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Fabricating Carbon Fiber Airframes, Part 2: Finishing

Cover Photo: Lift-off shot by Erin Card at NARAM56 in Pueblo, CO
Congratulations! You’ve moved onto what is frankly the most tedious part of fabricating tubing: getting it to look pretty. One of the reasons carbon fiber is so highly valued is its aesthetic characteristics. For this reason, bare carbon fiber is an attractive option for the finish on high-end sports cars, bikes, motorcycles and, of course, rockets. Getting a smooth gloss “naked” carbon fiber is tiresome at best, especially starting with a peel ply texture. The basic idea is to give it a series of epoxy coats and sand each coat down with a different series of sandpaper grits with each epoxy pass. While the process involves a lot of work, the results are worth it!

**Supplies Needed:**
- Epoxy resin
- Chip brushes
- Playing cards
- Sandpaper grits 80, 120, 400, 600, 1000+
- Acetone
- Clear gloss spray paint (or polish)
- Patience

**Mandrel Removal**
Let’s start where we left off last time. With our tube cured, we need to release our mandrel and remove both our mylar and our peel ply. I usually prefer to remove the mandrel and mylar before the peel ply, but you can do this in the opposite order and still be fine. The mandrel should slide right out from under the mylar, depending on how snug the mylar is on the tube. You might be kicking yourself for wrapping it too tightly. If it appears to be stuck, don’t worry; it’ll just take a little more persuasion to get it separated from the tube. With those especially tight tubes, I recommend getting a friend to hold one end of the tube while I twist the mandrel out from the other end. If all else fails, you can get the mandrel out by soaking the tube in water. This will, of course destroy the mandrel, but you’ll be able to salvage the tube so it won’t be a complete loss. With the mandrel removed, we need to remove the mylar that we used as our release film. You need to be very gentle and cautious with this step. Mylar can tear and leave pieces of stray plastic inside your tube.

Removing the peel ply is simple. Start by peeling an unlaminated section of the outer seam along the seam line. Then, gradually pull the peel ply off the tube. The difficulty of removal depends on the type of peel ply you used. Dacron peel ply is fairly tough to remove. It will take a good amount of effort and you’ll have sore hands and hurt fingernails by the end. Both Nylon- and Teflon-coated peel plies release with much less stress. Be careful with the inner seam of the peel ply. Ripping it off too quickly could cause stray fibers from the peel ply to be left behind in your finished layup. If you get any of these leftover fibers, they can be removed with a knife.

*Figure 1: Using a rod to break the bond between the mylar and the tube.*

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With the peel ply removed, we can begin our first epoxy coat. The purpose of this coat is to fill the texture left by your peel ply. Mix up a small batch of laminating resin. This doesn't need to be much, just enough to coat the tube. 10 to 20 grams was perfect for the 54mm tube I made. Using a chip brush, give the tube a liberal coat of epoxy. This needs to be enough to fill the peel ply texture completely. Try to keep the runs and drips under control, although it isn't the end of the world if you get a few. In the end, this should be a good thick coat and no texture should be visible. Try to keep this layer as even and as smooth as possible. I find that running the brush over the tube quickly helps spread the epoxy evenly and efficiently. Once you complete this coat, continue to rotate this tube every 15-30 minutes to control runs and drips.

Figure 2: Removing peel ply

Once this coat is cured I like to trim the excess carbon fiber off the ends of the tube. From this point on, that excess will cause nothing but painful carbon fiber slivers and trouble. I like to keep it on for the first coat to protect the inside of the

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tube from epoxy runs but after that it’s useless. The excess can be trimmed a number of ways. The ideal way would be to use a miter saw. This will give you a clean, reliable straight cut fairly easily. If you don’t have a miter saw, you can do it the old-fashioned way. Wrap a piece of scrap paper around the tube and match the paper all the way around. This will act as a guide and should result in a clean, square cut with minimal clean up. Carbon fiber is too tough to be cut with with a hobby knife (like paper and phenolic airframes) but a hacksaw works well. I prefer to proceed 1/8 of a turn at a time, cutting with the hacksaw and following my paper line. Don’t try to do this all in one cut. Take your time!

Once we’ve finished cutting the tube we can move on to sanding it down. At this stage it’s okay to use rough grit sandpaper. We’ll be coating it with epoxy again to fill sanding scratches, so it’s fine to be rough with this sandpaper pass. I usually use a combination of 80 grit and 120 grit. The 80 grit tackles the large imperfections, such as runs or epoxy build-ups and the 120 does the general sanding and smoothing. Take your time with this pass. The goal isn’t to get the tube to look pretty, but to get the tube to be extremely flat and even. You can usually tell which parts are unsanded. The unsanded parts will be dark and glossy against, the grey, matte sanding scratches. At the end of this process, the tube should look dull and rough, but even.

This is long and boring work for even small tubing. I generally recommend setting up a small “sanding station” near a TV. Sanding doesn’t take much mental effort so it’s easy to multi-task.

If there are still imperfections that you were unable to get rid of with the sandpaper, such as wrinkles, then give it another coat of epoxy and sand it down again. The number of epoxy

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**Figure 4: A rough, even tube**

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coats needed to get a tube to look good is dependent on the quality of the tube. If you have wrinkles, excessive pinholes, or small voids, be prepared to do more epoxy coats then you would have otherwise. This 54mm tube was close to perfect so I only needed one thick coat to fill any imperfections. If you need more, that’s perfectly fine. Some of my earlier tubes needed five or more coats of epoxy (with sanding in between each) in order to look decent. Remember to wash the tube occasionally to remove the dust that builds up on the surface.

All these passes of rough sandpaper will leave the tube rough and dull. It’s time for the final epoxy coat. While the other coats of epoxy were to fill large imperfections, fill texture and even the tube, this last coat is only for getting rid of the deep sanding scratches caused rough sanding. This coat should generally be thinner then the others. Unlike the previous coats, it doesn’t need to fill any wide gaps. If your epoxy is too thick, it may need to be thinned with acetone. Be aware that too much acetone will cause your epoxy to be too thin, and it’ll fail to fill the sanding scratches. And too little acetone means you need to add more epoxy then is necessary to fill the scratches. You also need to keep in mind that acetone dissolves different kinds of plastic and foam, so check your mixing container to see it it’s compatible with acetone. In my particular case, my epoxy didn’t need thinning before application.

Since this is a thin layer, we can use different methods to spread it. I find that a playing card works best for getting a nice, even coat of epoxy. Drizzle a small amount of epoxy onto the tube and spread it around. You’ll only need a little. You would be surprised at how much area a drop or two of epoxy will cover when spread thin. Constantly clean the spreader to keep the epoxy from building up and flowing over the edges. You’ll only be sanding this tube with 400 grit sandpaper and above, so any drips or runs will take a long time to cut through. Unlike the previous epoxy coats, monitor this one for anything that might be a problem to sand through.

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Figure 5: Epoxy can be spread with a playing card

Figure 6: The thin coat of epoxy

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The goal of sanding this final coat is to make it as smooth as possible. It should already be flat and even, so your goal is no longer to eat through material. No matter how consistent your spreading job is, there will always be imperfections, so I like to start with 400 grit sandpaper and work my way up from there. From this point on you will need to be “wet sanding.” Different people prefer to wet sand in different ways. Some like to submerge the component completely underwater while sanding, while I like to get my sandpaper and component wet before beginning to sand. Either approach will work as long as there is water between your sandpaper and your carbon fiber. The water, by acting as a lubricant, will aid in smoothing the epoxy further than dry sandpaper would. While sanding, constantly check your sandpaper. Sandpaper with epoxy dust build up will leave deep scratches in your finish. I’ve damaged quite a few tubes because I wasn’t cautious about checking my sandpaper.

A wire brush is good for cleaning up the sandpaper when this happens. Remember, that your goal is to smooth, not remove material, so let the sandpaper do the work. I dip the sandpaper in water and sand in wide circles for 10-20 seconds before checking my sandpaper and re-wetting it. Make sure the entire surface of the tube has been sanded before progressing to the higher grits. After this pass of 400, an “intermediate” pass with 600 works well to sand down those miniscule scratches from the 400 grit. Use the exact same process as you did with 400, wet-sanding and checking the sandpaper every few seconds. After this run, it’s time for your final pass of sandpaper. Use sandpaper with a grit of 1000 or higher. You can generally find 1500 at your local hardware store. This is the exact same as the first 2 passes, but it’ll feel different. Since the sandpaper is so fine, it’s difficult to tell what is sanded and what isn’t. 1500 grit sandpaper will glide over a smooth area, but will encounter a bit of resistance over an unsanded area. Continue sanding and polishing until the entire tube is slick and smooth. Give the tube a final rinse to get rid of sanding dust. The finish should be very smooth and almost mirror-like at some angles. Once this surface is achieved, it’s time to move on to bonding or final finishing!

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A Word on Bonding

There is a lot of misinformation out there about bonding to fiberglass and carbon fiber components with a peel ply finish. Peel ply is widely advertised as having great properties for secondary bonding. As you may have noticed, peel ply leaves a noticeable, fabric-like texture in the finish. This helps because it slightly increases the bond area of the epoxy by creating deep valleys and trenches through the composite. While this does improve bond strength, we can do better. The real secret to bond strength is to increase the ability of the epoxy to “wet” into the surface of the composite. “Wetting” is a liquid’s ability to spread over an area. You can do a little experiment at home. Find a perfectly smooth material, such as glass. Place a drop of water on it. You can observe the water droplet “bead up” around the edges because of surface tension. Now, sand the surface thoroughly with 120 grit sandpaper. The water droplets will now spread out without beading up. Epoxy is similar to the water. It will wet better over a rough surface than a smooth one. This will lead to a stronger, tougher bond. Even though peel ply feels rough, on the microscopic level, each peel ply fiber releases with a relatively smooth finish. To achieve better wetting characteristics, the peel ply must be sanded or sandblasted off. A sanded (or lightly sandblasted) finish will result in a bond strength increase of 56%! (See PDF link). In extreme structural applications, every bit of bond strength is needed. For this reason, I encourage builders to bond during the final stages of finishing, not right after the component is released from the peel ply. For a high strength bond, you will need to sand all the way down to the fibers with 100-200 grit sandpaper. Do this over the entire bond area. Once the tips of the fiber are reached, we will need to remove all grease and contaminants from the surface. Grease will prevent the epoxy from adhering properly to the bond area. This cleaning is

Figure 8: A mirror-like finish at this angle
best done with a clean rag and acetone. I do not recommend using paper towels, as paper towels leave behind tiny paper remnants that may result in a decrease in bond strength. Once it is clean, don’t touch it with anything. Use gloves to protect the surface from your oily hands. (you should be using gloves with epoxy anyway). Bond as soon as the acetone is dry. By following these practices you can increase bond strength and build stronger, more durable rockets.

**Final Finishing:**
There are several different routes you can take to further improve the finish of your airframe. For one, you can leave it as is. I recommend this option for rockets where performance is everything, such as a competition model or an altitude record attempt. Extra coatings will only add extra weight and surface texture that will lead to poorer performance and aerodynamics. Another option is a gloss or wax rub on coating, like those used on automotive finishes. It’s easy to apply, but will need to be serviced constantly and rebuffed. My personal favorite is a coat of clear gloss paint. This is easy and leaves a beautiful, deep finish. For those with extra deep pockets, you can go to your local paint shop and get a treatment of professional clear coat. For those do-it-yourselfers (and most of you are; you made tubing from scratch after all!) Clear gloss spray paint is available from any store that sells spray paint. I personally recommend Krylon Clear Gloss as I’ve found it to smooth better but any brand will do. Feel free to experiment to see what gives you the best results.

Step back and admire your finished product! At this point you can weigh it and input the data into your preferred simulation and design program. Keep in mind that you need to enter the specific weight of the tube, and not let the program guess the weight. Different tubes have different ratios of fiber and epoxy and the program’s estimate may not match your tube. If your tube isn’t perfect, don’t worry. These things take practice and you’ll get better.

This article only scratches the surface, so to speak, of making composite tubing. To me, this is the standard practice.
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and I believe everyone should try making tubes this way before progressing to different methods. Once you’ve successfully made a few tubes, start experimenting. There are lots of other techniques and practices: I haven’t even touched on alternate methods of tube fabrication such as filament winding, compression, fiber orientation, and fiber angles. There is still lots more to learn about fabricating tubing!

There’s a lot you can do with this simple process. You can make tubes of any thickness and any size. I personally use this method for most of my minimum diameter rockets. I used the steps presented here exactly to make the tubing for my 3 inch minimum diameter with fantastic results.

More information on peel ply bonding:
http://www.niar.wichita.edu/niarworkshops/Portals/0/Jun17_0200_JimM.pdf

Figure 10: My 3-inch minimum diameter, fabricated with the methods shown above

About the Author:

Alex Laraway has been making carbon fiber airframes and rockets for three years. He flies with UROC and occasionally AeroPac. He loves everything and anything that has to do with altitude, speed, and just about every kind of material. If you have questions regarding this article or about getting started with composites in general, he would love to answer them at Aksrockets@gmail.com.

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