**Science Education Collection**

# Tension Test of Fiber-Reinforced Polymeric Materials

URL: https://www.jove.com/science-education/10417

## Abstract

Source: Roberto Leon, Department of Civil and Environmental Engineering, Virginia Tech, Blacksburg, VA

Fiber-reinforced polymeric materials (FRP) are composite materials that are formed by longitudinal **fibers** embedded in a polymeric **resin**, thereby creating a polymer matrix with aligned fibers along one or more directions. In its simplest form, the fibers in FRP materials are aligned in an orderly, parallel fashion, thus imparting orthotropic material characteristics, meaning that the material will behave differently in the two directions. Parallel to the fibers, the material will be very strong and/or stiff, whereas perpendicular to the fibers will be very weak, as the strength can only be attributed to the resin instead of the whole matrix.

An example of this unidirectional configuration is the commercially available FRP reinforcing bars, which mimic the conventional steel bars used in reinforced concrete construction. FRP materials are used both as stand-alone structures such as pedestrian bridges and staircases, and also as materials to strengthen and repair existing structures. The thin, long plates are often epoxied to existing concrete structures to add strength. In this case, the FRP bars act as external reinforcement. The FRP bars and plates are lighter and more corrosion resistant, so they are finding applications in bridge decks and parking garages, where de-icing slats lead to rapid deterioration of conventional bars.

In this laboratory exercise, the tensile behavior of a unidirectional specimen will be studied, with emphasis on its ultimate strength and deformation capacity. The behavior of the specimen is expected to be elastic until failure, which is expected to occur in a sudden and explosive manner. This behavior should be contrasted with those of ductile steels, which exhibit extensive deformation capacity and strain hardening before failure.

## Transcript

1. Take proper safety precautions, and wear eye protection because the explosive failure typical of these specimens sends many small, sharp shards flying.
2. Obtain four FRP specimens. Two will be from a unidirectional 0.5-inch E-glass FRP plate cut into 1" x 8" specimens, one along the direction of the fibers and one perpendicular to the fibers. The third specimens will be a 0.25-inch carbon FRP rebar, and the fourth will be a 0.25 FRP E-glass rebar. The rebar specimens should be about 24 inches long.
3. Attach holders for the instrument by embedding 12 in. of the ends of the specimens into slightly larger steel round and rectangular sections and infill the empty spaces with high-strength epoxy. Let the epoxy cure as per manufacture's specifications. This type of end connection is needed because the serrations in conventional UTM grips will destroy the resin and lead to premature end failures.
4. Proceed in the same manner as the other tension tests by turning on the UTM and initializing its software.
5. Insert the specimens into the grips and tighten them.
6. Load the specimens in deflection control at a rate of about 0.2 in. per minute.
7. If an extensometer is used to measure Young's modulus, make sure to demount it at a strain of 0.01.
8. As the specimen begins to fail, popping sounds and small shards will begin to fall off the specimen, followed by an explosive failure of the material, which separates into a fibrous flower-like structure.

Fiber-reinforced polymeric materials, FRP, are composite materials that are formed by embedding fibers in a polymeric resin, creating a matrix that is very strong in the direction of the fibers.

In their simplest form, fibers in FRP materials are aligned orderly in one direction, and encased in resin, causing the material to behave orthotropically. Mechanical properties of these materials are very different in the direction of the fibers compared to the other two principle directions.

An FPR material is very strong in the direction of the fibers because of the high strength of the fiber, behaving elastically until the fibers fracture, and the material fails in an explosive manner. The material is, however, very weak in the perpendicular direction because of the very much lower strength of the resin.

In this video, the tensile behavior of a unidirectional specimen will be studied, with emphasis on its ultimate strength and deformation capacity.

The strength of FRP materials is directly related to the strength of the individual fibers. As the percentage of fibers in a material increase, the strength of the material increases. Typical materials have approximately 50% fibers by volume.

The unidirectional strength of FRP is often used in reinforcing bars, or rebars, but can be realized in more than one direction of the material by controlling the direction of the fibers.

Fibers can be places in random directions, or single plys of uniaxial layers can be place in alternating directions, resulting in two strong directions and one weak direction. The fiber and resin used to make an FRP must be chosen to be compatible with each other and meet application requirements.

The class of the fiber used, typically glass, aramid, or carbon, affects the properties and cost of the final product. In general, the fibers have very low strain capacity, resulting in sudden failures without any evidence of ductility.

The resin primary acts to transfer stress and protect fibers from mechanical and environmental damage. During manufacturing, pressure is applied to squeeze out as much resin as possible to increase the strength of the material. It is important to note that the individual fiber properties are not the properties of the composite. Instead, according to the rule of mixtures, properties of the composite are a result of the weight and mean of the constituent parts.

In the next section, we will conduct simple tension tests on a Universal Testing Machine to compare the stress/strain behavior of glass and carbon FRP, while taking care to properly prepare the samples to obtain valid results.

Obtain four FRP specimens. Two will be from a unidirectional 0.5 inch E-glass FRP plate cut into one-by-eight inch specimens: one along the direction of the fibers, and one perpendicular to the fibers. The third specimen will be a 0.25 inch carbon FRP rebar, and the fourth will be a 0.25 glass FRP rebar. The rebar specimens should be about 24 inches long.

Prepare the FRP rebar specimens in advance by embedding 12 inches of the ends in slightly larger steel round and rectangular sections and filling the empty spaces with high strength epoxy. Allow several days for curing, according to the epoxy specifications.

This type of end connection is needed because the serrations in conventional UTM grips will destroy the resin and lead to premature end failures. Proceed in the same manner as the other tension tests, by turning on the UTM and initializing its software. Then, insert a specimen into the grips, and lock it in place.

Load the specimen in displacement control at a rate of about 0.2 inches per minute. As the specimen begins to fail, popping sounds will be heard and small shards will begin to fall off the specimen. Followed by an explosive failure of the material, which separates into a fibrous flower-like structure.

Here is the stress/strain curve for the E-glass FRP plate specimen being loaded in the direction of the fibers. From this graph, we can determine the maximum force, tensile strength, and strain and calculate the modulus of elasticity. These results are reasonable for a material specified at 50% E-glass fiber volume showing essentially liner behavior.

This graph shows the same material loaded perpendicular to the direction of the fibers. We can see a decrease in the maximum force, tensile strength, strain, and the modulus of elasticity. Note that a significant amount of the strength measured in this particular specimen comes from the fibers in the outside protective layers, in which the fibers are randomly oriented. The very large difference between the two directions emphasizes the tailorability of the material properties. In this case, we have a material that is strong in one direction, and weak in the other.

The failure surfaces bear witness to this, with the one for the fibers aligned longitudinally showing numerous broken fibers, and the one with the fibers aligned perpendicularly showing the typical surface for a resin failure at an interface. Comparing the behavior of the FRP rebars, there is a very significant difference in strength and modulus of elasticity. Both materials fail immediately after carrying their maximum load.

The difference between the strong carbon FRP bar, and the softer, but far more ductile E-glass one, is obvious in this linearized graph. However, there is little ductility, as they fail at a fraction of the strain of metals such as a36 steel.

FRP materials are used in a myriad of civil engineering applications, including original construction and repair applications. Let's look at a couple of common uses of FRPs.

FRP sheets, laminates, and bars can be impregnated with resin and precured for use in field applications. The FRP bars and plates are light and corrosion resistant, so they're finding applications in bridge decks and parking garages, where deicing leads to rapid deterioration of conventional bars.

Many marine applications also use FRP materials for their resistance to corrosion and salt. FRP is used extensively in the boating industry, as well as for naval structures and pipelines.

You've just watched JoVE's introduction to tension testing of fiber-reinforced polymeric materials, or FRPs. You should now understand the components of FRPs and standard laboratory testing for determining their strength.

Thanks for watching!