Weight and Strength Advantages From Pultruded Fiber Architecture

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Introduction:

Fiber architecture can be defined as allocation of fibers (and their direction) in a given volume. In the simplest definition, one would say that a 100% unidirectional composite, having all fibers aligned in one direction, is at the lowest end of fiber architecture. It may be perfectly adequate for the application, but will have limited capability.

Conversely, a pure 3-dimensional composite, one having 33.33% of the fibers oriented in each the x, y, and z directions, may be said to have the highest level of architecture. This type of composite may have a wider set of capabilities; and then fiber architecture can be enhanced even further by interlocking or weaving the x, y, and z fibers.

In the end, it is important that the loading requirements of the composite are understood. By doing so, for a given volume, or a given composite profile, the fiber architecture can be developed, and the fiber allocation can be submitted to the final product, which gives the most efficient use of raw materials. In this way, the composite is made in the absolute lightest fashion possible – being able to handle all loads, with appropriate factors of safety – yet using only the minimum amount of fiber. By supplying only the lightest material "to do the job," the composites industry will ensure transportation costs are at a minimum, because weight is at a minimum, and energy is thus saved.

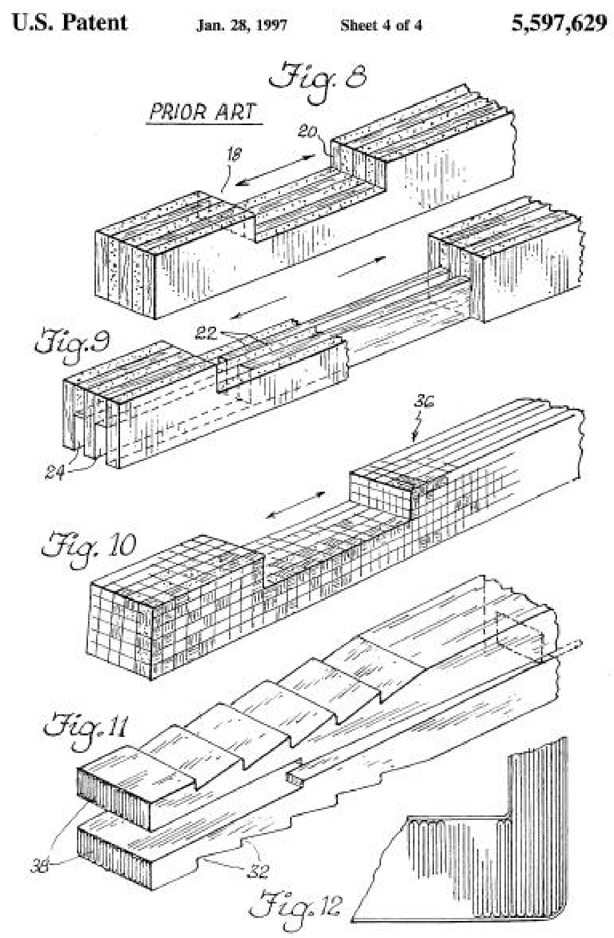
Discussion:

With fiber being 7-10 times stronger then the matrix holding a typical composite together, it is very important to understand load paths and to make sure a composite component won't have "matrix only failure." Said in another way, in any load path, one should make sure the composite must break fibers in order to fail. This can be tricky, but not impossible.

Take for example Ebert's revolutionary composite transmission tower. W. Brandt Goldsworthy was a key subcontractor to Ebert on this effort, and it is through many hours of discussions, that his beliefs were evolved into actual working products. Through this process, Ebert was able to design unique architectural composite profiles to meet the needs of the transmission tower specification.

The key requirement of the transmission tower was that it must be assembled in the field without the use of adhesives. Adhesives required a controlled environment, and Ebert knew the weather could adversely effect integrity of a bonded joint.

Ebert began investigating joints that were an improvement over bolts. But in doing so, we learned much about fiber architecture. The first interlocking member we investigated was a lay-up of 0/90 glass in a vinyl ester matrix. The Drawings below show the various Figures 8, 9, 10, 11, and 12 from Ebert's US patent 5,597,629.



Note in Figure 8 above, we describe a 0/90 lay-up of material with a notch. The idea was to notch (or machine) a joint with a ledge and then to hold the part, placing the ledge in tension – to observe the failure stress point, but to also observe the manner of failure.

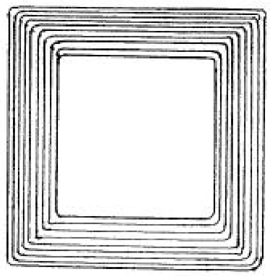
To our own surprise, the part failed in the manner of Figure 9. Look at what happened! The part failed in pure matrix failure; not one fiber was broken or sheared. If one examines this failure mode, one can see it makes sense, but was totally unexpected.

How we asked, can we get around this? We know from experience that a pure uni-directional notched part would fracture in an interlaminar failure, but we never expected a 0/90 part to fail in this way. Clearly, we said, a different approach would be needed.

And so, with the goal to **ensure** the breaking of the part would actually break fiber, we selected the fiber architecture of Figure 10. Here, interlocked woven roving was layed-up, forcing glass to be broken in a tension failure of a notch. And to our amazement, the joint of Figure 10, went to 7(seven) times the failure load of the joint of Figure 8! A seven times improvement for the same weight.

Of course, now that we knew what was required to achieve a very high shear strength, we were determined to pultrude the transmission tower bracing members with this new fiber architecture. We would then machine the joint, and it would still have a very high strength interlocking connection.

Fig. 6



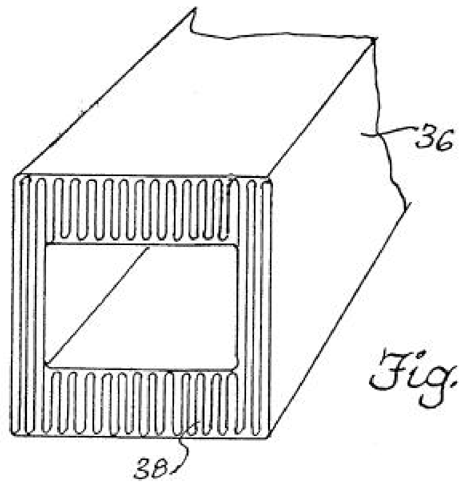


Fig. 7

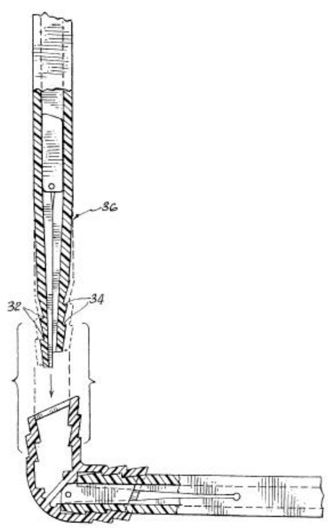
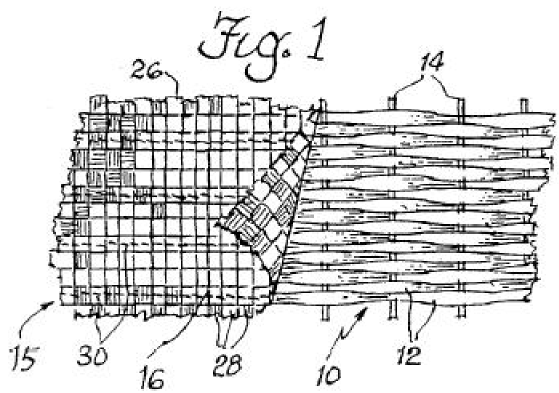


Fig. 3

A bracing member typically pultruded might look like Figure 6 (of patent 5,597,629) as seen above. Layers of fabric might be layed on top of each other, as normal pultrusion lay-ups may go. But we needed to place multiple layers of woven roving at a different orientation – shown above in item 38 in Figure 7. This orientation would ensure, after machining a ledge, or series of ledges, we would get the very high shear values of our testing. In this way, an interlocked bracing member – after machining – might look like Figure 11 (on previous page). In the end, only z ledges were needed (we called these future joints) and the transmission tower looked like Figure 3 shown to the left.

For simplification, let’s refer back to item 38 of Figure 7; a configuration also known as, “corrugated woven roving.” How does one pultrude corrugated woven roving? The answer is two parts. First, it is well known that woven roving is difficult to pultrude. It wants to “neck-down” on the sides – a phenomenon we call “The Chinese-Finger-Grip,” coined after the common childhood toy. Also, slitting of woven material is problematic, as any pultruder will attest. And so, to make it pultrudable, Ebert procured a stitched fabric of unidirectional fiber stitched to woven roving, shown in Figure 1 of patent 5,597,629, shown on the next page. Now we had a substantially woven roving fabric, that was stable, slittable and pultrudable. How then did we arrive at the corrugation?



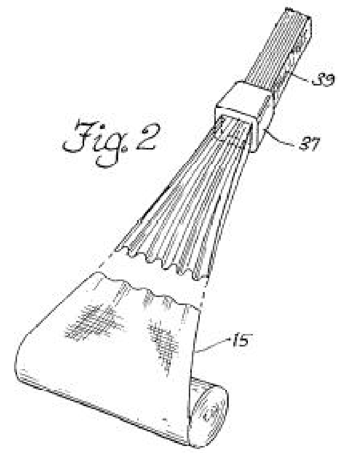
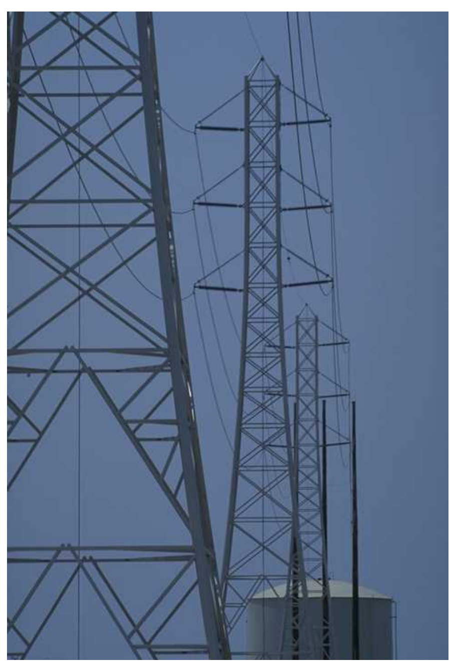


Figure 2 (5,597,629) above shows how. We developed tooling that folded flat stock material into a corrugation – as the material was pultruded to get the walls to look like Figure 7. Now we had our pultruded profile with the most efficient, high strength, interlocking fiber architecture. From this development, Ebert proved exceptional shear strength could be obtained. The picture below shows three composite transmission towers installed at a Southern California Edison coastal facility. As of February 2007, these towers have 11 continuous years of extreme coastal experience. There are 220 bracing members in each tower, with 440 interlocking joints. The total of 1320 interlocking joints have no adhesive and rely 100% on this unique and efficient fiber architecture!



By maximizing strength and minimizing weight, the completed electrical tower passed all necessary structural tests with ease. Yet, the tower was light enough to allow helicopter installation for remote and hard to reach sites. The same method of maximizing strength and lowering weight through fiber architecture analysis is being used by composite companies such as Ebert today. With the continual rise of fuel costs, transportation systems are scrutinizing every unnecessary pound of weight to save energy, reduce costs, and even reduce carbon emissions. Unique fiber architecture will help the pultruders of the future meet these demanding energy saving goals of today.

Acknowledgements:

Ebert Composites Corporation owes much of its success to W. Brandt Goldsworthy, who was not only a key subcontractor, a member of Ebert's Board of Directors, but was a loyal friend and mentor. Our continued success, whether independently, or through valued programs with the utility industry, the military, and NIST, in many ways are a tribute to Brandt's innovation, enthusiasm, and love of the industry he helped developed. We miss him greatly.

Reference:

A majority of the figures and drawings used in this report come from Ebert Composites Corporation's US patent 5,597,629 and 5,644,888