Cost modeling of the manufacture of a GFRP leisure boat hull for both open chopped spray moulding and resin infusion processes

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Introduction

A key aspect of manufacturing engineering is the reduction of risk, in order to increase the probability of success. Given that the majority of manufacturing scenarios are a commercial venture, risk associated with profitability is of significance and is often the centerpiece of such a discussion. It is necessary to capture and understand risk associated with profitability and general cost-driven topics, for manufacturing engineers. This is especially the case when a company is moving into less familiar territory, such as when there is a desire to innovate and keep ahead of the market curves for new trends in the adoption of new materials or process technologies [1].

Composites is an area of manufacturing that is subject to many opportunities for growth, as the material and process technologies available are highly tailorable with many potential configurations, which can provide significant cost effectiveness and advantage over other, more traditional materials and processes. For example, being able to consolidate thermosetting polymer composites into their final shape, while also developing material properties, can save on significant secondary, tertiary and post-processing requirements, leading to overall cheaper products [2]. However, given that this process is not sequential in nature and instead, there are many actions occurring in "one shot", it is also much easier for one out-of-spec variable to have a cascading effect and in turn cause the overall failure of the manufacturing process [3]. This is an inherent risk with composite parts, such as glass-fibre reinforce polymer (GFRP) boat hulls, depicted in Figure 1.

Figure 1: Example GFRP boat hull curing

Historically, due to the technically simple nature of the materials, glass-fibre and polyester resin composites have been used to manufacture composite boat hulls. However, there are many issues that arise from this process, including lower specific performance, uncontrollable environmental factors affecting each manufacturing run (ton which these materials are highly sensitive), the highly manual nature of the process, plus others. There has been a desire to shift towards some closed-mould processes, to reduce these sources of risk. Resin infusion has been adopted by some manufacturers in the leisure boat industry and working with a local industrial partner, it has been possible to capture the financial risk associated with such a process change, by using cost modeling tools. Figure 2 shows a boat hull being manufactured by the infusion process, where a dry reinforcement preform is infiltrated by a resin under vacuum, given a specific window of time to fill before thermosetting cure takes place and the process comes to an end.

Figure 2: Workflow employed to import 3D CAD models of complex tub shower geometry

The approach taken is to use cost modeling of both the historical and proposed future process, to compare the two. The potential savings by using the new materials and process will be weighed against the expert opinion-derived risk of workshop employees migrating to a new and unfamiliar technology.

Procedure

In this case study, a 21-foot GFRP leisure boat was considered as the manufactured part at the centre of this analysis. Initially, it is important to select an appropriate cost model to perform the work required. For this case study, the Ashby cost model was used [4],

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for its simplicity and ability to capture production scaling by increasing overhead costs associated with space and labour. The equation describing per-unit costs for manufacture is shown below.

$$C_S = \frac{mC_m}{(1-f)} + \frac{C_t}{n}\left\{Int\left(\frac{n}{n_t} + 0.51\right)\right\} + \frac{1}{\dot{n}}\left(\frac{C_c}{Lt_{wo}} + \dot{C_{oh}}\right) \qquad \text{Eq. 1}$$

Where m is the mass of the part, C_m is the cost per unit mass of the materials, f is the scrap fraction, C_t is the cost of tooling, n is the number of parts being made over the life of the project/contract, n_t is the lifespan of the tool (number of parts), $\dot{n}$ is the production rate, C_C is the capital cost for equipment and infrastructure, L is the load factor of the infrastructure (the relative amount of time it is being used on this project/contract), t_{wo} is the lifespan of the project/contract in days and $\dot{C_{OH}}$ is the overhead cost (labour, site lease, power etc.).

In order to gather the necessary data to populate the model and explore cost factors, the manufacturer has been extensively involved in this process and has provided a wide variety of information about material costs, scrap rates, labour intensities for current processes, amongst other details. The result is shown in Figure 3, which parametrically shows the cost per GFRP boat hull unit, for work orders of sizes between 1 – 500 units in total. It can be seen that by approximately the tenth unit, the cost per unit begins to asymptote at approximately \$12,600. This means that by this point, the price of all equipment, tooling and other non-recurring costs have been effectively amortized into the cost and only recurring costs, such as overhead and materials remain. This cost is in-line with the manufacturer's real costs, illustrating the potential robustness of this highly simple cost model.

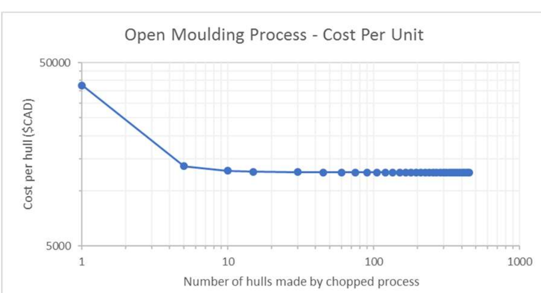

Figure 3: Cost per unit of GFRP boat hull manufactured using open moulding

Similarly, the same process was used for the same boat made by the infusion process. A trade study was performed on this case, where it was recognized that not only would the cost of materials differ from the previous case, but the amount of material would be less, due to the higher mechanical properties obtained. This was fed into the costing analysis to scale mass. Additionally, the differences in sequential manufacturing steps and labour units needed were also incorporated. The results below show that there is a similar point of asymptotic behaviour starting around 10 units, at \$9,700 per GFRP boat hull unit made by resin infusion.

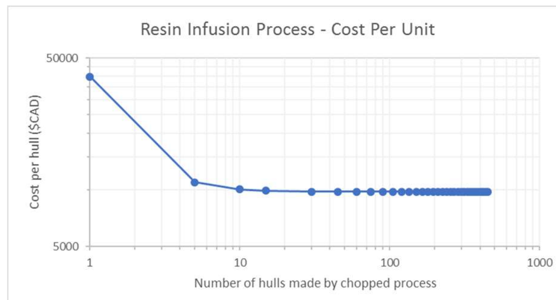

Figure 4: Cost per unit of GFRP boat hull manufactured using resin infusion

Results and Conclusions

The comparison between the cost models indicates that the resin infused GFRP boat hull is cheaper to manufacture than the open moulded GFRP boat hull, by approximately 23%. However, this is only the first stage of the decision-making process, which is to ultimately move to the new material and process technology, given the potential risks apparent in the transition. In the context of this topic specifically, the company has expressed that the new technology is worth pursuing, but not without extra planning and preparation. It is believed that without it, the increased cost associated with scrap rates under the new process will exceed the baseline cost of the historic process. This has helped the company form a strategic plan for technician training ahead of the migration to the new technology.

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