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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **138**

PAVEMENT MARKINGS: MATERIALS AND APPLICATION FOR EXTENDED SERVICE LIFE

TRANSPORTATION RESEARCH BOARD
National Research Council

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to maintenance engineers, traffic engineers, materials engineers, and others concerned with pavement-marking materials. Information is presented on the various types of traffic-marking materials being used by states to obtain extended service life.

Administrators, engineers, and researchers ae continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

Enormous quantities of paint, thermoplastics, glass beads, raised markers, and other materials are used every year to mark the highways of the United States. This report of the Transportation Research Board describes the need for markings, preparation of the pavement surface, and the various types of paint, thermoplastic, thermosets, tapes, and raised markers in current use.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

PAVEMENT MARKINGS: MATERIALS AND APPLICATION FOR EXTENDED SERVICE LIFE

SUMMARY

Fatigue, alcohol impairment, and visibility are seen as major contributing factors to highway accidents. Not much is known about fatigue as a contributing factor by itself; rather it is interwoven with alcohol impairment and visibility. Removal of alcohol-related accidents from the accident statistics does not alter the fact that it is more hazardous to drive at night than during the day. The driver must first detect something, then identify it, decide what action to take, and put that decision into effect. The interval currently assumed for this entire process is 2.5 seconds. Visibility and visual cues as offered by pavement markings are important to this process.

Approximately 37,000,000 gallons (140,000 m^3) of solvent-borne traffic paint, 55,000 tons (50,000 Mg) of thermoplastic marking material, 130,000 tons (118,000 Mg) of glass beads, and an unknown quantity of raised, recessed, tape, and thermosetting markings are used annually in the United States. If conversions are made in the consumption of solvent-borne traffic paint and thermoplastic markings, it appears that approximately 35 units or lineal feet of solvent-borne paint stripe are used for each unit or lineal foot of thermoplastic stripe used. Because solvent-borne paint is so widely used, it is the performance and cost standard by which other marking materials are compared and selected.

New pavement-marking materials include water-borne paints, thermoplastic epoxy (Epoflex), two-component internally mixed epoxy paints, polyester paints, and bituminous adhesives for placement of raised and recessed markers. It is too early to determine which of these materials will ultimately prove themselves and find long-term acceptance.

Multiple improvements have taken place in the mechanics of marking highways, including the use of tote bins for the handling of paint rather than 55 gallon (200 L) drums, the use of airless spraying systems, and the use of computers to record and track the application and performance of individual marking projects and materials.

Still, there are miles of highways that are unmarked or are only partially marked. There are unexpected, premature, and unexplained failures of marking materials, and there are instances in which failure can be directly related to improper surface preparation and application procedures. All of these situations are being studied by different agencies. The essence of marking highways to obtain the most out of the marking materials is the establishment of cooperation and efficient communication among the traffic engineer, the materials engineer, the application crew, the purchasing agent, and the supplier. When everything is right, then marking materials work well. If one thing is wrong, then chances of failure increase dramatically. There is a need for:

- New methods and equipment for evaluating pavement-marking materials.
- New low-cost marking materials for rural low-volume two-lane roads.
- New low-cost snowplowable marking materials that have wet-weather night visibility.
- Increased quality control over application procedures and improved record keeping.

CHAPTER ONE

INTRODUCTION

BACKGROUND

Pavement markings improve traffic flow and traffic safety by providing guidance and regulatory and warning information to the driver, all of which makes the driving task easier. Pavement markings, however, have certain limitations. They are obliterated by snow and may not be visible when wet. The information provided by markings is unfortunately sometimes ignored. The use of pavement markings has not been limited by public acceptance; rather, economic pressures are such that most agencies do as much marking as they can afford and look forward to the day when they can do more. Consequently, there are highways that are unmarked, only partially marked, or in need of re-marking. Thus, selection of the marking material to be used, how it is to be applied, and when it needs to be replaced are important decisions that must be made repeatedly by a relatively large number of jurisdictions and individuals. The objective of this synthesis is to present information that will assist those making these decisions. This synthesis is a follow-up to Synthesis of Highway Practice 17 (*1*) and is intended to serve as an update of that document by reporting on the latest developments that have occurred through research and practice.

NEED FOR AND PROBLEM WITH MARKINGS

There are more hazards associated with driving at night than during the day, as has been documented in statistics from the U.S. Department of Transportation's Fatal Accident Reporting System (FARS) (Table 1).

These statistics show that on an absolute basis fatalities increased from 1975 to 1980 and then decreased from 1980 to 1985 to about what they were in 1975. The percentage of fatalities occurring at night increased during the first five-year interval and then decreased in the second five-year interval. Interpretation of these statistics from the standpoint of "cause and effect" is not easy because so many factors are involved. One of the more complete studies of these data was done by Vanstrum and Landen (*2*), who concluded that, among other things, "innovation and implementation of effective visibility countermeasures" were called for.

Historically, the increased hazard of night driving has been attributed to alcohol involvement, visibility factors, fatigue effects, and the combined effects of these elements. Not much is known about fatigue as an accident-causation factor by itself; it is interwoven with the other two impairing factors, alcohol and night visibility.

Alcohol impairment and night driving is a high-risk combination in terms of fatalities. Moskowitz (*3*) reports that the major cause of alcohol-related traffic accidents is reduced capacity of drivers to adequately process information both from the road and the environment so as to safely maneuver their vehicles. The alcohol-impaired driver concentrates on guiding and steering at the expense of searching for environmental signals. Impaired drivers, on sobering up after an accident, often report that they never saw whatever it was they hit. Alcohol-related accidents are a form of perceptual failure, which is compounded at night.

To offset the interaction between alcohol and nighttime visibility, the Presidential Commission on Drunk Driving (*4*) recommended the following:

> States should give increased attention to improvement in roadway markings and signing, and roadside hazard visibility as important countermeasures to alcohol-related highway crashes. . .
>
> Because the majority of severe alcohol-involved crashes occur at night on rural two-lane highways, greater attention should be given to low-cost roadway environmental improvements having a cost-effective safety potential for the alcohol-impaired driver.
>
> Proven roadway environment technologies, such as adequate delineation through road markings, signing, and improving visibility of roadside hazards offset the visual impairment which medical and highway safety research has identified as a critical factor in alcohol-involved crashes. They are also beneficial for drivers who are unimpaired or who suffer from youthful driving inexperience or from visual impairment associated with fatigue or old age.
>
> Developing technologies, such as the use of wider edge lines, improved roadway signing, and other delineation techniques should be encouraged. . . .

By removing the fatal accidents caused by alcohol impairment from the statistics and looking at the fatal accidents not caused by alcohol impairment it was found that almost 6000 fatalities occurred in one year (1981) at night because of hazards and contributing factors not present during the day. The prime suspect is inadequate night visibility.

Inadequate night visibility is considered to be the primary contributor to serious accidents with or without alcohol. Leibowitz (*5*) points out that the amount of luminance needed to detect a given object increases as the eye ages. People in advanced years tend to avoid the problem by simply not driving at night. But long before the decision is made to give up night driving, the effects of reduced ability are present.

Some point to an overall material problem in maintenance of warning devices, such as pavement markings, brought about by economic and performance constraints. Pavement markings have relatively short lives in comparison with those of pave-

TABLE 1
OVERALL FATALITIES—1975-1985 (FARS DATA)

	Total	Day	Night	Unknown
1975	44,522	18,929	24,044	1,549
	100%	42.5%	54.0%	3.5%
1976	45,523	19,470	25,831	222
	100%	42.8%	56.7%	0.5%
1977	47,877	20,375	27,385	117
	100%	42.6%	57.2%	0.2%
1978	50,331	21,219	28,987	125
	100%	42.2%	57.6%	0.2%
1979	51,093	20,365	30,596	132
	100%	39.9%	59.9%	0.3%
1980	51,091	19,891	31,070	130
	100%	38.9%	60.8%	0.3%
1981	49,301	19,232	29,750	319
	100%	39.0%	60.3%	0.6%
1982	43,721	17,369	26,225	127
	100%	39.7%	60.0%	0.3%
1983	42,584	17,296	25,031	257
	100%	40.6%	58.8%	0.6%
1984	44,241	18,411	25.476	354
	100%	41.6%	57.6%	0.8%
1985	43,800	18,938	24,537	325
	100%	43.3%	56.0%	0.7%

ments. Pavement markings generally have service lives that range from 3 months to 10 years, whereas pavements generally have lives that range from 12 to 20 years.

Pavement markings must be visible, and if they are not visible, for whatever reason, then they are not effective and are not fulfilling their function. Factors that influence their visibility at night include viewing position, illumination, contrast, placement, size, shape, brightness, glare from opposing headlights, rain, fog, and time of exposure. The downsizing of automobiles, with the accompanying lowering of the position of the driver and the headlights, has been detrimental to night visibility. Olson et al. (*6*) report that driver eye height over the years has dropped from 54 in. (1.37 m) to the present level of 42 in. (1.07 m).

Assuming a level pavement, a ray of light from a typical automobile headlight strikes the pavement at an angle of less than one degree, with the horizontal 150 ft (46 m) in advance of the vehicle. The light from a headlight striking the surface of the pavement marking ahead of the vehicle is largely reflected forward or absorbed by the marking material. For the light from a headlight striking the pavement marking to be directed back to the driver's eyes and present a clearly visible image, some type of retro-reflective medium is required. Most commonly used are glass beads or molded plastic or glass lenses that are incorporated into the pavement-marking material. At night these materials focus the incoming light and redirect it by reflection back to the vicinity of its source with varying efficiency, depending on the retro-reflective medium. If the retro-reflective medium in a marking material is physically removed by traffic or is broken, scratched, or covered by snow, ice, or road film, or submerged in water, or in any fashion rendered nonretroreflective, then the marking material is no longer serving its major intended purpose and most important function. A driver who cannot see something cannot respond to it. The driver must first detect something, then identify it, decide what action to take, and put that decision into effect. The interval currently assumed for this entire process is 2.5 seconds. If the decision is to stop, distances required for controlled stops by a car with worn tires on typical wet roads are as given in Table 2.

If an agency cannot cost-effectively apply a marking material, it is of little value irrespective of its field performance. In the past some new materials that proved to be most durable in service were so difficult to apply that their use had to be abandoned. Difficulties can be related to time consumption, technical complexities, operator skill requirements, personnel hazards, or any combination thereof.

Although pavement markings are desirable and well accepted by the public, the application of pavement markings is not well accepted. Delay of traffic and hazards imposed are serious problems. Conflicts between the public and the marking crews caused by the disruption of traffic during the marking process are more than just inconveniences. Many of them involve accidents with financial loss and personal tragedies. Improving the speed by which markings can be applied, as well as using markings that have a longer life, reduces the hazards and improves public relations.

Pavement markings are meant to be in place and visible, and if they fail (particularly if they fail prematurely), their failure is apparent to the world. Ideally, the proper equipment is used to apply the proper material with the proper application procedures to the proper substrate with the proper surface conditions. The desired result is that the markings have a long service life and are ultimately physically worn away. Marking materials available today are sophisticated materials and have the ability to perform well. Failures are more often related to improper application procedures and applications to improper substrates and surfaces. Pavement markings are not applied in a controlled environment under controlled conditions. Compromises owing to weather, road surface conditions, traffic, and other variables are inherent in the marking process. Obtaining the most out of marking materials requires focusing one's attention in many different directions at the same time.

The principal materials system used to mark highways (paint and glass beads) has the serious limitation of losing its visibility at night in wet weather when the driver's need for guidance becomes the greatest. This means that the paint and glass-bead marking system needs to be complemented with raised markers or recessed markers or some other type of marker system in order to provide wet-weather night visibility.

Clearly, driving is more hazardous at night than during daylight. All of the reasons for this are not fully understood. Pavement markings contribute to reducing the hazards of driving by providing visual cues. In the nighttime they may be virtually the only cues present. The added use of pavement markings and any improvement in the performance of pavement-marking materials, particularly their nighttime performance, is being pursued to lessen the hazards of driving.

TABLE 2
STOPPING DISTANCES WITH WORN TIRES ON WET ROADS

Speed (mph)	Stopping Distance (ft)	Speed (km/h)	Stopping Distance (m)
30	20	48	6.1
50	85	80	26
60	190	97	58
70	350	113	107
80	550	129	168

CHAPTER TWO

WARRANTS

FIRST-TIME MARKING

The Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) (*7*) sets forth the basic principles that govern the design and use of pavement markings. The MUTCD presents standards for all streets and highways, regardless of type or class or the governmental agency having jurisdiction. The MUTCD states that pavement markings "shall" be used on the Interstate system. It further states that edge markings "shall" be used on the Interstate system and any rural multilane divided highway. The MUTCD calls for no-passing stripes on all highways where sight distance is inadequate. In all other instances the MUTCD states that pavement markings "should" be used. In virtually all states, pavement markings are placed in accordance with state manuals, which are in substantial conformance with the MUTCD. The hierarchy of the Interstate, primary, secondary, county, and other road systems prevails with respect to priorities. Accordingly, the Interstate system is the most uniformly and completely marked and low-volume road systems are the least uniformly marked.

Although it is recommended in the MUTCD and other jurisdictional manuals that pavements 16 ft (4.9 m) in width and wider be striped, there are miles of pavements 16 ft in width and greater that have never been striped. The marking of low-volume rural roads presents a real dilemma in balancing the need for marking these roads with the cost. Low-volume rural roads (those carrying 400 vehicles per day or fewer) only carry about 8 percent of the total U.S. highway travel, yet they constitute 2 out of every 3 miles of public highway (*8*). The justification for using center-line and no-passing markings on low-volume rural roads was studied by Glennon (*9*).

First, predictions were made of the number of head-on (opposing) meetings for various low-volume rural-road traffic volumes. This yielded the following expected rates:

Average Annual Daily Traffic	Estimated Number of Head-On (Opposing) Meetings Per Mile Per Day
50	1.5
100	6.2
200	25.0
300	56.0
400	100.0

Using a solvent-borne paint center-line cost of $200/mile, a 1.5-year life, and a $9500 average cost of accidents, a benefit-cost balance was found at an average annual daily traffic (AADT) of 300 vehicles per day. Thus, Glennon concludes that center-line markings are warranted on paved low-volume roads when the AADT equals or exceeds 300 vehicles per day.

The need for no-passing stripes was then examined by predicting the expected number of head-on conflicts created by passing maneuvers. This yielded the following expected rates for various low-volume rural-road traffic volumes:

AADT	Expected Annual Number of Passing Conflicts Per Mile
50	0.02
100	0.17
200	1.44
300	4.81
400	11.06

A benefit-cost analysis similar to that conducted for center-line markings indicated that no-passing stripes are not cost-effective on low-volume rural roads.

Film-type markings such as paint, thermoplastics, and tapes have the inherent disadvantage of losing their visibility at night in the rain. Raised reflective markers, because they project up through the water films, provide dry- and wet-weather night visibility. Their use greatly enhances nighttime visibility, and this is attested to by the vast number of them being used. Yet, written warrants for their use are largely found in state manuals. They are used because they work in conjunction with film markings to make a complete day-and-night, wet-and-dry marking system.

There exists a paradox in the hierarchy of priorities for marking roads: The Interstate system is the most well-marked system and yet the majority of the fatalities occur on the less well-marked rural two-lane roads.

RE-MARKING

Once an agency marks a highway, it assumes a responsibility for keeping the markings in good condition (*10*). Markings that are not in good condition are most often that way because they have lost their retro-reflectivity, are worn out, have been damaged by traffic, or they have been covered over by road films or repaving operations. They are restored to good condition by re-marking.

The warrants for re-marking, an activity that constitutes the bulk of the marking activities done by agencies, varies dramatically. All of the agencies respond to complaints. Approximately half of the agencies do not inspect or measure marking performance in the field. Rather, they have a periodic replacement schedule that is usually an annual occurrence for painted markings. In some states weather conditions are such that marking operations are restricted to May through September. One method is to repaint last year's markings plus any new markings that were added to the system. Another method is to repaint all of the Interstate system and primary system with center lines, lane lines, and edge lines, and repaint all the center lines and as much of the edge lines on the secondary system as time and the budget allow.

Another method is to use daytime inspections, thus avoiding, in some instances, the payment of overtime. There are instruments that can be used in the daytime to measure nighttime retro-reflectivity of markings. These are discussed later in this section. One method of judging nighttime retro-reflectivity in the daytime that is not recommended is to view the markings with the sun over one's shoulder, the sun's light being reflected by the retro-reflective medium in the marking back to the viewer's eyes. The intensity of the sun's light, the viewing position, and the distance from the marking to the viewer's eyes are such as to make any retro-reflective material visible under these conditions. The reason this method is not recommended is that very often the same materials, when viewed at night with vehicle headlights at a distance, can be totally indistinguishable.

About half of the agencies send personnel out at night and visually inspect the performance of markings and re-mark in response to the inspector's recommendation. Some inspectors use the rating system in the ASTM D 713, modifications of this, or their own system. Sometimes restriping is done for cosmetic purposes when it is not really warranted. One system is to re-mark when, in the inspector's visual opinion, the night visibility of the marking has fallen to 50 percent or less of the visibility of the marking when it was new.

Only a few of the agencies actually send personnel into the field to physically measure the retro-reflectance of marking materials. The basic components of an instrument to measure the retro-reflectance of markings consist of a light source directed at an angle commensurate with that of headlights and a photometer mounted at an angle commensurate with the driver's eyes to measure the returned light. The photometer measurements can be shown on a direct dial or digital reading instrument or recorded on demand or continuously. Over the years many jurisdictions have purchased or built instruments for field use. The most common type of instrument used consists of a rectangular box about 8 to 12 in. high by 8 in. wide by 4 to 6 ft long (200 to 300 mm × 200 mm × 1.2 to 1.8 m) and open on the bottom, with a light-shielding gasket around the bottom. With all the components placed in this box, and using battery power, the box is placed over a marking in the daytime or at night and a reflectance reading is obtained. The scale most frequently used is based on a piece of 3M Company reflectorized foil tape and a surface painted flat black. The foil tape is assigned a value of 100 and the flat-black-painted surface is assigned a value of 0. Forms of this basic system are many and varied. Minnesota (*11*) has mounted similar equipment on the side of a vehicle flush with the pavement that can drive along a highway at highway speeds in the daytime and measure marking retro-reflectance. Colorado has mounted its equipment on a van, with a photometer mounted near the driver's eyes. This equipment can be used at highway speeds in the night to measure marking retro-reflectance. The trend in the design of this equipment is to use low-angle-of-incidence retro-reflectometers. Some measuring systems are used for the purpose of purchasing one material rather than another, whereas others are used for determining when to re-mark.

Increased sophistication of retro-reflective measuring devices for pavement markings has occurred over the years. Lasers have been fabricated and are being developed to measure the retro-reflective properties of pavement markings. Hoffman and Firth conducted a study (*12*) to identify the use and availability of instruments used for making retro-reflective measurements of pavement markings. Their study concluded that because film markings reflectorized with glass beads fail from inadequate bead embedment or from excessive bead spacing (loss of beads), two different measuring instruments are required to properly measure these phenomena. They further observed that retro-reflectometers measure only the amount of reflected light and cannot evaluate the contrast between the reflected light and the pavement surface color. White lines of equal characteristics will be viewed differently by motorists if placed on different types of pavement. Similarly, ambient light will affect a viewer's perception of a pavement marking at night, but will not be measured by a retro-reflectometer. Finally, they concluded that new measuring devices are needed to evaluate the adequacy of markings to satisfy the needs of a motorist. Thus, until new measuring devices become available, there does not appear to be a consensus on the best method to use for determining when to re-mark.

It is not unusual for stripes whose nighttime retro-reflectance is still more than adequate to be re-marked because their daytime appearance has deteriorated. This most often occurs in the late summer and fall, when road films cover the markings. Bleeding pavements, rubber, and materials tracked onto the markings are the major contributors to this problem.

The ratings on appearance and retro-reflectance of film markings such as paint and thermoplastics are often functions of their age. When they are initially placed, their appearance is optimum, but they are relatively soft and are subject to picking up road film, which adversely affects their appearance. With time, loss of solvents or other volatiles and oxidation harden the marking material surface, traffic wears away any films, and the marking's appearance is restored. With further time, appearance declines because of wear, cracking, chipping, and other failure mechanisms. Retro-reflectance is greatest when the markings are first placed. Retro-reflectance declines as the larger or floating beads are dislodged by traffic. By design, the wear and dislodging of the surface beads are also intended to expose the smaller, partially and totally embedded beads so that the retro-reflectance of the stripe remains relatively constant over the life of the marking. In practice the retro-reflectance often declines to a relatively low figure as the upper beads are dislodged, and then rises as the smaller, partially and totally embedded beads are exposed by wear.

MATERIALS

The MUTCD does not specify the actual materials that are to be used for markings. For as long as pavement markings have been used no one has been able to devise a laboratory test that will accurately predict the field performance of a marking material. The American Society for Testing and Materials (ASTM) has a standard (D 713) for conducting road service tests of traffic paint. A replacement that would cover all fluid marking materials is in the approval process within ASTM.

The degree to which test procedures are followed varies greatly among states and other agencies. Some agencies do not conduct field road tests at all. Other agencies conduct them, but with different degrees of completeness. In any given year, only about 30 to 40 percent of the agencies are conducting any type of field road testing where transverse line test areas are being used, as shown in Figure 1. The leading states in evaluating pavement-marking materials include: Arizona, California, Colorado, Florida, Georgia, Mississippi, Kentucky, Ohio, New York, Pennsylvania, Texas, Virginia, and Washington. These evaluations are expensive to conduct and involve a great deal of repetition. Because of this, the Federal Highway Administration has proposed and is investigating Regional Test Centers where performance testing could be done for a group of agencies.

Some marking materials, such as raised markers, have technical specifications relating to their design and optical performance, but do not have defined road service tests. More often these materials and other materials work their way into the system through invitation by agencies (many of which do not conduct formal road service tests) to manufacturers to place their new materials in service alongside of, or in conjunction with, their conventional materials. Some agencies are constantly seeking out and road testing new materials, whereas other agencies admit their hesitancy to use new materials. The various agencies are exceptionally cooperative in providing road test sites and assisting those public and private concerns working on the development of new or improved marking materials. The materials used in the manufacture of traffic paints, thermoplastics, tapes, and raised markers are not dramatic new materials. Rather they are, for the most part, materials that have been around a long time. Changes in materials and performance occur very slowly. The current interest in water-borne paint in California, Louisiana, and elsewhere is being driven by a new type of warrant, which is the environment. Water-borne traffic paints are at present slightly more costly than their solvent-based counterparts and their use often involves equipment modifications. It is anticipated that with time their cost will decline and their performance will improve. Certainly, the environment is a valid warrant system in that pollution problems continue in many metropolitan areas.

Most state agencies and larger counties and cities apply their own traffic-marking paint, whereas most of the smaller cities

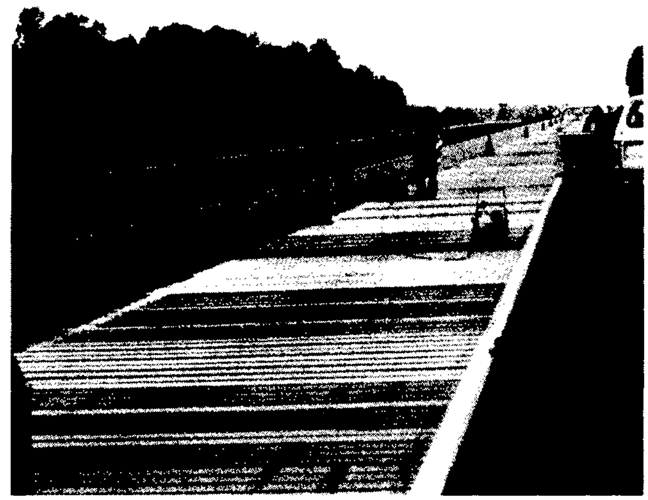

FIGURE 1 Transverse line test area.

and towns have their traffic-marking paint applied by contractors. Most of the durable marking materials, such as thermoplastic, are placed under contract. The contracts are generally awarded on the basis of cost. When a premature failure occurs, it is not unusual for the application contractor to claim that it was the material manufacturer's fault. The material manufacturer in turn will say that it was the application contractor's fault or it was the inspector's fault. This endless circle of trying to pass the responsibility on to someone else might be alleviated if the contracts were written so that the application contractor accepts full responsibility for the performance of the material within the guarantees provided for in the contract. North Carolina has developed a Four Year (Performance) Pavement Marking Contract wherein the contractor not only furnishes the markings but maintains them for a period of four years.

Warrants for when and where to use markings are, in some instances, very specific, and in other instances, very nonspecific. There are few warrants on what materials are to be used. Once the determination has been made on the material to be used on a roadway, it is not unusual for all markings on that roadway to be marked with that same material, thereby driving up the costs. Reason suggests that for many roadways a combination of materials may be the best solution. Officials in Louisiana suggest that they may, on heavily traveled roadways, mark the center and lane lines with thermoplastic (complemented by raised markers) and mark the edge lines with paint—each material making its contribution commensurate with its ability.

CHAPTER THREE

SURFACE PREPARATION AND STRIPE REMOVAL

Surface preparation and stripe removal are important requirements of pavement marking. Failure to perform these functions or take them into consideration is inevitably costly. The situations encountered are constantly changing, and someone has to be aware of the need to perform these functions if they are called for. Surface preparation can involve stripe removal, and stripe removal can involve the more aggressive use of some surface-preparation technique. Therefore, these subjects have been combined in this chapter.

PAVEMENT SUBSTRATES

The substrates to which markings are to be applied, in order of encounter, are normally: previous markings, bituminous pavements, and portland cement concrete pavements. Applying new markings over previous markings that are in the process of failing by loss of adhesion is to be avoided if at all possible. Very often the warrants for re-marking are such that only remnants of the old markings may be in place, whereas in other instances there may be multiple layers of the old markings in place. As long as the old markings are well adhered to the pavement and to each other, as in the case where there are multiple layers, and there is no incompatibility between the previous markings and the material to be applied, then previous markings can be better substrates over which to apply new markings than either bare bituminous pavements or portland cement concrete pavements. In essence, the bond between the marking material and the pavement has been made. Old pavements have a tendency with time to expose their large pieces of aggregate, which become polished by the traffic and become difficult for marking materials to adhere to.

The marking of new bituminous and portland cement concrete presents a variety of problems. New bituminous pavements are very susceptible to bleeding and can be difficult to adhere to because the aggregate on the surface is actually covered by a bituminous/hydrocarbon film. New bituminous pavements are soft and tender in comparison to the strength they obtain after time. Accordingly, raised markers placed on new bituminous pavements are often lost because the imposed deflections from traffic over the markers cause the bituminous pavement underneath the marker to fail. The markers literally fail by taking the pavement out with them. Allowing new bituminous pavement time to cure and weather before applying markings increases the service life of some markings, but this is inconsistent with safety and the need to mark the pavements as soon as they are finished.

New portland cement concrete pavements are difficult to adhere to because of the presence of curing compounds and laitance. These films deny marking materials access to the structure of the pavement and failure can be immediate. In addition, some marking materials, such as alkyd paints, are adversely affected chemically by the alkaline nature of fresh portland cement concrete. An alkyd paint stripe applied over new portland cement concrete can sometimes be washed off with a water hose. Many authorities accept this fact and restripe a new portland cement concrete pavement after the first major rainstorm and the failure of the first alkyd paint application. The migration of water through portland cement concrete pavements and the transported salts and other materials soluble in water also lead to problems. It is widely accepted that portland cement concrete pavements are, as a class, more difficult to adhere to than bituminous pavements. Only about 12 percent of the exposed pavement surfaces in the Unites States are portland cement concrete.

SURFACE CONDITIONS

Typical directions written on paint cans include: (a) remove all grease, oil, and other surface contaminants and (b) clean and dry the surface before application of the paint. The surface conditions of pavements to be marked are seldom, if ever, up to these standards. The actual surface condition of a pavement is changing constantly from the day that the pavement is placed in service to the day it is torn up or covered over.

The environment, traffic, and snow-removal techniques are constantly changing the surface condition of the pavements. Oil, grease, rubber, and products of industry and agriculture are constantly being dropped onto pavements. Soil and roadside materials are tracked by vehicles onto pavements. Wind and rain transport contaminants onto and, in some instances, off of pavements. There is some degree of road film on all pavement surfaces. It occurs less in the wheel track areas than in the areas to be marked because traffic tends to remove some forms of road film. Road films in autumn on Route 99 in California's San Joaquin Valley can be such that they turn the color of portland cement concrete pavements so dark that casual observers might easily mistake them for bituminous pavements. Road films cover not only the pavement, but they cover the markings, thereby reducing their day and night visibility.

Road films are not necessarily apparent to the naked eye. A simple test for water-soluble contaminants is to wet one's finger and rub it on the pavement. This will often reveal an amount of road film previously unappreciated. From a microscopic view, surfaces to be marked are largely a series of depressions, protrusions, and crevices. Ideally, these depressions and crevices should be clean, and the marking material could penetrate them and make an ideal mechanical, and in some cases chemical, bond. More often than not these depressions and crevices are filled with road film or some gross contaminant. Paints, because of their solvent content, have a relatively low viscosity and surface tension and are better able to wet through road film and bond to the pavement surface than can thermoplastics. Therefore, for a successful bonding, the surface condition is far more critical for thermoplastics than for paints.

With the exception of water-borne paints and a few selected epoxy systems, most marking materials are not water soluble, and consequently, if applied over a continuous water film, will not adhere at all, and if applied over a partially dried surface, will only be partially adhered. Successful use of thermoplastics is critical to their being applied to dry and clean pavements for several reasons. They cost on the order of four to five times more than paint, and their premature failure constitutes a substantial financial loss. Thermoplastics are applied to the pavement at approximately 425°F (218°C), and moisture on the pavement can cause blistering and interfere with the bonding mechanism between the thermoplastic and the pavement.

All pavements have different wet and dry surface colors. Just because a pavement has assumed a dry surface color does not mean that it is dry. Pavement moisture is not easy to measure. The Cataphote Division of Ferro Corporation (*13*) recommends laying a piece of tar paper [3 ft × 6 ft (1 × 2 m)] on the pavement surface to be marked. A thermoplastic application machine then applies a thermoplastic stripe directly over the tar paper. Approximately 15 to 30 seconds after the thermoplastic is applied, the tar paper is picked up and if the underside has heavy condensation, then thermoplastic should not be applied. In Texas a 2 ft (0.6 m) square of clear plastic film is taped to the pavement. After 20 minutes if beads of water form on the underside of the film, the pavement is considered too wet for application of thermoplastic marking material.

The temperature of the road surface is very significant in road-marking operations. It is most significant in the application of thermoplastics. Road surface temperatures are often equated with air temperatures, and many marking materials have air temperature application specifications when they should have pavement surface temperature specifications. Pavement and air temperatures can, at the same time, vary by as much as 60°F (33°C). Pavements have mass and conduct heat well compared with air, which is an insulator. A marking material's temperature is little affected by its passage from the dispensing head of an application machine through the air to the road surface. Seldom is a marking material applied at a temperature below that of the pavement surface. In most instances the temperature of the marking material is above the temperature of the pavement surface. The mass of the marking material is minor compared with the mass of the pavement, and thus the marking material quickly assumes the temperature of the pavement. Any volatilization of solvents or chemical reactions will therefore be occurring at near the pavement temperature rather than the air temperature.

The long-standing observation that a poor coating, well applied, will outlast a good coating, poorly applied, is another way of saying that the condition of the surface to which a coating is applied is extremely important. In watching a marking operation one sees the pavement surface. Then the marking machine goes by and one sees the marking material. What is not seen is one of the most important aspects of the marking process: what is happening at the interface between the marking material and the pavement surface. Very often the condition of the surface at the time of marking is revealed when the marking material fails and the underside of the failed marking reveals a heavy road film, bridging, blisters, or the like.

METHODS

Because surface conditions of pavements are changing constantly, there is no one surface-preparation method better than the rest. Likewise, selection of a method of stripe removal is contingent on the material to be removed, the condition of the old marking material, its adherence to the pavement, and other factors.

In the coatings industry, it is not unusual to find that sometimes as much as half the total cost of various coatings is spent on surface preparation. In most instances pavement markings are applied without any surface preparation. In other instances heavy road film or multiple layers of old and failing paint films might suggest the use of wire brushing, burning, sandblasting, or some other method of removal. Selection of a method for removal of old markings carries a heavy degree of responsibility with it because remnants of markings and pavement scars can be misleading and result in accidents. A stripe that appears to be removed in the daytime can be quite visible at night. A small amount of marking material and glass beads left in surface depressions can also be very visible at night. Removal of a stripe by grinding from a bituminous pavement made with a light-colored limestone can expose the limestone's light color and give the appearance of a stripe at night. Stripe removal on a given day should be followed by a nighttime inspection on that same day. One of the techniques that is not mentioned as a method in this report relates to the painting over of markings with coatings similar in color to the pavement surface, thereby disguising the presence of the existing stripe. This practice is disappearing and should be strongly discouraged, as with time the old stripes reveal themselves and serious consequences can result.

The potential combinations of marking materials, surface conditions, surface preparation and removal methods are extensive. Table 3 (*14*) shows the relative cost-effectiveness of the various surface-preparation and stripe-removal methods. It should be recognized that very often the preparation or removal methods cannot be selected on the basis of cost-effectiveness but are dictated by what is found in the field. Table 3 has been constructed around blowing as the least effective method and sandblasting as the most effective method with all other methods falling in between these two.

There are characteristic advantages and disadvantages to each of the various methods for surface preparation and stripe removal (*15*).

Blowing

The most widely practiced method of surface preparation is blowing the surface to be painted with either compressed air or engine exhaust. If compressed air is used, it generally requires

TABLE 3
RELATIVE COST-EFFECTIVENESS OF VARIOUS SURFACE-PREPARATION AND STRIPE-REMOVAL METHODS (*14*)

	Surface Preparation			Stripe Removal		
Method	Cost[a]	Eff.[b]	Cost/Eff.	Cost[a]	Eff.[b]	Cost/Eff.
Blowing	1	0.05	20.0	1	0.005	200.0
Burning (excess oxygen)	24	2.00	12.0	24	8.000	3.0
Chemical	54	6.00	9.0	54	5.000	10.8
Grinding	36	9.00	4.0	36	6.000	6.0
Sandblasting	52	10.00	5.2	52	10.000	5.2
Water Blasting	38	7.00	5.4	38	5.000	7.6
Wire Brushing	10	7.00	1.7	10	0.500	20.0

[a]Cost = cents per foot

[b]Effectiveness: Does not remove material - harms pavement = 0
Removes material - does not harm pavement = 10

additional compressor capacity. Although useful in removing dust, rocks, and gross contaminants, it is a superficial treatment that does very little, if anything, to road film. It is of little or no value as a stripe-removal method.

Burning (Excess Oxygen)

Road films are generally composed of inert materials that do not burn. Accordingly, burning is not employed to remove road films. Pavement-marking removal by burning is not new. The previous practice has been to burn butane or propane or mixtures thereof (liquid petroleum gas) with air. The flame temperatures achieved were approximately 2000°F (1100°C). Conventional traffic-marking paints and thermoplastics are heavily loaded with noncombustible pigments, extenders, and fillers, and they do not burn easily. It is necessary to direct the flame from a fuel-air burner at the surface to be burned for an extended period to destroy these materials. The rate of combustion of the marking is slow and the heat from the flame has an opportunity to penetrate the surface of the pavement, which can result in melting of bituminous pavements and spalling of concrete pavements.

More recently, attention has been directed to burning with excess oxygen (*16*). By this method, propane and pure oxygen are burned to produce a flame temperature of 4600°F (2500°C) in a burner tip directed at the marking material. Burning is a process of oxidation, and by directing additional or excess oxygen through a second tip or head at the surface being burned, the process of oxidation and decomposition of the unwanted marking material is further accelerated. Figure 2 shows the basic components of this system. This method is much faster than older burning methods. Because it is faster, less heat is transferred to the underlying pavement surface, thereby reducing the possible damage to the pavement. After burning, a film of inert combustion products that remains on the surface can be removed by wire brush or, if left alone, will be removed by traffic wear and weathering. Burning with excess oxygen has been found to be effective in removing old marking films up to 20 mils (0.5 mm) in thickness, but not effective with thicker films. Burning with excess oxygen is an excellent method for removing old foil tapes that, after being exposed to traffic, resist being pulled up or scraped off.

Chemical

Etching with 3 percent hydrofluoric acid has been shown by the Louisiana Department of Transportation and Development to improve the life of traffic-marking materials. The problem with its use was one of logistics and expense. The acid solution was first sprayed on the area to be marked. After a period of time sufficient for the acid to react with the surface, it was flushed off with water and then the surface was allowed to dry before markings were applied. This was particularly effective in improving adhesion to portland cement concrete pavements. However, there was a potential hazard with this system relating to damage to vehicles that might drive through the area when the acid is freshly applied. There was also the personnel hazard of handling hydrofluoric acid, which is one of the more dangerous acids. Although it is an effective system, the steps involved in its use and the hazards involved were too great to pursue its use.

Chemical removal of markings works best on films up to 20 mils (0.5 mm) in thickness. The chemical removal agents are first applied as shown in Figure 3 and then, after they react with the old films for some period of time, they are flushed off with a water jet unit as shown in Figure 4. The pavement must then be allowed to dry before marking can proceed. This is time consuming and adds traffic exposure to the overall operation.

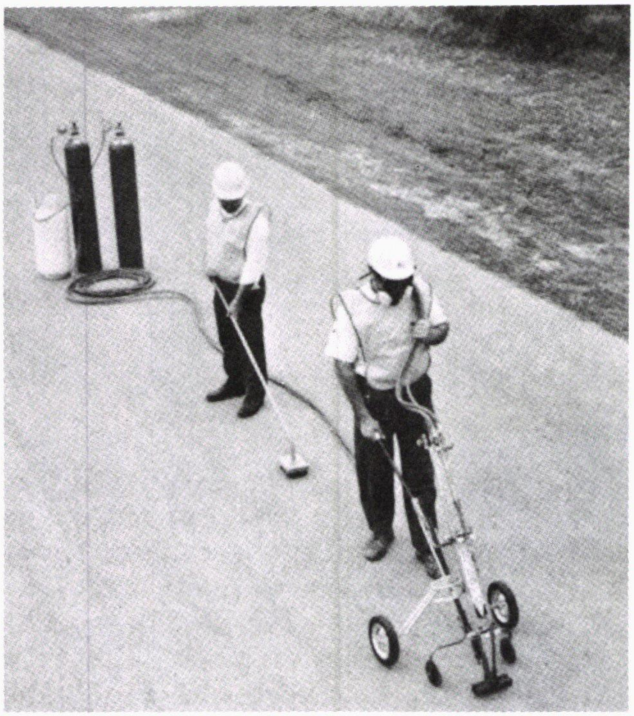

FIGURE 2 Basic components for burning with excess oxygen.

FIGURE 4 Removing chemically reacted markings with a water jet.

Grinding

Grinding, as depicted in Figure 5, is used extensively for surface preparation and stripe removal. It is an aggressive or positive method that works well in removing paint, thermoplastics, epoxies, and other marking materials, regardless of their thickness. The big disadvantage of grinding is that in some instances it alters the pavement surface texture and appearance, often leaving a depression or scar in place of the obliterated line. Because of the scarring problem, grinding is often favored for applications in which new markings are going to be placed over the area where the old markings were removed. Grinding is not generally recommended for open-graded friction course pavements or rough-textured portland concrete cement pavements.

Sandblasting

Sandblasting is effective as a surface-preparation method and as a stripe-removal method for traffic paint, thermoplastic mark-

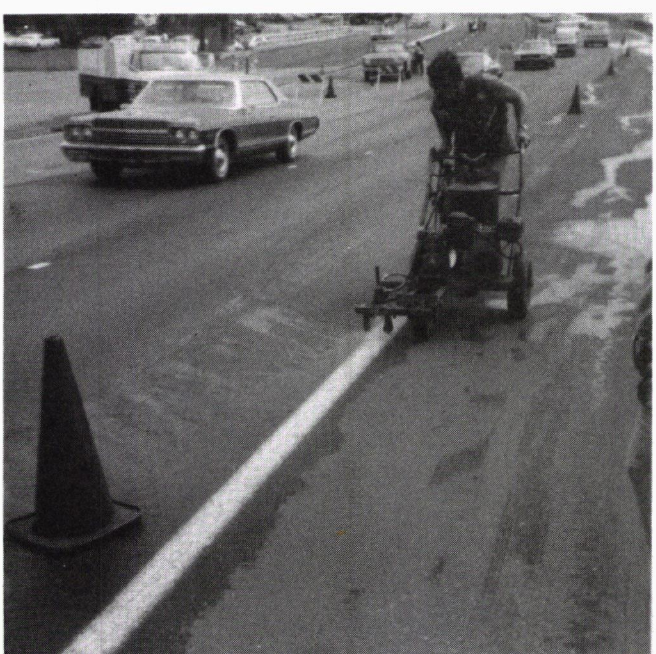

FIGURE 3 Applying chemical removal agent.

FIGURE 5 Removal of markings by grinding.

FIGURE 6 Cleaning pavement surface by sandblasting.

ings, and epoxy markings. Figure 6 shows a sandblasting nozzle mounted on a boom to clean the pavement where a raised marker is to be applied with an epoxy adhesive. The removal rate is a function of the road film or marking material thickness to be removed and the sandblasting equipment used. In many instances, for the results achieved, it is the least damaging to the pavement surface from the standpoint of color and texture changes. The amount of equipment necessary and the quantity and logistics of handling dried sand is extensive. Stray and deflected sand can contact passing vehicles. In some areas it is no longer acceptable to leave sandblasting sand on the road. Therefore, a sand-removal method is required. Some of those problems are overcome by the use of rotary sandblasters when the sand is recycled. Sandblasting is very slow in removal of foil tape and ineffective in removal of plastic tape.

Water Blasting

Water blasting consists of directing a high-pressure [2,000 to 10,000 psi (14 to 70 MPa)] water jet at the surface to be cleaned or the marking to be removed. If sand is added to the water, it is sometimes referred to as hydroblasting, as shown in Figure 7. This method provides results similar to those obtained with sandblasting, with the exception that time must be allowed after its use for the pavement to dry. Like sandblasting, the results are dependent on the thickness of the material being removed and the power of the equipment.

FIGURE 7 Stripe removal with hydroblasting.

Wire Brushing

Wire brushing lends itself well to surface preparation, although not to stripe removal. It is relatively easy to use, it works well over irregular surfaces, and it does not damage the road surface. It has no logistics or time-lapse problems, and it removes road film and scratches the surface. It is as effective or more effective than blowing, sandblasting, grinding, burning, washing, or etching in terms of improving adhesion. Figure 8 shows a wire brush assembly being used on a thermoplastic epoxy machine. Because wire brushing is easy to use, an experiment was set up in the South Texas Rio Grande Valley (*17*) in which a gasoline-engine-driven wire brush was mounted ahead of the spray gun on a Texas Department of Highways and Public Transportation solvent-borne paint-striping truck, and the surface in advance of every stripe applied by that truck for a period of several months was wire brushed. For control purposes, not all of the paint stripe was applied to the brushed surface. Observation of the performance of the paint over the subsequent months did not reveal any advantage from the brushing operation. It did point out the fact that there is no valid reason for conducting surface-preparation efforts unless there is gross contamination.

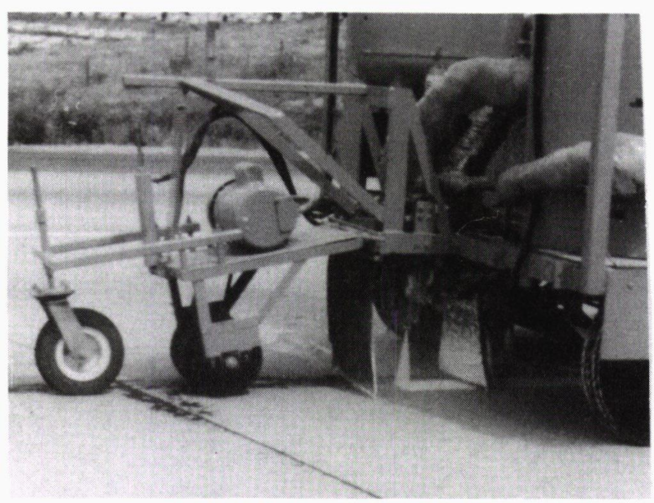

FIGURE 8 Surface preparation by wire brushing.

CHAPTER FOUR

MATERIALS AND APPLICATION FOR EXTENDED SERVICE LIFE

Approximately 37,000,000 gallons (140,000 m^3) of traffic-marking paint, 55,000 tons (50,000 Mg) of thermoplastic marking material, 130,000 tons (118,000 Mg) of glass beads, and an unavailable quantity of raised, recessed, tape, and thermosetting markings are used annually in the United States. If conversions are made in the consumption of paint and thermoplastic, it appears that approximately 35 units or lineal feet of paint stripe are used for each unit or lineal foot of thermoplastic stripe used. Growth in the use of thermoplastic has been rather steady over the years up until 1984, after which its use has leveled off.

Because paint is so widely used, it has become the performance and cost standard by which other marking materials are compared and selected. The performance of paint, however, is inconsistent. For many roads, especially in the snowbelt areas, painted markings cannot survive for an entire winter, and insufficient delineation is provided until the lines can be repainted in the spring.

To realize the maximum benefits from the materials, the equipment, and the application techniques available, it is necessary to establish and maintain cooperation and efficient communication among the traffic engineer, the materials engineer, the application crews, the purchasing agent, and the suppliers. It is not unusual for one agency to evaluate a material, piece of equipment, a procedure, or any combination of them and report success, whereas another agency may attempt the same evaluation and report failure. It has been known for an agency to undertake an evaluation and change the material formulation, alter the application equipment, and redesign the application procedure and report success in one instance and failure in another. It is for these and other reasons that each agency has its own specifications and practices.

PAINT

Solvent-Borne Paint

Traffic-marking paint is a unique type of paint that has been developed over the years to meet specific service requirements. It is one of the more heavily loaded paints, that is, it contains approximately 25 percent by volume of pigment, extender, and filler, whereas many other paints contain less of these materials. These solid and inert materials are often complemented in traffic paint by a 25 volume percent binder package and 50 volume percent solvent. The favored pigments for traffic paints are titanium dioxide for the white and lead chromate for the yellow. Both of these pigments are inorganic. Attention has been directed to the use of organic yellow pigments (*18*) because of the potential health hazards of lead chromate. The organic yellow pigments have historically been known to fade rapidly in sunlight. Some of the newer organic yellow pigments are more lightfast. As a class, organic yellow pigments are many times more expensive on a unit basis than lead chromate, but they require a fraction of the amount of the lead chromate to achieve the same color, and therefore, they are being considered. Care must also be exhibited in handling the organic yellow pigments because some of them have hazardous characteristics. The favored extenders and fillers for traffic-marking paint are inert materials, calcium carbonate (natural and precipitated), and various silica products. The type and form of the pigment, extender, and filler used in a paint can have a marked bearing on the durability and service life of a given formulation. Thus, careful consideration is given to the selection of these materials in paint formulations.

The binder or vehicle portion of traffic-marking paint is actually a combination of as many as 10 ingredients. The major component of binders for most solvent-borne traffic-marking paints is alkyd resin or alkyd resin modified by chlorinated rubber. To this are added small quantities of many different additives, such as antiskinning agents, dryers, and the like. It is the binder resin more than any other one thing that determines the service life of a paint. There are an extensive number of binder systems used in different types of paints, many of which are suitable for pavement marking, but the alkyd resin and alkyd resin modified by chlorinated rubber systems have proved to be the most cost-effective.

Thinners or solvents add little or nothing to the integrity of the dried paint film or its service life. Solvents are used in paint to improve the manufacturing and application characteristics of paint. Normally a gallon of traffic-marking paint containing 50 volume percent solvent ends up on the highway as ½ gallon of dried paint film. In other words, a 16 mil (0.4 mm) wet-film thickness of such a paint would have a dry-film thickness of 8 mils (0.2 mm). The solvent evaporates from the paint into the atmosphere. The concept of buying solvent that actually contributes nothing to the dried paint film and pollutes the atmosphere has prompted the move to higher solids paints, that is, paints with lesser quantities of solvents.

Moore (*19*) defines drying time as the "interval of time between the application of the paint and when a passenger car traveling 25-35 mph can pass over the line without showing visual tracking when viewed from a distance of 50 feet." Using this definition, the drying times of traffic paints are then categorized as follows:

Term	Drying Time
Instant dry	< 30 sec.
Quick dry	30 to 120 sec.
Fast dry	2 to 7 min.
Conventional	> 7 min.

Moore (*19*) gives the following factors that affect paint drying time:

I. Paint Characteristics
  A. Type of drying
    1. Solvent evaporation
    2. Cooling
    3. Oxidation
    4. Catalyst
    5. Combination
  B. Composition
    1. Type of pigment
    2. Volume of pigment
    3. Type of vehicle
    4. Volume of vehicle
    5. Type of thinner
    6. Volume of thinner
II. Temperature
  A. Paint
  B. Pavement
III. Wind Velocity
IV. Film Thickness

The most significant factor that affects paint drying time is the solvent used. The comparative speed of evaporation of various solvents is as follows:

Solvent	Seconds
Methylene Chloride	0.4
Acetone	0.8
Hexane	0.8
Benzol	1.2
Methyl Ethyl Ketone	1.5
Toluene	2.7
VM&P Naphtha	3.5
Xylol	10.8
Turpentine	15.5
Mineral Spirits	33.0
Kerosene	325.0

At first glance, the thought of reducing the drying time seems to be a totally positive step. However, there are both positive and negative aspects to reducing the drying time. Moore lists these as follows:

Positive
1. Decreased delay to traffic
2. Improved public-relation image
3. Reduced need for stripe protection
4. Reduced accidents related to striping
5. Reduced labor cost
6. Reduced application cost

Negative
1. Need for better equipment
2. Increased equipment cost
3. Increased paint cost
4. Reduced ability to wet pavement
5. Increased need for cleaner pavement
6. Reduced adhesion
7. Reduced durability
8. Increased problems with bead application

Selecting a paint formulation with a given solvent or mixture of solvents is not an easy task and involves many compromises. The striping of rural roads does not require the speed of drying as does a high-traffic-density Interstate. An Interstate does not need the speed of drying that crosswalk lanes do in a high-traffic-density area. Usually the best choice is the slowest drying paint compatible with the conditions under which the stripe must be placed. However, jurisdictions do not have the luxury of selecting a multiplicity of formulations. Rather, one formulation is selected for use. This formulation is often overdesigned for some applications and underdesigned for others. It is not unusual for the same formulation to be used for marking an urban Interstate carrying 50,000 average annual daily traffic (AADT) and a rural two-lane road carrying 350 AADT. The stripe wears out prematurely (6 months) on the Interstate, and the stripe is totally intact but dirty in appearance after 1 year on the rural two-lane road. In between these extremes, the demands of the location are fulfilled by the treatment; namely, the stripe provides guidance throughout the year to the motorist.

Water-Borne Paint

Over the years, as water-based paints were introduced, they were looked at for use as traffic-marking paint, but were set aside for various reasons, including cost and extended drying time. In July 1977, the California Air Resources Board proposed a model rule for local air quality districts that strictly limited the quantity of volatile organic compounds contained in traffic-marking materials. The level of volatile organic compounds was set at a maximum of 250 grams per liter of paint, minus the water content. The proposed rate was scheduled to become effective September 2, 1982. In most cases, exemptions were granted that extended this date to September 1984. The South Coast Air Quality Management District (Los Angeles) was one of the first districts to enforce Rule 442, which limited volatile organic compound emissions to a maximum of 600 lb/day. This limited the application of solvent-borne paint to 175 gal/day (660 L/day) for each striping truck. Each truck is capable of applying 500 gal/day (1900 L/day). As a result of these air quality regulations, the California Department of Transportation looked at all practical alternatives to solvent-borne traffic paint (*20, 21*), and with the aid of suppliers, developed a new family of water-borne traffic-marking paints. The use of water-borne traffic paint is now operational in most of Southern California. In 1984 the California traffic-paint contract included an order for 243,000 gallons (920 m^3) of water-borne traffic paint. Use has grown each year since then, such that it was anticipated that more than half of all the traffic paint used in California in 1987 would be water-borne. Texas and Louisiana are also looking at water-borne paints. Figure 9 shows a striping truck in the process of applying water-borne paint.

FIGURE 9 Applying water-borne paint.

California has developed a performance specification for water-borne traffic paint (Appendix A) in which the formulator is allowed to choose from a wide range of vehicles and pigment loading so as to be able to try the latest improvements in water-borne technology. Most of the present formulations are based on acrylic and latex resins and have a dry time of 10 minutes by ASTM D 711. As part of their work on water-borne paints, California has also developed a lead-free yellow pigmentation system for their water-borne paints, which is also described in the above-referenced reports. Waterproof glass beads are used in the water-borne traffic-marking paints. Although the water-borne traffic paints are currently slightly more expensive than the solvent-borne traffic paints, California concludes that they:

- Are proven alternatives to solvent-borne paints.
- May be hot or cold applied depending on equipment and weather conditions.
- Provide service life equal to or better than solvent-borne paints.
- Provide bead retention superior to solvent-borne paints.
- Have no strong solvent odor and induce few respiratory complaints from users.
- Have safer application characteristics and reduced shipping and handling hazards owing to reduced flammability.

California expects use of water-borne paints to increase in cases in which conditions do not warrant application of thermoplastic and is specifying that all new paint-striping equipment purchased be compatible with water-borne paint. Some problems have been encountered in converting solvent-borne paint equipment to use with water-borne paints.

Beads

The best system yet devised for reflectorizing paint is with small glass beads made by projecting particles of crushed glass up into a furnace where they are melted, pulled by gravity and surface tension into spheres, and then allowed to fall, cool, and be collected for use. This process produces a wide gradation of bead sizes, with not all of the beads being spheres. Some of them end up as spheres with tails and others end up as miniature barbells and the like. The gradations of glass beads used to reflectorize paint stripes were not arrived at scientifically; rather the characteristics of the beads produced by the process became the specifications. The specifications vary in small ways from agency to agency, with regard to percentage of rounds, surface treatments, etc. Their general grading requirements are shown in Table 4.

Any beads smaller than the 106 μg size are normally sold as premix materials or for applications other than for use in pavement markings. Interestingly, virtually all of the agencies purchase and use the same type and gradation of beads. At the same time, the agencies use different paint formulations, having different resin types, solvent materials, solids percentages, and drying times.

The fact that traffic-marking glass beads perform extremely well under so many different conditions of paint film thickness, loading, etc., is indeed extraordinary. Some (*22*) have questioned the gradation of the beads used. The ultimate difficulty may be in the inability of the existing traffic-paint application equipment to operate at the level of application accuracy necessary to be able to realize the benefits of special bead gradations. The use of more rapidly drying paints often results in the need for special bead application equipment because the accelerated drying of the paint reduces the time for bead introduction and for bead distribution.

Application

Most of the traffic-paint application equipment used relies on air pressure to force the paint from the paint tank to the spray heads and onto the road as shown in Figure 10. Any variation in the speed of the truck, the temperature of the paint (thereby changing the paint viscosity), and the hydraulic head of paint

TABLE 4
GRADING REQUIREMENTS FOR GLASS BEADS

Sieve		Opening	Percent Passing
Std.	Alt.	(in.)	(by weight)
600 μm	30	0.0234	100
250 μm	60	0.0098	40-70
180 μm	80	0.0070	15-35
106 μm	140	0.0041	0-5

FIGURE 10 Solvent-borne paint-striping truck.

in the tank can change the wet-film thickness of the paint being applied. The traffic-paint application equipment that does not rely on air pressure uses circulating pumps. This system offers better control but still delivers a given quantity of paint to the road. Any variation of truck speed results in a variation of paint film thickness. There is a trend to use airless spraying equipment, that is, spray equipment that does not use atomizing air.

A new system that is gaining favor in Europe requires pumping the paint with a positive displacement pump having a pumping rate directly related to the truck speed. This ensures a constant paint film thickness. This system has not been adopted in the United States. Likewise, bead application equipment used in this country is independent of truck speed and other variables.

One of the time-consuming elements of applying paint has been the transferring of the paint from the 55 gallon (200 L) drums as it is received from the manufacturer to the tanks on the striping trucks. A current trend is for the paint manufacturer to supply paint in several hundred gallon (1 to 3 m^3)-size tote tanks, which are loaded onto the paint trucks. The spray guns are fed directly from the tote tanks.

THERMOPLASTICS

Thermoplastics are materials that change their physical state (reversibly) with changes in temperature. Thermoplastic marking materials are solids at ambient temperatures and liquids at elevated temperatures. They are applied at elevated temperatures by spray or extrusion equipment, and cool rapidly on the road to solid marking materials. There are no solvents in thermoplastics.

Alkyd and Hydrocarbon

Thermoplastic marking materials are a mixture of resins, glass beads, pigments, and fillers. A typical composition is as follows:

Material	Percent by Weight
Resin	18
Glass Beads	25
Pigment & Filler	57

Developed in Great Britain before World War II, the first resins used were mixtures of wool grease and various waxes. After World War II alkyd resins were adopted for the binder systems. These were largely replaced by hydrocarbon resins in the 1960s and early 1970s. Having much the same physical properties, the alkyd and hydrocarbon resins have vied for position largely on the basis of price. Accordingly, the use of hydrocarbon resins lost position in the late 1970s and early 1980s. Currently these materials are largely cost competitive. About 70 percent of the thermoplastic being used employs hydrocarbon resin and 30 percent employs alkyd resin at this time.

Although it is not readily apparent because of the terminology, traffic-marking paint (alkyd base) and alkyd-base thermoplastic marking material end up on the road as much the same material. The paint is placed with a solvent or water as a thin film, the thermoplastic is placed with heat as a thick film. In their final form on the road they each contain an alkyd resin binder, glass beads, pigment, extender, and filler. A large percentage of the alkyd and hydrocarbon thermoplastic marking material used is applied by contract applicators. The applicators receive the thermoplastic marking materials in two forms from the manufacturers. About 20 percent of the materials being used is melted and blended together by the manufacturer and then cast into blocks and allowed to cool. The applicator then remelts these blocks on use. The other 80 percent of the materials being used is dry blended by the manufacturer and the granulated materials are bagged. The granulated material is then melted and blended in the applicator's melt tank. Often the bags are made of thermoplastic materials, such that the bag with its contents is thrown into the melter and the bag becomes a part of the marking material. The added cost of melting and blending the materials by the manufacturer is meant to ensure that the materials are properly blended. Proper blending of the materials in the applicator's melters can be and is done on a routine basis, yet there is an increased risk of improperly blended material being applied.

California recently conducted laboratory tests (*21*) on two different alkyd-based and two different hydrocarbon-based thermoplastic marking materials obtained from different suppliers. Figure 11 shows the viscosity of these materials as a function of temperature and shows quite clearly their thermoplastic nature. Most thermoplastics can be agitated once their temperature exceeds 300°F (150°C). Spray and extrusion thermoplastic application equipment calls for materials to be in the 20 to 70 poise (2 to 7 Pa·s) range.

Interruptions of striping operations caused by traffic interruptions, moving sites, and other reasons and the need to remelt materials make it necessary that thermoplastic marking materials have stable or near stable viscosities at application temperatures for at least 6 hours. Figure 12 shows the viscosity stability of the materials at 425°F (218°C) as a function of time. The increase in the viscosity of the alkyd materials is thought

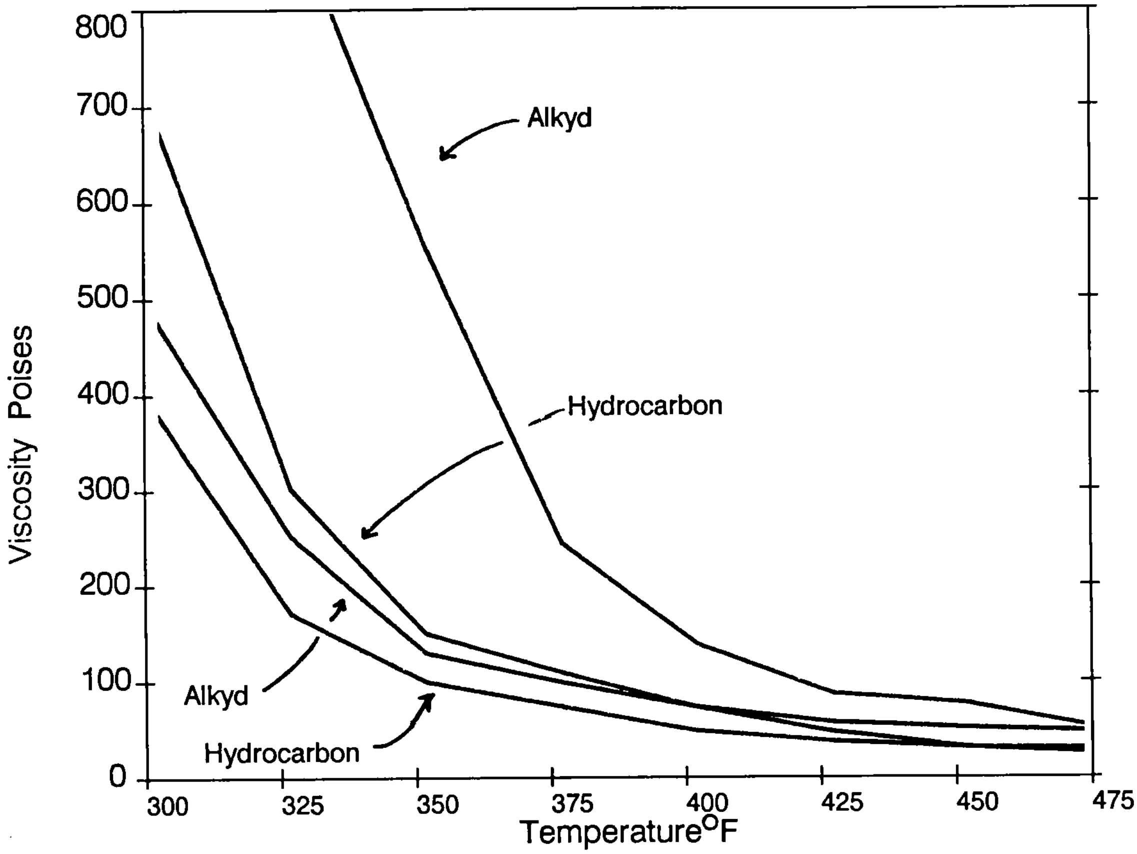

FIGURE 11 Brookfield thermosel viscosity vs. temperature, alkyd and hydrocarbon thermoplastics.

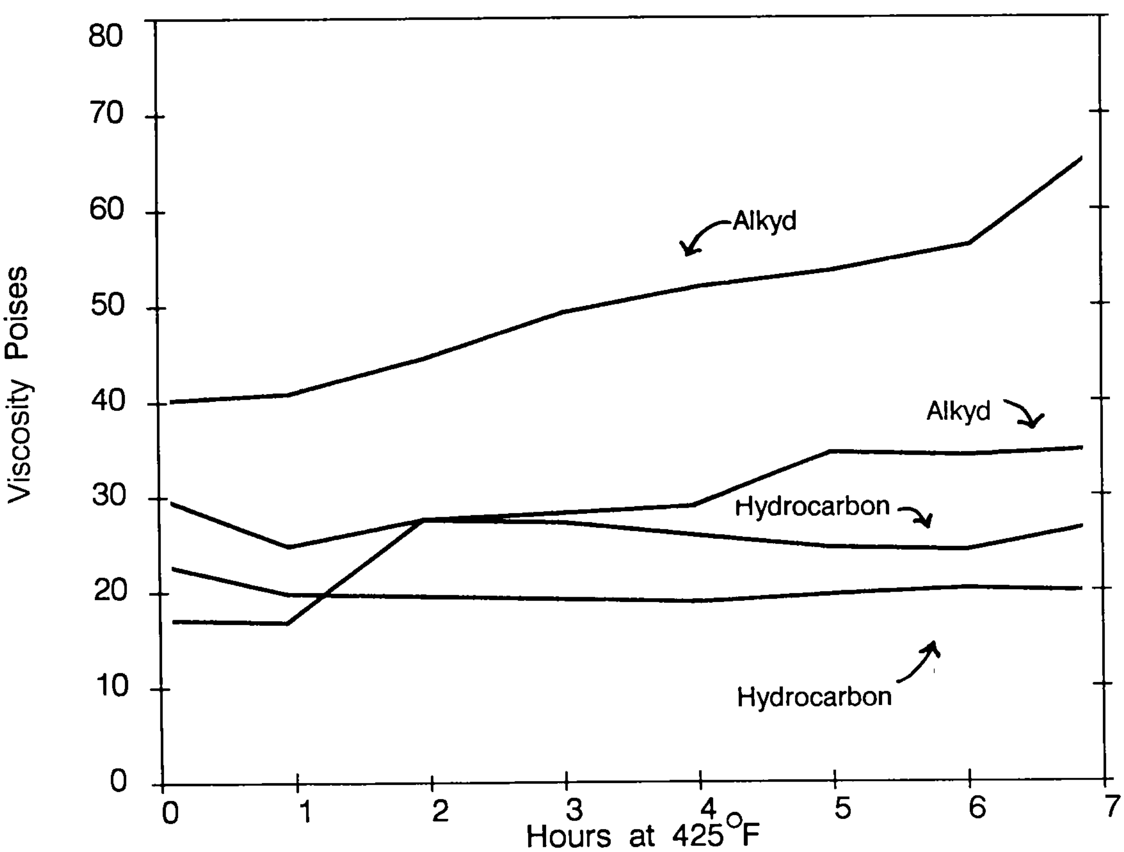

FIGURE 12 Viscosity stability at constant temperature, alkyd and hydrocarbon thermoplastics.

to be related to the fact that alkyd resins are derived from natural products (naval stores), whereas the hydrocarbon resins are derived from the high-temperature cracking of petroleum.

Over the years, it has been learned, many times the hard way, that use of the proper application temperature is crucial to the successful performance of thermoplastic marking materials. Figure 13 shows the bond strength to portland cement concrete as a function of temperature. Most application specifications call for an application temperature of 425°F (218°C), which, as can be seen from Figure 13, provides near optimum bond strength for these materials. It is possible in melting thermoplastic in application machines to damage the thermoplastic by scorching it. This often occurs when kettle temperatures are raised above acceptable levels to increase melting and production rates. Application temperature and the temperature of the material in the application machine tank are not synonymous. Application temperature of the materials should be taken as the material exits the spray gun or the extrusion head. This can be done with remote infrared temperature sensing devices or by direct insertion of a thermocouple into the material. Although thermoplastic marking materials contain no solvents, they do contain small quantities of volatiles. When the thermoplastic is applied, these volatile materials will sometimes form a white vapor or smoke-like cloud around the point of discharge. This most often occurs in spraying operations and occurs more frequently when alkyd-based rather than hydrocarbon-based thermoplastics are used. Care must be taken in measuring the application temperature when a vapor cloud is present because many of the infrared measuring devices measure the temperature of the vapor cloud, rather than the temperature of the material. The use of atomizing air in spraying thermoplastic introduces a serious problem in terms of temperature control, and there is a trend to the use of airless equipment for this work. Some specifications call for an atmosphere and pavement temperature of 50° to 60°F (10° to 16°C) and a rising atmospheric temperature.

Spray-applied thermoplastics are often applied at thicknesses between 60 and 90 mils (1.5 and 2.3 mm), whereas extrusion-applied thermoplastics are often applied at thicknesses between 90 and 120 mils (2.3 and 3 mm). There are two basic methods used to extrude thermoplastic marking materials. One method is called the "dragging die" or shoe method. By this method the hot material pours into a die or shoe that has a gate. When the gate is opened to a preset gap, it forms the width and thickness of the line as the applicator drags the shoe forward. This is the most widely used method of extruding thermoplastic. The other method is the "ribbon extrusion" method, in which a ribbon of molten thermoplastic from a moving application machine is allowed to lie down on the pavement. Although the extrusion methods of application are slower than spraying, they provide lines with sharper, clearer edges than those obtained with spray equipment.

There is universal agreement that thermoplastics should be applied to clean and dry pavements. There is almost universal agreement that thermoplastics applied to portland cement concrete should be preceded by a surface treatment with a two-part epoxy primer. Figure 14 shows primer being applied and

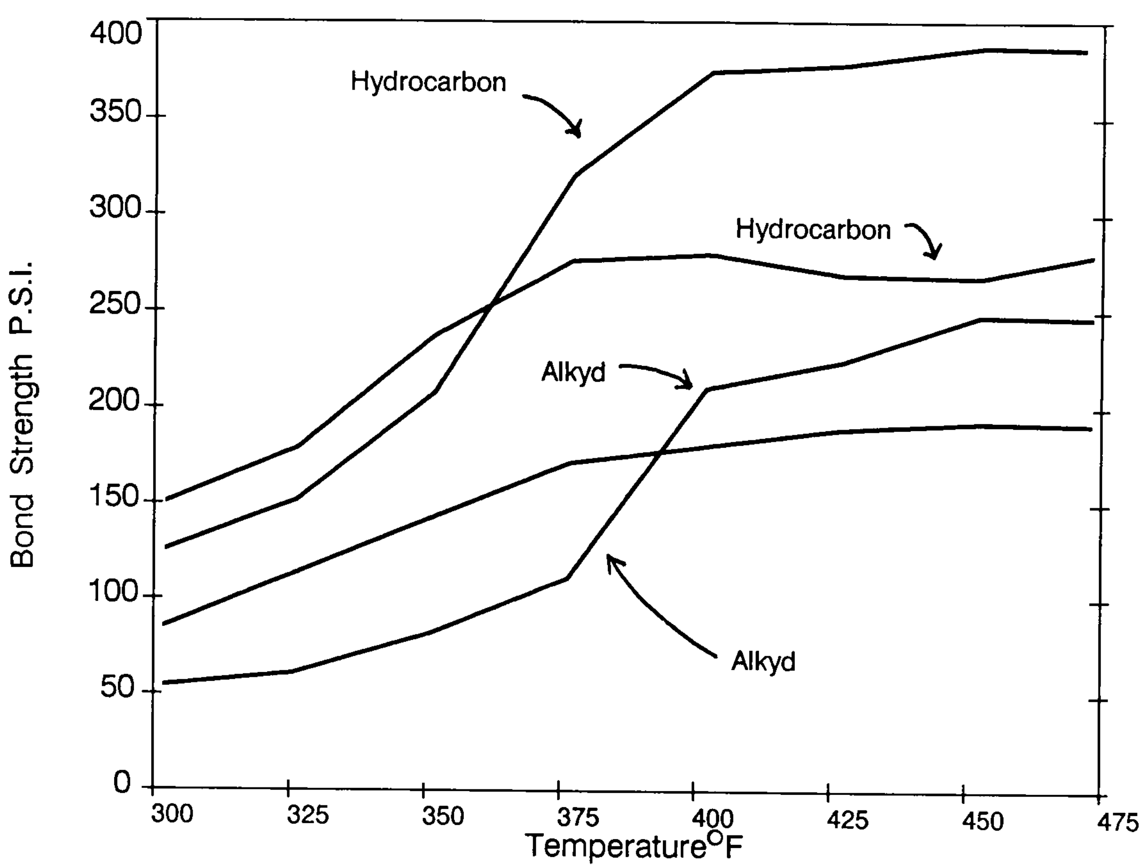

FIGURE 13 Temperature vs. bond strength, alkyd and hydrocarbon thermoplastics.

FIGURE 14 Primer being applied prior to application of thermoplastic.

FIGURE 15 Extrusion application of thermoplastic.

Figure 15 shows the extrusion application of thermoplastic. The need for use of a primer on new asphaltic concrete is debated on the basis that asphalt is itself a thermoplastic. The asphalt and the thermoplastic literally weld themselves together on application. One-part latex adhesives are sometimes used on new asphaltic concrete surfaces. Two-part epoxy primers are recommended for old and worn asphaltic concrete surfaces.

Because thermoplastics cost on the order of five to six times more than paint and their successful performance is so closely tied to proper application, more attention to crew training and the use of better trained inspectors is highly recommended. When purchasing thermoplastics on a contract basis, the purchaser wants to make sure that the full thickness of material contracted for is applied. The applicator wants to apply what is called for and no more. It is difficult and expensive to measure film thickness of thermoplastics after they are applied. Film-thickness measurements of materials being applied are normally done by placing metal plates in the path of the application machine and then picking them up and measuring the film thickness after the application machine has passed over them and applied the thermoplastic. An adhesive-backed tape similar to duct tape (but of a color similar to that of the pavement to be marked) has been used in place of metal plates to avoid possible bias by the machine operator. Thermoplastic marking materials most often last 3 to 5 years, and over this period of time records of the materials used, contractors used, and application conditions are sometimes hard to maintain. The existence of such records can be of great benefit when re-marking becomes necessary.

If it is possible, contracts for the purchase of contractor-applied thermoplastics should call for a certain number of days of dry weather rather than simply a certain number of days, to encourage the contractor to apply material only when pavement moisture conditions are favorable.

Thermoplastic marking materials being applied at 60 to 120 mils (1.5 to 3 mm) in thickness project more easily through submerging water films and drain water more rapidly than thin-film markings such as paint. Corrugation of thermoplastic lines as they are being installed can also improve their water drainage and enhance their wet nighttime visibility. Protruding above the surface as they do makes them subject to damage from snowplows. The use of rubber snowplow blades was examined in the 1960s but abandoned. For many years in Europe, particularly in Denmark (*23*), thermoplastics have been installed flush with the pavement surface to avoid snowplow damage. On existing asphaltic and portland cement concrete pavements, grinders are used to cut a groove in the pavement, and then the thermoplastic is extruded into this groove. A unique and successful technique also used there is to extrude the thermoplastic onto asphaltic concrete pavement right after the pavement is placed and while the pavement is still warm. A heavy roller with a well-wetted roll follows a short distance behind the thermoplastic application machine and rolls the thermoplastic into and flush with the surface.

Epoxy Thermoplastic

A thermoplastic epoxy marking material (Epoflex) was developed by Southwest Research Institute in the late 1970s under sponsorship of the Federal Highway Administration (*24-27*). Traffic paints were characterized by a slow drying time and low durability but were largely protected from snowplows because of their low profile. Conventional alkyd and hydrocarbon thermoplastics were characterized by a moderate set time and high durability but were vulnerable to snowplow damage because of their high profile. Epoflex was developed to meet the need for a fast-setting, durable, low-profile marking material. The name "epoxy" has become widely accepted as the name given to a two-liquid component adhesive. The two liquid components are mixed together and react chemically in a heat-releasing (thermosetting) reaction to form a solid adhesive. One of the liquid reactants is epichlorohydrin-bisphenol A (epoxy resin) and the other liquid reactant is a hardening agent, which can be one of a number of compounds. The epichlorohydrin-bisphenol A contains the epoxide group, which is the group that has the adhesive characteristics and the group from which "epoxy" derives its name. The epichlorohydrin-bisphenol A epoxy resins are compounds that occur as thin liquids, viscous liquids, and solids, depending on their molecular weight, which can be controlled during their manufacture. These compounds are thermoplastic in nature. The binder for Epoflex is made by plasticizing a solid epoxy resin with a viscous liquid epoxy resin to give a product with the proper temperature-viscosity relationship for use as a pavement-marking material binder. The materials system contains no hardener and no chemical reaction is therefore involved. The material is a true thermoplastic. It is and remains throughout its life a solid at ambient temperatures and becomes a liquid at elevated temperatures and vice versa. Epoflex has the following formulation (*27*):

Parts by Weight		Material
White	Yellow	
30	30	Solid epoxy resin
20	20	Liquid epoxy resin
10	—	Titanium dioxide (ASTM D 476, Type II)
—	9.3	Lead chromate
10	10	Calcium carbonate (ASTM D 1199, Type GC, Grade I)
14	14	Premix beads (ASTM D 2205, Type I)

Each of the components of Epoflex has numerous equivalents that are available from multiple manufacturers in the United States. Epoflex is heated to 450°F (230°C), at which time it has a viscosity of approximately 600 centipoises (0.6 Pa·s) and is applied as a spray to the pavement to a thickness of from 10 to 20 mils (0.3 to 0.5 mm). To achieve good adhesion, it is imperative that Epoflex be applied to the pavement at 450°F. To minimize cooling of Epoflex on application, a low-pressure airless (no atomizing air) system is used for its application. The equipment used to apply Epoflex is nothing more than a heated tank with low-pressure, 50 to 60 psi (340 to 410 kPa), air above the material to force the material down a heated line through a valve and out a fan-spray nozzle. Unlike other hot-spray marking materials, Epoflex on spray application is virtually smokeless, as can be seen in Figure 8. Drop-on, gradation-type traffic-marking beads are gravity dispensed onto the top of the molten Epoflex material immediately behind the spray gun, where they embed themselves to just below their horizontal axis. Within approximately 5 seconds from the time the material strikes the pavement, it has cooled sufficiently to accept traffic. There is no solvent in Epoflex to evaporate. The wet (or molten) and dry (or cooled) film thickness of the material are the same.

Based on field trials conducted in California, Colorado, Minnesota, and Texas from 1978 to 1981, the service life of Epoflex under varying conditions was determined to be anywhere from 2 to 10 times that of conventional traffic-marking paint.

When Epoflex was introduced in the early 1980s, most organizations looked upon it as just another thermoplastic hot-spray material and applied it with heating cycles and atomizing air spray systems used with alkyd- and hydrocarbon-based thermoplastics. Epoflex is more sensitive to heating than alkyd- and hydrocarbon-based thermoplastics, and, because it is applied as a thin film [10 to 20 mils (0.3 to 0.5 mm)], compared with conventional thermoplastics, which are applied as thick films [60 to 90 mils (1.5 to 2.3 mm)], the use of atomizing air spray systems inevitably cools the material below its proper application temperature. Because of these reasons and, in some cases, indiscriminate formulation changes, Epoflex test installations have not performed well. Several developments have occurred that could help stimulate future acceptance of Epoflex. Applicators have become aware that Epoflex is more heat sensitive and are handling it accordingly. Union Carbide Corporation has introduced a new line of epoxy resins that are more heat resistant. More important, applicators have come to realize that Epoflex must be applied with airless (no atomizing air) spray equipment.

THERMOSETS

Thermosetting materials are those in which two different components are brought together and a chemical reaction takes place that liberates heat. Using thermosetting materials as pavement markings involves conducting a chemical reaction on the highway and requires a degree of sophistication not generally encountered with the use of most other marking materials. Because thermosetting materials liberate heat on reacting, if they are brought together in a large vessel (for example, a tank), the liberated heat causes the rate of reaction to increase, thereby liberating more heat and further speeding up the reaction. Very shortly the entire reaction is out of control. To avoid this problem the two components of most thermosetting systems are brought together external to the component holding tanks.

Both the thermosetting polyester and epoxy systems have found their place as road-marking materials. The quantity of their use is not available, as it is proprietary information.

Polyester

Much of the original developmental work and testing of polyester pavement-marking materials was done by the Ohio Department of Transportation and the Glidden Company during the 1970s (*28*). The objective was to develop a thin-film marking material that would not be affected by snowplowing and would be more durable than conventional alkyd-base traffic-marking paint. California (*20*), New York (*29*), and others have applied and studied the performance of those materials.

Polyester traffic-marking paint is a two-component, thermosetting system. The first component, which comprises 95 to 99 weight percent of the total system, is composed most often of polyester resin, styrene monomer, wetting agent, adhesion promoter, pigment (titanium dioxide or lead chromate), and calcium carbonate. The second component, which comprises 1 to 5 weight percent of the total system, is most often a methyl-ethyl-ketone peroxide catalyst, which, when mixed with the first component, causes it to convert to a hard, durable material. The actual compositions of polyester traffic-marking materials are proprietary to the major manufacturers, which include Reichold, Glidden, and Baltimore Paint Company.

In the case of polyester traffic-marking materials, a separate spray gun is used for each of the two components, with the second component, the catalyst, being sprayed into the first component after the first component has exited the spray gun, but before the first component has contacted the road. Polyester marking materials are normally applied by truck-mounted equipment at traffic-paint application speeds, as shown in Figure 16. The methyl-ethyl-ketone peroxide catalyst must be contained in a stainless steel or Teflon-coated tank and has certain toxic characteristics that must be observed. The first component containing the polyester resin, styrene monomer, and other additives may be contained in the standard steel tanks used on paint-striping trucks. The styrene monomer has certain toxic characteristics that must be observed.

FIGURE 16 Truck-mounted application of polyester pavement-marking material.

Polyester pavement-marking materials are applied to a wet-film thickness of approximately 16 mils (0.4 mm) and, because they contain no solvent, the hardened line retains the 16 mil thickness. Glass beads of the type applied to conventional traffic paint at loadings of 12 lb/gal (1.4 kg/L) to flooding are applied to the polyester materials. Minimum application temperature is 50°F (10°C). Drying times vary with the ambient temperature and the formulation, but normally occur in the range of 10 to 45 minutes, thereby requiring line protection from the traffic. There seems to be a difference of opinion on the use of polyester on portland cement concrete, whereas there is general agreement that polyester does perform well on aged asphaltic concrete. Polyester is not recommended for use on new asphaltic concrete unless a primer is first applied. Two weeks after paving, a primer is no longer considered necessary.

Epoxy

Much of the original developmental work on two-component, thermosetting epoxy pavement-marking materials was done by the Minnesota Department of Transportation and the H.B. Fuller Company during the 1970s. Since that time, two-component epoxy-marking materials of one form or another have been placed in almost every state. The objective of adopting the two-component epoxy systems for use as a pavement-marking material was to obtain a thin-film, snowplow-resistant pavement marking capitalizing on the unusual adhesive and durability properties of the epoxy materials. In a typical two-component epoxy marking material, the first component contains the epichlorohydrin-bisphenol A epoxy resin, the pigment (titanium dioxide or medium chrome yellow), extenders, and fillers. The second component, which is the catalyst, can be one of a large number of compounds. Very often an amine is used. The ratio of the first to the second component can be anywhere from 1:1 to 5:1, depending on the specific chemistry of the system. The specific formulations used are almost all proprietary.

The speed of the reaction, and therefore the set or hardening time, is largely controlled by the selection of the second component, which is the catalyst. Unlike the polyester materials (in which the second component or catalyst is simply sprayed into the first component and the reaction proceeds), in the epoxy system the second component, the catalyst, must be mixed intimately with the first component so that a proper product may be obtained. In most application systems the two components are pumped by metering pumps and encounter one another in an in-line or power mixer, after which they exit immediately through a spray gun, as shown in Figure 17. If the application operation is forced to stop, the mixing device and the spray gun must be immediately flushed. Application thicknesses are often 16 mils (0.4 mm) wet and harden to 16 mils, because no solvents are employed. Traffic-marking beads employing a variety of surface treatments are used with the different epoxy formulations.

One of the unusual features about the two-component epoxy systems is that some of the formulations are compatible with water. This means that they can be applied not only to damp pavement, but to wet pavement. In some instances, some of the epoxy application equipment actually employs a water spray gun ahead of the epoxy spray gun to wet the pavement so that the epoxy may more easily wet-out the pavement before it cures. It is possible to select a catalyst that cures the resin so rapidly that line protection is not needed. Most systems in use cure on the order of 15 to 30 minutes and require line protection. The epoxy resins themselves are, for the most part, quite safe to handle. Special precautions are necessary for handling some of the catalysts.

The epoxy marking materials are applied to portland cement concrete and asphaltic concrete pavements with success. Their use in the snowbelt area of the country on high-volume roads to provide all-year delineation is an important contribution.

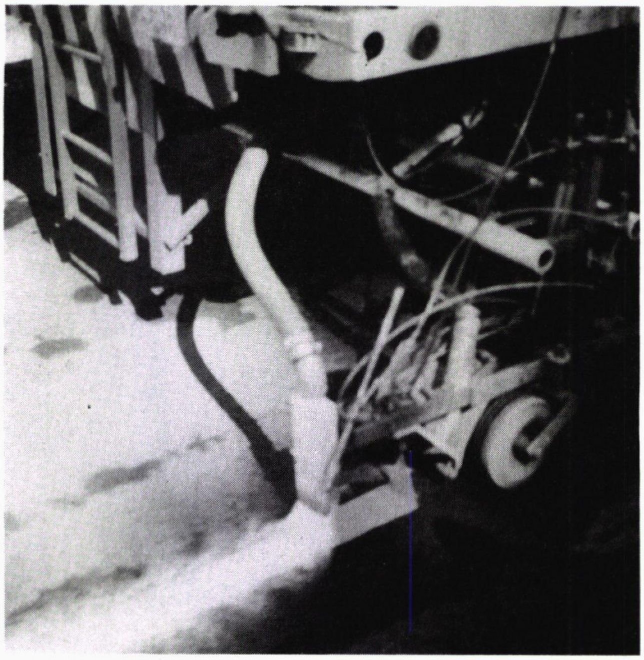

FIGURE 17 Applying two-component epoxy-marking material.

TAPES

Regular tapes are used for permanent installations, whereas temporary or removable tapes are used in construction zones.

Regular

Regular tapes (preformed plastic strips) are fabricated as roll sheet stock or cut-out legends in a factory. Because of their perfectly cut edges, when they are properly applied and first installed, they are just about the ultimate in appearance as film-type pavement markings. If they fail and become distorted or relocated by the action of traffic, they can become the least attractive of pavement markings. They are for the most part manufactured using polyvinyl chloride (vinyl) resin binders that are complemented in formulations with pigment, filler, and glass beads used both in the premix and surface-embedded form. There are two types of regular tape marking materials (*30*), which have the following specifications:

	Type I	Type II
Thickness	90 mil	60 mil
Composition*		
Resins	40	20
Pigment & Filler	38	30
Glass Sphere	14	33

*percentage by weight

Tapes normally come with a factory-installed preapplied adhesive that has a protective paper backing. In the field, application is achieved by removing the protective paper backing and pressing the tape to the pavement with either a roller or a truck tire, as shown in Figure 18. For those tapes that do not come with preapplied adhesive, the adhesive is applied to the pavement or the tape at the time of the application. Epoxy primers are also frequently used in the application of regular tapes. One of the more durable of the pavement-marking materials systems, tapes on a unit-cost basis are relatively expensive. Because of this, special attention is given to the pavement surface condition to which tapes are applied. It is not unusual for pavement surfaces to which tapes are to be applied to be cleaned and a treatment applied to the pavement before the tape application. A pavement temperature of at least 70°F (21°C) is recommended for application (*31*). On new asphaltic concrete pavements, tapes are sometimes placed on the pavement while the pavement is still warm and rolled into the surface with a compaction roller, thereby giving snowplow resistance.

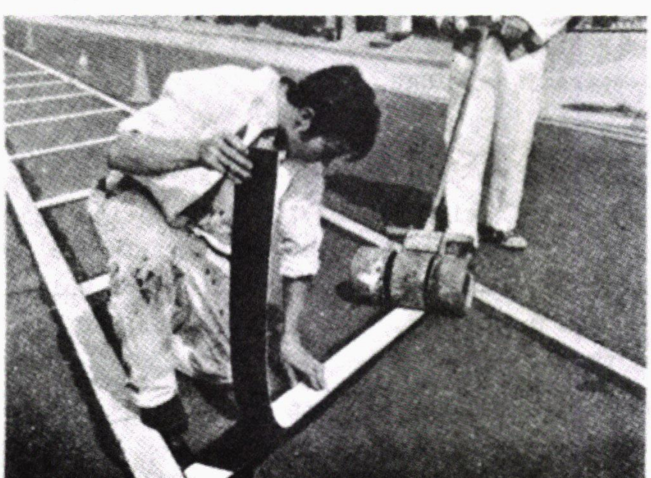

FIGURE 18 Applying tape markings.

Temporary

Special foil-back and removable temporary tapes are frequently used as temporary marking materials around construction sites and on repaving operations. Once construction is completed, the tapes are simply pulled up by hand. On repaving operations 1 ft (0.3 m) (plus or minus) length pieces of tape are applied at intervals to provide immediate delineation until such time as the regular markings can be applied. Because of their attractiveness, temporary tapes are especially suited for marking sites for special occasions (on pararde routes, for example). The use of temporary tapes in construction zones is often complemented by the use of temporary raised markers.

Tapes are well suited for installations where the conditions are severe and frequent replacement is required. Tapes can be applied with little or no equipment, and once installed, the roads can be opened immediately to traffic. Their slow application rate and high material cost result in their infrequent use on rural highways. Tapes used in crosswalk and other transverse applications can become distorted because of the action of traffic turning, accelerating, and decelerating over the tapes. Primers are often used to improve tape adhesion for these uses.

PAVEMENT MARKERS

Regular

Pavement markers are available in a large variety of shapes, sizes, and types, and are made from a variety of materials. The most widely used nonreflectorized raised markers are those made of ceramic with a glazed surface. These markers are preferred over those made with plastics and other materials because of their resistance to scratching and to picking up road film and tire marks. Likewise, after a period of inclement weather, surface road film on these markers is quickly removed by traffic. Reflectorized raised markers most often employ cube-cornered acrylic lenses, tempered-glass lenses, or glass-bead lenses, mounted in either a plastic, ceramic, or metal base. In the past the majority of raised markers were placed in the field with a two-component epoxy adhesive (*32*) that was mixed at the site either manually or mechanically. The markers are applied by hand or mechanically, with the epoxy adhesive being applied to either the pavement or the marker, depending on the preference of the applicator. The quantity of adhesive used is significant to the retention of the marker. It is recommended that enough adhesive be applied so that when the marker is pressed in place a bead of adhesive approximately ⅛ in. (3 mm) in diameter is extruded around the base of the marker. Currently, there is a trend to replace the epoxy adhesive with a bituminous adhesive (Figure 19). Texas and Mississippi have reported successful use of the bituminous adhesive. Raised markers in metal mountings are almost exclusively used in markers that are partially buried so that snowplow blades are lifted up and over the reflective lenses by the metal housing. In most raised markers using metal housings the reflective elements can be replaced if they are damaged.

Applying raised markers to unmarked pavements is time consuming and requires skilled crews to obtain satisfactory alignment. To speed up installation of raised markers and overcome the alignment problem, some authorities first stripe the highway with paint. Within several months after the paint has properly cured, markers are then installed on patterns used by the agency. Typically, four nonreflective raised markers are used over or in place of the 10 ft (3 m) painted stripe, and a retro-reflective marker is placed at the center of every other gap [80 feet (24 m)]. In curves, center lines may employ raised reflectorized markers on spacing as close as 1 ft (0.3 m). In Florida a raised retro-reflective marker is often placed at the beginning of each stripe with an epoxy adhesive of the same color as the stripe.

Raised markers are used because they are a durable, day-and-night, wet-and-dry marking system whose use can be justified in high-traffic areas, and because their use along with painted lines provides wet-weather night visibility that painted lines alone do not provide. A large portion of the painted lane lines on the Interstate system in the sunbelt section of the United States has a raised reflectorized marker in the center of every second gap. The back side lens on these raised markers is often red, thereby serving as a distinguishable warning to an errant wrong-way driver.

When the raised-marker concept first became popular in the United States in the 1950s, the use appeared to be confined to the sunbelt section of the country. Experiments with rubber snowplow blades in Washington and other states were not successful because, although the rubber snowplow blades offered some measure of protection to the raised markers, they were ineffective in removing ice and snowpack, particularly in the late winter. This led to the development of the snowplowable raised marker (*33*), which is mounted in a metal housing and embedded in the pavement. Large installations of these markers in Kentucky, Ohio, New Jersey, and other states have shown that they can be used with snowplows equipped with tungsten carbide blades. More recently, in California, Georgia, Virginia (*34*), and other states, installations have been made wherein a groove is cut in the pavement and a raised reflectorized marker is placed in the groove, as shown in Figures 20 and 21. The

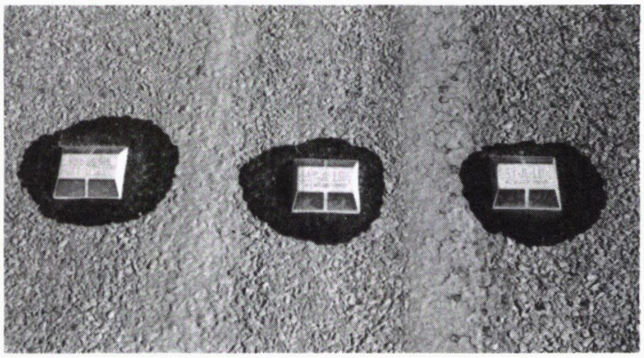

FIGURE 19 Raised marker applied with bituminous adhesive.

FIGURE 20 Cutting a groove in the pavement.

dimensions of the groove are such that the top of the raised marker is flush with or below the surface of the pavement, thus removing it from potential contact with snowplow blades. Georgia (*35*) found that installing raised reflectorized markers in a groove greatly enhanced their survivability in areas where no snowplows were used. Until such time as a retro-reflective system is developed for film-type markings that has wet-weather nighttime visibility, raised or recessed reflectorized makers are seen as an essential complement to film-type marking installations.

Temporary

A number of raised reflectorized temporary markers are available. Some of these come with special adhesive pads that allow for their easy removal, whereas others are nailed into the pave-

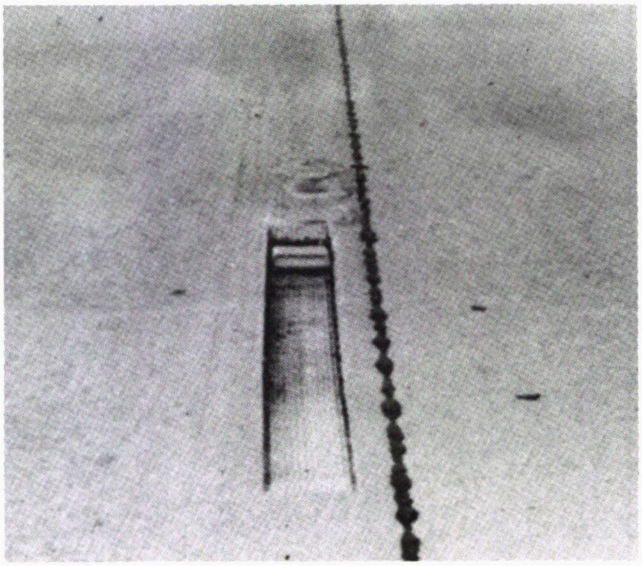

FIGURE 21 Raised marker installed in pavement groove.

ment. Temporary raised markers with a cover over the reflective element are used with considerable success in surface-treatment operations to delineate existing marking patterns. After the surface treatment is completed the cover protecting the reflective element is removed. The markers are then used as a guide for restriping operations. In construction zones it is recommended that the use of temporary raised markers be complemented by the use of temporary tape.

CHAPTER FIVE

COST-EFFECTIVENESS

If a given pavement-marking material is applied to a properly prepared surface, using the recommended application procedure, then its life expectancy becomes a function of the type of pavement, the volume of traffic, the type of traffic, the environment, and the environmentally induced factors. The environmentally induced factors include: salt and sand, snowplowing, studded tires, and chains.

With the exception of two-component internally mixed epoxy marking materials, and raised pavement markings that have been applied with two-component internally mixed epoxy, most all other pavement-marking materials are observed to fail more rapidly on portland cement concrete pavements than on asphaltic concrete pavements. There are multiple reasons for this, but in most cases it relates to the loss of adhesion. The volume of traffic at a site directly affects the life expectancy of markings. The type of traffic, i.e., the speed of the traffic and the makeup of the traffic (cars vs. trucks), affects the life expectancy of the markings. The dynamic load imposed by the tires of a vehicle traveling 60 mph (100 km/h) is some four to five times the static or stationary load that the same tires would impose. The amount of lane changing and vehicles turning over markings affects the service life of the markings.

The environment takes its toll, just as it does on everything. The ultraviolet light attacks the resin and pigment components of pavement-marking materials, causing them to chemically crosslink or their chemical bonds to break, with the loss of their original properties. Fluctuations of temperature, not only between winter and summer but on a daily basis, cause both the pavement and the marking materials to expand and contract. Any differences in the coefficient of linear expansion between the pavement and the pavement-marking material can result in stresses developing between the two. This can result in a loss of bond. If the bond strength is greater than the tensile strength of the marking material, then stretch marks or cracks will sometimes develop in the marking material. The presence of a white paint stripe on a black asphaltic concrete pavement, one reflecting the sun's heat and the other absorbing the sun's heat, is sufficient in some cases to cause a crack to develop in the asphaltic concrete along the edge of the stripe. Some states have extreme variations of climate. Texas, for example, has areas along the Rio Grande that seldom experience freezing weather, whereas the Texas Panhandle experiences numerous freezes. The Texas gulf coast around Houston experiences 60 in. (1500 mm) of rain annually, whereas the El Paso area experiences 9 in. (230 mm) of rain annually. The Texas traffic-marking paint is designed to stand up under all of these conditions and, indeed, does so very well.

Winter weather, as characterized by snowfall, calls forth the use of salt and sand, snowplows, studded tires, and chains. Each of these is detrimental in its own way to the life expectancy of pavement-marking materials. The use of studded tires is controversial, and, accordingly, each state has its own laws about their use (Appendix B). It is easy to visually observe the gouge marks in pavement markings left by tire studs (*36*).

It is possible to find many locations in the United States where one can mark a location in April and by the following April the site will need remarking. If the marking schedules are such that the same site does not get marked until September, the adverse conditions of winter are such that it will still need remarking by April. Thus, the same marking material applied to the same site can have a 1-year or 6-month service life, depending on its time of placement.

California is unique with respect to pavement markings because of its diversity of sites and environments. A paint stripe applied to a site in Southern California with an asphaltic concrete pavement, a moderate traffic count, and a location near the coast with moderate year-round climate can easily have a 1-year service life. The same paint applied to Interstate 80 at the top of Donner Pass near Truckee, California, has been known to last for one major snowstorm. The pavement at this site is portland cement concrete, whose surface consists of large pieces of polished aggregate, which is difficult for any material to adhere to. When a winter storm hits, the California Department of Transportation salts, sands, and plows. The vehicles come with their studded tires and chains, and the heavy trucks, which make up a large portion of the traffic, mount their chains. The result is devastating to pavement markings.

Life expectancy of pavement-marking materials as developed at a field test site is a good measure of performance at that site and similar sites. It may or may not translate to other sites. It is a measure of relative performance between materials at that site. The data used to construct Figures 22 through 31 depicting life expectancy of longitudinal markings and costs of the various types of marking materials were collected from various sources as divergent as California and New York and relate to experience at different sites. They may or may not relate to locations of interest to the reader.

Figures 22 and 23 show an average life expectancy of solvent-borne traffic-marking paint on asphaltic concrete and portland cement concrete, respectively. Water-borne traffic-marking paints are new, but as noted earlier in this report, California, which has done the most work with them, reports that their life expectancy is equal to or greater than that of solvent-borne paint, and their cost is slightly greater than that of solvent-borne paint, so that their cost-effectiveness is commensurate with that of solvent-borne paint (*21*).

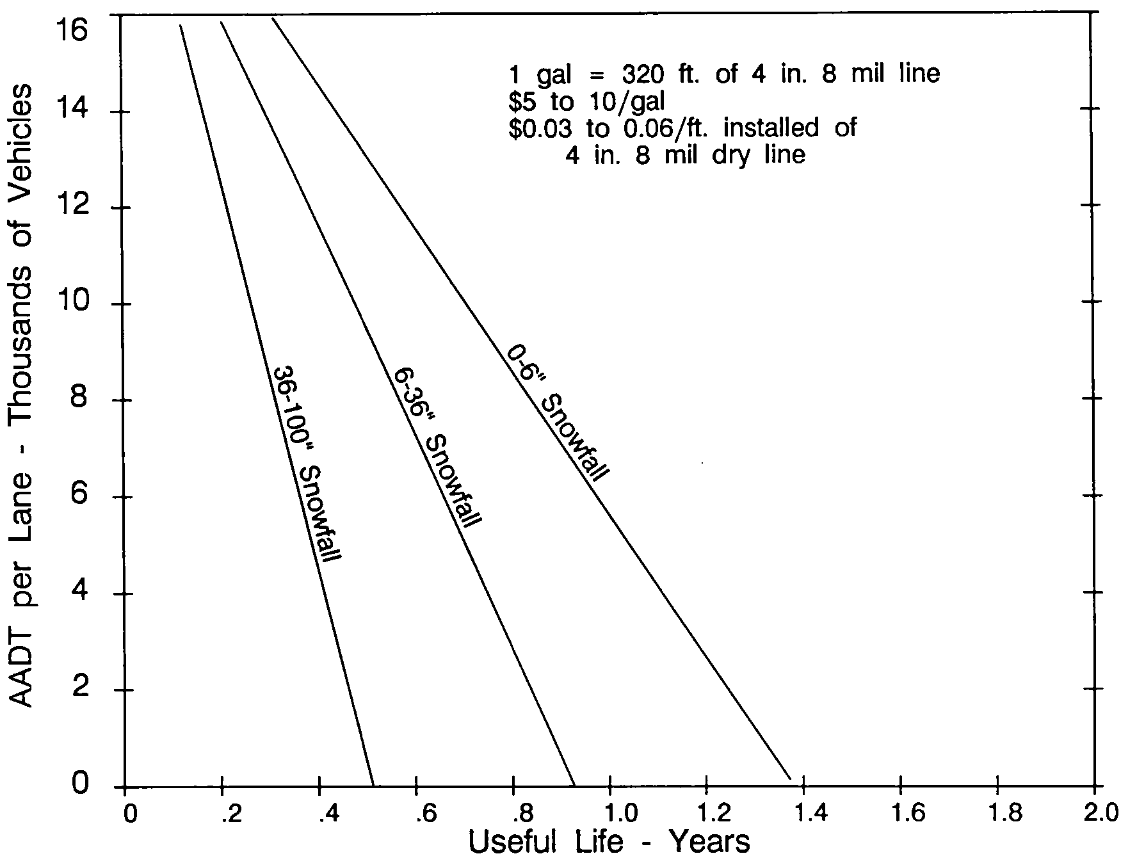

FIGURE 22 Life expectancy of solvent-borne traffic-marking paint on asphaltic concrete.

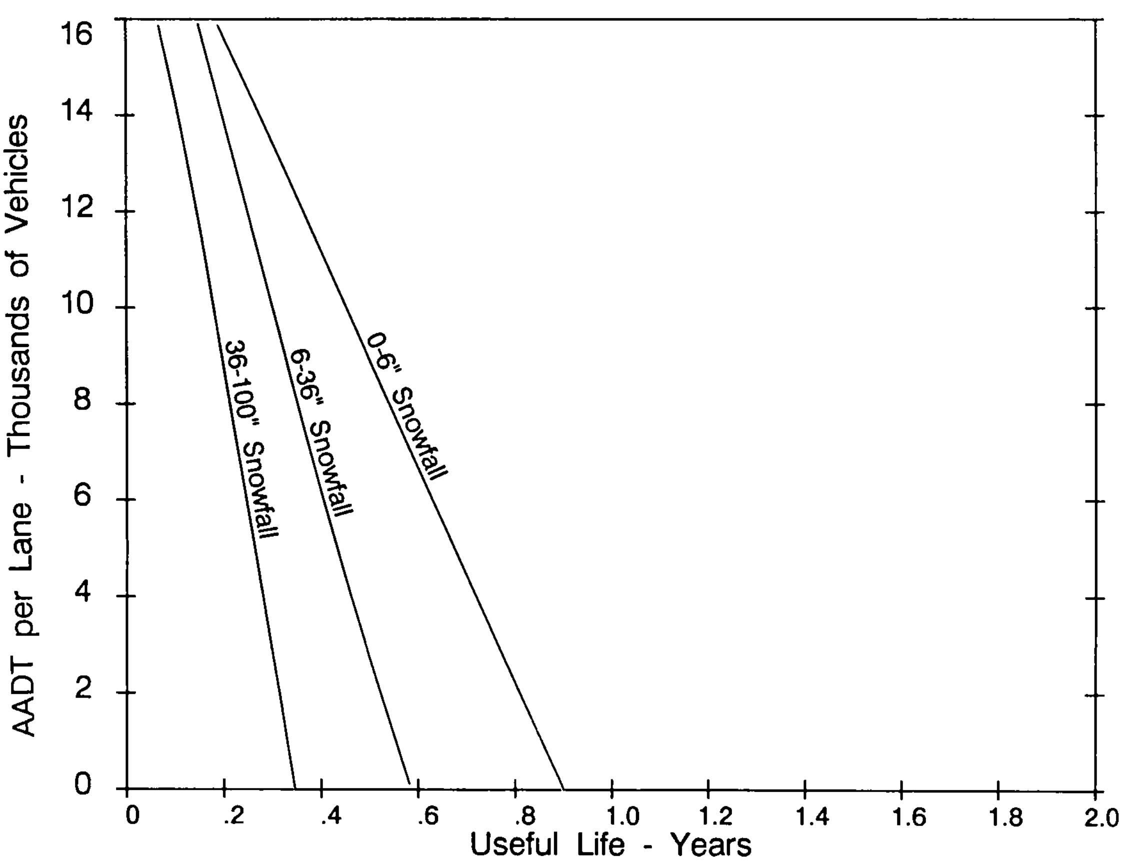

FIGURE 23 Life expectancy of solvent-borne traffic-marking paint on portland cement concrete.

The life expectancy of alkyd and hydrocarbon thermoplastics, which are very much alike, is most often related to winter-weather-induced failures and the type of pavement being marked. An 8 mil (0.2 mm) dry film of alkyd-base solvent-borne traffic-marking paint and a 120 mil (3 mm) film of alkyd-base thermoplastic are compositionally very close to one another, the main difference being their thickness. Their life expectancy, as shown in Figures 24 and 25, is very nearly a direct function of their thickness. If it were not for the snowplow damage to the higher profile thermoplastic material, the life expectancy of the two might be directly related.

The life expectancy of thermoplastic epoxy (Epoflex) is based on field trials conducted in California, Colorado, Minnesota, and Texas from 1978 to 1981, during its development (*26*). Figures 26 and 27 reflect the performance characteristics of thermoplastic epoxy on asphaltic concrete and portland cement concrete. Being a thin-film marking, thermoplastic epoxy enjoys a measure of protection from snowplow blades not enjoyed by thicker marking materials.

The life expectancy estimates for polyester marking materials as shown in Figure 28 are for applications on asphaltic concrete and are based on experience in Ohio (*28*) and California (*21*). No life expectancy estimates are shown for polyester marking material on portland cement concrete because it is not recommended for use on this type of pavement.

The two-component internally mixed thermosetting epoxy systems are the only pavement-marking materials that are reported to perform as well on portland cement concrete as they do on asphaltic concrete. Accordingly, Figure 29 shows the life expectancy on the two pavement types as being the same and reflects experience cited by Minnesota (*37*) and New York (*30*). One of the observations that is noted on the use of two-component internally mixed epoxy systems is that the white formulations tend to yellow with time.

Much of the preformed tape materials are used for temporary markings because they are easy to apply and easy to remove. Kentucky and Virginia have applied significant quantities of these materials and report (*31*) life expectancies as shown in Figure 30. No differentiation is made between life expectancy on asphaltic concrete compared with portland cement concrete.

California has more raised pavement markers in place than any other state (*38*). With more than 30 million markers in use in California, the observations are that marker loss is directly related to truck volumes and the traffic volumes that make lane changes across a given line of markers. Generalized life expectancies are shown in Figure 31. Marker loss has also been rèlated to improper mixing of the epoxy adhesive, improper surface preparation prior to placement of the markers, and placement of markers on asphaltic concrete pavements before the pavements have cured. Newly placed asphaltic concrete is too soft to sustain the markers, and they are soon dislodged by traffic, taking with them portions of the underlying pavement.

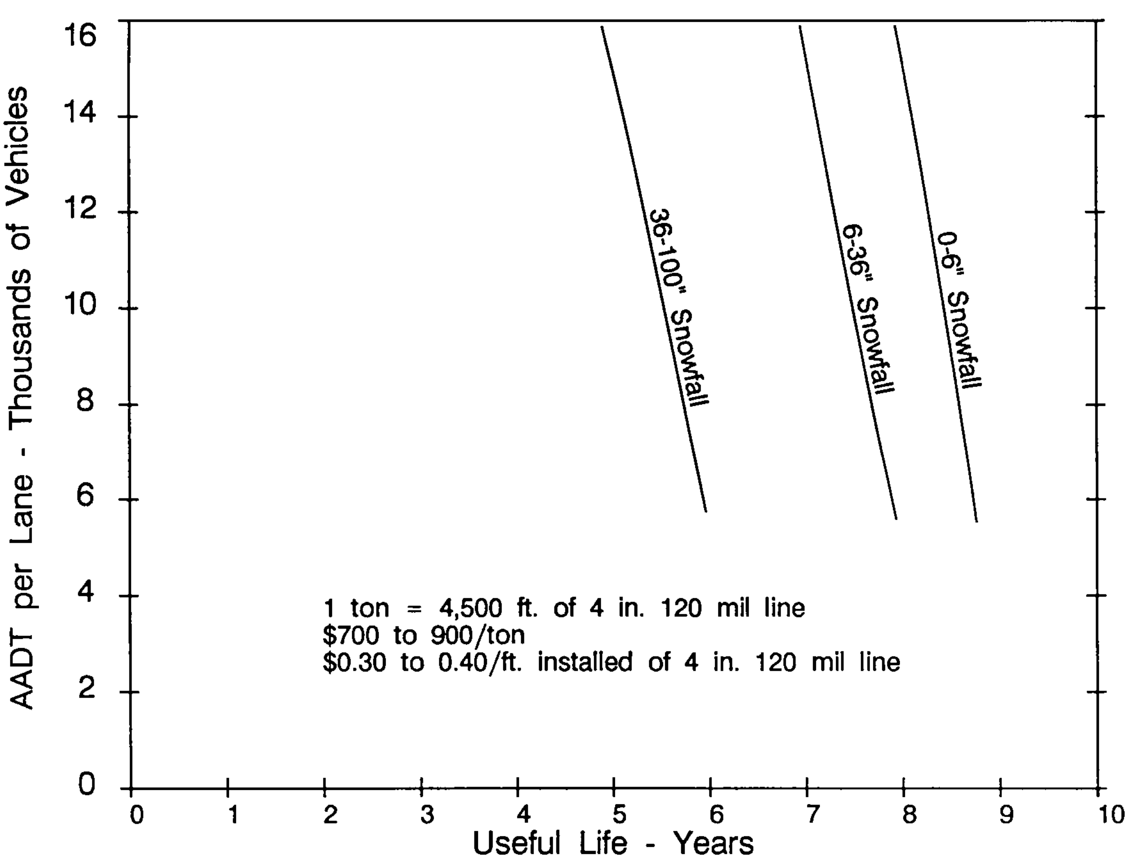

FIGURE 24 Life expectancy of thermoplastics on asphaltic concrete.

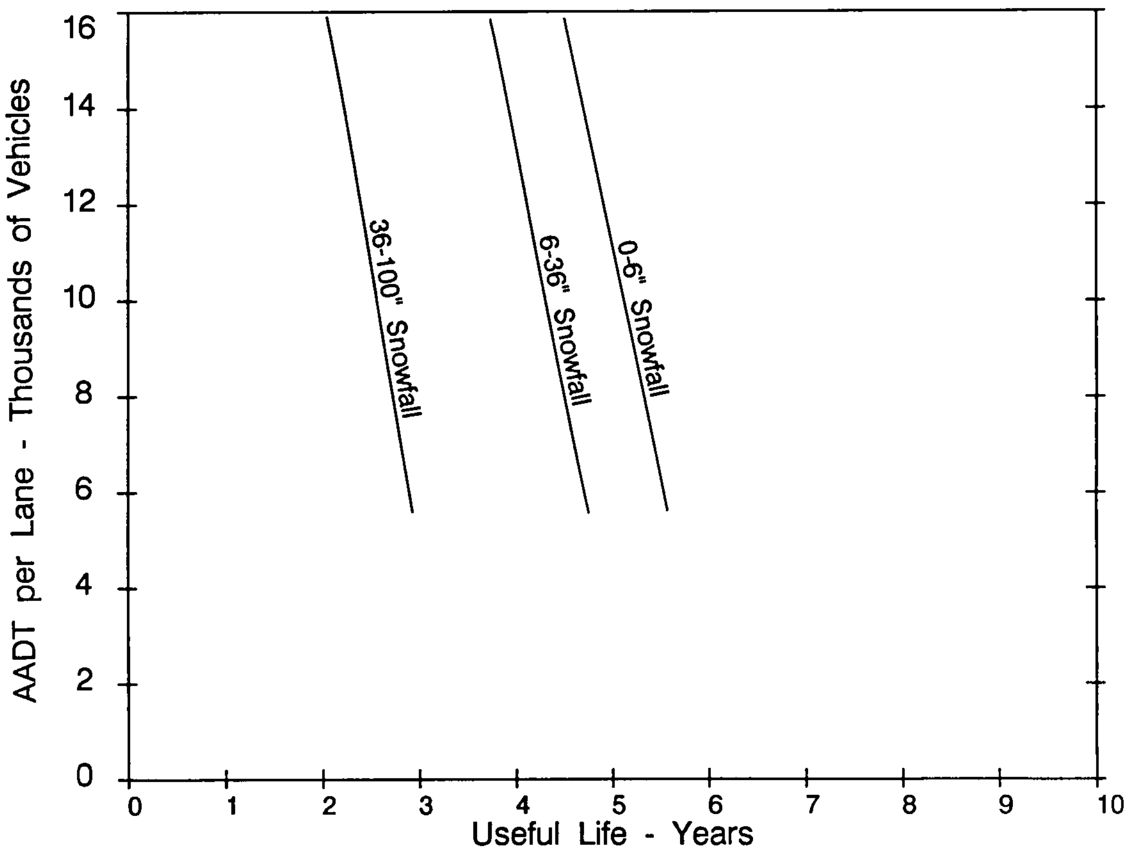

FIGURE 25 Life expectancy of thermoplastics on portland cement concrete.

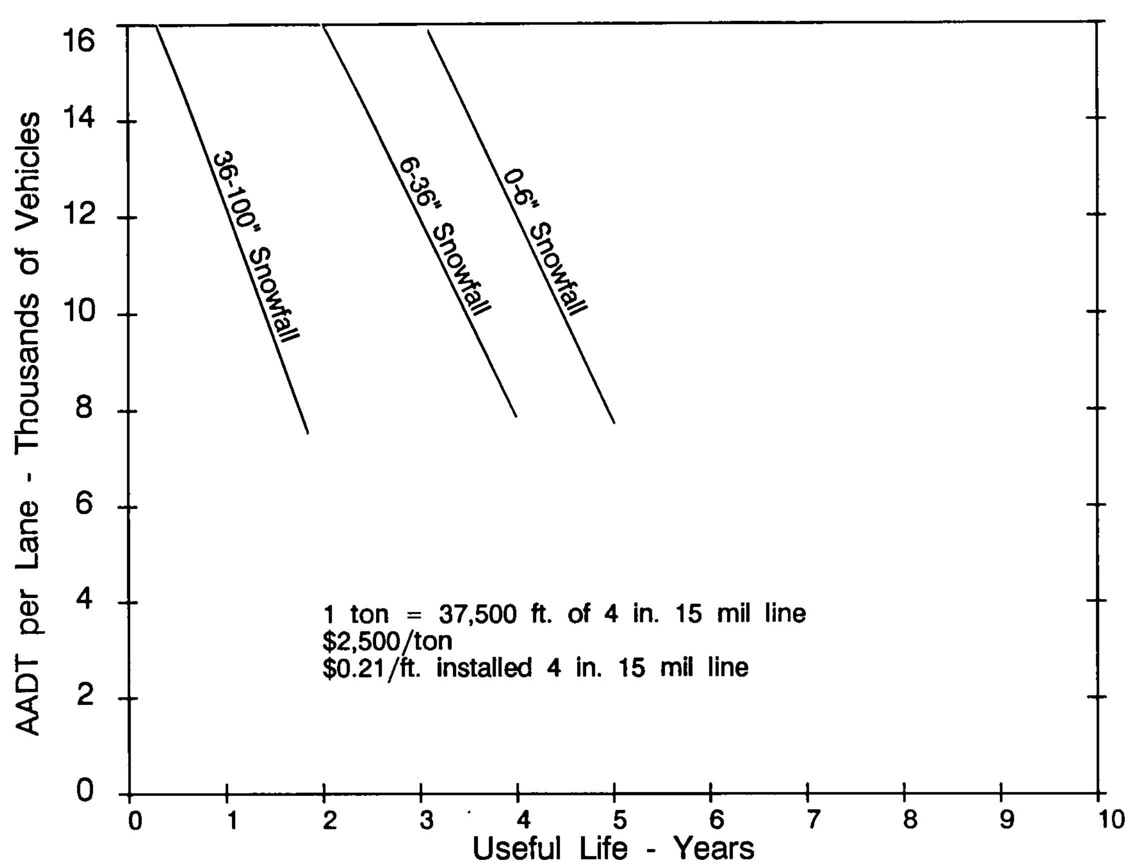

FIGURE 26 Life expectancy of thermoplastic epoxy (Epoflex) on asphaltic concrete.

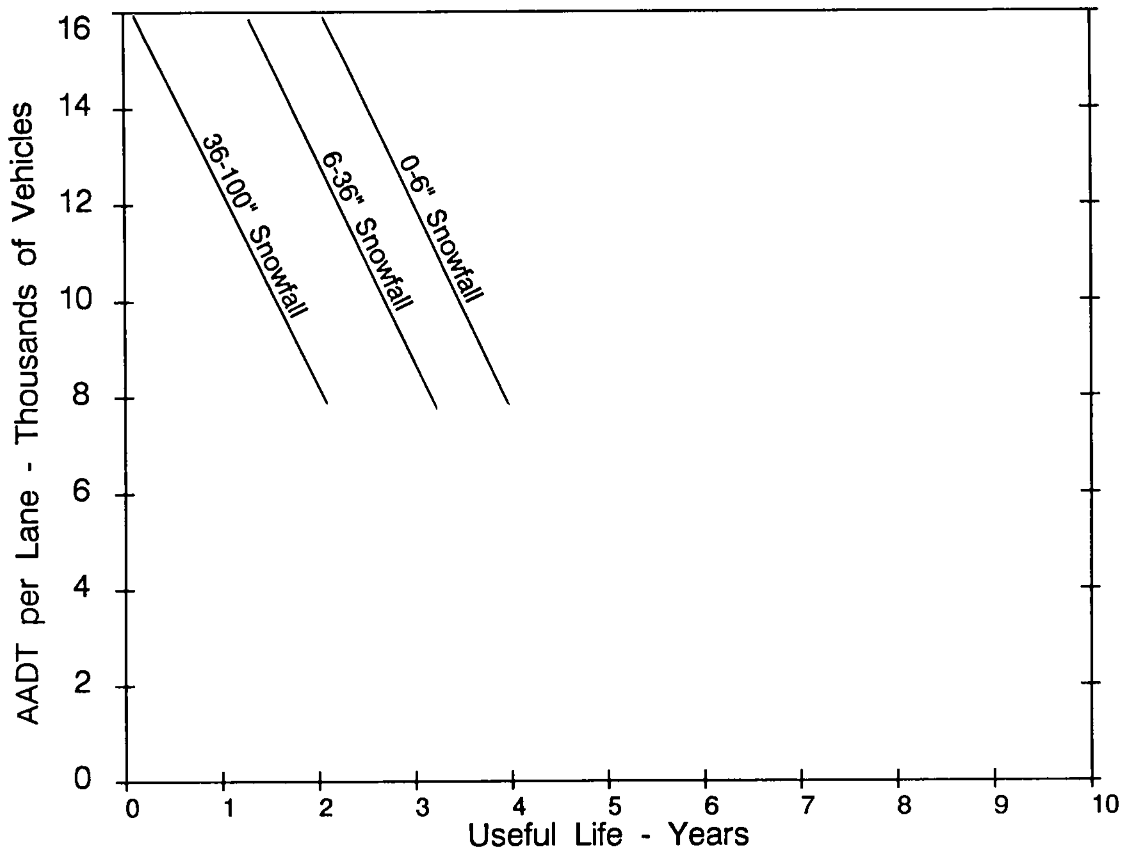

FIGURE 27 Life expectancy of thermoplastic epoxy (Epoflex) on portland cement concrete.

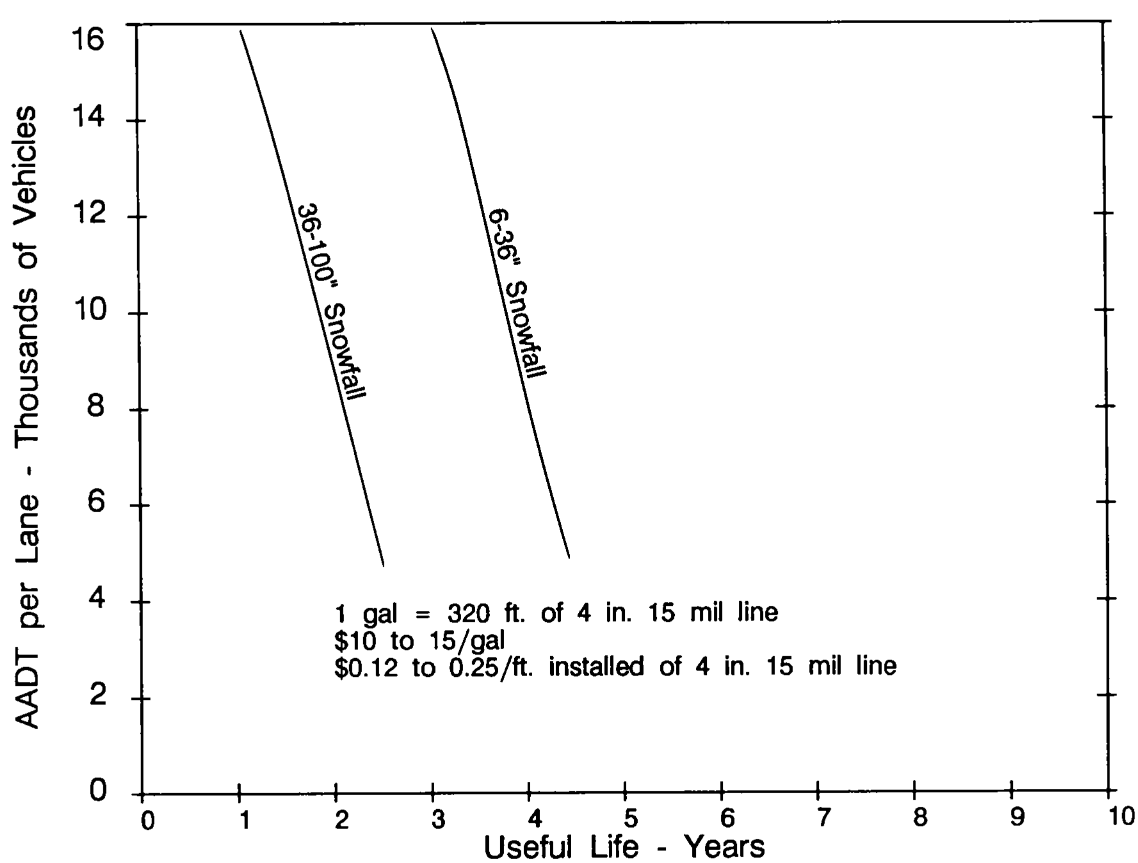

FIGURE 28 Life expectancy of polyester on asphaltic concrete.

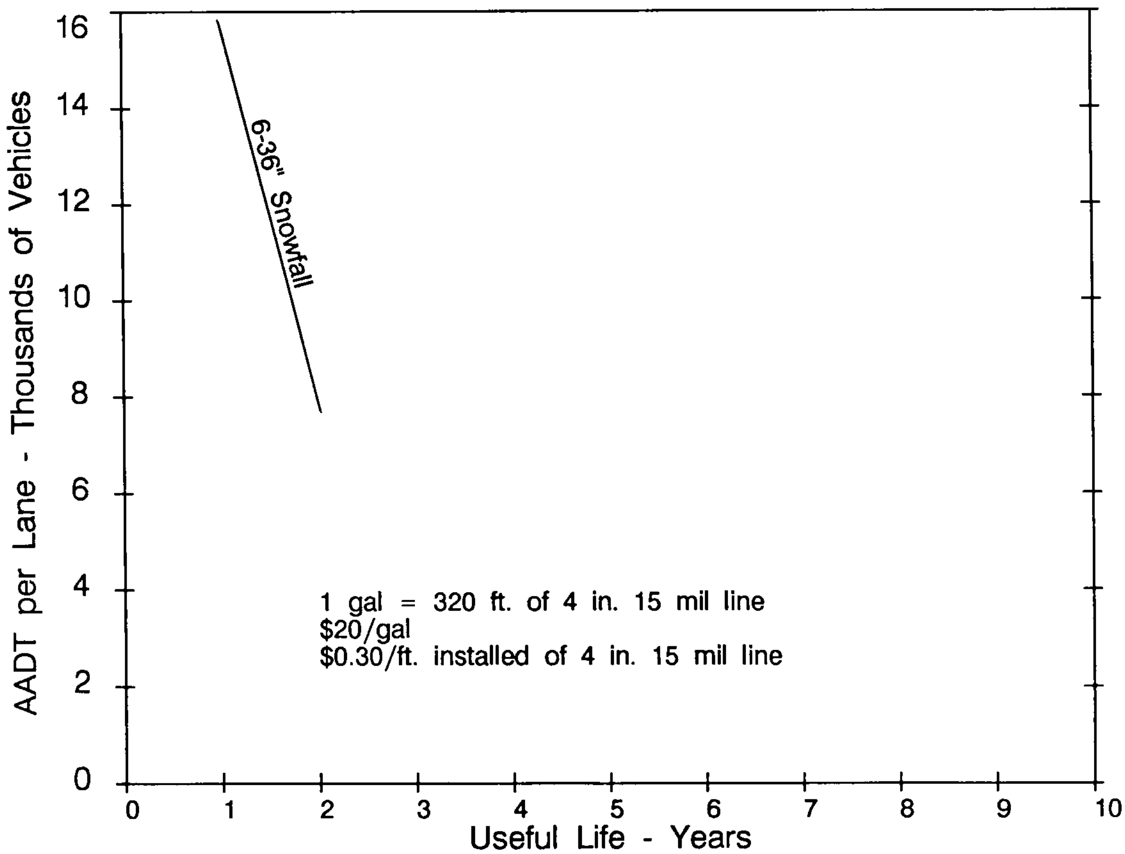

FIGURE 29 Life expectancy of two-component internally mixed epoxy on asphaltic concrete and portland cement concrete.

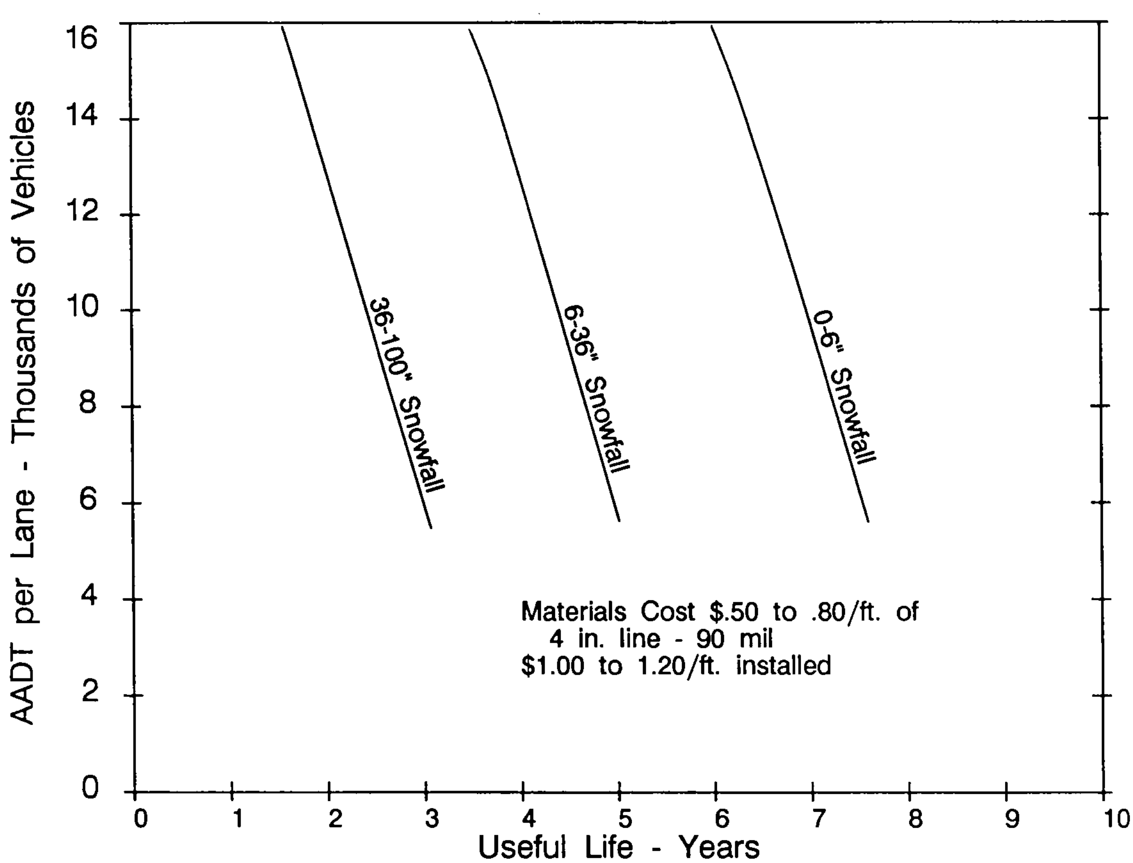

FIGURE 30 Life expectancy of preformed tape on asphaltic concrete and portland cement concrete.

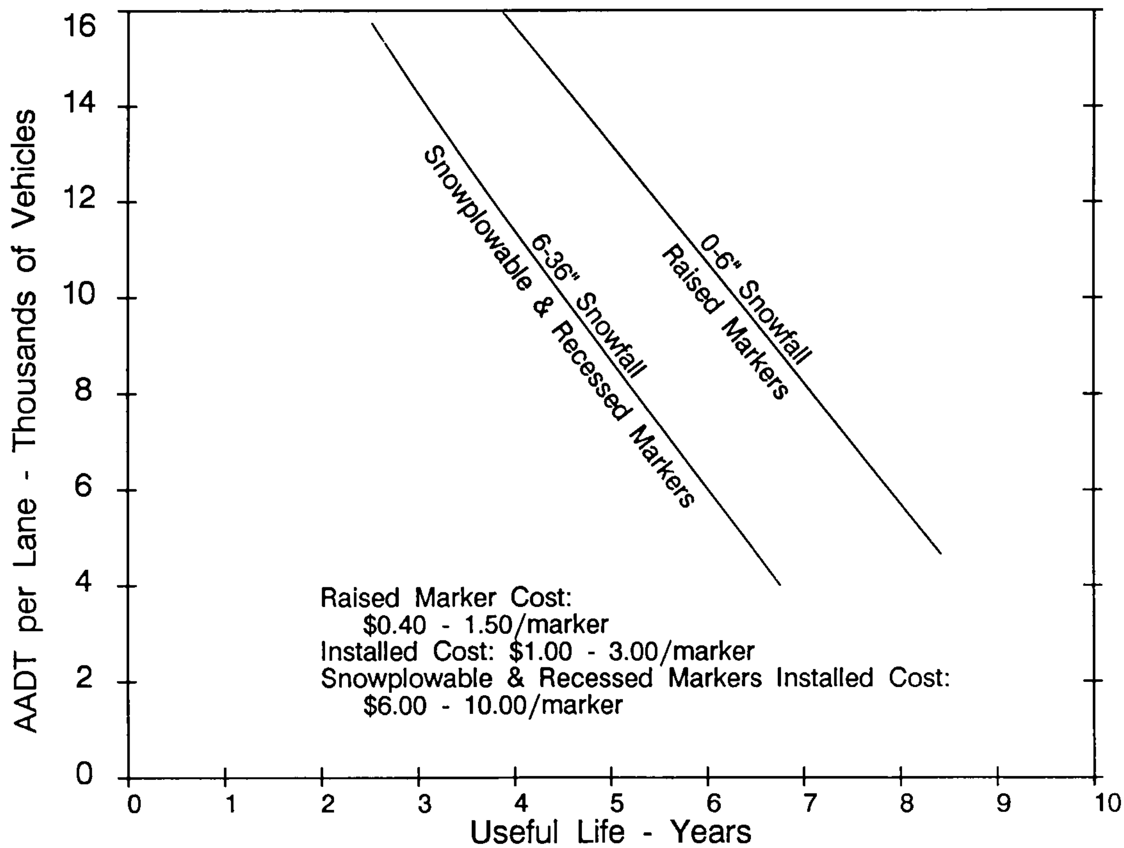

FIGURE 31 Life expectancy of raised markers, snowplowable, and recessed markers on cured asphaltic concrete and portland cement concrete.

CHAPTER SIX

RESEARCH NEEDS

Very little research and development is being conducted currently by industry or governmental agencies on pavement-marking materials. Some of the specific research needs in the area of pavement-marking materials are as follows:

1. The method of evaluating pavement markings using the "useful life" yardstick needs to be reexamined on a "motorists served" basis and on a "hazardous location" basis.
2. Driving at night on rural two-lane roads is more hazardous than during daylight. Many rural two-lane roads are not marked or are only partially marked. New low-cost marking materials and high-speed, low-cost methods of applying them are needed.
3. New low-cost snowplowable marking materials and low-cost methods of applying them to provide wet-weather night visibility are needed.
4. Research is needed into how quality control over application procedures may be obtained.
5. A method should be developed for improved record keeping on application and performance of marking materials.
6. New methods are needed to measure nighttime visibility that relate to what the human eye perceives.
7. Devices and methods are needed to compare marking materials in terms of their visual adequacy at night.

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APPENDIX A

CALIFORNIA SPECIFICATION FOR WATER-BORNE TRAFFIC PAINT

#24/1529A

STATE OF CALIFORNIA

Specification 8010-61G-30

Paint, Water-Borne Traffic Line,
Rapid Dry, White, Yellow and Black

1.0 SCOPE

This specification is intended to cover ready-mixed one component water-borne traffic line paint to be applied to either asphaltic or portland cement concrete pavements.

2.0 APPLICABLE SPECIFICATIONS

The following specifications, test methods, and standards in effect on the opening date of the Invitation for Bid form a part of this specification where referenced.

ASTM D562, ASTM D1475, ASTM D1210, ASTM D2369, ASTM D711, ASTM D1640, ASTM D2486, ASTM G53, ASTM D821, ASTM D2243, ASTM E70, ASTM D93, and ASTM D3723.

California Test Method No. 660.

Federal Specification TT-P-1952B.

Federal Specification 595a, Color 33538 and 37038.

State of California Specification 8010-XXX-99 (except for shelf life), Inspection, Testing and Other Requirements for Protective Coatings.

Department of Transportation, Standard Specifications, 1984.

Department of Transportation Code of Federal Regulations, Hazardous Materials and Regulations Board, Reference 49CFR. ICC Regulations.

Cancels &
Supersedes
8010-42L-30

§ Indicates Revision
(Excluding Date and Spec. No.)

Paint, Water-Borne Traffic Line, Rapid Dry, White, Yellow and Black 8010-61G-30

3.0 REQUIREMENTS

3.1 General:

This specification is intended to specify paint that will meet service requirements for highway construction and maintenance.

3.1.1 Pre-Bid Qualification

To qualify for a purchase order award, all vendors must submit samples of the paint to Caltrans Lab, 5900 Folsom Blvd., Sacramento, CA 95819. Paint submitted must meet the requirements of this specification before an award will be made. Vendor must qualify for white, yellow and black paints, no partial qualification will be allowed.

3.1.2 A minimum of four (4) gallons each of white and yellow and one (1) gallon of black is required. If clean up and flushing solvent is other than water, the recommend solvent shall be printed on the label. All shipping and transportation charges shall be prepaid by the vendor.

3.1.3 All paint manufactured by the successful bidder must be the same as submitted for Pre-Bid Qualification and be within the tolerance limits as specified in the Requirements of this specification.

3.2 Composition:

3.2.1 The composition of the paint shall be determined by the manufacturer. It will be the manufacturer's responsibility to produce a pigmented water-borne paint containing all the necessary co-solvents, dispersants, wetting agents, preservatives and all other additives, so that the paint shall retain its viscosity, stability and all other properties as specified herein.

No pre-mix glass beads will be permitted in the finished paint.

3.3 Characteristics of the Finished Paint:

		White	Yellow	Black
3.3.1	Viscosity, KU at 77°F $\pm$ 1°F, ASTM D562	70-85	70-85	70-85
3.3.2	Fineness of Grind, HEGMAN, minimum, ASTM D1210	3.0	3.0	3.0
3.3.3	Dry to No pick up without beads, minutes, maximum, ASTM D711	10	10	10
3.3.4	Dry thru, minutes, maximum	20	20	20

Test may be performed on same draw down sample as in (3.3.3). This test is the same as outlined in ASTM 1640, except that no thumb pressure is used. The thumb is turned thru an angle of 90° while in contact with the film. The drying time at which this rotation does not break the film is recorded.

		White	Yellow	Black
3.3.5	Volatile Organic Compounds, Grams per liter of paint, excluding water, maximum.	250	250	250

Use current ASTM or other adopted method in effect at time of paint manufacture to determine VOC level and water content of the paint.

3.3.6	Flash Point, ASTM D93, Method A, °F, minimum	100	100	100
3.3.7	Flexibility, TT-P-1952B	Pass	Pass	Pass
3.3.8	Static Heat Stability, 1 week at 120°F, Viscosity, KU	68-90	68-90	68-90

Place 1 pint of test paint in sealed can and heat in an air circulation oven at 120 ± 1°F for 1 week. Remove from oven and check viscosity in KU at 77 + 1°F. Observe any signs of instability.

3.3.9	Heat-Shear Stability, Viscosity, KU	68-95	68-95	68-95

One pint of the paint is sheared in a Waring Blender at high speed to 150°F. Blender should have tight fitting lid and taped to minimize volatile loss. When paint reaches 150°F, stop the Blender and immediately can and apply cover. Let cool overnight and examine for gelling or other signs of instability. Measure viscosity at 77 ± 1°F with Stormer Viscometer.

Run total solids on sheared paint and adjust solids by adding water to original solids content. Again check viscosity in KU.

3.3.10	Scrub Resistance, Cycles, minimum	800	800	-----

ASTM D2486. Use an appropriate doctor blade to provide a dry film thickness of 3 to 4 mils. Cure 24 hrs. at 77°F ± 2°F and 40-55% relative humidity.

		White	Yellow	Black
3.3.11	Dry Opacity, minimum	0.90	0.90	-----

On a black-white Leneta Chart, Form 2C Opacity, draw down film covering both black and white portions of chart. Use a 10 mil gap doctor blade. Dry for 24 hours at 77°F. Use a Photovolt Reflection Meter Model 670 with Search Unit provided with Tristimulus filters, green, blue and amber. Calibrate according to manufacturer's instructions and measure the reflectance over the white and black portions with the green filter. Dry Opacity is calculated as:

$$\frac{\text{Reflectance over black}}{\text{Reflectance over white}} = \text{Dry Opacity}$$

		White	Yellow	Black
3.3.12	Yellowness Index, maximum	10	-----	-----

Proceed as described in 3.3.11, only use a 15 mil gap doctor blade. Measure the reflectance of the paint film, using the green, blue and amber tristimulus filters. Calculate the Yellowness

$$\text{Index} = \frac{\text{Amber-Blue}}{\text{Green}} \times 100$$

3.3.13	Reflectance, minimum	85	-----	-----

With same draw down sample as in (3.3.12), measure the reflectance of the paint film, using the green tristimulus filter.

3.3.14 Yellow Color - shall match Federal 595a, Color 33538, and chromacity limits shall lie within HUE,580-583.5 nanometers, CHROMA, x = 0.7050-0.5000y and BRIGHTNESS, Y = 42-59, when measured acccording to California Test Method No. 660.

3.3.15 Black Color - shall match Federal 595a, Color 37038.

3.3.16 Ultra Violet Light and Condensate Exposure, ASTM G53. 300 hours total: alternate 4 hours UV exposure at 60°C; 4 hours condensate exposure at 40°C.

	White	Yellow	Black
White - yellowness index, maximum	12	-----	-----
Yellow - must meet chromaticity limits as specified in 3.3.14			

3.3.17	Spray Application Test.	Pass	Pass	-----

The paint shall be applied at 5 to 7 mils dry thickness with the laboratory heated striping unit. The paint shall show the following properties at ambient temperatures of 50° to 100°F with a paint spray temperature of 150°F, maximum, and 4 to 6 lbs. of post-applied glass beads per gallon of paint. Beads shall conform to the current State Specifications.

a. Dry to a no-track condition in 5 minutes or less when line is crossed over in a passing maneuver with a standard sized automobile.

b. Produce a clean cut, smooth line with no overspray or puddling.

c. Paint shall accept glass beads so that the spheres shall be imbedded into the paint film to a depth of 50% of their diameter.

d. Paint, when heated to the temperature necessary to obtain the specified dry time, shall show no evidence of instability such as viscosity increase, gelling or poor spray application.

		White	Yellow	Black
3.3.18	Freeze-Thaw, ASTM D2243	Pass	Pass	Pass
3.3.19	Road Service Rating, minimum	7.0	7.0	-----

The test stripes shall be applied transversely across the road, 4 inches in width and approximately 12 ft. long. Transportation Laboratory equipment and personnel will be used to apply the stripes.

Dry paint thickness of the test stripes shall be from 5 to 7 mils as determined from samples taken during application. For this determination, information is required from the manufacturer on the dry density of each paint submitted, in lbs/gal.

Current State Specification glass beads (water proof type) will be applied concurrently with the paint at a rate such that the initial bead retention on the test line is a minimum of 4 lbs. of beads per gallon of wet paint. The initial bead retention will be determined analytically in the Transportation Laboratory concurrently with the determination of the dry paint thickness. The paint shall accept the glass beads so that the spheres are imbedded into the paint film to a depth of 50% of their diameter. Test stripes will be observed for a period of 180 days from date of application. Paints will be evaluated for wear according to ASTM D821.

After 180 days of service, on a scale of 0 to 10, paints with a rating of No. 7 or better will be accepted. All ratings will be taken in the wheel track area. Glass beads shall show no more than a 30% loss after 180 days of test. This is determined by taking close-up photographs of the paint film and by count, determining the average bead loss.

The road service test may be waived at the option of the Engineer or evaluated for a period of less than 180 days. If evaluated for less than 180 days, the rating must be 7.0 minimum.

3.4 Allowable Variations:

The following properties will be measured at the time of qualification and again during delivery of production lots. These properties must remain within the allowable variations as indicated.

		White	Yellow	Black
3.4.1	Density, Lbs/Gal at 77°F ± 1°F ASTM D1475, allowable variation from qualifying sample	± 0.3	± 0.3	± 0.3
3.4.2	Pigment, Weight %, ASTM D3723 Allowable variation from qualifying sample	± 2.0	± 2.0	± 2.5
3.4.3	Total Solids, Weight %, ASTM D2369, Procedure B. Allowable variation from qualifying sample.	± 2.0	± 2.0	± 2.5
3.4.4	Vehicle Infrared Spectra, allowable variation from qualifying sample	None	None	None
3.4.5	X-Ray Diffraction Analysis of Pigment, allowable variation from qualifying sample	None	None	None
3.4.6	pH, ASTM E70 allowable variation from qualifying sample	± 1.0	± 1.0	± 1.0

3.5 Workmanship:

3.5.1 Paint shall be free from foreign materials, such as dirt, sand, fibers from bags or other material capable of clogging screens, valves, pumps, and other equipment used in a paint striping apparatus.

3.5.2 The paint pigment shall be well ground and be properly dispersed in the vehicle. The pigment shall not cake or thicken in the container, and shall not become granular or curdled. Any settlement of pigment in the paint shall result in a thoroughly wetted, soft mass permitting the complete and easy vertical penetration of a paddle. Settled pigment shall be easily redispersed, with minimum resistance to the sidewise manual motion of the paddle across the bottom of the container, to form a smooth uniform product of the proper consistency. If the paint cannot be easily redispersed, due to excessive pigment settlement as described above, or due to any other cause, the paint shall be considered unfit for use.

3.5.3 The paint shall retain all specified properties under normal storage conditions for 8 months after acceptance and delivery. The vendor shall be responsible for all costs and transportation charges incurred in replacing paint that is unfit for use. The properties of any replacement paint, as specified in (3.3), shall remain satisfactory for 8 months from date of acceptance and delivery.

3.5.4 The paint shall comply with all air pollution control rules and regulations within the State of California in effect at the time the paint is manufactured.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Inspection:

This material shall be inspected and tested in accordance with State of California Specification 8010-XXX-99, or as otherwise deemed necessary. State Specification 8010-XXX-99 is on file and obtainable at the Office of Procurment.

All traffic paints intended for use by the State of California must be sampled and approved by the Transportation Laboratory.

Manufacturers within the State of California must contact the Berkeley or Los Angeles Caltrans Inspection Office for sampling procedures.

Manufacturers outside the State of California must submit the following information before shipment.

1. State specification number.
2. Color and number of gallons.
3. <u>Exact</u> address of shipment
4. Number and identification of batches comprising shipment.
5. Date of manufacture.
6. Purchase order or contract number.

The above information is to be sent to, Transportation Laboratory, 5900 Folsom Boulevard, Sacramento, CA 95819. On delivery, the paint will be sampled for compliance to specification. Material not meeting the specification shall be removed and replaced by the manufacturer at his expense, including all costs for handling, re-testing and shipping.

4.2 Sampling and Testing:

Unless otherwise permitted by the Engineer, paint shall be sampled at the place of manufacture and application will not be permitted until the paint has been approved by the Engineer.

Check samples of finished paint while being applied will be taken at intervals as determined by the Engineer.

Infrared, x-ray, and other analytical methods in use by the Transportation Laboratory may be used.

5.0 PREPARATION FOR DELIVERY

5.1 Packaging:

All manufactured paint shall be prepared at the factory ready for application.

The finished paint shall be furnished in container size as specified in the purchase order or contract. When 5-gallon containers are specified, they shall be round and have standard full open head and bail.

If 55-gallon steel drums are specified, they must have removable lids and airtight band fasteners. All shipping containers must comply with the Department of Transportation Code of Federal Regulations, Hazardous Materials and Regulations Board, Reference 49 CFR. The containers and lids must be lined with a suitable coating so as to prevent attack by the paint or by agents in the air space above the paint. The lining must not come off the container or lid as skins.

Containers shall be colored white, including lids, and containers may have an identifying band of the appropriate color around and within the top one third of the container.

All containers shall be properly sealed with suitable gaskets and shall show no evidence of leakage and shall remain in satisfactory condition for a period of 12 months after delivery. Vendor shall be held responsible for replacing containers unfit for use and will be responsible for all costs and transportation charges incurred in replacing paint and containers.

All containers shall be palletized and banded for shipment.

5.2 Marking:

All containers of paint shall be labeled showing the state specification number, manufacturer's name, date of manufacture, color and manufacturer's batch number. Containers shall be clearly labeled Rapid Dry Water-Borne Traffic Paint.

All containers of paint shall be labeled to indicate that the contents fully comply with all rules and regulations concerning air pollution control in the State of California.

The manufacturer of the paint shall be responsible for proper shipping labels with reference to whether the contents are toxic, corrosive, flammable, etc., as outlined in Code of Federal Regulations, Hazardous Materials and Regulations Board, Reference 49CFR.

6.0 NOTES

6.1 Patents:

The Contractor shall assume all costs arising from the use of patented materials, equipment, devices, or processes used on or incorporated in the work, and agrees to indemnify and save harmless the State of California, and its duly authorized representatives from all suits at law or action of every nature for, or on account of, the use of any patented materials, equipment, devices or processes.

6.2 Certification of Compliance:

The manufacturer shall furnish a Certificate of Compliance with each batch of paint, in accordance with the provisions of Section 6-1.07 of Department of Transportation Standard Specifications, 1984.

DEPARTMENT OF GENERAL SERVICES
Office of Procurement
July 1986

APPENDIX B

STATE REGULATIONS REGARDING USE OF STUDDED TIRES

State	Regulation	Conditions
Alabama	Prohibited	
Alaska	Allowed	Sept. 15 - May 1
Arizona	Allowed	Nov. 15 - Apr. 15
Arkansas	Allowed	Nov. 15 - Apr. 15
California	Allowed	Nov.1 - Apr. 1
Colorado	Allowed	
Connecticut	Allowed	Nov. 15 - Apr. 30
Delaware	Allowed	Oct. 15 - Apr. 15
District of Columbia	Allowed	Oct. 15 - Apr. 15
Florida	Prohibited	
Georgia	Prohibited	
Hawaii	Prohibited	
Idaho	Allowed	Oct. 15 - Apr. 15
Illinois	Prohibited	
Indiana	Allowed	Oct. 1 - May 1
Iowa	Allowed	Nov. 1 - Apr. 1
Kansas	Allowed	Nov. 1 - Apr. 15
Kentucky	Allowed	
Louisiana	Prohibited	
Maine	Allowed	Oct. 1 - May 1
Maryland	Allowed (in certain counties)	Nov. 1 - Mar. 31
Massachusetts	Allowed	Nov. 2 - Apr. 30
Michigan	Prohibited	
Minnesota	Prohibited (30 days non-residents only)	
Mississippi	Prohibited	
Missouri	Allowed	Oct. 1 - Apr. 1
Montana	Allowed	Oct. 1 - May 31
Nebraska	Allowed	Nov. 1 - Mar. 15
Nevada	Allowed	Oct. 1 - Apr. 30
New Hampshire	Prohibited	
New Jersey	Allowed	Nov. 15 - Apr. 1
New Mexico	Allowed	
New York	Allowed	Oct. 16 - Apr. 30
North Carolina	Allowed	
North Dakota	Allowed	Oct. 15 - Apr. 15
Ohio	Allowed	Nov. 1 - Apr. 15
Oklahoma	Allowed	Nov. 1 - Apr. 1
Oregon	Allowed	Nov. 1 - Apr. 30
Pennsylvania	Allowed	Nov. 1 - Apr. 1
Rhode Island	Allowed	Nov. 15 - Apr. 1
South Carolina	Allowed	

State	Regulation	Conditions
South Dakota	Allowed	Oct. 1 - Apr. 30
Tennessee	Allowed	Oct. 1 - Apr. 15
Texas	Allowed	
Utah	Allowed	Oct. 15 - Apr. 15
Vermont	Allowed	
Virginia	Allowed	Oct. 15 - Apr. 15
Washington	Allowed	Nov. 1 - Mar. 31
West Virginia	Allowed	Nov. 1 - Apr. 15
Wisconsin	Prohibited	
Wyoming	Allowed	

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The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Frank Press is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

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