

Manufacturing methods for composite materials in extreme sports niche market applications

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1. Introduction *USE PAST TENSE*

This document will be evaluating the manufacturing processes for extreme sports equipment companies. With extreme sports itself being a niche market it will not further divide that market by sport or otherwise. This document will also detail the manufacture of a carbon fibre Stand up paddleboard paddle.

Fibrous composites were introduced to engineering in the 1930's (MAR-BAL INCORPORATED, 2017) since then it has been used in a wide range of both military and civilian based applications from aerospace to automotive to sporting goods. (Sanjay K. Mazumdar, 2002) Carbon fibre reinforced plastics are used because they are both light weight and have a high tensile strength.

2. Materials, Equipment, Software, Health and Safety

2.1. PRE-PREG HANDLE

- CNC machine and tooling; 20mm cutter, 10mm cutter, 6mm ball cutter
- PU600 Polyurethane model board
- Sandpaper grades; 120,400,800,1000,1200
- Paint brushes
- High build primer
- Meguiars mirror glaze mould release wax
- 2 part tooling gelcoat
- Epoxy
- Carbon shears
- Fibreglass
- Semi-permanent release agent
- Carbon fibre pre-preg 2x2 twill

NARRATIVE ?

2.2. ROLL WRAPPED SHAFT

- Mandrill
- Release film
- Peel-ply
- Carbon fibre pre-preg 2x2 twill
- Felt
- Vacuum bag
- Vacuum pump, hoses and valves
- Adhesive putty strip

2.3. PRE-PREG BLADE

- EP700 High Temp Epoxy Tooling Board
- Carbon fibre pre-preg 2x2 twill

2.4. SOFTWARE

- PC with Solidworks and SolidCAM

2.5. PPE

- Dust masks
- Ventilation system
- Protective eyewear
- Nitrile gloves
- Heat resistant gloves
- Workshop jacket
- Steel toe cap boots

3. Composite manufacturing methods used in the production of the sup paddle

3.1. MOULD PREPARATION

For all composite manufacturing methods apart from additive manufacturing a mould must be created. The manufacturing process and part geometry will generally determine whether the mould is a negative mould or a positive buck or plug. (FIBREGLAST, 2019)



Figure 2 Negative mould (FIBREGLAST, 2019)



Figure 1 Positive mould (SCEADU DESIGN, 2019)

The part geometry can also determine the type of mould for example a positive mould would not be applicable to a sealed hollow part. (FIBREGLAST, 2019)

The material that the mould is made of depends on a number of factors such as the manufacturing process and the final part material. Moulds that will be used for mass production are usually made from robust metals such as aluminium that are able to be used repeatedly without affecting the quality of the final part (Composites world, 2016). However moulds that are being used for small production runs are often made from cheaper materials such as glass fibre or model board (Tibbott, 2019).

For the SUP paddle three different types of mould were used;

3.1.1. T-Grip handle mould

The handle for the sup paddle was designed in CAD before being split and placed on a flange. CAM software was then used to create a program for the CNC mill to use to create a buck from which the mould could be created. For educational and economic reasons a Polyurethane model board was milled to create the buck. Once sanded smooth a thick layer of high build primer was painted on and sanded back smooth once dry to fill in any porosity or imperfections. Once smooth a fine layer of high gloss primer was applied using a spray gun. Finally 10 layers of Meguiars mirror glaze mould release wax was applied and then buffed off between each layer to enable mould to be released from the buck.

3.1.2. Shaft mould

The shaft of the paddle was roll wrapped. To do this a mandrill of equal diameter to the spigot on the bottom of the handle was wrapped tightly in 4 layers of 15 micron thick release film and taped

to hold its tension. This was done to enable the removal of the mandrill post cure and to remove any small imperfections.

3.1.3. Blade mould

The blade mould was milled out of EP700 High Temp Epoxy Tooling Board. To save time the mould was milled out very finely to minimise post machine finishing.

3.2. WET LAYUP

Wet layup is a very basic way of laminating composites it is how most Glass fibre moulds are made. It is not normally how final parts are produced due to the very poor surface finish (Tibbott, 2019). Wet layup also has a much higher resin to fibre ratio meaning that the parts or moulds produced are overly heavy and stiff. (Tibbott, 2019) This can be improved by using consumables such as peel ply to absorb excess resin. (Tibbot, 2017)

To produce a wet layup part laminating resin is painted onto the mould before a layer of fibre lamina is applied. This is then repeated until the final layer of fibre lamina has been applied. A final layer of epoxy is then applied to ensure that the top layer is fully 'wet out'.

3.2.1. T-Grip handle mould

This process was used to create the handle mould for the SUP paddle. A tooling gel coat was applied to the waxed and buffed mould. Once tacky the first of 10 layers of powder bonded chop strand glass fibre and 11 of epoxy laminating resin was applied after that it does not matter whether that layer hardens before the next is applied but the first must be applied whilst the tooling coat is tacky the mould was then left to cure at room temperature before being removed from the buck.

3.3. PRE-PREG

The process for pre-preg layup is mostly the same as wet layup the tackiness of the resin will hold the laminate in place during layup (Tibbott, 2019).

3.3.1. T-Grip handle and blade

Both the t-grip handle and blade were made using 2x2 twill carbon fibre pre preg. 4 plies were laid into each side of the mould at 0-90°, ensuring that each conforms fully to the mould. A silicone bladder will then be laid on top of on half of the material before the mould is closed clamped together and the bladder inflated to a pressure of 1 bar. This part was then cured in the autoclave

3.4. ROLL WRAPPING

Roll wrapping is a process where pre-preg fibre lamina is rolled tightly around a mandrill. Before being cured at room temperature in an oven or autoclave. First a release film then the prepreg lamina is rolled tightly onto the mandrill, finally peel ply is wrapped tightly around the carbon fibre to reduce the amount of post cure finishing required. (Sanjay K. Mazumdar, 2002) The part and mandrill are then put in a vacuum bag and covered with "Fluffy" (felt) before the bag is sealed with adhesive putty and the air is drawn out using a vacuum pump before being cured in an autoclave or oven. (Tibbott, 2019)

Surface finish must be considered when roll wrapping. In roll wrapping the mould that the composite is moulded from in a positive internal mould, therefore the internal surface will have the better surface finish. This issue can be limited by both the use of peel ply and post cure finishing. (Tibbott, 2019)

3.4.1. Shaft

After an appropriate amount was cut from the roll the pre-preg was trimmed to size to allow for four layers before being wound tightly around the release film already on the mandrill. This was then wound in peel-ply before being loosely covered with felt and sealed in a vacuum bag. A vacuum was then drawn on the bag and a vacuum drop test was performed before the part was put in the autoclave.

3.5. AUTOCLAVE

The Autoclave is also a curing process. Like the hot press the autoclave uses heat and pressure to hasten the cure of parts. (Sanjay K. Mazumdar, 2002) Parts are placed in the autoclave and the temperature and/or pressure are increased during the ramp up phase. The part then cures at an accelerated rate, after which the pressure and temperature are reduced during the ramp down phase. (Tibbot, 2017)

The autoclave has advantage over the hot press because it uses air forced into the autoclave to increase the pressure the pressure is applied equally over all faces of the part. Also like the hot press the mould material used must be considered due to the high temperatures and pressures that the autoclave produces. (Gunstone, 2016)

3.5.1. Final parts

All three final parts were cured in the autoclave. The ramp up cycle ran over 30 minutes from room temperature to 120°C where the curing cycle ran for one hour before the ramp down cycle back to room temperature.

4. Methods not used in the production of the carbon fibre SUP paddle

4.1. VACUUM BAGGING

The fibre resin ratio of wet layup laminates can be improved by using a vacuum pump to draw out excess resin. When using this process the choice of mould material may be affected. Care must also be taken to ensure that resin is drawn out evenly from the part and that not too much resin is drawn out, both of which may cause dry (absent resin) patches (Sanjay K. Mazumdar, 2002)

4.2. VACUUM ASSISTED RESIN TRANSFER MOULDING (VARTM)

VARTM is a process where dry fibre lamina is laid into a mould usually using a fine spray adhesive to hold the fibre in place once conformed to the mould. For this reason the part geometry that this process would be applicable to is lessened. Once the laminate has been laid into the mould consumables such as infusion mesh and peel ply are used to facilitate resin flow and absorb any excess resin respectively. Finally a vacuum bag is laid on top using pleats to allow the bag to fully conform to the part and is sealed with an adhesive putty.



Figure 3 VARTM of carbon fibre bike seat (Chappell, 2017)

(Tibbot, 2017) Inlet valves are located in areas of the vacuum bag that will facilitate the resin to flow through the part easiest. Outlet valves are run to a catch pot to ensure any resin cannot be drawn into the pump. Once the resin is flowing through an outlet tube it is clamped off and therefore no longer drawing resin through it. Once all the outlets have been clamped off all valves are closed so that the part will remain under vacuum. It is then either left to cure at room temperature or placed in an oven or autoclave to hasten the curing process. (Tibbot, 2017)

4.3. FILAMENT WINDING

Filament winding is a process by which a fibre tow is wound onto a rotating mandrill after being soaked in resin. The dry tow is threaded from the bobbin through a pulley before dropping into a resin bath. The tow is then threaded around another 2 pulleys. As the fibre is drawn through the resin, the resin coats the fibre tow. This will allow the tow to stick to the mandrill and as the process progresses, itself. The resin coated tow is then up to a final pulley at a set angle to wind the fibre onto the mandrill. (Sanjay K. Mazumdar, 2002)

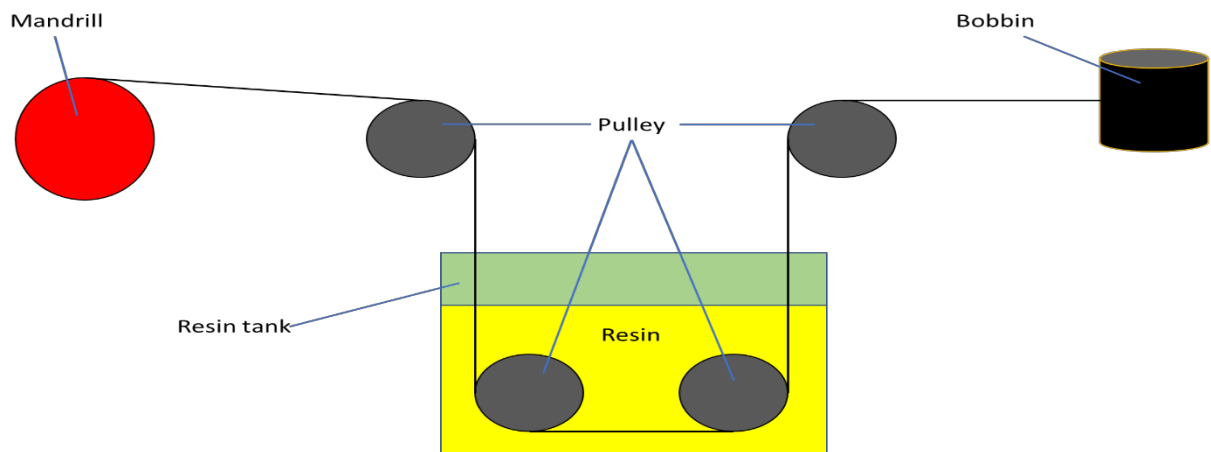


Figure 4 Diagram of filament winding process (Chappell, 2019)

there are many things to consider when using Filament winding primarily the wind angle and part geometry. The wind angle controls the direction that the fibre is wound in this is important due to composite materials anisotropic nature, therefore, the wind angle controls in which direction(s) the strengths of the part are. This gives advantage over woven fabric laminates because there is more control over fibre orientation. (Sanjay K. Mazumdar, 2002) Part geometry must also be considered because complex geometries, such as varying angled parts, parts with sharp corners and concave faces are much more difficult to produce. However recent studies at UWTSD suggest these geometries may be becoming more feasible

4.4. HOT PRESS

The hot press is a curing process that uses high temperatures and pressures to accelerate the curing process. Once the full mould has been placed in the hot press the preheated plates are closed and pressed together to a pre-set pressure. (Gunstone, 2016)

When using the hot press a number of factors must be considered such as part geometries and mould materials. Part geometries must be kept simple because the hot press only applies pressure in one direction this may cause distortion or damage to more complex parts as the mould is closed and the pressure increased. The mould material must also be considered as some cheaper easier to produce moulds would deform or break when large pressures are applied. (Gunstone, 2016)

4.5. ADDITIVE MANUFACTURING

Additive manufacturing (3D printing) composites is a comparatively new process. Additive manufacturing composites comes in two forms. The first is short filled plastics used in FDM printers this is where carbon fibre is cut down to lengths of less than a millimetre and mixed into the plastic before it is extruded into filament. (Raoul Chappell, 2019) The second is continuous fibre layup. In this process the continuous fibre is extruded within the thermoplastic filament to be used in FDM (M.A. Caminero, 2018)

Part geometry and mechanical properties of the desired part must be considered when additive manufacturing composite materials. Part geometry is limited in continuous fibre deposition because all sections of the part will be joined together. This not only creates more post processing work but also has the potential to weaken the mechanical properties of the final part. (M.A. Caminero, 2018) When using short filled filament some of the mechanical properties associated with carbon fibre parts such as tensile strength are reduced significantly. This is because the filaments are very short and disconnected from each other (Raoul Chappell, 2019)

5. Evaluation of methods for niche market applications

5.1. ECONOMIC FACTORS

Niche markets such as extreme sports are comparatively very small in terms of the industries that these processes were designed for. They also have much more limited capital and a much smaller cash flow. It is for this reason that the economic factors are a high priority when choosing a manufacturing method. (Hudson, 2016) (PR Newswire, 2018) Many of the factors discussed in this report must be considered at the same time for example if the parts being produced has to be as light and as strong as possible then an autoclave or a hot press would be a worthwhile investment

5.1.1. Equipment

The equipment used in composites are inherently expensive for example even second hand basic autoclaves cost around £15000 (Taricco Corporation, 2019) which can be inhibitive for some niche market applications. (Jones, 2017) Although the expectations and demands of customers within these markets are still high it is not as high as in other larger industries such as aerospace or motorsport. Therefore companies in niche markets can afford to use manufacture methods that are cheaper in terms of capital investment but produces parts that for example may have a higher resin to fibre ratio. The demand for the products is also less (Office for National Statistics, 2019) meaning that the production rate could be lowered. A lower production rate would mean cheaper materials and processes could be used in mould production. (Tibbott, 2019)

5.1.2. Tooling

The demand for the products is also less in niche markets (Hudson, 2016) (PR Newswire, 2018) meaning that the production rate could be lowered. A lower production rate would mean cheaper processes could be used in mould production. For example more time could be spent hand finishing the moulds or mould tooling meaning less machine time (Tibbott, 2019) which is expensive especially if the company does not have its own CNC machine (get it made, 2019). Cheaper materials could also be used for example wet laid chop strand glass fibre or model board could be used to produce the mould rather than a CNC milled aluminium mould. (Tibbott, 2019)

5.1.2.1. Consumables

The number of and cost of consumables such as peel ply, infusion mesh and vacuum bag must also be evaluated. Any consumables that apply to all processes such as mould release wax will be

removed from consideration in this section. All of the processes listed above apart from the hot press and wet layup require vacuum bags, sealant, peel-ply and baring VARTM, felt, to facilitate air flow while the vacuum is being drawn. however VARTM does require infusion mesh to facilitate resin flow within the part. (Sanjay K. Mazumdar, 2002)

Due to their single use nature most of these consumables are relatively cheap. (Easy Composites , 2019) Therefore consumables alone should not be the sole economic consideration when selecting a manufacturing process

5.1.3. Overheads

Overheads for some of these processes are incredibly high compared with others for example a vacuum pump used in vacuum bagging or VARTM uses approximately 0.25kw (BES, 2019) of electricity costing less than 20p/hr (Switchwise, 2017) and is only run for a small amount of time whereas autoclaves can cost around £800/hr to run and need to run significantly longer per part depending on its geometry (Tibbott, 2019). It also needs to be considered that the autoclave is an additional process as it still requires the part to be placed under vacuum before being used.

Another overhead that needs to be considered is workshop space. Although equipment like vacuum pumps are generally small, other pieces of equipment such as a Hot press, autoclave or CNC machine take up a lot of space (Chappell, 2019), therefore, a niche market company may need to find a larger premises. This would incur additional costs that may not be justified by the improved quality of part.

5.2. TECHNICAL FACTORS

There are a number of technical factors such as training staff to use any new equipment, risk assessments, standard operating procedures, PPE and Health and safety procedures.

5.2.1. Staff training

When implementing new procedures an employer must provide training and instruction on how to use machinery, complete a process and store hazardous materials or equipment (Health and Safety Executive, 2012). This can become expensive not only in terms of the cost of training but also in that the longer the training takes the longer production is potentially shut down for. In larger companies it may be possible to make the change in shifts whereas extreme sports niche market companies in general do not have the staffing numbers to continue production while the training takes place, therefore requiring a full shutdown. (McConnachie, 2017) (Jones, 2017) (Thorn, 2018-19)

5.2.2. Health and safety

Health and safety factors also need to be taken into consideration when choosing a manufacturing process. For example certain processes require more PPE than others (Tibbott, 2019), however this is a very small factor in comparison with others. Processes such as the autoclave or hot press may also require a more expansive risk assessment, annual checks and may increase the rate of employer's liability insurance due to a higher risk. (Chappell, 2019)

5.3. ENVIRONMENTAL FACTORS

In recent years there have been ever increasing reasons for companies to be more sustainable such as tax benefits, marketability and the increased chance of earning larger contracts (STAPLES, 2019). Therefore it has never been more important for companies to consider their environmental impact when making changes to their manufacturing process.

5.3.1. Materials used

In sports that use composite materials there are regulations around equipment to make the sports safer and more accessible to all. One of these regulations is a minimum weight. (ICF, 2018) If that weight can be reached without using pre-pregs or autoclaves then there is no justification for using materials that are harder to recycle and/or processes that are far more energy intensive than others.

5.3.2. Energy usage and efficiency

Energy usage needs to be considered when choosing a manufacturing process not only for the economic cost but the environmental cost as well. Manufacturing premises usually have three phase power available, capable of running the autoclave or hot press. Many niche market companies however start out small in sheds/garages (Jones, 2017) (McConnachie, 2017) that would need that resource put in, this can be very expensive.

There are ways that a niche market company could reduce the amount of energy usage coming from fossil fuels such as solar panels, however, although the solar panels may cover the energy consumption for processes like vacuum bagging or VARTM it would not nearly cover the usage of an autoclave (assuming 20m² coverage and average uk output (Centre for Alternative Technology, 2019)). This also another large capital expenditure.

5.4. FINAL PRODUCT QUALITY

5.4.1. Fibre-Resin ratio

Pre-preg gives the best resin fibre ratio but needs a source of heat to cure properly this could come from an autoclave, hot press or a simple improvised curing oven. For niche market applications wanting to use pre-preg on a budget this is the most likely option. however using VARTM a the resin fibre ratio can be brought very close to that found in pre-preg (Sanjay K. Mazumdar, 2002)

6. Conclusions

6.1. SUP PADDLE MANUFACTURE

6.1.1. Handle mould

There were a few issues when attempting to release the handle from the plug. Firstly some of the excess resin had run down the side and underneath the bottom of the plug sealing the two together. This was solved by cutting through the cured resin with a Stanley knife. After this some shims and a small hammer were used to release the mould, however, whilst doing this the plug split in two. The reason was that too much pressure was applied when buffing the wax from the mould essentially lifting the wax off the plug.

6.1.2. Shaft

There was another issue when attempting to remove the shaft from the mandrill. The release film had partly melted in the autoclave and therefore stuck to both the mandrill and the shaft this made removing the shaft from the mandrill impossible. For this reason the shafts had to be cut from the mandrill using a dremel cutter. The shafts will now be made using the same process as the handle and the blade.

6.2. EVALUATION OF MANUFACTURING METHODS FOR NICHE MARKETS

The choice of manufacturing process is dependent on a wide variety of factors and must be made by each company individually. However, for extreme sports niche markets a VARTM or wet layup and vacuum bagging process either alone or in conjunction with a simple curing oven would be the best option for a niche market company in the extreme sports industry because although the Autoclave and hot-press produce a higher performance part it is not enough to justify the massively increased capital expenditure, running costs, additional risk and energy consumption in comparison with vacuum bagging or VARTM.

- FURTHER PICTURES WOULD HAVE MADE YOUR EXPLANATIONS OF THE PROCESSES CLEARER
- APPLICATIONS OF INDUSTRIES THAT USE THE PROCESSES DISCUSSED

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