International Journal on Smart Material and Mechatronics
IJSMM Vol. 2 No. 2 2015

p-ISSN: 2356-5314
e-ISSN: 2460-075X

Effects of Stress Concentration on the Mechanical Properties of Carbon Fiber Reinforced Plastic

Ryo Naito[1)], Mitsuhiro Okayasu[1)] and Daisuke Fukuyama[2)]
[1)]Graduate school of Natural Science & Technology, Okayama University
3-1-1 Tsushima-naka, Kita-ku, Okayama, 700-8530, Japan
[2)]Graduate school of Materials Science & Engineering, Ehime University
3 Bunkyo-cho, Matsuyama, Ehime, 790-8577, Japan
p6w80e3h@s.okayama-u.ac.jp , okayasu@okayama-u.ac.jp

Received: 15 September 2015 / Revised: 10 October 2015 / Accepted: 26 October 2015 / Published online: 10 January 2016

***Abstract*— Mechanical properties of conventional CFRP plates with small holes were investigated systematically. Those artificial holes are considered to be rivet connection between CFRP and other materials. The machining holes were employed with different number (*n*=0-5) and different mode, e.g., parallel (Sample A), 45 degree (Sample B) and perpendicular (Sample C) against the loading direction. To understand the mechanical properties of the CFRP plates clearly, tensile tests and failure analysis were conducted experimentally. Excellent mechanical properties were obtained for Sample A, compared to the other ones. This is due to the different size of the cross-section area in the specimen. With increasing the number of rivet hole, the mechanical properties were lineally decreasing. Such mechanical properties were analyzed by direct observation using a high speed camera, i.e., in-situ measurement of deformation during the tensile loading was carried.**

***Index Terms*—CFRP plates, mechanical properties, failure characteristics.**

I. INTRODUCTION

In recent years, CFRP has been used widely in aerospace industries. This is due to the weight reduction and improvement of the controllability of the flight.

In fact, CFRP has received special attention, because of its excellent material properties, e.g. light weight and high strength. The specific weight of CFRP is approximately 1.8, which is about 60% less than that for the other light metals e.g., titanium.

Recently, CFRP has also been tried to employ for various automotive parts. Even though CFRP has excellent material properties, there are technical limitations due to its poor connectability. At the moment, rivet connecting method has been employed. As a number of rivet holes are machined directly to the CFRP plates, their mechanical properties could be reduced. To use CFRP for automobile industries, a reliability assessment for CFRP would be indispensable. Thus, the aim of this work was to examine the influence of the rivet holes on the mechanical properties, where the rivet holes were made by various patterns.

II. EXPERIMENTAL PROCEDURE

A. Material preparation

In the present study, the commercial CFRP (60% epoxy) plates made by Nippon Steel and Sumikin Materials co., Ltd were used. To investigate the mechanical properties, rectangular shape specimen (62×10×1.0mm) with and without holes were machined by water jet technology. The specimens were made by different pattern with changing the holes number (*n*) and holes position (Sample A, B and C): *n*=0~5, A (parallel), B (45 degree) and C (perpendicular to the loading direction). The detailed specimen information is schematic illustration of Fig. 1.

B. Experimental

To better understand the mechanical properties of the CFRP tensile and fatigue tests were conducted experimentally. Because it is difficult to make chucking CFRP for the testing machine, aluminum plates were attached on the both CFRP specimen, see Fig. 1. In the tensile test, the applied load was statically executed at 1mm/min to final failure. The stress and strain values were examined by a commercial load cell and strain gauges, respectively. In the fatigue test, cyclic loading was applied to the samples at 1Hz and *R*=0.1 until the specimen is fractures or 10^6 cycles, i.e., endurance limit. After the mechanical testing, failure analysis was made by direct observation, where the fracture surface was observed by SEM (Scanning Electron Microscope).

Furthermore, in-situ failure observation was carried out using a high speed camera, where 3D image of strain on the specimen doing the tensile tests was examined. To obtain mechanical properties, finite element analysis was conducted using ANSYS ver. 13.

p-ISSN: 2356-5314
e-ISSN: 2460-075X

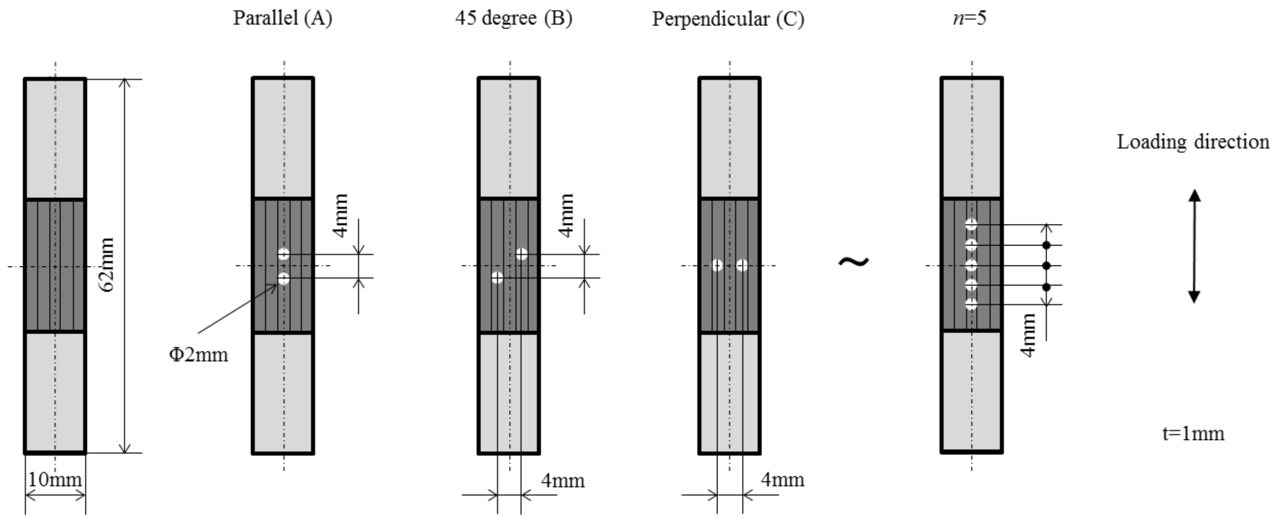

Fig. 1 Schematic illustration of the CFRP specimens

III. Results

A. Tensile test results

Fig. 2 shows representatine stress-strain curves for Sample A, B and C. As seen almost linear stress vs. strain can be detected for the three samples, so those were fractued without plastic deformation. It is also clear that different tensile strength and different elastic constant can be observed, in which the ultimate tensile strength for Sample A is about 1100MPa, which is about 40% higher than that for Samples B and C. On the other hand, no clear difference in the fracture strain is obtained. In the case, the different UTS is simply considered to be caused by the different area fraction of the machning hole on the fracture surface.

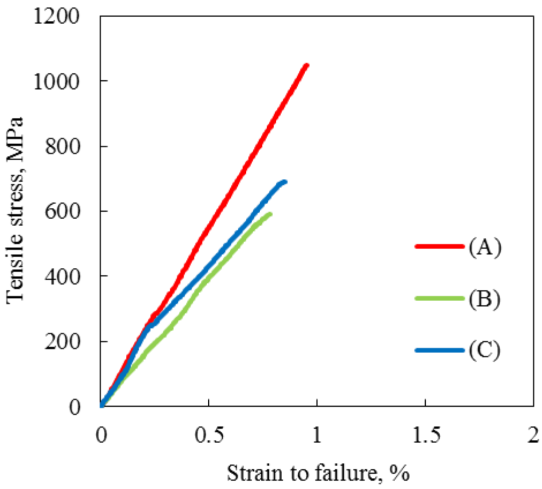

Fig. 2 Tensile stress vs. tensile strain curves of Sample A, B and C

The tensile properties of the CFRP were further examined using the specimens with the different hole number (*n*=0-5). Fig. 3 displays their stress-strain curves and Fig. 4 presents the results of the UTS value. For the samples with holes (*n*=2-5), the tensile strength drops instantly to about 1000MPa, which is less than half of that for *n*=0. It is interest that for the samples with *n*=2-5, UTS is almost same lined. To better understand the failure analysis of the CFRP fracture surface observation after the tensile tests were carried out, see Fig. 5. From the SEM observation, similar fracture mode could be observed for all specimens: shear fracture and delamination of fibers.

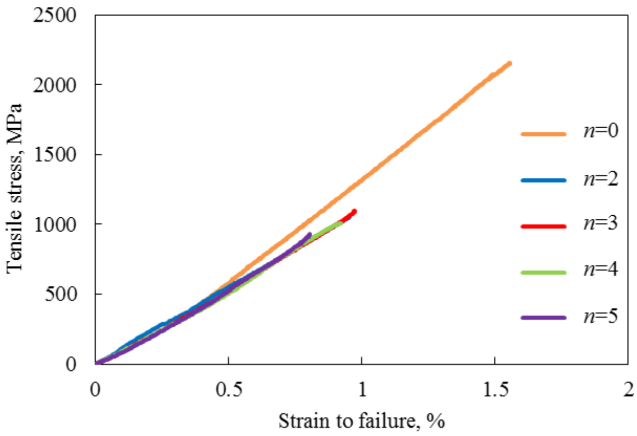

Fig. 3 Tensile stress vs. tensile strain curves for the samples with (*n*=0-5) and without hole

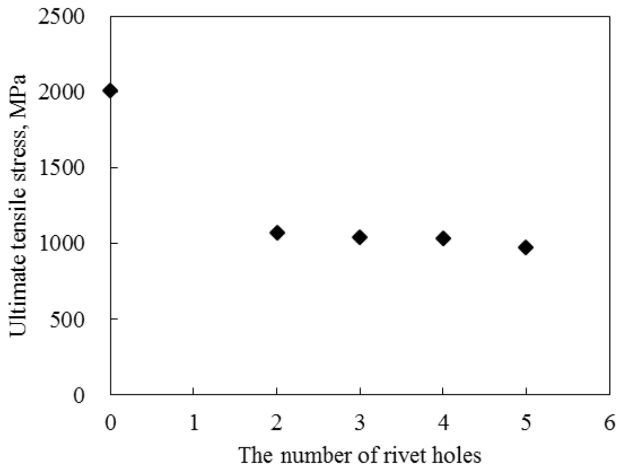

Fig. 4 Relations of the quantity of holes and the maximum tensile stress

p-ISSN: 2356-5314
e-ISSN: 2460-075X

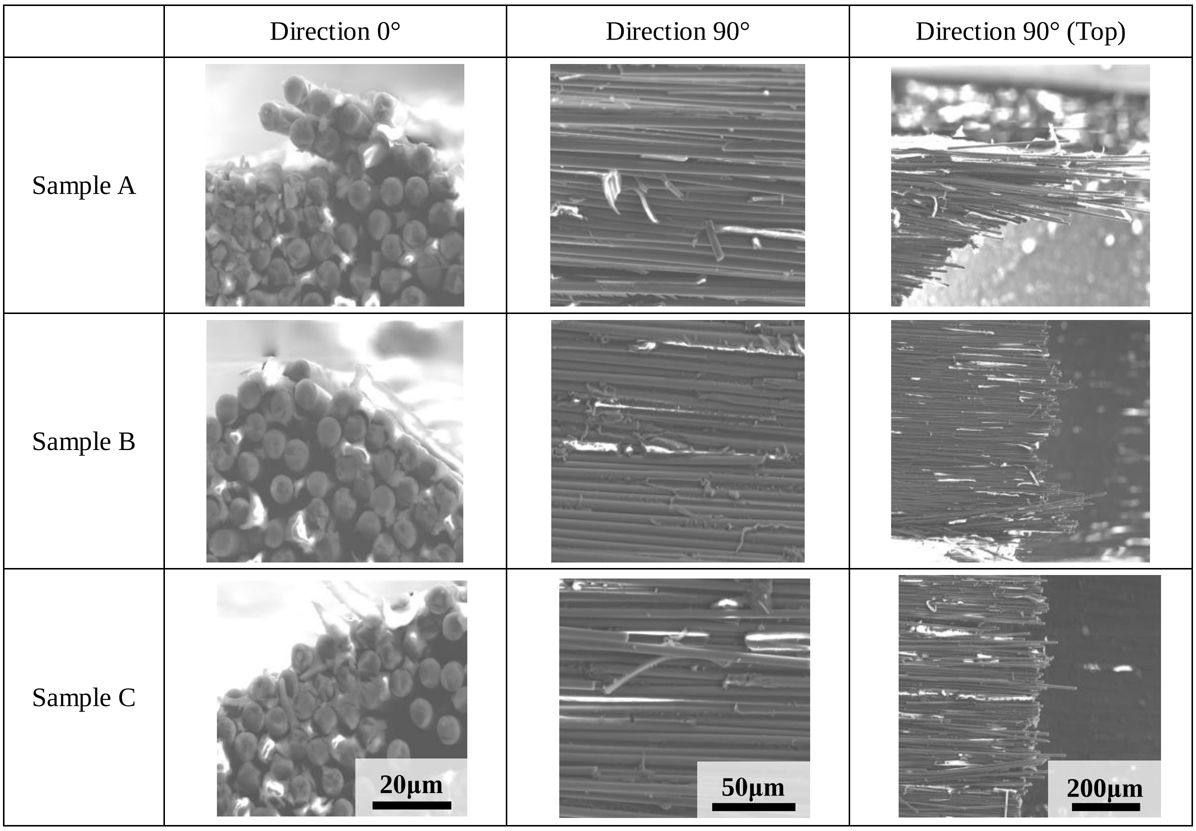

Fig. 5 SEM images of the fracture surfaces for Samples A, B and C after the tensile test

B. Strain analysis

Strain distribution was analyzed by a high speed camera for Samples A, B and C, see Fig. 6. From this analysis, it is clear that crack growth and shear fracture occur from the side of the holes for all samples before the final fracture because of the high stress concentration, in which high strain value of more than 1.0 is seen. Because of the high strain distribution (2-hole) in the wide area for Samples B and C, their tensile strengths could be lower than that for Sample A.

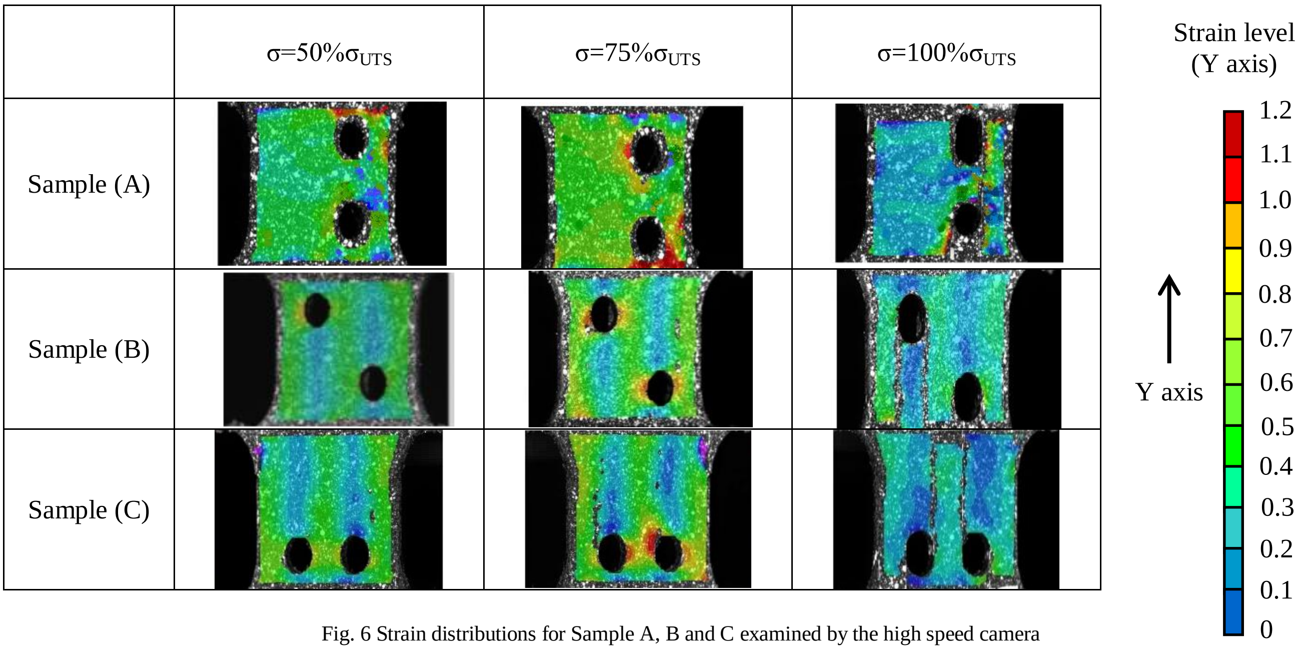

Fig. 6 Strain distributions for Sample A, B and C examined by the high speed camera

p-ISSN: 2356-5314
e-ISSN: 2460-075X

IV. Conclusions

1) Tensile strength and elastic constant of the CFRP are different depending on the rivet hole mode. The ultimate tensile strength and elastic constant for Sample A are apparently higher than those for Samples B and C. This is caused by the different area of the cross-section in the sample. On the other hand, no clear difference in the fracture strain is obtained, as the CFPR has originally brittle characteristics.

2) For the samples with holes (n=2-5), the tensile strength decreases rapidly to about 1000MPa, compared to that without hole. However, no clear difference in the tensile properties for CFRP with n=2-5.

3) In-situ strain measurement using the high speed camera is conducted, and it appears that the crack growth and shear failure occurs from the holes due to the high stress concentration during the loading process just before the final fracture.

References

[1] P. T. Curtis, The effect of edge stresses on the failure of (0°, 45°, 90°) CFRP laminates, Journal of materials science 19 (1984) 167-182.

[2] S. F. Brena, G. N. Mcguirk, Advances on the behavior characterization of FRP-anchored carbon fiber-reinforced polymer (CFRP) sheets used to strength concrete elements, Journal of Concreate Structures and Materials 7 (2013) 3-16.

[3] N. Balhi, N. Vrellos, F. J. Guild, Intra-laminar cracking in CFRP laminates: observations and modelling, Journal of materials science 41 (2006) 6599-6609.