COMPARISON OF SHEARING TEST METHODS FOR PULTRUDED MATERIALS

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ABSTRACT

This paper compares several different test methods for obtaining the shearing modulus and strength of pultruded materials. They are (a) 45°tension test, (b) Iosipescu test, (c) asymmetric four-point bending test (AFPB), (d) Johnson-type test, and (e) double-notch shear test (DNS). Two types of pultruded materials were evaluated and it was found that the choice of an appropriate test method depends on the material type.

1. INTRODUCTION

It is well-known that FRPs are superior to metals for lightweight and corrosion resistance. Among various FRPs, pultruded FRPs have several advantageous characteristics such as flexible cross sectional shape and manufacture length, uniformity of strength, and extremely precise size. For years, pultruded FRPs have been used in civil infrastructures. Because the reinforcement fibers of pultruded FRPs are primarily arrayed in the longitudinal direction, the transverse properties or shearing properties may be inferior and this is a major issue to be overcome for pultruded materials, especially for large scale structural components. In the present study, as a basis of the above subject, we tried to measure the shearing modulus and strength of two kinds of pultruded materials by five test methods. The advantages and disadvantages of each test method will be discussed.

2. MATERIALS

As was described in Introduction, pultruded materials generally exhibit extreme anisotropy which may results in inferior properties in the transverse direction. Recently, knitted fabrics are gaining attention as a promising candidate for pultrusion processing [1-2]. Figure 1 shows a typical knitted fabric along with a conventional unidirectional roving cloths. The advantageous properties of the knitted fabrics are well described in Ref.[1] and a comparison between knitted fabrics and roving cloths is found in Ref.[2].

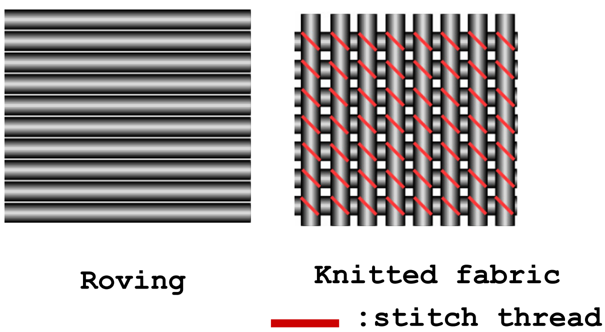


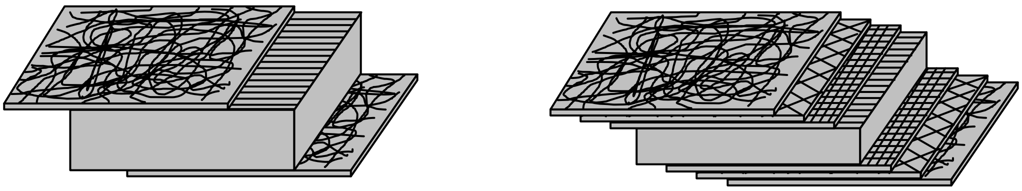
Fig.1 Knitted fabric

Two kinds of pultruded GFRPs were used in the present study, which were fabricated by Asahi Glass Matex Co., Ltd. One type GFRP (denoted as Type 1) primarily consists of unidirectional glass rovings and it has strong anisotropy. Another type of GFRP (denoted as Type 2) is made of the combination of glass rovings and knitted fabrics; the degree of anisotropy is moderate. In both cases vinylester resin was used for the matrix. Table 1 shows the details of these two materials together with the schematic view of stacking sequence. The total thickness of both specimens was the same, $t = 3.8$mm.

Table 1 Specimen configuration

Type 1			Typ 2		
Fiber	Vf(%)	thick.(mm)	Fiber	Vf(%)	thick.(mm)
CSM #450	25	0.47	CSM #300	25	0.47
Roving	50	2.96	Knit (±45) #600	50	0.47
CSM #450	25	0.47	Knit (0,90) #800	50	0.62
			Roving	50	0.66
			Knit (0,90) #800	50	0.62
			Knit (±45) #600	50	0.47
			CSM #300	25	0.47

CSM: Continuous Strand Mat
Knit: Knitted fabric



3. TEST METHODS

In the present study, five kinds of test methods were tried. They are (a) 45° tension test [3], (b) Iosipescu test [4], (c) asymmetric four-point bending test (AFPB), (d) Johnson-type test [5], and (e) double-notch shear test (DNS). Although a so-called rail shear test [6] might be popular, we did not try this test due to the limitation of the specimen size and test fixtures.

(a) 45°tension test

This is one of the most popular methods for obtaining the shear properties of fiber reinforced composites. By applying a tensile load to a coupon which is cut in the 45° direction from the fiber direction, the shearing stress as well as the shearing strain along the fibers can be calculated as

$$\tau_{12} = \frac{\sigma_x}{2}, \qquad \gamma_{12} = |\varepsilon_x| + |\varepsilon_y|$$

where σ_x is the applied stress (the tensile load divided by the cross sectional area), τ_{12} and γ_{12} are the shearing stress and strain along the fiber direction and the subscripts x and y denote the longitudinal and the transverse direction, respectively. By measuring σ_x at failure, we can calculate the shearing strength.

(b) Iosipescu test

Figure 2 illustrates the Wyoming type test fixture for the Iosipescu test. In this case, the shearing strength is calculated by

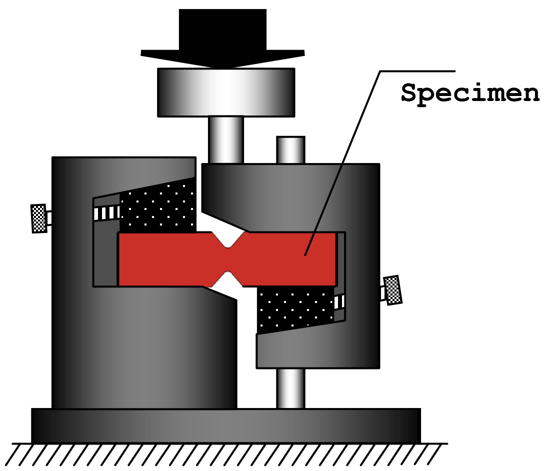


Fig.2 Iosipescu test fixture

$$\tau_{\max} = \frac{P_{\max}}{wt}$$

where $P_{\max}$ is the applied load at failure, t and w are the specimen thickness and the specimen width between notch roots, respectively. If we attach a pair of strain gages in the $\pm 45°$ direction between the notch roots, the shearing strain can be obtained and hence, the shearing modulus can be also calculated.

(c) Asymmetric four-point bending test (AFPB)

Figure 3 is a schematic view of test he idea of which is similar to the Iosipescu method. For this test, only a set of 4-point bending jig is necessary to prepare. The shearing strength can be calculated by

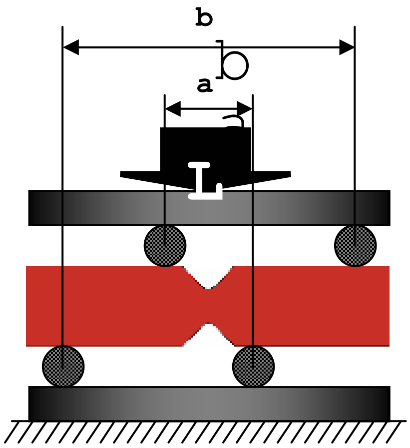


Fig.3 AFPB test

$$\tau_{\max} = \alpha \frac{P_{\max}}{wt}$$

where α is a function of a and b in Fig.3, which can be easily obtained by the simple beam theory.

(d) Johnson-type test

The Japanese Industrial Standard (JIS) [5] designates this test method for measuring the out-of-plane shearing strength and we applied this method to the in-plane shearing strength just by rotating the specimen. Figure 4 is a schematic view of the test fixture. The average shearing strength can be calculated by

Fig.4 Johnson-type shear test

$$\tau_{\max} = \frac{P_{\max}}{2th}$$

where t is the specimen thickness and h is the specimen height (width). In the test, parametric study was conducted by varying the clearance, C, the specimen height, h, and the corner radius of the indentor, R.

(e) Double-notch shear test (DNS)

A double-notch shear test is sometimes used to evaluate the interlaminar shearing strength. We applied this method for measuring the in-plane shearing strength. Figure 5 shows the test fixture and the specimen is shown in Fig.6. This fixture is essentially the same as the simplified compression test method of JIS [7]. The shearing strength is

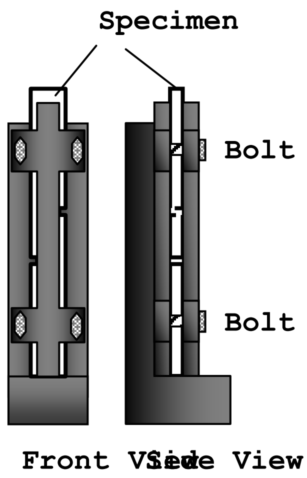


Fig.5 Double-notch shear test fixture

$$\tau_{max} = \frac{P_{max}}{lt}$$

where l is the distance between the two notches and t is the specimen thickness. The notch was made by a diamond disc cutter so that the notch tip comes to the center line of the specimen width. The notch distance was either $l = 5\text{mm}$ or $l = 10\text{mm}$. We prepared two different sizes of specimens. One is a "small specimen" of height (length) $h = 78\text{mm}$, width $b = 14\text{mm}$ and the other is a "large specimen" of $h = 118\text{mm}$, $b = 25\text{mm}$.

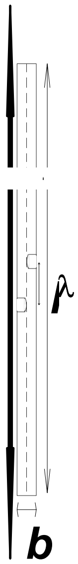


Fig.6 Double-notch shear specimen

Table 2 Summary of test results

	Type 1		Type 2	
Test method	Shear strength (MPa)	Shear modulus (GPa)	Shear strength (MPa)	Shear modulus (GPa)
45 tensile	30.8 [7.9]	3.5 [3.8]	72.9 [2.7]	5.2 [1.8]
Iosipescu	54.3 [8.4] 63 [7.0]	3.5 [2.9] 3.2 [6.5]	110.9 [1.8]	5.1 [1.6]
AFPB	36.6 55.9 [7.5]	3.0 3.5 [6.9]	75.1 112.6 [2.4]	4.6 5.0 [7.0]
Johnson type	69.2 [1.7]	-	104.8 [6.3]	-
DNS	69.3 [1.0]	-	115.6 [8.5]	-

@ without tab, with tab   [ ] : CV %

4. RESULTS AND DISCUSSION

In all the cases, a minimum of 5 specimens were tested. The test results are summarized in Table 2 and somewhat detailed discussion will follow below.

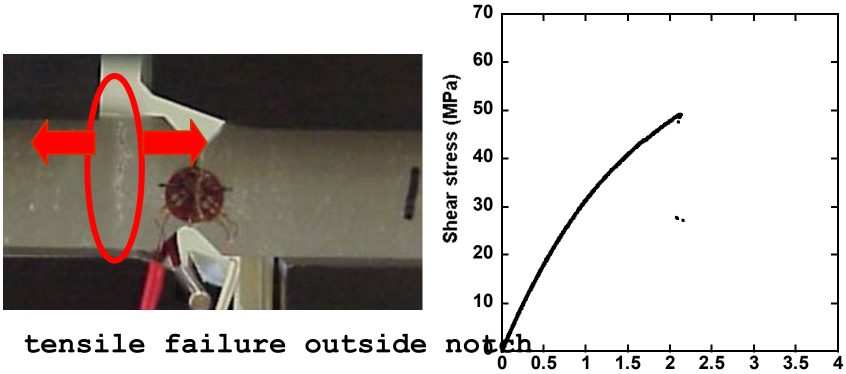
(a) 45°tensile test

Although the 45° tensile test is easy and convenient to carry out, the test results of the strength seems inferior to others. However, the shearing modulus can be obtained by this 45° tension test.

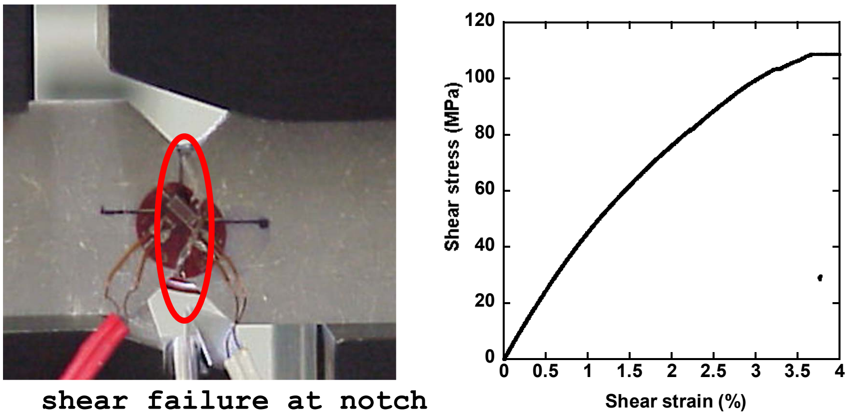
(b) Iosipescu test

Figure 7 shows a typical stress-strain curves and a failure patterns of (a) Type 1 and (b) Type 2 specimens. The Iosipescu test seems to be applicable for specimens with moderate anisotropy such as the Type 2 specimens. On the other hand, the Type 1 specimens of almost unidirectional composites did not fail at the notch area. Instead, the failure took place near the corner of the supporting jig.

To confirm the validity of the above failure pattern of the Type 1 specimens, we



(a) Type 1



shear failure at notch

(b) Type 2

Fig.7 Iosipescu test results

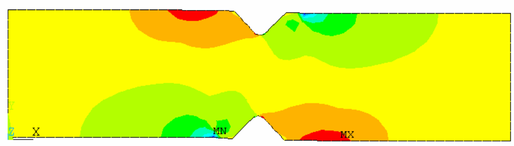


Fig.8 FEM result

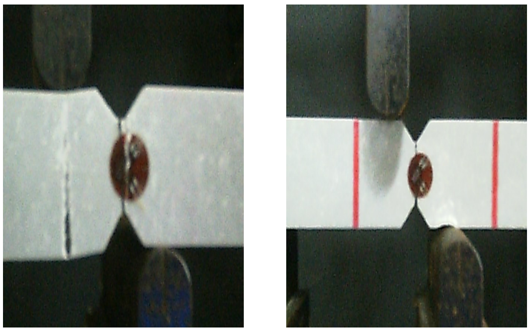
σ_x distribution (Type 1 specimen)

conducted an FEM analysis and Fig. 8 shows the normal stress distribution in the longitudinal direction for the Type 1 specimens. The maximum tensile stress is seen at the top-left and bottom-right parts, near the end of the fixture. By rough calculation, this tensile stress was found to be almost the same as the transverse tensile strength of the Type 1 material. Thus the FEM result indirectly suggests the failure mode of Type 1 specimens.

In some case, the ASTM [4] recommends to attach tabs on the surface to eliminate undesirable failure. Thus, we tried to attach tabs for the Type 1 specimens to avoid the tensile failure outside the V-notch area and the shearing strength increased from 54.3 MPa to 63 MPa, as shown in Table 2.

(c) Assymmetric four-point bending test (AFPB)

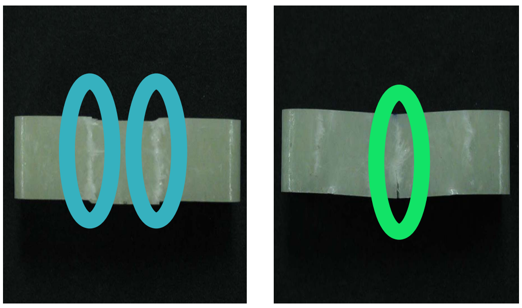
Figure 9 shows the typical failure patterns. The Type 1 specimens failed by tension at just the opposite side of the loading nose, which is similar to the case of the



(a) Type 1 specimen
tensile failure at the opposite side of the loading node

(b) Type 2 specimen
bearing failure by the loading nose

Fig.9 Failure modes at AFPB test



(a) shearing failure
(R=0.3mm, C=1mm, h=10mm)

(b) bending failure
(R=0.3mm, C=5mm, h=10mm)

Fig.10 Failure modes at Johnson-type shear test.

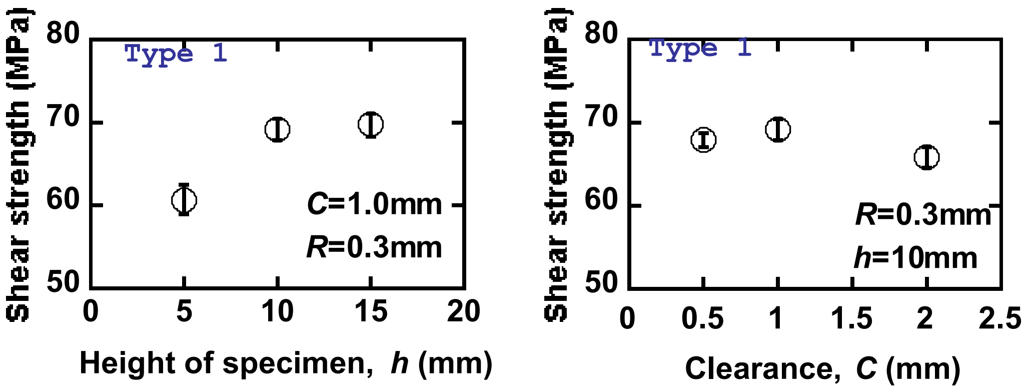
Iosipescu test. By attaching tabs, it was overcome although the result was still unsatisfactory.

The Type 2 specimens exhibited bearing failure due to the loading nose if a tab was not attached. By attaching tabs, the result became satisfactory. In summary, this test was inferior to the Iosipescu test, although it could be used as an alternative to the Iosipescu test.

(d) Johnson-type test

Various failure modes took place by this test and Fig. 10 shows two typical failure patterns. Figure 10(a) shows a patteren of what we think desirable while Fig.10(b) shows the specimen broken by bending because the clearance (see Fig.4) was too large.

Figures 11 and 12 are the Johnson-type test results. For the Type 1 specimens in Fig.11, parametric study was possible it was estimated with a high probability that the shearing strength was about 70MPa as was shown in Table 2. In the case of the Type 2 specimens in Fig.12, on the other hand, it is unlikely that shearing failure occurred



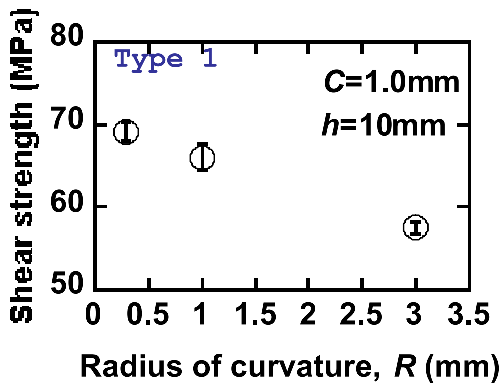


Fig.11 Shearing strength by means of Johnson-type test (Type 1).

and the data shown in Fig.12 were all we could measure.

(e) Double-notch shear test (DNS)

Figure 13 shows the failure mode of the Type 1 small specimens where the notch distance was 5mm. It

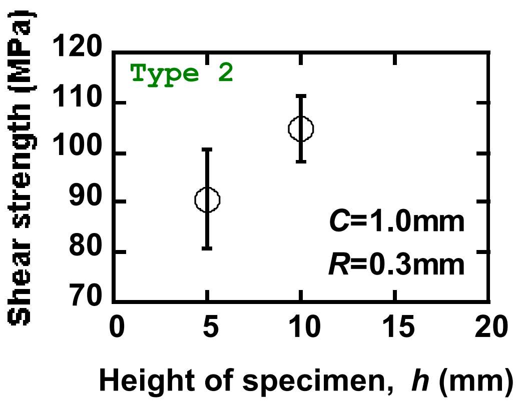


Fig.12 Shearing strength by means of Johnson-type test

exhibits clear shear failure. For the Type 1 specimens, shear failure took place for all the cases regardless of the specimen size (large or small) and the notch distance (5mm or 10mm).

For the Type 2 specimens, the DNS test was rather difficult. Figure 14(a) does not show shear failure whereas Fig.14(b) shows the shear failure. Among the combination of specimen size (large or small) and notch distance (5mm or 10mm), only large specimens with small notch distance could cause the shear failure.

It might be possible to measure the shearing strain if we glue strain gages in between the notch tips, although we have not tried it so far.

5. CONCLUSIONS

In the present paper, several test methods are tried and compared to obtain reliable shearing modulus and shearing strength. The major conclusions are drawn as follows:

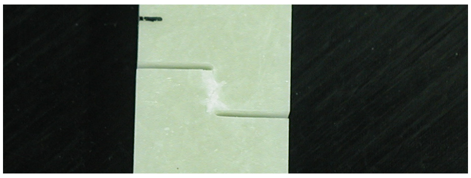
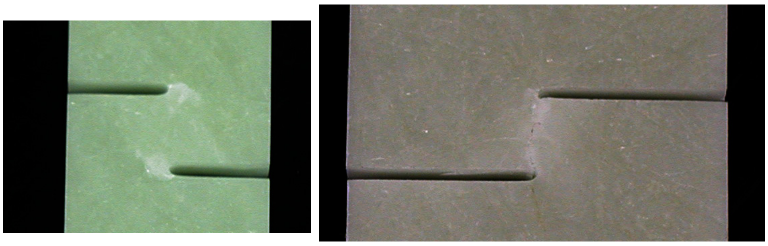


Fig.13 Failure mode of DNS test Type 1 specimen

(1) The shearing modulus can be measured by the 45 ° tensile test although this test is not suitable to obtain the shearing strength.



(a) small specimen (b) large specimen

Fig.14 Failure mode of DNS test Type 2 specimen

(2) For highly anisotropic materials such as the Type 1 specimens, the Iosipescu test is not suitable. Instead, the Johnson-type test and/or DNS test is recommended.

(3) On the other hand, for moderately anisotropic materials such as the Type 2 specimens, the Iosipescu test or its simplified version, AFPB test, can be used.

(4) It is finally concluded that appropriate test methods should be selected in accordance with the material to be tested.

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