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White Paper

Hollow Fiber Measurement Technique

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Hollow Fiber Measurement Technique

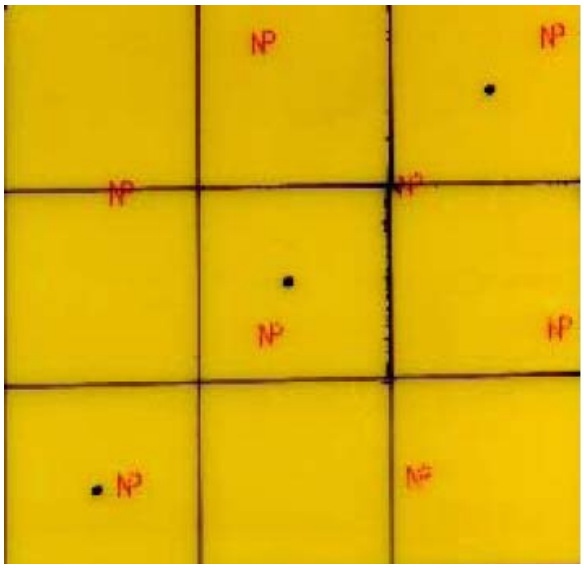
Introduction

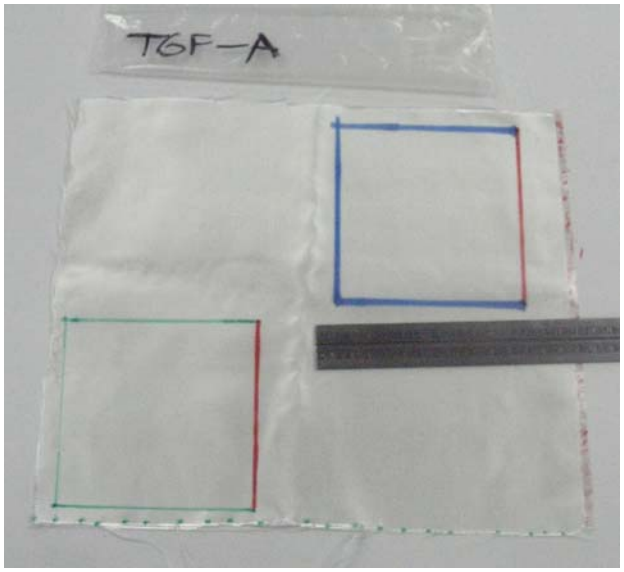
Laminate manufacturing in the electronics industry consists of four fundamental steps: conversion of raw materials into molten glass, fiber drawing, fabric weaving, and resin coating. The raw materials of E-glass are batched together in a furnace and melted at temperature in excess of 2500 F. After the molten mixture is deemed homogeneous, it is allowed to flow into a forehearth where it drops through bushing nozzles. While in the nozzle, each drop converts into a glass fiber that is pulled in tension and simultaneously cooled. If the molten glass contains a sufficient level of impurities, air bubbles may become trapped inside the fibers while being drawn through the bushing. These air bubbles, unless very large, do not cause fiber breakage but end up as capillaries in the glass fibers

Sample Size and Selection

To detect hollow fibers within a typical finished laminate with woven glass fabric, laminates are cut along the diagonal into 10 cm x 10 cm (4 in x 4 in) test coupons. Since hollow fibers usually traverse the entire length of the laminate, samples cut along the diagonal ensure that each hollow fiber is accounted for only once. The 10 cm x 10 cm size is chosen to facilitate handling, sample preparation, and observation through an optical microscope.

Examples of a laminate and raw glass cloth divided into 10 cm x 10 cm test coupons are shown in the images below. The laminate marked with the dark dots is along the diagonal and will be used for hollow fiber measurement. In the same regards, the squares marked on the glass cloth are also along the diagonal and measure 10 cm x 10 cm.





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Sample Preparation

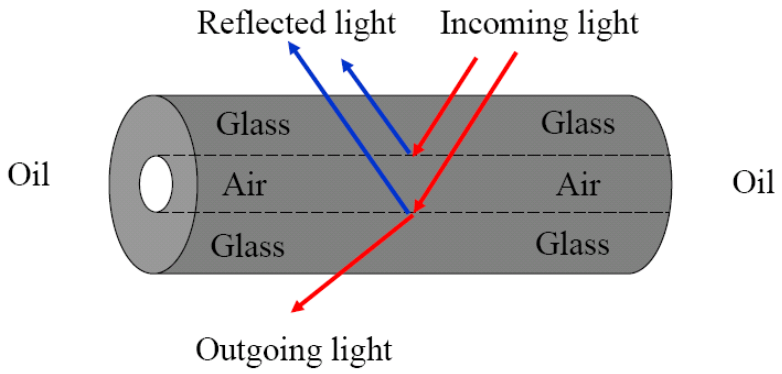
Samples are then placed in an oven at 538 ºC (1000 ºF) for approximately one hour to burn off the resin and expose the bare glass bundle matrix. The number of bundles per inch of fabric can be counted to identify the fiber style and the direction of warp (machine direction) and fill (weft, woof) yarns. The edge of each side of the test specimens is then dipped in wax to prevent wicking (capillary action of a fluid into a hollow fiber). The sample is immersed in index matching oil and then placed in a vacuum chamber and left at low vacuum for about five minutes to remove trapped bubbles between fibers.

Images of a coupon before (left) and after (right) resin burn off at 538C for one hour.

Image of a 10 cm x 10 cm glass fabric with wax on all four sides

Hollow Fiber Identification

Light is directed onto the sample, where it travels freely until it hits a hollow fiber (air). The change in refractive index at the fiber/air boundary partially reflects it. The unreflected light continues to propagate until it hits the outgoing air-fiber boundary, where again it is partially reflected. Although hollow fibers are visible with the naked eye, a microscope with a camera attachment is best to identify them. Examples of hollow fibers can be seen below.



Schematic detailing the reflection / refraction behavior of hollow glass fibers in oil

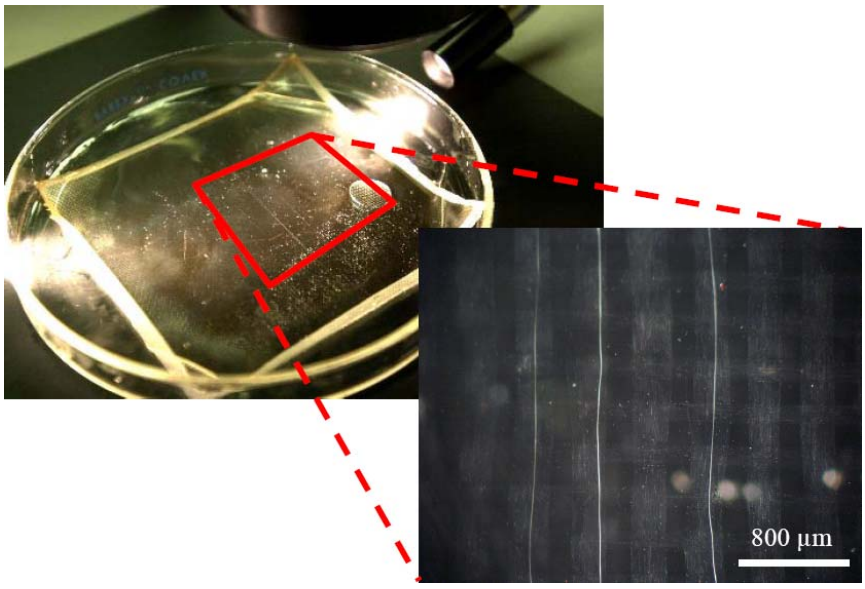
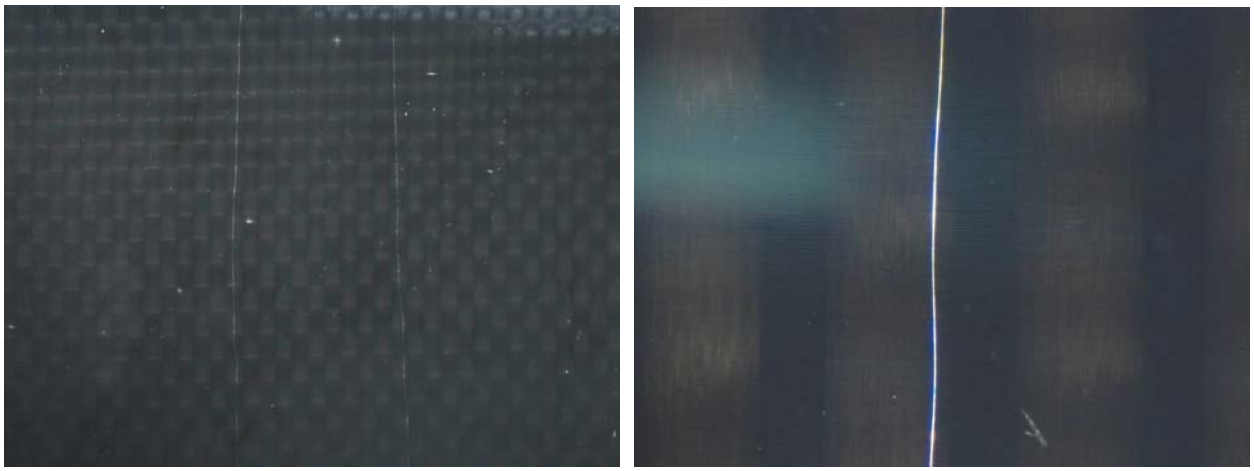


Image detailing the experimental setup for imaging glass fibers and an example image of hollow fibers in glass fabric



Additional examples of hollow fibers

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