Physical Testing of Traffic Stripe Paint Durability

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Two laboratory tests were used to evaluate several physical properties of traffic stripe paints. The objective of this evaluation was to provide a better understanding of these properties as they relate to predicting durability of paint stripes in the field. Tensile tests of free film specimens of paint yielded several properties derived from the stress-strain curves. Abrasion tests provided results for paint specimens tested both dry and submerged in distilled water. The tests produced consistent and repeatable results. Ten paint samples representing several different volatile and nonvolatile vehicles were evaluated using the two laboratory tests. The paints were different as reflected in the tensile properties. The water-based paints were considerably more ductile than the organic solvent–based paints. The load rate used for the test had significant effect on the results because of increased viscous creep introduced at slower load rates. The 10 paints were evaluated in the field for 5 years. Three water-based paints exhibited superior performance. The performance of these water-based paints correlated well with modulus of toughness computed from tensile tests and wear indices from dry Taber abrasion tests.

Highway pavement markings are subjected to traffic and environmental forces that cause their deterioration and the need for a continuous remarking effort. Pavement markings that become unacceptable because of deterioration are safety and operational hazards. Any improvements in durability or means of evaluating durability will reduce maintenance costs.

Possible modes of failure for pavement markings include poor adhesion, chipping, abrasion, loss of reflectivity (poor bead retention), and discoloration. Factors that affect the performance of traffic paint include paint formulation, substrate, surface preparation, humidity and temperature, traffic volume, and striping equipment.

Field tests have been used in the past to evaluate durability, reflectivity, and other characteristics of pavement marking materials. However, the rapid introduction of new materials is not conducive to lengthy and loosely controlled field evaluations.

Physical properties of paint, determined by a laboratory testing procedure, that can be used to predict paint durability in service would be useful to highway officials in selecting pavement marking materials. The tests could also be used in quality control programs to ensure that delivered and applied products meet specifications. To this end, a laboratory testing program was developed and carried out on 10 traffic stripe paints. Physical properties derived from tensile tests and abrasion tests were obtained. A field study was implemented to develop performance data for the 10 paints for correlation with laboratory-measured properties. Performance was judged on the basis of paint stripe area loss under the action of environmental forces and traffic, but evaluation of reflectivity was not included.

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BACKGROUND

Traffic Paints

Pavement marking paints contain pigments, volatile vehicles, and nonvolatile vehicles. The type of vehicle used has considerable effect on the physical properties of interest. The volatile vehicle is either an organic solvent or water. Organic solvents evaporate into the atmosphere and have been criticized for being an unacceptable form of air pollution in some areas. This has been one of the factors in a change to more water-based paints or modified solvent-based paints with a greater percentage of nonvolatile vehicle. The most widely used type of nonvolatile vehicle (resin) is a drying oil that cures by oxidation after the evaporation of the solvents. Alkyds have been the most commonly used resin in traffic stripe paints. To increase reflectivity, glass beads are added to the paint. These can be premixed into the paint, dropped onto the freshly painted stripe, or both.

The selection of paint formulation is a trade-off between (*a*) drying time, (*b*) airborne organic solvent regulations, (*c*) flexibility, (*d*) hardness, (*e*) bead retention characteristics, and (*f*) adhesion of the substrate. One of the primary considerations in selecting a pavement marking paint is the drying time required. The organic solvent–based paints dry the fastest, but this subsequently reduces the flexibility of the paint. The water-based paints dry more slowly and have greater flexibility and lower abrasion resistance. The slower curing time required by alkyd resin paints has been improved by the addition of chlorinated rubber, but this has been known to decrease flexibility. Water-based paints require more attention to surface preparation to achieve a good bond, whereas organic solvents are much better in this respect, especially on asphalt surfaces.

All of these characteristics of paint are generally known, but better ways of quantifying the relevant properties that can be used to predict the service life of the paint are still sought. The results reported in this paper will advance the knowledge of the physical properties of typical traffic stripe paints.

Past Research

Several research efforts (*1–4*) have been conducted to develop accelerated laboratory testing procedures to predict paint durability. General information regarding testing to determine durability of organic coatings can be found in ASTM STP 691 (*5*) and ASTM STP 781 (*6*).

The literature revealed numerous laboratory test methods for traffic stripe paint, including tensile tests on thin films and various abrasion resistance tests. Field tests are regarded as the most thorough method for assessing stripe durability with mixed correlation reported between laboratory-measured paint properties and field performance. Chipping and abrasion are identified as predominant painted traffic stripe failure modes and are related to film tensile properties and abrasion resistance. Placement conditions and quality, particularly as related to bond development, affect stripe durability.

EXPERIMENTAL DESIGN

Two testing methods were selected on the basis of the findings and recommendations cited in the literature review, types of failure modes expected of paint, and tests most likely to predict susceptibility to these failure modes. Tensile tests of free film samples were used to quantify susceptibility to cracking, and abrasion tests were used to quantify susceptibility to normal wear.

Paints Tested

Four traffic paints that were in inventory were provided by the Alabama Highway Department as follows (identification code is in parentheses):

- Water base (white) (WB-2-W),
- Water base (yellow) (WB-3-Y),
- Organic solvent base (white) with premixed beads (SB-1-W), and
- Organic solvent base (yellow) with premixed beads (SB-2-Y).

In addition, three companies provided the following five paints for the study:

- Water base (white) (WB-1-W),
- Modified alkyd-chlorinated rubber (white) (CR-1-W),
- Modified alkyd-chlorinated rubber (yellow) (CR-2-Y),
- Alkyd resin (yellow) (AR-1-Y), and
- Modified alkyd resin (white) (MAR-1-W).

For an extreme data point, a sample of white latex (water base) house paint (HP-1-W) was tested.

Tensile Tests

Free film tensile tests, used successfully in other cited research efforts, involve applying the paint to a backing material from which the paint can be separated after drying. Cut into the shape of a tensile coupon (bone shape), the sample can then be tested while load-deformation data are recorded for evaluation of several tensile properties.

The following procedure was used to produce the tensile test coupons:

1. A 5-cm-wide Teflon tape was applied to a metal plate.
2. The paint was puddled at one end of the taped plate and a Bird film applicator was used to draw a 0.38-mm wet film thickness across the surface. A dip-coater (ASTM D 823-84 Method B) was also tried to obtain a uniformly coated surface, but this method did not work well for all of the paints because the tape tended to "shed" some of the paints when placed in a vertical position to dry.
3. The samples were allowed to dry for 24 hr at room conditions and then cut to the desired shape. The die cutter was manufactured to specifications that provided a gauge length of 3.8 cm and a throat width of 0.6 cm.
4. After being cut, the paint coupon was peeled from the Teflon tape and hung vertically to cure for an additional 48 hr.

A Tinius Olsen universal testing machine fitted with rubber-lined, low-capacity grips was used for the tensile testing of the paint samples. A load cell with a capacity of 44.5 N was installed between the crosshead and the upper grip for greater sensitivity and resolution. Tests were conducted under a controlled deformation rate mode. The thickness of each paint sample was measured with a micrometer to the nearest 0.001 mm and recorded for use in the conversion from force to stress, calculated as follows:

$$s = 1{,}000P/(t_w * t) \qquad (1)$$

where

s = stress,
P = force,
t_w = throat width, and
t = thickness of paint.

Strain was calculated as

$$\varepsilon = \delta/g \qquad (2)$$

where

ε = strain,
δ = LVDT deflection, and
g = gauge length.

Abrasion Tests

Abrasion tests performed on paints typically use either an abrading rotating wheel or sand falling onto a painted surface. A Taber Abraser, of the former variety, was selected because of its wide use by other highway departments and research studies. The reliability of Taber Abraser results has been questioned in the past. However, it was believed that the Taber Abraser offered the best available method when procedures for preparing the abrading wheels are carefully followed. ASTM D-4060 and Federal Test Method Standard 141a provide testing procedures for using the Taber Abraser.

The following procedure was used to produce the specimens used for the abrasion tests:

1. Paint thinner was used to clean 10- × 10-cm steel specimen plates.
2. A Bird applicator was used to apply a 0.38-mm wet film thickness of paint. Five specimens were prepared for each paint sample.
3. The prepared specimens were allowed to dry for 24 hr at room conditions.

The three testing parameters for the Taber Abraser are the choice of abrasive wheels, the weight placed on the wheels, and the number of cycles to which the specimen is subjected. The wheels selected were CS-17 resilient wheels composed of rubber and abrasive grain, which produce a harsh abrasive action. The arms were weighted each with 1000 grams. The specimens tested dry were subjected to 2,000 cycles, and the specimens tested submerged were subjected to 500 cycles. The following test procedures were followed:

1. The specimen plates were weighed.
2. The weighed specimen plate was mounted on the Taber Abraser and the CS-17 wheels lowered into position.
3. The automatic counter was set to the appropriate number of cycles and started. A vacuum pickup was used to remove loose particles from the specimens during dry testing.
4. At the end of the cycles, the specimen plate was weighed and the wear index computed as

$$\text{Wear index} = [(A - B) \times 1{,}000]/C \quad (3)$$

where

A = weight before abrasion,
B = weight after abrasion, and
C = number of cycles.

Field Evaluation

Transverse test stripes were placed across the outside lane of US-29 east of Auburn, Alabama, in March 1987 at the junction of a 1-year-old and a 3-year-old asphalt surface. The AADT for the four-lane facility is approximately 13,000. Two stripes each of the 10 paints were placed on both the 1- and 3-year-old surfaces. Stripes were placed by experienced Alabama Highway Department personnel with a walk-behind unit. Calibrations were done to try to achieve a film thickness of about 0.25 mm. The average for all stripes was 0.26 mm. There was, however, considerable between- and within-stripe film thickness variability, but no apparent relationship with performance. Placement temperature was approximately 21°C.

The condition of the stripes was observed periodically to assess their performance. Estimates of paint surface area retained form the basis for evaluation of performance and comparison with measured paint properties. The paint areas lost in 1.2-m-wide strips across wheelpaths were estimated and used to compute a percentage of stripe area remaining. The reported results are the average from two raters rounded to the nearest 5 percent. Results from individual raters were always within 15 percent. Initially observations were made frequently, but the interval between observations increased with time. A final 5-year evaluation was made in March 1992.

RESULTS AND DISCUSSION

Tensile Tests

Tensile tests were performed on nine paints [samples of (CR-2-Y) could not be prepared because of extreme brittleness]. Samples cured at room conditions were tested at load rates of 1.25 cm/min. The properties of the paints are given in Table 1. At least three samples were tested for each paint. The mean and coefficient of variation are reported for film thickness, ultimate strength (peak of stress-strain curve), modulus of toughness (area under stress-strain curve to ultimate strength), failure strength (breaking strength), and elongation at failure and initial modulus (initial slope of stress-strain curve).

Representative stress-strain curves for three paints are shown in Figure 1. These plots show the significant differences in the tensile characteristics between the paint formulations. The solvent-based alkyd resin paint (AR-1-Y) is very brittle, whereas the modified alkyd resin paint (MAR-1-W) has considerably more ductility but a lower ultimate strength. The water-based

TABLE 1 Tensile Properties (Cure, Room Condition; Load Rate, 1.25 cm/min)

	Thickness (mm)		Ultimate Strength (kPa)		Mod. of Toughness (kPa)		Failure Strength (kPa)		% Elongation at Failure		Initial Modulus (MPa)	
Paint	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
HP-1-W	0.22	0.45	2737	0.13	724	0.31	2427	0.19	30	0.29	74	0.24
WB-1-W	0.38	0.18	4082	0.05	1345	0.06	2882	0.06	39	0.11	83	0.10
WB-2-W	0.36	0.25	1738	0.09	2055	0.25	1365	0.08	133	0.19	26	0.35
WB-3-Y	0.31	0.32	1744	0.06	1441	0.25	1179	0.07	100	0.27	26	0.17
CR-1-W	0.32	0.21	8605	0.26	138	0.32	8605	0.26	2	0.30	414	0.37
MAR-1-W	0.50	0.09	1207	0.03	421	0.07	883	0.06	40	0.10	20	0.14
SB-1-Y	0.40	0.15	2930	0.04	48	0.13	2930	0.04	2	0.23	288	0.56
SB-2-Y	0.24	0.05	4675	0.09	124	0.12	4675	0.09	4	0.15	138	0.14
AR-1-Y	0.38	0.09	4709	0.06	103	0.12	4709	0.06	3	0.15	191	0.21

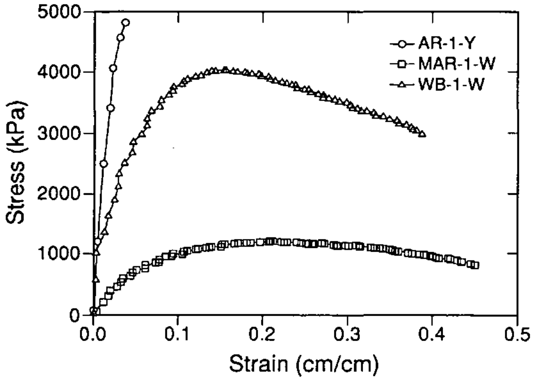

FIGURE 1 Representative stress-strain curves.

paint (WB-1-W) has good ductility, high ultimate strength, and a failure strength considerably lower than the ultimate strength.

Abrasion Tests

Abrasion tests were run on five specimens of each of the 10 paints as previously described. The specimens were tested dry for 2,000 cycles. Abrasion tests were also run on the same number of specimens submerged in distilled water for 500 cycles. Results for the house paint (HP-1-W) were not useful because the paint lost adhesion to the specimen plate. The mean of the wear indices and coefficient of variation for each series of tests are given in Table 2. Note that the smaller the wear index, defined by Equation 3, the more abrasion resistant is the paint and that the index approaches zero for no wear. Table 2 also contains the relative ranks of the paints tested. The lower the rank, the better the performance for that test.

The most significant findings of these tests were the relatively poor performance of the water-based paints when submerged in water. The alkyd resin paint was the best performer overall considering both conditions. The generic solvent-based paints (SB-1-W and SB-2-Y) performed poorly in the dry test but did better in the submerged test. The modified alkyd resin paint performed poorly for both abrasion test conditions.

Field Evaluations

The transverse stripes were observed periodically to assess their performance for comparison with paint properties. The early response of the stripes provides interesting insight into the influence of bond and paint stress-strain characteristics. Long-term performance appears to be controlled primarily by wear and abrasion resistance.

Table 3 contains a summary of the performance of the stripes after 5 years. These data indicate that except for the paint (WB-1-W), the stripes on the 3-year-old pavement surface performed at least as well as the stripes on the 1-year-old pavement surface. Replicate samples on the 1- and 3-year-old surfaces performed similarly.

The house paint (HP-1-W) was incompatible with asphalt pavement surfaces. The paint did not adhere to the pavement surface and the stripes were completely obliterated in 2 or 3 days.

The water-based paint (WB-1-W) experienced severe early chipping on the 3-year-old surface and accounts for the poor long-term performance (Table 3). The water-based paint (WB-2-W) experienced limited early chipping, but this did not increase with time. The performance of these two paints suggests that the effects of poor adhesion will be apparent early in stripe life.

The solvent-based (SB), chlorinated rubber (CR), and alkyd resin (AR) paints were brittle, and the water-based (WB) paints tended to be more ductile. The more brittle paints also tended to be stiffer and have higher tensile strength. The brittle paints experienced early cracking within and around the periphery of the stripes that progressed in size and number for about 1 year. These cracks penetrated the asphalt surface.

Brittleness is primarily responsible for the transverse stripe cracking. As the paint dries and shrinks and as the pavement/paint expands and contracts with temperature, shear stresses at the paint-pavement interface induce tensile stresses in the paint film that cause cracking. The more ductile paints are able to develop the necessary strain without exceeding tensile strength, whereas brittle paints are not able to accomplish this even though their tensile strength may be greater. As for the periphery cracks in the asphalt, the expansion and contraction of the pavement in response to temperature gradients are inhibited by the stripe. The more flexible and ductile paints are better able to conform to pavement movements.

TABLE 2 Taber Abraser Results

	Wear Index					
	Dry			Submerged		
Paint	Mean	CV	Rank	Mean	CV	Rank
HP-1-W	0.419	0.048	7	–	--	10
WB-1-W	0.167	0.045	1	0.586	0.220	6
WB-2-W	0.198	0.053	2	0.458	0.045	5
WB-3-Y	0.222	0.022	5	0.758	0.058	8
MAR-1-W	0.574	0.026	8	0.762	0.198	9
CR-1-W	0.221	0.201	4	0.366	0.063	2
CR-2-Y	0.350	0.045	6	0.611	0.260	7
SB-1-Y	0.691	0.234	9	0.455	0.178	4
SB-2-Y	0.761	0.052	10	0.383	0.112	3
AR-1-Y	0.220	0.041	3	0.284	0.057	1

TABLE 3 Summary of Paint Performance After 5 Years

Paint	% Paint Surface Remaining 3-yr old	1-yr old	Average	Comments
HP-1-W	0	0	0	–
WB-1-W	20	90	55	Early chipping on 3-yr old surface
WB-2-W	95	95	95	–
CR-1-W	0	0	0	–
MAR-1-W	55	15	35	Diff. 3- and 1-yr surface
SB-1-W	50	10	30	Diff. 3- and 1-yr surface
CR-2-Y	70	30	50	Diff. 3- and 1-yr surface
WB-3-Y	100	100	100	–
AR-1-Y	40	20	30	–
SB-2-Y	70	30	50	Diff. 3- and 1-yr surface

Other studies have observed the same periphery cracking around traffic stripes and sealers on asphalt. This has also been explained as being caused by the traffic paint deforming the asphalt underneath the edges (7).

The influence of early cracking on long-term performance could not be definitely ascertained. Progressive loss of area appeared to be due to wear or abrasion and some chipping that did not appear to be directly related to the early cracking. However, comparison of long-term stripe performance with paint stress-strain properties indicated that paints that cracked early lost area faster.

Correlations

Average percent remaining paint surface from Table 3 and various paint stress-strain properties from Table 1 were plotted to examine relationships between tensile properties and stripe performance. The plots do not show any strong continuous relationships, but there is a distinct grouping of the two water-based paints (WB-2-W and WB-3-Y) that exhibited superior performance. This grouping is strengthened if the performance of the third water-based paint (WB-1-W) on the 3-year-old surface is discounted and the performance on the 1-year-old surface used instead of the average. The plots indicated that high ductility, as measured by percent elongation at failure, may be important but that ultimate tensile strength may not be important. Figure 2 indicates that modulus of toughness, which combines strength and ductility, is definitely important. The water-based paints with large toughness performed well, whereas the SB, CR, and AR paints with small toughness performed poorly. This suggests that the early cracking may be a factor in performance, although not discernible with periodic visual observations.

Dry wear index values from Table 2 and average percent remaining paint surface from Table 3 are plotted in Figure 3. Again the three water-based paints that had superior performance are grouped. However, the chlorinated rubber paints (CR-1-W and CR-2-Y) and the alkyd resin paint (AR-1-Y), which had poor performance, also have low abrasion loss. This suggests that stripe performance is a function of both paint stress-strain and abrasion characteristics, and that physical tests for both should be included for evaluation. Although additional testing and evaluation are needed to establish definitive criteria, the data from this study suggest that a modulus of toughness greater than 1400 kPa and a Taber dry wear index less than 0.25 are required to ensure long-term stripe performance. Wear indices from submerged abrasion testing were also compared with stripe performance but did not differentiate the superior-performing water-based paints.

Bond is also important but may be controlled through chemical compatibility with pavement surface materials. Bond

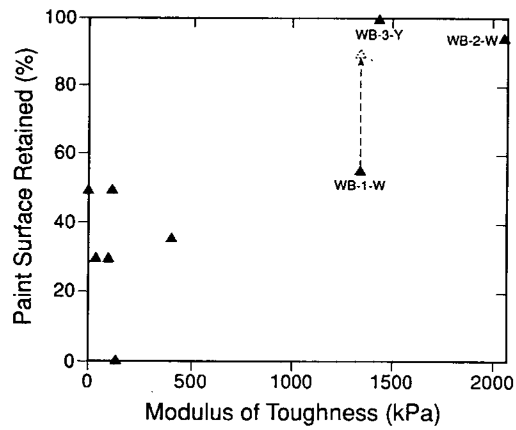

FIGURE 2 Stripe performance versus paint toughness.

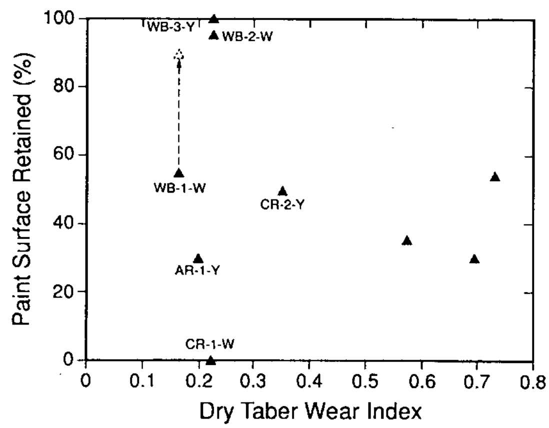

FIGURE 3 Stripe performance versus wear index.

development is also sensitive to application conditions. It is suspected that improper application was the cause of poor adhesion of the paint (WB-1-W) on the 3-year-old surface, which led to early chipping. To evaluate paints for acceptance and possibly for quality control purposes, some form of bond test is needed to complement toughness and abrasion tests. A possibility would be to modify the Taber abrasion tester to test samples applied directly to pavement surfaces rather than metal plates. This modification would provide an evaluation of adhesion as well as resistance to abrasion.

CONCLUSIONS

Two laboratory tests were performed to evaluate physical properties of traffic stripe paints. Tensile tests of free film specimens of paint yielded several properties derived from stress-strain curves. Abrasion tests provided abrasion resistance for both wet and dry conditions. The tests produced consistent and repeatable results that varied widely for the different types of paints tested.

Ten paint samples representing a variety of volatile and nonvolatile vehicles were tested and evaluated using the laboratory tests developed. The paints were quite different as reflected in the tensile properties. The water-based paints were considerably more ductile than the organic solvent-based paints.

The abrasion tests also produced a wide variation of results among the 10 paints tested. Dry testing produced lower wear indices, and water-based paints performed poorly when tested wet. The alkyd resin paint tested had the highest abrasion resistance considering both wet and dry test results. Dry wear indices correlated best with field stripe performance.

The 5-year field performance of the ductile water-based paints was superior to the more brittle solvent-based, chlorinated rubber, and alkyd resin paints. Correlation of stripe performance with modulus of toughness and dry Taber abrasion wear index indicated that paint properties measured by both are important and should be considered in paint evaluation.

ACKNOWLEDGMENT

This research was sponsored and supported by the State of Alabama Highway Department through the Highway Research Center of Auburn University. The authors are grateful for the sponsorship and assistance of the Alabama Highway Department.

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Publication of this paper sponsored by Committee on Coatings, Signing and Marking Materials.