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Bicycle Wheel Rim Reflective Materials Test Method Development

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U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, *Secretary*

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At the request of the Consumer Product Safety Commission (CPSC), a program was established in the Product Safety Technology Division of the National Bureau of Standards to evaluate reflective materials applied to bicycle wheel rims. The purpose of this program was to develop proposed test methods for determining the abrasion and peel resistance of pressure sensitive reflective tape on bicycle rims.

Current regulations promulgated by the CPSC for bicycles, 16 CFR 1500.18(a)(12) and Part 1512, do not include tests for retroreflective materials applied to or incorporated into bicycle wheel rims. A retroreflective material is one that reflects light back in the general direction of the source of the incident light. At the present time, there is one such commercial product available, in the form of a pressure sensitive tape, which is intended for use in lieu of spoke reflectors or retroreflective tires, on bicycles which are not equipped with caliper brakes. Consequently, a major objective of this program was to develop a prototype abrasion test apparatus, and attempt to establish test parameters using this material as a model. The intent was to make the test apparatus and testing procedures sufficiently broad in scope as to be amenable, without major modifications, for evaluating other types of reflective materials such as paint, lacquer, or integrally molded-in reflective materials that might be developed in the future.

The requirements for abrasion resistance, and the photometric methods of measuring the retroreflectance of tires are addressed respectively in paragraphs 1512.16 and 1512.18 of the current regulations. However, the abrasion tests prescribed for compliance testing of the tires is not directly applicable for use on the wheel rims. Therefore, the intent of this program was to develop a test apparatus that would be useful in compliance testing of the reflective materials after they were placed on the rim. The tape manufacturer has proposed an abrasion test based on modifications of Federal Test Method Standard No. 141A, Method 6142, entitled "Scrub Resistance." This method, designed to evaluate the scrub resistance of paints, involves the use of an apparatus which imparts a reciprocating motion to a brush lengthwise across a test panel. To use this procedure for compliance testing would necessitate removal of several pieces of the reflective tape, each about 6.4 cm (2.5 in) in length, from the rim. Since a major criterion, established by the CPSC, was that the reflective material be difficult to remove, the use of the modified Method 6142, for compliance, was essentially precluded.

A second area of concern was the peel resistance of the tape. There is no counterpart for this property in the tires, since the reflective material is molded into the sidewalls and cannot be peeled off. Peel adhesion strength and tensile breaking strength of the tape were determined as a potential aid in establishing a compliance test for peel resistance.

Abrasion Tester Development

In developing the abrasion tester, the following design parameters were established:

1. the abrader would be a circular wire-bristle brush

2. the brush would be motor driven to provide for controlled speed

3. the brush and motor would be mechanically balanced so that a known force could be applied to the brush

4. the wheel would be rotated continuously in order to uniformly abrade the reflective material around the complete circumference

5. the wheel mounting would be such that an entire wheel assembly could be removed from a bicycle and then tested with little or no modification.

Figure 1 and 2 are illustrations of the completed prototype test apparatus. Since the reflective tape was 0.32 cm (0.125 in) in width, a 1.27 cm (0.5 in) - diameter wire brush was selected as the abrader to ensure that the tape would be abraded across its width, and that a scrubbing action would be produced along both edges. The brush shank was attached to the end of the shaft of a variable speed motor by means of a chuck. The motor was mounted on a clamp so that the brush bristles were pointing downward. The motor clamp was attached to a pivot mounted on miniature ball bearings. A threaded rod containing a counterweight was attached to the opposite side of the pivot. This arrangement provided a means of balancing the weight of the motor and brush. Any known weight placed on top of the motor was then transmitted directly to the material under test. This assembly was then clamped to the platform of a scissors jack, which allowed positioning of the brush immediately above the surface of the reflective tape prior to addition of the test load. A strobe light was used to check the rotational speed of the brush and a motor speed control was used to adjust the brush speed to the desired number of revolutions per minute (rpm).

The wheel mount consisted of a rectangular open-ended box, of sufficient width to accommodate wheels up to 71 cm (28 in) in diameter. The top and bottom panels were slotted to allow the wheel axle to be positioned and fastened in place. The box was mounted on both ends with a single bolt and nut to a pair of vertical supports. This arrangement permitted the wheel to be tilted downward from a horizontal plane. This allowed wheels with varying rim geometries to be positoned so that the reflective material surface would be essentially normal to the brush bristles during the abrasion test. For driving the wheel, an electric motor was attached to the box, and an idler of appropriate diameter affixed to the end of the motor shaft. A constant speed motor, operating at 72 rpm, was selected for this purpose. A microswitch-activated electric counter, mounted on the box, monitored the number of wheel revolutions during tests.

Prior to the start of this program, several 51 cm (20 in) diameter bicycle wheels had been submitted by the CPSC to demonstrate the use of the reflective tape. These wheels were not suitable for the actual testing

program, because of varying degrees of damage, some intentional, to the tape. They did provide a means for preliminary evaluation of various test parameters, and for testing the functionality of the test apparatus.

Test Parameter Development

An arbitrary decision was made to revolve the rim at 25.4 cm (10 in) per second (about 10 rpm for a 51 cm (20 in) wheel). To achieve this, a 5.72 cm (2.25 in) diameter, grooved, metal idler was attached to the constant speed motor, and adjusted to contact the tire tread surface of the fully inflated tire. In preliminary tests, the steel wire brush was rotated around an axis perpendicular to the tape surface at approximately 800 rpm. This parameter was selected because it is comparable with the linear speed of the brush used in the Scrub Resistance testing apparatus. Various loads, ranging from about 3.9 to 9.8 N (0.86-2.2 lbf) were applied to the brush. These preliminary procedures did not result in any evident problems with the basic concept of the test apparatus. Since the tape was affixed to the wheel rim by means of a pressure sensitive adhesive, a primary concern was that the test load, applied to the brush, would not physically distort the tape, and that the rotational speeds of the brush and/or the wheel would not produce sufficient frictional heat to cause distortion. Visual examination indicated the presence of abrasion damage, especially at the higher loading levels. The extent of abrasion with respect to compliance requirements for the retroreflective properties could not be estimated. However, there was no other visual evidence of damage to the tape in terms of distortion or tearing, that might have an adverse effect on its retroreflective properties or that would not be consistent with actual use conditions.

Six new 51 cm (20 in) and three 71 cm (28 in) rims, with factory applied tape on both sides, were obtained through the CPSC. Attempts to obtain the requisite components needed to construct complete wheels with these rims were not successful, since wheel hubs apparently are not readily available as replacement parts. Subsequently, a temporary modification of the apparatus was made in order to mount the rims for testing. A circular metal plate, having a diameter of approximately 0.64 cm (0.25 in) greater than a 51 cm (20 in) wheel rim was fabricated. This plate was attached to a shaft and bearing assembly, substituting for the wheel axle. Clamps, designed for insertion into the spoke holes, were located on the plate inside the rim. The 5.72 cm (2.25-in) metal idler was replaced by one of approximately 3.18 cm (1.25 in) in diameter, to which a piece of 1.3 cm (0.5 in) thick foam rubber was attached, as a means of rotating the metal plate. No other modifications were required for the abrasion apparatus. However, a modification was required for the device used to mount the rim for the measurement of the retroreflective properties.

Test Procedures

On the basis of the preliminary evaluation, a wheel rotation speed of 25.4 cm (10 in) per second, and a brush speed of 800 rpm, were used for the tests on the new rims. Four rims were abraded on one side. The force

applied to the wire brush was either 4.9 or 9.8 N (1.1 or 2.2 lbf), and the rims were rotated for either 1000 or 2000 revolutions.

These four rims plus a fifth unabraded rim were submitted to the NBS Radiometric Physics Division for photometric measurements. Prior to conducting these measurements, the exposed metal portions of the rims were masked with an opaque, matte black tape. The retroflective properties of both the abraded and unabraded tape on each of the rims were determined.

Results of Abrasion Tests on the Retroreflective Properties

The results of the photometric measurements, and the effect of the various abrasion parameters on the ratio "A", in metres, the performance parameter, are given in table 1. The results indicate that all six values of "A" were below the minimum requirements listed in the bicycle standard for the sample abraded for 2000 revolutions while subjected to a load of 9.8 N (2.2 lbf). Two of the six values were below minimum for the sample abraded for 1000 revolutions while subjected to a load of 9.8 N (2.2 lbf). The two samples abraded using a test load of 4.9 N (1.1 lbf) met all of the minimum requirements although the values for A, measured at an entrance angle of 40^{o} and an observation angle of 1.5^{o} were marginal. Since it was not the intent of this study to develop a test procedure and testing parameters that would result in failure of the reflective tape, three of the rims were then subjected to somewhat less severe test conditions. These tests consisted of applying a 3.92 N (0.86 lbf) load to the reflective tape for 1000 revolutions, in order to evaluate the reproducibility of the test procedure. The results of these tests are also given in table 1.

Comments on Abrasion Test Parameters

In developing the abrasion test procedures, several selected parameters were used. These include the type and size of the steel wire brush, the applied force on the brush, the rotational speed of both the wire brush and the bicycle rim, and the number of rim revolutions per test. The selection of these parameters were based on the preliminary studies, and on some basic concept of the properties of the components comprising the reflective material under evaluation. Although the chosen test parameters are arbitrary to a certain extent, they were selected as a means of at least equaling the severity of abrasion, occurring in the flat panel, scrub test developed by the manufacturer, which does not, incidentally, lead to failure. This test was considered by the CPSC to be an adequate means for evaluating the abrasion resistance of the tape, and for quality control purposes. In conducting the tests on the bicycle rims, it seemed reasonable to expect a decrease in reflectivity to occur as the applied force increased, and as the number of rim rotations increased. These two variables were the only ones that could be assessed with respect to changes in reflectivity, at this time. It was hoped that the selected procedures would subject the material to abrasion ranging from "moderate" to "severe." The latter was achieved, the former may not have been.

One change that will probably have to be made is in the type of wire brush used. Originally, it had been intended to use a 1.27 cm (0.5 in) diameter cup brush for these tests. However, during the preliminary work there was some evidence that an applied test force of 9.8 N (2.2 lbf) might result in permanent distortion of the wire bristles before a test were complete. For this reason, as well as the lack of knowledge as to the effect of the selected test procedures on the retroreflective properties, and the limited number of samples, a solid wire brush was used. Both brushes were constructed of 0.13 mm (0.005 in) diameter steel wire.

As a result of the photometric data obtained on the abraded rims, it seems apparent that the applied force need not exceed 4.9 N (1.1 lbf). Under these circumstances, a cup brush should perform satisfactorily. Subjective observations of both types of brush while in operation, seemed to indicate that the cup brush conformed better to the rim than did the solid brush. This may be an important consideration if other reflective materials of greater width become available. For example, paragraph 1512.18(c)(2)(i) of the bicycle regulations, permits measurement of the retroreflective properties on material between two concentric circles, the larger of which is no more than 0.02 m (0.79 in) greater in radius than the smaller.

The prototype abrasion test apparatus seems to produce reasonably consistent results, based on the small sample size. The design is such that any of the test parameters are easily changed and the approach should provide a suitable method for compliance testing. However, in developing the apparatus and test procedures, no attempt was made to simulate actual use conditions.

Peel Resistance

A number of 0.32 cm (0.125 in) wide samples of the reflective tape, in ready to use form were supplied for the purpose of evaluating the peel strength. These samples were in the form of cut strips, the useful portion of which did not exceed 17.8 cm (7 in) in length. Normally, 180° peel strength tests are conducted using a 30.5 cm (12 in) long specimen, applied to a test panel in a specified manner. The peel strength is determined by the average force required to remove 5.1 cm (2 in) of the specimen from a test panel, usually using a testing speed of 30.5 cm (12 in) per minute. As a general rule, most commonly used pressure-sensitive tapes do not break under these test conditions. However, the reflective tape under evaluation was so fragile that it was felt that slower testing speeds should be used to lessen the initial impact forces on the tape, and to obtain useful data.

The test specimens were prepared by pressure bonding approximately three inches of the strip to a chromium plated steel panel. The specimens were tested on a Universal Testing Machine at a crosshead speed of 5.1 cm (2 in) per minute. During the tests some stretching occurred in the unbonded portion of the specimen. There was virtually no peeling of the specimen from the test panel. The tape essentially ruptured at the site of the initial 180° bend. The maximum peel strength, considered to be a more

important parameter for this material than the average peel force, was for all practical purposes synonymous with the breaking strength. Similar phenomena occurred during tests conducted at the crosshead speed of 2.54 cm (1 in) per minute, except that the tape broke at lower load levels. The average maximum force sustained by the specimens was 0.33 N (1.18 ozf) at 2.54 cm (1 in) per minute, and 0.40 N (1.45 ozf) at 5.1 cm (2 in) per minute. On the basis of the behavior of the test specimens and the results obtained, these data do not represent the true peel adhesion strength. The tests do indicate that the bond between the adhesive and the metal, and between the adhesive and the support layer (backing) are greater than the cohesive strength of the support layer, which also contains the reflective material on its outer surface. This is an extremely desirable property, with respect to the intended use of this material.

Tensile Tests

Tensile breaking strength tests were also conducted at a crosshead speed of 2.54 cm (1 in) per minute. The average breaking force was 0.38 N (1.38 ozf) for the 0.32 cm (0.125 in) tape, or approximately 1.20 N per centimeter of width (0.69 lbf per inch of width). Elongation to break was 112% on specimens tested with a 2.54 cm (1 in) gage length. It should be noted that the tensile strength is not significantly different than the force values obtained at break during the peel tests.

Manual Tape Removal

Attempts to lift the tape from the rim, e.g., by scraping off a section and then trying to lift the exposed end with the fingernails, were not successful. It was possible to remove the tape with a sharp edged device such as a razor blade, but when the lifted section was grasped with the fingers, the tape broke immediately.

Comments on Peel Resistance

The results of the tensile and peel strength tests obviously indicated that the reflective tape evaluated in this program would be essentially resistant to all but abnormal abuse. Consequently, the development of a generic test for resistance to peeling, using this particular pressure-sensitive tape as a model, was virtually precluded.

One possible means of compliance testing for the peel resistance would be to lift a portion of the material, attach a specified weight to this portion in such a manner as to induce a 90° peel angle, and limit the amount of material that could be peeled off over a specified period of time. Such a procedure, however, would be suspect, since even microscopic damage encurred in removing the material from the rim, could result in premature failure. In the case of this particular application, premature failure would be an asset, since a damaged section of material might be expected to break more readily than an undamaged section and therefore pass a requirement for peel resistance.

Summary

A prototype testing apparatus was designed and built for use in conducting abrasion tests on reflective materials applied to bicycle wheel rims. Data were obtained to determine the effects of various arbitrarily selected test parameters on the retroreflective material used as a model. These results, although preliminary in nature and based on a small sample, indicate that the apparatus and procedure are suitable for compliance testing.

It was not the purpose of this program to attempt to simulate use conditions, nor to recommend specific test parameters. The design of the apparatus is sufficiently flexible to allow a rather broad range in test parameter options. These options involve the type and size of the abrader brush, speed of rotation of both the brush and the bicycle wheel, the force applied to the abrader, and the number of wheel rotations.

Attempts to establish some bases for measuring the adhesive peel resistance were not successful. The cohesive strength of the tape matrix was less than the adhesive strength of the pressure sensitive adhesive used in this system. As a result, the tape tended to break before a measurable amount of peel could be achieved.

TABLE 1. The Effects of Abrasion on Bicycle Wheel Rim Reflective Material

Observation Angle	Entrance Angle	A, in Metres a/								
		Spec. b/	Measured at Test Condition c/							
degrees	degrees		A	S.D. d/ (A)	B	C	D	E	F	F(Range)
0.2	-4	2.2	7.36	0.37	4.40	3.45	4.00	1.99*	4.26	3.84-4.54
0.2	20	1.9	6.78	0.22	4.20	3.51	3.00	1.70*	3.91	3.75-4.00
0.2	40	1.3	3.35	0.17	1.81	1.84	1.34	0.90*	1.70	1.61-1.77
1.5	-4	0.22	0.43	0.04	0.28	0.30	0.20*	0.14*	0.29	0.28-0.30
1.5	20	0.19	0.39	0.04	0.28	0.21	0.22	0.15*	0.27	0.25-0.29
1.5	40	0.13	0.23	0.04	0.14	0.14	0.10*	0.07*	0.16	0.14-0.18

a/ The ratio, A, as defined in paragraph 1512.18(o)(2)(iii).

b/ Minimum value as specified in part 1512, table 3.

c/ Test condition:

A: unabraded-average of six samples
B: 4.9 N (1.1 lbf) @ 1000 revolutions
C: 4.9 N (1.1 lbf) @ 2000 revolutions
D: 9.8 N (2.2 lbf) @ 1000 revolutions
E: 9.8 N (2.2 lbf) @ 2000 revolutions
F: 3.92 N (0.86 lbf) @ 1000 revolutions - average of three samples

d/ S.D. = standard deviation

* Failed minimum specified value

FIGURE 1

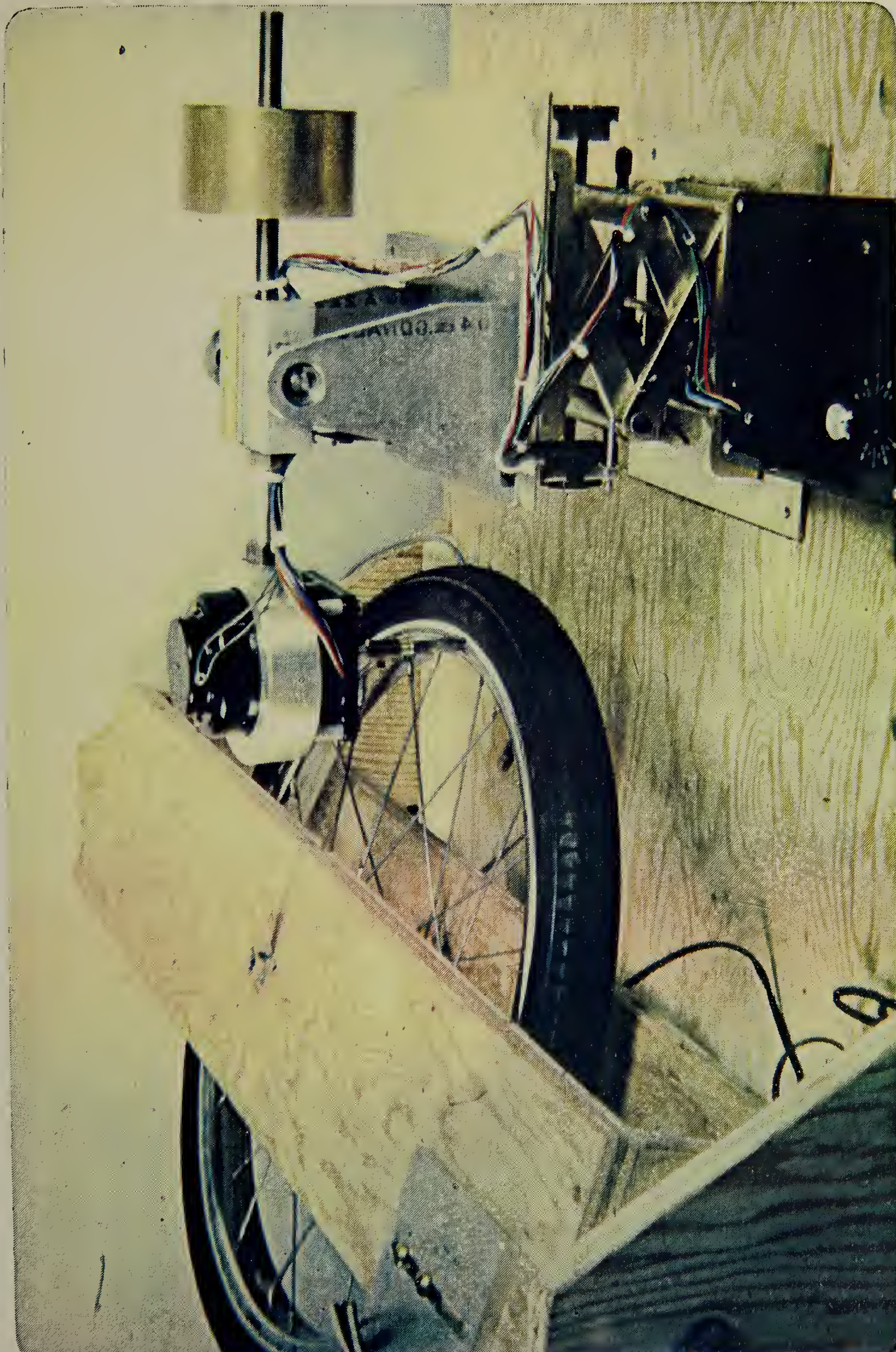

FIGURE 2

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A prototype testing apparatus was designed and built for use in conducting abrasion tests on reflective materials applied to bicycle wheel rims. Data obtained on the effects of various arbitrarily selected test parameters on a pressure sensitive reflective tape, used as a model, indicate that the abrader and test procedures are suitable for use in compliance testing of rim-applied retroreflective materials. Materials of this type, intended for use in lieu of spoke reflectors or retroreflective tires, are not included in the current bicycle safety regulations promulgated by the Consumer Product Safety Commission.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Abrasion test development; bicycle compliance tests; bicycle safety; reflective materials for bicycles; safety of bicycles; safety standards.

18. AVAILABILITY ☒ Unlimited

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