongst those that look at us using composites that there's some risks associated with using them, and that you might only want to use them on a high performance boat. That’s wrong, and that’s what I'm going to really talk about today. The other thing that I think we see a lot of in terms of potential problems or perceived problems with the use of composites is in production boats—there's a long development process and it's sort of regarded as acceptable at the moment that you can sort out issues in the development phase. And we've been saying for a very long time that that’s wrong, and you shouldn’t need to, and engineering was invented in order to apply numbers to these things so that you don’t have to just build it and then find out if it's strong enough. I think last time at this forum I might have re-told a cartoon which was better in cartoon form than in verbal form but it was all about driving trucks over bridges and how you know whether it's strong enough, and the answer that was given was that you just drive a bigger and bigger truck over it every time and when it breaks you know that's how strong the bridge was, and you rebuild it then stick a sign up saying it's that strong. This is not what engineering's about. But there are large sectors of the production boat industry where that is how it's done. And we're working hard against that.

We're seeing a lot of use of composites in large superyacht projects and some of it we're very used to. This is not a composites boat but the rigs there are carbon fibre rigs and we're seeing carbon fibre masts as being fairly standard on not just performance boats but on large sailing superyachts all the time. We're also quite familiar with large performance sailing yachts the likes of this Wally 100 here—they're quite high end, high tech, high cost sort of projects but we are also seeing a lot of production motor yachts getting larger and larger—this here is a Sunseeker but we're also working with people like Christiansen and there's guys like Westport and Delta and Benetti and a whole pile of others who are doing some very very large composite motor yachts and I'll be speaking a little more about one of those shortly. We're also seeing specialist components for metal boats, hatches and superstructures and communications masts being used in very much larger boats and again I've got a couple of examples. So basically it's not just the high tech, high cost areas where we're seeing people adopting composites—it's also in the production areas, the low cost areas, where composites are not only a better solution than metal but they're actually lower cost as well. And we're quite familiar, and I think Bob's going to talk about the ways in which composites are different from metals but it's not just about weight, or stiffness and strength.

I said better than metal—there are several areas in which composites are better than metal and the product will be better than a metal one. We're doing a lot of work on these radar masts; it's all about low maintenance in those cases, there's no corrosion issues which is really the biggest appeal for why you might use composites in these sorts of projects. This is one that was built by Rijsbergen here in Amsterdam; that we're doing a lot of work with on these large motor yachts and there's all sorts of sides of this that make composites a lot better. Dimensional stuff, the corrosion side, the low maintenance time between painting, refits, etc. We're seeing a lot of composite masts going on to otherwise metal boats. Another really big driver in those projects is tuning for vibrations; all objects have a natural frequency, the frequency at which they will vibrate and the frequency at which an object will resonate if a function of really three factors, the geometry, the mass and the stiffness of that object. For a given geometry, stiff light structures will resonate at a higher frequency than soft heavy structures. And the real key in boats is that you don't want to have something that has a resonant frequency the same as what your engine driving frequency is, because you'll get a resonance. And so in a lot of areas of these structures we're now getting into tuning the structure at the design stage so that the natural frequencies of the structures are deliberately moved into bands that are away from where the excitation frequencies are in the project. So we can do that by adding stiffness or reducing stiffness, and increased stiffness tunes things towards a higher frequency and vice versa. We can do it by weight, increased mass tunes the structure towards a lower frequency and vice versa. Or through geometry again, by affecting the stiffness, by changing panel spans or frame spans you can shift the frequency of the panel or the beam into specific areas. And these days the analytical tools that are available to us enable us to tune the structure in the design stage quite well. What's sort of interesting is that if you have a vibration problem the most common response, at the design stage or later, is to try and make things stiffer, usually by adding material. The funny thing is, the more material you add the stiffer it gets and the heavier it gets and in most cases the natural frequency actually stays the same. So the result is no change to your natural frequency but an increase in stiffness so the amount of vibration that you get is reduced but your problem hasn't gone away. Now in metals your opportunity to tune the structure is quite small but really you've got to change the geometry in order to shift the natural frequency. In composites you've other opportunities as well. If you've got an e-glass mast like this one here that we're designing at the moment, and you add bands of carbon fibre to it you'll increase the stiffness a great deal without adding much weight and so you'll shift the natural frequency. You could equally go the other way and have a carbon fibre structure that you added e-glass to that you were increasing the weight of. And that's an intelligent combination of different materials is what makes composites particularly good for this type of application. And it means that the designer can come up with a mast that he thinks looks good for the boat and we don't have to keep changing the geometry, as you often do have to with a metal mast. This is very much a growing area for us and in the past 3 years we've engineered composite comms masts for more than a dozen motoryachts between 30 and 120 metres and at that top end they're very substantial structures in their own right and many of them are now involving quite high end analytical processes. Speed and accuracy of manufacture is also a really big thing. We're doing a lot of composite hatches, designing a lot of composite hatches for metal boats because if you build a metal hatch the weld distortion issues make it quite difficult and you can end up with—it's just a lot easier to do it in composite to make it fit. They can be delivered, completed and painted, reducing your overalls, the build time and some of those areas. So we've been involved in a lot of sort of fore deck hatches, transom hatches, topsides hatches, those types of things. The sort of electronic transparency thing is also quite a big deal; as well as the pleasure boats we've been involved in quite a few naval projects where they don't really, for various reasons, whether it be Naval or pleasure projects, want to have to design the mast around having bits of structures in areas where you accept blind spots. They'd rather not have any blind spots at all or only have what there is on the equipment itself. With e-glass based laminates there's very little shadow and there's quite a few things that we can do to eliminate the interference of the structure for the electronics. This mast here in fact had quite a lot of antennae domes and so on inside the lower box area of it and you know that's quite unusual for a yacht project, we normally see all these domes and radars and so on sprouting all over the boat but they can actually be put inside things if we design that specifically to allow for it. There's other areas that we're more familiar with—reduced weight, reduced costs, creativity of design and shape, all that sort of stuff, which I won't go into because most of us are fairly familiar with those sorts of benefits of composites.

I guess at the same time there's quite a few issues that still deter the adoption of composites in the large yacht market. Fire has got to be the biggest one. It's been quite widely felt for quite a while that you can't achieve equivalence to steel in a composite structure. That's not true. And we've been recently working very closely with a shipyard on a fire solution for equivalence to steel and that solution has now been approved, I think in this case it was by Cayman Islands Shipping Registry, and really what it came down to was defining—it very much comes down to some of the earlier debates we had on this. It comes down to defining what the criteria are rather than just having some—it's got to be equivalent to steel. Defining what equivalence to steel means, turning it from a bureaucratic problem into an engineering problem and in that case it's been a very smooth process, relatively easy process, and now here we are doing very significant projects, all-composite motor yachts over 500 gross tons and I think we're going to see a great explosion of all-composite boats breaking through that previous sort of area.

Toughness has been another one. There's been a common perception that composites aren't as durable as metals because we see a lot of lightweight composite boats out there. For weight equivalence, composites are very tough, can in fact be tougher than metals for some situations. It's just a case of defining what the problem is, moving away from bar check perception and nailing it down to a technical problem and actually addressing what the real concerns are. Reliability—there's a perception that composite boats don't last. That's also wrong. I mean the skipper of this boat is here, Mike, how many miles have you done on this boat now? 50,000? In 4 years. Still going extremely well; it's an all composite motoryacht, you can design very reliable structures in composites and it's what we do all the time. So they're actually ideal materials for that and you just have to define what fitness for purpose is and what the target for the project is.

There's also a perception that composites are difficult to design. They're certainly different to design. But you wouldn't just grab someone that's designing aluminium structures and suddenly ask them to design a composite one, and expect it to come out great. But if you know what you're doing, and there are a number of organisations, not only ourselves, that do know what they're doing, it's not a risk. And it isn't difficult. So what are the obstacles that we've got, to getting more use of composites into superyacht projects? There's a general conservatism, we've just got to address that perception of risk and let people understand that it's not risky in itself. We need to manage the various criteria for the boat and design for that and the risk can be eliminated. I think that the critical mass in composites that we're seeing—things like Boeing launching the 787 is vastly increasing the confidence that the world has for composite materials and I think we're seeing that very strongly in our market, people are quite rapidly growing their confidence in that.

Another big one is the regulation versus innovation and we very much encourage regular dialogue with the classification societies, sharing the outcomes of our research, our thoughts behind the design, you know, there was some discussion on the class debate the other day about goal based versus prescriptive regulations. Whether it's goal based or prescriptive there's always going to be an equivalence to it and really that just involves discussions with the people about exactly how we define equivalence. And ultimately you've got to take your business to the class societies that contribute to rather than hinder the innovation and I'm happy to say that we're quite well served for that in our industry at the moment. So I guess a good example for that is the fire discussions we've had, we've been involved with Christiansen and their 60 metre composite production motor yacht project in Tennessee—it's the largest all-composite motor yacht ever built in the world and they're going into full production with them. The fire solution for that boat has been approved and they haven't even started building moulds. They've involved flag right at the beginning of the project. They're involving class right in the beginning of the project. And that's really the recipe for success. Like everybody else has been saying, it's all about communication and the world's our oyster with that. Thank you.

Martin

Michael, thank you. Bob, please join us.

Robert Curry ABS Europe

Good afternoon ladies and gentlemen. What I'm going to do instead of immediately replying to Michael's proposals, I'm not sure how many experts there are among the delegates on FRP so what I'm going to do is give a brief introduction. Michael was talking essentially about replacing equipment and components presently built of steel or aluminium and building them of GRP or FRP and therefore it becomes a question of comparing aluminium and steel with composite materials. There are big differences—aluminium and steel materials, the material technology is complete before the material is provided to the builder. It's been approved by the class society and the mechanical properties of the material have already been established by test. Aluminium and steel are ductile non combustible materials, aluminium and steel are isotropic in that they have the same mechanical properties in the plane of the plate. Composites are very different. The resin, the fibre reinforcement and the core materials are supplied to the builder. These materials are then subject to the builder's quality control that covers receipt of materials ensuring the proper materials are received, through the resin and fibre laminating process to final testing. Even with the same resin, fibre reinforcement the cured laminate mechanical properties can vary substantially depending upon the effectiveness of the builder's quality system. Composites are not subject to corrosion and this of course is a great advantage that they have over both aluminium and steel. Laminates can be isotropic in plane similar to steel and aluminium, however they can be designed to be un-isotropic which means they have different mechanical properties in the two principle directions, longitudinally and transversally. This is often done where the applied loads are also un-isotropic then you can actually design your reinforcement to correspond actually with the loads, and this is a very efficient design feature of composites, that does not exist with aluminium and steel. However, cured laminates are not very ductile materials, the resins, carbon and aramid fibres are flammable, only glass fibres are non flammable. Looking at the composite itself, you have a cured resin matrix in which you have fibre reinforcement. The reinforcing fibres provide the laminate strength, ideally the strength of the fibres should be fully developed before the resin matrix has fractures. That’s the ideal design but it doesn’t always happen. The cured resin matrix provides stability to the fibres when the laminate is subject to compression in plane loads, the cured resin matrix transmits loads between the fibre reinforcement. The cured resin matrix is water resistant and protects fibres from moisture or similar harmful exposure. The cured resin matrix also protects the fibres against abrasion and mechanical damage.

Modes of failure. This is where there is a big difference between aluminium and steel and composites. The two main failure modes of aluminium and steel are fracture, either ductile fracture or fatigue fracture and buckling or deformation. Buckling and in plane compressive loads, deformation when the load is normal to the plate but is of such magnitude that the yield of the material is exceeded. Then you have excessive corrosion which of course results in loss of strength. Composites you have a number of additional modes of failure and this is one of the disadvantages of composite materials. You have many more potential modes of failure. There is fracture of the resin matrix or of the fibre, there is debonding of the fibres from the resin matrix, there is inter-laminar sheer failure of the laminate; in the case of sandwich laminates there is debonding of the skin from the core, again in sandwich laminates there is sheer failure of the core. Whereas aluminium and steel are welded, the GRP elements are connected together, the frames offer stiffness to the plating by secondary bonding tapes and there is a potential for debonding of those tapes. In the case of sandwich laminate shell there is the potential, if you have a sandwich laminate shell and fairly light outer skin, of impact or breach or puncture of the outer skin of the sandwich and there is inter-ply delamination, while in all of the potential modes of failure of aluminium and steel there is engineering theory to predict the failure or the load at which it would fail. In some cases this is true of a composite but in a number of cases there is no engineering theory to predict the failure mode and it becomes a matter of quality assurance and testing to verify the quality.

Quality control—with aluminium and steel the quality control requirements are not so rigorous, they concern the welding process, structural detail, workmanship, fit up and deformation. With composites by virtue of the material's technology being carried out by the builder and corresponding effect on the mechanical properties, it requires a high level of quality control. This relates to control of the environmental conditions on the premises, control of the humidity, control of the temperature and also control to make sure that you don’t have dust or sunlight on the laminating areas. Then there must be freedom of resin fibre reinforcement and core from contamination. Contamination could be due to moisture, grease, dust or anything in there that would prevent bonding between either the sandwich or the fibre and the resin. Also there needs to be control of the ply lamination, the fibre content of the laminate, the fibre direction and very importantly, to ensure complete wet out of the fibre reinforcement. This means you must eliminate all void spaces, because void spaces have a very critical effect on the mechanical properties. Then there is control of bonding in cores, you have to be very careful when you're bonding in a core material, control of the resin curing, control of the catalyst or the polyester or vinylester or control of the hardeners with epoxy resins. Control of vacuum bagging, vacuum bagging is carried out, it is a compression—you apply a vacuum and it pulls all the laminates together with the idea that you eliminate void spaces. That has to be very carefully controlled. And control of post curing.

Classification societies have in their rules comprehensive quality control requirements for the manufacture of composite structures and equipment. The requirements include qualification tests and production tests of the laminates, class societies also have yacht rules for yacht hulls to which these quality control requirements are applied. Aside from the classification requirements class societies also provide a type approval service so that some of the components that Michael was talking about such as hatches, doors, or those two at least, they can be quality controlled, they could be type approved by the class society. The type approval process includes a design approval and then a quality control approval of the facilities and annual monitoring or auditing of the premises by the class society. Class societies also type approve resins, core materials, and fibre reinforcement that are used in the manufacture of laminates.

Structural design. The structural design of composite structures—the theory and the design are more complex than for aluminium and steel. As you might understand, because there are more potential modes of failure then of course the design is more complicated. I would say more complicated, not necessarily difficult. As Michael said, when people fully understand the theory in that, it is not a problem. The other thing is that composite structures generally have a greater efficiency than steel or aluminium in terms of their weight for the strength provided. This is particularly the case with sandwich laminates. One disadvantage of composites is that the laminates have a relatively low modulus of elasticity; this means while they might have the same strength as aluminium or steel they will deflect much more under the particular load, consequently sandwich laminates are used and there are very definite criteria for limiting the deflection of the structure under load. Class societies have detailed requirements for the design of composites based on design loads and the mechanical properties of the laminate. There are published rules for building and classing FRP composite hulls. Requirements for other composite components and equipment can be based on design loads and the laminate mechanical properties. Requirements include guidance on structure detail and secondary bonds.

I would make one brief comment about secondary bonds. There are two bonds. There is a primary bond which is when you have a ply and the resin is still uncured and you put another ply on that, and they bond. That's called a primary bond. A secondary bond is when the laminate is already cured and you apply a wet resin and fibre to that. Secondary bonds never have the same strength as primary bonds.

I would say the main big disadvantage of composites is their resistance to fire and the design of composites against fire. The mechanical properties of materials reduce with the increase in temperature. For steel, from what I can find out, you have a 15-20% reduction in mechanical properties at about 320°C and as the temperature increases so the mechanical properties continue to reduce. In the case of aluminium again it's 15-20% reduction at about 200°C. With composites there is the heat deflection temperature, and the requirement for the structural fire protection of composites is that the heat deflection temperature should never be reached within the designated 30 minutes or 60 minutes of the fire test. The heat distortion temperature should not be exceeded if it's an A30 bulkhead within 30 minutes, or if it's an A60 bulkhead the heat distortion temperature should not be reached within those 60 minutes. Heat deflection temperature of the laminate depends on the resin. Typically 80°C to 120° C depending on the resins. The other big disadvantage, especially if we're talking about composites inside the hull is that when resins burn they give off noxious smoke and fumes. The structure is insulated to limit the temperature rise in the event of fire and usually with aluminium it's limited to 200°C—you shouldn't reach 200°C either in the 30 minutes or the 60 minutes designated time, and as I've already mentioned you shouldn't reach the heat deflection temperature of composites of 80° or 120° within the designated 30 or 60 minutes. Technology is available to use various means of protecting load carrying composite structures against the effects of fire. There are several ways of doing it in addition to simply insulating it.

In conclusion what Michael has presented is certainly valid; composites are very good structural materials for yacht hulls and for light to medium duty equipment and components. They do require though a rigorous quality control standard throughout the whole building process from receiving the materials to final testing. Class societies have requirements for structural design, structural detail, resin and core materials specifications and quality control of manufacture of FRP composites from receipt of resins, fibre reinforcement of core materials to the final testing. So the big problem with composites is fire, you need a very rigorous quality control system to ensure quality and to ensure that you have adequate strength against all these potential modes of failure. Thank you. If there are any questions I'd now be glad to answer them.

Martin

Thank you Bob. Can we have some light please?

Tork

There seems to be a slight divergence of views on structural fire protection because Michael you were saying that you feel you've reached the stage of being at steel equivalence and you don't seem to think so, Bob ?

Bob

Yes, FRP hulls are being built; they are being insulated. Up to 500 gross tons it isn't too much of a problem, only the engine room and the galley essentially have to have structural fire protection and to date we're providing adequate insulation. There is the means of doing that. So it is not a problem with yachts up to 500 gross tons. When you get over 500 gross tons then I think it becomes much more of a problem because you have to comply with SOLAS requirements and then they're much more rigorous. There are various ways though. I think that the glass fibre is probably the best fibre to be used if we're considering structural fire protection. Carbon fibres or aramid fibres would burn. Glass by itself is not flammable and there have been instances where there has been a fire and if you have a thick enough laminate the first 5 or 6 mm of that laminate the resin burns, the glass chars and eventually the charred glass forms an insulant itself. So there are potentials you can perhaps, as well as insulation, you could possibly fit high glass content fibre laminates that would certainly prevent failure. The only problem would be of course these noxious gases that would be given out when the resin burned.

Tork

But Michael you were saying in your presentation over 500 gross tons you think you're there?

Michael

Yes. You've got to insulate. So I'm not saying—but you insulate a steel structure too to some extent. But I guess things are different over 500 gross tons to under 500 gross tons and historically people have believed that they're so different that it rules out the use of composites. What Bob's saying is right, you can do it through insulation and really it's a combination of insulation and design. It's a testing exercise really; it's defining what steel does, finding what the equivalence to steel really is and in most cases that's a load bearing something and how much does it deflect in a given fire situation, and then achieving equivalence to that. As Bob says, composite materials themselves, I'm not sure whether the flammability of the fibre itself comes into it, but it's generally the resin that burns off so much earlier than the fibre that it's really dominated by what your resin system is. But if you break down the fire requirements for say an A60 bulkhead—you've got spread of flame, you've got toxicity of smoke, you've got heat transfer from one side of the structure to the other. Toxicity of smoke is a problem for composites at the moment; the reason is that it's hard to get around to this as an insulation exercise but both spread of flame and transfer of heat are actually relatively easily dealt with without any insulation at all.

Bob

May I add one feature of composite, for example glass reinforced plastic itself is resistant to heat, whereas with steel and aluminium they conduct heat very rapidly and it's possible you could have some insulation and you could design your FRP structure such that you have a higher factor of safety for the load and some of your actual GRP structure would be serving also as an insulant. There is that possibility which is an advantage in GRP and there's a possibility that you could design against fire also that way.

Martin

Any questions from the floor? Yes, Peter Southgate. Old Faithful.

Peter Southgate Cayman Islands Shipping Registry

Thanks guys. That was interesting. I've got a question for Michael and Bob if you wish. My experience of structural fire protection on vessels over 500 gross tons which you know I would reiterate has been done, we can do it, and I'm glad you mentioned Cayman Islands Shipping Registry in your presentation, Michael, you had a pleasant experience with us, which is good. But my understanding of the difficulties is, you have a composite hull and all the weight saving benefits that you get with that, and then you go and stick tons and tons of insulation in there. Now I would be interested in Michael's experience—you said you did that successfully. How did you deal with that issue?

Michael

I can't comment publicly on exactly what the solution is in this particular case except to say that it's not a Rockwool system that we're using and it's still winding up substantially lighter than a steel or aluminium structure. You're certainly right, that you can wind up with extremely heavy insulation and you to some extent undermine the weight benefit of the composite structure. But you've still got all the other benefits of having it. The solution that we've been working with you guys on is substantially lighter than most of the previous solutions that we've been involved in using. So there's quite a lot of good products coming on the market, the aeroplane guys particularly have been doing a lot of work on that because now they're building lots of composite planes and they have to make them safe and they don't want them to be too heavy. So the weight side of it is OK on this project.

Bob

The one thing I would add is that perhaps up till now the design of the composite structure itself hasn't been fully used as I mentioned before. Instead of using a factor of safety of 2 on the design loads you perhaps use a factor of safety of 4. this means that your strength will reduce, but of course because you have a much higher factor of safety after 30 minutes you still may have an effective factor of safety of 2 whereas at the start you had 4. So I think there is that potential in designing composites to more effectively use the fact that GRP itself is an insulant.

Tork

There's some variation between class societies as to how they look at composite structures. Not in terms of fire protection but in terms of strength etc. And some societies appear to accept load cases which can be proven mathematically, where others specify simply thickness. And when it comes to the thickness, as I'm sure Michael will confirm, you start paying a tremendous weight penalty for very little apparent reason. I wonder if either of you would like to comment on that.

Michael

I can certainly start commenting on that. All the classification societies do have load case based design formulae but you can very quickly wind up in a situation if you have over conservative skin thickness requirements you can end up in a situation where once you've met the skin thickness criteria it doesn't matter what the loads were and I think there's been something published in The Yacht Report recently about a project which certainly that was the situation for.

Bob

Can I just add to what Michael said—it really is not the thickness of the laminate that matters, it is actually the weight of the reinforcement. It is the reinforcement that carries the load. And therefore essentially on the face of it requirements are given in thickness; the important feature is the weight of the fibre reinforcement in the laminate.

Michael

We completely agree with that. And ABS is one of the classification societies that follow that system but there are some that don't.

Martin

OK. Final question please of the day ?

David Reams Camper & Nicholsons

Having started out in this business when they were doing chopper guns and resin ratio was about 80% to glass, are you finding it much easier to get approvals with the scrimp process and things like that, when you have the infusion process and much much higher fibre to resin ?

Michael

You can design an appropriate structure using any materials but certainly the vacuum infusion processes have very much increased the consistency of the materials, so for a given set of design criteria you'll actually wind up with a more reliable structure because you've pulled out a lot of the variability. We've got a large project on the go at the moment to quantify the variability of the various different processes and to start to try and feed that back into the design process so that we can get some proper benefit from improving the process, rather than just making the boats stronger. Because certainly while there are some sprayed chop boats out there that aren't strong enough, we have a great many of our customers that still use sprayed chop and I'm happy to say those boats aren't breaking. So there's an argument there that says well, if we're using sprayed chop now, and it's strong enough, as evidenced by the fact that the boats aren't breaking, then where's the incentive to change to a better process? What's the point in improving my quality. And we're saying well there's lots of incentives and one of them is if you improve the quality you can actually reduce the amount of material and labour going into it and save yourself some costs.

Martin

Bob — a final comment?

Bob

You should be very careful about fibre content. The idea is of course that you should increase the fibre content as much as you can. However there is a point that you reach, and I've asked several people to research this, at which point if your fibre content gets too high your interlaminates sheer strength reduces because you do not have enough resin to transmit the sheer between the two plies. So I think from what I understand 60% by weight glass is about the upper limit so you have to be careful when you're continually driving to get an increasing fibre content that you do not reach the point where your interlaminate sheer strength starts to reduce.

Michael

Yes, but it's still glass reinforced plastic and we've got to have the plastic there.

Martin

OK, I don’t know about you, but I need a beer. Thank you for your stamina today. You’ve been amazing. A good session, an interesting day, and I'll see you tomorrow for breakfast at 8.30.   Good night, thank you.