The original version of this manual was a one–student senior design project written by Katherine White, the Composite lab assistant, during Spring 2016 semester under supervision of Dr. Peter L. Bishay who captured almost all pictures in this manual.

This current version (version 1) has been modified and amended by Dr. Peter L. Bishay during Fall 2016 semester in order to be used by students enrolled in ME436/L course: Mechanics and Design with Composite Materials, as well as Senior Design students.
1. **Introduction:**

This laboratory manual is intended to teach you the basics of composites manufacturing using wet lay-up and prepreg lay-up process. It is recommended that all experiments be performed with an individual that is experienced with composites to help guide your learning process and prevent major accidents. In addition, pre-reading of your intended lab experiment is absolutely mandatory preparation to help avoid confusion and accidents. This manual covers basic composites terminology, wet layup, pre-preg layup, vacuum bagging, post-cure processing, and mold making. Please note that by working with composites you understand and consent that you are working with toxic chemicals and you must take appropriate measures to protect yourself by using appropriate personal protective equipment, this is covered in Section III. Please review Section III **THOROUGHLY** and practice these measures every time you work with composites for the safety of your self-preservation as well as others’.

2. **The lamination process:**

Our goal is to make a composite structure/laminate that has a specific shape (plate, curved shell, complex shape, etc.) that is composed of several plies. Each ply or lamina is made of matrix that contains continuous fibers in a specific orientation. In order to do this, we need something that has the final shape of our structure so that we can build our laminate on. This is called the mold or the tool (See figures 1 to 3). The tool should be strong and able to withstand the temperature in the oven or the autoclave without any significant deformations. It should also be smooth in order for us to get a smooth surface in the resulting composite. Any roughness or defects in the tool will show up on the surface of the resulting composite. The tool can be a simple glass plate if we are building a flat composite plate (Figure 2), or it can be a piece of high density foam with the shape of the composite structure engraved in it using a 3D router as shown in Figure 3. Foam molds need to be polished in order to make its surface smooth and ready for the lamination process.

![Figure 1: 2D illustration of the lay-up process](image-url)
Figure 2: 3D illustration of the lay-up process (flat configuration)

Figure 3: 3D illustration of the lay-up process (curved configuration)

Remember that the matrix is made of resin (polymer) which is very sticky. So we do not want our laminate to stick to the mold/tool. Hence we have to add something between the mold and the laminate that facilitates releasing the composite from the tool after the end of the curing process. This is called the release agent (See Figure 12).

After applying the release agent to the mold, you can start laminating your laminae in the proper sequence based on your design (whether using prepreg, or wet lay-up lamination techniques).

Again we don’t want our laminate to stick to any other layers that will be placed on it, so we add another release film directly over the laminate. The release film could be perforated (used with wet lay-up technique) or non-perforated (used with prepreg lamination). Perforated release film is used in the wet lay-up process in order to force any excess resin to seep through and go up to the breather fabric that absorbs the excess resin.
It is very important to apply pressure on the laminate during the curing process. The pressure compacts the laminate, removing air, humidity, excess resin, and volatiles from the resin which can all compromise the curing process and the performance of the finished part. This compaction improves the fiber-to-resin ratio, which is the key to maximizing the strength-to-weight advantages of any composite. Hence we have to seal the laminate and all other layers above and below it from all sides by vacuum sealant tape, and finally add the bagging film. In order to apply pressure using the vacuum pump, we have to attach the vacuum valve where the vacuum hose will be hooked to.

3. **Terminology and Required Materials**

**Autoclave:** an oven with integrated pressure that cures laminates under high pressure and temperature (see Figure 4).

![Figure 4: Autoclave](image)

**Aluminum roller:** eliminates air bubbles trapped in layers of resin and fiber (See Figure 5 left).
Adhesive film: used to bond laminates to core layers (such as honeycomb) to form sandwich structures.

Bagging material: used to apply vacuum to the composite layup in combination with vacuum sealant tape (yellow tape) seen in Figure 7. Bagging material is generally thicker than release film.
Breather Fabric: placed between release film and bagging material. It is the white fabric seen above in Figure 7. Breather allows the pump to have airflow, releases volatiles from the resin, and absorbs resin during the cure. Breather fabric roll is shown in Figure 5 right.

Bridging: is what happens when the reinforcement (composite fabric) has not fully conformed to a corner of the mold and has instead formed a “bridge” over the corner (see Figure 8).

Caul Plate: transmits a normal pressure to the composites during cure and creates a smooth surface.

Core: A core material is used between laminae, either during a cure or through a post cure process, to add stiffness to the composite but keeping it lighter than if more laminae had been added for the same strength. Examples of cores include aeromat (lantor soric), aluminum honey comb, or Nomex honey comb.

Cure: process in which the resin hardens into a tough material as it adheres itself to the fibers to which it was applied.

Cure Temperature: temperature required for the resin to cure. This can vary and higher temperatures can lead to shorter cure times and stronger composites for most resins.
De-bulking: applying a temporary vacuum to the composite to remove air and allow the laminae to come together better.

Epoxy resin: the resin acts as the matrix of the composite to ‘bind’ the composite materials together and transfer the component stresses that may act on the part to the fibers in the composite. The fibers are designed and selected to handle the designed stresses imposed.

Gel: refers to the state when resin begins to become more viscous and hard to spread. This is the initial part of the cure phase.

Gel time: (pot life) the gel time is how much time passes until the resin begins to thicken and gel. This is the time allowed to apply to the composite, once the pot life has been reached bagging of the part should begin. This information can be found on the technical data sheet of the resin. Don’t begin a layup until everything is prepared so that you can get the most out of your gel time for application.

Gel Coat: a resin that is put on after the product is finished to improve surface finish and to create a protective layer.

Glassing Temperature: the temperature at which the polymer transitions from a hard, rigid, state to a pliable state.

Gloves: gloves need to be worn when handling resin, pre-preg, and toxic release agents. It’s best to wear thicker gloves (7mm-9mm) to avoid getting splinters from the composite. It’s recommended that gloves be worn while handling the fabrics as well so that debris and oils don’t disturb the fibers.

Flash tape: high temperature, pressure resistant tape. Can be used to hold bagging consumables (release film and breather cloth) in position or as a surface that can be released from due to its highly non-stick surface.

Lamina: One layer of pre-preg, or one layer of dry reinforcement with resin.

Laminate: fabric reinforcement impregnated with resin and cured (multiple laminae cured together).

Lay-up: the process of applying reinforcement material and resin together on a mold.

Mold: Generally, a mold must be used for making parts using the lay-up process to place the layer in or on in order to obtain the desired shape. However a tabletop can be used instead to hold the
flat shape of the layup. A ‘mold’ is also called a ‘tool’ in industry when referring to composites processes. Different materials may be used as molds (metal, composites, wood, plaster, rubber, high density foam, etc.)

![Image of high density foam pieces](image)

*Figure 10: High density foam pieces*

**Mold Polish/ Release Wax:** creates high gloss surface that also releases the surface. Wax should be applied to the mold with a microfiber cloth, 3–4 layers thick, and buffed to a high gloss.

![Image of release wax](image)

*Figure 11: Release wax*

**Peel Ply:** Peel ply is used when you want to secondarily bond to another part later. When laid directly next to your laminate in the vacuum bag, Polyester Peel Ply leaves behind a rougher surface on your part once the process is complete. This rougher surface improves mechanical bonding between your finished part and other resins, fabrics, or adhesives. Although tightly woven, it also allows excess resin and air to flow through, eliminating voids in your part. (Fibreglast)

**Plastic mixing cups:** plastics that will not melt with acetone or resin should be used. Paper cups or aluminum cans are good for this as well.

**Post-Cure:** process done after the initial cure has finished. Post-cure temperature is higher than initial cure as stated on the technical data sheet to increase the materials mechanical properties.

**Pre-preg:** A pre-impregnated lamina. This is a fabric that has a specific proportion of resin added to it already. The pre-preg is thus stored in a freezer to prevent it from cuing. It should be noted
that pre-pregs have expiration dates. Pre-pregs are superior because they have a perfect
distribution of resin making them lighter and they also tend to be stronger. However, for
complicated geometries it can be harder to manufacture with pre-pregs than by a wet layup process.

**PVA Release**: PVA is another liquid release which leaves a film on the surface which peels off.
As a dry film, PVA is resistant to the solvents in a resin system, but is water soluble.

**Release Agents**: Plastic sheeting, waxes, sprays or liquids that prevent resin from sticking to the
mold. Release agents are usually applied to the composite molds or tooling in a separate
designated area as they can act as a contaminate if accidentally integrated into the composite layup.

![Image](image.png)

*Figure 12: Sealer Release TR-910 and Release TR-930*

**Release Film**: is the film placed between the composite layup and the breather fabric that prevents
the breather fabric from permanently bonding to the composites piece when the resin cures.
Release film may also be used between the surface you layup on and the composite instead of
liquid release. Release film can give a worse surface finish than the liquid release. There are two
main types of release film, they can also vary depending on the temperature of cure. Higher
temperature cures require special materials.
-Perforated release film: used for wet-lay up to allow excess resin to escape to the breather
-Non-perforated release film: used for pre-pregs.

**Release wedge**: facilitates removing the laminate from the mold after the part is completely cured.
**Resin-rich:** an area where the laminate is mostly or all resin.

**Resin-poor:** an area where the laminate is starved of resin and it’s mostly fiber.

**Rollers (paint rollers):** paint rollers that resist chemicals are great for applying resins especially if you’re making a large part. Paint brushes with natural bristles can also be used to apply resin.

**Scale:** a digital scale to measure out ratios of resin to hardener (catalyst) for mixing when doing wet layups.

**Spatulas:** plastic spatula used to apply pressure to pre-pregs (not directly on the fibers; make sure a film is protecting the side of the pre-preg to which you are applying pressure).

**Wooden mixing sticks:** wooden sticks are best for mixing resins for wet layups because they won’t react with the chemicals.
Figure 14: Scale (protected from resin), Epoxy Cure (hardener), and Epoxy Resin

Figure 15: Oven