

Extended Abstract: Improvement of Fiber Reinforced Composites

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Composites represent an important new class of materials made by imbedding fibers or other reinforcements into a polymeric resin. They are often lighter and stronger than other materials of equivalent volume, and are being used in the production of new generations of airplanes, military protective gear and sporting goods, among others. Their properties depend not only on the bulk properties of the resin and the fibers, but also on the adhesion between the fiber surfaces and the matrix, and arrangement of the fibers within the matrix. Surface treatment of fibers to improve adhesion is a common method of improving composite strength. Our research has been exploring different surface treatments of glass fibers, specifically dendrimer coatings, that help improve adhesion and potentially decrease unwanted inter-fiber effects.

Background

While there are many types of composites, the type we studied was a fiber reinforced resin material. Typical composites of this type consist of a matrix with a large number of fibers running parallel through it. To create the composite, several layers of this type are combined, with the fibers in each layer running perpendicular to those in the adjacent layers. This intermediate is known as the prepreg. From there an autoclave compresses the layers into a single lightweight, strong material.

The objective of our research is to investigate whether the use of an appropriate primer coating on the fibers can improve the mechanical properties of fiber-reinforced composites. We wish to accomplish this by getting better adhesion between the fiber and matrix and getting the fibers completely wetted by the matrix. The fibers can be more wetted by the matrix if we reduce fiber-fiber touching and reduce inter-fiber effects.

One of the primary issues with fibers in composites is that the interactions between fibers lead to effects that weaken the mechanical strength of the composite. Inter-fiber effects can be seen in as few as 20 fibers grouped together. Some of the common interactions are fiber-fiber touching, air gaps between fibers, and twisting of the fibers within the matrix. We believe that some of these inter-fiber effects can be reduced through treatment of the fibers before creation of the composite.

Methodology

The system that we used to test different treatment of fibers is a Poly(vinyl butyral) (PVB) matrix with E-glass fibers. The PVB polymer is common in crash-proof windshields and the E-glass fibers are very common in composites. The test we used in this study is known as the fiber fragmentation test. This is a common test for measuring the adhesion between the fiber and the matrix and can be used for both single fibers and bundles of fibers.

In the fiber fragmentation test a single fiber or fiber bundle is suspended in a dog-bone shaped sample and pulled from the ends at a constant rate of 1 mm per minute using an Instron tensile tester. As the matrix stretches, it transfers stress to the fiber through adhesion until the amount of stress over the length of fiber is enough to break it. The fiber breaks repeatedly until it won't break anymore. The lengths of the fiber segments at this point have reached the critical length. The critical length of the fiber in the matrix is the point at which the force of the matrix pulling on the segment is not enough to break it, and is a measure of the level of adhesion.

The critical length will be used to calculate the interfacial shear strength (IFSS), which represents the amount of adhesion between the fiber and matrix. This is calculated by Equation 1.

$$\tau_{\max} = \frac{\sigma_f * d}{2 * l_c} \quad (1)$$

The IFSS is represented by τ_{\max} , l_c is the critical length, σ_f is the tensile strength of the fiber, and d is the diameter of the fiber. The diameter of the E-glass fibers that we used is 17 μm , which is about one quarter of the diameter of the human hair. The critical length, l_c , is a factor of a Weibull distribution based on the failures of the imperfections in the fiber. For simplification we assumed that this length was the sum of all the length segments divided by the total number of segments. The tensile strength of the fiber, σ_f , was used as a value supplied by the manufacturer of 1057 MPa.

Once the sample of fibers within the matrix has been fractured, the critical length can be measured optically using a microscope and counting the number of breaks. The breaking region is shown by a dark area where the fiber has split and a de-bonding zone around each break. One issue with this method arises when trying to count breaks in large bundles of fibers when all fibers cannot be seen. This led to studies looking at measuring breaks with large bundles of fiber through use of acoustic techniques to register each break in the sample. This technique was confirmed in samples where the result could be verified optically. The problem with this technique is that it is very labor intensive and sensitive to picking up cracks in the matrix and other non-fiber breaks. Through this process, however, it was determined that the fibers broke in zones. With all the fibers breaking together, the critical length can be determined optically. The technique of counting all the breaks optically was then re-verified using the acoustic method.

Surface Treatments

As suggested in the objectives, a primer applied to the fibers can increase the adhesion and reduce inter-fiber effects. Primers for fibers in composites are common, but we tried a different type of primer, specifically a dendrimer, that coats all the fibers and shows promise of increasing adhesion and decreasing fiber-fiber touching. A dendrimer is a molecule that is repeatedly branched and is characterized by its structural perfection. The particles can become very large, although the type we used is a 2-generation, amino-based dendrimer. They can become multiply bonded and have a unique modulus that soaks up stress. The dendrimer, however, cannot bond directly to the fiber so a silane

must be added to bridge the gap. A silane functional group with an epoxy group attached to the glass fiber in a manner that allows the epoxy group free to react with the dendrimer.

The dendrimer is designed to affect the fiber in two main ways. The first is to reach out into the epoxy and provide a type of mechanical interlocking with the resin. The second utilizes the large size of the dendrimer by providing spacing between the fibers so that there is no fiber-fiber interaction and so that the fibers may be completely wetted by the matrix. Initial results have shown proof of principle by increasing the interfacial shear strength about 30%. From here there are many further areas that may be explored such as the application of larger dendrimers or verification of complete coating of the fibers by the dendrimer.