Micro Deformation Measurement System Construction For Highly Dimensional Stable Composite due to Out-gassing in Space

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ABSTRACT: Since 1960′s, satellite telescopes have been used to obtain high resolution image of ground. Resolution of the telescope heavily depends on size and dimensional stability of the telescope structure in operation condition in terms of temperature variance and vacuum condition. Relative position change of optical components in the telescope causes de-focus phenomena and degrades quality of image. Recently, CFRP (Carbon Fiber Reinforced Plastics) which shows thermally and mechanically stable characteristics has been employed for the telescope structure. However, especially in vacuum condition, macromolecule matrix in the CFRP releases gases and induces shrinkage which can degrade performance of diffraction limited optical systems. To verify dimensional stability performance of the CFRP space telescope structure, out-gassing deformation measurement system is needed. However, long time of out-gassing process (~3weeks) and small amount of deformation (~2με) of the CFRP make it hard to measure the deformation due to out-gassing.

In this research, we construct micro deformation measurement system which includes vacuum chamber, PID temperature controller, and precise deformation measurement system. The vacuum chamber and the PID temperature controller give simulated space environment about 10^{-5} torr vacuum state and 0~115℃ temperature variance. The precise deformation measurement system using optical scale sensor is mechanical invar dilatometer that minimizes thermal expansion disturbance. Precision of the dilatometer is verified by comparison with thermal expansion measurement using interferometer from 1 to 300μm range. Long term stability of the whole measurement system is verified by measuring deformation of steel in constant temperature environment for 5 days which does not shrink in vacuum condition.

We measured micro deformation of several composite specimens such as M55J unidirectional composite preserved in 760 torr and RH 59% environment for 3 weeks. As a result, the M55J specimens shrink 2.71με and 77.22με for each longitudinal and transverse direction from the preserved condition to vacuum condition.

Keywords: *Composite telescope structure, Out-gassing deformation, Precise Measurement, Mechanical dilatometer, Dimensional stability*

1. Introduction

An optical structure in space needs to maintain its dimension to keep its optical components alignment, performance of which is very sensitive to its alignment status. Composite materials are widely used for large space optical structures due to the lightweight and low thermal expansion characteristics [1]. However, composite structure is shrunk by out-gassing of macromolecule in the composite due to space vacuum condition. As previously concerned, deformation of composite is important for optical performance and out-gassing shrinkage of the composite should be evaluated.

In this paper, mechanical dilatometer is designed to measure out-gassing shrinkage of composite structure in simulated space environment. Long term stability and precision of the dilatometer are verified and the measurement process is established. Finally the minute dimensional change of unidirectional M55J lamina specimens due to out-gassing is measured.

2. Measurement system design

In order to measure out-gassing shrinkage of composite, precise mechanical dilatometer, using optical scale sensor, is designed. Out-gassing process takes about two or three weeks for full saturation [2] and requires long-term stability of the measurement system during this period. Optical scale sensor is appropriate option for long term measurement [3] and the design of the proposed dilatometer is shown in Figure 1.

Two flexible beams in dilatometer follow deformation of the composite which we want to measure. Amount of displacement for optical scale sensor is given by difference between the scale and reader. Initial displacement and narrow slot are given to keep specimen attachment. Whole dilatometer structure is made of invar to prevent thermal expansion error during the measurement. Moreover, kinematic coupling is used to isolate dilatometer from bottom plate.

Vacuum chamber system, containing dilatometer and specimen during measurement, is developed in the author's previous work [4]. High vacuum (10^{-5} torr) condition is maintained inside the chamber, and temperature variation is controlled (28±1℃) so that the thermal expansion of the composite is prevented.

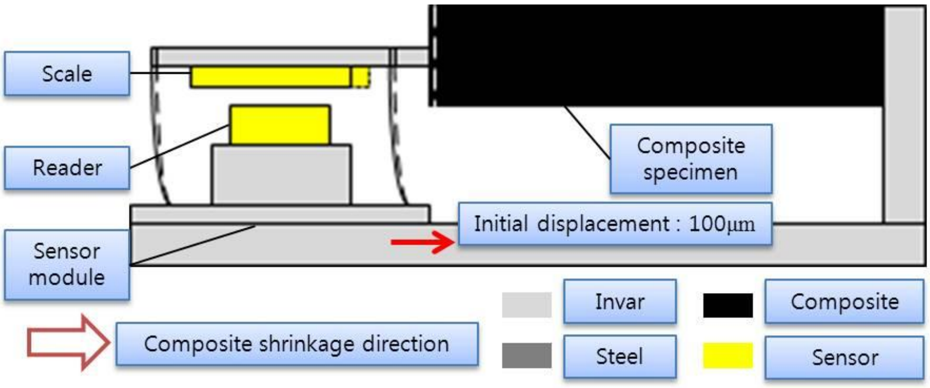

Figure 1 Schematic of initial mechanical dilatometer design

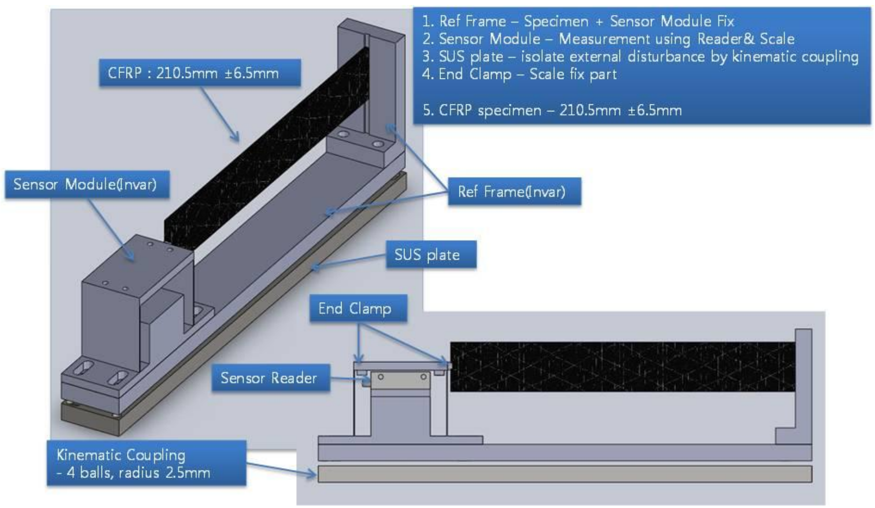

Figure 2 Complete design of the dilatometer

3. Verification of the system

Most important requirements of the measurement system are the precision and the long term stability. The system should measure displacement from less than 0.5 to 100 μm range for at least three weeks. Precision of the system is verified by interferometer used for precise thermal expansion measurement system [4]. Both the dilatometer and interferometer measures thermal expansion of steel as shown in Figure 3. From this experiment, measurement value of the two systems should be same. If there is a difference between values of these two systems, it means that dilatometer cannot measure deformation of specimen precisely. Thermal expansion of the steel is from 0 to 200μm range which is more than two times of expected maximum displacement. In that range, as shown in Figure 4, the measurement system shows good agreement with the interferometer.

Long term stability of the system is proved by the measurement of non-deformed specimen. Stainless steel does not deform in vacuum condition due to out-gassing. Therefore, if system measure out-gassing deformation of the stainless steel in vacuum condition, measured value of the system should be zero. If system shows tendency of decreasing or increasing of measurement value, the system cannot be used for long term measurement. The measurement system, including vacuum chamber, temperature controller, and mechanical dilatometer, measures stainless steel for 35 hour by same procedure of composite specimens. As a result in Figure 3, we can see that measurement value of the system is stabilized in zero.

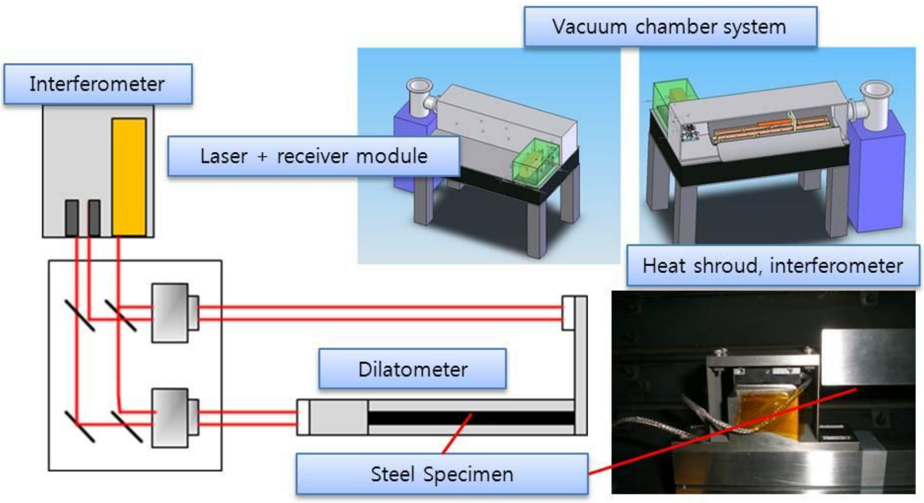

Figure 3 Schematic of verification experiment

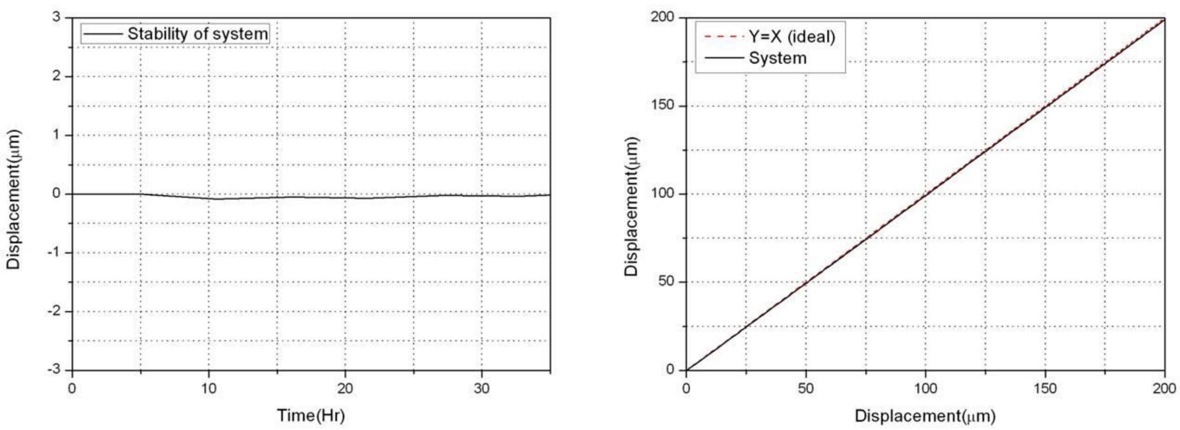

Figure 4 Verification test result

4. Measurement result

Two kinds of composite specimens, longitudinal and transverse fiber direction of M55J/Cyanate lamina, are measured by the measurement system. Two specimens are measured for each kind of the laminas and the average value is presented. Specimens are preserved in 760 torr (RH 59%) more than three weeks for full saturation before measurement begin. During the measurement, vacuum chamber, containing specimen and dilatometer, keeps 10^{-5} torr for simulated space vacuum condition.

Fig. 5 shows full deformation histories of two types of specimens around two weeks. The longitudinal specimen deforms -2.71με, and the transverse one shows much larger deformation as much as -77.22με in given vacuum condition.

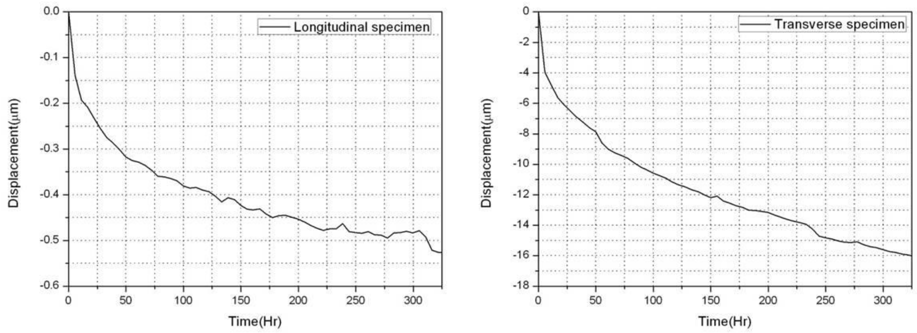

Figure 5 measurement result of out-gassing deformation (left: longitudinal, right: transverse)

5. Conclusion

In this paper, a mechanical dilatometer, using a long-term stable optical scale sensor, is designed to measure out-gassing deformation of composites. The precision of the dilatometer is verified by an interferometer and the long term stability of measurement system is proved by measurement of non-out-gassing material, stainless steel. The proposed dilatometer provides very well agreed results with the interferometer and shows stability for long time measurement. The out-gassing deformation in longitudinal and transverse directions of composite specimens is measured by the dilatometer. The specimen shrinks -2.71με and -77.22με in longitudinal and transverse directions in two weeks in 10^{-5} torr vacuum condition.

6. Acknowledgement

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7. Reference

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