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Industrialization of the composites infusion moulding process

Harper, AR

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The Conference Of the Parties (COP26) in Glasgow last year considered how we might limit global warming driving climate change. The light-weighting of transport structures and systems that is possible using fibre-reinforced polymer-matrix composites can make a significant contribution to the reduction of use of (either fossil or renewable) fuels. The wind (and other renewable energy technologies in due course) turbine industry is heavily dependent on composite technologies for large arrays, with one recent turbine design having a rotor diameter of 236 m (Vestas V236-15.0 MW™). The composites industry should seek alignment with the Sustainable Development Goals (SDG): 8 Decent Work and Economic Growth, 9 Industry Innovation and Infrastructure, and 12 Sustainable Consumption and Production.

Authors I Alan R Harper, *CEO,* ***Alan Harper Composites Ltd.*** **John Summerscales,** *School of Engineering,* ***Computing and Mathematics (SECaM), University of Plymouth***

The adoption of resin infusion processes produces composites with higher fibre volume fractions (FVF) and more uniform fibre distribution than those made by hand-lamination processes. High FVF reduce the component mass needed to achieve the product specification through increases in both stiffness and strength. More uniform fibre distribution decreases resin-rich volumes (RRV) and voids to minimize stress concentrations [1]. Infusion significantly reduces volatile organic compounds in the workplace (SDG 8). Infused composites achieve the required performance with a lower mass of material (SDG 12).

However, traditional modes of infusion leave much to be desired in respect of efficiency, even while producing higher quality components in a more comfortable workspace. The process normally involves the creation of a separate vacuum bag for each component. A skilled operator takes considerable time to realise a vacuum tight bag and confirm vacuum integrity. A significant mass of consumable materials (bagging film, flow medium, release film, pipework and tacky tape) are consigned to the waste stream after each single cycle.

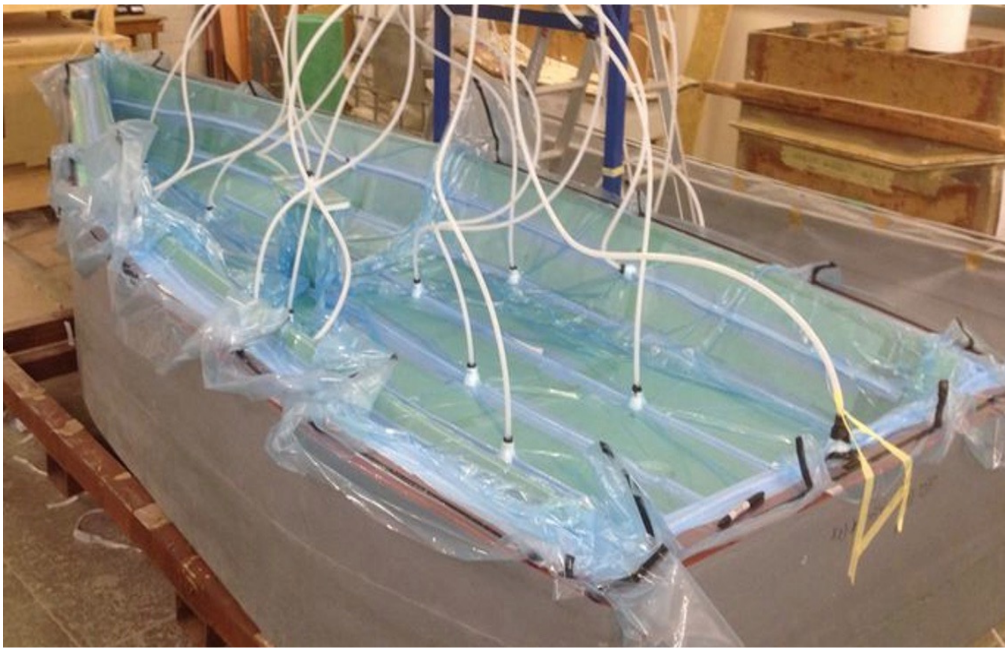

Fig. 1: Traditional bag production consumables used to make one part

A path to the elimination of a waste legacy

A production engineer once remarked that composite manufacture by the vacuum infusion-in-a-bag process appears to remain in the dark ages of the previous century's industrial revolution. The process has long set-up times, is labour-intensive, and the single-use consumables are incompatible with sustainable manufacturing in the twenty-first century (SDG 12). Many composite moulders regularly admit to frustrations with the painfully slow and wasteful nature of vacuum bagging. Such comments and views should inform reconsideration of current practices in composite production. Industry Innovation and Infrastructure (SDG 9) suggests reusable systems!

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In their infancy, the alternative new reusable vacuum infusion membrane systems simply replaced the single use film and tacky tape edge sealing with tailored-to-fit membranes and silicone seals to provide a totally reusable production tooling advantage. One elastomeric bag can be a substitute for more than 600 unsound consumable single use bags. There is a strong economic and environmental argument for the elastomeric solution as the higher initial cost is compensated by break-even around 20 production cycles, and by less contaminated material in the waste stream! Furthermore, when labour and the other factors are taken into account, many manufacturers would confirm economic break even within 6-8 cycles. The savings will come quicker as landfill charges progressively increase.

Continuous waste problem

Those who use infusion on a daily basis are well aware that there are further infusion process factors involved other than simply creating a vacuum tight environment for complete resin saturation of the fibre stack with or without cores. Some applications can involve multiple layers of fibres to achieve at least 55% FVF. The closely bound reinforcement has low permeability for the resin to infuse so process times are extended. This becomes a major issue with flow distances of several meters in, for example, boat hulls and wind turbine blades. Fabrics with flow-enhancement tows are commercially available, but normally the composite properties are compromised by the pore-space becoming resin-rich volumes (RRV).

The use of production flow aids are therefore common. These flow aids comprise various forms of plastic distribution/transport mesh which are kept separate from the laminate by a further additional plastic peel ply (and sometimes release film) layer to ensure easy removal of the single-use cured-resin-contaminated mesh after resin cure. Also, to transport the resin more efficiently, spiral wrap plastic channels are installed bringing yet more resin contaminated consumables. The quantity of resin which does not become product is not only a financial cost to the composites company, but also the production of resin which does not become component incurs the same environmental burdens from resin production as the material that does become product (Figure 2).

Fig. 2: Typical single use resin contaminated flow mesh with release film being stripped off cured part after each cycle

The development of "flow fields" built into reusable infusion membranes eradicates not only unsound single use flow mesh, flow channels and release film, but also the wasteful resin contamination. Furthermore, the labour costs associated with cutting, tailoring, positioning and fixing such single use aids, and the eventual unpleasant removal from the moulded part, and the subsequent waste management (to incineration or land fill) are all eliminated. Reduced contact with resin is better for the staff and a more content workforce generally produces a better product. Reusable membrane simply pays for itself and provides a much cleaner and, in the race to zero carbon, a professional approach to composite part production.

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Legacy of waste

The infusion moulding community continue at unbridled speed to create and bury mountains of waste and yet seem unperturbed as long as marketable product comes out of the process. However, when asked to reflect on the financial and environmental impacts of the fallout from their process on future generations, they would agree to not being happy about this situation. School age children are increasingly questioning the way in which the inaction of their elders will impact on their own adult lives. Grandparent's luxury sports utility vehicle (SUV) is grandchild's nightmare!

Costs and environmental impacts arise from resin waste, consumable waste, workforce labour and disposal management. It should be no surprise even to the casual observer therefore, especially those keen on reducing costs, that there is a considerable advantage here to change from "doing things right" to doing "the right thing". Reusable systems now offer so many saving possibilities that ignoring such opportunities will lead to commercial peril and/or accusations of environmental immorality!

Win Win - Race to zero carbon

We are all witnessing unprecedented cost increases for materials, waste treatment and services, which the planet cannot afford. Single-use disposable plastic cups and straws were found to be unnecessary. The same philosophy applies to waste within manufacturing industries. Not a difficult concept, yet few in the labour intensive composites industry feel it possible to manage waste through better worker practices. Ask your workforce where improvements can be implemented, and use the clues to enhance the profit and environmental standing of your operations.

The new membranes offer a paradigm shift requiring no commitment by the worker to control the waste. It is industry innovation and infrastructure changes which can provide significant waste reduction. Reusables are making this possible for closed mould part manufacture and, by default, a step change in waste control never possible before. The savings realised are so significant that moulders who have adopted this approach become more competitive and make more profit.

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The positive environmental impact remains so significant it is seen as sales advantage being gained entirely due to emphasis on this "greener" manufacturing card being promoted - a noble and truthful claim!

Practical examples of the reusable membranes innovation advantages

Staying focused upon the simple infusion process, the number one requirement is that of tooling reusability and the most significant element is for the main film to not only cover the reinforcement stack and seal under full vacuum, but also to become reusable.

Sprayable high quality platinum cure silicone entered the market in 2007 and gave moulders a chance to manufacture zero shrink silicone membranes which were tough and had excellent self-releasing properties to become an alternative to the single use plastic film. Sealing around the mould flange periphery to gain vacuum security is achieved in various ways but most common is an in-built profile within the silicone membrane itself which simply achieves the desired result and does not require the user to make any changes to their existing mould tool flat flange. This therefore eliminates the conventional single use tacky tape sealing.

As previously mentioned, the infusion process is mainly associated with high fibre volumes which have historically used a plethora of above-dry-fibre-pack flow aides all of which are single use. When the laminate includes cores these are sometimes used as flow aides by including fine precut channels within their surface to provide easy resin flow paths under the fibre. These channels however remain and fill with cured resin adding unnecessary weight and built-in waste.

It is proven that the plastic flow mesh aides consume a minimum of 0.6 kg/m² which has zero cost advantage in process but a total waste cost in process labour, post cure removal and disposal. To put it mildly such technology is unsound both commercially and technically when zero waste alternatives now exist. Careful cost analysis has shown their true cost is more than £34/m² (USD 38,56/m²) when the mesh material with offcuts, labour to tailor and fix with sprayable glues, waste resin, and removable labour with disposal costs are all factored in.

The introduction of reusable membranes has brought about far greater design and innovation freedom to overcome the wasteful nature of consumable bagging. Here we review three further major innovative steps currently in production use today which are incorporated within the reusable membrane structure and are the main reason the process can now be considered productionized.

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On large area infusions involving resin flow lengths of several meters, it has been common practice to use porous piping/channeling (spiral wrap) which allow resin to spread unheeded and rapidly along remote flow mesh zones. These however remain during resin cure and add not only additional total resin waste but also potential high exothermic solid resin cure lines which can impact negatively upon the finished part cosmetics due to uneven shrinkage.

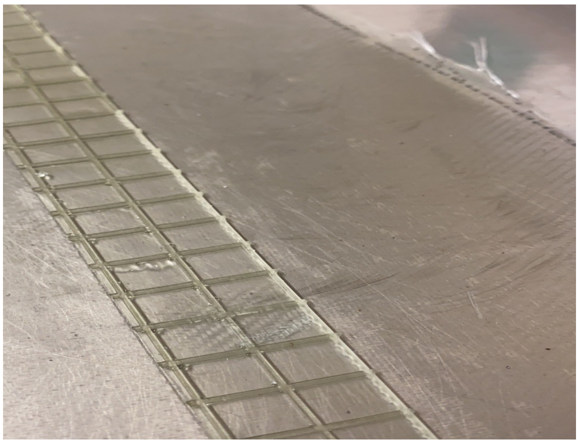
In 1999, ARH filed a patent for flexible flat surfaces incorporated within the back face of LRTM tooling. This surface comprised a silicone sealed channel which could be made to form, at will, a resin channel during the injection stage but return to flat non channel before cure. This idea remained dormant for at least 10-15 years but as reusable silicone membranes gained prominence the previous resin flow channel idea was found to be more relevant and methods of incorporating this within the silicone reusable membrane were developed. This provides what is now commonly termed morph flow channels. Figure 4 shows morphing process from flat to a channel form and back to a flat form before resin gel. This has been further developed and world patent application was made in 2021.

Various styles have been trialed and most successfully are now currently used for large infusions 54 m² where morph channels in the order of 16 mm diameter were employed. The immense cost and environmental benefit of this system cannot be underestimated through the elimination of wasteful consumables with wasteful resin contamination over such large areas.

In 2021, Micro morphs were introduced having equivalent flow of 6 mm bore. Figure 5. It is now perfectly viable to one-time build as many resin flow morphs as necessary to allow rapid fibre wet-out and thus create reusable "flow fields" with zero waste by replacing flow mesh. This idea would not be commercially viable with the conventional consumable flow spiral wrap channels due to excessive labour and resin waste per cycle.

Fig. 3: Large reusable membrane with reusable resin feed channels

Fig. 4: MicroMorph lines provide reusable flow fields eliminating flow mesh



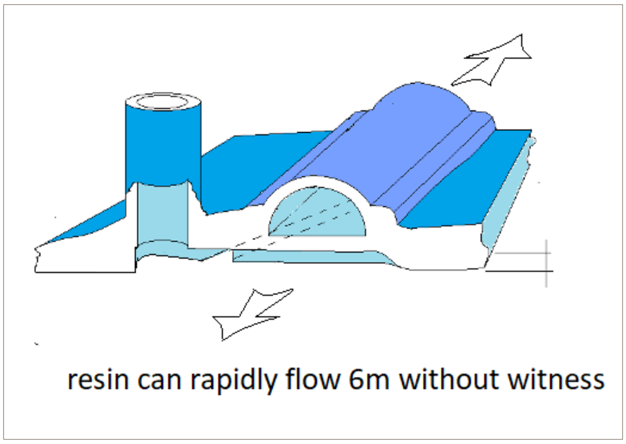
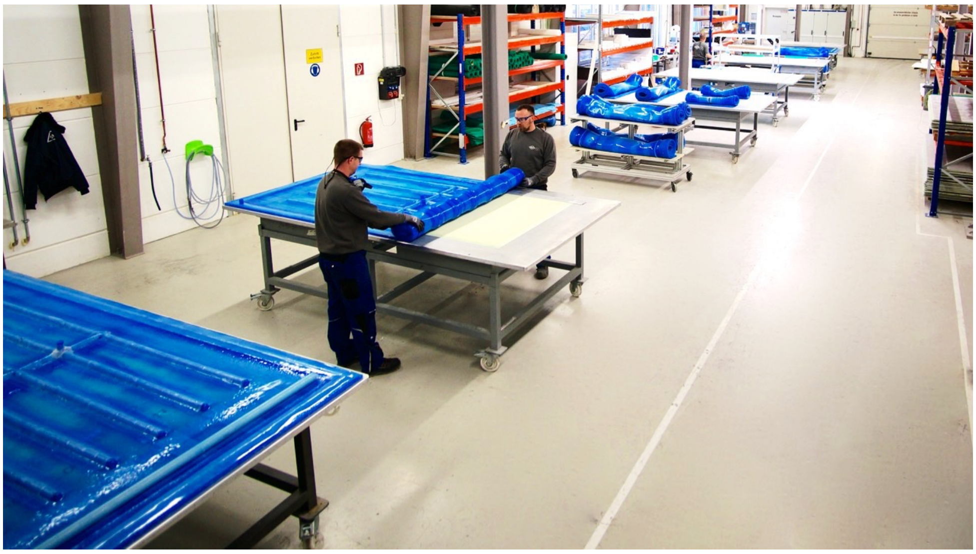


Fig. 5: REFLOW reusable flow aid illustrates resin moulded witness 1mm section used for intricate zones

Another reusable development to address the smaller intricate shape components when even the micro morph is impractical to apply. This is "REFLOW" ™ and is a less than 1 mm recess formed as a 10 mm spaced grid moulded within the reusable surface. Although here, it remains after cure and thus a witness of resin remains upon the moulded part in a similar pattern, Figure 5, many users consider it not worthy of removing with peel ply. After all, reflow only accounts for 200g/m^2 wasted resin and it is installed very sparingly.



SMT Germany Innovation award JEC 2019- ICE Train new composite flooring produced using reusable membranes

Conclusion

The recent developments and innovations in reusable membranes and infrastructure has changed the very nature of the previous labour intensive conventional consumable methods and is set to rapidly capture the production infusion market. Lower process labour leads to reduced costs and improved working conditions and worker satisfaction. The elimination of single-use membranes, pipework and flow aids lead to reduced costs and a significant decrease in process waste and the post-use costs of waste handling and disposal. We believe these developments align with three Sustainable Development Goals (SDG): 8 Decent Work and Economic Growth, 9 Industry Innovation and Infrastructure, and 12 Sustainable Consumption and Production.

More information: **https://alanharpercomposites.com**