Composite Engineer's Viewpoint

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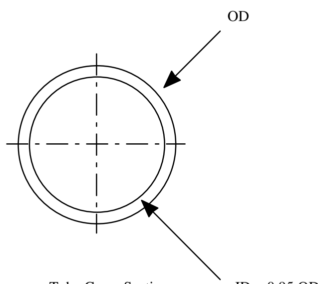
Designing with Composite Materials
Part 6B – Initial Costing Analysis: Example

In the last article we introduced initial cost estimation and now we undertake an example of the initial costing analysis. This example demonstrates the importance of early costing estimations. This example is based on work prepared by Abaris Training Pty. Ltd., Reno NV.

The cost/quantity tradeoffs of several of the manufacturing processes and materials are compared by using the simple example of a cantilever tubular beam with simple structural requirements. **Note that there are some gross assumptions made for the comparisons and they should be interpreted more as an example of the method rather than taken literally as a true cost comparison.**



Tube Cross-Section

The beam diameter will be varied in order to meet the most critical condition: either maximum deflection (controlled by modulus) or maximum tensile bending stress. An arbitrary factor of safety of 4.0 is applied to ultimate stress which eliminates local compressive buckling.

The processes and material combinations to be compared as well as the tube weights and costs which result from the structural requirements will be compared. Note that the simple tube configuration is not suited as well to some of the manufacturing processes such as spray-up or RIM, but is ideal for pultrusion or filament winding.

Sizing, Process and Material Cost Assumptions

Material	Process	Modulus (GPa)	Ultimate Stress (MPa)	Tube Dia (mm)	Weight (kg)	Material (cost/kg) 1995 USD	Material Cost (in quantity) 1995 USD
Polyurethane/ 15% milled glass	RIM	0.69	34	223.4	10.4	2.43	$25.27
Polyester/20% chopped glass	BMC	6.9	48	156.4	5.9	1.76	$10.38
Polyester/glass roving & mat	Pultrusion	27.6	552	88.9	1.8	2.42	$4.36
Polyester/carbon tow & mat	Pultrusion	75.8	758	81.3	1.2	18/30	$21.96
Polyester/glass rovings & mat	RTM	27.6	414	96.5	2.2	2.42	$5.32
Polyester/ glass rovings	Filament winding	27.6	552	88.9	1.8	2.42	$4.36
Polyester/ glass fabric	Wet lay-up	27.6	414	96.4	2.2	4.96	$10.91
Epoxy/glass fabric prepreg	Prepreg lay-up	27.6	552	88.9	1.8	13.23	$23.41
Polyester/ glass rovings	Spray-up	6.9	103	134.6	4.0	1.98	$7.94

<u>Tooling Costs</u>: The matched metal die costs assume that aluminum is half the cost of hard steel, but is limited to less than 1,000 cycles. RIM dies are assumed three times as expensive ($200/in^3 in steel) as compression molding of BMC due to higher pressure and complexity of integral runners, ports and heating. Tool cost is also a function of tool size; thus the higher performance materials result in a smaller part requiring smaller tools.

Tooling Materials and Cost Assumptions (1995 USD)					
Production Quantity	**10**	**100**	**1,000**	**10,000**	**100,000**
RIM	Matched Al $465,000	Matched Al $465,000	Matched Steel $930,000	Matched Steel $930,000	Matched Steel $930,000
BMC	Matched Al $85,000	Matched Al $85,000	Matched Steel $165,000	Matched Steel $165,000	Matched Steel $165,000
Pultrusion (polyester/glass)	Steel $15,000	Steel $15,000	Chrome steel $25,000	Chrome steel $25,000	Chrome steel $25,000
Pultrusion (polyester/carbon)	Steel $12,500	Steel $12,500	Chrome steel $20,000	Chrome steel $20,000	Chrome steel $20,000
RTM	Matched G/E $2,200	Matched G/E $4,400	Matched Al $17,000	Matched Steel $35,000	Matched Steel $35,000
Filament Winding (includes repair of tooling)	One Sided G/E 1 set - $1,000	One Sided G/E 1 set $2,000	One Sided G/E 3 sets $8,000	One sided Al 3 sets $35,000	One sided Steel 3 sets $70,000
Wet Lay-up	One Sided G/E 1 set $1,100	One Sided G/E 1 set $2,200	One Sided G/E 3 sets $8,800	One sided Al 3 sets $38,000	One sided Steel 3 sets $77,000
Prepreg Lay-up	One Sided G/E 1 set $1,100	One Sided G/E 1 set $2,200	One Sided G/E 3 sets $8,800	One sided Al 3 sets $38,000	One sided Steel 3 sets $77,000
Spray-up	One Sided G/E 1 set $1,100	One Sided G/E 1 set $2,200	One Sided G/E 3 sets $8,800	One sided Al 3 sets $38,000	One sided Steel 3 sets $77,000

Process Equipment: The cost of capital equipment needed for the different processes can be amortized over the number of parts produced. In the following table some assumptions about equipment cost and cycle times yield a rough cost per part of equipment.

- This method assumes that the machine is in constant production of parts. In most cases being considered here, the production runs are much smaller than the capability of the equipment over its useful life. This means that the equipment is constantly running batches of different parts at all times.
- Equipment downtime between jobs would add to the cost of the part.
- Equipment purchased solely for production of a run of a single item would have to be amortized over the number of parts produced.

Process Equipment Cost Assumptions							
	Equipment	**Cost 1995 USD**	**Life**	**Cycle Time**	**Parts/ Shift**	**Parts/ Year**	**Cap. Equip Cost/Part**
RIM	Injection Molder	$250,000	20 years	4 minutes	105	52,500	$0.24
BMC	Heated Press	$100,000	20 years	4 minutes	105	52,500	$0.10
Pultrusion	Pultruder	$100,000	20 years	1 minute (@ 5 fpm)	420	210,000	$0.024
RTM	RTM	$15,000	20 years	30 min	14	7,000	$0.11
Filament Winding	Winder	$20,000	20 years	10 (high)* 30 (low)	42 14	21,000 7,000	$0.05 $0.14
Wet Lay-up	Small Equip.	$2,000	2 years	30 min	14	7,000	$0.14
Prepreg Lay-up	Oven & Misc.	$3,000	10 years	3 hours	3	1,500	$0.20
Spray-up	Spray/	$2,500	1.5 yrs	1 hour	7	3,500	$0.47

	Chopper Gun						

*High production winding assumes that three tools are available to keep the winder in operation continuously. While one part is being wound the previous part is allowed to cure time while the third mandrel tool is stripped of a part and prepared for the next winding.

Other Cost Assumptions

Materials:

- An additional scrap/waste rate of 20% is applied to hand lay-up parts over and above the net part material cost, 10% is applied to spray-up, 15% to filament winding, 10% to pultrusion and 5% to the other processes.
- Material costs are increased with decreasing production runs per the function described in the previous article on material costs. The material costs in the table above are assumed to correspond to the cost at a quantity of 100,000 lbs.

Labor: Hand lay-ups are assumed to start at 0.44 hours/kg for the first article and follow the previously described learning curve: Total Labor hours = man-hours for 1st article * (number of articles produced)$^{0.65}$

- RIM - 1 operator
- BMC - 2 operators
- Pultrusion - 2 operators
- RTM - 1 operator
- Filament Winding - 3 operators
- Spray-up - 2 operators

Labor is assumed to cost $18.00USD/hr direct, including provisions for vacation, sick leave, insurance, and pension.

Design/Development: This is the cost to design and develop a product. This cost must be amortized over the total production run of the product. This has **not** been included in this example.

Overhead: For the sake of simplicity, overhead is assigned a simple value of 100% of direct costs and is assumed to include the costs of facilities, utilities, and management. In this case the costs of tool repair and equipment maintenance will also be considered as being included in overhead. In a more rigorous estimate of production cost, many of the cost factors lumped into "overhead" for this simple comparison should be detailed and would include:

- Facility space — i.e. a shop producing lay-up prepreg parts needing autoclaves and freezers will require much larger facilities per mass of material than a pultrusion operation.
- Utilities — Ovens and autoclaves require more energy than a room temperature cure system.

Cost of Money or "Opportunity Cost": This is the interest cost (if financed) or the lost interest on money required to purchase capital equipment, tooling, design, and develop a product. This cost is not included.

Total Manufacturing Cost Comparisons: ***Net Cost-Quantity Comparison Manufacturing: Cost/Part(1995 USD)***

QUANTITY	10	100	1,000	10,000	100,000	Material*
RIM	$93,139	$9,411	$1,949	$258	$77	$26.57
BMC	$16,660	$1,709	$370	$65	$30	$10.92
Pultrusion (glass)	$3,026	$321	$67	$19	$12	$4.88
Pultrusion (carbon)	$2,626	$350	$120	$68	$52	$24.64
RTM	$504	$146	$88	$57	$48	$5.54
Filament Winding	$262	$96	$50	$38	$30	$5.11
Wet Lay-up	$300	$103	$62	$42	$28	$12.89
Prepreg Lay-up	$381	$166	$112	$82	$60	$28.80

Spray-up	$337	$152	$118	$74	$57	$8.71

*Material cost per part includes assumed scrap rate

- In small quantities RTM, spray-up, lay-ups, and filament winding are competitive.
- The filament winding example is unrealistically low due to the simplifying assumption that the winding equipment is in continuous operation and its cost can be amortized over just the running time. A shop running small batches of different parts would incur significant idle time not accounted for here. This same argument applies to some degree to all processes.
- The higher production processes are prohibitively expensive in small quantities.
- Note that the carbon pultrusion is competitive with the glass in small quantities. This trend would hold true for small quantities RTM, filament winding, lay-up, and spray-up processes. In small quantities the material cost is less a factor than tooling cost, and if the part is stress or stiffness designed, the tooling may be reduced in size such that carbon is actually a cheaper alternative.
- The simple two-dimensional configuration is ideal for pultrusion, and the costs reflect it. Most parts are three dimensional and pultrusion is not feasible.
- The RIM and BMC parts are at a serious disadvantage in this comparison: a simple configuration sized solely by stiffness and strength puts the weak short glass reinforcement at a serious disadvantage. These processes are better suited to parts of more complex three dimensional shapes for which simple stress and stiffness are not the sole design criteria.

In the next article, we will develop the design detail aspects in composite structures. I also welcome questions, comments and your point of view. Feel free to contact me via r.heslehurst@adfa.edu.au. I may publish your questions and comments, and my response in future newsletters.