Early Cost Estimation for Manufacturing of Tooling in Resin Transfer Molding

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Due to the increasing demand for strong and lightweight parts, the aerospace and automobile industries began using composite materials in their parts manufacturing. Of the three main methods of composites processing, manufacturers increasingly use the Resin Transfer Molding (RTM) process because it provides a moderate alternative between the high volume, large capital investment compression molding and low volume, low capital investment vacuum infusion molding. The RTM balance between volume and investment on machines and tooling makes it important to develop an early cost estimation for RTM tools.

Understanding RTM

RTM consists of a thermoset resin injected into a two-part matched mold containing a dry fiber reinforcement. The basic RTM process includes the loading of the preformed reinforcement into the RTM tool, closing the tool, injecting the thermoset resin into the mold, curing the resin, and removing the part from the mold as shown in Figure 11.

The dry fiber reinforcement, often called a preform, consists of a wide range of materials from natural wood fibers to synthetic polyester fibers. The automobile industry most commonly uses glass fibers, whereas the aerospace industry uses mostly carbon fibers.[2] Because of the differing part requirements, industries use various perform fibers and fiber preparation methods to create the preform. In most cases, the toolmaker manually places a shaped perform into a prepared mold cavity. Much like injection molding, the index pins align the two mold halves, while a press closes the mold. Clamps hold the two mold halves in place as the resin injects into the mold.[3] The resin wets the preform, and when resin begins filling the venting ports, the injection stops. An oven, platens, or integral heaters elevate the temperature of the mold, curing the resin. Finally, one removes the cured resin part and if required, finishes the part by trimming or polishing.[1]

Costing

Traditionally, companies assign the cost estimation of these RTM tools to the most experienced mold makers, because the increasing number of manufacturing materials and processes used in RTM makes pricing difficult. Often toolmakers admit ignorance to an exact method for determining cost. Despite the difficulties, cost estimation is an essential part of the design for manufacturing (DFM) of a RTM tool on two different levels.

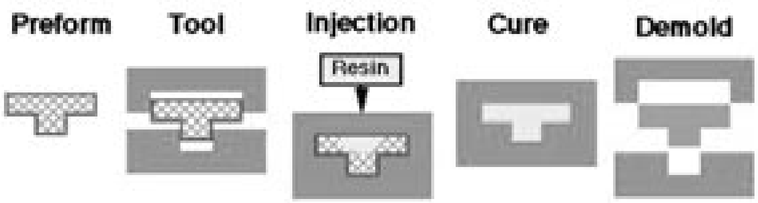

Figure 1

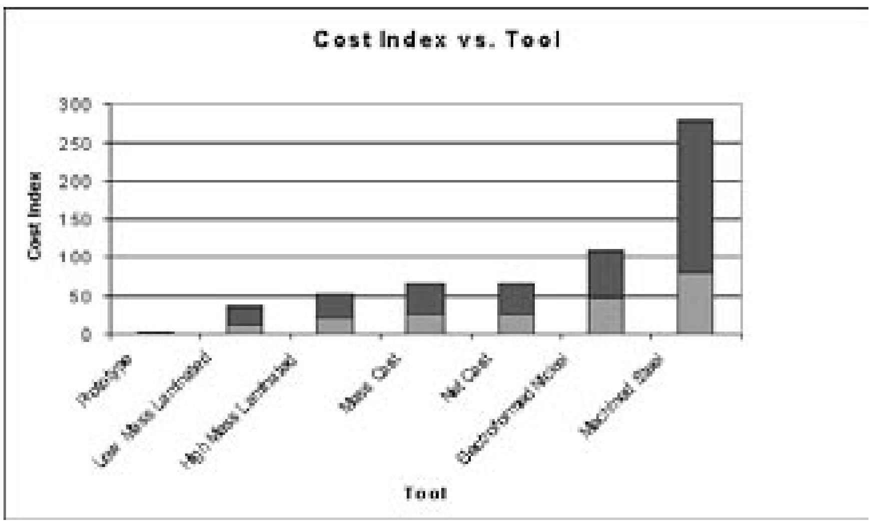

Figure 2

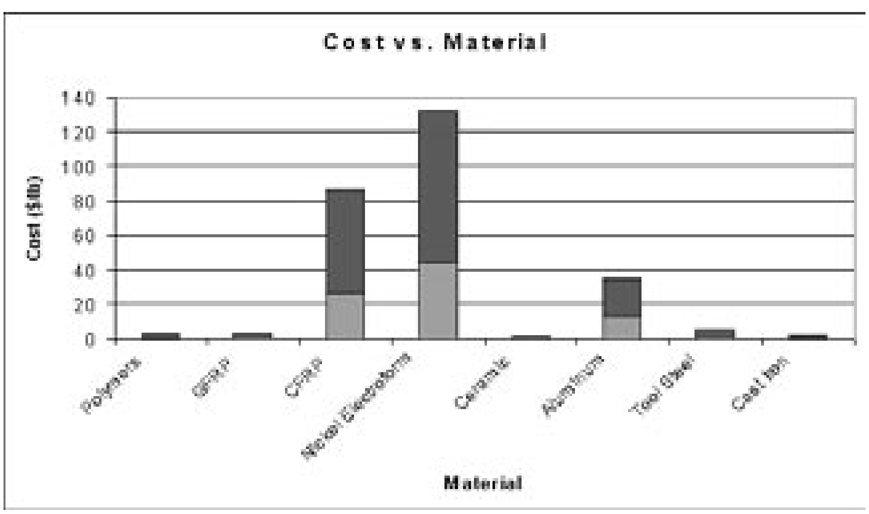

Figure 3

A demand for the part initiates the first level of RTM tooling. The part designer creates a part with strength and dimensional requirements to fulfill a task. At this level, an early estimation method for RTM tooling helps the part designer create an economically viable tool. Therefore, even before the conception of the tooling design, the parts designer considers the cost. For instance, the designer chooses certain features because a long z-axis part adds to the tooling cost or the strength requirement of a slender component in the part call for large manufacturing pressures achieved only with expensive material such as Electroformed Nickel (Interview with Eric Johnson, Everett Pattern and Manufacturing).

On the second level, the tool designer creates a tool to match the part. Due to the relative newness of the composite RTM process, few tool designers know how to choose and design an economically viable tool for a given part. An early cost model helps the tool designer decrease costs on this tooling design level. This is especially important in RTM because so many feasible mold designs exist for a given part. Thus, the use of a cost estimation model can overcome some of the limitations of relying only on design experience in selecting the designs, materials, and production methods for a particular part and tool. This paper presents some guidelines for early cost estimation in RTM tooling.[3]

There are three major steps in tool manufacturing. First, the manufacturer designs the tool for manufacturing (DFM). Then the toolmaker performs analysis on the design. When the tool design passes the analysis, the toolmaker manufactures the tool. Finally, after the final inspection, the toolmaker ships the tool to the customer. Because the methods for estimating shipping costs do not rely solely on the toolmaker, this paper concentrates on the first two steps of manufacturing. In considering an early cost model of RTM tooling, the designer should also split the cost modeling into these major categories to simplify the process.

Design and Analysis

Initially, a designer creates a part, which requires a tool to produce. Next, a toolmaker designs a tool for manufacturing the part (DFM). This is usually done using a computer-aided design to model the tool (CAD model). Unlike injection molding and other manufacturing processes, depending on the performance requirements, several methods exist for RTM tooling. Two basic categories separate RTM tools. Tools made from composite make up the first category of tooling. The different materials and laminating processes divide the composite tools into low-mass laminate, high-mass laminate, and composite-mass cast tools. Tools made from metal compose the second category of RTM tools. Differing manufacturing processes such as near-net casting, nickel electroforming, and machining divide this category of tooling. Table 1 gives a rough estimation of the appropriate type of tool for the part production volume (Interview with Global Glass, Able Body Corporation, Fiberglas and Plastic).

In choosing a tooling process, the designer should keep in mind the limitations for each type of tooling as well as the approximate tooling costs. Figure 2 provides a rough costing index useful in the design stage of the tool (Lacovara B (1995), Considering Resin Transfer Molding, CFA Paper).

Manufacturers build RTM tools out of many materials using many processes. Not only do the material costs differ, each material requires a different manufacturing process to build. Thus, the material choice becomes a major cost driver. Some considerations for choosing a material include the strength, coefficient of thermal expansion (CTE), cost, and weight of the material. The required part volume, and the tooling type also limit the list of possible materials.[4]

The geometric complexity of the tool affects both the design and the manufacturing costs of the tool. The main cost-driving features that significantly affects the cost of the tool includes the long z-axis depth of the tool and the amount of material removed in this direction. The small radii also affect the cost. The design and analysis stages of creating the tool account for 30 to 50 percent of all costs (Site tour, Everett Pattern and Manufacturing).

Manufacturing and Verification Costs

Other major contributors to the tooling cost are the manufacturing and inspection of the tool. The material cost, the labor costs, the machine costs, and the detailing costs are buried within the manufacturing costs. The 3-D CAD data fully defines the volume and the dimensions of the final RTM tool. Given the density and cost per unit volume of a material, the manufacturer can calculate the total material cost. Figure 3[5,6] compares the cost of materials for RTM tools. It is important to note that the material selection differs from the tooling selection. After the selection

Table 1

Tools	Part Count
Low Mass Laminated Tool	Less than 1000
High Mass Laminated Tools	Less than 5000
Mass Laminated Tools	Less than 10,0000
Near Net-Cast Tools	Less than 50,000
Nickel Shell	5,000 annual
Metal Fabricated	10,000 Annual

Table 2

Composite Tooling Process (note that inspection occurs after most steps)
Create and Finish the Pattern
Apply Tooling Gel Coat
Lay and Cure Coats of Resin
Lay Core Material
Build and Attach Reinforcement Frame
Glass the Frame
Demold Plug/Finish the Tool
Build Channel
Fix Seal
Make Male Part Similarly
Build Alignment
Build Injector System
Build Venting System
Final Inspection and Shipping

Table 3

Metal Tooling Process
Machine Out Basic Block for Female Part
Inspection
Create Surface Features: i.e. Shipping Holes, Lock Mechanisms, and Demolding Bolts
Inspection
Create Surface: Rough Pass, Finish Pass, and Bench Pass.
Create Secondary Features: Rough Pass, and Finish Pass.
Inspection
Final Finish: Sanding/Buffing, and Hand Finish.
Make Male Part Similarly
Final Inspection and Shipping

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(3) Reinhart TJ (1987), Engineered Materials Handbook: Composites ASM International Handbook Committee Volume 1, Metal Parks, Ohio: ASM International.

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(7) Ostwald PF (1998), AM Cost Estimator: Cost Estimating Database, Cleveland, Ohio: Penton Publishing, Inc., 4th Ed.

(8) Polgar KC (1994), Simplified Time Estimation for Basic Machining Operations, Cambridge: MIT Laboratory for Manufacturing and Productivity.

of an appropriate tool, it narrows down the list of possible materials, but the toolmaker still must choose an appropriate material to build the tool. For instance, a toolmaker must select from different materials such as invar, tool steel, cast iron, or aluminum to build a metal fabricated tool.

Next, the designers must estimate the costs of the actual building of the part. Equation 1 shows a good estimation for these costs.

$$Cost_{total} = T_{mfg} Cost_{labor} + T_{mfg} Cost_{machine}$$

Where, the cost of labor per hour differs for each company. However, one can use $100/hr as a quick estimate in early cost approximations. The cost for running the machine every hour also differs for each company. However, $100/hr. is also a reasonable rough approximation. Thus, multiplying the manufacturing time by the labor cost per hour and the machine costs per hour results in a sound estimation of the building cost.[7]

The time for manufacturing (T) comes from a summation of the times for each step in the process plan. The manufacturer should perform several analyses to calculate early estimations for the manufacturing time.

1) Make a rough process plan for the tool. Table 2 (Interview with Falls Fiberglas Products, Inc., A-1 Fiberglas, Accura Industries, Inc.) and Table 3 (Interview with Mark Bellanger, Technician at the Laboratory for Manufacturing and Productivity at MIT) show the rough process plans for the two categories of RTM tools

2) For each step in the process plan, determine the time required to set up the process. Three major steps contributed to the set up time. First, preseting the tool contributes to the manufacturing time. For instance, on a metal tool, each tool requires 15 minutes to preset on a 5-axis CNC machine. Secondly, changing the tool also adds time to the manufacturing. In metal tooling, it requires about 0.5 minutes to change a tool. Lastly, positioning or repositioning the tool to do the process also requires time.[8]

3) Calculate the time required to complete each process in the process plan. For instance, in metal tools, calculate the material volume of the removed material. Then use the material removal rate to find the time require or the actual roughing and finishing machine processes.

4) Find the time required to inspect the tool after each important process and add up the times for each step in order to find the total manufacturing time.

Using these tables above and incorporating more detail according to each particular part, one can estimate the time required for each part. Next, applying Equation 1 results in an early cost estimation for the tool-building steps of RTM tooling.

Conclusion

Adding up many categories of tooling costs gives an early cost estimation for RTM tooling. First, the design costs section reviews the main criteria for determining the costs of the tool. Secondly, the total manufacturing costs come from the material costs as well as the labor and machine costs. Lastly, the shipping costs add minimally to the overall cost of the tool. Using these basic guidelines will help both the part and tool designer in building an economically viable RTM tool.