MANUFACTURING AND DESIGN, 1st edition, 2014
Erik Tempelman, Hugh Shercliff, Bruno Ninaber van Eyben

Chapter 10: Resin transfer moulding – HINTS

THIS DOCUMENT IS INTENDED FOR USE BY STUDENTS.

Exercise 10.1   Search the web for interesting examples of RTM products. Even better, find actual products, if you can get your hands on them! For each product, why do you think a composite has been selected rather than an unreinforced plastic? What are the implications of this choice for recycling?

Hint 10.1: for tips regarding you search terms, see also the first paragraph of Section 10.6. Also, be warned that while UK English uses ‘moulding’, USA English uses ‘molding’ – in some searches you will find somewhat different answers.

Exercise 10.2   Compare the specific stiffness (modulus/density) and specific strength (strength/density) of the five fibres, HSLA steel and aluminium. Which one ‘wins’, and how do the metals come across in the comparison?

Hint 10.2: this should be straightforward. Tip: use a spreadsheet, as you can then address several of the following exercises also.

Exercise 10.3   Choose a combination of fibre and resin. Estimate the strength and stiffness of a unidirectional composite that has a fibre volume percentage of 50% (on the basis that the fibres carry all of the load). Now repeat for a value of 20%.

Hint 10.3: again, a simple question. Consider that the lower the fibre volume gets, the lower the composite's performance will be, in terms of specific strength or stiffness. The resin adds weight but not strength or stiffness.

Exercise 10.4   Increasing the fibre volume percentage clearly benefits strength and stiffness, but what could be the benefit(s) of lowering this percentage?

Hint 10.4: Section 10.3 holds the answer: there is one major benefit to be gained.

Exercise 10.5   Repeat Exercise 10.3, but this time for a cross-ply composite with equal amounts of fibres in both directions, and neglecting the stiffness and strength of the transverse (90) plies (total fibre volume: 50%). Now estimate the specific stiffness and specific strength of your composite, and compare again with the metals in Table 10.1. What are your conclusions?

Hint 10.5: again, a simple question once you realize that only the fibres that are aligned with the external load can contribute to the strength and stiffness in that direction.

Exercise 10.6   Even with equal fibre volume percentages, a random mat composite has a lower strength and stiffness than a quasi-isotropic composite (at least for in-plane loads). Explain why.

Hint 10.6: think about how effectively loads in all in-plane directions are carried by fibres.

© Erik Tempelman, Hugh Shercliff, Bruno Ninaber van Eyben, 2014

Exercise 10.7   Fibre layers always have a certain thickness, which is typically around 0.1 mm. What does this mean for the available thicknesses of UD, cross-ply and quasi-isotropic composites? Note that fibre layers should preferably be stacked symmetrically over the thickness!

Hint 10.7: sketch how the lay-up would look and consider how many layers you need if it is to be symmetrical over the thickness.

Exercise 10.8   Which fibres have been used in your sample products (Exercise 10.1)?

Hint 10.8: all kinds of possibilities. Of course, carbon fibres will be used predominantly in expensive, high performance products, while E-glass fibres will be found mainly in more affordable products. R/S-glass and aramid are in fact special cases, with specific strengths and applications. For instance, a single top layer of aramid fibers can significantly add to the impact resistance of a CFRP part.

Exercise 10.9   Assume we use RTM to produce each half of a rectangular suitcase measuring 90 x 60 x 20cm (so the depth of each half is 10cm). Injection is done using a runner around the product and a single suction cup in the middle. Plot how the injection speed varies with time during the process, assuming that $\Delta p = 0.8$ bar, $\mu = 0.2$ Pa.s, and $k = 0.8 \times 10^{-9}$ m^2.

Hint 10.9: simply use the formula correctly!

Exercise 10.10   What is the injection length for the situation in Exercise 10.9? Hence, determine the injection time. What would this time be if the injection length is doubled?

Hint 10.10: this length is essentially the distance from the runner to the suction cup. The time follows from Equation 10.2.

Exercise 10.11   By increasing the pressure difference, we can decrease the injection time, which is generally a good thing. However, does this approach have a drawback?

Hint 10.11: the answer can be found in the paragraph immediately below.

Exercise 10.12   Calculate the total force acting on the suitcase featured in Exercise 10.9 during production (don't forget the runner!). Are the mould halves pressed towards, or away from each other? Assuming that some mould deformation occurs, what happens to the permeability?

Hint 10.12: force is of course equal to pressure × area; assume the runner adds 10% to the net cross-sectional area of the product.

Exercise 10.13   Assuming we use RTM to produce a carbon fibre-epoxy bicycle frame. Roughly how many products can we make per year if we have one mould?

Hint 10.13: you will need an estimate for the effective production hours, which is typically 1,500 (one-shift production) or 3,000 (two-shift production) per year. Also, note that injection and curing are not the only process steps (see also Exercise 10.16).

Exercise 10.14   If injection and curing both take one hour, what would be the benefit of having more than one mould?

© Erik Tempelman, Hugh Shercliff, Bruno Ninaber van Eyben, 2014

Hint 10.14: just think about it – carefully.

Exercise 10.15   Epoxies and polyesters both shrink some 4% during curing. For parts with a low fibre volume percentage, this shrinkage may give tolerance issues. Explain why this is generally less of a problem for parts with a high fibre volume percentage.

Hint 10.15: the answer lies in the difference in Young's modulus for the fibres and resins.

Exercise 10.16   Which other manufacturing step(s) are needed to get a finished part, apart from fibre placement, injection and curing?

Hint 10.16: the key word here is 'runner' (which, as always, must be removed from the product, just as in casting or injection moulding).

Exercise 10.17   Suppose we make a product with four fibre layers and a 40% fibre volume fraction. How does the permeability change in areas where we add a fifth layer? Use Figure 10.3 to give a quantitative answer.

Hint 10.17: of course, here you can assume that the thickness of the cavity is not changed. In other words, where we normally place four layers, we now add a fifth one.

Exercise 10.18   Think of a solution to the problem raised in Exercise 10.17. Hint: what if we can somehow assure that the resin flow front always stays parallel to the area with decreased permeability?

Hint 10.18: difficult question, but consider what would happen if (as in Figure 10.4) you only inject through the reinforced areas.

Exercise 10.19   Using 'internal runners' can also be deployed as a deliberate design strategy to minimize injection time. Can you describe how this works, in words or a sketch?

Hint 10.19: another difficult question, but just think about it. Also consider that RTM products are often made with inserts, such as foam cores, which are placed in the mould along with the fibre mats prior to resin injection.

Exercise 10.20   Take a closer look at your sample products (Exercise 10.1). How large are the radii that you can see?

Hint 10.20: just observe. In this, you can ignore trimmed-off edges of products where the fibre mats simply stop and need not be draped into corner radii.

Exercise 10.21   Which method offers the most design freedom? Think of functional aspects such as shape, size and production volume, but also of fibre volume fractions.

Hint 10.21: the answers are different, e.g. for product size and production volume.

Exercise 10.22   Which method offers the highest production speeds? And which one has the lowest investments? NB – even though the methods are generally used for quite different parts (e.g. with respect to size), aim to answer these questions for comparable applications.

© Erik Tempelman, Hugh Shercliff, Bruno Ninaber van Eyben, 2014

Hint 10.22: again, you will get different answers for the various elements of the question.

Exercise 10.23 Which method offers the best quality? Consider in particular the aspects of roughness, surface defects and reproducibility.

Hint 10.23: there actually are two good answers here.

Exercise 10.24 Can you identify which method was used to make your product examples (Exercise 10.1), and what kind of composite (resin and fibre type) was used?

Hint 10.24: the method will be difficult to tell, especially if you have no information regarding the production volume. Fibre and resin, however, should follow quite logically from the application (see also Exercise 10.8).

Exercise 10.25 Propose one design guideline, aimed specifically at a certain combination of material and method. Explain your guideline on the basis of the theory covered above in this chapter, or common sense. Has it been used to design the product examples you found? If so, how?

Hint 10.25: key concepts such as the D'Arcy equation or considerations about defects (radii) will be easily extended towards design rules; in addition, you can carry over the usual design rules for products made using moulds (pertaining to parting planes, etc.). Be aware that RTM involves certain key trade-offs you will recall from the manufacturing triangle, notably the one between mechanical properties/quality (high fiber volume) and part price/cost (low production speed), and the one between high injection pressure (high production speed) and heavy, stiff molds (high investment).

© Erik Tempelman, Hugh Shercliff, Bruno Ninaber van Eyben, 2014