Characterization of Electrical and Mechanical Properties of CFRP/ABS*

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Abstract: This paper presents electrical and mechanical properties of compound consisting of thermoplastic resin mixed with carbon fiber reinforced plastic (CFRP) pieces. CFRP pieces made by crushing CFRP wastes are utilized in this material. Nine kinds of compounds with different weight fraction and size of CFRP pieces are prepared. Firstly, electrical impedance of the compounds was measured as a function of frequency. Electromagnetic shield effect of the compounds was also investigated and compared with that of a CFRP laminate. Secondly, mechanical properties such as tensile and flexural strength were measured. Finally, the polished surface and fracture surfaces of the specimens were microscopically observed to investigate the effect of orientation and distribution of CF and CFRP pieces on mechanical and electrical properties. The compound has a variety of conductivity depending on content of CFRP pieces. Mechanical properties also increase with increasing CFRP content.

Key Words: CFRP, Thermoplastic resin, Electrical resistivity, Electromagnetic shield, Mechanical properties

1. INTRODUCTION

Since carbon fiber reinforced plastics (CFRPs) have excellent mechanical properties such as high specific strength and modulus, they have been used as light-weight structural materials for aerospace vehicle, automobiles and so on. CFRPs have also been utilized as electromagnetic shield material by taking advantage of their electrocoductivity. However, materials reinforced with virgin CF are not likely to be used to a lot of products because of high cost.

In general, CFRP is difficult to be recycled due to its hardness and chemical stability. In material recycling, wasted CFRPs are directly utilized through mixture with base material. A project to establish the recycling system of glass fiber reinforced plastics (GFRPs) was conducted by Government Industrial Research Institutes (GIRIS, former AIST) in Japan about ten years ago[1]. As material recycling in this project, a device to cut large scale GFRP wastes such as boats was developed and also some composites including crushed GFRP were fabricated. More recently, an attempt has been made to develop new concrete reinforced with crushed CFRP pieces[2] in a project for establishing crushing and classification technique of CFRP wastes in Japan.

However, most of CFRP wastes are presumed to be buried in the ground or left as they are whilst it is estimated that five thousand tons of CFRP are wasted in a year in the world. As far as the authors know, products using recycled CFRP have not been reported although some research may be conducted in laboratories. Consequently, a recycling system for CFRP wastes has not been established in the world so far.

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When CFRP is used for electromagnetic shield, the material is usually fabricated through an injection molding process using thermoplastic resin mixed with short carbon fibers. In this paper, recycled CFRP crushed into small pieces instead of virgin short carbon fiber is utilized as conductive filler. Nine kinds of compounds with different weight fraction and size of CFRP pieces are prepared for the measurement of mechanical and electrical properties. Firstly, electrical impedance of the compounds was measured as a function of frequency. Electromagnetic shield effect was also investigated and compared with that of a CFRP laminate for practical application. Secondly, mechanical properties such as tensile and flexural strength were measured. Finally, the polished surface and fracture surface of the specimens were microscopically observed to investigate the effect of orientation and distribution of CFRP pieces and the interface between fiber and resin on the mechanical and electrical properties.

2. EXPERIMENTAL PROCEDURE

2.1 Material

The material used consists of acrylonitrile butadiene styrene (ABS) resin and recycled and crushed CFRP (CF/epoxy) pieces with average length by width of 3.4mm x 0.4mm. Some CFRP pieces experience further crushing by a ball mill to investigate effect of CFRP size on mechanical and electrical properties.

Fig. 1 shows the geometry of the specimens. Dumbbell-type specimens (JIS K7139, gage length 100 mm, width 10 mm, thickness 4mm) and square plates (150mm x 150mm, thickness 3mm) were fabricated using injection molding technique. Table 1 summarizes the mixture ratio of the specimens. The weight fraction of CFRP pieces varies from 0 to 0.7. The milled CFRP pieces were used in No. 9 specimens. Fiber volume fraction V_f of the compound was calculated through V_f (=0.6) of CFRP and density of CFRP and ABS resin.

2.2 Electrical tests

Firstly, electrical impedance of the specimens at a frequency ranging from 1 kHz to 1 MHz was measured with an LCR meter (Agilent 4284A). Four-terminal method was adopted for precise measurement. Resistivity was calculated from impedance at a low frequency (1 kHz).

Secondly, the shield effect against electrical wave with a frequency varying between 60 MHz and 1.2 GHz was investigated according to ADVANTEST method with the aid of a network analyzer (HP 8720C).

2.3 Mechanical tests

At first, tensile tests were performed using an electrohydraulic testing machine for the dumbbell-type No. 1

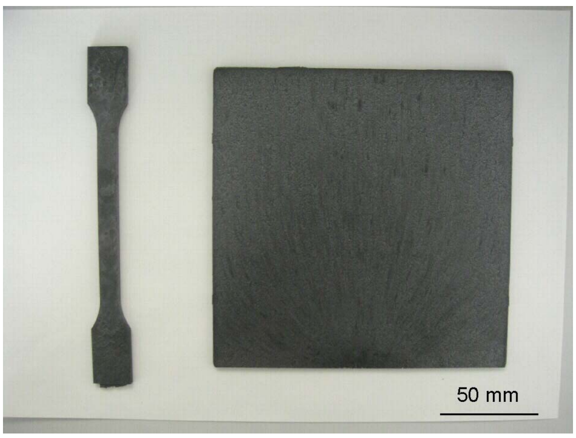

Fig. 1 Dumbbell-type specimens (left) and square plates (right). (No. 6 specimens)

Table 1 Mixture ratio of CFRP/ABS compound.

No	CFRP	ABS	V_f
1	0.0	1.0	0.000
2	0.1	0.9	0.041
3	0.2	0.8	0.085
4	0.3	0.7	0.132
5	0.4	0.6	0.182
6	0.5	0.5	0.238
7	0.6	0.4	0.298
8	0.7	0.3	0.364
9	0.3	0.7	0.132

to 9 specimens. A strain gage was adhesively bonded on the specimen surface to measure elongation and calculate Young's modulus. Next, flexural tests were conducted using the same testing machine for coupon specimens (80mm x 10mm x 4mm) cut from the dumbbell-type specimens. Flexural strength and modulus were calculated from the load-displacement curve. All the mechanical tests were carried out at room temperature.

2.4 Microscopic observation

Polished surface and cross-section were optically observed to investigate the state of dispersion and orientation of CFRP and CF in the resin. In addition, the fracture surface was observed using scanning electron microscopy (SEM) to characterize the fracture behavior focusing on the interface between fiber and resin.

3. RESULTS AND DISCUSSION

3.1 Electrical properties

Fig.2 shows impedance and phase angle of the specimens as functions of frequency. Impedance is almost constant for No. 4 (30 wt%) to 8 (70 wt%) specimens. The phase angle is kept to be nearly zero for No. 4 to 8

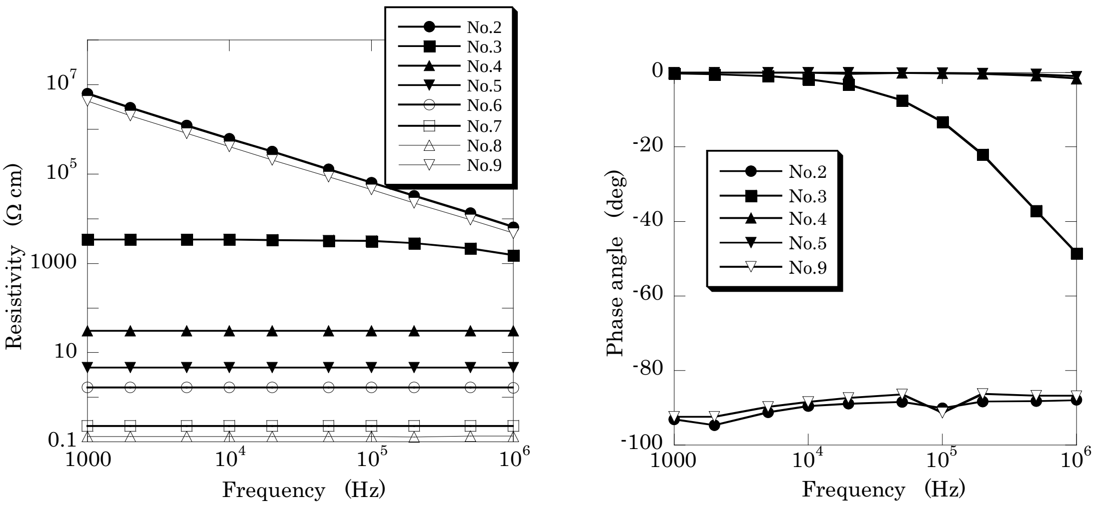

Fig. 2 Impedance (resistivity) and phase angle vs. frequency in CFRP/ABS compound.

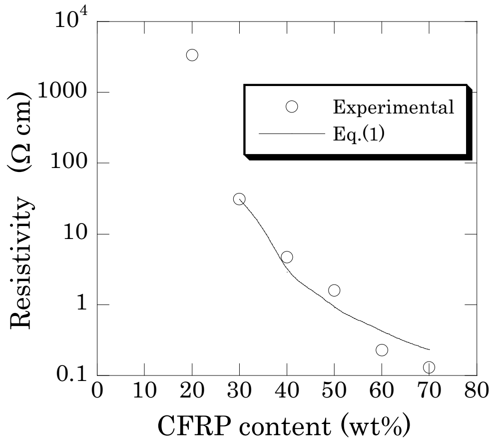

Fig. 3 Resistivity vs. CFRP content in CFRP/ABS compound.

specimens which are regarded as pure resistant materials. On the other hand, it is around 90-degree for No. 2 (10 wt%) and 9 (small 30 wt%) specimens, which indicates that these two specimens are dielectric or insulating materials.

Fig. 3 shows resistivity as a function of CFRP content ranging from 20 to 70 wt%. Resistivity decreases with increasing CFRP content or fiber volume fraction. Generally, resistivity ρ_V of material including conductive filler is predicted by the following scaling law[3]:

$$\rho_V = \beta\left\{V_f - \alpha\left(\frac{D}{L}\right)^2\right\}^{-2} \tag{1}$$

where L/D denotes the aspect ratio of the filler and α and β are material constants. The value of $\alpha(D/L)^2$ means the critical volume fraction of filler V_C, that is, the specimen with V_f lower than V_C is insulating. In this material, this value is estimated to be 0.11. The fitted curve on the basis of eq. (1) is represented by a solid curve in Fig. 3.

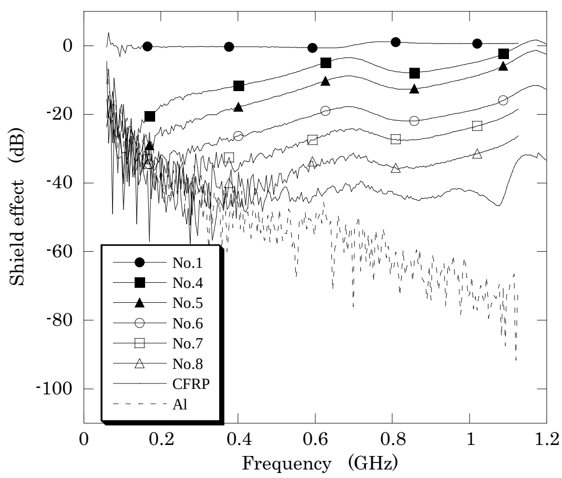

Fig. 4 Shield effect against frequency for CFRP/ABS, CFRP and aluminum.

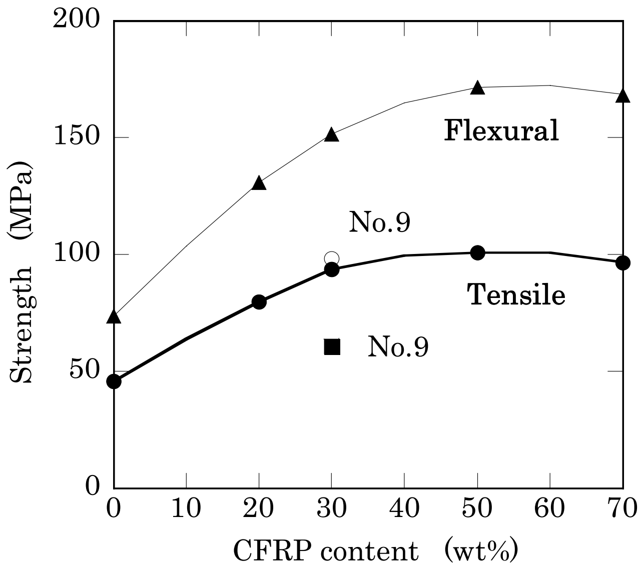

Fig. 5 Tensile and flexural strength vs. CFRP content of CFRP/ABS compound.

Fig.4 shows shield effect against frequency up to 1.2 GHz for No.1 (ABS resin) and No. 4 (30 wt%) to 8 (70 wt%) specimens together with a CFRP laminate ($V_f = 0.6$) and aluminum. Shield effect increases with increasing CFRP content although it attenuates at high frequency. Since the CFRP laminate containing long CF has shield effect between 40 and 50 dB, the shield effect of the present material with lower V_f and shorter fibers is expected to be at most 40 dB.

3.2 Mechanical properties

Fig.5 shows tensile and flexural strength against CFRP content. Both strength increases with increasing CFRP content below 40 %. After the strength saturates at around 50 %, it decreases slightly at higher content.

Fig. 6 shows tensile and flexural modulus against CFRP content. Both moduli increase linearly with CFRP content which means that the moduli obey the following modified rule of mixture[4]:

$$E = k\,E_f V_f + E_m (1 - V_f) \tag{2}$$

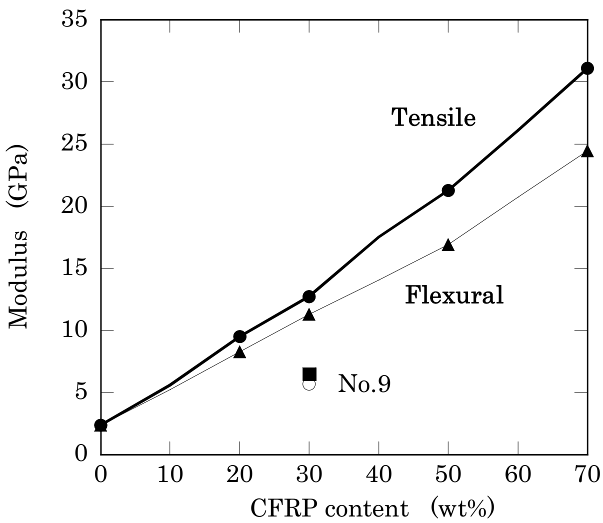

Fig. 6 Tensile and flexural modulus vs. CFRP content of CFRP/ABS compound.

where E_f and E_m represent Young's modulus of fiber and matrix resin, respectively, and k is a reinforcement efficiency depending on fiber length and orientation and can be estimated to be 0.33 in this case. As stress-strain behavior of all the specimens is almost linear, strength is approximately proportional to a product of elastic modulus and elongation. The modulus increases and elongation decreases approximately linearly with CFRP content. As a result, strength becomes the maximum at around 50 %.

The strength and modulus of No. 9 specimen having smaller CFRP pieces are much lower than those of No. 4 specimen with the same CFRP content. This is probably because the efficiency of reinforcement is lower in No. 9 specimen reinforced with shorter fibers.

3.3 Microstructures

Fig. 7 shows optical micrographs showing the polished surface of No. 6 specimen. Most CF are separated individually and dispersed homogeneously in ABS resin whilst some fiber bundles arising from the original CFRP pieces are observed. Fibers, as well as fiber bundles, are oriented along the direction of injection flow denoted by arrows. Average length of fiber is about 200 μm, which is comparable to that of usual short fiber reinforced composites although it is much shorter than the original length of the CFRP pieces.

Fig. 8 shows a SEM photo showing the fracture surface after the tensile test of specimen No. 6 (50 wt%). Some fibers are pulled out from the resin and randomly oriented rather than in the direction perpendicular to the fracture surface. The resin observed on the surface of a carbon fiber, indicated by a white arrow, is identified as ABS resin through detail analysis. This implies that epoxy resin surrounding carbon fiber is removed from the fiber during crushing and fabrication processes. Therefore, it is probable that conductive paths are formed when fibers are in contact with each other and that conductivity is improved by adding appropriate conductive filler together with CFRP pieces.

4. CONCLUDING REMARK

Electrical and mechanical properties of compound consisting of ABS resin mixed with CFRP pieces are experimentally characterized. Resistivity decreases and shield effect increases with CFRP content. Mechanical properties such as strength and modulus are improved almost linearly with an increase in CFRP content although strength saturates at CFRP content of 50 %. Carbon fibers are not coated by epoxy resin and dispersed

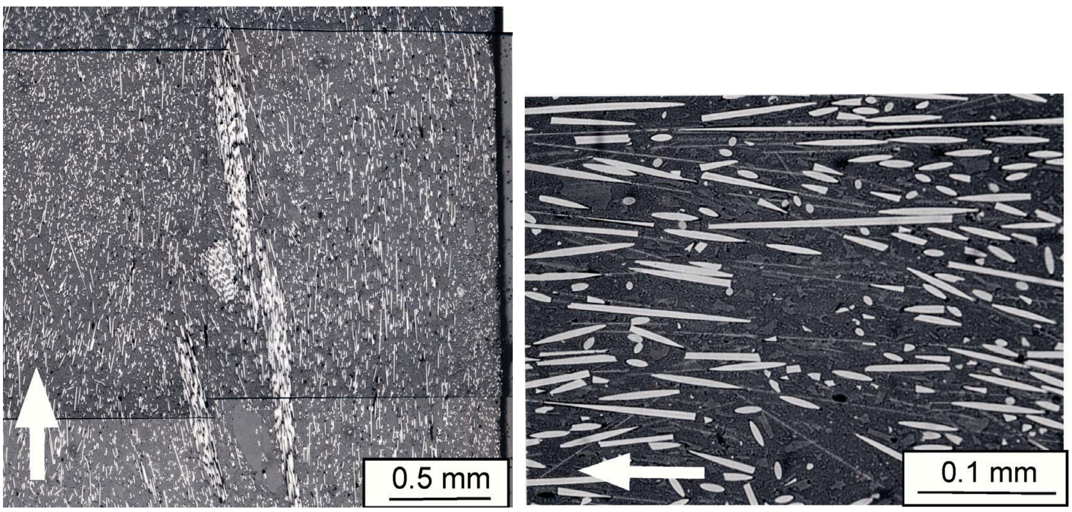

Fig. 7 Optical micrographs showing polished side surface of a No. 6 specimen.

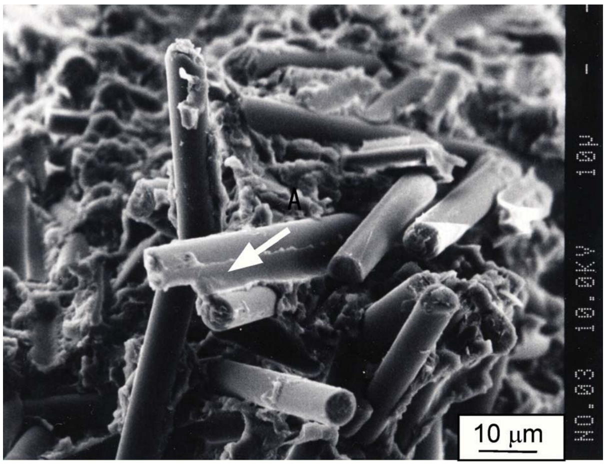

Fig. 8 SEM photo showing fracture surface of a No. 6 specimen after a tensile test.

individually in ABS resin whilst some fiber bundles coming from the original CFRP pieces are included. For practical application to electromagnetic shield, other kinds of conductive filler should be mixed with CFRP pieces to obtain better conductivity.

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