INFLUENCE OF ELECTRON RADIATION AND WATER ABSORPTION ON IMPACT AND CAI FRACTURE BEHAVIOR OF CARBON/EPOXY COMPOSITE

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SUMMARY: The influence of water absorption and electron radiation on impact fracture and compression after impact (CAI) behavior was investigated using carbon fiber reinforced epoxy matrix composite (MM-1/982X), having a quasi-isotropic stacking sequence of $[0°/\pm45°/90°]_{2S}$. Some specimens were immersed in deionized water at 80°C for about two months, which will be referred to as wet specimens. Both wet and dry (conditioned in air: RH 30%) specimens were irradiated in air with electron energy of 1.5MeV, resulting in a total absorbed dose of 10 MGy (1×10^3Mrad). The impact tests were carried out by a falling weight tester. Impact induced internal damage was observed with a scanning acoustic microscope (SAM). The delamination area was slightly increased by electron radiation and sharply increased by water absorption. The CAI strength was decreased in the order, dry specimens, irradiated specimens, irradiated after water absorbed specimens, wet specimens. The fracture surface was closely examined using a scanning electron microscope, and the fracture mechanisms were discussed.

KEYWORDS: Water Absorption, Electron Radiation, Impact, Compression after Impact, Delamination, Fiber/Matrix Interface, Scanning Acoustic Microscope, CF/Epoxy

INTRODUCTION

Advanced fiber-reinforced polymer matrix composites (FRP) that have high strength and high stiffness-to-weight ratios are now widely used in high technology engineering applications. In the near future, they will be more often used for structures operating in severe environmental conditions. To utilize the full potential of the composite materials, the effects of environment must be clarified. In particular, due to the humidity of the atmosphere, the influence of water absorption must be first taken into account [1-3]. When these are used for space structures, the effects of the space environment, such as electron, ultraviolet and proton radiation as well as vacuum and high-low temperature cycling are important issues [4-7]. Especially the effect of electron radiation must be clarified because the electron penetrates deeply [8-11]. Moreover they are exposed to not only single environmental condition but also combined ones. For example, composite materials, which absorbed water on the earth, are used for space structures. In this study, the effects of water absorption, electron radiation and electron radiation after water absorption on impact fracture and compression after impact (CAI) behavior were investigated using carbon fiber reinforced epoxy matrix composite (MM-1/982X).

EXPERIMENTAL PROCEDURES

The composite used was carbon fiber reinforced epoxy matrix composite (MM-1/982X), having a quasi-isotropic stacking sequence of $[0°/\pm45°/90°]_{2S}$. Details of the composite and the mechanical properties of the fibers are shown in Tables 1 and 2, respectively. Shape and dimensions of impact specimen are shown in Fig.1. Some specimens were conditioned in deionized water at 80°C for about two months, which will be referred to as wet specimens. The water gain was about 0.9 wt. %. A Van de Graaff type electron accelerator (Mitsubishi Electric Corp., VE20) was used to expose the shaded area of dry and wet specimens (shown in Fig.1) to 1.5MeV electrons in air, resulting in a total absorbed dose of 10MGy (1×10^3Mrad). The temperature of the specimens was kept for 60±5°C by air cooling.

Table1 Construction of composites.

Fiber	Mitsubishi Pyrofile MM-1
Matrix	Imide-modified Thermo-resistant Epoxy
Curing Condition	183±3°C × 120 min
Fiber Volume Fraction	59 %

Table2 Mechanical properties of carbon fiber (MM-1).

Tensile Strength	3.92GPa
Tensile Modulus	275GPa
Elongation at Break	1.4%
Density	1.79Mg/m^3

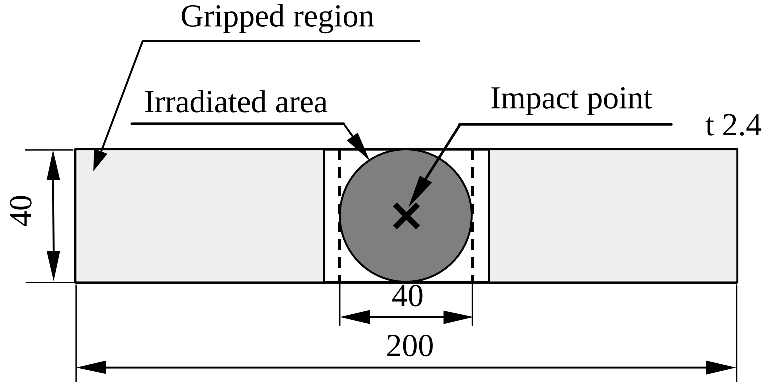


Fig.1 Shape and dimensions of impact specimen. All dimensions are in mm.

The impact tests were carried out by a falling weight tester. The center of the specimen (Fig.1) whose both ends (75mm) were fixed was impacted by a steel ball (1/2 inch in diameter) attached to the falling weight with a total mass of 1kg. Compression tests were carried out at a constant crosshead speed of 1.7×10^{-2}mm/s (1mm/min), using an electro-hydraulic servo controlled fatigue testing machine (Shimadzu Corp., EHF-FB20, Load Capacity: 200kN). An anti-buckling guide was attached to the specimens during the tests: see Fig.2.

The internal damage before and after impact test was observed using a scanning acoustic microscope (SAM, Olympus Optical Co., UH3) with a pulse wave of 50 MHz for 1600 ns gate time. The fracture surfaces of the specimens were observed using a scanning electron microscope (SEM, Hitachi Ltd., S4500).

EXPERIMENTAL RESULTS AND DISCUSSION

Electron Radiation Test

In the case of dry specimens irradiated at an electron radiation rate of 13.3MGy/h, no internal damage was observed. However, for wet specimens irradiated at the same radiation rate, internal damage was detected using a SAM (Fig.3 (a)). Optical microscope observation shows that both interlaminar and intralaminar fracture occurred (Fig.3 (b)). Fiber/matrix interfacial debonding was observed and the matrix fractured in a brittle manner (Fig.4). A high electron radiation rate of 13.3MGy/h is not suitable for wet specimens and therefore they were irradiated at a lower radiation rate of 6.7MGy/h. In this case, no damage was observed with a SAM and an optical microscope.

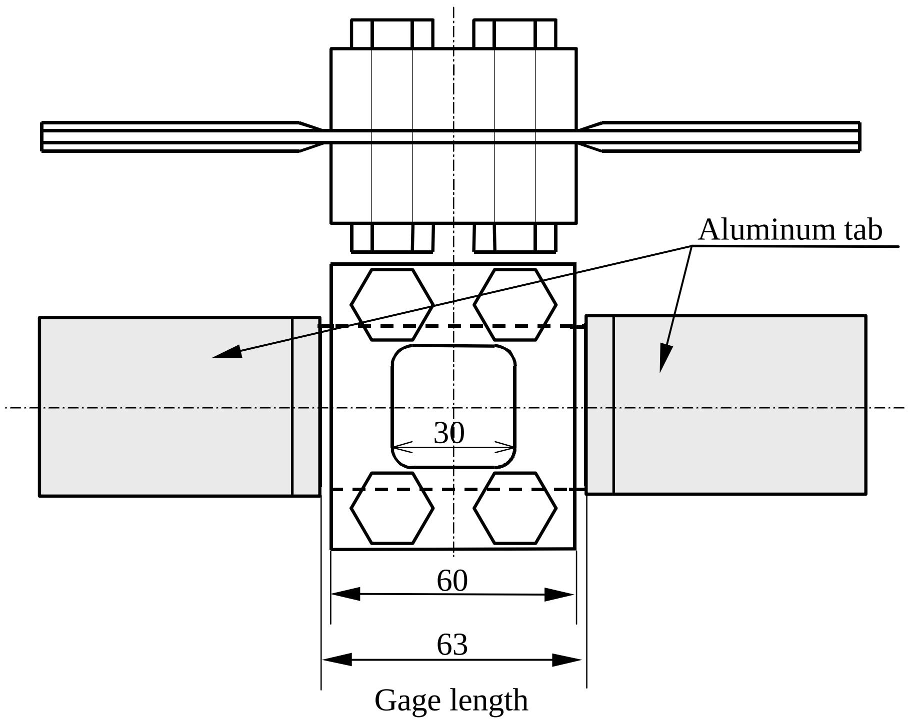
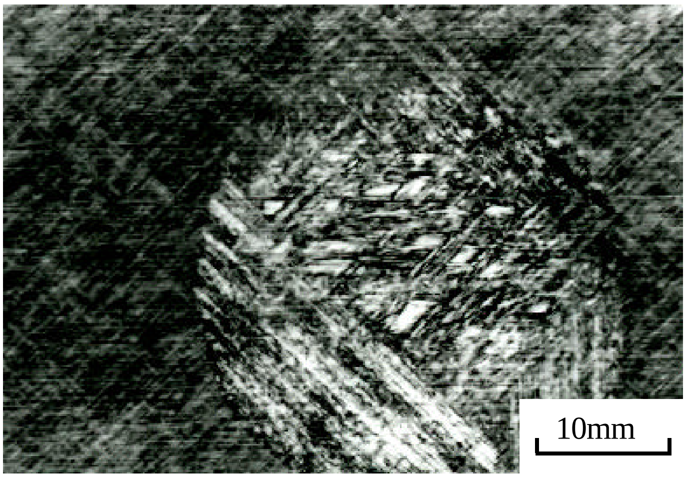
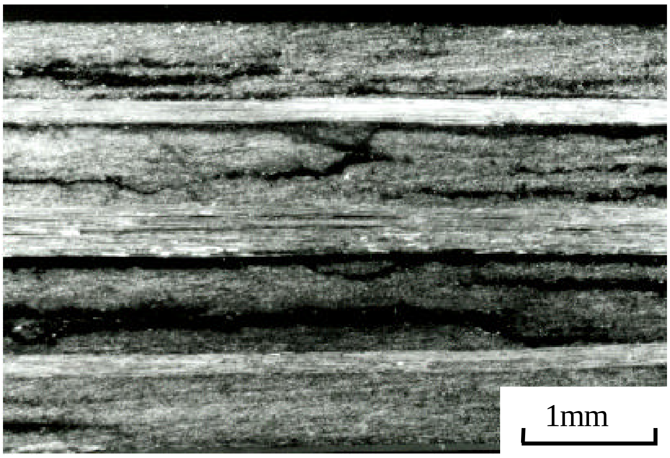


Fig.2 Anti-buckling guide. All dimensions are in mm.



(a) SAM photograph. White area shows the delamination.



(b) Cross section.

Fig.3 SAM and optical microscope photographs of the sample irradiated after water absorption at a high radiation rate of 13.3MGy/h.

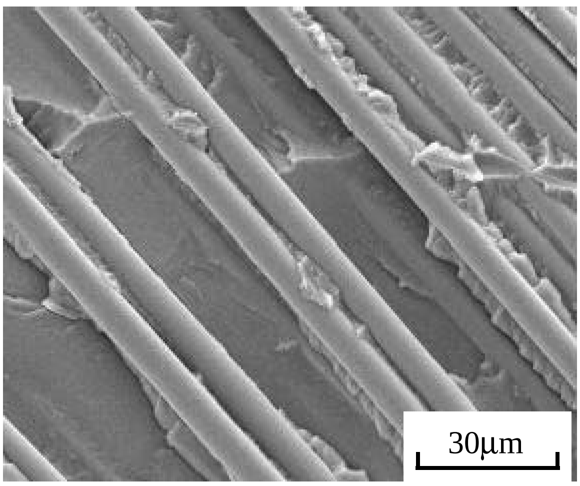


Fig.4 Fracture surface induced by electron radiation (13.3MGy/h, Wet specimen).

Impact Test

To evaluate impact-induced delamination areas, specimens were observed with the SAM before and after impact test, and the subtraction of the SAM images between virgin and impacted specimens was computed [1]. In this investigation, the sum of delamination areas observed from impacted and rear surfaces is defined as the delamination area. Figure 5 shows the impact-induced delamination area as a function of impact energy. Delamination area was slightly increased by electron radiation and was sharply increased by water absorption. There is no difference of delamination area between wet specimens and that of irradiated after water absorption.

Figure 6 shows the fracture surfaces of dry, wet, irradiated and irradiated after water absorbed specimens. Magnified photographs of irradiated and irradiated after water absorbed specimens are shown in Fig.7. For wet specimens, the fracture was mainly caused by interfacial debonding, indicating low fiber/matrix interfacial strength. Water absorption degraded the fiber/matrix interfacial strength, resulting in larger impact induced delamination area (Fig.5). The characteristic fracture feature of the irradiated specimens is that the wavy hackles, which were observed in the dry specimens (shown by arrow in Fig.6 (a)), are not observed, and that the matrix fractured in a more brittle manner. Besides these, no gap between the fiber and the matrix was observed (Fig.7 (a)), indicating that the interfacial strength between fibers and matrix is good. Electron radiation degrades the fracture toughness of the matrix and could increase the fiber/matrix interfacial strength. For irradiated after water absorbed specimens, the gap between the fiber and the matrix was larger than that of irradiated specimens and the matrix fractured in a similar manner as irradiated ones (Fig.7). This indicates that water absorption degraded the fiber/matrix interfacial strength and electron radiation lowered the toughness of the matrix. Although the both effects of water absorption and electron radiation on the fracture morphology were clearly observed, the delamination areas of irradiated and irradiated after water absorbed specimens were almost the same.

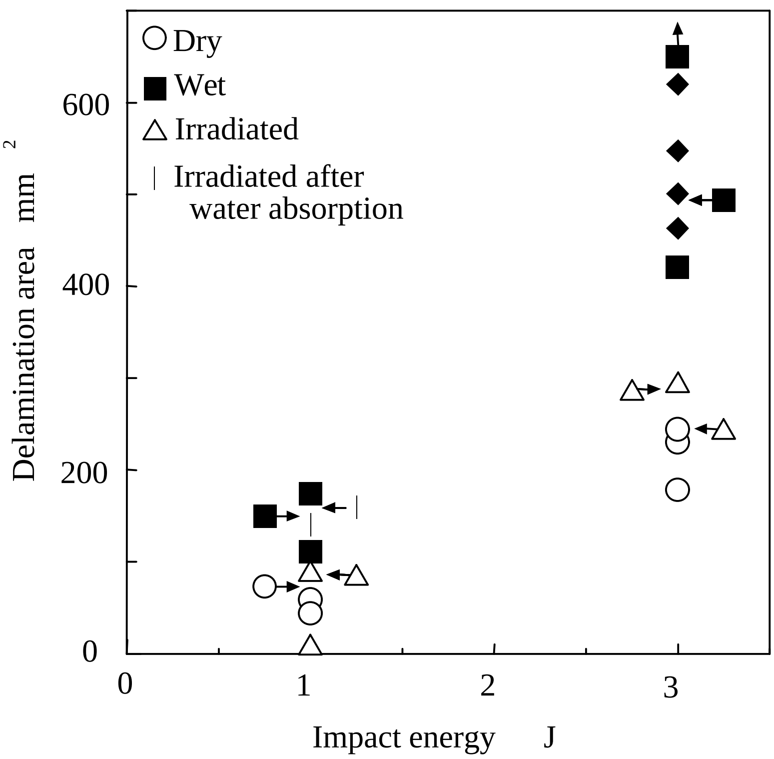
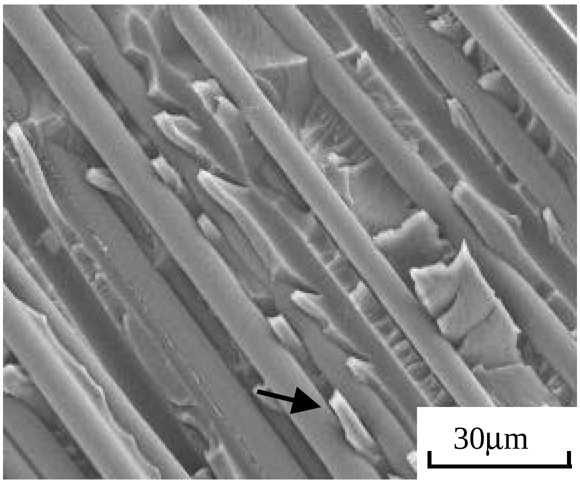
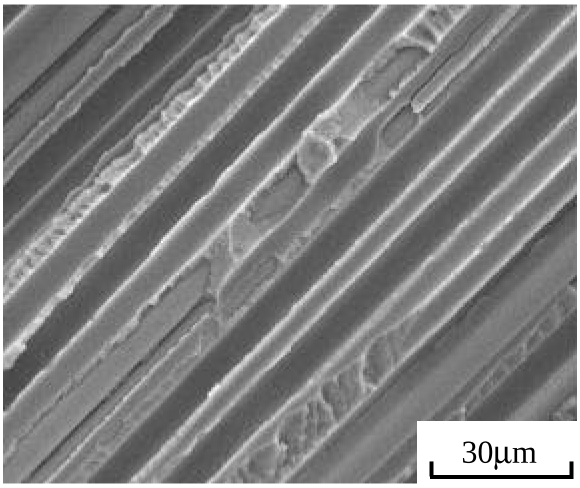


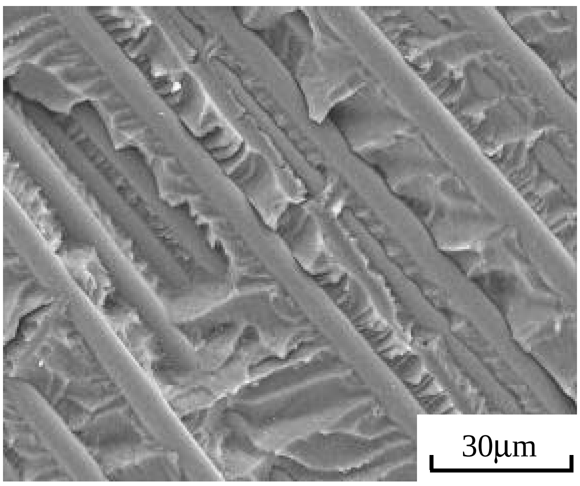
Fig.5 Relationship between impact energy and delamination area.



(a) Dry.

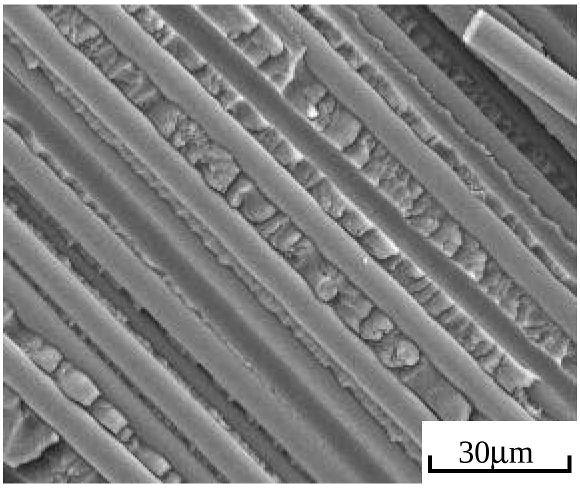


(b) Wet.

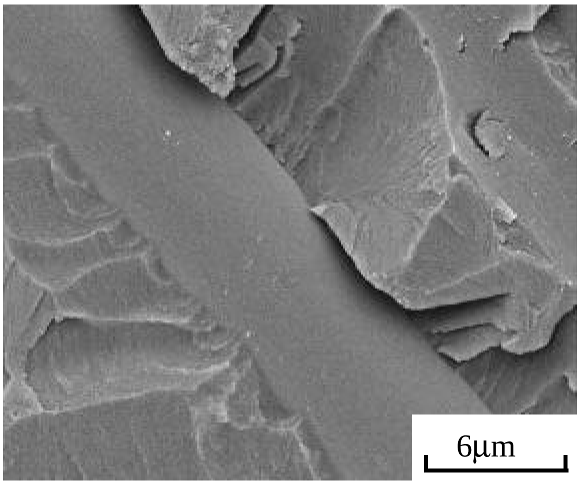


(c) Irradiated.

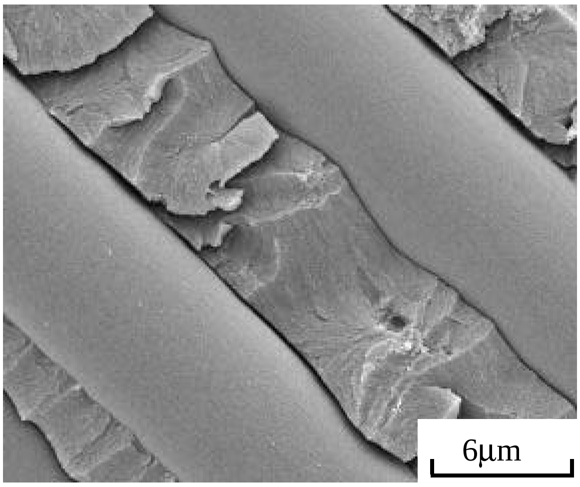
Fig.6 SEM photographs of impact induced delamination.



(d) Irradiated after water absorption.
Fig.6 SEM photographs of impact induced delamination.



(a) Irradiated.



(b) Irradiated after water absorption.
Fig.7 Magnified SEM photographs of impact induced delamination.

CAI Tests

The relationship between impact energy and residual compressive strength after impact is illustrated in Fig.8. The compressive strength decreased in the order, dry specimens, irradiated ones, irradiated after water absorbed ones, wet ones. However a difference of residual compressive strength became smaller at a high impact energy of 3J. At a high impact energy, delamination areas dominated over the residual compressive strength, and the influence of water absorption and electron radiation was negligible.

Figure 9 shows the SEM photographs of fracture surfaces after CAI test. Many fine textures (shown by allows in Figs.9 (b) and (d)) are observed on the fracture surface of the matrix in wet and irradiated after water absorbed specimens. These are owing to degradation of matrix resin by water absorption. The matrix of irradiated specimen fractured in a brittle manner, which was similar to the impact fracture surfaces.

CONCLUSIONS

(1) Impact induced delamination area was slightly increased by electron radiation and sharply increased by water absorption. Electron radiation degraded toughness of matrix and could increase the fiber/matrix interfacial strength. On the other hand, water absorption degraded the fiber/matrix interfacial strength.
(2) In the case of wet specimens, electron radiation at a radiation rate of 13.3MGy/h caused internal damages.
(3) The compressive strength was decreased in the order, dry specimens, irradiated ones, irradiated after water absorbed one, wet ones

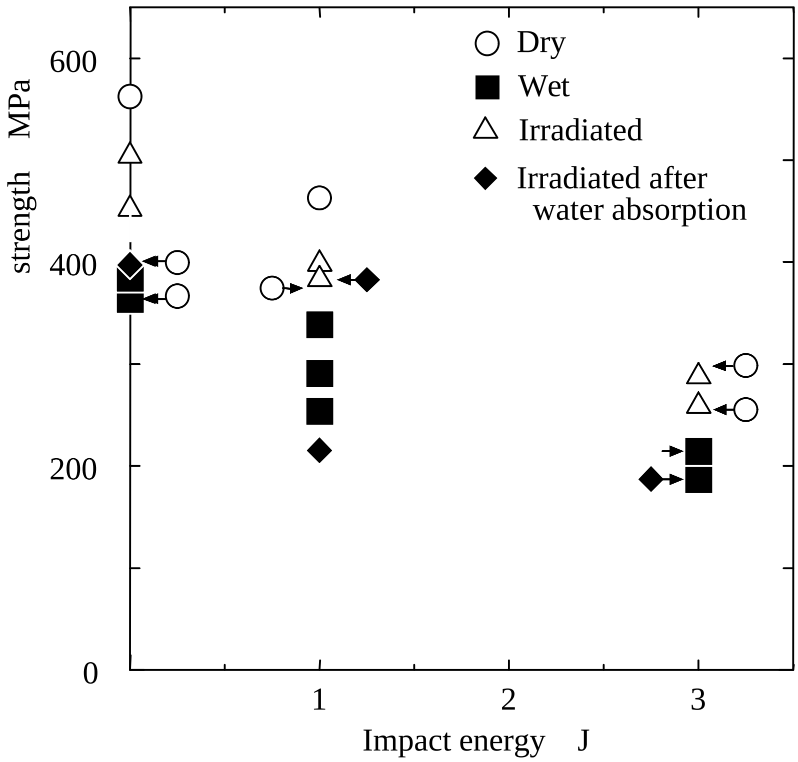
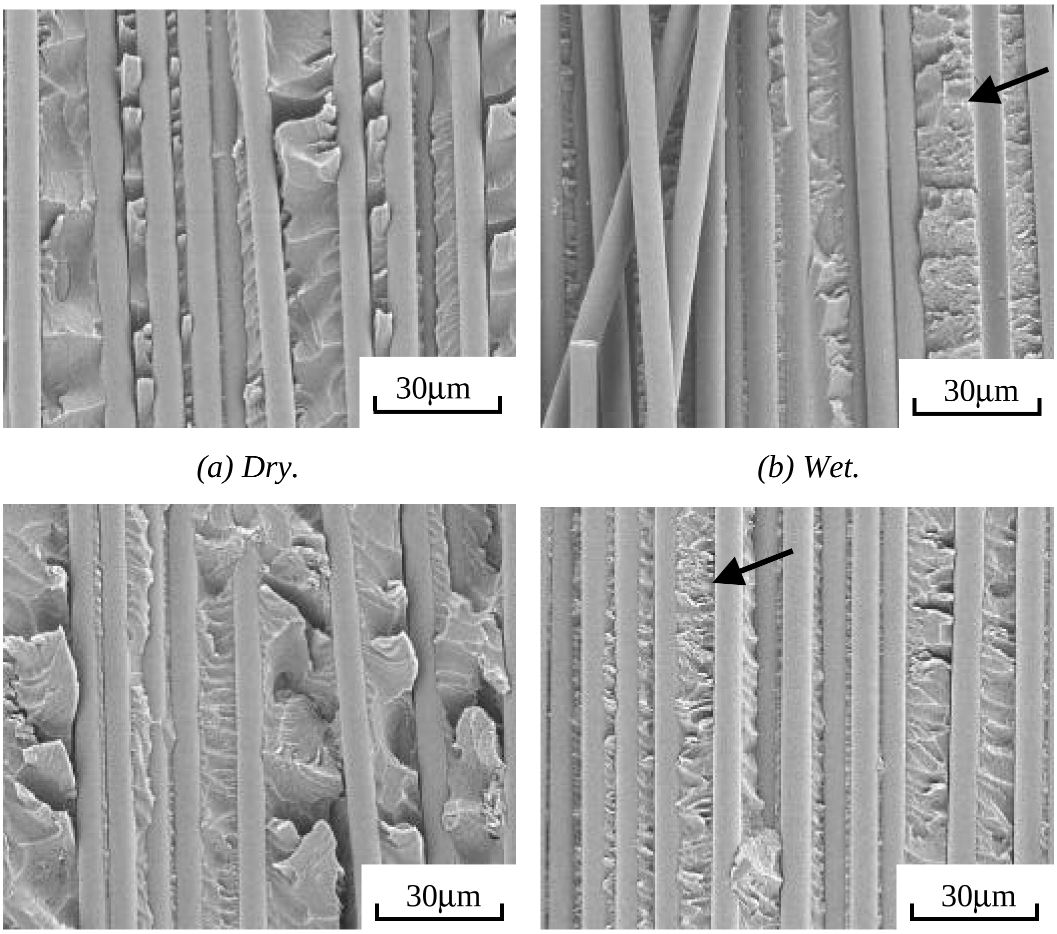


Fig.8 Relationship between impact energy and residual compressive strength.



(a) Dry. *(b) Wet.*

(c) Irradiated. *(d) Irradiated after water absorption.*

Fig.9 Fracture surface of CAI test (1J).

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