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North American and European Flexural Testing Methods – Impact on CIPP Flexural Properties

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ABSTRACT: Since its inception, CIPP has developed from a proprietary, to a standards based technology with numerous systems available to choose from. Globalization has shaped the trenchless industry and many of the CIPP systems in use today were developed outside of North America.

The measurement of flexural properties is one of the most common QA/QC techniques to verify the satisfactory curing of a CIPP installation. North American procedures rely on measurements taken in the longitudinal direction while European procedures measure flexural properties primarily in the hoop direction. This paper examines the differences between the two methods for measuring flexural properties and illustrates the differences in actual test data taken from CIPP field samples.

1.0 INTRODUCTION

CIPP is a widely used technology for the rehabilitation of underground pipeline infrastructure. Since the early 1970's, it has evolved from a proprietary, patented technology to a standards-based commodity product produced by many different manufacturers using a variety of different resin and curing systems. The systems that are in use in North America today were developed both in North America as well as in Europe.

It's only been since the late 1990's that the the trenchless rehabilitation industry in North America first adopted, ASTM F1743 for pulled-in-place CIPP installations and then ASTM F1216 for inversion CIPP installations as standard practices. Then later in 2002, the standard EN 13566-4 was also adopted for CIPP installations in Europe.

Both the ASTM and European standards specify flexural strength and modulus as the primary mechanical properties for gravity sewer system design. However the methodolgy for deriving these flexural properties differs in many respects between the ASTM and EN standards. Short term flexural modulus and to a lesser extent flexural strength are routinely used in CIPP contracts to confirm not only material properties but also compliance with the design calculations.

Since the CIPP industry is now effectively a global supply chain, we felt that it would be useful to examine the differences between the two methods to determine how CIPP flexural properties measured by the North American methods compare with those determined by European methods.

2.0 OVERVIEW OF THE STANDARDS

Both ASTM F1216/F1743 and EN 13566-4 measure flexural properties using the three point loading test. In the case of F1216/F1743, ASTM D790 is the test method used to determine flexural strength and flexural modulus. EN 13566 uses ISO 178 as the test method along with an additional annex to EN 13566, Annex C, which describes modifications to the ISO 178 method that are specific to CIPP.

There are many differences between ASTM F1216/F1743 and EN 13566-4. These differences can be grouped into four broad categories, field sampling, test specimen, test orientation, span/test conditions.

Although ASTM D790 and ISO 178 substantially similar, there are important differences which are described below.

2.1 Field Sampling

Determining the flexural properties of a CIPP installation is a destructive process. Ideally, a sample would be removed from the actual installation in an area of the pipe that best represents the conditions of the installation. This is done occasionally but requires that the sampled area be subsequently repaired. To avoid this costly process, the accepted industry practice is to prepare a restrained sample with similar dimensions and heat sink properties in either a manhole or a termination. Once the installation is cured, the field sample is cut out and the remaining excess cured liner is trimmed flush to the existing pipe.

ASTM F1216 specifies that field samples for pipe sizes less than 18 inch should be should be cut from a restrained CIPP section removed from an intermediate manhole or a termination. The restraint used is usually a sample of PVC pipe that closely matches the inside diameter of the installation (Figure 1). For larger diameter pipes a flat plate type sample is clamped in a mold and placed in the downtube or silencer (Figure 2). Sandbags around the form are used to restrain the form and to simulate the heat sink present around the actual installation.

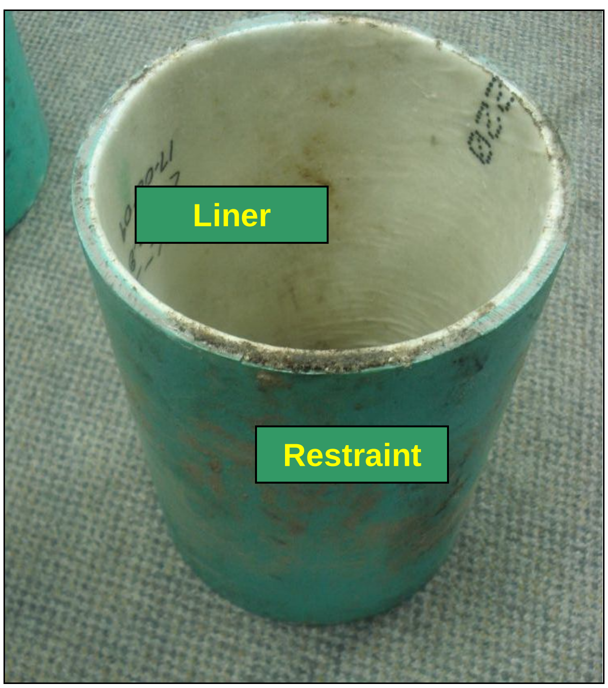

Figure 1. Typical CIPP field sample

ASTM F1743 requirements for field samples are substantially similar to ASTM F1216. Flat plate type samples are used for fiber reinforced materials in ASTM F1743 to permit testing in both the longitudinal and circumferential directions.

A pipe section restraint is also used in EN 13566 as a form to restrain field samples, but EN 13566 defines more specifiic restraint conditions than the ASTM standards. EN 13566 specifies that the form be made of clay or concrete pipe or a material with similar thermal characteristics. Additionally EN 13566 requires of the temperature within the wet sand surrounding the form to be limited to 30C maximum at a distance of 300 mm from the CIPP. All of the samples which we tested for this study using the EN 13566 method, were restrained using the typical North American practice.

2.2 Test Specimen

Both ASTM F1216/F1743 specify that flexural properties be measured in accordance with ASTM D790. The specimen described in D790 is a simple beam with a square or rectangular cross-section. Typically five full-thickness rectangular test coupons are removed from the field sample such that the coupon axis is parallel to the pipe axis (Figure 2).

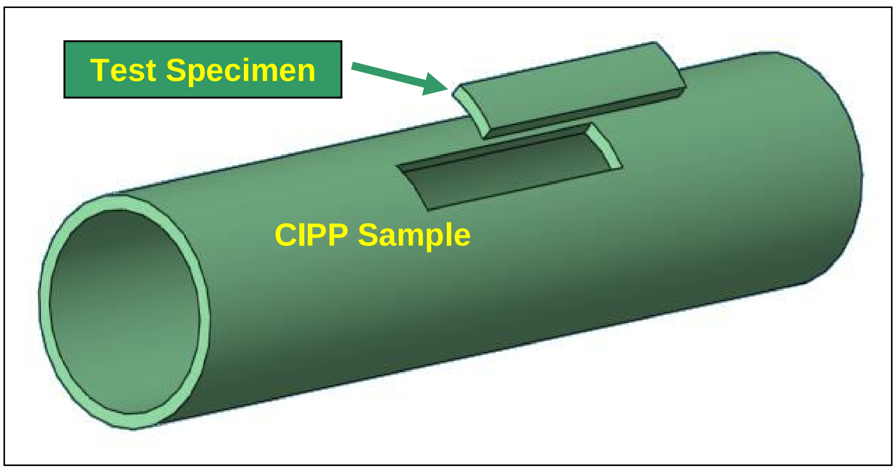

Figure 2. ASTM F1216/ ASTM D790 longitudinal test specimen orientation. The longitudinal axis of the pipe is aligned with the length of the test specimen

The dimensions of the flexural test coupon are described by ASTM D790 and depend upon the type and thickness of material that is being sampled (ie. sheet materials, laminated thermosetting materials…, molding materials and high strength reinforced composites, including highly orthotropic laminates). D790 does not explicitly recognize the CIPP form of material, so the user of the method must decide which of the four material forms in the method most closely represents the CIPP material being tested.

ASTM F1216 does not provide guidance on test specimen selection so the user is free to choose from three different specimen types defined by ASTM D790, a) full thickness with existing interior and exterior surfaces, b) rectangular section with minimum exterior and interior material removal or c) 127 mm x 12.7 x 3.2 mm specimen (Figure 3). The effect of this ambiguity was documented in an earlier No-Dig 2010 paper[1]. F1216 does not describe a method for measuring properties in the hoop direction.

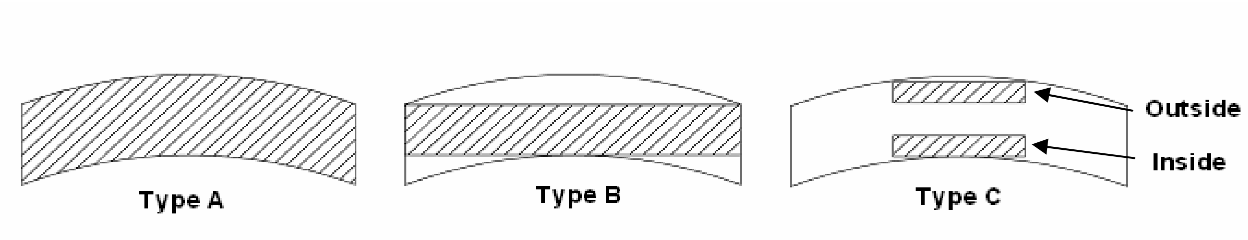

Figure 3. The three specimen types and sampling locations permitted by ASTM F1216/ASTM D790 (see Figure 2 for specimen orientation in a CIPP liner sample). The shaded portion represents the test specimen cross-section and its relation to the original wall thickness of the CIPP pipe.

ASTM F1743 addresses some of the test coupon ambiguities found in ASTM F1216 but it is still not entirely clear if the existing exterior and interior surfaces of the specimen are to be maintained. Section 8.1.3 states that "the full wall thickness of the CIPP samples shall be tested" however the next section 8.1.4 states: "Special consideration should be given to the preparation of flexural specimens to ensure that opposite sides are parallel and adjacent edges are perpendicular". F1743 also provides a method for measuring flexural properties in the hoop direction but only if the flat plate-type field sample is used.

EN 13566 describes testing in both the longitudinal and hoop directions. In the longitudinal direction, the method describes a full thickness section specimen with the existing outside and inside surfaces of the CIPP maintained (Figure 3, Type A). The hoop direction specimen is a transverse rectangular specimen that also retains the existing outside and inside surfaces of the CIPP as well as the curvature of the pipe wall (Figure 4).

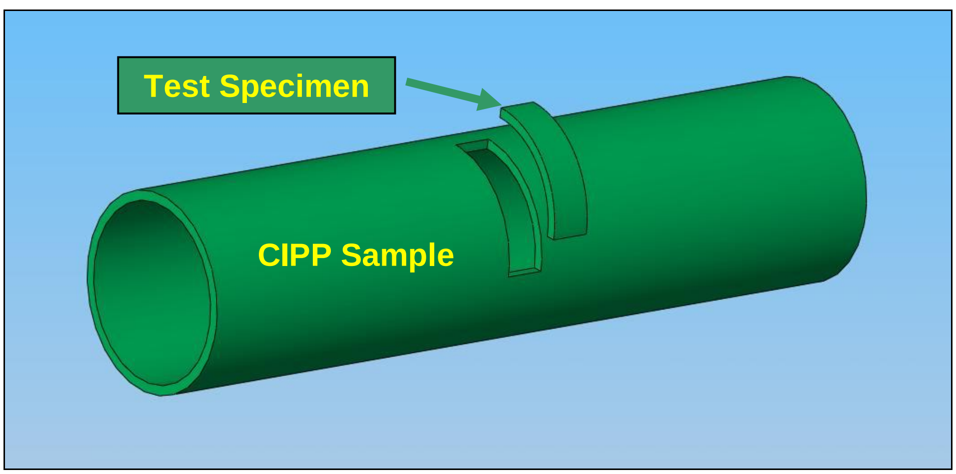

Figure 4. EN 13566 hoop test specimen orientation.

2.3 Test Orientation

CIPP liners have been shown to exhibit loading direction dependent properties (No-Dig 2010 presentation[1]). Generally CIPP exhibits higher flexural properties when the inside diameter surface is loaded in tension. This loading condition represents the actual installed loading condition for non-pressure pipes.

ASTM F1216 does not provide guidance on test orientation. The user is free to test the coupons in either direction

ASTM F1743 specifies that the coupon be tested with the inside pipe face surface in tension. (ASTM F1743 does however reference ASTM D5813 for test specimen preparation. The ASTM D5813 test method does require that the interior surface of the CIPP be placed in tension).

EN 13566 specifies that the coupon be tested with the inside pipe face surface in tension.

2.4 Test Conditions

The test methods ASTM D790 and ISO 178 are substantially similar but there are some key differences in the test conditions based upon which standard is being used.

Span

All three standards specify the span for the test as a ratio of the depth of the test coupon.

ASTM F1216 does not specify the span to be used for the test. The user must refer to ASTM D790 to determine the appropriate span to use for the test. ASTM D790 defines the span as a function of the material type and configuration. The span to depth ratio can be anywhere between 14:1 (for sheet materials) to 60:1 (for highly anisotropic high strength composites).

ASTM D1743 specifies a 16:1 span to depth ratio

EN 13566 specifies a 16:1 span to depth ratio but permits the ratio to be decreased to 10:1 for smaller diameter and thicker walled liners (with the caution that lower span to depth ratios can result in under-estimation of the flexural modulus and strength)..

Speed of Testing

ASTM D790 contains two procedures, A and B. The default procedure, Procedure A, controls the speed of the test to a strain rate of 0.01mm/mm/min.

ASTM F1216 does not specify which procedure from ASTM D790 should be used. Therefore the default speed is 0.01mm/mm/min

ASTM D1743 specifies that Procedure A should be used (0.01mm/mm/min)

EN 13566 specifies a speed of 10 mm/min.

Strain Limit

ASTM D790 terminates the test at 5% strain

ISO 178 does not define a strain limit for the test. Testing is continued until specimen failure

Modulus Determination

ASTM D790 determines the flexural modulus by drawing a tangent to the “steepest initial straight-line portion of the load deflection curve” (Figure 5)

EN 13566 modifies the ISO 178 requirement determines the flexural modulus by determining the steepest slope of the stress/strain curve that is evident within the strain range 0.0005 and 0.0025 to 0.0005 and 0.006 (Figure 5).

Strength Determination

ASTM F1216 / ASTM D790 determine the flexural strength from the maximum flexural stress (Figure 5).

EN 13566 / ISO 178 determine the flexural stress at first break (a different property than flexural strength) from the stress at the first discontinuity of the stress strain curve (Figure 5). ISO 178 also has a property "flexural strength" which determines the flexural strength from the maximum flexural stress in the same manner as the ASTM procedures. However, flexural strength is not a property used in EN 13566.

Test Fixture

ASTM D790 has fixed position loading nose and supports (Figure 6).

EN 13566 requires that the loading nose be free to rotate in a plane perpendicular to the axis of the sample (Figure 7).

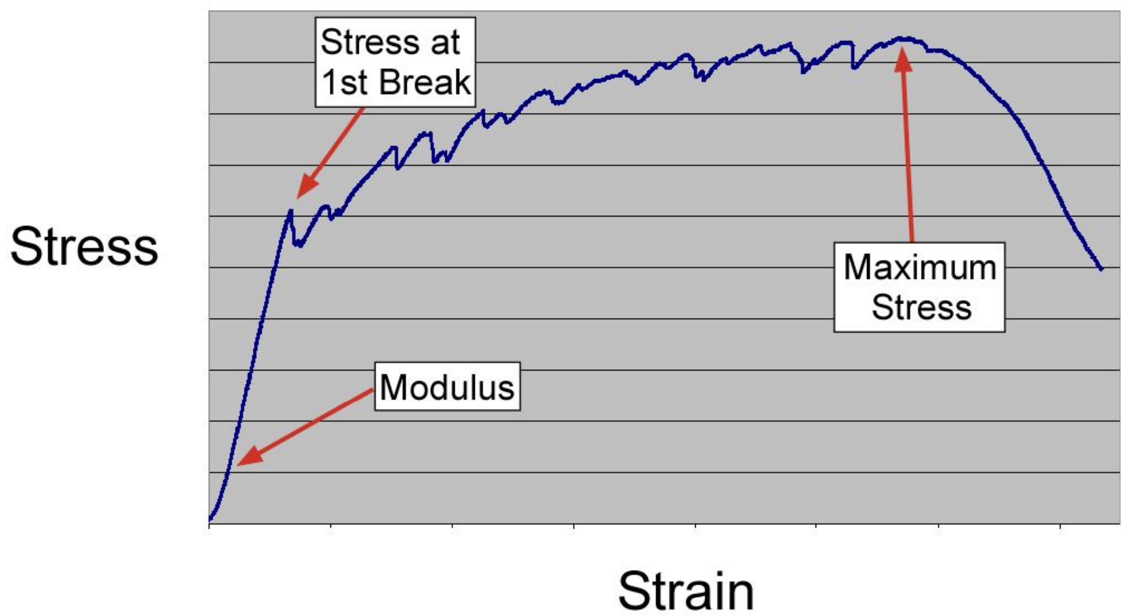

Figure 5. Typical stress/strain curve for a CIPP flexural test

3.0 DESIGN OF EXPERIMENT

Paragon Systems is a materials testing laboratory that provides mechanical testing of CIPP materials to customers throughout North America. We test a large variety of CIPP materials and thus have access to a ready supply of CIPP field samples. Given the many differences between the North American and European test methods, we judged it impractical for the purpose of this paper, to examine the effect of all of these differences in detail. Instead we set out to determine if there is a measurable difference in the flexural strength and modulus determined when these properties are measured in accordance with the ASTM F1216 and EN 13566 methods.

We chose two CIPP material types for the experiment a UV cured reinforced vinylester liner and a steam cured non-reinforced vinylester liner. The UV cured liners were either 600mm or 800 mm in diameter with a wall thickness ranging from 6.4 mm to 10.2 mm. The diameter of the steam cured liner ranged from 250 mm to 450 mm with a typical wall thickness ranging from 4.2 mm to 6.4 mm. Five different field samples from different installations were selected from each of the two liner systems.

3.1 Test Specimen Preparation

From each field sample we prepared five longitudinally oriented flexural test coupons for testing according to ASTM D790. Each test coupon represented the thickest rectangular cross section that could be removed from the existing wall thickness of the liner. The minimum amount of material was machined from both the outside and inside diameter surfaces in order to provide the required rectangular cross section.

The fiber reinforcement in reinforced liners is usually responsible for a large proportion of the flexural properties and as such it is critical to ensure that these reinforcing fibers are left as undisturbed as possible during test coupon preparation. Because of this, it is not always possible to achieve a fully rectangular cross-section on the reinforced liner test coupons and also avoid disturbing the fiber reinforcement near the outside and inside diameter surfaces.

From these same field samples we also prepared five hoop test coupons for testing in accordance with EN 13566 and ISO 178. All of these coupons were 50 mm wide and retained the original outside and inside diameter surfaces.

All test coupons were removed from the field samples by sawing to an approximate shape and then finish machining to the final size. Appropriate cutter selection and machining conditions were used to ensure that test coupon heating or other deleterious preparation effects were avoided.

3.2 Description of the Tests

Testing was performed on a SATEC 22EMF 100 kN capacity universal test machine using either a 1.3 kN or 8.9 kN capacity load cell as appropriate for the loads exerted during each test.

3.2.1 F 1216 / ASTM D790 Longitudinal Tests

The longitudinal test coupons were tested in accordance with ASTM D790. The inside surface of the test coupons (corresponding with the inside surface of the field samples) was placed upon the test fixture supports ensuring that the inside surface of the test coupon was placed in tension. The loading nose and supports were fixed in position and parallel to each other (Figure 6).

The span to depth ratio for all longitudinal tests was 16:1. The longitudinal test coupon dimensions and test conditions are shown in Table 1 for both materials.

Five test specimens were tested and the results of the five tests were averaged. The test results for the longitudinal tests are summarized in Table 2 and presented graphically in Figures 9 and 10.

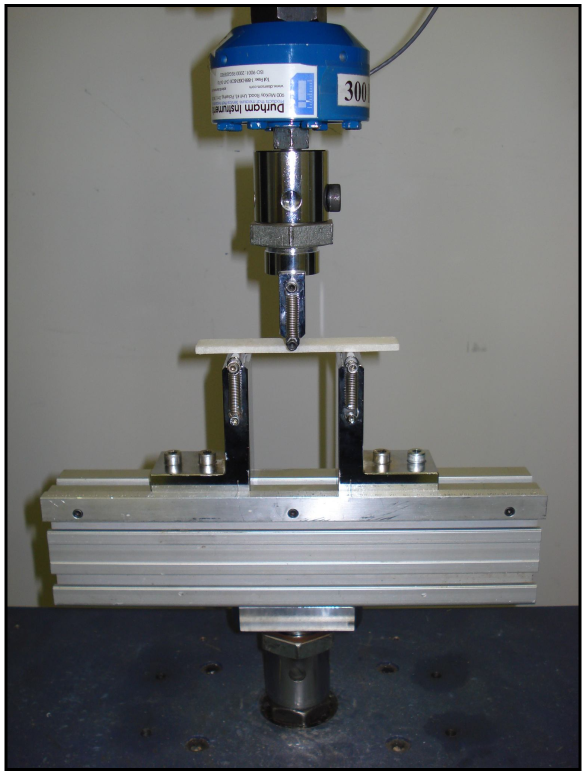

Figure 6. ASTM D790 flexural property test fixture setup. Both the loading nose and supports are fixed in their horizontal planes.

Figure 7. EN 13566/ISO 178 flexural property test fixture setup. Both the loading nose and one support are free to rotate in their horizontal planes

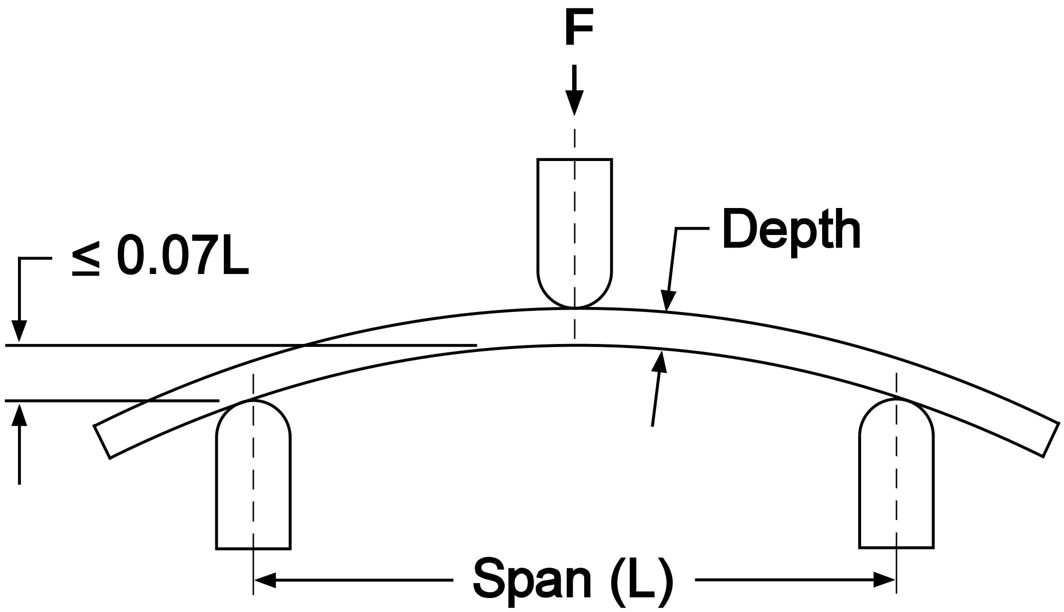

Figure 8. EN 13566/ISO 178 flexural property test fixture setup showing the 0.07L limitation for hoop type specimens

	ASTM F1216 / D790			EN 13566 / ISO 178		
Sample Number	**Depth (mm)**	**Width (mm)**	**Span (mm)**	**Depth (mm)**	**Width (mm)**	**Span (mm)**
1	6.1	20.5	97.2	7.6	49.9	79.4
2	5.0	21.0	80.0	6.8	50.1	86.5
3	6.4	23.9	102.6	8.4	50.3	97.2
4	4.2	16.5	67.7	5.2	49.4	56.1
5	4.2	16.5	67.8	4.8	50.3	56.8

TABLE 1. Non-Reinforced material test coupon dimensions and test conditions (average of the 5 test specimens)

	Flexural Modulus		Flexural Strength	Flexural Strength	Flexural Stress at First Break
Orientation / Procedure	**Longitudinal**	**Hoop**	**Longitudinal**	**Hoop**	**Hoop**
Sample Number	ASTM F1216 / D790 (MPa)	EN 13566 / ISO 178 (MPa)	ASTM F1216 / D790 (MPa)	ISO 178 Only (MPa)	EN 13566 / ISO 178 (MPa)
1	3,690	2,910	49.5	56.8	34.4
2	3,750	3,110	52.1	51.6	32.8
3	3,590	2,520	50.8	50.0	30.8
4	3,810	3,010	50.8	58.8	34.5
5	3,150	1,930	51.8	61.9	36.6

Table 2. Non-reinforced materials test results for the longitudinal tests.

3.2.2 EN 13566 / ISO 178 Hoop Direction Tests

The hoop test coupons were tested in accordance with EN 13566 Annex C and ISO 178. The ASTM D790 test fixture was modified to permit the loading nose and one support to rotate in a plane perpendicular to the axis of the sample (Figure 7). This permits the fixture supports to accommodate slight variations in test coupon geometry.

The span to depth ratio for all hoop tests varied from 16:1 for the 600 mm and 800 mm diameter liners down to 10:1 for the 250 mm diameter liner. EN 13566 permits the span to depth ratio to be reduced for smaller diameter or thicker liners to ensure that the height of the test coupon does not exceed 0.07 L above the supports. (Figure 8). The hoop test coupon dimensions and test conditions are shown in Table 3 for both materials.

Five test specimens were tested and the results of the five tests were averaged. The test results for the hoop direction tests are summarized in Table 4 and presented graphically in Figures 11 and 12.

	ASTM F1216 / D790			EN 13566 / ISO 178		
Sample Number	**Depth (mm)**	**Width (mm)**	**Span (mm)**	**Depth (mm)**	**Width (mm)**	**Span (mm)**
1	9.1	19.1	145.4	7.2	49.7	116.0
2	5.2	19.1	83.4	6.8	49.6	109.1
3	5.8	24.1	92.8	7.9	49.7	127.2
4	11.2	24.9	178.5	10.6	49.7	169.9
5	7.3	24.1	117.4	8.8	50.0	141.3

TABLE 3. Reinforced material longitudinal test coupon dimensions and test conditions (average of the 5 test specimens)

	Flexural Modulus		Flexural Strength	Flexural Strength	Flexural Stress at First Break
Orientation / Procedure	**Longitudinal**	**Hoop**	**Longitudinal**	**Hoop**	**Hoop**
Sample Number	ASTM F1216 / D790 (MPa)	EN 13566 / ISO 178 (MPa)	ASTM F1216 / D790 (MPa)	ISO 178 Only (MPa)	EN 13566 / ISO 178 (MPa)
1	8,720	7,300	195	169	164
2	10,480	5,680	178	143	82
3	8,850	6,120	212	143	104
4	10,160	9,690	160	200	178
5	9,300	10,840	207	218	214

Table 4. Reinforced materials test results for the longitudinal tests.

4 EXPERIMENTAL RESULTS

4.1 Non-Reinforced Liner

The data sets for the non-reinforced liner were combined into two charts, one each for flexural modulus and for flexural strength. Flexural strength is really only defined as a property in ASTM D790. EN 13566 / ISO 178 determine the flexural stress at first break (which is a different property than flexural strength). Because of this we presented the strength data from the Hoop EN 13566 tests in two ways. First we calculated the maximum stress achieved during the test (in the same manner as is defined in ASTM D790). This is shown in the charts as “Hoop – Max Stress”. Secondly, we calculated the flexural stress at first break as defined by EN 13566. This is shown in the charts as “Hoop – At First Break EN 13566.

Figure 9 shows the flexural modulus results for the two test methods. All of the five samples showed lower modulus results from the EN 13566 hoop tests than those from the D790 flat tests. The hoop direction test results ranged from 21.0% to 38.7% lower than the flat longitudinal test results.

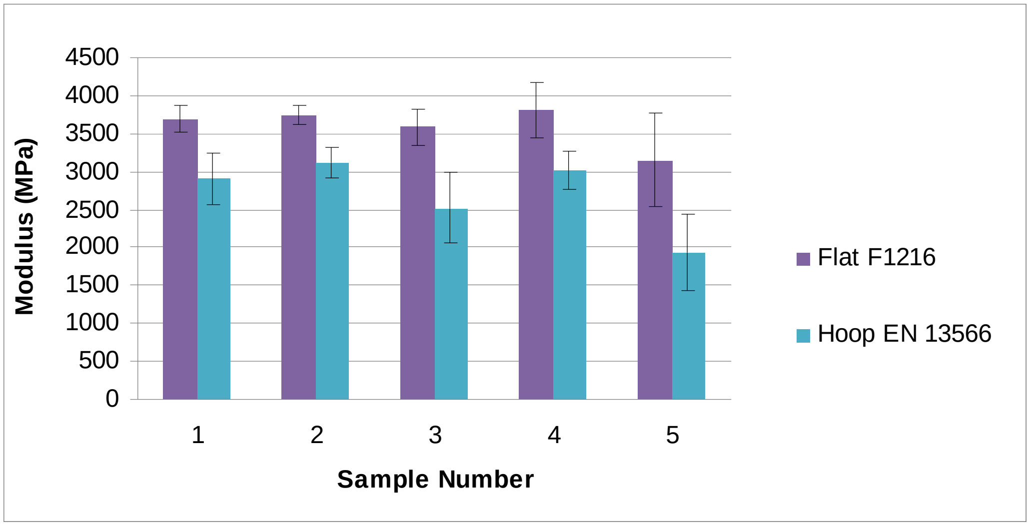

Figure 9. Flexural modulus results from non-reinforced liners.

Figure 10 shows the flexural strength results for the two test methods for the non-reinforced liners. The results for flexural stress at first break results from the hoop tests are all lower than the flexural strength results from the flat - longitudinal tests. The hoop direction test results range from 27.8% to 39.2% lower than the flat longitudinal test results.

If instead of calculating the stress at first break as defined by EN 13566 for the hoop tests, we were to use the maximum stress, the flexural strength results from the two methods become much more comparable. In this case the hoop direction tests are similar to the flat – longitudinal test results.

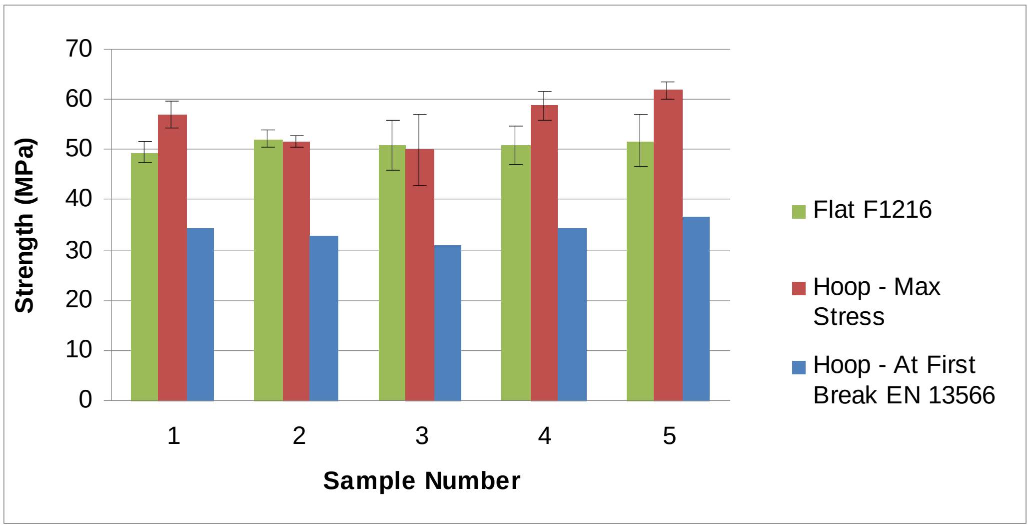

Figure 10 – Flexural strength and stress at first break results from non-reinforced liners. The “Hoop – Max Stress” result uses the maximum stress achieved during the hoop test to calculate flexural strength.

4.2 Reinforced Liner

The data sets for the reinforced liners were also combined into two charts, one each for flexural modulus and for flexural strength. We presented the flexural strength and flexural stress at first break data in the same manner as the non-reinforced samples.

Figure 11 shows the flexural modulus results for the two test methods for the reinforced samples. Four of the five samples showed lower modulus results from the hoop tests than those from the flat longitudinal tests. The difference ranged from 4.6% to 45.8% lower. The Sample 5 hoop direction test showed a higher modulus (16.6% higher) than the flat – longitudinal direction test. The average hoop direction test results were 16.2% lower than the average flat longitudinal test results.

Figure 12 shows the flexural strength results for the two test methods for the reinforced liners. Three of the four hoop test results (at first break) are lower than the longitudinal strength test results ranging from 15.8 % to 54.2% lower than the longitudinal results. The hoop test results for Samples 4 and 5 are higher than the longitudinal results (11.0% and 3.5% respectively). On average the hoop results (at first break) are 21.3% lower than the longitudinal results.

We performed the same calculations for the hoop strength results (using maximum stress instead of stress at first break) as we did for the non-reinforced liners. In this case as well, the flexural strength calculated using the maximum stress for hoop and longitudinal are more comparable than using the stress at first break for the hoop tests.

Three of the four hoop test results (at first break) are lower than the longitudinal strength test results ranging from 13.1 % to 32.7% lower than the longitudinal results. The hoop test results for Samples 4 and 5 are higher than the longitudinal results (11.0% and 3.5% respectively). On average the hoop results (at first break) are 21.3% lower than the longitudinal results.

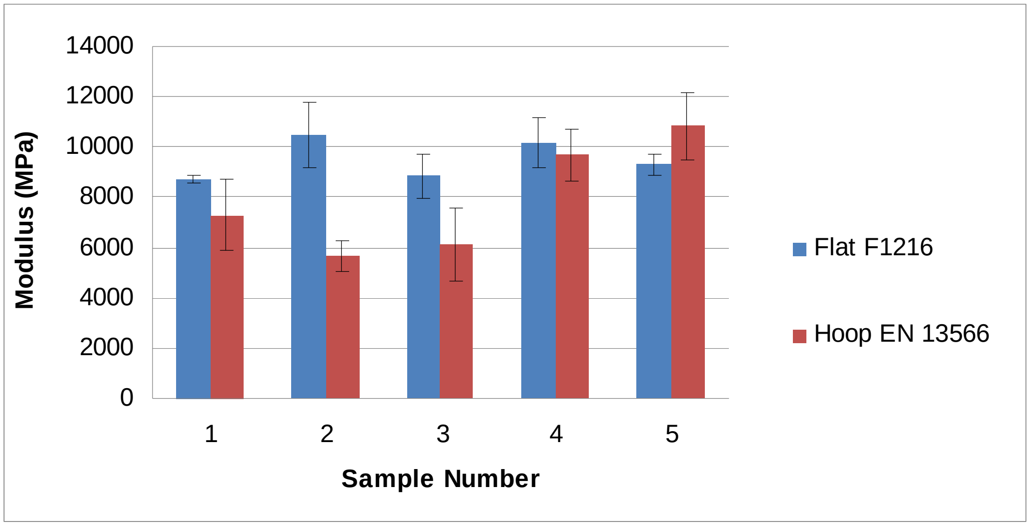

Figure 11. Flexural modulus results from the reinforced liners.

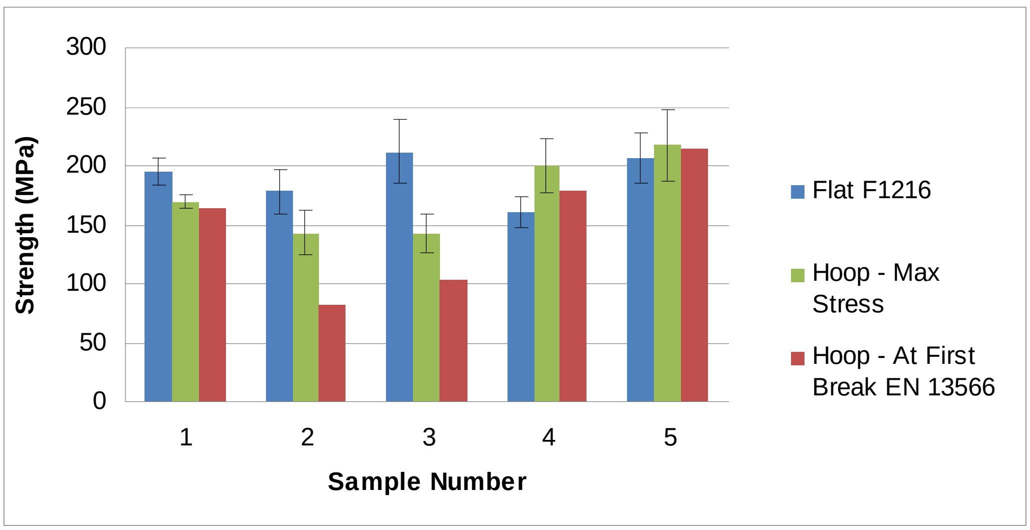

Figure 12. Flexural strength and stress at first break results from the reinforced liners. The "Hoop – Max Stress" result uses the maximum stress achieved during the hoop test to calculate flexural strength.

5.0 DISCUSSION AND OBSERVATIONS

There does appear to be a measurable difference the properties determined with the two methods. The most consistent relationship appears to be in the flexural modulus determination where 9 of 10 tests showed lower modulus using the EN 13566 method.

For the non-reinforced material we expected the modulus would be similar in the longitudinal and hoop directions. All of the non-reinforced flexural moduli were lower when measured using the EN 13566 method.

The reinforced material was expected to exhibit a higher modulus in the hoop direction because of the layout of the reinforcement. This was true only for Sample 5. Sample 4 exhibited about the same modulus between the two methods. Samples 1, 2 and 3 all showed lower modulus in the hoop direction test performed in accordance with EN 13566.

The differences in flexural strength results are somewhat more easily interpreted. The ASTM F1216/D790 method uses the maximum force attained during the test to calculate the flexural strength. The similar strength parameter in EN 13566 is flexural stress at first break. Given the typical stress/strain performance of a CIPP flexural test (Figure XX) it is obvious that the flexural stress at first break force will almost always be lower than the maximum force attained during a test. On some tests the maximum force and the force at first break will be nearly identical when the specimen ruptures immediately at or just after first break.

In the non-reinforced material flexural strength tests, the flexural strength at first break for the hoop tests was lower than the flexural strength of the longitudinal tests for all five samples tested. If we used the maximum force attained during the hoop flexural test (ie. the force that would typically be used in an ASTM D790 test), these data more closely matched the longitudinal flexural strengths.

The flexural strength relationship for the reinforced materials is somewhat less well defined. Samples 1, 2 and 3 showed the same relationship between the two methods as were illustrated by the non-reinforced materials. Samples 4 and 5 did not exhibit the same relationship.

6.0 CONCLUSIONS

There is a measurable difference in flexural properties determined with these two methods.

6.1 The flexural modulus determined from non-reinforced CIPP field samples, was lower when determined using the method EN 13566/ISO 178 than when determined using the method ASTM F1216/ASTM D790 for the five non-reinforced field samples examined in this study.

6.2 The flexural modulus determined from reinforced CIPP field samples, was lower when determined using the method EN 13566/ISO 178 than when determined using the method ASTM F1216/ASTM D790 for four of the five reinforced field samples examined in this study.

6.3 The flexural stress at first break determined from non-reinforced CIPP field samples, was lower when determined using the method EN 13566/ISO 178 than the flexural strength determined using the method ASTM F1216/ASTM D790 for the five non-reinforced field samples examined in this study.

6.4 The flexural stress at first break determined from reinforced CIPP field samples, was lower when determined using the method EN 13566/ISO 178 than when determined using the method ASTM F1216/ASTM D790 for three of the five reinforced field samples examined in this study.

REFERENCES

Araujo, T., Yao, B., Sabeshan, S. (2010). Factors Affecting the Quality of Flexural Properties from CIPP Field Samples. Proceedings of 2010 NoDig Conference, Chicago, Illinois, May 2-7, 2010.