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Monitoring and Control of Voids in Resin Infused Composite Sandwich Laminates

by

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Resin Infusion (RI) can be used to create a sandwich panel in a single step by including a closed cell foam core in the dry preform. One method of ensuring full wet out of the mould side of the low permeability core is to drill a pattern of small perforations through the core which allows the resin to flow along the top laminate of the preform then through the perforations to the laminate on the mould side of the part. The drawback of including perforations is that they become completely saturated with resin during the infusion process, increasing the final weight of the component due to the higher density of resin than that of the foam core. A compromise must be reached between avoiding dry areas while still minimising the weight of the part.

Objectives

During research into the effects of core perforation spacing on permeability in panels manufactured using RI it was observed that two different mode of void formation were present on the underside of the panel, as shown in Figure 1. Some of these void patches were caused by lockout, which is the meeting of several radial flow fronts from the perforations trapping a small pocket of air.

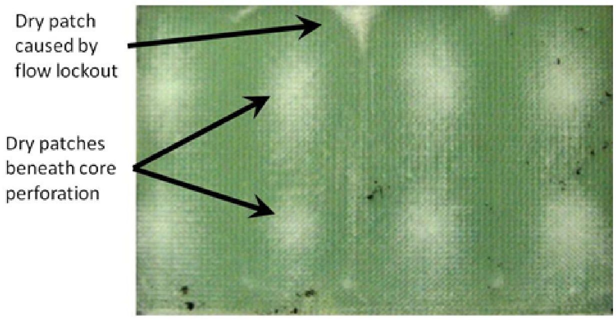

Figure 1: Underside of panel exhibiting dry patch formation

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Inside this Issue

President's Message

Ian MacLeod

As summer approaches and the RWC is now safely behind us we start to look towards 2012 and the opportunities and challenges ahead. Markets remain volatile and talk of recovery is tempered with news of financial difficulties in the Euro Zone and uncertainty of even the near future.

While the super yacht news is stacked with international awards and new orders for bigger and more splendid vessels the commercial end of our industry is being questioned over the RENA grounding and the slow and painful breakup of the stricken vessel. It is unfortunate that it takes such

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a tragic event for our profession to gain mention in mainstream media.

Our Institution remains strong and active within New Zealand with regular members meetings and technical presentations being held, while much of the activity is within the Auckland region we are committed to supporting our members throughout the country and doing whatever we can to help publicise local events or meetings within your area. Please feel free to contact the committee if there is anything that we can help you with.

We have an enthusiastic committee who I must thank for their support and energy over the past 12 months, we all lead busy lives and the members give up their free time to attend meetings and organise events.

Recently members of the New Zealand branch have undertaken professional review interviews for members seeking their MRINA and UK Chartered Engineer status and we now have three RINA approved interviewers who can undertake these interviews locally. I f you wish to upgrade your membership or apply for your UK Chartered Engineer status please contact the membership department in the UK HQ or contact any of us on the committee.

I wish you all a very pleasant and relaxing summer break so that we can be ready to grasp the opportunities of 2012.

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The other dry patches formed directly underneath the perforations in the core, an area of high resin flow.

Three objectives were identified for this research:-

- Identify the factors involved in the formation of dry patches beneath the core perforations.
- Determine the effect of post filling pressure on the presence of voids in the cured part.
- Document the effects of dry patches on single skin sandwich panel compressive strength

Preliminary Investigations

Materials

Initial dry patch observations occurred in a laminate consisting of two skins, each of 6 layers of EQ850 (quadraxial fabric with the individual lamina orientated at [0°/45°/90°/-45°]) on a C70.75 foam core, 20mm thick with Ø2mm perforations spaced in a 64mm square pattern. The fibres were aligned to maximise the nesting between layers. Nesting occurs when parallel fibre tows from two adjacent fabric layers fit between each other. This reduces the size of the channel between the fibre tows in each fabric layer. The reduction in channel size restricts the fluid flow through the reinforcement stack giving lower stack permeability.

Prime 20LV Epoxy infusion system from SP-High Modulus was used for this research. This resin system has been developed for resin infusion exhibiting a low viscosity and low heat emissions during curing. Full details of the resin system can be obtained from High Modulus. For these experiments, a 90/10 mix of slow to fast hardener has been used to allow for sufficient time to infuse the panel and perform experiments before the resin gels, altering the resin properties.

Dry patch behaviour

Experiments were undertaken to examine the flow front behaviour around the relevant area in a controlled

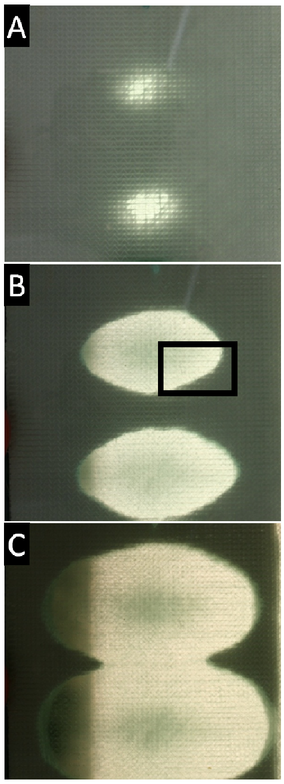

Figure 2: Radial Flow front progression on mould side of sandwich laminate during infusion with inlet back pressure of 500mBar. Images after 2 minutes (A), 7 minutes (B), and 17 minutes (C)
Inset in B refers to Figure 3

experiment. The dry patches were observed appearing during the infusion process as the resin wet out the lower surface of the part, becoming less intense as the filling process progressed then clearly presenting in the final cured part. Figure 2, taken at time steps during infusion, shows the radial flow front progression with dry patches appearing as a cloudy region in the centre of the radial flow fronts of Figure 2-B and clearly visible in Figure 2-C.

Replacing the upper laminate and core with a transparent flat plate allowed for improved visualisation of the formation of dry patches, and resulted in a part with a set thickness. This shows that the particular core used is not a driving factor in dry patch formation. An infusion was undertaken using oil, with similar mechanical properties as Prime20LV, as the infusion fluid, however this did not produce result in dry patches in the part. Initial observations showed dry patches occurring in high flow velocity areas of the preform varying in intensity throughout the infusion process. Dry patches are visible directly beneath the core perforations as the resin front flows radially in the lower skin. During this period the local resin pressure is changing. It was shown that a panel cured under a post filling pressure of 200mbar exhibited greater dry patch formation than the panel cured at atmospheric pressure.

Dry Patch Analysis

Further experiments examined the effect of flow front behaviour on initial void formation and the subsequent void response to changes in

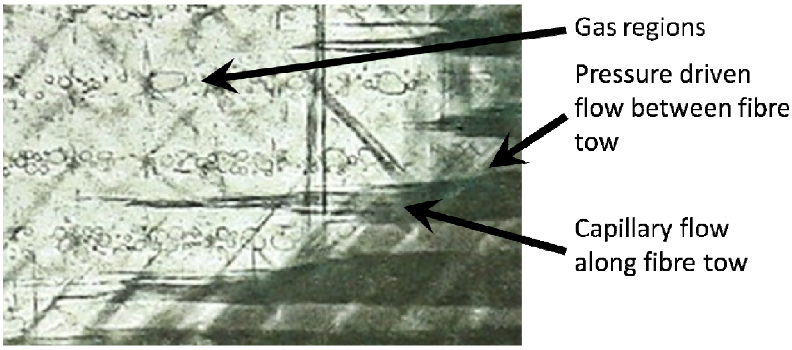

Figure 3: Enhanced image, showing section of Figure 2-B. Radial flow front showing dual scale flow with gaseous regions present

the local resin pressure. For this a pressure transducer was mounted directly beneath a core perforation with image analysis used to correlate void size with local resin pressure.

Flow Behaviour

High resolution images taken of the mould side of the panel show the fluid flow behaviour as it travels through the laminate and show the dual scale permeability of the fabric, with the pressure driven flow between the tows leading the capillary flow inside them. In Figure 3 gaseous regions can be clearly seen between the fibre tows. These gaseous regions result in dry patches present in the cured part. Experiments were undertaken with a partial vacuum applied at the inlet to lower pressure differential across the part. With the inlet at atmospheric pressure and full vacuum applied at the vent it took 26 minutes to fully wet out the preform. This experiment was repeated with the pressure at the inlet lowered to half vacuum, resulting in an increased fill time of 52 minutes. Figure 4 is an enhanced image of a dry patch, the light area represents fully wet out fibres, and the dark areas dry patches. These images suggest a higher flow velocity through the preform results in more intense dry patches.

Void Appearance Relative to Local Pressure

The global void content in a part can be reduced by increasing pressure in the panel during the post filling process. This reduces the level of compaction, increasing the resin content and the weight of the part. To determine the effect of the local resin pressure on the presence of dry patches images of one dry patch were taken at set pressure levels and enhanced to

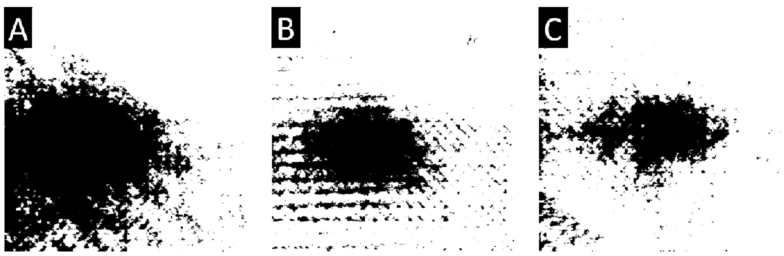

Figure 4: Void Content at 400mbar in Panels filled with inlet pressures of (A) Atmospheric, (B) 750mbar, (C) 500mbar

Figure 5: Void Content in Panels filled with full inlet vacuum at pressure (A) 400mbar, (B) 200mbar, (C) 0mbar

show void content in the panel.

From these images it can be seen that by lowering the local resin pressure in the panel a higher intensity of dry patches is observed in the part. The image at 400mbar (Figure 5-A) has a noticeably lower void content when full vacuum is applied. Voids are gas bubbles in the resin solution, as the local resin pressure decreases so does the gas solubility, resulting in larger voids in the part. During the process of lowering the pressure gaseous regions were observed migrating towards the vent. In particular bubbles were observed flowing up through the core perforations and onto the top surface of the preform. As the experiment continued it was observed that, under the conditions of slow setting resin and a short infusion length, it was possible for the voids to migrate through the part entirely, resulting in a panel with lower void content. In a larger panel with a shorter process time there is the potential for the voids to become trapped throughout the part, resulting in a global reduction in quality.

Laminate Analysis

Microscopy

Six samples were prepared and inspected under a microscope, three samples with dry patches present and three samples showing fully wet out areas. Figure 6 (A) shows a very low level of microscopic void formation in the panel. Figure 6 (B) shows large macrovoid formation between the fibre tows from an area below a core perforation, exhibiting dry patch formation. The formation of macrovoids in regions of high fluid velocity suggests that dual scale flow effects are not the driving force behind dry patch formation beneath the core perforations.

Compressive testing

Two panels were tested according to ASTM D6641-09 to determine the effect of the presence of dry patches on the local compressive strength. Panel 1 was post cured at 0mBar (Full vacuum) and Panel 2 post cured at 400mBar. Samples were prepared from these panels, six samples with dry patches in the gauge length and six samples fully wet out inside the gauge length. The results showed that there is a difference in the average compressive strengths of the four samples. There is very strong evidence that the average compressive strength of Panel 2 is higher than that of Panel 1. There is also strong evidence that the average compressive strength of a fully wet out laminate is higher than that of samples with voids in the gauge length. These results confirm that the presence of dry patches in a panel results in a significant reduction in compressive strength.

Discussion

The results of flow front analysis and panel cross section microscopy showed that dry patches are the result of macrovoids forming in the high velocity flow channels between the fibre tows, rather than microvoids within the fibre tows. The main cause of macrovoid formation in a dual scale flow situation is when the capillary flow leads the pressure driven flow through the laminate, yet shows that the capillary flow along the fibre tows lags behind the pressure driven flow. Based on this it is highly unlikely that dry patches are formed due to the dual scale flow behaviour of the laminate. Experiments have shown that the intensity of dry patches is influenced by

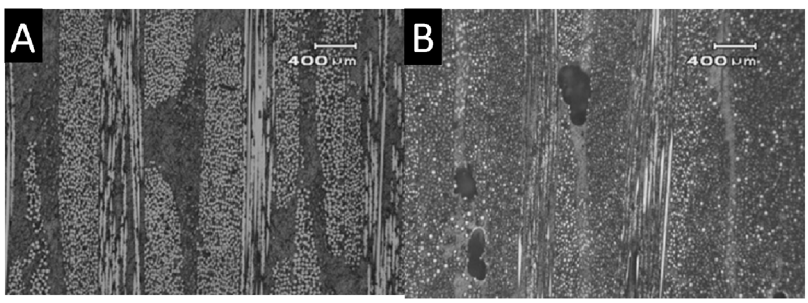

Figure 7: Cross section of panel viewed at 400um.
Fully wet out region (A) and section containing macroscopic voids (B)

the flow front velocity. The flow of the resin through this particular fibre architecture is a key influencing factor in the dry patch formation. More research is required to determine the accuracy of the hypothesis that the formation of dry patches is related to turbulence induced by higher flow velocity as the resin passes through the preform.

By observing the radial flow front progression, it was seen that reducing the pressure differential between inlet and vent reduces the global filling speed and the local flow front progression in both upper and lower laminates. While this has the effect of reducing the void content in the part, it also has the potential to substantially increase the manufacturing time. This means it may not be a feasible solution for adoption by industry, unless they are prepared to accept an increase in the overall process. It has been shown that the intensity of voids can be reduced by reducing the level of vacuum applied to the laminate. This increases the solubility of gas into solution in the resin, but has a trade off of reduced compaction of the laminate reducing the fibre volume fraction and increasing the overall weight of the part.

Conclusions

- Dry patches are made up of macrovoids in high resin velocity area between the fibre tows
- Flow front speed influences the intensity of dry patch formation in the part
- Dry patch intensity can be reduced by increasing the post filling pressure of the part
- The presence of dry patches results in a panel that is weaker in compression than a panel that is fully wet out.

Acknowledgements

We would like to acknowledge the support and assistance provided to us from SP-High Modulus, the industry partner for this research project, the Technical staff and PhD Student Chris Hickey at The University of Auckland Centre for Advanced Composite Materials.

James Brown and David Isaacs were recipients of the Royal Institution of Naval Architects, Babcock Fitzroy Ltd prize for the best marine related final year project at Auckland University Faculty of Engineering in 2010.

HPYD Update - Registrations Now Open

Final papers are now flooding in for the 4th High Performance Yacht Design conference to be held 12-14 March 2012 in Auckland, NZ. The papers will now be sent off to the international technical review committee.

The conference will be held in the Auckland Maritime Museum which is right next to the Viaduct Basin where the Volvo 70s will be moored. In addition to the conference, we will be holding a public session featuring designers and sailors from the Volvo teams, who will discuss a number of key topics related to design and seaworthiness.

The University of Auckland, one of the key event partners, will be hosting a social event to launch their new Masters in Yacht Engineering. Anyone interested in enrolling can email yru@auckland.ac.nz for more information.

If you are interested in providing sponsorship, several levels of sponsorship opportunities are available. Please contact info@hpyd.org.nz for more details.

Registration, via the website, is now open. www.hpyd.org.nz.

HIGH PERFORMANCE YACHT DESIGN CONFERENCE 2012
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Planning the Next Generation

by Michael Grey, MBE

It pays to look ahead, as the Master of the Titanic instructed his watchkeeping officers, and while the shipping industry is clearly facing some economic icebergs, they won't last forever. This year and next are going to be tough times in most sectors, with the overhang of orders which seems an inevitable legacy of about three weeks of decent freight rates, and what could not be cancelled after the 2008 collapse.

One thing is very sure and that is eventually, as the final orders in this tonnage bulge are extruded from the shipyards, those same shipbuilders will be nervously looking at the huge white spaces in their advance bookings, thinking perhaps of the green grass that quickly grows over inactive building docks and slipways. These are people who, it will be recalled, have become used to seeing a stream of supplicant owners grovelling before them, even before their new shipyards had been transformed from the alluvial swamps and rice paddies of their previous owners. They have had a few years when they have been able to call the shots, dictate the designs and equipment choice and generally make owners pay through the nose for anything different. A different engine specification - out of the question! A few more cabins - that will put the price up by 10%! A delayed delivery date - the lawyers will be in touch!

But that was then and this is not far in the future, when this situation figuratively stands on its head and those same owners (or those who have husbanded their cash against this great day) will be in the driving seat. It is by no means here yet, but now is the time to be thinking of what you might be asking those shipbuilders; humble, obliging and helpful people that they will be, to construct for you.

Before coming up with the detailed specification, it might be worth considering what is wrong with the products you have been supplied with in recent years and what lessons might be used to ensure the next generation of ships is greatly improved. Sadly the words 'bog standard' have been used to describe rather too many ships and those which come after really need to reflect more of their owners' aspirations.

Too much steel 'optimised' out of the design to assure a reasonable longevity? Inadequate power for the dimensions, such as the master finds that he cannot make a decent lee for the pilot in anything over a Force 3 breeze, with the ship light. Not enough of anything, whether it is auxiliaries, pumps, purifiers, separators, generating capacity etc. Inadequate accommodation, of a standard worse than that available 40 years ago, with people having to share toilets and washrooms, and if a couple of extra hands are carried, they will have to doss down on mattresses in the hospital or smokeroom - that is if there are any spare mattresses and a smokeroom is available. The absolute minimum of everything with not a shred of generosity in the fittings or furniture, possibly not even the height you need on the bridge to see over the bow. The next generation will have to be better than this, on every count.

It is time for some radical design work, bearing in mind regulatory criteria is changing. We need more shapely ships, with specifications that will anticipate environmental requirements, like systems that won't require bilges to be discharged overboard in any circumstances, with the need for minimum ballast (or none), and machinery that can cope with the ever-demanding requirements of the greens. We surely have naval architects around who can think really radically, and design the industry something a bit new, rather than merely an extrapolation of what has gone before, or tidy up the same old designs with fancy names or some pointless fripperies.

Why do we have to build ships entirely of boring old steel? I hate to keep harping on about the aviation industry, but look at the way in which aircraft have adopted composites in their construc-tion and ceramics in their machinery. Why wasn't the 'Dreamliner' a containership or cruise vessel, before Boeing grabbed the copyright on this truly excellent name? Let us really encourage the design 'think tanks' to flourish and look around the world widely, far beyond the restricted parameters of the maritime mode. And now is the time for this R&D, for innovation that excites, as the alternatives look so stark.

We already have various exciting 'concept' designs based on the use of LNG as the primary fuel. Let us have the same open mindedness and breadth of vision in every element of the detailed design, from the hull form, through the machinery, the cargo handling equipment, to the chief engineer's bath.

And now is the time to have a fusillade of these ambitious demands ready to terrify the shipyards when they come knocking, looking for orders. But builders should be left in no doubt that change is in the air, that owners' new demands will be many and varied and they should be also joining the design party. They should be employing the best of creative naval architects to think big, to dream those dreams and to translate them all into designs that will excite those shipowners, when the economic ice melts and the next phase of ordering begins. When the going gets tough, the tough get going, not wait around for ruin and fate to intervene.

Michael Grey, MBE, is a columnist and correspondent and has been associated with the maritime industry for the whole of his working life. He was a master mariner and then worked in safety and technical department of the UK Chamber of Shipping. He was formally editor of "Lloyd's List".

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Site Visit to Core Builders

At the end of August, RINA NZ visited Core Builders Composite new facility in Warkworth. It was an opportunity for the local marine industry to see the technology behind the AC45 before access was restricted as the work for the AC72 gets underway.

Core Builders Composites moved to the Warkworth site specifically for the potential of the building which at one time was the site of the Rodney Times printing presses. The strong concrete floors and high ceilings provided a suitable home to the team which had been based overseas for the last 10 years. In particular it was the right space to put a large CNC machine that would enable Core Builders to manufacture one piece tooling for large parts.

The highlight of the tour was the unveiling of the new 5 axis CNC machine. With a working area of 18m in length by 6.2m wide by 3m high makes this new machine the largest machine in New Zealand and one of the largest machines in Australasia. It more than triples the size of parts and moulds from their current 5 axis and 3 axis machines.

Both of Core Builders' 5-axis machines have a static bed and the tooling head mounted on a gantry. This allows far greater size, accuracy and speed then the alternative of a moving bed and static cutting head. The machines can run at over 80m/min significantly decreasing cutting turnaround times. The other technological leap offered with the CMS machines is the ability to probe the surface and accurate determine the position removing the risk of misalignment and the time related to machining air. All to an overall surface accuracy of 0.2mm. The result of this investment is more efficient manufacturing of composite tooling and parts.

The immediate beneficiary of this technology will be Oracle Racing for whom Core Builders will construct two AC72 catamarans for the defence of the America's Cup in 2013. As required by the rules, the hulls for the catamarans will be built 'in country' (in the US) but this still leaves a large portion of the high tech platform and the state of the art wings to be built at the Warkworth site.

What CBC can now offer to the New Zealand composites industry is experience building and using tools combined with the machine resource. While America's Cup may seem like money is no object playing field, the reality is that developing cost effective solutions and using the right level of technology is often the key to success. The one thing money cannot buy. It is another example of America's Cup technology trickling down into the wider composites industry. This knowledge base is now on offer including access to tooling design team to assist in developing the right solution.

The site visit was kindly organized by Susan Lake who now works at Core Builders.

RINA– Babcock Award Winners

Once again in association with the Royal Institution of Naval Architects, Babcock Fitzroy Ltd has sponsored the award for the best marine related final year project at Auckland University Faculty of Engineering.

This year's award was presented to was 'Automatic, robotic sail trim to maximise boat speed' and the winning students were Gwendolyn Lemon and Emma Bain

In the next issue of the NZ Naval Architect the students will provide a summary of the project that won them the prize.

Gwendolyn Lemon and Emma Bain at the Final Year Project Displays awards ceremony.

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