# Dimensional and Geometrical Stability of CFRP Laminates in Hostile Environment

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## ABSTRACT

In this study, we focused on the geometrical change of cross-ply laminates that are widely used for the composite structures. The behavior of time-dependent out-of-plane deformation under high temperature and humidity was examined. The geometries of the CFRP plates were measured after constant time. The initial shape of the specimens was saddle shape, and the shape gradually became flat with time. Up to 500μm of out-of-plane deformation arose during moisture absorption. The displacement in out-of-plane direction was large along ±45° directions which isn't the fiber direction. The geometrical change of the laminates was only 50μm at vacuumed condition. It indicates that other factors such as the residual stress relief and self-shrinkage by physical aging have smaller effect on dimensional instability compared to swelling by moisture absorption at 80°C. Furthermore the deviation of fiber volume fraction was investigated to explain the deformation of cross-ply laminates.

## 1. INTRODUCTION

In these years the need of lightweight designs is increasing in terms of fuel reduction. CFRP is light and high stiffness, therefore it is expected that various structure are designed by CFRP. The examples of the need to apply CFRP are antenna reflector and mirror [1,2]. Especially for the structures boarded on satellite, they must be made light as soon as possible, because the weight limit exists for rockets. The most important parameter in those precise structures is dimensional stability. The precise structures must keep their geometry under hostile environment. CFRP is composed of the plastics as a matrix, so deformation due to moisture absorption [3], creep deformation by own weight, and self shrinkage by after curing or physical aging [4] will arise. To predict their deformation and assure their performance, these factors should be quantified and perform the simulation of actual devise model.

It has been reported the deformation by moisture absorption so large that it couldn't exclude when we discuss dimensional stability. The moisture diffusion behavior into FRPs can deal as an analogy of thermal transfer, and the behavior is subjected to Fick's law [5]. Beside, CME (Coefficient of Moisture Expansion), the value of moisture strain $\varepsilon^M$ normalized by moisture content $M$, is the reference for the deformation by moisture absorption. CME can be obtained by measuring curvature of asymmetric strip [0/90] [6]. The moisture expansion in 90° layer is large enough to negligible that of 0°

layer. So CMEs are calculated by monitoring the shift of curvature against moisture content. In regard to the deformation of asymmetric laminates, the deformation is too large to describe by infinitesimal theory. To describe that deformation exactly, non-linear term should be considered [7].

In above researches, the stacking sequence was asymmetric to measure the deformation easily. However the structures, which need high dimensional stability, are never made by asymmetric laminates. The symmetric laminates are usually adapted to the precise structures. The deformation of symmetric laminates has not been discussed until now because it is difficult to measure the deformation of symmetric laminate. Discussing the geometrical change of symmetric laminate is essential to design more stable laminates.

In this study, the symmetric cross-ply laminates were prepared, and measured their geometrical change under high temperature high humid environment and vacuumed condition. From the experimental results, the factors that cause dimensional instability were discussed.

## 2. EXPERIMENTS

### 2.1. Materials and specimens

Fig. 1 shows the geometry and size of specimens. The specimens were thin, square plates with a length and width of 280 mm and a thickness of 2.4 mm. Specimens were fabricated from a single batch of the prepreg tape made of pitch based high-elasticity carbon fiber (K13170, 650GPa) and thermosetting epoxy resin (AY33). They were cured in an autoclave that was controlled at a uniform temperature to reduce warping by residual stress at the curing stage [8,9]. The surface roughness of the specimens were $R_a$=1.6 μm. The stacking sequence of the specimen is $[0/90/0/90]_s$. Before the test, the specimens were exposed at 140°C vacuum conditions for 12 hours in order to dewater them.

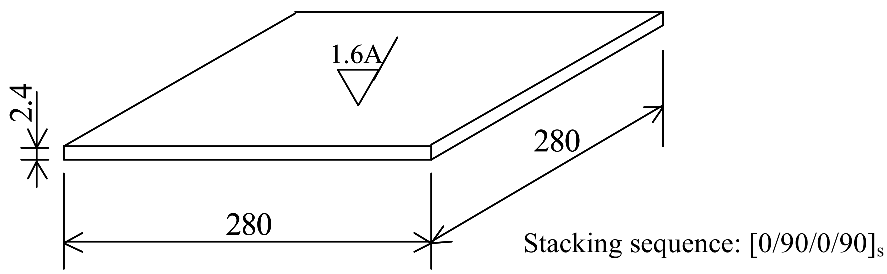



Fig.1 Geometry and size of cross-ply laminate

### 2.2 Measuring specimens geometry

The equipment of measuring the surface geometry is shown schematically in Fig. 2. The specimens were supported by three block gages on stable table. The probe attached to the slider measures the *z*-coordinates (height) of the upper side of the specimen. The accuracy of the probe is 0.1 μm. The probe slides automatically to the *x*-direction. Then, by sliding the arm of the probe to the *y*-direction and repeating the automatic slide in the x-direction, the surface geometry of the specimen can be obtained. After the dewatering procedure, the surface geometry of the specimens was measured at 20°C 50%RH. Specimens were exposed at two conditions; 80°C 90%RH, and 80°C vacuumed condition. After an arbitrary elapsed time, specimens were pulled out from the chamber, and measured their geometry at 20°C 50%RH.

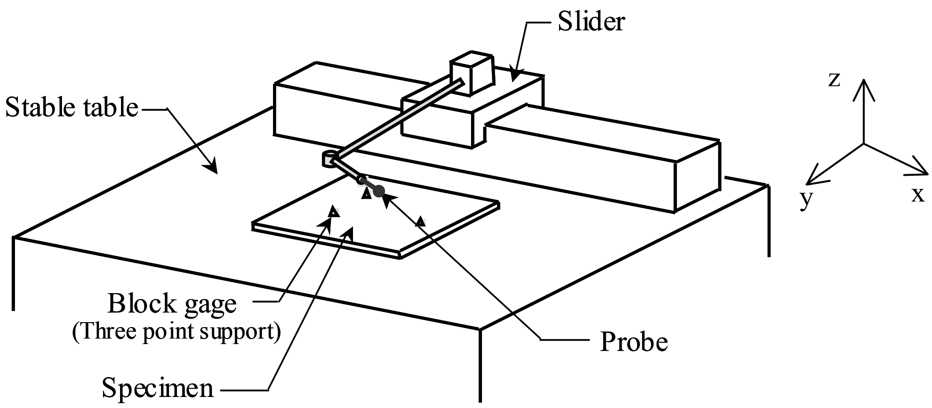
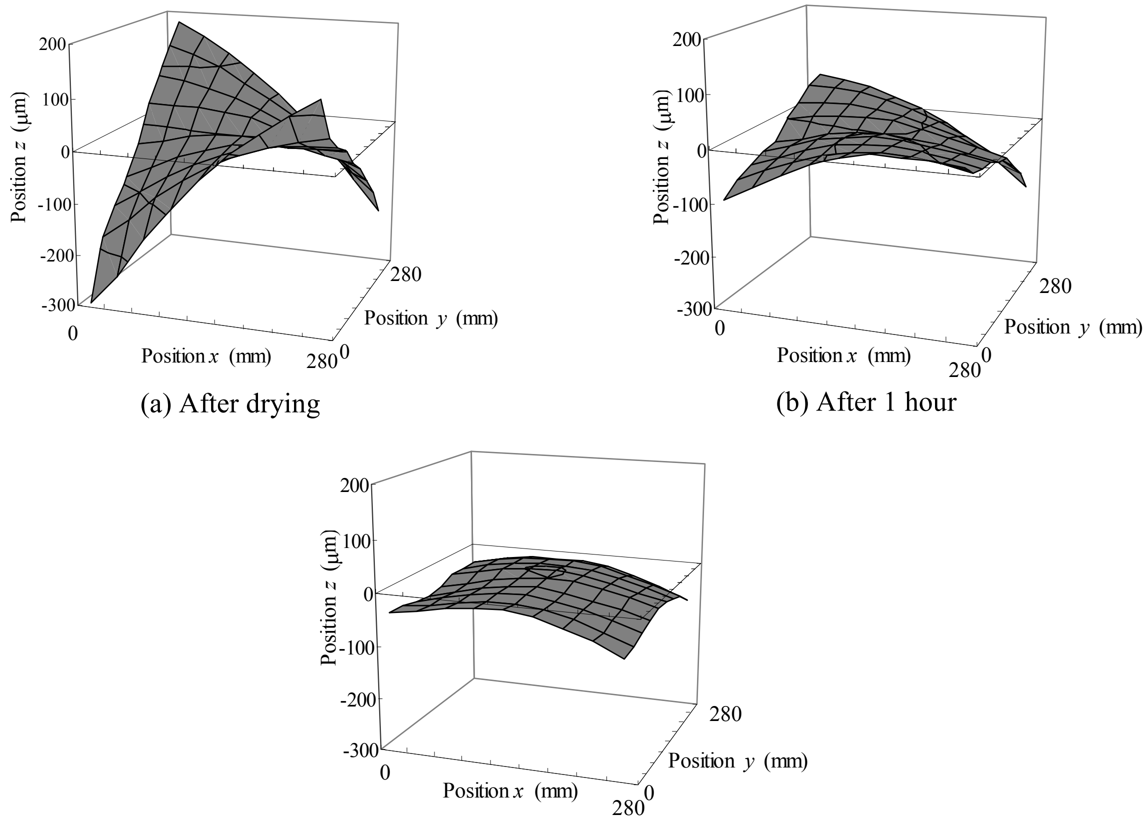



Fig.2 Schematic of measuring flatness

## 3. EXPERIMENTAL RESULTS AND DISCUSSION

### 3.1 Deformation at humid environment

The geometrical change at humid environment is shown in Fig. 3. Fig.3 (a) shows the specimen's shape after drying. The geometry of cross-ply laminate after drying were saddle shape. The backside was the reverse shape as it was, so it was not the deformation due to the gravity load. The cross-ply laminate gradually became flat with time. However the specimen didn't come to be completely flat, and warped in *x* direction. This behavior is same as the asymmetric strip [6]. The initial geometry of asymmetric stripe is warped due to the thermal shrinkage of 90° layers. But after 90° layers expanded by moisture absorption, the geometry come to be flat. In this experiments, the cross-ply laminate behave same as asymmetric strip. These results imply that the specimen might not symmetric nevertheless that the stacking sequence is symmetric. The fiber misalignment or deviation of fiber location might affect the geometrical change. These factors must be discussed by FEA analysis considering these factors. Beside, the maximum displacement arose at the corner of the specimens. It indicates that the fiber must be oriented to 45° direction to geometrical change of the laminates.




(a) After drying

(b) After 1 hour

(c) After 41.5 hours

Fig. 3 Geometrical change of cross-ply laminates exposed at 80°C 90%RH

### 3.2 Deformation at vacuumed condition

Fig. 4. shows the geometrical change of cross-ply laminate at vacuumed condition. All corner drooped down. It was not due to the gravity traction. Specimens didn't deformed dramatically compared to the result of Fig. 4. It indicates that the moisture absorption is the most influential against dimension instability. Other factors such as the residual stress relief and self-shrinkage by physical aging have smaller effect on dimensional instability compared to swelling by moisture absorption at 80°C.

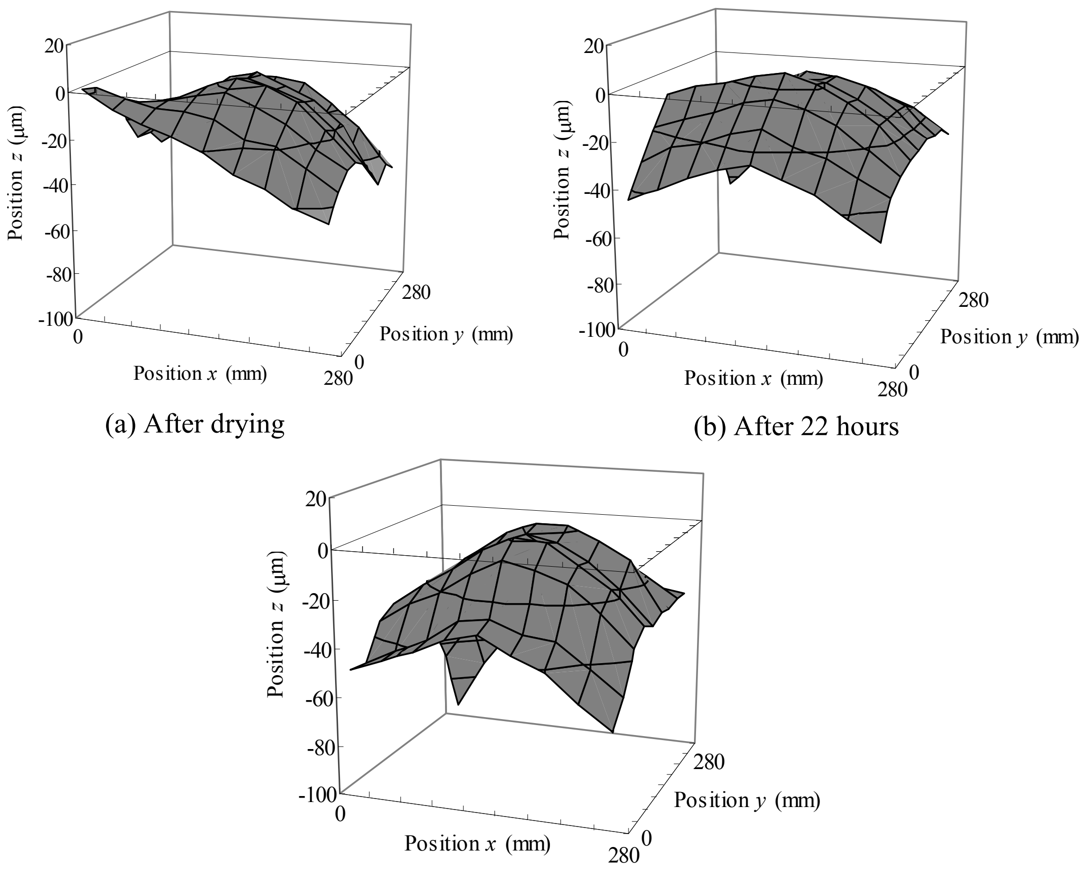
The reason that the all corner drooped down might be due to the deviation of fiber location. The density of fiber is different from that of epoxy. So the deviation of fiber location could be exist in cross-ply laminate. As next topic, we investigate the deviation of fiber in thickness direction by observation of cross section.

### 3.3 Deviation of fiber distribution

We measured deviation of fiber location by optical microscopic. As shown in Fig. 3, we separated the middle layer ($90°_2$) to 3 regions in the thickness direction, and measured local fiber volume fraction for each region. Each region included at least 200 fibers. The following equation was adopted to obtain the local fiber volume fraction,

$$V_f = \frac{2\pi r_a^2 n}{A} \qquad (2)$$

where $A$ is the area of each region, $r_a$ is the average fiber radius, and $n$ is the number of fibers in each region. We conducted this procedure for 5 cross-sections. Fig. 6 shows the local fiber volume fraction against the distance from the top of 90° layer (upper side of laminate shown in Fig. 4). The thickness of middle layer is 0.5 mm. The data includes some scattering, but for all cross-sections, the region located at 0.5mm from the top of 90° layer exhibited the highest fiber volume fractions of the 4 regions The 3% of $V_f$ deviation were observed The inclination of the local fiber volume fraction might occur while curing because the relative density of carbon fiber is greater than that of the polymer. The relationship between the results of Fig. 4 and deviation of fiber must be solved by FEM considering the deviation of fiber.




(a) After drying

(b) After 22 hours

(c) After 265 hours

Fig. 4. Geometrical change of cross-ply laminate at vacuumed condition

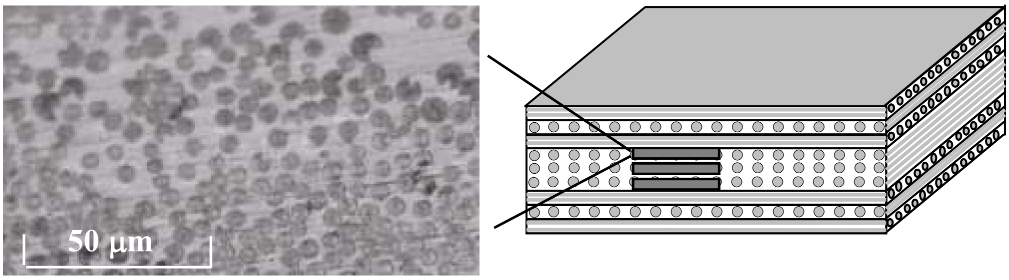



Fig. 5. Evaluation method of the deviation of fiber volume fraction in thickness direction

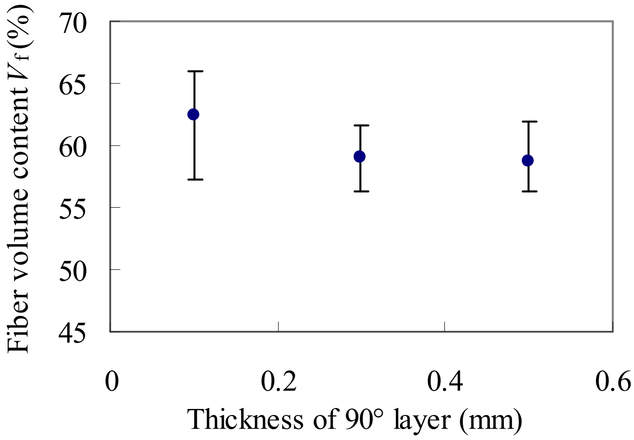



Fig. 6. Deviation of fiber volume fraction in thickness direction

## CONCLUSIONS

Geometrical changes of symmetric cross-ply CFRP laminates were investigated at various environments. Cross-ply laminates changed their shape at 80°C 90%RH, and the maximum displacement in thickness direction from initial shape was 500μm. Besides, the geometry of the laminates did not change at vacuumed condition. It is presumed that the fiber misalignment and deviation of fibers cause geometrical change with moisture absorption despite of symmetric lay-up. About 3% of fiber deviation was confirmed by the observation of cross section. From above results, it is expected that the cross-ply laminates inhere the asymmetricity in a narrow sense, and cause geometrical change by moisture absorption.

## ACKNOWLEDGEMENTS

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