Effect of Fiber Waviness on Compressive Properties of Quasi-Unidirectional Woven Fabric Composite Laminates

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論 文 名　：Effect of Fiber Waviness on Compressive Properties of Quasi-Unidirectional Woven Fabric Composite Laminates
（擬似一方向織物複合材積層板の圧縮特性に及ぼす繊維うねりの影響）

区　　分　：甲

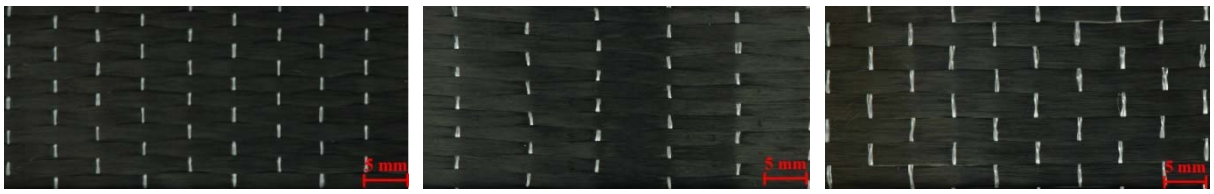
論　文　内　容　の　要　旨

Quasi-unidirectional (UD) woven fabrics are one type of woven carbon fabrics with unbalanced textile, which are woven with around 98% warp tows and a few weft yarns. The warp tows provide a loading capability after consolidation and the weft yarns make the fabric integrity for a good drapability. However, fiber misalignment in the quasi-UD woven fabrics is a kind of defects, which causes significant reductions in compressive mechanical properties of the CFRPs.

This study presents an investigation of the compressive failure mechanisms of the quasi-UD woven fabric composites due to fiber waviness. Three kinds of the quasi-UD woven fabrics, Standard pitch fabrics (SP), Long pitch fabrics (LP) and Thin pitch fabrics (TP), were selected for this research. Based on a measurement for in-plane fiber waviness and an evaluation for out-of-plane fiber waviness, the three fabrics are divided into two groups, the SP and LP are used for the study of effect of out-of-plane fiber waviness and the SP and TP are done for the study of effect of in-plane fiber waviness, respectively. Afterward, compressive tests were performed and the experimental results showed the negative effect of out-of-plane and in-plane fiber waviness on the compressive properties. Finally, finite element method (FEM) was implemented to account for failure mechanisms of the quasi-UD woven fabric composite as well. The results show the fiber waviness has a greater effect on compressive strength than that on the compressive modulus, and this research will benefit designing in architecture of the quasi-UD woven fabrics.

This dissertation consists of the following eight chapters.

Chapter 1: The previous researches on the fiber misalignment and fiber waviness and the motivation of the present study are introduced.



(a)　　(b)　　(c)

Fig. 1 Quasi-UD woven fabrics: (a) standard pitch fabric, (b) long pitch fabric and (c) thin pitch fabric

Chapter 2: Three kinds of the quasi-UD woven fabrics, Standard pitch fabrics (SP), Long pitch fabrics (LP) and Thin pitch fabrics (TP) in our laboratory were used for this research (Fig. 1), and the inspections of

in-plane fiber waviness were performed on these three fabrics. The inspections show that the SP fabric and TP fabric have the same wavelength but the LP fabric has longer wavelength than the SP and TP fabric, and it is because the SP fabric and TP fabric have the same pitch intervals in the warp direction but the LP fabric's pitch intervals is longer than the SP and TP fabrics'.

Chapter 3: Vacuum assisted resin transfer molding (VaRTM) process was introduced and three composite laminates (one from each fabric) were fabricated via VaRTM process. The ultrasonic testing was conducted after the VaRTM process to detect the quality of the composite laminates. The scanning results gave the useful area to fabricate the specimens for compression tests.

Chapter 4: A three-step method based on an FFT was performed to obtain the characteristics of the out-of-plane fiber waviness in the laminate SP, LP and TP. The results show that the out-of-plane wave amplitude in these three laminates are close to 0.015 mm because the weft yarns in the SP, LP and TP fabrics are all ECD450 1/2 4.4S weft yarns of glass fiber. It should be noticed that both the characteristic wavelength and the amplitude depend on the architectures of the quasi-UD woven fabrics, fiber volume fraction associated with the thickness and the stacking sequence of the laminates.

Chapter 5: Three standard test methods for compressive properties were compared firstly, and a modified CLC test fixture was used in our laboratory. In the modified CLC test fixture, using double-sided tape, paper face of sand paper (80 grit) is then affixed to the block and abrasive material glued face of the sand paper contacts with the specimen; thus the specimen undergoes shear loading owing to the clamping force exerted by eight screws of the fixture. This test method prevents premature failure of the specimen at the grips as well as ASTM D6641 and the cost of the sand paper is lower than recoating tungsten carbide particles on the gripping surfaces of the CLC fixture. Moreover, the modified CLC test fixture is able to be repaired more easily than the standard CLC test fixture.

Chapter 6: The effect of out-of-plane fiber waviness on the compressive strength of quasi-isotropic composite laminates was investigated in this chapter. Two kinds of out-of-plane fiber waviness in laminate SP and LP were analyzed. The effect of out-of-plane fiber waviness on the compressive strength was identified using experimental, theoretical, and numerical methods. It was found that the compressive strength of a composite laminate fabricated using LP fabric is greater than that fabricated using SP fabrics. The relationship between the compressive strength and fiber waviness configuration was investigated in a parametrical study, and four compressive failure modes were found: the axial compressive, normal, bending, and shear failure modes.

Chapter 7: Experimental and theoretical analyses were carried out to investigate the effect of in-plane fiber waviness on compressive strength of the quasi- UD woven fabric composite in this chapter. SP and TP fabrics were used for this study. The experiments show that the compressive strength of the quasi-UD woven fabric composite decreases with in-plane fiber waviness increasing. Furthermore, a two-dimensional model was proposed so as to explain our experimental results. The numerical results indicate that the tensile stress along the weft direction of the composite caused by the in-plane fiber waviness and compressive stress along the warp direction diminish the compressive strengths.

Chapter 8: The main research results of the dissertation were summarized in this chapter.