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Assessing the Elastic Moduli of Pavement Marking Tapes using the Tape Drape Test

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The Tape Drape Test – A Practical and Nondestructive Way to Assess Elastic Moduli of Pavement Marking Tapes in the Field

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ABSTRACT

Temporary pavement marking (TPM) tape adhesion with roadway surfaces is critical for tape performance. The two main TPM performance issues both stem from the adhesive strength. Weak adhesion results in premature detachment and excessive adhesion requires extensive removal processes that often leave ghost markings, both of which can cause dangerous confusion in road construction zones. Tape adhesion is directly related to the elastic modulus (E) of TPM tapes. Thus, accurate characterization of E prior to tape installation is essential to fully understand and predict the adhesion performance and ultimately the durability of TPMs. To determine the most appropriate E characterization technique for three different commercial TPM tape brands, two commonly used techniques – tensile and three-point bend testing - were compared to a less common technique; the Peirce cantilever testing or "Tape Drape Test (ASTM D1388-18). The Tape Drape Test was the only method that accurately characterized E of tapes with raised surface features. Results from tensile and three-point bend testing measured an artificially high E more than 177% and 162% greater than the expected value, respectively. The Tape Drape Test, which can be quickly implemented in the field before tape installation with little equipment, effectively characterized E for all the tapes.

Keywords: Temporary pavement marking tape, Mechanical characterization techniques, Roadway construction, On-site performance testing

INTRODUCTION

Temporary pavement marking (TPM) tape adhesion with roadway surfaces is critical for tape performance. The two main TPM performance issues both stem from the adhesive strength. Weak adhesion results in premature detachment and excessive adhesion requires extensive removal processes that often leave ghost markings, both of which can cause dangerous confusion in road construction zones. Tape adhesion is directly related to the elastic modulus (E) of TPM tapes. Thus, accurate characterization of E prior to tape installation is essential to fully understand and predict the adhesion performance and ultimately the durability of TPMs. An accurate assessment of E in the field is essential for predicting performance as E of TPM tape changes with temperature. Traditional E characterization techniques, such as tensile and three-point bend testing, may not be able to accurately measure E due to the complex structure of the tapes and are difficult to conduct at temperatures above or below room temperature without special equipment. Here, a new methodology that can be utilized which accounts for the complex tape structure and can be conducted in the field with minimal equipment.

TPMs are commonly deployed in construction work zones and temporary roadway areas. Highly visible, durable, and easily removable TPMs are necessary to provide drivers with a clear travel path through work zones without damaging the roadway surfaces.(1,2) In many areas, TPMs are also required to temporarily cover and/or replace existing permanent pavement markings to avoid potential lane confusion for drivers.(3–5) Durability and ease of installation and removal are high priorities for TPMs because reapplication and intensive tape removal processes can significantly increase both material and labor costs, delay roadway reopening, and damage roadway surfaces from grinding or milling.(6–10)

The components and structure of TPM tapes impact their overall performance on roadway surfaces. Generally, TPM tapes are comprised of synthetic polymer and pigment as well as glass beads added for increased retroreflectivity.(11) The top layer consists of glass beads embedded in polymer paint followed by a flexible rubber filled with additional glass beads, a reinforcing fabric, and a polymer-based pressure sensitive adhesive (PSA) on the bottom that allows the tape to adhere to surfaces. Some TPM tapes have raised surface features that improve friction and retroreflectivity properties of the tape (**Figure 1c)** while others do not (**Figure1a-b).** Other factors such as the application procedure, environmental conditions, and roadway surface conditions have a significant impact on tape performance as well but are not investigated in the scope of this work.(12–15)

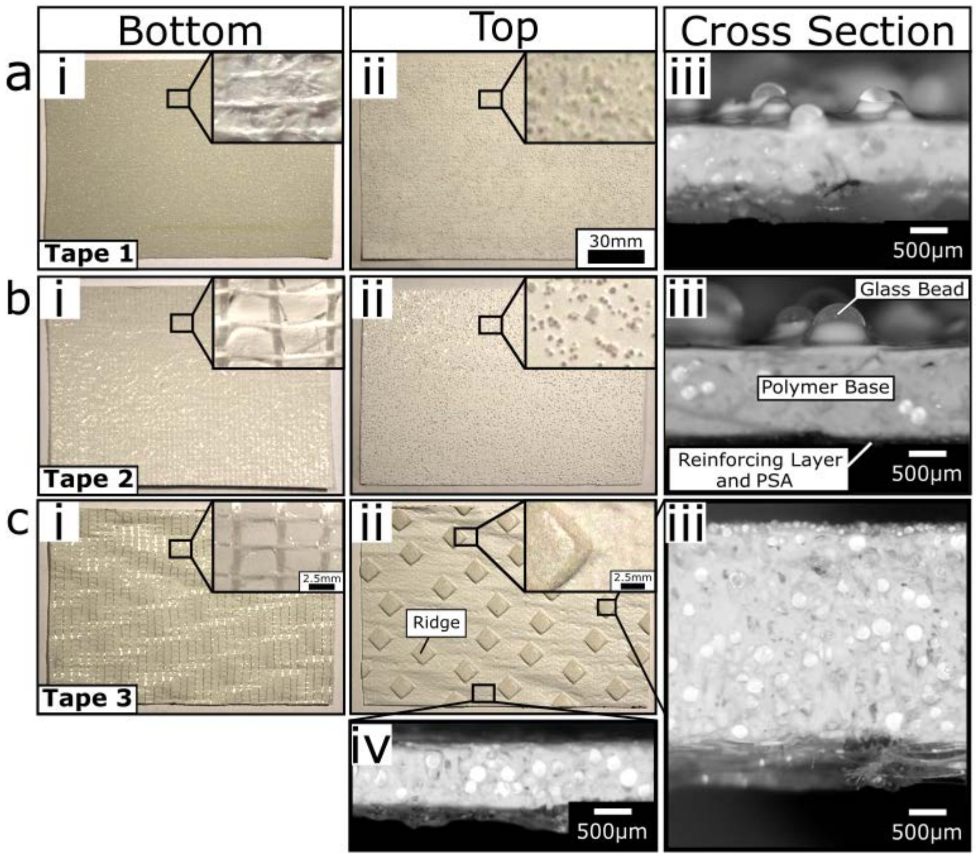

Figure 1 Representative images of TPM tapes. A macroscopic image of the *ai)* back, *aii)* front, and *aiii)* cross-sectional image of Tape 1. A macroscopic image of the *bi)* back, *bii)* front, and *biii)* cross-sectional image of Tape 2 with labels of structural features. A macroscopic image of the *ci)* back, *cii)* front, and cross-sectional image *ciii)* through a raised ridge and *civ)* away from a ridge.

To remove a PSA from a surface, a critical force required for debonding (F_c) must be achieved. F_c can be related to the ratio of the surface area (A_s) to compliance (C) by Eq. 1,(16)

$$F_c \sim \sqrt{G_c}\sqrt{\frac{A_s}{C}} \tag{1}$$

where G_c is the critical strain energy release rate, a property of the interfacial energy between the TPM tape and substrate. C can be defined by Eq. 2 and is dependent on the geometry and effective modulus of the tape (E).(17,18)

$$C = \frac{1}{E}\left(\frac{t}{ba}\right) \tag{2}$$

Here, t is the tape thickness, a is the tape length, and b is the tape width. Eq. 2 can be substituted into Eq. 1 to show the dependence of F_c on G_c and E (Eq. 3).

$$F_c \sim \sqrt{G_c}\sqrt{(E)\left(\frac{baA_s}{t}\right)} \tag{3}$$

Eqs 1 and 2 show that the main material properties that govern TPM adhesion performance are G_c and E. G_c is determined by the surface energies of the PSA and the substrate. Since most TPM tape PSA chemistries are similar, G_c values are effectively constant amongst all TPM tapes(16) when contacting the same substrate (e.g., asphalt pavement). If G_c is considered to be constant, then E of the tape becomes the most significant material property that impacts the critical adhesion force of TPM tapes on roadway surfaces (Eq. 4).

$$F_c \sim \sqrt{\mathrm{E}} \tag{4}$$

TPM tape adhesion must be durable enough to remain affixed to the roadway over a range of traffic loads and environmental conditions yet must be easily removed once construction is complete.(11,15) PSAs with lower E tend to have a stronger adhesive bond with surfaces, but from a TPM tape perspective can cause removal difficulties. Therefore, E must be low enough to ensure sufficient adhesion with pavement surfaces but high enough to allow for easy removal and durability throughout the project lifetime.(19) Given the impact of E on TPM tape performance, it is critical to accurately measure this value for various products.

Measuring E of TPM tapes in the field is important because changes in temperature can significantly affect E.(19) Pavement and air temperatures can drastically change day to day or even hour to hour depending on the location and season. Since temperature significantly affects E and subsequently adhesion on pavements, it is essential to test TPM tapes in an environment similar to the application environment for quality assurance.(20) The change in E due to temperature are attributed to the glass transition temperature (T_g) which is the temperature that polymers and bulk plastic materials transition between a brittle glassy state to a rubbery, more ductile state.(21) Interestingly, T_g of most commercial TPM tapes lies within the range of potential application temperatures at the work-zone depending on the geographical location and time of year.(22,23) TPM tapes that are applied at temperatures below their T_g may not make full contact with the pavement surface during application due to the temperature-induced increase in E or be more difficult to remove due to brittle fracture, preventing detachment as one piece. Alternatively, when temperatures exceed T_g, the tapes can transition to a more ductile regime leading to an increase in F_c that prevents effective tape removal. The ability to characterize E in the field enables temperature effects to be accounted for during application.

Traditional E measurement techniques are unable to be employed in the field to accurately assess E due to changes in temperature. Techniques that are traditionally employed to characterize E are tensile testing and three-point bend testing. Both techniques require large stationary, expensive equipment that does not typically integrate well with testing above or below room temperatures. Additionally, these methods are destructive examination techniques requiring tapes to be cut before testing, and plastic deformation of the tapes caused by testing does not allow tapes to be applied afterward. While tensile and three-point bend testing can determine E for TPM tapes, the composite structure of the tape and textured surface of some products lead to high variability in these measurements. Further, specimen preparation, specifically how the specimen is sectioned, such as size and orientation relative to the machine direction, can play a significant role on the measured value of E.

In this study, three commercial brands of TPM tape approved by the Indiana Department of Transportation were tested to compare traditional E characterization techniques with one other potential technique that may be implemented in the field. Tensile testing following ASTM D638-

14 and three-point bend testing following ASTM D790-17 were the selected commonly utilized techniques. The Peirce cantilever test herein referred to as the Tape Drape Test follows ASTM D1388-18. This test, developed by F.T. Peirce in 1930, was selected as the potential field test because it requires minimal sample preparation and no heavy or stationary equipment.(24) By comparing the measured E values from the tensile and three-point bend testing with the results from Tape Drape Testing, a proper E determination method can be verified for TPM tapes and other material systems similar to TPM tapes. Accurately assessing E of TPM tapes will aid in the selection process of which TPM tapes to apply under a given set of environmental conditions.

MATERIALS AND METHODS

All TPM tapes used in this study are commercially available and were chosen from an Indiana Department of Transportation list of approved TPM materials. Tensile testing and three-point bend testing have typically been used to characterize E of polymeric materials. While these methods are appropriate for polymeric materials with a uniform cross section, TPM tapes have a complex structure that complicates specimen preparation and data interpretation. The new methodology proposed here to characterize E of TPM tapes is the Peirce cantilever test, referred to here as the "Tape Drape Test". The Tape Drape Test can consistently measure the effective E of TPM tapes as a whole and can be conducted with minimal equipment in the field.

Tensile Testing E Determination

Tensile testing was conducted based on ASTM D638-14.(25) The experimental set-up for tensile testing is shown in **Figure 2a**. The tapes were supplied by the manufacturers and used as received. The thickness (t) of Tape 1 (1.19 mm), Tape 2 (1.19 mm), Tape 3 without ridges (0.91 mm), and Tape 3 with ridges (2.37 mm) were measured. The standard error across all thickness measurements was 0.1 mm. The TPM tapes were cut into dogbone specimens with a gauge width (w) of 3.80 ± 0.3 mm and gauge length (l_o) of 15.25 ± 0.5 mm. Tensile tests were performed at a rate of 0.5 mm·s^{-1} (TA.XTplusC Texture Analyser, Stable Micro Systems). A minimum of three trials were performed for each TPM tape using a different specimen each trial.

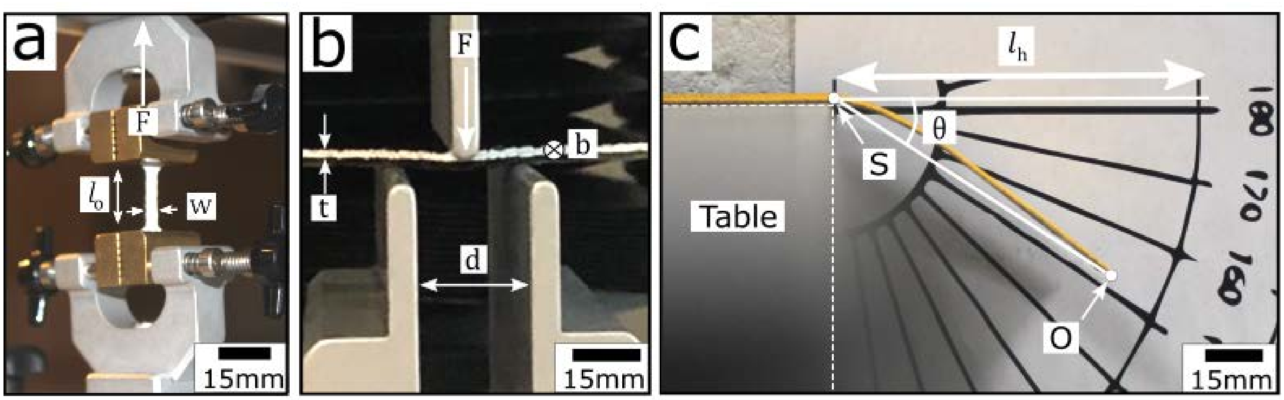

Figure 2 Experimental set-ups of *a)* tensile testing, *b)* three-point bend testing, and *c)* Tape Drape Testing.

Force (F) and displacement (Δl) values from each tensile testing trial were captured to determine the stress (σ) and strain (ε) behavior of each tape. σ was calculated from Eq. 3 where A_x is the cross-sectional area ($A_x = wt$) and ε was calculated from Eq. 4 where l_o is the initial length of the tested sample.

$$\sigma = \frac{F}{A_x} \quad (3)$$

$$\varepsilon = \frac{\Delta l}{l_o} \quad (4)$$

At small strains, each tape exhibited a linear elastic behavior governed by Hooke's law (Eq. 5). E was determined from the initial slope of each tensile curve until a strain of 0.02 to ensure the tapes were in the elastic regime.

$$\sigma = \mathrm{E}\varepsilon \quad (5)$$

Using Hooke's law, E of each tape can be determined from the slope of the elastic region of each σ-ε curve.

Three-Point Bend *E* Determination

Three-point bend testing was conducted based on ASTM D790-17.(26) The experimental set-up for the three-point bend testing is shown in **Figure 2b**. The TPM tapes were cut into rectangular specimens for three bend testing with widths (b) of 12.7 ± 0.1 mm and lengths of 65.0 ± 0.1 mm using a span (d) of 25 mm. Three-point bend tests were performed at a rate of 0.01 mm·s^{-1}. A minimum of three trials were performed for each TPM tape using a different specimen each trial.

Three-point bend testing was employed to determine the flexural modulus (E_{Flex}) of the TPM tapes. At low strains below the proportionality limit, E_{Flex} can be considered to be equivalent to E. Therefore, by determining E_{Flex} via three-point bend testing, E is also determined. During each trial, the crosshead moved in the y-direction to cause a lateral bending deflection (δ) in a rectangular tape specimen spanning the bottom two points. δ was taken as equivalent to the crosshead displacement.

Similar to tensile testing, F and δ values were collected and analyzed to determine E_{Flex}. A similar analysis technique for determining E_{Tens} was used to determine E_{Flex}, where the bending stress (σ_{bend}) and bending strain (ε_{bend}) are plotted instead of σ and ε. σ_{bend} was calculated through Eq. 6, and ε_{bend} was calculated through Eq. 7.

$$\sigma_{bend} = \frac{3Fd}{2bt^2} \quad (6)$$

$$\varepsilon_{bend} = \frac{6\delta t}{d^2} \quad (7)$$

E_{Flex} was determined from the slope of the elastic region of each σ_{bend} - ε_{bend} curve.

Tape Drape *E* Determination

The Tape Drape Test was performed based on ASTM D1388-18.(27) The experimental set-up for the Tape Drape Test is shown in **Figure 2c**. The TPM tapes were trimmed from the as-received roll to have a length of 160 mm. The edges of each tape were unmodified so that width (b) was set by the manufacturer. For Tape 1, Tape 2, and Tape 3, b was 60 mm, 70 mm, and

100 mm, respectively. A digital camera (EOS Rebel TS5 DSLR, Canon) was employed for imaging. Before each trial, the camera was leveled with the 0° mark on the protractor. The TPM tape was tested with the PSA side facing down. Before recording the drape angle (θ), the specimens were allowed to equilibrate for 60 s to improve the consistency of the measurement. A minimum of three θ values were taken for 3 separate specimens for each tape. Details on measuring θ can be found in the Supplemental Material.

The Tape Drape Test has historically been utilized to determine the stiffness of textiles by measuring the angle of drape due to gravity as a function of the overhang length (l_h) of a piece of fabric draping off a ledge.(24,28) However, the tape drape has also been employed for measuring E of materials other than textiles. For example, Hall et al. utilized the Tape Drape Test to measure E of aged paper.(29) Since this method is non-destructive, it is ideal for materials that need to be applied after testing.(29) Additionally, the Tape Drape Test is easy to implement, requiring only a ruler, protractor, and horizontal surface. Thus, the Tape Drape Test can be utilized in the field as the testing "equipment" is readily available and transportable.

In the Tape Drape Test, θ is measured from the end of the tape draping off a ledge ("O" in **Figure 2c**) and the edge of the ledge ("S" in **Figure 2c**) while the other end is fixed. The horizontal line going through "S" sets the reference for $\theta = 0°$. The bending length (c) which is roughly related to the contour length of the bent portion of the tape can be related to l_h and θ (Eq. 8a).(30) **Figure 3a** shows that as θ increases, c decreases which corresponds well with Eq.8a. In literature, the expression containing θ is often substituted for $f(\theta)$ (Eq. 8b).(29–31)

$$c = (l_h)\left(\frac{\cos\frac{\theta}{2}}{8\tan\theta}\right)^{1/3} \qquad (8a)$$

$$f(\theta) = \left(\frac{\cos\frac{\theta}{2}}{8\tan\theta}\right)^{1/3} \qquad (8b)$$

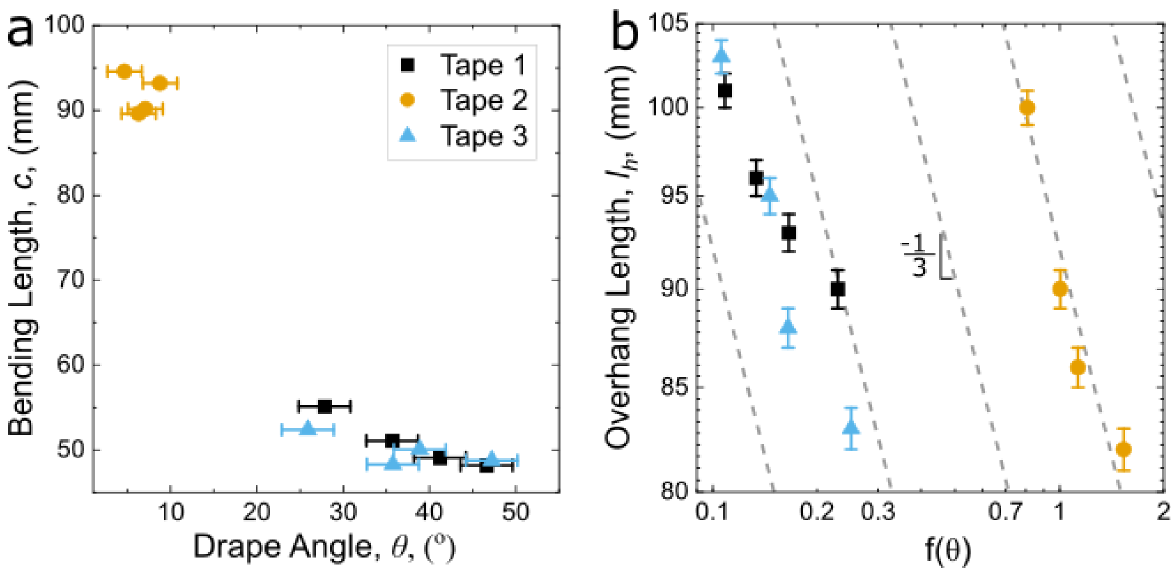

Figure 3 ***a)*** **Tape Drape Testing plot of *c* with respect to θ.** ***b)*** **The scaling relationship between $f(\theta)$ and l_h. The parallel dashed lines have a slope of -1/3 and are a guide to the eye. The error bars in *a)* and *b)* represent a standard 5% measurement error.**

The relationship between θ and l_h is shown in **Figure 3b** where the slope of the dashed lines are -1/3 which corresponds to $l_h \sim f(\theta)^{-1/3}$ when plotted on a log-log scale. **Figure 3b** shows that the relationship between θ and l_h in Eq. 8a holds for TPM tapes. Since the Tape Drape Test is typically used with textile materials, it is important to validate the test by showing that the methodology follows the relationship in Eq.8a when testing TPM tapes. Once the Tape Drape Test is validated, c can be used to determine the flexural rigidity (G) through Eq. 9 (30,32),

$$G = (9.81 \times 10^{-12})(\omega)(c^3) \tag{9}$$

where ω is the areal density with units of g/m^2 ($\omega = m/ab$) and m is mass. G be related to E through t and the Poisson's ratio (ν) which was assumed to be 0.49 (Eq.10).

$$E_{Drape} = (G)\left(\frac{12(1-\nu^2)}{t^3}\right) \tag{10}$$

Eq.10 was used to determine E from the Tape Drape Test.

RESULTS AND DISCUSSION

E Determination Technique Comparison

Representative F- Δl and $\sigma - \varepsilon$ plots used to determine E from tensile testing are shown in **Figure 4a** and **Figure 4c**, and F- δ and σ_{bend} - ε_{bend} plots from three-point bend testing in **Figure 4b and Figure 4d.** E determined through tensile testing (E_{Tens}), three-point bend testing (E_{Flex}), and the Tape Drape Test (E_{Drape}) are reported in **Table 1**. E_{Flex} values reported in **Table 1** are in relatively good agreement with E_{Tens} values of Tape 1 and Tape 2. Due to this agreement, E_{Flex} can be approximated as E_{Tens}.

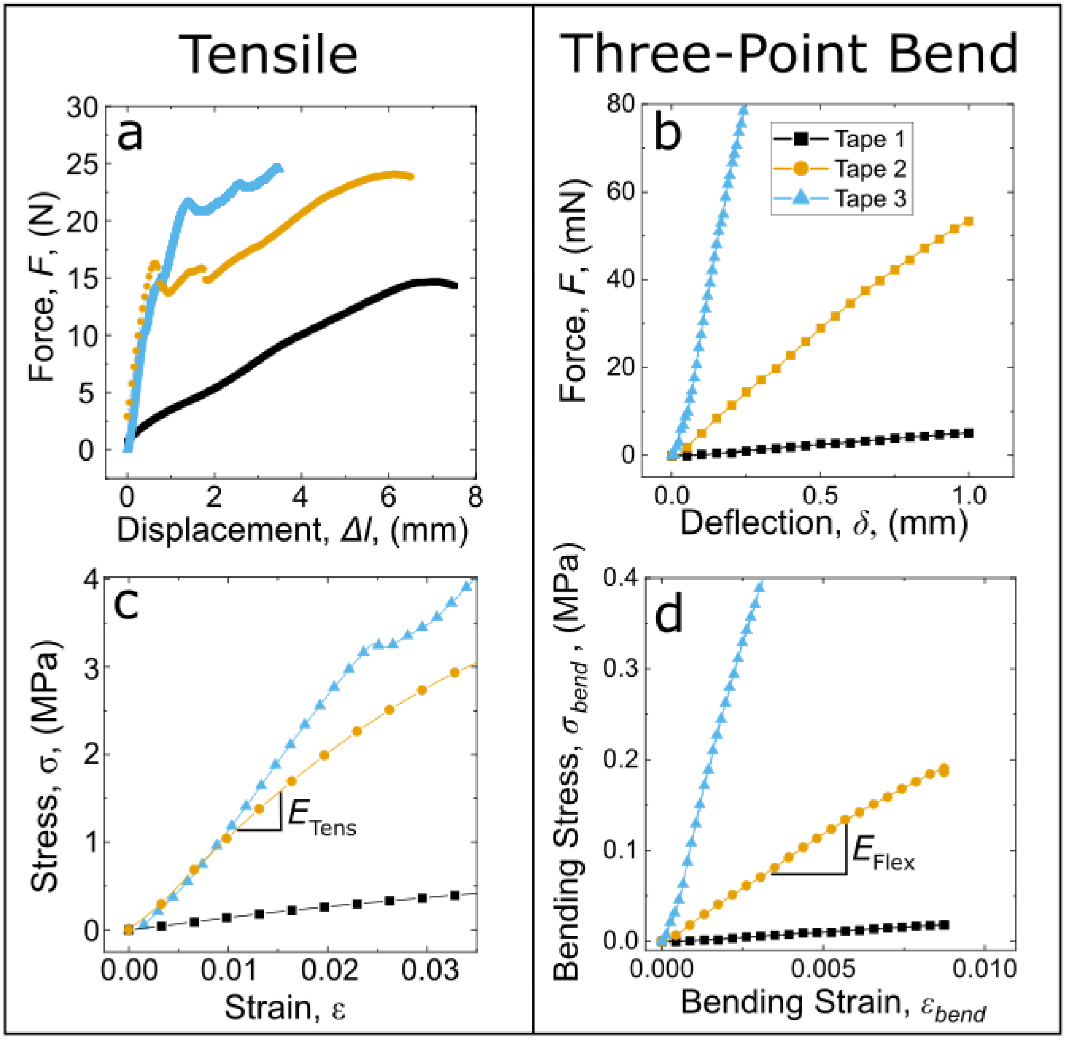

Figure 4 *a)* Representative force-displacement curves from tensile testing. *b)* Representative force-deflection curves from three-point bend testing. *c)* Initial portion of representative stress-strain curves from tensile testing. *d)* Initial portion of representative bending stress-bending strain curves from three-point bend testing. The legend in *b*) applies to all plots.

TABLE 1 Comparison of *E* Determined by Various Test Methods

	E_{Tens} (MPa)	E_{Flex} (MPa)	E_{Drape} (MPa)
Tape 1	7.70 ± 1.10	9.90 ± 2.40	14.8 ± 2.40
Tape 2	52.0 ± 13.20	44.6 ± 6.30	46.9 ± 1.80
Tape 3	124 ± 48.9	94.1 ± 10.1	15.9 ± 3.60

A graphical comparison of E determined by each measurement technique is shown in **Figure 5**. E values between all measurement techniques were in good agreement for Tape 1 and Tape 2 while Tape 3 had an average percent difference of 148% for E_{Tens} and E_{Flex} when compared to E_{Drape}.

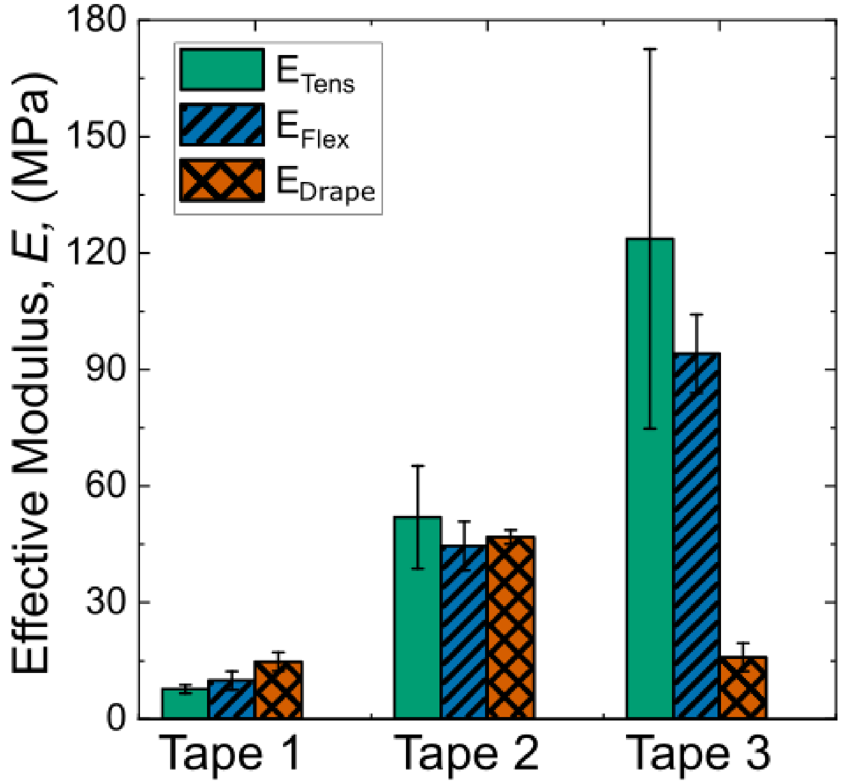

Figure 3 The measured E from tensile testing, three-point bend testing, and Tape Drape Testing for each tested tape. The error bars represent one standard deviation.

E is an intrinsic materials property that describes the resistance to deformation and can be qualitatively observed when handled. When physically manipulating Tape 1 and Tape 3, these two tapes appear to have similar E. However, the measured result found E_{Tens} of Tape 3 to be 177% different than E_{Tens} of Tape 1, 162% different for E_{Flex}, and 7% different for E_{Drape}. The large discrepancy between the measured E_{Tens} and E_{Flex} of Tape 1 to Tape 3 and the predicted E based on qualitative handling and manipulation indicate the traditional E characterization techniques have difficulty characterizing a trustworthy E value for TPM tapes.

The small percent difference between E_{Drape} of Tape 1 and Tape 3 correspond well with the physical hypothesis developed from handling the tapes. The agreement of the measured E values with the expected result from handling is a positive indicator that the Tape Drape Test can accurately measure E of TPM tapes while having the ability to be implemented in the field.

Tape Geometry and Composition Effects on E Measurement Techniques

A major difference between the traditional modulus measurement methods (tensile testing and three-point bend testing) and Tape Drape Testing is the requirement to cut specimens to a specific geometry for the conventional methods. The geometry and composition of the TPM tapes play a major role in E of the tapes. Tape 3 had significant variation in measured E values between the techniques, while Tape 1 and Tape 2 had relatively good agreement across all methods. While all the tapes are comprised of similar materials, the composition of the various layers and surface topographies are different. To ensure an appropriate assessment of tape modulus, tested specimens should be representative, when possible, of the product geometry that will be deployed on roadways.

Referring back to **Figure 1**, the most noticeable difference between the surface structures of all the tapes are the ridges on the top surface of Tape 3 (**Figure 1cii**). Upon further observation, the ridges on Tape 3 have a greater thickness, and therefore stiffness, than the underlying flat regions of this tape. Depending on whether one of these ridges was present on the three-point bend specimens, the measured E_{Flex} varied greatly. The Tape 3 specimens with ridges had a measured $E_{Flex} \approx 94$MPa while a specimen without ridges measured $E_{Flex} \approx 21$MPa. By measuring E on portions of Tape 3 containing these raised ridges, a larger than expected value of E_{Flex} was observed in three-point bend test results for Tape 3.

During tensile testing, it is unlikely that the presence of ridges would create such a discrepancy in E_{Tens} from the expected value because deformation will occur first in the part of the gauge (i.e. between the ridges) with the smallest cross sectional area. Each tested tape has a plain weave fabric reinforcement between the polymer substrate and the adhesive layers. The woven structure on each tested TPM tape is shown in the inset of **Figures ai, bi, and ci**. This fabric backing layer increases the overall stiffness and strength of the TPM tapes. If the threads in the backing are stiff and strong, this feature will be effective in transferring load applied in the axial direction causing an artificially high E_{Tens}. Additionally, the number of threads in the axial direction of a prepared sample will affect E_{Tens}. Depending on the number of threads in a tested sample the E_{Tens} value will vary which can cause high variability in the measurement of E_{Tens}. It is possible that these factors caused an artificially high value with a large variability of E_{Tens} for Tape 3.

The presence of ridges and the probable higher stiffness of the plain fabric weave reinforcement in Tape 3 specimens led to a large discrepancy between E_{Flex} and E_{Tens} measurements in comparison to the Tape Drape Test values. E_{Drape} reflected the expected E values from a tactile examination while E_{Flex} and E_{Tens} did not follow the expected trend for Tape 3 as a result of tape geometries affecting E determination during testing. The Tape Drape Test was not sensitive to the dramatic increase in E because these specimens were much larger, and the methodology does not call for any sample preparation or application of external forces allowing for the measured E to accurately characterize the tape.

The Tape Drape Test can easily be implemented for E characterization for TPM tapes. Prior to installation on roadway surfaces, the Tape Drape Test may be performed to assess E at the exact temperature of installation. Based on temperatures, a TPM tape with a higher or lower modulus can be selected to improve tape performance under the specific environmental conditions during installation. Further testing needs to be conducted to determine the exact effect that temperature has on E and therefore adhesion strength of TPM tapes on roadway surfaces.

Currently, the Tape Drape Test will allow for real-time assessment of E prior to installation and inform decisions on which TPM tapes to apply based on temperature.

CONCLUSION AND IMPLICATIONS

Traditional E characterization techniques require specific sample geometries that are not necessarily representative of the complete structure of TPM tapes. The three-point bend and tensile testing methods both require specific geometries prior to testing, while the Tape Drape Test only required specimens to be cut to length, leaving the structural features of the as-received materials intact. E was consistently characterized for Tapes 1 and Tape 2. For Tape 3, the results of the traditional test measurements were different from the Tape Drape Test results due to tape geometries. The Tape Drape Test was the only technique with the ability to characterize E of the tapes with what is expected from a tactile assessment due to the sample being reflective of the as-received tape geometry. This reason leads to the conclusion that the Tape Drape Test is the most accurate of the three E characterization techniques when determining E for the TPM tapes.

One advantage the Tape Drape Test has over the tensile and three-point bend test is its simplicity, leading to the ability to be conducted in the field. Tensile testing and three-point bend testing both require a load cell and actuator, while the Tape Drape Test requires only a camera, ruler, and protractor. Most portable electronic devices can act as a camera, ruler, and protractor, making the implementation of the Tape Drape Test simple and straightforward. The major requirement to employ this technique is the need for a horizontal ledge. Some suitable ledge selections that can commonly be found on a roadway construction site are the edge of a truck bed, pieces of equipment, or hoods of vehicles.

Characterizing E in the field is important for TPM tapes because E of TPM tapes can change depending on the temperature. When temperatures drop below T_g, the TPM tapes will transition into a glassy phase, resulting in an increase in E. At room temperature (approximately 25 °C), TPM tapes are ductile, but as temperature increases, E of the tapes can decrease when the tape transitions to an even more ductile state. For most commercial TPM tapes, these transitions occur at temperatures that can be reached outside depending on the climate and season.

In laboratory conditions, room temperatures are customary unless special equipment is employed to characterize E at higher or lower temperatures. Characterizing E exclusively at 25 °C when tapes will be applied and removed over a fairly wide temperature range can adversely affect the prediction of tape adhesive performance in the field. The Tape Drape Test can be employed to overcome this challenge and allow for on-site E characterization of TPM tapes under the conditions in which they will be utilized.

Depending on the characterized E based on the temperature, the application and removal procedure may need to be modified to ensure tape durability and ease of removal. When the tape is in a more ductile state, a slower application rate will reduce stretching and any potential plastic deformation caused by the application procedure, thus improving durability. However, during the removal process, a faster removal rate will improve the ease of removal of TPM tapes. As a result of measuring E in the field, a more effective approach can be taken for the application and removal of TPM tapes.

Tensile testing and three-point bend testing were unable to effectively determine E of all the TPM tapes due to the presence of ridges on the surface of Tape 3 and plain fabric weave. The Tape Drape Test is able to account for these tape geometries which makes the technique more appropriate for characterizing E of TPM tapes. Additionally, the Tape Drape Test can be employed in the field, accounting for the temperature-dependent E variation upon application. The Tape Drape Test can effectively determine E of TPM and allows the option to be implemented in the field.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: M. Rencheck, K. Erk, C. Davis; data collection: J. Gohl, H. Grennan; analysis and interpretation of results: M. Rencheck, J. Gohl, C. Davis, K. Erk; draft manuscript preparation: M. Rencheck, C. Davis; All authors reviewed the results and approved the final version of the manuscript. The authors do not have any conflicts of interest to declare.

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Supplemental Material: The Tape Drape Test – A Practical and Nondestructive Way to Assess Elastic Moduli of Pavement Marking Tapes in the Field

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Determining $\boldsymbol{\theta}$ for the Tape Drape Test

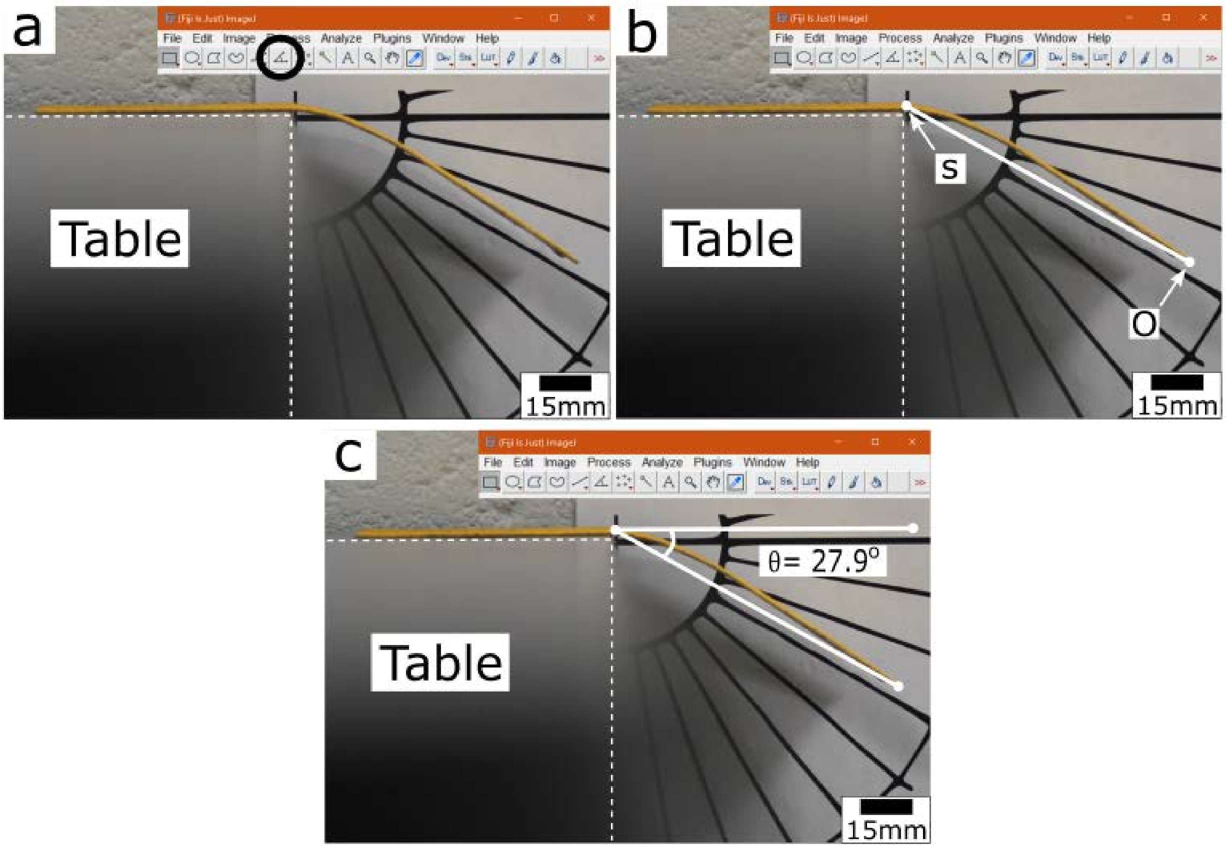

Figure S1 The ImageJ analysis to determine $\boldsymbol{\theta}$ for the Tape Drape Test using a) the angle tool, b) specifying the endpoint of the tape to the horizontal, c) establishing the horizontal and calculating $\boldsymbol{\theta}$.

ImageJ was used for the analysis of the drape angle (θ) for the Tape Drape Test. The image file was uploaded to ImageJ, and the angle tool in ImageJ was selected as the method to measure θ **(Figure S1a)**. The line segment from the draped end of the tape (Point “O”) to the point where the tape leaves the table (Point “S) was drawn (**Figure S1b)** for each trial. It is important to note the y-coordinate of Point “S” as this will help define the horizontal line needed to determine $\boldsymbol{\theta}$**.** Using the y-coordinate of Point “S”, a horizontal line is drawn to an arbitrary length which defines the reference line from which $\boldsymbol{\theta}$ was measured (**Figure S1c)**. The measurement function was used to determine $\boldsymbol{\theta}$ which was 27.9° for this trial.