# Improvements and mechanisms of the interface strength between fiber and epoxy resin filled with the alumina nanoparticles

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**Abstract:** The effect of alumina nanoparticles on the interfacial properties between fiber and epoxy resin was investigated. Well-dispersed nanoparticles enhanced significantly the interface strength between fiber and matrix. The fracture surface analysis demonstrated that the quality of fiber/matrix interface was improved after the addition of alumina nanoparticles.

**Keywords:** interfacial strength, fiber, epoxy, nanoparticles

## 1. Introduction

The interfacial properties between fiber and matrix are quite important in the design of fiber-reinforced epoxy composites (FRPs). Recently epoxy resin modified with nanoparticle reinforcement as “new matrix” in FRPs has been shown to be a possibility to enhance the interfacial properties of composites. For example, a significant improvement in performances of FRPs in which nanoparticles were incorporated was obtained [1-6]. However, the nanoparticles agglomerate was inevitable in some work; and the relative reinforcing mechanisms are still not well understood. The aims of this work are to investigate the interfacial properties between fiber and epoxy resin modified well-dispersed nanoparticles. The TFBT approach, which can resemble the deformation state in real high fiber volume laminate [7-10], is used to evaluate the quality of the fiber/matrix interface.

## 2. Experimental

The polymeric matrix was a commercial epoxy resin (E54, WUXI RESIN FACTORY OF BLUESTAR NEW CHEMICAL MATERIALS CO.,LTD.). Alumina (aluminum oxide, $Al_2O_3$, Degussa Corporation) nanoparticles were not treated and used as reinforcement. Carbon fiber (T300) with diameter distribution about 6-8 μm were used in this study. For the nanocomposite fabrication, a high-speed mixer (Dissolver, DISPERMAT AE) and a three-roll

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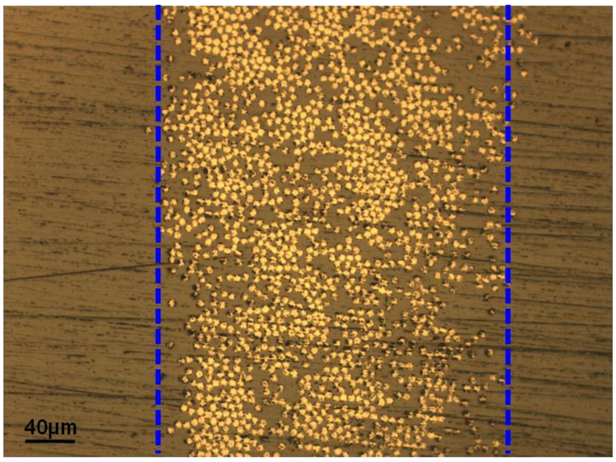
mill (EXAKT 80E) were used to break up the nanoparticles agglomerates and hence generate highly dispersed nanoparticles-filled epoxy dispersion [11]. When preparing the TFBT specimens, the fiber bundle was stretched in the middle of the steel mould before the resin was cast into the mold, as reported in our previous work [10]. Fig. 1 displays the polished cross-section of an untested TFBT specimen. The fiber volume content in the area between the dot lines is estimated to be approximately 50%. It can be seen that the fibers distribute quite uniformly with a good impregnation of the resin.

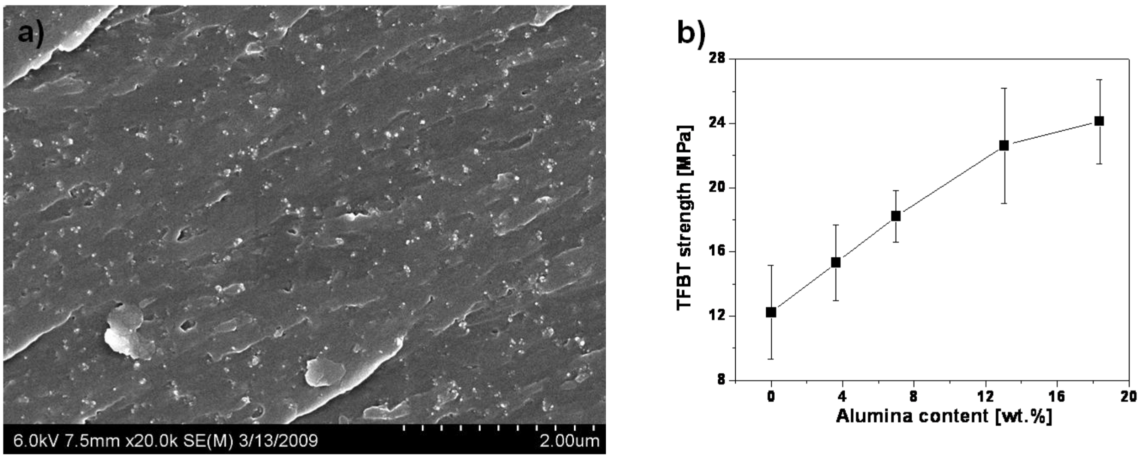
**Figure 1** Optical microscopy photo on fiber distribution in TFBT specimen.




## 3. Results and discussion

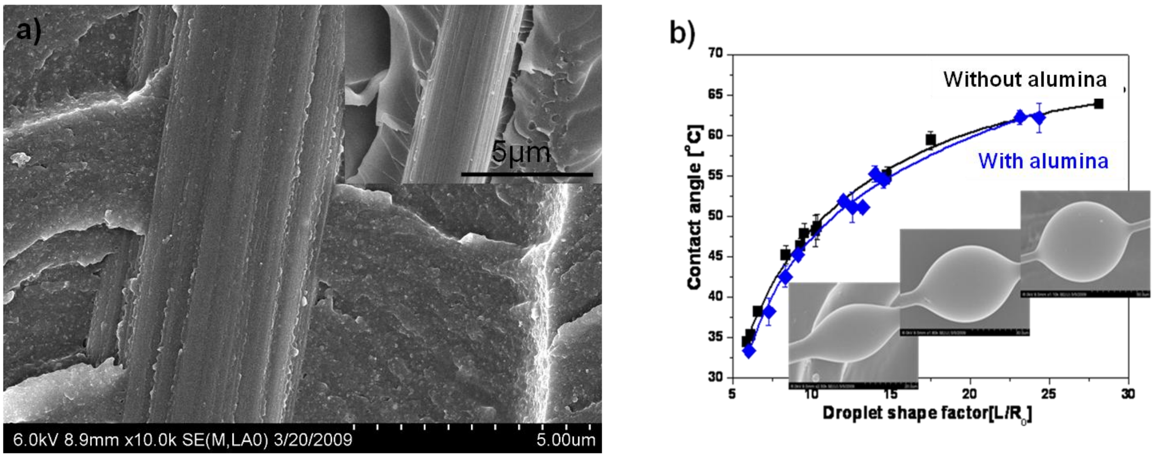
Via a convenient mechanical mixing produce, the alumina nanoparticles are well dispersed in epoxy matrix (see Fig. 2a). The interface strength of TFBT samples increase almost linearly with the alumina nanoparticles. As shown in Fig. 2b, the incorporation of 18.4 wt% alumina leads to the best overall reinforcing effect in interface strength by about 97%.

**Figure 2** a) SEM graph of fracture surface of alumina/epoxy composites and b) the tensile strength of TFBT samples with different content of alumina nanoparticles.



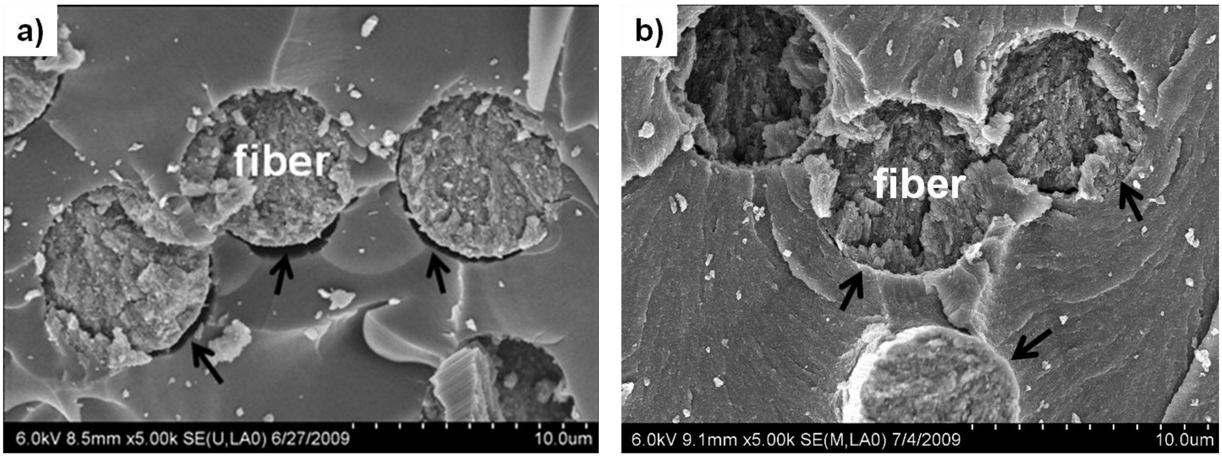
The fracture surfaces after TFBT tensile test are examined by SEM. The clean surfaces of the exposed carbon fibers on the fracture surface and a obvious fiber/matrix debonding can be seen in the inset in Fig. 3a. In contrast, with 18.4 wt% alumina nanoparticles, better interfacial adhesion between carbon fibers and matrix is observed in Fig. 3a. Careful investigation demonstrates that some matrix fragments are still stuck on the surface of the carbon fiber. These phenomena suggested that the presence of alumina nanoparticles did seem to affect the wettability between fiber and matrix. According to the method [12], the contact angles between fiber and matrix can be obtained and measured using epoxy microdroplets on fiber (see the inset in Fig. 9); however, the contact angle between fiber and matrix in Fig. 3b did not almost change with the addition of alumina nanoparticles, indicating that the nanoparticles did not affect the wettability of matrix on fiber.

**Figure 3** a) fracture surface of TFBT samples b) the contact angle between the fiber and matrix measured by the micro-droplet method




The fracture surfaces of TFBT sample taken in the cross section were shown in Fig.4. As shown in Fig. 4a, the debonding between fiber and matrix are clearly visible in TFBT samples with neat epoxy resin. Comparatively, with 18.4 wt% rigid alumina nanoparticles, the fiber/matrix deboning almost cannot be found on the fracture surface (see Fig. 4b). Obviously, the well-dispersed nanoparticles are effective for improving the quality of fiber/matrix interface. The improved fiber/matrix interface could be attributed to the changes of matrix microstructures and properties endowed by the nano-reinforcements such as the improved fracture toughness, the mismatch of coefficient thermal expansion between fiber and matrix, matrix plastic deformation, nanoparticles debonding and so on.

**Figure 4** Fracture surfaces of the TFBT specimens in cross-section direction: a) neat epoxy and b) 18.4wt.% alumina/epoxy nanocomposites.




## 4. Conclusions

Well-dispersed alumina nanoparticles were achieved in epoxy matrix after intensively mechanical mixing. The interface strength between fiber and epoxy resin modified with nanoparticles was increased significantly. The highest improvement of about 97% in interfacial strength beteen carbon fiber and epoxy matrix was obtained with 18.4wt.% alumina nanoparticles, which should be attributed to the improved fiber/matrix interface. Additional work is still needed to fully understand the fundamental reasons.

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