차세대 레시프로케이터 무릎 보조기에 적용되는 CFRP의 와전류 탐상 특성

Eddy Current Characteristic of CFRP Applicable Next Generation Knee Brace using the Reciprocator

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1. Introduction

Carbon Fiber Reinforced Plastic (CFRP) laminate is being increasingly applied to the primary or secondary structure of orthopedic surgeries such as knee brace in Fig. 1, because of its high specific strength and stiffness compared to conventional metals. The CFRP laminate, however, is easy to delaminate by a relatively small impact, resulting in a reduction of the compression strength. If it is used as a structural component, it will become a problem to maintain the structural reliability. Conventional monitoring methods, such as ultrasonic wave inspection and X-ray inspection, are very costly and time-consuming, with a difficulty of real-time monitoring. Therefore, a simple structural health monitoring method is urgently required to maintain structural reliability and reduce huge periodic inspection costs. The Eddy Current (EC) technique has been used in nondestructive testing for metallic materials[1,2]. Since CFRP laminate consists of electroconductive carbon fibers and insulative resin, it is inhomogeneous material with strongly anisotropic electrical property. The EC technique can also be applied to CFRP laminate. Electric current path, however, may be complicated in the laminate because of the strong anisotropy. Flaw configurations in the laminate are different from those in metallic material. The EC technique must be developed to apply to CFRP laminate. Since a delamination is debonding of interfaces of plies, electric current in the through-thickness direction plays an important role to measure electric resistance change. In EC technique, delamination with defects location and length are estimated by measuring electric resistance changes between EC signals on the laminate.

2. Experimental Method and Materials

The EC inspection of CFRP tube manufactured by carbon/epoxy prepreg is not possible due to the high resin contents (over 40%). Therefore, to accomplish the purpose of this research which is the electric conductivity improvement of CFRP tube, the CFRP tubes are fabricated with lamination of the aluminum alloy foils on the carbon/epoxy prepreg. Fig. 2 indicates the geometries of CFRP tube specimen. The circular holes defects whose diameter were 1.5 mm, were made by the micro-drill and the depths of them was machined as 20%, 40%, 60%, 80% and 100% of the specimen thickness. The method can be applied at low cost by simply mounting electrodes on laminate surfaces. This method, although the analytical accuracy of the estimation is high, requires numerous electric charges to measure the electric resistance changes between adjacent electrodes across the laminate[3,4]. The two-probe method used in the ERCM may affect the measured electric resistance because it is sensitive to the contact resistance between the electrodes and carbon fibers, which will result in an estimation error. The electric potential change method (EPCM) has been introduced to resolve these problems. In this method, two current electrodes and several voltage electrodes are attached on the surface of the specimen to adopt a four-probe method. The method, however, has the disadvantage that the electric current perpendicular to the surface (i.e. the thickness direction) disappears at the center segment of the current electrodes. In this method, if a delamination is estimated during the 1st stage estimation to exist at the center segment of the current electrodes, a 2nd stage estimation will be conducted by charging electric currents from the center electrode to the end-electrode. In the two-stage EPCM, response surface methodology is adopted as a solver of the inverse problem to estimate the delamination location and length from electric potential changes due to a delamination between electrodes. As CFRP laminate consists

Table 1 Mechanical properties of CFRP prepreg (USN-150, SK Chemical Co.)

E_1 (GPa)	E_2 (GPa)	ν_{12}	ν_{21}	G_{12} (GPa)	X_t (MPa)	Y_t (MPa)	S (MPa)
120	7.5	0.31	0.02	3.2	2200	30	120

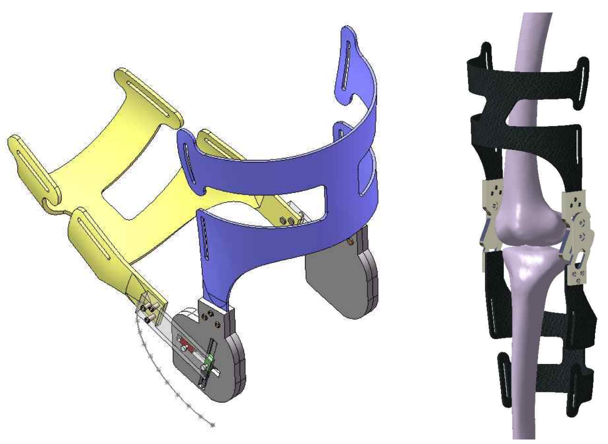

Fig. 1 Reciprocator type osteoarthritis knee brace using CFRP laminates made by our research group

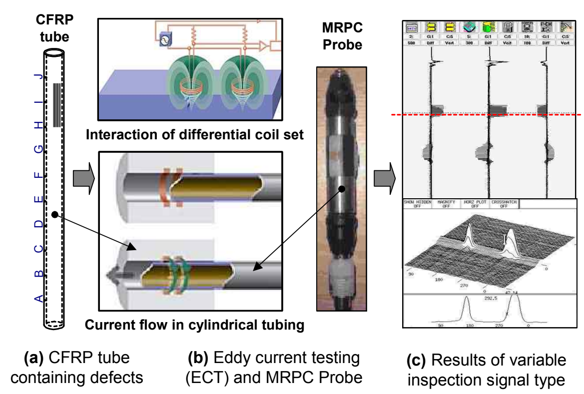

Fig. 2 Schematic illustration of ECT for CFRP tube specimen

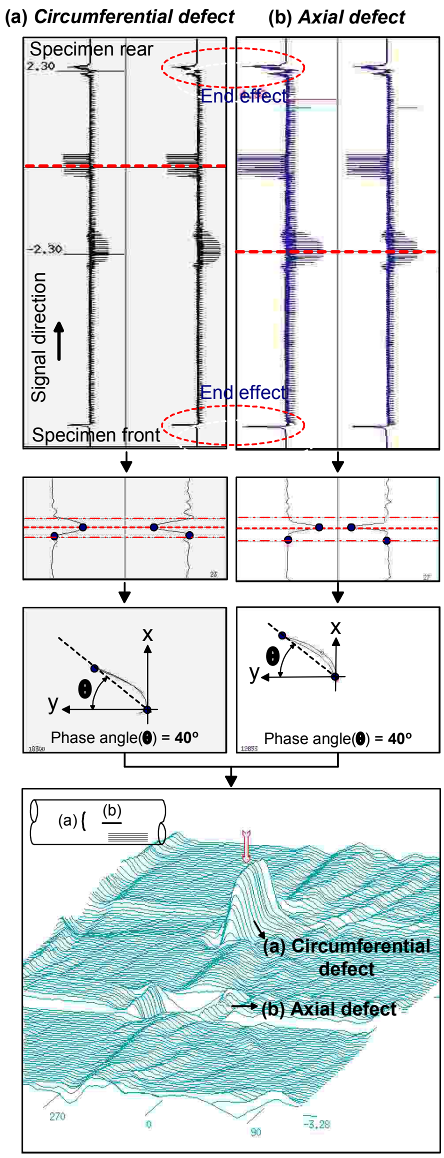

Fig. 3 ECT results of Reciprocator type CFRP knee brace for inspection of saw-cut defect in CFRP tube *with treatment*, (a) circumferential direction defect, (b) axial direction defect

of electrically conductive carbon fibers and insulative resin, it is electrically inhomogeneous with strong anisotropy. Resin rich layers between laminas also create a strong local inhomogeneity, affecting electric conductivity in the thickness direction. The measured electric conductivity varies depending on the specimen.

3. Results and Discussion

ECT inspection of CFRP tube manufactured by CFRP prepreg is not possible due to the high resin contents (over 40%). Therefore, to accomplish the aim of this research which is the electric conductivity improvement of CFRP tube, the CFRP tubes are fabricated with the lamination of the aluminum foils on the CFRP prepreg. Fig. 3 shows the good inspection of the saw-cut defect by the same way and the satisfactory detection of the circular defect with the different depths. MRPC coil consists of two pancake coils and one plus point coil. While the defect inspection using the pancake coil was not possible, the plus point coil made it possible to inspect the defects definitely. The through axial and circumferential saw-cut defects in CFRP tube were detected by ECT and demonstrated at Fig. 3. The reason why the signal of the axial saw-cut is longer than that of the circumferential saw-cut, is that the inspection time of the axial saw-cut is longer than that of the circumferential saw-cut due to the rotation and the axial movement of detection probe. Since the saw-cut defect is reproduced for the internal crack of the real materials, which its width is narrow and depends on the depth, the 3-dimensional view analysis is required. Therefore, the A-scan of Fig. 3 results in the 3-D pictures. Fig. 3 shows the difference of 3-D defect shape depending on the direction due to the strong anisotropy of CFRP tube while the general metallic tubes are isotropic. The deeper the depth of the defect, the lower the phase angle and the larger the amplitude of EC. The fact that the EC is an alternative current, made the flow of the EC increasing from the center to the surface of specimens. Therefore, since the EC is the function of the frequency, the electric conductivity and the magnetic permeability, the permeable depth is increasing with them.

4. Conclusion

This research was carried out to characterize the EC inspection effect on the defect-shapes such as the saw-cut with circumference and axial direction defects of CFRP tube and on the ratio of the defect-depth to the specimen thickness and the next conclusions were obtained.

1) For the manufactured inhomogeneous CFRP tube, the inspection of the defect between 100 Hz and 1 kHz was not possible and it had nothing to do with the defect-shape. The high frequency such as 100 kHz ~ 500 kHz made the inspection of defects possible. Especially, the best S/N ratio was appeared at 300 kHz.

2) The different 3-D information was obtained by the direction of axial direction and circumferential saw-cuts that have the same shape. The fact that both the sum of magnetic vector potential and the interference components were considered for the circumferential one, made them exaggerated.

3) While the depth of the defect was increasing, the phase angle was lowering and the amplitude of ECT was gradually increasing. Therefore, while the lower amplitude of ECT made the permeable depth of the signal deeper, it made the sensitivity of the defect lower. For this reason, it was not possible to inspect the circular defects with the 20% and 40% defect-depth ratio to the specimen thickness.

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