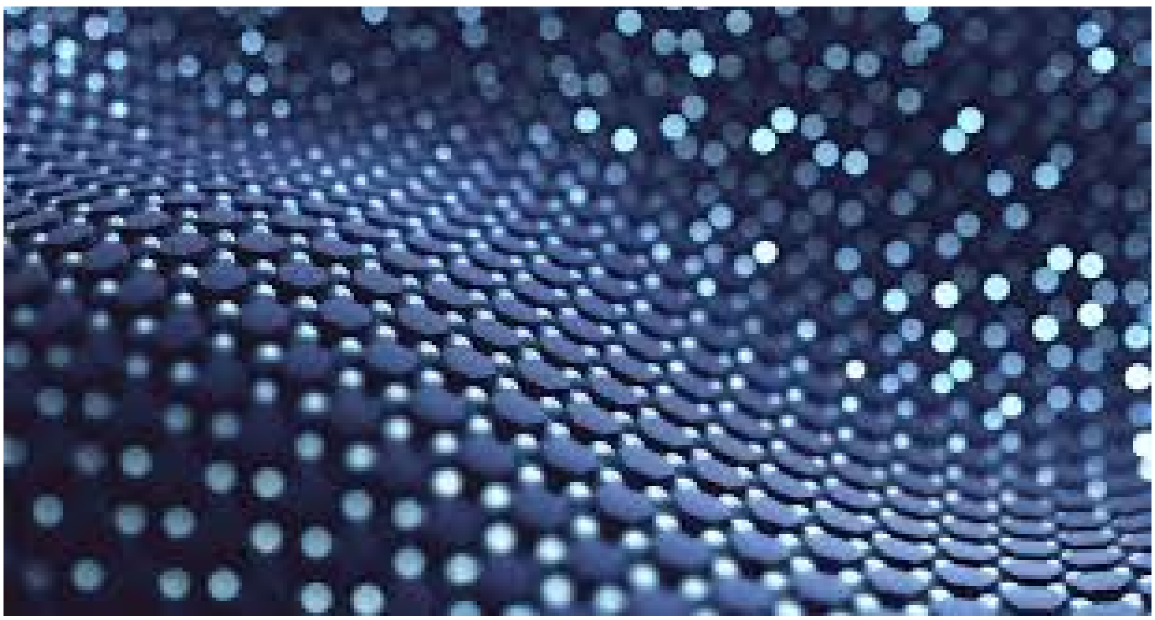
MINI-PROJECT

COMPOSITES



ME 270: *Design for Manufacturability*

Ashank Behara, Yutian Gao, Anisha Rao

AB5_3

SAMPLE PRODUCTS

An example of a resin transfer molded product would be a firefighter helmet. This product uses a composite rather than an unreinforced plastic because of the harsh conditions and extreme heat that the helmet must endure. Composites are used because of their structural properties. They are able to combine multiple properties in a single material which is not found otherwise.Composites are able to be designed to withstand a specific amount of load which is needed for the helmet to deflect any hard objects falling on the user's head. The composites are also resistant to thermal properties which is the key reason firefighting helmets use RFM. It is able to provide lightweight material with thermal-resistant properties and is able to be load specific. The implications of this choice for recycling is dependent on the type of helmet used. If the helmet is thermoplastic, the material can be grinded down into smaller pieces, combined with other virgin thermoplastic pieces in used in injection molds. However, if the helmet is thermaset, the resin part of the composite cannot be recycled and must go into a special machine to separate the fibres from the resin and filler. The fibres can be reused as reinforcing material as well as the resin and filler can be used as filler in other applications. The implications of this ensures that each helmet is able to be recycled and reused for other applications rather than thrown away all together.[1] Another product that uses fabric-resin composites would be a carbon fiber bike frame. The ratio of strength to weight must be extremely high and that is a quality of fiber-resin composites.

[1] https://www.thespruceeats.com/the-anatomy-of-a-chefs-knife-995818
https://healthykitchen101.com/forged-vs-stamped-knives/

SPECIFIC STRENGTH AND STIFFNESS OF FIBERS

Material	Yield Strength	Young's Modulus	Density	Specific Stiffness	Specific Strength
E-Glass Fiber	2000	78.5	2.575	30.48543689	776.6990291
R/s glass fiber	4750	89.5	2.495	35.87174349	1903.807615
Aramid Fiber	3250	71	1.44	49.30555556	2256.944444
Carbon Fiber (HM)	2405	505	1.95	258.974359	1233.333333
Carbon Fiber (HT)	4650	235	1.82	129.1208791	2554.945055
HSLA Steel	575	207.5	7.85	26.43312102	73.24840764
Aluminum 6061-T6	280.5	71	2.7	26.2962963	103.8888889

Based on the calculated values of specific stiffness and specific strength, Carbon Fiber (HT) “wins”. This is due to the fact that it has the second highest specific strength and second highest specific stiffness. It is the only material to have both on the higher end of the spectrum. The HSLA Steel and Aluminum 6061-T6 in comparison have the lowest specific stiffness and significantly lower specific strength. They are the “losing” materials.

STRENGTH AND STIFFNESS COMBINATION

Using E-Glass fiber with the Epoxy Resin

	E-Glass Fiber	Epoxy Resin
Young’s Modulus	78.5	3.2
Yield Strength	2000	70
Density	2.575	1.75

CHART 1

Estimated strength and stiffness for 50% volume of fiber

STIFFNESS

$$78.5 / ((2.575 \times 0.5) + (1.75 \times 0.5)) = 36.301 \times 10^{-9} \text{ N/m}$$

STRENGTH

$$2000 / ((2.575 \times 0.5) + (1.75 \times 0.5)) = 924.855 \text{ MPa}$$

Estimated strength and stiffness for 20% volume of fiber

STIFFNESS

$$78.5 / ((2.575 \times 0.2) + (1.75 \times 0.8)) = 44.992 \times 10^{-9} \text{ N/m}$$

STRENGTH

$$2000 / ((2.575 \times 0.2) + (1.75 \times 0.8)) = 1044.386 \text{ MPa}$$

As shown by the calculations, the strength when the volume of the fiber is less than 100%, is drastically lower. However, the stiffness increases. This is due to the fact that there is less density but the same Young's modulus and Yield strength used in the calculation since the resin only adds volume and no other properties.

FIBER VOLUME PERCENTAGE

As shown by the calculations above, by decreasing the fiber volume percentage, there is an increase in the specific stiffness and specific strength. This is due to the fact that the density of the material is lower than that of just the fiber. The Young's modulus remains the same for the calculation of the specific stiffness and the decrease in the density results in a higher specific stiffness. And same thing happens to specific strength. This is a benefit because the cost of the resin is cheaper than the fiber and it will result in a higher specific stiffness and specific strength of the composite.

CROSS-PLY COMPOSITE

The calculations are made using *CHART 1*

STIFFNESS

78.5 / ((2.575 x **0.25**) + (1.75 x 0.5)) = 51.687

STRENGTH

2000 / ((2.575 x **0.25**) + (1.75 x 0.5)) = 1316.872

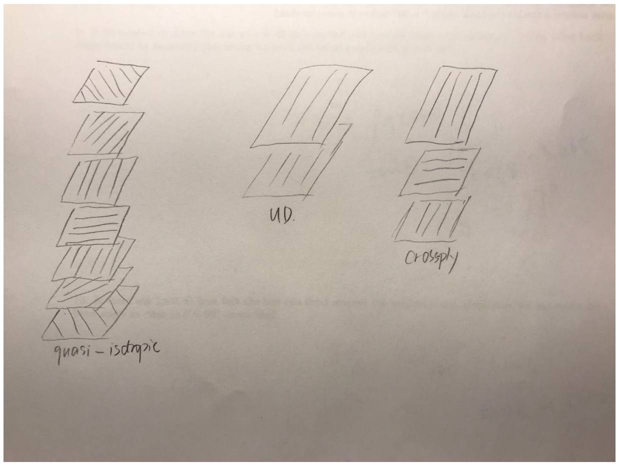
Specific Stiffness and specific strength are both increased. This is due to the fact that the Young's modulus and yield strength values are the same however, the density is a decreased value due to the fact that only 25% of the fiber density is taken into account because only the fibers that are in line with the external load are used for the calculations and since it is evenly spread in both directions, half of the volume for the fiber is used.

QUASI-ISOTROPIC COMPOSITE[2]

The term quasi-isotropic means that no matter the orientation or direction of the force applied to the material will have constant strength and stiffness. Even with increasing the fiber volume percentages, the strength and stiffness of a composite will not be constant in all orientations unlike a quasi-isotropic composite.

FIBER LAYERS

[2] https://www.scribd.com/doc/106811326/Quasi-Isotropic



From the diagram above, we can find that the minimum available thickness of UD is 0.1 mm. For cross-ply composite, it will be 0.3 mm. And for quasi-isotropic composite, the available thickness that has -45/45 ply, the minimum available thickness is 0.7 mm. Besides, if larger thickness is needed, the difference between each available thickness of quasi-isotropic composite will be the largest.

FIBERS IN SAMPLE PRODUCTS

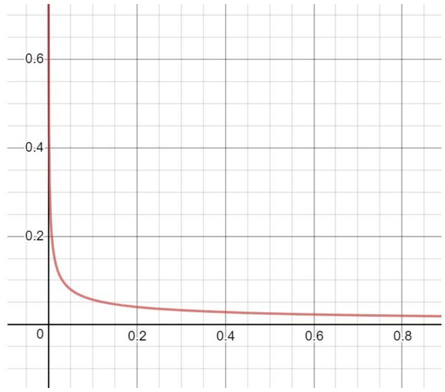
Fire-retardant fabric can be used in the product we chose. Since it is a firefighter helmet, fireproof is the top priority. Besides, carbon fiber can also be included to reduce the weight of the helmet while increasing the strength at the same time. Cost is not an important concern for this product, since it is related to life safety, so only the best materials should be considered when making this product.

RESIN TRANSFER MOLDING: SUITCASE

$$v = \frac{\Delta p \times k}{L\mu}$$

$$L = v \times t$$

$$v = \sqrt{\frac{\Delta p \times k}{t \times \mu}} = \sqrt{\frac{0.8 \times 100000 \times 0.8 \times 10^{-9}}{0.2t}}$$



PLOT OF VELOCITY VS TIME

D'ARCY'S EQUATION

$$L_{inj} = 60/2 = 30\ cm = 0.3\ m$$

$$T_{inj} = \frac{L_{inj}^2 \times \mu}{2\Delta p \times k} = 140.625\ sec$$

If L_{inj} is doubled: $T_{inj} = 4 \times 140.625 = 562.5\ seconds$

RTM: CARBON FIBER-EPOXY BICYCLE

Assume that we are applying one shift production:

$\#\ of\ product = \frac{1500 \times 3600}{140.625} = 38400$ pieces

Two-shift production:

$\#\ of\ product = 76800\ pieces$

MULTIPLE MOLDS

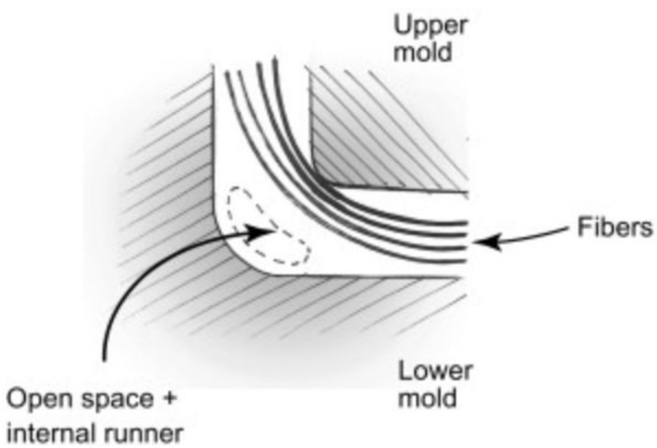
If we have only one mold, while the product is curing, the production cycle have to stop because the mold is in use. However, when there are 2 molds available, workers can work on the other mold while the first one is curing. In this case, we have a continuous production cycle to get higher efficiency.

SHRINKAGE: EPOXIES AND POLYESTERS

Fibers are responsible for the majority of the mechanical properties that a composite material inherits. Because of the strength traits of a fiber, if there is a lower composition of fiber in a material, naturally, the Young's Modulus and Yield Strength of a material will decrease and will be more susceptible to shrinkage. Epoxies and polyesters have lower concentrations of fibers and naturally will shrink more. On the contrary, fibers with a higher volume percentage will shrink less because they have higher strength and stiffness.

INTERNAL RUNNERS[3]

Internal runners are not typically used deliberately when designing for injection molded parts as they are often the result of poorly designed parts. The internal runner is formed by fibers that create an open space at sharp radii that are found at bends. When filling the mold through typical RTM processes, the resin will tend to take the fastest path to fill up the open space that is created from the fibers.



PRODUCTION METHODS OF RTM

DESIGN FREEDOM

Volume-controlled RTM provides the most design freedom because it is dependent on the volume of the product and is thus performed in an open system. Pressure-controlled RTM and resin infusion both occur in closed systems which does not allow for a lot of design freedom. Buecase of these traits of these methods of RTM we can deduce the volume-controlled RTM is the best.

HIGHEST SPEED

Pressure-controlled RTM produces parts at the highest speed. In this method of RTM, users are given the option of injecting and compressing with larger amounts of pressure which in turn decreases cycle time which gives credit towards being the method with the highest speed.

[3] https://www.sciencedirect.com/science/article/pii/B978008099922700010X

BEST QUALITY[4]

Resin infusion produces the best quality parts out of the the resin transfer molding methods. Resin infusion is widely recognized as a low cost alternative to high quality RTM processes such as autoclave cured prepreg as products produced by both methods have very comparable mechanical properties.

METHOD FOR SAMPLE PRODUCTS

For the helmet and the carbon bike frame, it can be concluded that is was not procured using resin infusion because that RTM process is typically made for small pieces. For a very large and precise like a carbon fiber bike frame, we can conclude that it was either made from pressure or volume-controlled RTM. Carbon fiber bike frames are precision made and have fairly complex designs so these bike frames are most likely made from volume-controlled RTM.

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[4] https://www.vacmobiles.com/resin_infusion.html