Solution for homework problems in chapter # 1

<u>Question 1:</u> *Indicate four main functions provided by the matrix in a composite material. Indicate the main functions provided by the fiber in a composite material.*

The three main functions provided by the matrix in a composite material are:

1. Alignment of the fibers. Fibers have very small diameters (about 10 microns) and there are millions and millions of fibers that are located side by side in a composite piece of practical size. These fibers need to be aligned along a certain direction to carry loads. They have to act in concert to have effect. The matrix serves as a glue to hold the fibers in place. Without the matrix, the fibers are strayed and their orientations are random, and can not act in concert with each other.
2. Transfer the loads between one fiber to the neighboring fiber, by shear action. The transfer of the load from one fiber to its neighboring fiber is essential for the stronger fiber to help the weaker fiber. Since fibers are brittle materials, there is a significant variation in the strength of one fiber compared to another within a bundle of fibers. Without this load transfer, the strength of a dry bundle of fibers will be governed by the strength of the weakest fibers, and this is not effective.
3. Provide compression and shear strengths and moduli to the composite laminate. Fibers are strong in tension but fibers do not have any strength in compression. If one were to push on a string, the string offers no resistance. Similar situation applies to the case of a fiber. However, when the fiber is supported on its side by matrix material (which acts as a side foundation), the fiber maintains its straight orientation against the compression load. This provides compressive strength and modulus to the laminate. Similar situation applies for the provision of shear strength and modulus for the laminate.
4. Protect the fibers from environmental attack. Fibers are brittle. Bare fibers may rub against neighboring fibers and this may initiate fracture. Also, moisture in the environment may adhere to the surface of the fibers and degrade the bonds between the fibers and the matrix. By placing the matrix on the surface of the fibers, the matrix helps the fibers from rubbing against each other, and shields the fibers from exposure to the environment.

The main function provided by the fiber to the composite material is good mechanical properties such as strength and stiffness. Fibers are usually made up of strong and hard material, and are relatively lighter than metals. People use fibers for their strength and stiffness.

<u>Question 2</u>: *Indicate the four most common manufacturing processes for making components using thermoset composite materials. For each process, indicate which sector of the industry that the process is used the most. Give a reason why this is so.*

The four most common manufacturing processes for making components using thermoset composite materials are:

1. Autoclave process. An autoclave is a pressure vessel that can provide both pressure and heat. Composites made by autoclave usually have resins that require high temperature for

curing. These resins have good mechanical and thermal properties such as high temperature cured epoxies (as compared to room temperature cured epoxies). The process is time consuming and expensive. This process is usually used to make composite parts for the aerospace industry, due to the high performance and high cost.

2. Liquid Composite Molding (LCM). In LCM process and its many variations (such as RTM, VARTM, RFIM, SCRIMP etc.), dry fiber preforms are first made. These are placed inside a closely fit mold, then liquid resin is infused into the dry fiber preforms to wet the fibers. Resins used for this process usually have relative low viscosity (less than 1000 centipoise). This process is suitable to make composite components for the automotive, wind turbine, and marine industries. This is due to the relatively high speed of production, the ability to handle 3-D reinforcement, and the ability to make large structures.
3. Pultrusion. In pultrusion, dry fibers are first immersed in a bath of resin for wetting, then the fiber bundle is pulled through a heated die to make the shape of the component and for curing the resin. Pultrusion is usually used to make structural components to be used in civil infrastructure applications. This is due to the highly automated nature of the process, resulting in relatively low cost components. The quality of the product may not be as good as those made using autoclave when wet process is used.
4. Filament winding. In filament winding, tows of fibers are first wetted and these tows are placed onto a mandrel one band at a time. This is similar to the lathing in machining except that the materials are added rather than being removed. Filament winding is usually used to make pressure vessels, or pipes. The applications include light weight pressure vessels used in oxygen tanks in airplanes, rocket nozzles, or pipes used to transport corrosive liquids. Filament winding requires that the mandrel be convex curvature.

<u>Question 3</u>: *Indicate in what way manufacturing using composites is different from the manufacturing using metals*.

The manufacturing process using materials requires many steps. In metal technology, the property of the material does not change drastically when one moves from one step to another. In composites technology, the properties of the material change drastically, particularly for the final steps. This can be best illustrated using the example of a simple plate. If the plate is made out of metals, the steps are:

1. The minerals are dug out from the mines. Impurities are removed,
2. The minerals are heated, melted in crucibles,
3. The minerals are poured into molds to make ingots. Liquid metal becomes solid metal,
4. The ingots are rolled to make thin sheets,
5. The sheets are cut to make the plate.

If the plate is made out of carbon/epoxy composite, the steps are:

1. Fibers (carbon) are made from precursors such as PAN or pitch,
2. Resins (epoxy) are made from petroleum products,

3a. Fibers and resins are combined to make prepregs (step 4 is necessary),
3b. Fibers and resins are combined make the final plate directly (step 4 is not necessary).
4.Prepregs are combined to make the final plate.

Even though the number of steps does not seem to differ so much for the two types of materials, the way how the material properties change is very different. For metals, once the liquid metal has solidified into solid metal, in the steps that follow(steps 4, 5) mainly the geometry of the final part changes, but the material properties may not change that much. For composites, as one moves from steps 1, 2 to step 3b or 4, the raw materials transform directly into the final part. The implication of this is that a great amount of knowledge and control are necessary to ensure good quality parts for the case of composites.

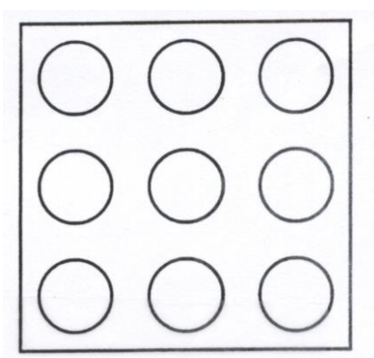
Question 4: *Why is wetting of the fibers important? What are the two most important aspects that affect wetting of the fibers?*
Wetting of the fibers by the matrix is important because this assures good bond between fibers and matrix. The two most important aspects that affect wetting of the fibers by the matrix are: ***Availability*** of the matrix at the surface of the fiber, and ***Compatibility*** between the matrix and the fibers. Simply put, if a first person wants to bond with a second person, the first requirement is that the first person has to be available to be in contact with the second person. After the contact is made, the second requirement is that they need to be compatible. In terms of composite manufacturing, the availability requirement consists of four factors. These are the mobility of the matrix molecules (*viscosity* of the matrix), the empty spaces in the fiber network (*permeability* of the fiber network) to allow for the flow of the matrix, the *pressure* that pushes the matrix molecules in the flow, and the *distance* that the matrix has to flow from its source to the surface of the fibers. The four factors are summarized in a simple rule called Darcy's law. The compatibility requirement involves the relative surface energy of the fiber material and of the matrix material. Matrix with surface energy smaller than that of the fibers tends to spread over the fiber surface and is more compatible with the fibers (bonding can be made).

Question 5: *Using the square packing array, show that the interfiber spacing is given by:*

$$\delta = d_f \left(\sqrt{\frac{\pi}{4v_f}} - 1 \right)$$

where δ is the interfiber spacing,
d_f is the fiber diameter
v_f is the fiber volume fraction.

The square is shown in the figure.



The assumption is that the volume of material has a unit thickness. The fiber volume fraction therefore has the same value as the fiber surface fraction. Let *n* be the number of fibers along one side of the square.

$$\nu_f = \frac{n^2 \pi \frac{d_f^2}{4}}{[n(d_f + \delta)]^2}$$

$$\nu_f = \frac{\pi}{4}\left(\frac{d_f}{d_f + \delta}\right)^2$$

$$\left(\frac{\delta + d_f}{d_f}\right)^2 = \frac{\pi}{4\nu_f}$$

$$\delta = d_f\left(\sqrt{\frac{\pi}{4\nu_f}} - 1\right)$$

<u>Question 6</u>: *What is the general difference between the viscosity of thermoset resins (in general as a group) and thermoplastic resins (in general as a group). What is the implication of this phenomenon on the manufacturing strategy?*

There are many types of thermoset and thermoplastic resins. The viscosities of thermoset resins vary from about 100 Centi-Poise at room temperature to around 100 Centi-Poise at 177 ^{o}C. The viscosities of thermoplastic resins vary from about 10^6 Centi-Poise to 10^9 Centi Poise at about 350^{o}C. The low viscosity of thermoset resins at relatively lower temperature renders thermoset resin to be able to flow and wet fibers at relatively low temperature. As such, thermoset resins require less expensive equipment and set up for combining with low fibers. To process thermoplastic composites, one needs high temperature equipment which is more expensive. Special arrangement is necessary to make good quality thermoplastic composites.

<u>Question 7:</u> *What are the three important advantages that a material (like glass material) existing in fiber form over the same material in bulk form?*

For reinforcement purposes, hard and strong materials in fiber form (small diameter, relatively long length) have many advantages over the same materials in bulk (part of relatively larger dimensions) form. Three advantages of the fiber form over the bulk form are:

1. Fiber form has less defects. When one is making a smaller amount of materials, there are less defects as compared to when makes a larger amount of material. As such materials in fiber form tend to have higher strength.
2. Ability to bend to smaller radius of curvature. The enables the material in fiber form to fit into tight corners. This increases the drapability of the material and one can use the material to make parts with complex geometries.

3. There exist many techniques to make fibers. These consist of drawing, oxidation, chemical vapor deposition etc. As such, fibers can be made from a variety of different raw materials with different properties.