FINAL REPORT

DEVELOPMENT AND EVALUATION OF THERMOPLASTIC STREET MAINTENANCE MATERIAL

Submitted To:

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NASW-2388 Modification 5

July 11, 1973

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This Final Report is submitted to the
National Aeronautics and Space Administration
as fulfillment of the provisions of Modification 5
of NASA Contract NASW-2388.

July 11, 1973

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Mr. Edward Clarke, Superintendant of Streets, Department of Public Works, Burbank, California
Mr. John T. Frawley, Public Service Director, Bangor, Maine
Mr. Alan F. Hendrickson, Public Works Director, South Lake Tahoe, California
Mr. William D. Hurst, Consultant to the Board of Commissioners, Winnipeg, Manitoba, Canada
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Mr. James C. Smith, City Manager, New Carlisle, Ohio
Mr. H. James Spelman, Engineer of Street Construction and Maintenance, District of Columbia
Mr. John A. Teipel, Director, Department of Streets and Sanitation Services, Dallas, Texas

Special note must be made of the contribution of those men who voluntarily ripped up sections of their streets so that the improved material could be field tested; Ed Koonce of Anchorage, Alan Hendrickson of South Lake Tahoe, and particularly Edward Clarke of Burbank. Ed Clark was present at every field test, and himself developed and delivered the equipment for installation and application of the material.

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BACKGROUND

BACKGROUND

On February 12, 1973 NASA Contract NASW-2388 was modified to permit Public Technology, Incorporated to pursue four additional tasks in the overall program to apply advanced technology to state and local government needs.

These four tasks, briefly stated, are as follows:

First, Public Technology was asked to identify four significant urban problem areas in the general field of public works which were not being addressed through existing federal, state, local or industry efforts. Second, Public Technology was to utilize the appropriate resources available to the NASA Technology Utilization program to identify relevant aerospace technologies which might constitute potential solutions to those problems selected. Third, Public Technology, working with representatives of local governments and NASA, was to take responsibility for the applications engineering required to ensure that a solution to at least one of the problems selected was carried through. Fourth, Public Technology was to ensure that the appropriate standards approval agencies were fully apprised of the projects relating to their interests.

To accomplish the tasks set forth as above, Public Technology developed a list of four problem areas in the general category of street maintenance. This list was developed through problem and priority statements of eighty cities working in cooperation with Public Technology. The four problems identified were pavement marking and materials, less noisy pavement cutting techniques, street maintenance planning, and improved street patching materials. A survey and evaluation of aerospace technology related to the above problems indicated that a thermoplastic material, originally developed by JPL as a rocket propellant binder and later investigated under NASA contract by the Stanford Research Institute, had the greatest potential for early application and benefit to the municipalities.

A joint decision to pursue and improve street patching material was made with NASA (see letter dated February 7, 1973, Exhibit I) to pursue this area of investigation.

The applications engineering required to develop and evaluate the street patching material has been performed, and a material developed which can potentially meet the needs of local government street patching operations, as defined by the User Design Committee convened for the purposes of requirements definition.

Cognizant officials of the Federal Highway Research Board and the Department of Transportation have been kept informed as to the progress on this project. Copies of this final report are being sent to those agencies.

This final report will present the history and methodology by which the improved street patching material was developed. It is being submitted as fulfillment of the contractual obligations incurred under Modification 5 to NASA Contract NASW-2388.

SECTION II:

PROBLEM STATEMENT

PROBLEM STATEMENT

INTRODUCTION

Asphaltic concrete is a relatively brittle, unyielding material. When subject to the normal expansion and contraction cycles caused by alternate heating and cooling during its day to day exposure to the elements, it has a tendency to crack rather than to give. These cracks then become the site for abrasion and degradation, and for the entry of water, which upon freezing, will induce even further failure in the roadbed. These failures are alternately known as "chuckholes" or "potholes", depending upon the area of the country. Beyond being an irritant or nuisance to drivers, they can cause damage to vehicular traffic, and injuries as well. The emergency repair and maintenance of these potholes is a significant problem for all state, county, and local governments. The problem is particularly severe in areas with a high water table, which weakens the roadbed and makes it more susceptible to potholing; and in areas of repeated freeze-thaw cycle, which also accentuates the development of potholes.

The problem that state and local government street maintenance authorities are faced with is the fact that there is no truly effective all-weather emergency patch available to them. The "hot mix", which is the preferred solution, duplicates the material content of the roadbed itself, and provides an adequate patch; however, during cold or inclement weather, the hot patch cannot be used. It will not adhere to a wet hole, and is generally unobtainable during the winter months in the colder climates. Local hot mix plants shut down during cold months, because there is very little call for the material due to the fact that it cools so much during transshipment to the repair site.

The cold mix materials which are available for winter application also suffer from the problem of incompatibility with wet surfaces. This problem is further accentuated by the fact that, for a number of reasons, the cold mix material degrades very quickly, and generally has to be replaced several times before the end of the winter season.

With current materials and technology, road and street patching is an expensive operation. It is estimated that about 800 million dollars is annually spent for materials and equipment in municipalities, counties, and states for road and street maintenance. Further, patching and resurfacing is a labor intensive proposition, with less than half of the total cost of maintenance being devoted to equipment and materials. The bulk of the 800 million dollar figure applies to municipalities and counties, with a small portion attributed to the states. It should be noted that this is a conservative figure because of the unavailability of aggregate cost data for these operations at the various local governmental levels, and the consequent requirement for estimates based on sampled city/county/state cost data.

The development of an effective, all-weather street patching material would not only provide potential benefits to the cost of street maintenance, but would also be a public service in that fewer streets and roads would be closed to traffic for less time. The requirement to redo emergency repairs (up to fifteen times during the course of the winter) could potentially be eliminated. Also, in addition to providing an effective pothole patching material, focus should be made on lateral applications for the developed material in the areas of crack filling and resurfacing.

REQUIREMENTS

The operational requirements for an all-weather, permanent street patching material for flexible and rigid pavements were developed by a PTI-convened User Design Committee. The scope of this requirements definition included both surface patching, crack filling and pothole patching operations. The products and/or processes developed were to result in a system for which the total street patching operation is more cost effective than provided by currently existing technology.

Two factors were to determine the cost effectiveness of street patching operations. First, the availability of a permanent patching material which can be applied in all (or most) weather conditions, thus avoiding the costly process of replacing emergency patches put down in cold and/or wet weather. Second, a material which can be applied more productively; i.e., the material should require decreased man-and-equipment-hours per repair site.

A next step in more precise requirement specifications was to relate each requirement to laboratory test procedures. The User Design Committee agreed that current asphalt tests are inadequate and in some cases inappropriate for rubberized asphalts. This statement is corroborated by a recent report entitled "An Annotated Bibliography On Use of Rubber Asphalt Pavements" (May 1971), F. S. Rostler, Materials Research and Development, Incorporated, Oakland, California, NTIS Acquisition Number PB-206 965, in which it is recommended that new test procedures be developed for rubberized asphalts and suggests several improved tests.

The requirements set forth are divided into economic, operational and material requirements.

Economic Requirements

1. The cost constraints of the material are related directly to the effectiveness of the material as an all-weather permanent patch, and to productivity increase in man and equipment hours required per pothole repaired. A high percentage increase in material costs can be offset by a relatively low percentage decrease in labor costs.
2. The material should be more durable than standard emergency repair mixes. Durability is primarily related to its ability to remain in the pothole a minimum of two seasonal cycles. However, the exact duration required will depend on total cost/performance tradeoffs.

Operation Requirements

3. Material application should minimize traffic disruption, therefore, application procedures at the scene should be simple, not involving more total pieces of equipment than current procedures, or too complex application procedures; and, time-to-bear-traffic should be minimized. Barricades should be required only when crew is at work at the scene. This implies that material should bear traffic in about ten to twenty minutes.
4. The material should be easy to store, and packaged in reasonably sized, easy to handle configurations.

5. Material should have a sufficient shelf-life; a minimum of one seasonal cycle.

6. Material should be applicable in ambient temperature ranges from -20° to 120°F (-29° to 49°C).

7. Material should be applicable to wet potholes with little or no pothole preparation required.

8. Material application should not be potentially dangerous to crew either in terms of toxic fumes, flash point or other dangers to health and safety.

9. Material and its application should not cause significant air pollution or water pollution from leachate run-off.

10. Material should not require elaborate mixing and heating procedures at the scene. If possible, the process should use commercially available equipment.

Material Requirements

11. Material should be less susceptible to temperature variations for number of properties such as flexibility, ductility, penetration, viscosity.

12. Material should have increased flexibility over a wide temperature range so that the patch is less affected by expansion and contraction or shifting of pavement surface and base structures.

13. Material should have increased adhesion and bonding to edges of pothole or surface of pavement (in surface patch) and to aggregate and chips.

14. Material should have comparable resistance to both abrasion and penetration.

15. Material should have decreased permanent plastic deformation under stresses and strains; i.e., the stress/strain curve should be time dependent.

16. Material should be resistant to de-icing chemicals and at least as resistant to petrochemicals as surrounding pavement.

17. Material should not degrade under sustained heating for at least one work shift; similarly, material should not degrade significantly upon reheating the material at least once prior to application.

SECTION III:

PROGRAM HISTORY

PROGRAM HISTORY

INTRODUCTION

Previous work by the Stanford Research Institute and others indicated that the flexibility, tensile strength, elongation, elasticity, penetration, temperature response and adhesion of asphalt could be improved significantly by combining the asphalt with ethylene-vinyl acetate(EVA) copolymers such as the Elvax® series of resins from Du Pont. It was felt that improved street patching materials could result from utilizing this EVA-modified asphalt in their composition as a binder for the aggregate.

Public Technology then employed the services of Products Research and Chemicals Company, Inc. to perform the necessary laboratory development work and to provide the pilot-scale materials for field testing.

Accordingly, development work was conducted to determine the most promising combinations of EVA resins with asphalts and aggregate for this application. A typical paving asphalt, 85-100 penetration, was combined with ten different representative EVA resins in a 60/40 weight ratio. The EVA resins used were Elvax 420, 150, 40, 220, 240, 310, 350, 4310, 4320, and EP 4824. These resins differ in their vinyl acetate content, molecular weight, melt index, melt viscosity, solubility, softening point, tensile strength, ultimate elongation, and hardness. The physical and handling properties of each combination were determined. The five resins of the first ten that exhibited the best properties were retested at an 80/20 weight ratio of 85-100 penetration asphalt to EVA resin. These five resins were Elvax 150, 240, 420, 4320, and 350. Of these five, the Elvax 150 and 420 asphalt combinations were chosen to undergo field testing as the binder for aggregate-filled patching compositions for potholes. These two resins tend to represent the extremes of cost and of vinyl acetate content, which is related to adhesion and tack. Other properties, such as melt viscosity, tensile strength, ultimate elongation, and hardness are comparable.

In every instance, the modification of asphalt with EVA resins in amounts of 20% by weight or greater resulted in the imparting of significant elastomeric qualities to the asphalt.

FIELD TESTING

Field test applications were conducted in three cities: Burbank, California; South Lake Tahoe, California; and Anchorage, Alaska (see Exhibits II and III). The latter two were chosen because of severe freeze/thaw weather cycles which, it was felt, would be a critical factor in the success of any patching composition. Details of each field test site are contained in Appendix A. At each site, dish-shaped potholes 16"-18" (41-46 cm) in diameter and from 4"-6" (10-15 cm) in depth were cut into existing pavement in the wheel track. Two premixed binder/aggregate compositions were used in the field tests. Each consisted of 5% by weight Elvax 150 or 420 binder (80/20 85-100 penetration asphalt/EVA resin) and 95% dense graded aggregate. At each test site, the premixed materials were supplied cold in five gallon pails and had to be heated to 260-300°F (127-149°C) before using.

With each premixed composition, four types of potholes were patched; dry, wet with water; dry and primed, and wet and primed. The primer used was a 60% solids 80/20 85-100 penetration asphalt/Elvax 40 combination. Heating the premixed materials to proper application temperatures at the test site proved to be a difficult problem. Only the Department of Public Works at Burbank, California, which happened to have a large walk-in oven, was suitably equipped for heating the material in the form supplied. At the other sites, much improvisation was necessary.

The premixed material, when heated to temperature, was applied in much the same manner as conventional hot-mix asphalt. As many 2" (5 cm) courses as required to patch the hole were hand-temped in place. A heated roller was used to finish off the top layer.

A limited number of potholes were patched using a layering technique. This technique consisted of pouring alternate layers of cold or hot aggregate and hot liquid binder.

The performance results of the patches have been monitored and compared to standard asphalt patching materials put down at the same time to serve as controls. In every instance, the standard asphalt patching material appears to be performing equally to or slightly better than the Elvax 150-based composition and moderately better than the Elvax 420-based composition. The most significant mode of failure to date has been a ravelling of the material at the edges. No significant differences have appeared between wet and dry holes. Only between primed and unprimed holes have differences appeared; primed holes tend to show less edge ravelling than unprimed holes. These results, however, are based only upon a test period of three to six weeks.

In the case of potholes filled by means of the layering technique, incipient failure through dishing caused by compaction of the aggregate was rapidly apparent.

The application requirements for patching materials containing EVA-modified asphalt were investigated and these included packaging types and configurations, equipment needs, and methods of application.

Supplementary laboratory work was performed to evaluate Elvax 150 and 420 as a 20% weight modification of 40-50 penetration and 200-300 penetration asphalt so that regional variations in grade of available asphalt and climatic conditions might be taken into account. The 40-50 penetration asphalt was found to give a tough, dry, leathery elastomeric material well suited to regions with hot summers and mild winters. The 200-300 penetration asphalt gave a comparatively weak, soft, stick elastomeric material of doubtful utility.

Elvax 150, 350, and 420 were also evaluated as a 10% weight modification of 85-100 penetration asphalt with a view to determining the lower limits for significant property modification of asphalt with EVA resins. In each case. extremely soft, sticky, plastic materials of little elastomeric quality were obtained.

The adhesion of the standard Elvax 150 and 420/asphalt combination (80/20 85-100 penetration asphalt/EVA resin) to samples of asphalt pavement from different cities was tested and found to be good with no significant differences.

Supplementary field testing was conducted in Burbank, California, by the Public Works Department to evaluate an experimental heater/mixer derived from a small portable cement mixer. On site heating and mixing of aggregate with binder was attempted with good results. Reheating of cold, crushed premixed material was also attempted, again with good results.

The use of EVA-modified asphalts as a crack filler was investigated. Twenty percent weight modifications of 40-50 penetration asphalt with Elvax 420, 85-100 penetration asphalt with Elvax 420, and 85-100 penetration asphalt with Elvax 150 were used. The results thus far are quite encouraging.

A small scale preliminary feasibility study of two possible routes for the large scale production and distribution of EVA-modified asphaltic materials was made. Materials sources, equipment requirements, and manufacturing quality control methods were outlined.

The results of this program indicate that the physical properties of asphalt, such as tensile strength, ultimate elongation, penetration, adhesion, and low temperature susceptibility, can be significantly improved by modification with suitable amounts and types of EVA resins.

Limited field testing of aggregate-filled street patching compounds made from EVA-modified asphalt has not tended to confirm their anticipated better performance when compared with conventional patching compounds. Standard hot mix asphalt, properly applied, appears to perform creditably. Either further optimization of EVA-modified asphalt patching compound formulations is necessary or insufficient testing time has elapsed for the true differences to become apparent.

Due to the thermoplastic nature of EVA-modified asphalt suitable heating and mixing equipment, preferably of the portable type, is mandatory. This requirement imposes a severe hindrance upon the utility of any aggregate-filled patching material derived from it. Appropriate heater/mixers, while available, are not commonly found in public works departments.

The use of EVA-modified asphalt without aggregate as a crack filler appears to have considerable merit. Suitable hearing equipment, such as a tar kettle, is widespread and preliminary field tests are encouraging.

For the true potential of EVA-modified asphalt patching compounds to be verified, additional development of formulations and of heating/mixing equipment is necessary in conjunction with appropriate field testing.

During the field tests conducted at the User Design Committee meeting in South Lake Tahoe, a new coated pre-mix approach was tried, with interesting potential applications. Aggregate had been coated with the thermoplastic binder, then allowed to cool in a non-compacted fashion. The mix was spread out, without the intersticial forces present that would otherwise occur when immediately tamped into the 5-gallon transport cans.

When cool, the material had no appreciable tendency towards self-adhesion at ambient temperatures. It could be bagged, poured, and handled in a pelletized form. When emptied from its container during the Tahoe test, the material exhibited a flow-like property, which greatly facilitates handling.

In this condition, the amount of heat required to transform it to a useable patch mix was apparently in the range of 120-140^{o} F. (49 - 60^{o} C.) At that temperature, hand tamping was sufficient to set up a monolithic block.

This technique, if successful, could overcome many of the problems of the new material which currently requires temperatures of 300^{o} F. (149^{o} C.) for setting. Similarly, the use of pelletized material could be much more acceptable to small jurisdictions which do not have the facilities for heating and mixing otherwise required.

PATENT SITUATION

Early development work on modification of asphalt with EVA resins dates back to U.S. Patent 3,268,461 by H. C. McAninch and to Canadian Patent 746,062 by R. L. Adelman, both issued in 1966. This project is ultimately based upon U.S. Patent 3,527,724 by F. J. Hendel issued in 1970. Inasmuch as the development work in the Hendel patent was performed in conjunction with a contract to the National Aeronautics and Space Administration, this agency is the ultimate assignee (see Exhibit IV).

The patent claims and disclosures indicate that substantial improvements in the physical properties of asphalt are possible with EVA resins. Of special interest is the improvement in low temperature properties such as flexibility and ductility. Adelman and Hendel, especially, claim great utility for EVA resins as modifiers for asphalt paving materials. Economic considerations currently tend to rule out direct replacement of standard paving asphalt in roadway construction with EVA-modified. However, for specialized applications, such as street patching, the higher raw material cost of EVA-modified asphalt could be offset if better durability, versatility, and performance are obtained. Thus, the net result would be an advanced material more cost effective than present materials. This result is possible due to the fact that labor and equipment costs constitute approximately 90% of the total cost of patch installation, while only 10% is attributable to material costs. This project was initiated to develop just such advanced patching materials.

A prior patent which may apply, U.S. Patent 3,442,841, was issued in 1969, to E.I. Du Pont de Nemours and Company, similar to the Hendel patent, but without requiring the use of fluxing oil in the asphalt/EVA blend (see Exhibit V). Du Pont has agreed to license any manufacturer, depending upon quantity purchased. In small lots, they would enter into a licensing agreement; in large quantities, a "bottle license" would be conveyed with purchase (see Exhibits VI and VII).

SECTION IV:

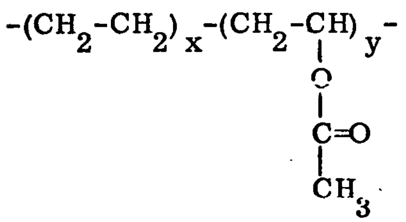
LABORATORY DEVELOPMENT

LABORATORY DEVELOPMENT

INTRODUCTION

This work has as its scope the area of thermoplastic asphalt street patching compositions and is limited to combinations of ethylene-vinyl acetate copolymers with asphalt and with or without aggregate.

Chemically, ethylene-vinyl acetate copolymers (or EVA resins, as they are often named.) may be represented by the following structure:



By varying the value and ratio of x and y, one can produce polymers with a wide variety of properties.

The plan of development was divided into seven parts as follows:

1. Select representative EVA resins and asphalts.
2. Select a grade of asphalt and modify it 40% by weight with each of the EVA resins.
3. Determine the optimum mixing procedures, the handling and the physical properties of each modification. Evaluate ways of incorporating aggregate.
4. Using key performance parameters, select the most promising EVA resins for retesting at a 20% weight modification level.
5. Select best two EVA resin/asphalt/aggregate compositions to undergo field testing.
6. Develop suitable manufacturing processes.
7. Conduct supplementary development work as needed.

Previous development work in the area of EVA-asphalt compositions by the Stanford Research Institute employed the Elvax® series of EVA resins produced by E.I. Du Pont de Nemours & Company, Inc. For comparative purposes, the Elvax resins were used in this development work.

TECHNICAL DISCUSSION

The Elvax series of EVA resins are divided into five main groups, four of which differ primarily in their vinyl acetate content. The fifth group differs from the other four in that its members are all acid terpolymers; that is, they contain acid groups interpolymerized with ethylene and vinyl acetate to impart improved adhesion to polar substrates. Table I lists the properties of the ten representative Elvax resins that were chosen for study.

Four grades of paving asphalt from the Newhall Refinery, Newhall, California, were chosen for evaluation. These grades were 40-50, 85-100, 120-150, and 200-300 penetration.

The first phase of the evaluation of EVA-modified asphalt was conducted using 85-100 penetration asphalt with EVA resins in a 60/40 weight ratio. 85-100 penetration asphalt was used because it is one of the grades most often used in asphalt pavement. The 60/40 weight ratio has its origins in suggestions made by the Stanford Research Institute, who conducted research in this area earlier.

Various mixing procedures were tested. The optimum procedure consisted of heating the asphalt to approximately 50°F (28°C) above the softening point of the Elvax resin and then slowly adding the pelletized resin with constant mixing using a Mooney Disperser blade, which is similar to a Cowles Dissolver blade. The mixing time tended to be proportional to the melt index of the resin and inversely proportional to its vinyl acetate content. For most resins, a mixing time of 10-12 minutes at a speed of 800-1000 rpm was sufficient to ensure complete uniformity. Those resins with softening points above 250°F (121°C) were much harder to work with than those with softening points below that temperature. In fact, Elvax resin EP-4824 (softening point = 340°F [171°C]) proved almost intractable even at temperatures in excess of 400°F (204°C).

Elvax® Resin	% Vinyl Acetate	Tensil Strength	Elongation at Break	Melt Index	Shore A-2 Hardness	Softening Point, R&B	Cost in Bulk
40	39.0 - 42.0	650 psi	1450%	45-70	40	200°F	$0.46/lb.
150	32.0 - 34.0	850 psi	1050%	38-48	65	240°F	$0.40/lb.
220	27.2 - 28.8	550 psi	850%	134-168	69	190°F	$0.38/lb.
240	27.2 - 28.8	1050 psi	900%	38-48	73	250°F	$0.34/lb.
310	24.3 - 25.7	400 psi	700%	365-440	70	190°F	$0.39/lb.
350	24.3 - 25.7	1600 psi	900%	17-21	80	280°F	$0.34/lb.
4310	24.0 - 26.0	300 psi	600%	420-580	68	181°F	$0.50/lb.
420	17.5 - 18.5	950 psi	700%	136-165	84	210°F	$0.31/lb.
4320	24.0 - 26.0	750 psi	900%	125-175	72	195°F	$0.43/lb.
EP-4824	1.2	3100 psi	830%	3	93	340°F	N/A

TABLE I. SOME COMPARATIVE PROPERTIES OF SELECTED ELVAX® RESINS
(Courtesy E. I. DuPont de Nemours & Company, Inc.)

An in-process uniformity test was devised. This test consists of drawing samples of the hot liquid mix from time to time and spreading the material over silicone-impregnated paper or metal, mold-released with a Teflon spray. When the sample has cooled and acquired an elastomeric nature, it is stretched manually in several directions until it is thin enough to be translucent. If striations or granularity are observed, mixing is continued until the material is homogeneous and uniform in appearance.

Each of the ten 60/40 asphalt/Elvax resin combinations was evaluated for handling properties. This consisted of noting the ease of mixing to uniformity at the mix temperature, observing tendencies toward phase separation after sixteen hours at 300°F (149°C), and judging tractability, or ease with which the mixed material could be worked. Generally, resins of high vinyl acetate content tended to mix in more readily than those of low vinyl acetate content and showed no tendency toward phase separation. Resins of low vinyl acetate content (below 18%) did show some phase separation, but not enough to be regarded as significant. Resins of low softening points and, hence, high melt indices tended to mix in more readily than those of high softening points and low melt indices. All the resin-asphalt combinations could be handled readily with two exceptions. Elvax 350 proved moderately difficult and Elvax EP-4824 very difficult to handle. This result is due to a combination of high melt viscosity and high softening point.

The physical properties of each of the ten asphalt/Elvax resin blends was determined. These properties included melt viscosity, penetration at 77°F (25°C) and at 32°F (0°C), Shore A hardness, tensile strength, elongation at break, 100% modulus and tear strength. Table II summarizes the results of these tests. Testing methods used were ASTM, except as otherwise noted in Appendix C.

Elvax® Resin	Asphalt Grade	Mix Ratio	Viscosity 300°F (149°C)	Hardness	Penetration	Tensile Strength	Tear Strength	100% Modulus	Elongation
40	85-100	40/60	208 Poises	20 Shore A	41 @ 77°F (25°C)	153 psi (11.05 kg/cm³)	24 lbs/inch (4.29 kg/cm)	28 psi (2.0 kg/cm²)	1,150%
150	85-100	40/60	272 Poises	25 Shore A	33 @ 77°F (25°C)	204 psi (14.23 kg/cm³)	35.5 lbs/inch (6.34 kg/cm)	35.5 psi (2.49 kg/cm²)	1,175%
220	85-100	40/60	101 Poises	35 Shore A	29 @ 77°F (25°C)	94 psi (6.53 kg/cm³)	32.5 lbs/inch (5.70 kg/cm)	54.5 psi (3.82 kg/cm²)	900%
240	85-100	40/60	144 Poises	41 Shore A	26 @ 77°F (25°C)	260 psi (18.20 kg/cm³)	52.2 lbs/inch (9.32 kg/cm)	69.6 psi (4.87 kg/cm²)	1,000%
310	85-100	40/60	69 Poises	27 Shore A	42 @ 77°F (25°C)	31 psi (2.17 kg/cm²)	16.5 lbs/inch (2.95 kg/cm)	30 psi (2.10 kg/cm²)	175%
350	85-100	40/60	544 Poises	48 Shore A	23 @ 77°F (25°C)	269 psi (18.83 kg/cm²)	62 lbs/inch (11.07 kg/cm)	94 psi (6.58 kg/cm²)	975%
420	85-100	40/60	208 Poises	48 Shore A	24 @ 77°F (25°C)	98 psi (6.86 kg/cm²)	41.4 lbs/inch (7.39 kg/cm)	88 psi (6.16 kg/cm²)	250%
4310	85-100	40/60	91 Poises	27 Shore A	41 @ 77°F (25°C)	52 psi (3.64 kg/cm²)	12.3 lbs/inch (2.20 kg/cm)	52 psi (3.64 kg/cm²)	100%
4320	85-100	40/60	208 Poises	38 Shore A	30 @ 77°F (25°C)	62.3 psi (4.36 kg/cm²)	26.8 lbs/inch (4.78 kg/cm)	57 psi (3.99 kg/cm²)	350%
EP-4824	85-100	40/60	880 Poises @ 400°F (204°C) only	72 Shore A	11 @ 77°F (25°C)	207 psi (14.49 kg/cm²)	72.3 lbs/inch (12.91 kg/cm)	179 psi (12.53 kg/cm²)	250%

TABLE II: PHYSICAL PROPERTIES OF 40% WEIGHT MODIFICATIONS OF ASPHALT WITH ELVAX® RESINS

Several methods for incorporating the EVA-resin modified asphalt with aggregate were investigated. Hot, liquid EVA-modified asphalt--in this case a 60/40 blend of 85-100 penetration asphalt with Elvax 420--was alternately mixed with cold aggregate, poured over cold aggregate, mixed with hot aggregate, and poured over hot aggregate. Only the last two had any promise. Pouring the hot, liquid modified asphalt over hot aggregate had interesting possibilities for repairing potholes. Conceivably, alternate layers of hot EVA-modified asphalt and hot aggregate could be used to repair such defects. Direct mixing of hot EVA-modified asphalt with hot aggregate resulted in a material with much the same handling characteristics and appearance of conventional hot-mix asphalt. A five percent addition of EVA-modified asphalt to an aggregate composition conforming to Type IV-b dense graded mix gave a material of substantially improved flexibility at 77°F (25°C) when compared with a five percent addition of 85-100 penetration asphalt to the same aggregate.

Based upon the work thus far conducted, certain key performance parameters became apparent. These parameters consisted of the cost of the EVA resin versus improvement in physical properties of the asphalt, melt viscosity at 300°F (149°C), tensile strength and ultimate elongation, penetration at 77°F (25°C) and 32°F (0°C), which is related to low temperature susceptibility and handling properties based upon phase separation tendencies, ease of mixing and tractability.

Using these key performance parameters, one of each of the five groups of Elvax resins was selected for further testing at a 20% modification level with 85-100 penetration asphalt. These Elvax resins were Elvax 150, 240, 420, 4320 and 350. Handling and physical properties were evaluated in a manner identical to previous combinations. Table III summarizes these physical properties.

Elvax® Resin	Asphalt Grade	Mix Ratio	Viscosity @ 300°F (144°C)	Hardness	Penetration	Tensile Strength	Tear Strength	100% Modulus	Elongat
150	85-100	20/80	14.4 Poises	15 Shore A	127 @ 100°F (38°C) 95 @ 77°F (25°C) 9 @ 32°F (0°C)	32 psi (2.24 kg/cm²)	10.2 lbs/inch (1.82 kg/cm)	10 psi (0.7 kg/cm²)	1,550%
240	85-100	20/80	16.0 Poises	22 Shore A	76 @ 100°F (38°C) 61 @ 77°F (25°C) 9 @ 32°F (0°C)	35.8 psi (2.50 kg/cm²)	13.8 lbs/inch (2.46 kg/cm)	22 psi (1.54 kg/cm²)	1,250%
350	85-100	20/80	21.6 Poises	30 Shore A	50 @ 100°F (38°C) 42 @ 77°F (25°C) 9 @ 32°F (0°C)	155 psi (10.9 kg/cm²)	13.0 lbs/inch (2.32 kg/cm)	48 psi (3.36 kg/cm²)	1,050%
420	85-100	20/80	19.2 Poises	35 Shore A	56 @ 100°F (38°C) 32 @ 77°F (25°C) 8 @ 32°F (0°C)	28 psi (1.96 kg/cm²)	10.5 lbs/inch (1.88 kg/cm)	----	90%
4320	85-100	20/80	22.4 Poises	17 Shore A	123 @ 100°F (38°C) 57 @ 77°F (25°C) 11 @ 32°F (0°C)	18 psi (1.26 kg/cm²)	8 lbs/inch (1.43 kg/cm)	17 psi (1.19 kg/cm²)	500%
----	85-100	----	1.7 Poises		325 @ 100°F (38°C) 100 @ 77°F (25°C) 6 @ 32°F (0°C)	----	----	----	----

TABLE III. PHYSICAL PROPERTIES OF 20% WEIGHT MODIFICATIONS OF ASPHALT WITH ELVAX® RESINS

The five Elvax resins that were rejected were rejected for the following reasons:

1. Elvax 40 - excessive cost when compared with improvement in physical properties.
2. Elvax 220 - high cost, poor physical properties.
3. Elvax 310 - high cost, very poor physical properties.
4. Elvax 4310 - very high cost, very poor physical properties.
5. Elvax EP 4824 - poor handling and application properties due to very high melt viscosity. Material very difficult to mix.

Recognizing that adhesion to existing asphalt pavement is a prime requirement for a patching material, a suitable test was devised. This test consisted of cutting rectangular blocks, approximately 1 1/2" x 1 1/2" x 3" (38mm x 38mm x 76mm), from a slab of asphalt pavement. A thin layer of hot liquid EVA-modified asphalt was spread across the center half of one each of the rectangular faces of two blocks. The coated faces were then pressed quickly and firmly together with the long axis of each block at right angles to the other. The blocks were then stabilized at the desired test temperature (77°F or 0°F [25°C or -18°C]) for twenty-four hours before testing. Once stabilized, the blocks were placed in an Instron tester and pulled apart at a crosshead speed of 0.05"/min. (0.127mm/min.). The force per unit area required to separate the blocks, the nature of the failure whether adhesive or cohesive, and the jaw separation at failure all are indicative of adhesion and were recorded. The five 20% Elvax resin modifications of 85-100 penetration asphalt were tested in this manner at both 77°F and 0°F(25° and -18° C.) with the results given in Table IV. 85-100 penetration asphalt was used as a control. As can be seen by the results, the modified asphalts exhibited superior adhesion to asphalt pavement. In fact, in some of the 0°F (-18°C) tests, cohesive failure occurred within the pavement itself. Of special interest is the comparison between the force/distance curves of modified and unmodified asphalt. The areas under these curves are the amounts of work required to separate the blocks. A glance at Figure 1 will show that considerable more work is required to separate blocks bonded together

Elvax® Resin	Asphalt Grade	Mix Ratio	PSI	Kg./cm²	Nature of the failure
150	85-100	20/80	19 @ 77°F (25°C)	1.33	100% cohesive failure in binder
			124 @ 0°F (-18°C)	8.68	85% cohesive failure in binder, 15% cohesive failure in pavement
240	85-100	20/80	44 @ 77°F (25°C)	3.08	95% cohesive failure in binder, 5% adhesion failure to pavement
			156 @ 0°F (-18°C)	10.92	90% " " " " 10% " " " "
350	85-100	20/80	34 @ 77°F (25°C)	2.38	98% cohesive failure in binder, 2% adhesion failure to pavement
			96 @ 0°F (-18°C)	6.72	95% " " " " , 5% " " " "
420	85-100	20/80	20 @ 77°F (25°C)	1.40	100% cohesive failure in binder
			180 @ 0°F (-18°C)	12.60	85% " " " " , 15% cohesive failure in pavement
4320	85-100	20/80	12 @ 77°F (25°C)	0.84	100% cohesive failure in binder
			156 @ 0°F (-18°C)	10.92	100% " " " "
Control	85-100 only		22 @ 77°F (25°C)	1.54	100% cohesive failure in binder
			90 @ 0°F (-18°C)	6.30	100% " " " "

(all specimens pulled at a crosshead speed of 0.05" (0.127 cm.)/minute)

TABLE IV. INTERFACIAL ADHESION OF 20% WEIGHT MODIFICATIONS OF ASPHALT WITH ELVAX® RESINS USING BURBANK, CALIFORNIA PAVEMENT BLOCKS

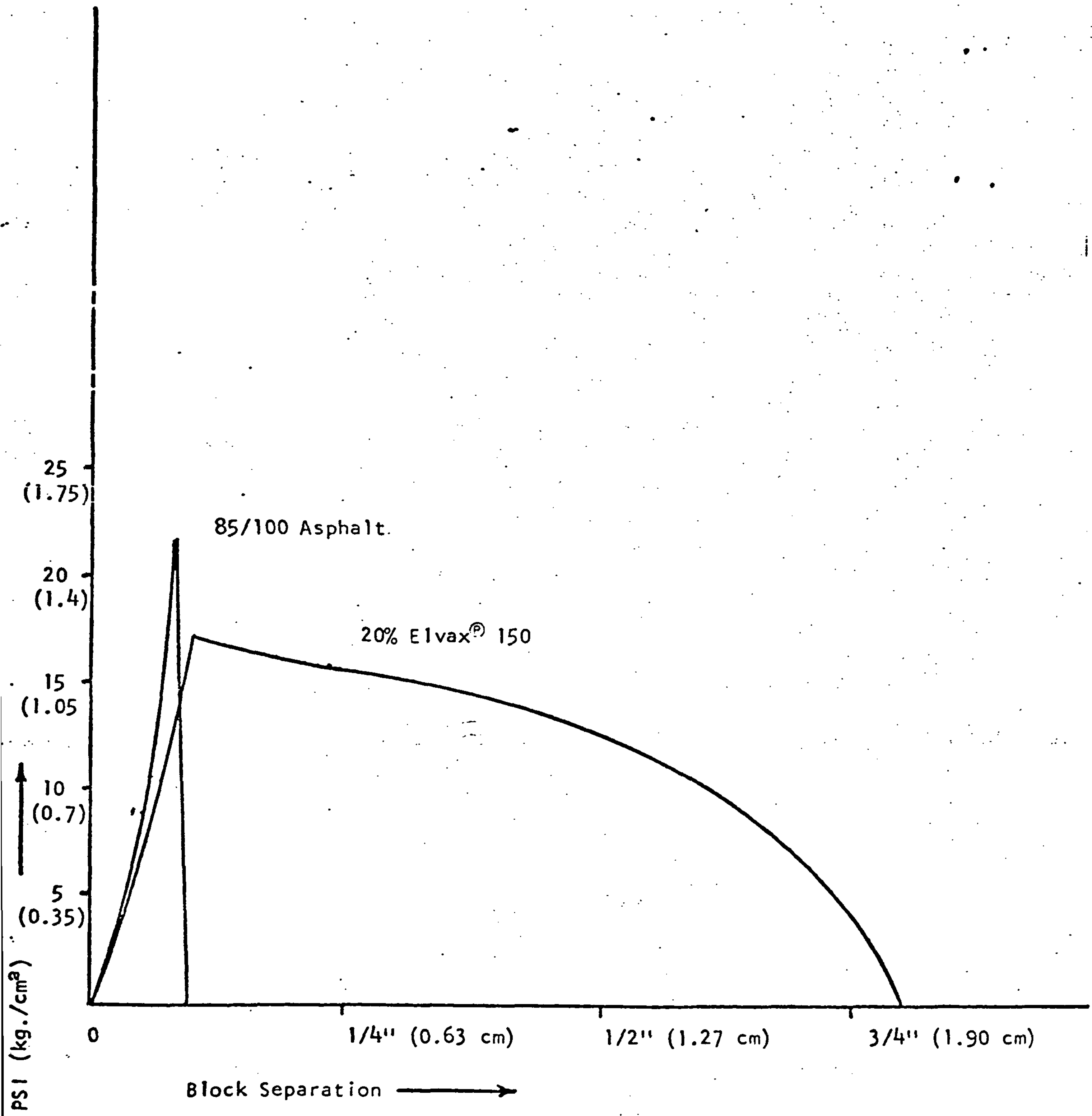


FIGURE 1. COMPARATIVE INTERFACIAL ADHESION CURVES @77°F

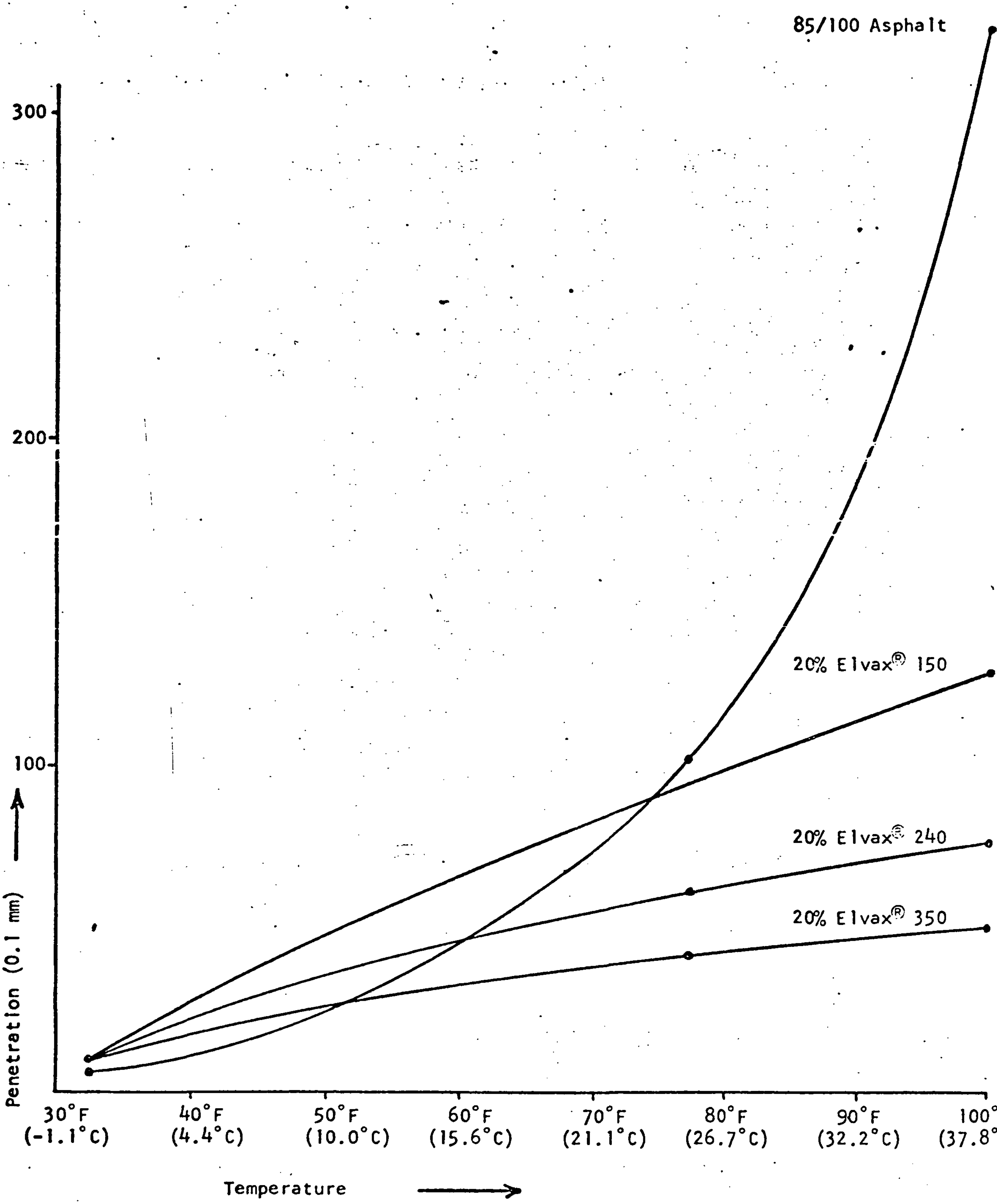


FIGURE 2. COMPARISON OF PENETRATION PROFILES OF EVA-MODIFIED ASPHALT WITH UNMODIFIED ASPHALT

with modified asphalt than with unmodified asphalt. Again, this is an indication of superior adhesion. Of course, it must be borne in mind that the results of these types of tests are only relative and not absolute because of the highly variable nature of cross-sections of asphalt pavement.

Another type of test was devised to demonstrate the differences in temperature susceptibility between modified and unmodified asphalt. This test consisted of measuring the penetration of modified and unmodified asphalt at temperatures of 100°F (38°C), 77°F (25°C) and 32°F (0°C) using weights of 50, 100, and 200 grams respectively for five seconds each. As Figure 2 will show, the modified asphalts have much flatter penetration curves or profiles than 85-100 penetration asphalt, which indicates lower temperature susceptibility.

Based upon the various test results, cost considerations, and handling properties, it was decided that a 20% weight modification of 85-100 penetration asphalt with Elvax 150 and with Elvax 420 would be used for field testing, both with and without aggregate. These two resins tend to impart the best physical properties to asphalt while maintaining good handling properties. In addition, they represent to a large extent the extremes of cost and of vinyl acetate content, which is related to tack and adhesion.

Current street patching techniques advocate the use of a tack-coat or primer for the sides of a pothole before the patching material is installed. Typically, emulsified asphalt is used. For the purposes of field testing, it was decided that a suitable EVA-asphalt based primer should be developed and tested concurrently with the patching compounds themselves. This primer had to meet the requirements of adhesion to wet and dry asphalt pavement, compatibility with the patching material, and applicability at low ambient temperatures without heating. Such a primer was made from a 20% weight modification of 85-100 penetration asphalt by Elvax 40 with the combination reduced to 60% solids with xylene.

Manufacturing processes for the production of large quantities of both aggregate-filled and unfilled EVA-modified asphalt were developed. Five gallon quantities of the EVA-modified asphalt could be produced using a Mooney mixer. The asphalt was first heated and then weighed into a six gallon (22.7 liter) container fitted with a 3000 watt snap-on band-type pail heater. The asphalt temperature was brought up to 300^{o}F (149^{o}C) with a slow stirring. When temperature was reached, the Elvax resin pellets were added slowly while mixing at 400-500 rpm. After all the resin was added, the mixing speed was increased to 700-800 rpm and maintained until the uniformity test discussed earlier was satisfactory. Typical mixing times at the higher speeds ranged from five to ten minutes.

For mixing the modified asphalt with aggregate a steam-jacketed rotating vertical blade mixer of eighty gallon (303 liter) capacity proved satisfactory. The aggregate could be preheated to 300^{o}F (149^{o}C) by placing it in drums in a large walk-in oven for several days or by using the steam jacket on the mixer to heat the exact amount required. The aggregate type used was one conforming to the Standard Specification for Public Works Construction 203-6.3.1 Class F. The modified asphalt or binder portion of the mixture was heated separately to 300^{o}F (149^{o}C) and added to the hot aggregate while mixing. Within seven to ten minutes, the binder had completely and uniformly wetted out the aggregate.

The aggregate/binder mix ratio was 19/1 by weight. Before filling into five gallon pails at sixty pounds (132 kilograms) each, the mixed material was checked for appearance and uniformity and was satisfactory. In this manner, 1500 pounds (3,300 kilograms) of each Elvax resin/asphalt/aggregate composition was made in 500 pound (1100 kilogram) batches.

Additional development work of a supplementary nature was conducted. This work consisted of evaluating Elvax 150 and 420 as 20% modifications of 40-50 and of 200-300 penetration asphalt. This was done with a view to developing EVA-modified asphalts that would take into consideration the grade of asphalt available locally and the service temperature requirements. As Table V will show, the lower penetration grade asphalt gives much better properties than the higher penetration grade.

Elvax® Resin	Asphalt Grade	Mix Ratio	Viscosity @ 300°F (149°C)	Hardness	Penetration	Tensile Strength	Tear Strength	100% Modulus	Elongati
420	40/50	20/80	37 Poises	53 Shore A	62 @ 100°F (38°C) 28 @ 77°F (25°C) 13 @ 32°F (0°C)	6[illegible] psi (4.62 kg/cm²)	20 lbs/ inch (3.57 kg/cm)	66 psi (4.62 kg/cm²)	1200%
150	40/50	20/80	35 Poises	16 Shore A	176 @ 100°F (38°C) 58 @ 77°F (25°C) 22 @ 32°F (0°C)	3[illegible] psi (2.59 kg/cm²)	7.55 lbs/inch (1.35 kg/cm)	9.4 psi (.658 kg/cm²)	>1500%
420	200/300	20/80	14.8 Poises	23 Shore A	131 @ 100°F (38°C) 57 @ 77°F (25°C) 26 @ 32°F (0°C)	2[illegible] psi (1.4 kg/cm²)	6.32 lbs/inch (1.16 kg/cm)	20 psi (1.4 kg/cm²)	600%
150	200/300	20/80	21 Poises	1 Shore A	303 @ 100°F (38°C) 98 @ 77°F (25°C) 45 @ 32°F (0°C)	*	*		*

*Unable to fabricate specimens; material extremely soft and tacky.

TABLE V. PHYSICAL PROPERTIES OF EVA-MODIFICATIONS OF DIFFERENT GRADES OF ASPHALT

Elvax 150, 350 and 420 were evaluated as 10% weight modifications of asphalt with the idea of reducing still further the raw material cost of the modified asphalt while maintaining acceptable physical properties. The asphalt used was 85-100 penetration grade paving asphalt. The resulting material was in each case very soft, sticky and semi-plastic with ill-defined physical properties. Further study of its suitability for street patching is needed.

The adhesion of the two standard modified asphalt compositions (20% weight modifications of 85-100 penetration asphalt with Elvax 150 and 420) to pavement samples from Kalamazoo, Michigan, and Winnipeg, Canada, was tested using the block method described earlier. In each case, there was no significant difference in the quality and quantity of adhesion from that of the Burbank sample.

PRODUCTION AND DISTRIBUTION OF MATERIAL

Three production sources are possible for EVA-modified asphalt patching compositions. On a regional level, an oil refinery would be ideally suited to take advantage of the economies of large scale production of the EVA-asphalt blend. This blend could then be supplied to local hot mix plants or to local public works departments for incorporation with aggregate when desired. On an intermediate level, the local hot mix plant could produce binder and/or premixed material for local consumption. A third possibility is the local public works department producing its own material, either for stockpiling or at the actual patch site using suitable equipment.

Three types of raw materials are required. These are EVA resin, available from Du Pont, asphalt, available from the refinery, and aggregate, available from local sources. Production of the binder is best done at a regional level while incorporation of aggregate is best done at a local level.

The kinds of equipment necessary to produce the binder portion include mixers capable of vigorously mixing large quantities of 2000 to 10,000 centipoise viscosity material at temperatures of 300° to $325^{\circ}F$ (149° to $163^{\circ}C$), heated lines, mixing vessels, and storage tanks, as well as pumps of sufficient capacity. Suitable reservoirs for the asphalt as well as hoppers and bins for the EVA resin are also necessary.

Two types of manufacturing processes are possible, batch and continuous. The former is more suited to local producers and the latter to regional producers. Incorporation of aggregate, best done locally, would use conventional pug mill equipment.

Quality control procedures involve testing at three different points during manufacture. First, all raw materials are checked for conformance with published specifications. Second, the EVA-asphalt blend is tested for hardness/penetration, tensile strength, ultimate elongation, melt viscosity, and uniformity. Third, when combined with aggregate, the mixed material is evaluated according to standard asphalt hot mix procedures.

APPLICATION OF MATERIAL

EVA-modified asphalt can be made available in several forms depending upon the end use. As a premix with aggregate, it can be supplied as precast blocks or as 1/4"-1/2" (0.63cm-1.27cm) granules in sacks. Quite probably, the granulated material would be easier to heat to application temperature. The unfilled binder can be supplied cast into pails, drums, or cartons for later reliquification. Alternatively, the binder can be extruded, chopped, dusted with talc, and sacked. For many applications, this latter form might be the most useful.

The most important requirement for the application of EVA-modified asphalt patching materials is suitable heating and mixing equipment. If aggregate-filled premixed material is used, then the minimum requirement is a temperature-controlled oven or heater truck. If bulk aggregate and containers of binder are to be combined at the patch site, then each component may need its own heater unless it is feasible to heat them together in the same unit.

When at temperature, each component would then be charged to a mixer and mixed together before applying. A possible alternative here is to charge the aggregate to a heater/mixer, bring it up to temperature, and then add cold, pelletized binder, relying on the heat supplied by the mixer and the aggregate to melt the binder during the mixing process.

Where it is desired to use straight binder as a crack filler, an oven can be used to heat the containers or a tar kettle to heat the pelletized binder, after charging the desired number of sacks. The premixed material, once it has been brought to temperature, is applied in exactly the same manner as conventional hot mix asphalt. Holes are swept free of debris and standing water, primed around the edges, and as many 2" (5 cm) courses of patching material as necessary are hand-temped into place, the final course being finished off with a few passes from a heated roller.

SECTION V:

COST ANALYSIS

COST BENEFIT ANALYSIS

INTRODUCTION

Preliminary thermoplastic street patching material test results look generally promising, but now we must address ourselves to the question: "Just how successful must the new patching material be in terms of increased road life in order to prove cost effective?"

Obviously, cost-effectiveness entails more considerations than that of basic material cost alone. One must also consider the labor cost benefits which result directly or indirectly from the material change. Total patching costs will vary from jurisdiction to jurisdiction, dependent strongly on local labor costs, availability and condition of existing muncipal equipment, local raw material costs, etc. The particular manner in which any individual jurisdiction chosses to utilize the thermoplastic patching material further exerts a strong influence on the overall patching costs.

It is the purpose of this analysis to set up a sufficiently general methodology by which each individual jurisdiction can evaluate its own unique situation, and thereby determine the cost-effectiveness of utilizing the new material. Detailed case studies for the cities of Burbank and Dallas are presented in Appendices D & E.

SCOPE OF ANALYSIS

The street patching cost-effectiveness analysis that follows results ultimately in a single, linear equation which expresses the total street patching cost in terms of material costs, labor costs, and equipment costs.

Several assumptions are made throughout the analysis, and are identified as they are made. The most notable assumption, however, is that total street patching costs are directly proportional to the amount of street patching material used. This assumption allows us to refer to "material costs per ton," "Labor costs per ton" and "equipment costs per ton." We are saying that if by some act of nature during a given year, a streets department is required to use only one-half the amount of patching material normally used during a year, not only would the material cost be halved, but labor and equipment costs directly related to the patching operation would also be reduced by one-half.

The assumption of linearity at best only approximates the real-life street patching situation. It does however, allow us to analyze a very complex situation in a simple and relatively accurate manner, using cost data which is readily available to municipal officials.

The cost equation so derived is then used to evaluate the material, labor, and equipment costs associated with current emergency road patching operations. The data used is an average of cost figures received from eleven cities throughout the country. (See Table IV). A copy of the questionnaire used to obtain this data is included with this report as Exhibit VIII.

For comparison to these currently realized average street patching costs, corresponding evaluations are made assuming the use of the thermoplastic patching material as purchased and prepared in three distinct cases. These cases and their variations are defined in detail in a later section of this report.

As would be expected, most of the alternative methods considered require investment by the user in new equipment not necessarily available as standard street patching equipment. For each case, the new equipment total costs are calculated and presented.

Use is made of the cost equation to calculate the "road life" factor which would be required in each case to equalize thermoplastic patching operations costs and current patching methods costs. The "road life" factor is the number of times an average thermoplastic street patch outlives the traditional emergency street patch.

Finally, the average annual savings which can be realized by using the thermoplastic material are shown for several reasonable "road life" factors.

BACKGROUND ON THERMOPLASTIC PATCHING MATERIAL

The Elvax-Asphalt-Aggregate patching material is viewed as a potential replacement for traditional emergency patching materials. The basic hypothesis upon which the proposed change is based is that the new material will allow longer lasting temporary patches, even when applied under adverse conditions, which in turn will result in labor cost savings sufficient to justify the increased material costs and outlay for associated equipment. We intend to investigate the validity of this hypothesis with the analysis that follows.

In order to test this hypothesis, we must first develop an equation which takes into account all the known costs associated with street patching. The equation should contain, as variables, the amount of street patching used, associated labor and equipment costs, material costs, and the "road life" factor described previously.

DEVELOPMENT OF A STREET PATCHING OPERATIONS ANALYSIS

For the purposes of this analysis, street patching will be divided into hot and cold patching with the former including only true hot patching, and the latter including all other emergency or temporary methods.

In order to include all aspects of street patching we may write:

$$\begin{matrix}\text{Total Street} \\ \text{Patching Cost}\end{matrix} = \begin{matrix}\text{Total Hot} \\ \text{Patching Cost}\end{matrix} + \begin{matrix}\text{Total Cold} \\ \text{Patching Cost}\end{matrix}$$

or;

$$TC_{SP} = TC_{HP} + TC_{CP} \quad (1)$$

The analysis that follows will develop only an expression for TC_{CP} since this expression is the one we will use to evaluate the thermoplastic material usage. Keep in mind, however, that the expression for TC_{HP} is an identical equation. In the analysis that follows, the subscript CP will be dropped.

Components of Total Patching Costs

Street patching costs may be broken down into material costs (MC), labor costs (LC), and equipment costs (EC). Obviously;

$$TC = MC + LC + EC \qquad (2)$$

At this point, it should be noted that material, labor, and equipment costs as used here are COSTS TO THE USER. In all analysis that follows, costs will be assumed to be referenced in this manner.

Material Cost

Since hot or cold patching material is actually a combination of sub-components which in some cases are purchased separately, provisions must be made within our analysis to account for their individual costs and respective proportions. Also, we must allow provisions for material storage and handling costs which might be incurred by the user. Thus:

$$MC = V[r_1c_1+r_2c_2+r_3c_3 + s] \qquad (3)$$

where: MC = Material Cost

V = Volume of Material Purchased (tons)

r_1 = Fraction of 1st Component in the Overall Material

c_1 = Cost per ton of the 1st Component

s = Storage cost per ton for the total material.

In calculating the storage costs, one should include also any transportation, handling, or packaging costs above and beyond the basic materials cost. Again, we are only interested in costs to the actual user.

Any labor or equipment costs which the user incurs in mixing or preparing the material will be accounted for in the expressions for labor and/or equipment.

Labor Cost

Total labor costs (LC) can be generally grouped into Direct Labor (DL) and Overhead (OH). We may then write:

$$LC = DL + OH \tag{4}$$

Overhead (OH) as used here should also include any management costs which can be identified as relating directly to the street patching operation.

As stated earlier, the assumption is made that total material, labor, and equipment costs are directly proportional to the total volume of material used. Under this assumption, we can therefore define a parameter known simply as "Labor Cost per Unit Volume" (L/T). The units of this value are dollars per ton. Thus:

$$L/T = \frac{LC}{V} \tag{5}$$

where V = total volume of material used.

The labor cost (LC), may then be written

$$LC = V \times L/T \tag{6}$$

The expressions "volume of material used" and "volume of material purchased" have been used interchangeably to this point. This may or may not be an accurate representation since the difference represents wasted or lost material.

If the patching material is relatively inexpensive, then waste may be tolerated, in fact, it may even be cost-effective. If the material is relatively expensive, as is our thermoplastic material, then there is a good chance that "volume purchased" will equal "volume used".

For the purposes of this analysis, the assumption is made that the volume figures are identical.

Equipment Cost

Equipment Cost (EC) as used in this portion of the analysis represents only the recurring equipment expenses associated with the street patching operation.

Included in the recurring equipment cost (EC) are maintenance costs (M), operating expenses (O), and depreciation write-off (D) of the equipment normally used in street patching operations. Not included are recurring costs, or the initial investment in any new equipment which may be required. Thus:

$$EC = M + O + D \tag{7}$$

We again make the assumption of linearity of cost, in this case equipment cost, with volume of patching material, and define an "equipment cost per unit volume", E/T:

$$E/T \equiv \frac{EC}{V} \tag{8}$$

The total recurring equipment cost (EC) is then:

$$EC = V \times E/T \tag{9}$$

Linear Street Patching Analysis

The equation to express total patching costs, in this case for cold patching costs, may be written by combining Equations (2), (3), (6), and (9), to yield:

$$TC = V\frac{1}{n}\left\{ (r_1c_1+r_2c_2+r_3c_3) + s + L/T + E/T \right\} \tag{10}$$

The factor n, is the "road life" factor which affects total costs in that it reduces the number of times the same hole must be repatched. Again, we are assuming that the total cost is proportional to total volume used, or equivalently, the number of times the same hole must be patched.

USE OF THE STREET PATCHING EQUATION TO EVALUATE THE COST EFFECTIVENESS OF USING THE THERMOPLASTIC MATERIAL

The motivation for developing a street patching operations analysis was two-fold. First, a methodology was required with which to evaluate a specific project; i.e., the use of thermoplastic patching material in municipal operations. Secondly, it was desired to place the thermoplastic project in its proper perspective. How does a material change affect the overall patching operation?

In the section that follows, three alternative methods of utilizing the new material are outlined in detail. The plastic material alone is referred to as "Elvax". The Asphalt-Elvax mixture is referred to as A/E.

The only A/E mixture considered in this analysis is the 80% asphalt -- 20% Elvax mixture.

Alternative Schemes for Procuring and Using A/E in the Street Patching Operation

Case I - City Performs All Material Preparation

In this case, the city purchases all of the required raw materials from their respective suppliers. (Elvax, Asphalt, Aggregate) The patching material is then prepared by a city-owned facility and transported (hot or cold) to the required patching site. The available options are:

Option A: City produces and stores A/E at a central location. A/E is transported (cold) to the patching site where it is heated and mixed with aggregate in a portable heater/mixer unit.

Equipment Requirements:

- Central A/E high speed blender.
  Cost: Approx. $10,000. [1]
  One Required.

- Portable A/E-aggregate heater/mixer.
  Cost: $2,750. [2]
  One Required per crew.

Other Requirements

- Storage space for A/E.

Option B: City produces both A/E and mixes it with aggregate at a central location. In effect, city operates a hot-mix facility. Patching material is then deployed hot in heater-bed trucks or insulated bed trucks for patching.

Equipment Requirements

- Central A/E, aggregate hot mix facility.
  Cost for 50 ton/day capacity: $50,000. [3]
  Cost for 10 ton/day capacity: $20,000. [3]
  Cost for 1 ton/day capacity: $ 5,000. [3]
  One Required.

---

(1) Estimated

(2) Quoted: McConnaughay HDT-4-T truck mount hot mixer.

(3) Estimate based on 100 ton/day capacity Boeing machine at approximately $100,000.

- Heated bed trucks for transporting hot thermoplastic material.

  Cost: $25,000.[4]

  One Required per crew.

  or

- Insulated bed trucks

  Cost: $7,500.[4]

  One Required per crew.

Option C: City produces and stores A/E aggregate mix at a central location. Patching material is then transported (cold) to site, heated in portable heaters, and applied.

Equipment Requirements:

- Central A/E, aggregate hot mix facility

  Cost: Same as Option B

  One Required.

- Portable heater/mixer

  Cost: $2,750

  One Required per crew.

Other Requirements:

- Storage space for A/E, aggregate mix. 19 times as much as Option A.

Case II - City Purchases A/E, Mixes with Aggregate

In this case, the city purchases A/E from a refinery or local hot mix plant set up to mix Elvax and asphalt. A/E is mixed with aggregate, on site, using portable heater mixers.

Equipment Requirements:

- Portable heater/mixer

(4) Average figures based on PTI user questionnaire response.

Cost: $2,750

One Required <u>per crew</u>.

<u>Other Requirements</u>:

- A/E storage space.

<u>Case III - City Purchases Patching Material Ready-Mixed</u>

By this method, the city purchases the patching material (Elvax-Asphalt-Aggregate) from a local hot mix plant. Two major options exist:

Option A: Patching material purchased hot from hot mix plant and transported to site.

<u>Equipment Requirements</u>:

- Heater bed trucks

  Cost: $25,000

  One Required <u>per crew</u>.

<u>or</u>

- Insulated bed trucks

  Cost: $7,500

  One Required <u>per crew</u>.

Option B: Patching material is purchased in batches from hot mix plant and stored. Material is transported (cold) to the site and heated for use.

<u>Equipment Requirements</u>:

- Portable heater/mixer

  Cost $2,750

  One Required <u>per crew</u>.

<u>Other Requirements</u>:

- Storage space equivalent to Case I, Option C.

Evaluation of A/E Material Costs

It has been experimentally determined that a good Elvax-Asphalt-Aggregate mixture for street patching applications is 1% Elvax, 4% Asphalt, and 95% Aggregate.

The per volume costs will be calculated for each of the three methods of municipal usage of the final product.

Case I - City Produces material itself. Raw Material Costs are as follows:

Material	High	Low	Average
Elvax	600/ton	600/ton	$600/ton
Asphalt	$55.00/ton	$27.50/ton	$44/ton
Aggregate	$4.57/ton	$2.00/ton	$3/ton

Source: PTI municipal questionnaire (1973).
Products Research Corp. (1973)

Applying Eqn. (3);

$$MC = V\left\{r_1c_1+r_2c_2+r_3c_3\right\}$$

$$= 10.61\ V$$

where average costs of the various components were used.

Thus for CASE I, material cost (excluding labor, processing, packaging, storage, and transportation) is $10.61/ton.

Case II - City purchases A/E, mixes aggregate at patching site

Current A/E cost as produced by PRC on a batch process basis and in limited quantities.

Cost = $2,000/ton

A/E cost as produced by PRC or PRC-like outfit on a large scale with equipment devoted to production 100% of the time.

Cost = $800/ton

Using a proportion of 5% A/E to 95% aggregate, Equation (3) may be written:

$$MC = V\left\{.05\ c_1 + .95\ c_2\right\}$$

or:

$102.85/ton for the case of A/E = $2,000/ton

$ 42.85/ton for the case of A/E = $800/ton

Here the average aggregate cost of $3.00/ton has been assumed.

Case III - City purchases fully processed patching material

One situation involving the supply of ready mixed A/E - aggregate to the city by a local hot-mix plant would be as follows:

Plant purchases A/E from the refinery at the cost of $800/ton, hot-mixes the aggregate, and delivers to the city.

The actual mix cost will be the same as in Case II, i.e., $42.85/ton using a 5% A/E - 95% Aggregate (@ $3.00/ton) proportion.

The plant will then add on its own costs and profit margin.

Determination of a typical hot-mix markup

If asphalt on the average costs $44/ton, and aggregate $3/ton:

The average mix is 5% Asphalt to 95% Aggregate, the cost of materials in a typical hot mix would be $(.05)(44) + (.95)(3)$ or $5.05.

The average price (as obtained in 1973 PTI questionnaire) of processed hot mix to local government was $7.93/ton. This represents an average mark-up of $2.88/ton or 57%.

As a minimum mark-up on the A/E material, we could expect a per ton mark-up of around $3.00, for a total selling price to the city of $45.85/ton.

As a maximum, we might expect the same percentage mark-up of 57% which would bring the selling price to $67.25/ton.

We might reasonably expect something near the average of these; i.e., split the difference for a price of $56.55/ton.

Summary of Thermoplastic Patching Material Costs

CASE I - City Performs All Processes

Cost: \$10.61/ton

CASE II - City Purchases A/E, Mixes Aggregate

Cost: \$42.85/ton

CASE III - City Purchases Material Ready Mixed.

Cost: \$56.55/ton

Note: Costs do not include city supplied labor, processing, equipment, or storage costs.

Sample Calculation of Patching Operation Total Costs Using Average Cost Parameters

Tables VI through IX of this report present material, labor, and equipment cost data derived from a recent (1973) PTI street patching questionnaire. Data is available for eleven cities. For the example that follows, average cost figures from Tables VI through IX are used.

Baseline Cost Analysis for Current Street Patching Methods

From Table VIII, the average unit material cost of cold patch material is \$8.80/ton. ($r_1c_1+r_2c_2+r_3c_3 = 8.80$)

From Table IX the average labor cost per ton of material is \$25.50/ton. ($L/T = 25.50$)

Also from Table IX the average equipment cost per ton of material used is \$13.00. ($E/T = 13.00$)

For the purposes of this example, storage costs will be omitted from the calculation. ($s = 0$)

Inserting these values into Equation 10 yields:

$$TC = V\left\{8.80 + 0 + 25.50 + 13.00\right\}$$

$TC = 47.30\ V$ for current patching techniques.

If our assumption of linearity holds, we may then say that; taking into consideration all labor and equipment costs, the average cost of applying one ton of cold patching material is $47.30 per ton.

Note that the "road life" factor in this case is 1.0 since current materials are the basis for comparison.

Thermoplastic Material Cost -- Case I

This case is the one in which the city performs all processing operations.

The only labor saving estimate we have received to date is from Dallas. They estimate a potential work force reduction from the existing 8 - 5 men crews and 8 - 3 men crews (total of 64 men) to that of 20 - 2 men crews (total of 40 men).

Assume then, that a labor reduction of 37.5% is possible. This reduces the average labor factor of $25.50 (See Table IX) to $15.90/ton. However, in this case we are assuming a central city operated facility which will require manning. The facility may or may not run year-around, but for this analysis we will assume the equivalent of 4 men, i.e., a 10% increase in the above mentioned 40. This brings the total labor factor up to $17.50/ton.

In the Dallas example, a 37.5% work force reduction was realized, but at the expense of an increase in crews, (thus equipment costs) from 16 to 20. This represents a 25% increase in equipment costs. For this example, we will apply the 25% to the average equipment factor, E/T (See Table IX) of $13.00/ton for a total of $16.25/ton.

The total recurring costs per ton for CASE I operations are then:

Material Cost	$10.61/ton
Labor Cost	$17.50/ton
Equipment Cost	$16.25/ton
Total Cost	$44.36/ton

Thus we can write,

$$TC_{CASE\ I} = \frac{\$44.36\ V}{n}$$

where the "road life" factor, n, is yet to be determined.

Obviously, if the city is going to go into the Elvax-asphalt-aggregate processing business, they will require investment in a processing facility or at least in processing equipment.

Except in the case where the city already owns some or all of the required equipment, Case I, Option A appears to be the least expensive option in terms of equipment. The requirements in this case are a high shear blender ($10,000) and one portable heater-mixer ($2,750) per crew.

We must further add annual equipment expenses for all new equipment to the total recurring cost. Assume that one crew can lay down 1,000 tons of material per year. This brings the total cost per ton of the portable equipment to $2.75 per ton. The yearly equipment cost per ton of material will be assumed to equal the annual write-off per ton over a ten year period, or $.28 per ton. This represents the operating, maintainance, and depreciation of the portable equipment only, and must be added to the existing Case I annual costs or:

$$TC_{CASE\ I} = \frac{\$44.64\ V}{n}$$

Note that the assumptions as to new equipment annual costs are not based on actual data; rather, on ball park estimates. Note also, that their magnitude is small compared to the overall costs, thus their impact is not highly significant.

Thermoplastic Material Cost -- Case II

In this case, the city purchases A/E and mixes it with aggregate on location.

As derived in the previous section, the Case II material cost is $42.85/ton.

In this case the full 37.5% labor force reduction will be realized, bringing the Labor factor down to $15.90/ton.

The equipment cost factor will be the same as derived in Case I or $17.50/ton.

The total recurring cost factor is therefore:

Material	$42.85
Labor	$15.90
Equipment	$17.50
Total Recurring	$76.25/ton.

The Case II new equipment requirements are one portable heater-mixer per crew ($2,750).

As in Case I, the new equipment operating expense will add approximately $.28 to the total, thus

$$TC_{CASE\ II} = \frac{\$76.53\ V}{n}$$

Thermoplastic Material Cost -- Case III

In this case the city purchases ready mixed A/E - aggregate from a subcontractor.

As derived previously, the cost of patching material is $56.55/ton.

The total labor reduction of 37.5% is realized in this case for a labor factor of $15.90/ton.

The Equipment Factor is up 25% as in Cases I and II to $17.50/ton.

The new equipment requirements are again as in Case I and Case II, and will add \$ .28/ton to the equipment cost.

Adding these components,

$$TC_{CASE\ III} = \frac{\$89.95\ V}{n}$$

Summary of Comparative Cost Figures Based on Average Parameters

Recurring Costs and Initial Equipment Outlay Requirements

Method	Annual Recurring Cost per Ton	Initial Equipment Outlay
Current	\$ 47.30	None Required
Case I	\$ 44.64	\$10,000 + \$2,750 per crew
Case II	\$ 76.53	\$2,750 per crew
Case III	\$ 89.95	\$2,750 per crew

Note: Road life factor, n, is assumed to be 1.0. No correction has been made to the costs to allow for the increased pothole life of thermoplastic material.

Road Life Factor Required of Thermoplastic Material for Method to be Cost Effective Relative to Current Methods

Method	Required Road Life Factor
Current	-
Case I	0.95 (better than current)
Case II	1.62
Case III	1.90

Annual Savings Realized From a Road Life Factor of 2.0 based on an Annual Material Usage of 1000 Tons.

Method	Cost/Ton	Annual Savings over Current Method
Current	\$ 47.30	-
Case I	\$ 22.32	\$ 24,980
Case II	\$ 38.27	\$ 9,030
Case III	\$ 44.98	\$ 2,320

Capital Cost Analysis

Strictly speaking, a capital investment analysis should be undertaken to determine whether or not the present value of the savings to be realized from going to the thermoplastic material over the long run equal or exceed the cost of new equipment.

Using the total recurring cost analysis as presented in this report will allow the expected savings to be calculated. For example, if Case I is employed, and the "road life" factor equals 2.0, then the savings to be expected per year are \$25,000. (See previous section)

Assume that in our hypothetical example, we anticipate ten crews, thus we require ten portable hot-mixers at a cost of \$27,500. We will also require a high shear blender at \$10,000. The question to be answered is: Does a yearly savings of \$25,000 justify the initial outlay of \$37,500? Obviously, under the assumptions we have made, it does. It would pay for itself in less than two years.

More correctly, if we assume a ten year equipment life and an 8% investment opportunity rate, the present value of the cash flow of \$25,000 per year for ten years is 1.7 x \$25,000 or \$42,500. It is thus worth \$5,000 present value dollars (\$42,500 - \$37,500) to make the required investment.

Since the manner in which capital investment decisions are made in municipal government vary considerably with jurisdiction, no great analytical detail will be attempted at this point. The analysis, as it stands, is sufficient to calculate future savings to be anticipated by going to the thermoplastic material.

COST ANALYSIS SUMMARY

1. Based on the figures utilized, and the assumptions made, the most cost effective method of using thermoplastic patching material appears to be Case I, in which the city performs all material processing.
2. A "road life" factor of approximately 1.6 is required in order for the material to be cost effective in Case II.
3. A "road life" factor of 2.0 is required to break even in Case III.
4. Each city should perform a similar analysis using their own cost figures. The cost-effectiveness of the method will vary with jurisdiction.

TABLE VI

Total Street Patching Costs

Eleven U. S. Cities

City	Total Material Cost	Total Labor Cost	Total Equipment Cost	Total Patching Cost
1	$ 126,300	$ 188,600	$ 48,300	$ 363,200
2	189,600	305,400	50,000*	545,000
3	57,400	52,000	18,000	127,400
4	49,900	122,600	20,000*	192,500
5	23,500	19,800	6,200	49,500
6	19,200	66,400	16,900	102,500
7	7,000	42,500	28,100	77,600
8	3,100	10,000	5,800	18,900
9	3,000	34,000	9,700	46,700
10	15,800	19,000	9,300	44,100
11	18,500	97,200	21,300	137,000

Source: PTI User Questionnaire, May 1973

* PTI estimate

TABLE VII

Material, Labor, and Equipment Costs as a Percentage of Total Street Patching Costs

Eleven U. S. Cities

City	Material Percentage	Labor Percentage	Equipment Percentage
1	35%	52%	13%
2	35%	56%	9%
3	45%	41%	14%
4	26%	64%	10%
5	48%	40%	12%
6	19%	65%	16%
7	9%	55%	36%
8	16%	53%	31%
9	6%	73%	21%
10	36%	43%	21%
11	13%	71%	16%
Average	26%	56%	18%

TABLE VIII

Material Costs in Eleven U. S. Cities*

City	Asphalt	Aggregate	Cold Mix	Hot Mix	Average All Material
1	$27.50	$4.57	$ 5.60	$ 5.74	$ 6.20
2	N.A.	N.A.	11.14	12.20	12.20
3	55.00	2.46	12.00	11.40	9.40
4	N.A.	N.A.	8.60	8.60	8.60
5	N.A.	N.A.	N.A.	5.80	8.55
6	N.A.	N.A.	6.00	N.A.	6.00
7	N.A.	N.A.	9.00	6.75	8.86
8	50.00	2.00	7.50	7.50	5.05
9	N.A.	N.A.	N.A.	5.45	5.45
10	N.A.	N.A.	8.00	7.50	7.50
11	N.A.	N.A.	11.50	7.80	10.35
Average	$44.16	$3.01	$ 8.80	$ 7.87	$ 8.00

Source: PTI User Questionnaire, May 1973

*All costs, including asphalt, are adjusted to a per ton basis.

TABLE IX

Total Volume, Labor Cost per Ton
and Equipment Cost per Ton

Eleven U. S. Cities

City	Total Volume (Ton)	L/T	E/T
1	20,350	$ 9.27	$ 17.85
2	15,530	19.60	32.20
3	6,100	8.50	2.94
4	5,800	21.10	3.45
5	2,750	7.20	2.25
6	3,200	20.70	5.27
7	790	53.60	35.40
8	600	15.60	9.50
9	550	61.70	17.60
10	2,110	9.00	4.40
11	1,790	54.30	11.90
Average	---	$ 25.50	$ 13.00

SECTION VI:
CONCLUSIONS

CONCLUSIONS

Based upon the laboratory development work and field test applications done to date, the following conclusions can be drawn:

1. Significantly improved physical properties can be imparted to asphalt by mixing with EVA resins in amounts of 20% or more by weight. This includes tensile strength, elongation, and modulus.
2. The quality and quantity of adhesion of EVA-modified asphalt to asphalt pavement is significantly better than unmodified asphalt. This holds true apparently regardless of the regional differences in asphaltic concrete.
3. Improved penetration profile, interfacial adhesion, tensile strength, ultimate elongation, and other elastomeric qualities indicate that EVA-modified asphalt compositions are good candidates for meeting street patching requirements.
4. EVA-modified asphalt patching compositions have not exhibited performance superior to conventional hot mix asphalt after one to two month's field testing. No empirical data has been obtained vis-a-vis cold patch material, since the UDC believes the cold patch would not hold at all.
5. The necessity for using more sophisticated heating and mixing equipment reduces the utility of EVA-modified asphalt patching compositions. The cost analysis implies, however, that this is not an excluding con dition. The potential savings of increased road-life offsets equipment expense.
6. Preliminary results indicate that a pre-mixed material, pelletized by cooling under non-compacted conditions, may obviate the need for heater/mixer equipment required in the application procedures developed to date.
7. EVA-modified asphalt compositions containing aggregate can be applied and produced in a manner similar to conventional hot mix asphalt.

8. The use of a primer improves the durability of EVA-modified asphalt patching compositions. This is particularly true in the case of wet holes. The fact that use of primer permits application under wet conditions mitigates strongly for continued testing and development.
9. Higher vinyl acetate content EVA resins exhibit better durability in patching compositions than lower vinyl acetate content resins although the former are more difficult to apply.
10. Lower penetration grades of asphalt give better physical properties when modified with EVA resins than higher penetration grades.
11. For optimum adhesion, the EVA-modified asphalt patching compositions require a temperature of 260^{o} to 325^{o}F (127^{o} to 163^{o}C) at the time of application.
12. EVA-modified asphalt patching compositions can be reheated and re-used several times without significant loss of properties.
13. EVA-modified asphalt has considerable potential as a crack filler.

The final User Design Committee meeting held on 21-22 June, 1973 was in general agreement with the conclusions and findings as presented here. A copy of the meeting summary is included with this report as Appendix B.

SECTION VII:
RECOMMENDATIONS

RECOMMENDATIONS FOR FUTURE EFFORTS

Based upon observation of thermoplastic street maintenance material developed, applied, and tested to date, Public Technology, in cooperation with the User Design Committee, and with the industrial representatives concerned, has developed the following recommendations for directions to be pursued to ultimately create a marketable, cost effective product:

1. Continued research and development on temperature susceptibility of the material, with particular emphasis on the low temperature properties. Investigations should determine whether it will be possible for a single material to suit both winter and summer conditions, or if two products will be necessary.
2. Continued field testing. The material should be made available to at least twenty selected cities by next fall, for application during the winter months. The application procedure should be sufficiently defined to lead to installation in high-stress areas, such as curbs, bus stops, turning and stopping zones, etc.
3. Further investigations and field testing should be conducted on the pelletized coated aggregate technique, which appears to have the potential for overcoming many of the equipment problems associated with the hot-mix material.
4. Refine the quality of the input data on cost. Develop a more accurate model for a city to use in making the determination of whether or not introduction of the thermoplastic street patching material would be cost-effective.
5. Testing of patching compositions already in place at the three field sites, should continue until such time as the true performance differences among the various materials are apparent.
6. If EVA-modified asphalt patching compositions are to be used as presently constituted suitable low cost heating and mixing equipment must be developed. If such equipment is commercially available, its use must be advocated.

7. The use of EVA-modified asphalt as a crack sealer should be thoroughly investigated.

SECTION VIII:

EXHIBITS

EXHIBIT I

February 27, 1973

Mr. Royal G. Bivins, Jr.
NASA Headquarters
Code KT
400 Maryland Avenue, S. W.
Washington, D. C. 20546

Dear Roy:

As you know, Public Technology, Inc. and the NASA Technology Utilization Office have jointly selected street patching as the area in which to conduct an applications engineering project under the tasks in modification #5 to contract NASW-2388. This selection was based on the identification of problems in the general area of street maintenance. Some of the priority problems included improved pavement marking methods and materials, less noisy pavement cutting techniques, street maintenance planning as well as improved street patching materials. Upon a survey and evaluation of aerospace technology relevant to the above problems, the thermoplastic material, originally developed by JPL as a rocket propellant binder and later investigated under NASA contract by SRI, has the greatest potential for early application and benefit to municipalities.

In designing a street patching applications engineering project, Public Technology, Inc., after examining a number of alternatives, has determined that the materials formulation and testing aspects of the project can most efficiently be conducted under subcontract to an organization with the appropriate chemistry capabilities and testing facilities. After discussions with a number of consultants and firms, it was determined that Products Research and Chemical Corporation had unique capabilities to perform this project on an efficient, timely and cost-effective basis. We believe that this approach will be more advantageous to NASA than the technical and engineering support arrangements which were set forth in our proposal.

The proposed changes will require a reallocation of funds as given in the attached revised cost estimate.

NASA's early approval of the modification proposedabove would be greatly appreciated.

Sincerely,

Warren D. Siemens
Vice President

Enclosure

WDS:slp

EXHIBIT II

April 18, 1973

Mr. Jeffrey T. Hamilton
Director
Technology Utilization Office
NASA Headquarters
Washington, D. C. 20546

Dear Jeff:

The field installations of the thermoplastic asphalt street patching material were successfuly completed last week in Burbank, California and South Lake Tahoe, California. As you will recognize, the site for the freeze-thaw application was changed from what was presented at our program review on April 6. The evening of the 6th I contacted Mr. Koonce, Director of Maintenance, Division of Public Works and Mr. Easley, Assistant City Manager for the City of Anchorage. Their weather situation had changed since I last contacted them several days earlier -- they were no longer getting heavy freezing and the weather service was projecting no more in the near future. So on Monday, April 9 I contacted Mr. Travis Smith, Director of Maintenance for the California Division of Highways about possible sites in California and he referred me to his Maintenance Engineer for District 3 (the northwest part of California including the Sierra), Mr. Meister. Mr. Meister's site recommendation for heavy city traffic and freeze-thaw during the next three or four weeks was South Lake Tahoe and suggested I contact Alan Hendrickson, their Director of Public Works.

I then checked with Bob Havlick, who has responsibility for PTI subscriptions, about previous contacts with the City of South Lake Tahoe. He had just been with their City Manager, Gary Chase, who had expressed very high interest in the street patching project. So when I called Gary Chase, he gave me immediate and full cooperation to work with their Public Workd Department however we wished.

On Tuesday, April 10, the field installations were made in Burbank; on Wednesday, arrangements were made to deliver the material to South Lake Tahoe;on Thursday preparations were made for field installation and on Friday the material was installed on Johnson Boulevard in South Lake Tahoe.

In both places, 12 constructed holes 18 inches in diameter and about six inches deep in the wheel path of a heavy traffic lane were filled with thermoplastic asphalt. In addition, another constructed hole in the area was filled with their normal patching material plust various natural holes were patched with the thermoplastic asphalt material. The twelve holes were carefully controlled to test for various combinations of the following parameters: (1) ELVAX 150/ELVAX 420 compositions, (2) wet/dry holes, (3) primed/unprimed holes. (4) pre-mixed/layered applications.

In Burbank, the ambient temperature was in the high 70's, the street surface temperature was about 110°F and the sun was shining. In Tahoe, the ambient temperature reaged from 31 to 38°F, the surface temperature was 33°F and it snowed most of the day of application. In Burbank, the highs and lows currently are about 80 and 50. In Tahoe the highs and lows are about 50 and 20. Since the application in Tahoe the temperature has been below freezing every night except one and the morning after the application there was a two inch layer of snow on the streets. Mr. Hendrickson said today that the patches look good and that heavy snows are predicted for the next several days. Tahoe will provide an excellent test for the material.

In both places, the material handled well during application, that is, it was as easy as hot-mix to work with, tamp, etc. even working at freezing temperatures, however, the ELVAX 420 formulation was superior in this regard. There is no visible difference yet between the wet hole patches and the dry hole patches or the primed and unprimed patches. Ed Clarke, Burbank's Street Superintendent, said today that his patches look good particularly the pre-mixed application. He said the layered applications were beginning to dish and he requested permission towork with Products Research and Chemicals Corporation on experimenting further with the layered application technique. He also requested testing the material as a crack seal. PRC will cooperate with him on both areas. Finally, he informed me that he was designing and constructing in his shop prototype heating equipment for the application of this material. He is convinced that the material has high potential for patching applications.

Products Research and Chemicals Corporation is also convinced that the material has high potential for this application and I held several hours of discussion with Joseph Amstock, Vice President of PRC about their role in commercializing the material and about what happens after June. We began formulating plans to work with PRC in a broader demonstration program, where the material would be installed in fifteen to twenty sites at various appropriate times. Phoenix would like to apply some of the material in mid summer at their hotest time. Tahoe would like to apply some next January under their worst conditions and so forth.

We plan to develop some manuals on how to install the material so each Public Works Department would install it on their own, with some technical assistance available from PTI and PRC. Hopefully, Dupont would supply the ELVAX and PRC produce the material. Some funding would be required for PTI to conduct the evaluation program.

I am very optimistic about the material at this time but, of course, a month or two from now we will know more about the material performance from the field tests. Both Miles Greenbaum and myself were very pleased with the way the field installations were conducted. PRC managed the field installations well and the cooperation and help from the Public Works Departments was very gratifying.

We will keep you current as the field reports and photos come in.

Sincerely,

Warren D. Siemens
Vice President

cc: Ronald Phillips
Tom Wakefield
Roy Bivins

WDS:slp

PUBLIC
TECHNOLOGY

1140 CONNECTICUT AVENUE, NW
WASHINGTON, DC 20036
202/833-9484

EXHIBIT III

TECHNICAL MEMORANDUM

Date: May 3, 1973

Project: Street Patching

To: PTI Senior Vice President - R. Philips and
NASA Technology Utilization Office - C. Farley, J. Hamilton,
L. Magavero, T. Wakefield, R. Bivins

From: PTI/NASA Program Manager - W. Siemens

Re: Anchorage Field Test Installations

On Monday, April 23, 1973, at the request of the Technology Utilization Office on Friday, April 20, PTI made all arrangements with Products Research and Chemicals Corporation (PRC) and the City of Anchorage. Since the layered application test patches in both Burbank and Tahoe are dishing quite badly, a decision was made with NASA/TU to only install the pre-mixed application test patches under similar conditions to Burbank and Tahoe. Eight constructed pot-shaped holes, 18 inches in diameter and 4 inches depth in the center, were filled with the thermoplastic asphalt composition pre-mixed with medium grade aggregate (3/8 inch). One hole was filled with their standard hot-mix. In addition, several natural pot-holes were filled with the thermoplastic asphalt mix. The controlled test patches were installed on East 5th Avenue (see map for location), one of the heaviest trafficed streets in Anchorage -- average traffic volume of 20,000 vehicles per day in four lanes with speed limit of 40 m.p.h. The conditions for the controlled test patches were as follows:

Test Patch #	Formulation	Hole conditions
1	420	Wet, unprimed
2	420	Wet, primed
3	420	Dry, unprimed
4	420	Dry, primed
5	150	Wet, unprimed
6	150	Wet, primed
7	150	Dry, unprimed
8	150	Dry, primed
9	hot-mix	Dry, unprimed

The weather conditions at installation were overcast, no precipitation, temperature about 40°F, street surface temperature about 60°F. The high and low temperatures the day before and the day of installation were 41-34 and 45-36 respectively. There is currently almost 17 hours of daylight.

The temperature of the material just before installation was at or near 300°F. The material handled well during installation and the test patches were in excellent condition several hours after installation having been subjected to evening rush hour traffic immediately after installation.

Robert E. Sharp, City Manager of Anchorage, was very interested in the street patching project and was pleased to be able to cooperate with PTI. He would have been at the test patch site except for a City Council meeting he had to attend. Herman Veselka, Director of Public Works asked that we work directly with Ed Koonce, Manager of Maintenance and Operations, from whom we received excellent assistance and cooperation.

Those attending the test installation are as follows:

- Herman Veselka, Director of Public Works
- Ed Koonce, Manager of Maintenance and Operations
- Street Foreman and his patching crew
- Jack Morrow, Anchorage Area Maintenance Engineer, Alaskan State Highway Department
- Carl Kay, PRC chemist
- Ed Clarke, Burbank Streets Superintendent
- Warren Siemens, PTI

On April 30, 1973 arrangements and preparations for the field installations were made with Ed Koonce. He arranged with Richard Starzer in the Army Corps of Engineers Soils Laboratory to heat the material in their oven. (Both Starzer and Koonce send their regards to Clare Farley). By 2:00 p.m. on May 1, 1973, even after 8 hours of heating, it became apparent that contrary to everyone's expectations, the electric oven did not have sufficient BTU output to heat the 500 pounds of material in time to conduct the installations that day. So alternative arrangements were made to heat the material in the city's portable hot-mix plant. By 5:00 p.m. the material was at 300°F and by 6:30 p.m. installation was completed and the lane was opened to traffic.

According to Carl Kay, Ed Clarke, and myself, the best field installations so far in terms of quality of the patch were made in Anchorage. Ed Koonce was very impressed with the way the material handled during patching operations. He feels the real test of the material will be next February, March, and April when freeze-thawing begins.

United States Patent Office

3,442,841
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3,442,841
ASPHALT-ETHYLENE/VINYL ACETATE COPOLYMER COMPOSITIONS

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This invention relates to an improved asphalt composition. More particularly, this invention relates to an improved asphalt composition comprising asphalt and an ethylene/vinyl acetate copolymer.

Several physical properties of asphalt compositions are commonly used to characterize the adaptability of a particular asphalt to various uses. For example, many uses require an asphalt which has a specific minimum softening point temperature.

The penetration ratio is another important property of asphalt. The penetration ratio is an indication of the amount of hadening which occurs when the temperature of an asphalt is lowered. Penetration ratio is commonly expressed as the ratio of the penetration at 39.2° F. divided by the penetration at 77° F., multiplied by 100. Since a higher penetration signifies a softer asphalt, an increased penetration ratio indicates that less hardening occurs as the temperature decreases.

Generally, the temperature range over which an asphalt is useful for a particular application is determined by the hardness requirements of that application and the effect of temperature on hardness. However, most asphalts are not useful over wide temperature ranges. An asphalt which is suitable for use at low temperatures as would be found in areas which experience low sub-freezing winter temperatures, ordinarily would be too soft at high temperatures for use in areas where hot summer temperatures are common. Similarly, an asphalt which has a sufficiently high softening point temperature, and a satisfactory degree of hardness for use at high temperatures may have a degree of hardness approaching brittleness at low temperatures. Consequently, in an area where extreme temperature fluctuations are common, asphalt roads may be much too soft in the summer and may become so hard in the winter as to crack or breakup quite readily.

Clearly, it is desirable to obtain an asphalt which is useful over a wide range of temperatures, that is, an asphalt which has a sufficiently high softening point temperature with an operable penetration at the higher temperatures, but which does not become unduly hard at low temperatures, i.e., has a relatively large penetration ratio.

Another significant property for the characterization of asphalt is toughness-tenacity, which is a measure of the work input necessary to dislodge an imbedded, hemispherical head from an asphalt sample. In some uses of asphalt, particularly in road construction, particles such as gravel are imbedded in the asphalt and it is important in order to obtain satisfactory road wear that the gravel does not work itself loose. Therefore, it is desirable to obtain an asphalt that has a high degree of toughness-tenacity.

Many uses of asphalt require that the asphalt have substantial elasticity. Torsional recovery is a measure of elasticity of asphalt, and hence, is still another significant property.

Where an asphalt composition is incorporated into a rigid form, for example, to produce battery boxes, impact strength becomes an important property.

It is an object of this invention to provide an improved asphalt composition. Another object is to provide a modified asphalt which has a higher softening point temperature than a corresponding unmodified asphalt. Still another object is to provide a modified asphalt which has a larger penetration ratio than a corresponding unmodified asphalt. A further object is to provide a modified asphalt which has a higher softening point and a larger penetration ratio than a corresponding unmodified asphalt. A still further object is to provide a modified asphalt with a greater degree of toughness-tenacity than a corresponding unmodified asphalt. Also, another object is to provide a modified asphalt which has a greater degree of torsional recovery than a corresponding unmodified asphalt. An additional object is to provide a modified asphalt with a higher impact strength than a corresponding unmodified asphalt.

These and other objects are attained by a composition *comprising asphalt and dispersed therein 0.1–40% of an* ethylene/vinyl acetate copolymer based on the combined weight of said asphalt and copolymer, said copolymer containing 5–40% by weight of vinyl acetate.

The ethylene/vinyl acetate copolymers employed in this invention may be prepared by suitable methods familiar in the art. Thus, a process as shown in U.S.P. 2,200,429 or U.S.P. 2,703,794, for example, may be used. Copolymers containing 5–40% by weight vinyl acetate may be used in this invention. In some applications, particularly where more than 5% polymer is blended with asphalt, a vinyl acetate content of 27–33% in the copolymer is preferred. Vinyl acetate content of the copolymer may be determined by infrared analysis or by saponification number determination. The melt index of these copolymers does not appear to be a critical factor in the effectiveness of the copolymers to modify asphalt in accord with this invention. Thus, the readily prepared copolymers, for example, those having melt indices (ASTM Test Method D–1238–57T) in the range of about 0.5 to 1000 may be used.

The ethylene/vinyl acetate copolymers may be dispersed into asphalt in any suitable manner. Compositions containing relatively small amounts of copolymer such as 5% or less copolymer based on the weight of asphalt, may be prepared by blending at temperatures of about 300–330° F. using high-speed agitation for 20 to 30 minutes. Compositions containing larger amounts of copolymer may be more conveniently prepared by blending in a sigma blade mixer at about 300° F. for 30 to 40 minutes. Use of a powdered or finely granulated form of copolymer will reduce the required mixing time.

The ethylene/vinyl acetate copolymers used in this invention are completely compatible with asphalt in all proportions. The exact amount of copolymer to be blended with asphalt depends primarily upon the specific asphalt being modified and the ultimate use to which it will be coatings, crack and joint sealers, paper lamination and saturation compositions, sound deadeners and automotive undercoatings, and the like, 0.1–5% of copolymer based on the combined weight of the asphalt and copolymer will provide significant improvements in the properties of the asphalt, although at least 1% copolymer is generally preferred for such purposes. Other applications may require larger amounts of copolymer, especially where it is desired to make rigid structures, such as battery boxes, in which cases, up to about 40% copolymer, based upon the combined weight of the asphalt and copolymer, may be used. Larger amounts than 40% copolymer are compatible with asphalt, however for most uses 40% copolymer based upon the combined weight of asphalt and copolymer, is a practical upper limit.

Some of the improvements attained by modification of asphalt with an ethylene/vinyl acetate copolymers are illustrated by the following examples which are designed only to show some of the advantages of this invention and are not intended to limit the scope thereof.

In the following examples, the physical property data shown were obtained by the procedures indicated below:

(1) Softening point temperature was determined by ring and ball method provided by ASTM D28-51T;

(2) Penetration was determined by the procedure of ASTM D-5-52;

(3) Torsional recovery was measured by the following method: A bolt and disk assembly was suspended and centered by means of a notched spider in a standard 3-ounce seamless ointment can having a diameter of approximately 2 inches. The disk used had a diameter of 1.125 inches and was 0.375 inch thick. The melted asphalt sample was poured into the can until it was flush with the surface of the disk. The assembly was then conditioned at 77° F. for a minimum of 2 hours before testing. By means of wrench and locked nuts on the bolts, the disk was rotated through an arc of 180° relative to the sample container and released immediately. The angle of the recovery was measured after 30 seconds and 30 minutes and values of percent of recovery were recorded.

(4) Toughness-tenacity was determined by a method described by Benson in "Roads and Streets," April 1955, which essentially consists in determining the relation between applied load and elongation when a hemisphere of $\frac{7}{16}$ inch radius, embedded in a mass of asphalt, is pulled out at a constant rate of 12 inches per minute. The load first increases rapidly to a peak and then falls again as the sample forms a rope between the hemisphere and the body of the asphalt. The entire work (in inch-pounds) done upon the samples is the toughness; the tenacity is the work (in inch-pounds) done after the samples begin to resist further elongation.

(5) Izod impact strength was determined in accord with ASTM D-256, using a 3-pound hammer.

Example 1

This example shows the improvement in the physical properties of asphalt which is attained by modification thereof with an ethylene/vinyl acetate copolymer. Five different ethylene/vinyl acetate copolymers were blended with an $^{85}/_{100}$ penetration grade asphalt from Lagunillas crudes, in the proportion of 5 parts by weight copolymer to 100 parts asphalt, for each of 5 runs. The compositions were prepared by mixing at a temperature of about 300° F. for 30 minutes, continually agitating with a high-speed mixer. The resultant blends appeared smooth and homogenous. To provide a control for comparative analysis, an unmodified asphalt sample was also evaluated. Table 1 summarizes the data obtained.

TABLE 1

	Run					
	1	2	3	4	5	6
Character of Polymer [1]	(2)	(3)	(4)	(5)	(6)	(7)
Softening Point, ° F.	116	152	143	131	132	128
Penetration:						
77° F./100 gm./5 sec.	85	46	47	62	60	72
32° F./200 gm./6 sec.	26	24	24	27	26	39
Penetration Ratio	30.6	52.2	51.1	43.6	43.3	54.2
Tortional Recovery Percent:						
After 30 seconds	3	12	12	30	32	28
After 30 minutes	4	24	17	46	45	45
Toughness-Tenacity:						
Tenacity, in.-lbs.	2	0	0	19	7	38
Toughness, in.-lbs.	21	35	29	54	47	71

[1] Percent VA refers to the weight percent of vinyl acetate in the ethylene/vinyl acetate copolymer. MI refers to the melt index of the copolymer as determined by ASTM D1238-57T.
[2] Unmodified.
[3] 9% VA, 0.8 MI.
[4] 7% VA, 20 MI.
[5] 29% VA, 15.7 MI;
[6] 28.6% VA, 22.4 MI;
[7] 31.4% VA, 22.4 MI.

Table 1 clearly shows the significant improvements attained by modification of asphalt with an ethylene/vinyl acetate copolymer. In each run, the softening point temperature was raised considerably, and the penetration ratio was increased without adversely effecting the low temperature penetration. Hence, the asphalt modified as shown in Table 1 is useful over a much broader temperature range than the corresponding unmodified asphalt. Each modified asphalt in this example showed a significant increase in torsional recovery, indicating that the ethylene/vinyl acetate copolymers impart a greater degree of elasticity to asphalt. In addition, the copolymers increased the toughness-tenacity of the asphalt. Therefore, the asphalt modified as shown, has a greater retention of particles, such as gravel, imbedded therein.

Example 2

This example illustrates the improvements obtained by modifying asphalt with comparatively small amounts of an ethylene/vinyl acetate copolymer. In this example, two samples of the asphalt employed in Example 1 were modified with 1% and 3% respectively, of an ethylene/vinyl acetate copolymer, based upon the combined weight of the asphalt and copolymer. The copolymer had a vinyl acetate content of 9% and a 0.8 melt index. Table 2 shows the results achieved.

TABLE 2

	Run	
	[illegible]	[illegible]
Percent Copolymer Blended with Asphalt [1]	1%	3%
Softening Point, ° F.	122	131
Penetration:		
77° F./100 gm./5 sec.	67	50
32° F./200 gm./6 sec.	22	18
Penetration Ratio	[illegible]	[illegible]

[1] Based upon the combined weight of asphalt and copolymer.

The data shown in Table 2 establishes that even small amounts of an ethylene/vinyl acetate copolymer significantly improves the physical properties of asphalt.

Example 3

This example shows the effect of larger amounts of an ethylene/vinyl acetate copolymer on asphalt. The asphalt used in Example 1 was selected for evaluation. Different ethylene/vinyl acetate copolymers were blended with the asphalt in the proportion of 5 parts by weight copolymer to 15 parts asphalt, for each of 4 runs. The samples were prepared by blending in a sigma blade mixer at a temperature of 300° F. and for 30 minutes. A 5 to 10 minute additional mix cycle was needed during which vacuum was applied to remove entrained air. This last step was necessary in order to obtain "pinhole-free" test samples. Table 3 shows the results obtained. For convenience of reference, data for the unmodified asphalt of Run 1, Example 1, are reproduced in this table.

TABLE 3

	Run					
	1	9	10	11	12	13
Character of Polymer [1]	(2)	(3)	(4)	(5)	(6)	(7)
Softening Point, ° F.	116	215	220	165	160	165
Izod Impact Strength at 32° F.:						
Notched, Energy, ft. lb./in. of notch	(8)	0.18	0.17	0.16	0.19	0.29
Unnotched, Energy, ft. lb./in.	(8)	0.73	0.34	6.41	6.64	6.17

[1] Percent VA refers to the weight percent of vinyl acetate in the ethylene/vinyl acetate copolymer. MI refers to the melt index of the copolymer as determined by ASTM D1233-57T.
[2] Unmodified.
[3] 9% VA, 0.8 MI.
[4] 7% VA, 20 MI.
[5] 29% VA, 15.7 MI.
[6] 31.4% VA, 56 MI.
[7] 32.2% VA, 23.2 MI.
[8] Too low for accurate measurement.

As shown in Table 3, an asphalt containing about 25% of an ethylene/vinyl acetate copolymer which has a relatively small vinyl acetate content, has a much higher softening point temperature than a corresponding unmodified asphalt. The copolymers containing larger amounts of vinyl acetate not only raised the softening point temperature considerably, but in addition, produced a vast increase in impact strength.

The foregoing examples have shown the improvements that an ethylene/vinyl acetate copolymer produces in one particular asphalt, namely an $^{85}/_{100}$ penetration grade asphalt from Lagunillas crudes. However, this invention is not restricted to the modification of any one particular asphalt. This invention is applicable to all types of asphalt, either naturally occurring or derived from crude oils of various sources.

The following examples illustrate the effect of an ethylene/vinyl acetate copolymer in an oxidized asphalt, namely, a blown asphalt from Lagunillas crudes.

Example 4

This example demonstrates the improvements achieved in a blown asphalt by the addition thereto of an ethylene/vinyl acetate copolymer. Four different ethylene/vinyl acetate copolymers were added to the blown asphalt in the proportion of 5 parts copolymer to 100 parts asphalt. These compositions were prepared by blending at about 300° F. for 30 minutes with continuous agitation supplied by a high speed mixer, except that it was necessary to increase the temperature to about 329° F. in order to disperse the copolymer used for Run 16. All of the blends were smooth and well dispersed. The data obtained are tabulated in Table 4.

TABLE 4

	Run				
	14	15	16	17	18
Character of Polymer [1]	(2)	(3)	(4)	(5)	(6)
Softening Point, ° F.	190	244	241	236	230
Penetration:					
77° F./100 gm./5 sec.	21	21	25	22	22
32° F./200 gm./6 sec.	8	20	21	20	20
Penetration Ratio	38.1	95.3	84	90.8	90.8

[1] Percent VA refers to the weight percent vinyl acetate in the ethylene/vinyl acetate copolymer. MI refers to the melt index of the copolymer as determined by ASTM D1238-57T.
[2] Unmodified.
[3] 9% VA, 0.8 MI.
[4] 29% VA, 15.7 MI.
[5] 31.4% VA, 56 MI.
[6] 32.2% VA, 23.2 MI.

Table 4 clearly indicates that 5% of an ethylene/vinyl acetate copolymer added to a blown asphalt gives a large increase in the softening point temperature and a remarkable improvement in the penetration ratio.

Example 5

This example shows the improvements derived by the addition of relatively small amounts of an ethylene/vinyl acetate copolymer to a different blown asphalt than that used in Example 4. Two samples containing 1% and 3% respectively, based on the combined weight of asphalt and copolymer, of an ethylene/vinyl acetate copolymer having a 9% vinyl acetate content and a melt index of 0.8

were prepared by the procedure indicated in Example 4. The data obtained are shown in Table 5.

TABLE 5

	Run		
	19	20	21
Percent Copolymer Blended with Asphalt [1]	(2)	1%	3%
Softening Point, ° F.	182.5	191	212
Penetration:			
77° F./100 gm./5 sec.	22	19	17
32° F./200 gm./6 sec.	14	13	13
Penetration Ratio	63.7	68.4	76.4

[1] Based on the combined weight of asphalt and copolymer.
[2] Unmodified.

The data shown in Table 5 show the significant improvements attained in blown asphalt by the addition thereto of very small amounts of an ethylene/vinyl acetate copolymer.

Example 6

The unmodified asphalt used in Example 4 had an Izod impact strength of 0.12 ft.-lbs./in. A blend of 75 parts by weight of this asphalt and 25 parts of an ethylene/vinyl acetate copolymer containing 32.2% vinyl acetate and having a melt index of 23.2, was prepared by blending in a sigma blade mixer at about 300° F. for 30 minutes, followed by de-aeration with vacuum at 300° F. The resultant blend had an Izod impact strength of over 6.0.

As will be apparent to one skilled in the art, many widely different embodiments of this invention may be practiced without departing from the spirit and scope thereof. Therefore, it is to be understood that this invention is not limited except as defined by the appended claims.

I claim:

1. A composition comprising asphalt and dispersed therein 0.1–40% of an ethylene/vinyl acetate copolymer based on the combined weight of said asphalt and copolymer, said copolymer containing 5–40% by weight of vinyl acetate.

2. A composition comprising asphalt and dispersed therein 0.1–5% of an ethylene/vinyl acetate copolymer based on the combined weight of said asphalt and copolymer, said copolymer containing 5–40% by weight of vinyl acetate.

3. A composition comprising asphalt and dispersed therein 1–5% of an ethylene/vinyl acetate copolymer based on the combined weight of said asphalt and copolymer, said copolymer containing 5–40% by weight of vinyl acetate.

4. A composition comprising asphalt and dispersed therein 5–40% of an ethylene/vinyl acetate copolymer based on the combined weight of said asphalt and copolymer, said copolymer containing 27–33% by weight of vinyl acetate.

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THERMOPLASTIC RUBBER COMPRISING ETHYLENE-VINYL ACETATE COPOLYMER, ASPHALT AND FLUXING OIL

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U.S. Cl. 260—28.5 1 Claim

ABSTRACT OF THE DISCLOSURE

A thermoplastic rubber is made from a mixture of between about 10% and about 50% of asphalt, between about 5% and about 30% fluxing oil, and between about 35% and about 70% of a copolymer of polyethylene and vinyl acetate.

The invention described herein was made in the performance of work under NASA contract and is subject to the provisions of the National Aeronautics and Space Act of 1958, Public Law 85–568 (72 Stat. 426; 42 U.S.C. 2451), as amended, and is a continuation-in-part of my copending application Ser. No. 508,864 filed Nov. 19, 1965, now abandoned.

This invention relates to a thermoplastic rubber compound which is easily molded or extruded into different shapes and objects, applied as a lining metal to concrete water tanks, swimming pools, as a sealant for coating or filling cracks in asphalt and concrete roads, especially where low temperature is a problem, and as a coating material such as for ships, soil and water tanks.

Briefly, this invention is a mixture of asphalt, a fluxing oil, and a copolymer which includes linear chains of methylene groups and polar side groups. The thermoplastic rubber of this invention has a very low glass-transition temperature. For example, it does not become brittle below 0° F. It has a softening point usually above about 160° F., and there is no exudation of blended ingredients at any temperature. There is good diffusion and evaporation of volatile light hydrocarbon solvents from it without the formation of pores. It is easily prepared and inexpensive. It can also be easily added to different formulations to enhance their properties.

Linear polymers without polar side groups, such as the well-known thermoplastic resin, polyethylene, has been mixed with petroleum products, but by itself it does not have good compatibility with petroleum oils such as fluxing oil or kerosene. The polyethylene is mixable with the oil at a high temperature, say 350° F., but on cooling, exudes a large proportion of the oil.

I have found that the addition of bulky side groups to the linear polymers makes the polymers completely compatible with petroleum products such as fluxing oil and asphalt which contains asphaltenes. Preferably, the bulky side groups are polar and include sulphur and oxygen. Examples of copolymers which provide the linear chain of methylene groups and the polar side groups are ethylene and vinyl acetate, ethylene and methyl acrylate, ethylene and methyl methacrylate. Various homologs of ethylenes, such as propylene, butene, pentene, and butadiene can be substituted for the ethylene. Apparently the polar groups on the linear chain interlock with the polar groups naturally occurring in the asphaltene to form a tough rubber-like compound which sticks tenaciously to all dry and roughened surfaces except Teflon (polytetrafluoroethylene). The presence of the fluxing oil gives the material

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a softening or melting point below about 200° F. so it can be melted and cast at a reasonably low temperature. Acetoxy groups are formed when ethylene is copolymerized with vinyl acetate forming a copolymer of ethylene and vinyl acetate. Ester side groups are formed when ethylene is copolymerized with methyl acrylate, methyl methacrylate, or the like. Methyl groups in the acetoxy and ester groups can be replaced by homologs such as ethyl, propyl or butyl groups.

Polyethylene containing some polyvinylacetate as a copolymer shows excellent compatibility with oil and asphalt at 250° F. to 350° F. in various proportions. Moreover, on cooling, the result is a tough thermoplastic elastomer which does not exude oil or asphalt; under certain circumstances, however, traces of oil and/or asphalt may be exuded. The elastomer also retains good tensile strength and elongation in the temperature range from −50° F. to 150° F. At temperatures below −50° F., the elastomer becomes hard but not brittle. In the preferred form of the invention, the polyethylene contains between about 20% and about 30% by weight of vinyl acetate as a copolymer, and the copolymer is present in the amount of about 30% to about 70% by weight. The fluxing oil is present in the amount between about 4% and about 50% by weight, and the asphalt between about 10% and about 65% by weight.

These and other aspects of the invention will be more fully understood from the following examples and detailed description.

EXAMPLE 1

A typical composition of the thermoplastic rubber was made by mixing 2.7 pounds of ethylene-vinylacetate copolymer containing 23.8% polyvinylacetate with .9 pound of steam-refined asphalt of ductility at 77° F. at 150 centimeters, and 1.5 pounds of kerosene having a specific gravity of 0.79. The copolymer of ethylene and vinyl acetate was blended with the kerosene and asphalt at approximately 250° F. until thoroughly mixed. The mixture was then cooled and cast into open containers. The cast product had a glass-transition temperature below −60° F. and a softening point about 200° F. There was no exudation of blended ingredients at any temperature.

EXAMPLE 2

A thermoplastic rubber was prepared by mixing the same ingredients in the same proportions as given in Example 1 but adding to it 4.5 parts by weight of normal hexane. All of the ingredients of Example 1 were heated with the solvent in a reflux condenser for two to three hours until a homogenized mixture was obtained. The mixture was then cooled and sprayed with air on to wooden and metallic surfaces. Addition of the solvent facilitates using the elastomer in various coating applications.

EXAMPLE 3

Another typical composition of the thermoplastic rubber was made by mixing 0.9 pound of semisolid steam-refined asphalt of ductility at 77° F. greater than 150 centimeters, and 0.1 pound of fluxing oil, which was a heavy hydrocarbon oil of 0.945 specific gravity and viscosity at 210° F.—70 S.S.U. obtained from the distillation of crude oil. To the above mix 1.0 pound of copolymer of 72% by weight of ethylene and 28% by weight of vinyl acetate. The copolymer was in the form of pellets 1/16 to 1/8 inch in size. Blending was achieved by leaving the entire mix in a 250° F. electric oven overnight and mixing it vigorously next morning. After cooling to room temperature a thermoplastic rubber was achieved.

EXAMPLE 4

A thermoplastic rubber composition was made by mixing 10 pounds of steam-refined asphalt with 1.5 pounds of fluxing oil, both as in Example 3, and 11.5 pounds of a copolymer of ethylene and propylene. Blending was achieved by leaving the entire mix in a 275° F. electric oven over night and mixing it vigorously next day at the same temperature. After cooling to room temperature a a thermoplastic rubber was achieved.

EXAMPLE 5

A thermoplastic rubber composition was made by mixing 12 pounds of steam-refined asphalt of ductility at 77° F. of 100 centimeters, 1 pound of fluxing oil, as in Example 3, and 7 pounds of linear polyethylene, containing 25% by weight of pendent vinyl acetate groups. Blending was achieved by preheating the mix to 250° F. and mixing it vigorously at the same temperature. After cooling to room temperature a thermoplastic rubber was achieved, which was, however, softer than the one in Example 4.

EXAMPLE 6

A thermoplastic rubber composition was made by blending 5 pounds of steam-refined asphalt with 0.5 pound of fluxing oil, and with 10 pounds of a copolymer of ethylene and vinyl acetate at 275° F. and afterwards cooling the blend to room temperature. All raw materials were the same as in Example 4. The thermoplastic rubber was much stronger and harder than the product of Example 4.

EXAMPLE 7

A thermoplastic rubber composition was as in Example 5, except kerosene was substituted for the fluxing oil. The product had good physical properties at low temperatures.

EXAMPLE 8

Thermoplastic tiles were made by casting at 270° F. the molten thermoplastic rubber prepared in Examples 1 through 5 into a horizontal mold 6 inches x 6 inches x ½ inch lined with Teflon. The mold and the thermoplastic rubber were held over night in an electric oven kept at 270° F. Next day the mold was removed and submerged in cold water to cool quickly the mold and the product. The product, a flexible, black tile, was easily removed from the mold because the thermoplastic rubber does not adhere to Teflon.

EXAMPLE 9

Another thermoplastic rubber tile was prepared as in Example 8 except a steel-wire screen 18 mesh (made of 0.025 inch wire) with 0.03 inch openings was embedded in the molten rubber. The product was much less flexible but of much greater tensile strength.

EXAMPLE 10

A thermoplastic rubber rod of ¾ inch diameter was prepared by extrusion at 250° F. of the molten thermoplastic rubber of Example 3 under pressure into cold water where it congealed.

EXAMPLE 11

Thermoplastic rubber ⅛ inch pellets were prepared by extruding molten thermoplastic rubber of Example 3 at 240° F. under pressure through a ⅛ inch opening and cutting the congealed, continuous, thin rod into ⅛ inch lengths.

EXAMPLE 12

A thermoplastic ruber strip 5 inches wide x ⅜ inch thick was prepared by extruding the molten thermoplastic rubber of Example 3 at 250° F. under pressure into cold water where it congealed. The above strip was reheated on the top surface with infrared heat so that it became tacky. The tacky surface was then covered with crushed white stone to form a white surface. The bottom surface was then reheated and in a tacky condition was applied to a concrete road and an asphalt road to form a dividing white line on each road.

EXAMPLE 13

A strip as in Example 12 was made tacky by heat and covered with ground glass to form a white road line which reflects car lights at night.

EXAMPLE 14

A strip as in Example 12 was laid cold on a preheated concrete and an asphalt road. After rolling the strip adhered to the roads, the strips were then sprinkled with *hot* white sand or white crushed stone, which was then rolled so it adhered very strongly to the thermoplastic strip. Other colors, such as yellow, can be used. An antiskid highway or runway can be prepared the same way.

EXAMPLE 15

Thermoplastic pellets from Example 11 were mixed with crushed stones (aggregates) and spread on an even surface, simulating a road substratum. Heat was then applied from top in order to melt the thermoplastic pellets. A cold asphalt-water emulsion was then placed on top of the thermoplastic-aggregate layer to provide a leveling medium (after the evaporation or running off the water). A simulated durable road surface was then achieved.

EXAMPLE 16

Cracks in an asphalt road, a concrete road, and in a tennis court were filled with finely divided dense-grade aggregates, followed by the molten thermoplastic rubber of Example 3, and topped with sand. Effective and durable patching with this combination was achieved.

EXAMPLE 17

A strip prepared like in Example 12 but only ¼ inch thick was first made tacky on the bottom and laid on top of a leaky roof. Then the top of the strip was made tacky and covered with dense-grade aggregate to provide an effective and durable roof patching with this sealant.

EXAMPLE 18

Holes at the apex of a leaky roof were covered as in Example 17 with the exception that the thermoplastic strip was pre-heated and bent to make it fit the V-shaped apex.

EXAMPLE 19

A cubical water tank was made by taking five ¼ inch square strips of the thermoplastic rubber of Example 3 and joining their ends simply by heating these ends with an infrared heater. The tank was impervious to water and algae which did not grow on the walls.

EXAMPLE 20

The water tank of Example 19 was painted with ordinary paints to the desired color. Small ceramic tiles were embedded two inches from the top on all sides simply by warming the thermoplastic rubber walls with an infrared heater to make them tacky and sticking the ceramic tiles on.

EXAMPLE 21

A letter was sealed by taking a chunk of thermoplastic rubber and heating it over a match (or candle) until the end of the thermoplastic rubber melted (and was slightly burning) and was dripping on the letter. A metallic seal was then wetted with water (or saliva) and impressed on the tacky or semi-liquid rubber.

EXAMPLE 22

A thermoplastic rubber strip was prepared, as in Example 12, except that the top tacky surface was covered with sawdust and that the bottom surface was not made tacky. Several of such strips were heated (by infrared) at the ends and joined to make a wider and longer portable surface for children's playground and for sport events (like tennis courts, running tracks, etc.).

EXAMPLE 23

A weather proof highway is built by sandwiching a thermoplastic rubber sheet about ¼ inch thick made in accordance with Example 3 and reinforced with a metal screen of about 18 mesh (1 millimeter openings) between layers of a conventional asphalt highway or street. In a typical highway, a subgrade material is disposed on the earth and covered by a coarse aggregate base, which is in turn covered by an asphalt concrete binder with a coarse aggregate base, which is in turn covered by an asphalt concrete binder with a coarse aggregate in it. The reinforced thermoplastic rubber sheet of this invention is placed on top of the asphaltic concrete binder, and then covered with the conventional asphaltic cement surface to a depth of about 1½ inches. In the past, the asphaltic surface has tended to crack so that water penetrates it. The water freezes, expands, and opens the cracks so that water can percolate down through the surface and wash out the underlying support. The layer of thermoplastic rubber in accordance with this invention prevents the penetration of water to the road base, and preserves the road even though the surface is open by cracks.

For the purpose of this invention, the term "fluxing oil" is used to mean a heavy hydrocarbon petroleum distillation product generally having a boiling point between about 150° F. and about 500° F., and having between about six and about thirty carbon atoms per molecule. The asphalt which can be used with the fluxing oil is the conventional asphaltic residue in a petroleum still.

The volatile solvent used in diluting the thermoplastic rubber includes compounds such as pentane, hexane, and heptane, and generally has a boiling point between about 96° F. and about 212° F.

The copolymer of ethylene and vinyl acetate is preferably present in the thermoplastic rubber in the amount of about 53%, but can vary between about 30% and about 70%. The product loses its strength if the copolymer is much less than 30%, and does not have the desired resiliency if the copolymer is more than about 70%. Preferably the copolymer has a molecular weight greater than about 2000, and a crystallinity less than about 40%.

Between about 20% and about 30% polyvinylacetate in the copolymer is required for the desired properties. If the vinyl acetate is much below this range, the product does not have the desired resiliency. If the vinyl acetate is much more than about 30% of the copolymer, the product has less than the desired strength.

The fluxing oil or kerosene can be varied between about 5% and about 50%. If it is less than about 5%, the product does not have the desired resiliency, and if it is more than about 50%, the product is lacking in the desired strength. Asphalt is added to the thermoplastic rubber composition in the amount between about 10% up to about 60% by weight to combine with the resin and produce the tough rubber-like composition of this invention.

The advantageous characteristics of the thermoplastic elastomer of this invention are:

(1) It has a very low glass-transition temperature below (0° F.);
(2) It has a softening point above 200° F.;
(3) It has no exudation of blended ingredients at any temperature;
(4) It has good diffusion and evaporation of light volatile hydrocarbon solvents from the elastomer without the formation of pores;
(5) It has low cost;
(6) It has ease of preparation of different formulations;
(7) It has ease of addition of various fillers;
(8) It has ease of molding and extrusion of different objects;
(9) It is easily applied as a liner or coating to concrete tanks and swimming pools, and as a sealant for filling cracks in asphalt and concrete roads, especially where low temperature is a problem; and
(10) It can be sprayed with or without volatile solvents by a stream of hot or cold pressurized air or other gases or vapors. Thus a soil may be stabilized to prevent dust and mud, and the hulls of boats and ships may be covered with a protective layer of this material to prevent corrosion and organic growth.

I claim:

1. A thermoplastic rubber comprising a mixture of a copolymer of ethylene and vinyl acetate in which the vinyl acetate is present in the amount between about 20% and about 30% by weight of the copolymer, asphaltic residue from a petroleum still, and hydrocarbon petroleum distillation product having a boiling point between about 150° F. and about 500° F. and having between about six and about thirty carbon atoms per molecule, the copolymer being present between about 35% and about 70% by weight of the mixture, the copolymer having a molecular weight greater than about 2000, and a crystallinity less than about 40%, the asphaltic residue being present between about 10% and about 50% by weight of the mixture, and the petroleum product being present in the amount between about 5% and about 30% by weight of the mixture.

References Cited

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2,783,162	2/1957	Mollring	106—278
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969,169	9/1964	Great Britain.
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ALLAN LIEBERMAN, Primary Examiner

U.S. Cl. X.R.

260—33.6

EXHIBIT VI

GP(73-42010) February 7, 1973

MEMORANDUM

TO: KT/Deputy Director, Technology Utilization Office

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Du Pont's Offer to License under Adelman U.S. patent N-. 3,442,841 for Thermoplastic Rubber

The enclosed January 24 letter from Mr. Szanto indicates that Du Pont will license others under the subject patent when such licensees purchase the copolymer Elvax from Du Pont. It is suggested that copies of this letter be forwarded to your contractors, SRI and PTI, to advise them of Du Pont's offer. Keep in mind, however, that the experimental work being conducted under the contracts with SRI and PTI is considered to be a non-infringing use of the Adelman invention and there is no need for a license from Du Pont to cover this experimental use for NASA. Mr. Szanto was advised on this point during our recent telecon and he understands that it will not be NASA or our contractors who will be seeking such a license, but potential suppliers of thermoplastic rubber. Of course, if SRI and PTI go beyond the scope of our contracts and actually produce thermoplastic road-patching material for non-experimental use, then they may need to consider the Du Pont offer of a license.

Mr. Szanto, in his letter, indicates Du Pont licenses others in two different arrangements, and perhaps the following will help you understand their approach to licensing such products as Elvax. As noted above, Elvax is Du Pont's trade name to an unpatentable copolymer of ethylene-vinyl acetate. The Du Pont-owned patent to Adelman, however, is directed to a mixture of Elvax with asphalt and if one were to purchase Elvax from Du Pont, such purchase does not license you to mix Elvax with asphalt as taught by the Adelman patent. Therefore, Du Pont states that under one arrangement they will license anyone under reasonable terms (probably a nonexclusive, royalty-bearing agreement) to practice the invention claimed in the Adelman patent if a small amount of Elvax is purchased for this purpose. This would mean that each purchaser of Elvax would have to pay, in addition to the purchase price of Elvax, a royalty if it is mixed with asphalt as claimed by Adelman.

The other type of license mentioned in the letter includes a paid-up license under the Adelman patent as part of the purchase price. This license is available when the volume of Elvax purchased is sufficient. Du Pont calls this a "label license," as the label on the container of Elvax would note the grant of the license under patent 3,442,841.

If your office or your contractors have questions regarding this offer from Du Pont, I will try to answer or contact Mr. Szanto for you. Mr. Szanto has been requested to advise us if they are ever able to identify the use of their thermoplastic material in Europe as a road-patching material.

John H. Warden
Office of Assistant General
Counsel for Patent Matters

2 Enclosures

JHW:lmg

EXHIBIT VII

GP(73-42009) February 7, 1973

Mr. Ivan G. Szanto
Legal Department
E.I. Du Pont De Nemours & Company
Wilmington, DE 19898

Subject: Du Pont's Offer to License U.S. Patent 3,442,841

Dear Mr. Szanto:

Thank you for your letter of January 24, 1973, wherein you confirmed our earlier telephone conversation that Du Pont would license others on reasonable terms to practice the invention claimed in the Adelman U.S. Patent No. 3,442,841 when such other parties purchased the copolymer of ethylene-vinyl acetate sold under your trademark, Elvax. NASA appreciates your offer and will forward copies of your letter to our contractors who are conducting experiments to determine if the mixtures of the copolymer and asphalt set forth in the Adelman patent and/or the Hendel patent (No. 3,527,724) will meet the requirements of a road-patching material.

Enclosed is the material I promised you during our telecon. The enclosed Hendel patent is to an invention made by Dr. Hendel of Caltech when he was working under the NASA contract for the operation of the Jet Propulsion Laboratory in Pasadena, California. Although NASA owned all rights to the invention, title to this invention has been waived to Caltech reserving a license to the Government. You will note the main distinction between Hendel's invention and Adelman's invention is the addition of a hydrocarbon petroleum distillation product (fluxing oil) to the mixture of the copolymer and asphalt.

The other two enclosures are technical papers or reports prepared by our contractor, Stanford Research Institute, which discloses the results of our experimental work with thermoplastic materials as an improved road-patching material. You will note that the copolymers used in all of these experiments were Du Pont's ethylene-acetate resins Elvax.

Thank you for your quick response to our inquiry. Also, if you become aware of the European country or organization that has used Elvax/asphalt blends as a sealer between concrete slabs or roadways, we would appreciate being advised.

Sincerely,

John H. Warden
Office of Assistant General
Counsel for Patent Matters

3 Enclosures

cc: KT/L. Mogavero

GP/JHW:lmg

EXHIBIT VIII

STREET PATCHING QUESTIONNAIRE

Please complete the following questions and return to Public Technology by 29 May, 1973. A self-addressed envelope is provided for your convenience. Please provide data for most recent year, unless question requests multi-year data.

1. What is your approximate annual use of street patching material? Please refer only to pothole or chuckhole patching; not to resurfacing or skin-patching. If more than one grade of material is used, please provide data for all.

Material	Annual Quantity	Annual Cost	Current Supplier
Asphalt (Penetration)			
________			
________			
________			
Aggregate (Size & Composition)			
________			
________			
________			
Pre-Mix (Hot-Mix) (Asphalt pen. & agg. size)			
________			
________			
________			
Pre-Mix (Cold-Mix) (Brand Name)			
________			
________			
________			

2. How are your materials purchased? For example, asphalt purchased from hot-mix plant, premixed with aggregate, and bought on basis of lowest sealed bid, etc.

____

____

____

3. Do your street-patching materials purchases vary appreciably from year to year? If so, why?

4. Do procurement specifications exist for your street-patching materials procurement? If so, are they adopted from state or county specifications; or are they locally generated? How stringent are these specifications; how rigorously followed?

5. If possible, we would appreciate receiving a copy of the specifications that you use to purchase street-patching materials.

6. What equipment do you maintain or use that is required for street-patching operations? (Exclude items under $50 each).

Number	Type	Est. Replacement Cost/Unit
______	Heater Trucks	$ ______
______	Insulated Bed Trucks	______
______	Flatbed Trucks	______
______	Heavy Rollers	______
______	Tailgate Heater/Mixers	______
______	Vibratory Plate Compactors	______
	Others:	

7. What is your estimated annual cost (operating, maintenance, and amortization) of equipment used for street-patching operations?

	Hourly Rate (Optional)	Annual Hours (Optional)	Total Annual Cost of Equip.
Vehicles (List Type)			
Other Equipment (Heaters, Compactors, rollers, etc.) (List Type)			

8. What is your estimated annual cost of labor used for street-patching operations?

Cost of Labor, plus Overhead $ ______________

Cost of Supervision associated directly with street-patching $ ______________

9. In the following question, please describe the important elements in your street-patching operation. If possible, please indicate areas that could be affected by the use of an improved patching material, or could result in savings.

a. Number and size of crews:

____

____

____

b. Winter vs. summer procedures; temporary patch in winter followed by permanent patch replacement in summer, etc.

c. Storage criteria and cost, on other special materials handling problems.

d. Others:

SECTION IX:

APPENDICES

APPENDIX A

FIELD TEST APPLICATIONS

To properly evaluate the performance of EVA resin-modified asphalt patching compositions test applications under field conditions are necessary. To this end, applications were conducted in Burbank, California, South Lake Tahoe, California, and Anchorage, Alaska. These latter two sites were chosen for the severe freeze/thaw temperature variations that occur.

At each test site, dish-shaped holes 16"-18" (41-45cm) in diameter by 4"-6" (10-15cm) in depth were cut into existing pavement in the wheel track. These potholes were then swept free of debris in a cursory manner. Some were left dry, some dry but with the primer applied to the sides, and others were wet down with water and the excess swept out and the remainder wet down with water and then primed. Thus, four basic types of potholes were filled at each site. The materials used at each site were aggregate-filled patching compositions using the 20% weight modification of 85-100 penetration asphalt with Elvax®150 and with Elvax 420 as the binder. Thus, two different patching compositions were tested in four different types of holes.

At Burbank and at South Lake Tahoe, California, additional holes of the four types were patched using a layering technique consisting of pouring alternate 2" (5cm) layers of aggregate, either hot or cold, and 1/4"-3/8" (0.63-0.95cm) of hot binder of the two types mentioned previously.

At each test site, a number of holes were patched using materials and techniques that were customary for the individual public works departments. These patches were put down at the same time under the same conditions, as nearly as possible and were used as controls.

The premixed aggregate/binder compositions were supplied cold in five-gallon pails and had to be heated to 275° to 325°F (135° to 163°C), ideally, before applying. The same requirement held for the straight binder that was supplied in one-gallon cans for the layering techniques of patching.

The actual application of the materials was accomplished in much the same manner at each site. Only the methods of heating the materials differed significantly. In Burbank, the pails were heated to 325^{o}F in a large walk-in oven and transported under blankets to the site while cans of binder were heated to the same temperature at the laboratories of Products Research and Chemical Corporation and transported separately as needed. At South Lake Tahoe, conditions were somewhat different. The best piece of equipment available was an asphalt hot mix transport truck equipped with an electric and propane heated recirculating oil bed heater box. The rate of heat transfer to the material within the pails inside the heater box proved very slow. The premixed material was finally brought up to application temperature at the site by charging two pails of the material at a time to two propane-fired open top oil drum heaters and mixing continuously by hand with a shovel to avoid scorching the material. Cans of binder were heated by placing them with the aggregate for the layering approach into the drum heaters and heating them both together. At Anchorage, Alaska, great hopes were placed in a large electric oven made available at the U.S. Army Corps of Engineers Soils Laboratory at Elmendorf Air Force Base. This heating device, too, proved vexingly slow. The premixed material was finally heated by lowering the pails into a vat of hot asphalt at 400^{o}F that was part of a truck-mounted small asphalt hot-mix plant. This last method is not recommended.

At each site, the premixed material, when heated to application temperature, was put down in 2" (5cm) courses and hand-temped until the hole, which was prepared previously, was filled. The top surface was then finished off by passing a heated roller across it a few times. The material based on Elvax 420 proved to be more free-flowing and granular in nature when hot than the Elvax 150-based material, which had a tendency to form lumps and clots. As a result, the former was easier to apply than the latter. No significant differences between the handling and application characteristics of the two binders were observed when holes were patched using the layering technique described earlier.

Hole #	Hole Type	Patch Comp	24 hrs*	48 hrs*	1 week*	2 weeks*	1 month*	2 months
1	Wet w/ Primer	Elvax® 420 Premix @ 285°F (141°C)	N/C	N/C	N/C	N/C		
2	Wet w/o Primer	" " " @ 290°F (143°C)	N/C	N/C	N/C	SER		
3	Dry w/ Primer	" " " @ 285°F (141°C)	N/C	N/C	N/C	N/C		
4	Dry w/o Primer	" " " @ 280°F (138°C)	N/C	N/C	N/C	SER		
5	Dry Layer w/ Primer - cold Agg.	" " " @ 280°F (138°C)	N/C	N/C	SD	E&H		
6	Dry Layer w/o Primer - hot Agg.	" " " @ 280°F (138°C)	N/C	N/C	SD	SB		
7	Wet w/ Primer	Elvax® 150 Premix @ 285°F (141°C)	N/C	N/C	N/C	N/C		
8	Wet w/o Primer	" " " @ 285°F (141°C)	N/C	N/C	N/C	N/C		
9	Dry w/ Primer	" " " @ 290°F (143°C)	N/C	N/C	N/C	N/C		
10	Dry w/o Primer	" " " @ 290°F (143°C)	N/C	N/C	N/C	N/C		
11	Dry Layer w/ Primer - cold Agg.	" " " @ 280°F (138°C)	N/C	N/C	D	HB		
12	Dry Layer w/o Primer - hot Agg.	" " " @ 280°F (138°C)	N/C	N/C	D	SB		
13	Dry Layer w/ Primer - cold 3/8" rocks	" " " @ 280°F (138°C)	N/C	N/C	SR	P		
14	Standard hot mix	" " "	N/C	N/C	N/C	N/C		
15	Standard hot mix	" " "	N/C	N/C	N/C	N/C		

Average Temp
* H=71°F L=54°F
(22°C-12°C)

N/C = No Change
ER = Edges ravelling
SR = Surface ravelling
D = Dishing
B = Bleeding
P = Push out at edge
H = Heavy
S = Slight

TABLE X. RESULTS OF FIELD TEST APPLICATION AT BURBANK, CALIFORNIA

Appendix A
contd.

Hole #	Hole Type	Patch Comp	Appearance 24 hrs*	48 hrs*	1 week*	2 weeks*	1 month*	2 months
1	Wet w/ Primer	Elvax® 420 Premix @ 270°F (132°C)	N/C	SSR-SER				
2	Wet w/o Primer	" " " @ 280°F (138°C)	N/C	SSR-SER				
3	Dry w/ Primer	" " " @ 280°F (138°C)	N/C	SER				
4	Dry w/o Primer	" " " @ 275°F (135°C)	N/C	SER				
5	Dry Layer w/ Primer -- hot Agg.	" " " @ 240°F (116°C)	N/C	HSR				
6	Dry Layer w/o Primer --hot Agg.	" " " @ 240°F (116°C)	N/C	HSR-SER				
7	Wet w/ Primer	Elvax® 150 Premix @ 300°F (149°C)	N/C	N/C				
8	Wet w/o Primer	" " " @ 300°F (149°C)	N/C	SER				
9	Dry w/ Primer	" " " @ 290°F (143°C)	N/C	N/C				
10	Dry w/o Primer	" " " @ 290°F (143°C)	N/C	SER				
**11	Dry Layer w/ Primer -- hot Agg.	" " " @ 220°F-200°F (104°C- 93°C)	N/C	HSR				
12	Dry Layer w/o Primer -- hot Agg.	" " "	N/C	HSR				
13	Standard hot mix	-----						

* Average Temp H=51°F L=27°F (12°C- -3°C)

**Poor patching job

N/C = No change
ER = Edges ravelling
SR = Surface ravelling
D = Dishing
B = Bleeding
H = Heavy
S = Slight

TABLE XI. RESULTS OF FIELD TEST APPLICATION AT SOUTH LAKE TAHOE, CALIFORNIA

Hole #	Hole Type	Patch Comp	24 hrs*	48 hrs*	1 week*	2 weeks*	1 month*	2 months
1	Wet w/o Primer	Elvax® 420 Premix @ 265°F (129°C)	N/C	SER	SER	SER	SER	
2	Wet w/ Primer	" " " @ 265°F (129°C)	N/C	SER	SER	SER	SER	
3	Dry w/o Primer	" " " @ 265°F (129°C)	N/C	SER	SER	SER	SER	
4	Dry w/ Primer	" " " @ 265°F (129°C)	N/C	N/C	SER	SER	SER	
5	Wet w/o Primer	Elvax® 150 Premix @ 300°F (149°C)	N/C	N/C	N/C	N/C	N/C	
6	Wet w/ Primer	" " " @ 280°F (138°C)	N/C	N/C	N/C	N/C	N/C	
7	Dry w/o Primer	" " " @ 290°F (143°C)	N/C	N/C	N/C	N/C	N/C	
8	Dry w/ Primer	" " " @ 290°F (143°C)	N/C	N/C	N/C	N/C	N/C	
9	Standard hot mix	-----	---	---	---	---	---	

Average Temp
* H=47°F L=34°F
(8°C-1°C)

N/C = No change
ER = Edges raveling
SR = Surface ravelling
D = Dishing
B = Bleeding
H = Heavy
S = Slight

TABLE XII. RESULTS OF FIELD TEST APPLICATION AT ANCHORAGE, ALASKA

The performance results of the test patches at each site were monitored and evaluated. Tables X, XI, and XII present the results of one to two month's testing. As can be seen, the durability of Elvax 420-based premixed patches seems less than that of the Elvax 150-based premixed patches, which, in turn, are about equal to the controls. This trend seems more pronounced at the sites with low prevailing temperatures. The chief mode of deterioration is that of edge and surface ravelling. Only continued testing will reveal if this deterioration will continue or if it will stabilize. In addition, it is apparent that the use of a primer contributes significantly to the durability of the patch, whether wet or dry holes were filled.

The layered holes at South Lake Tahoe and especially at Burbank, California, are not doing well. Holes filled using dense graded aggregate are dishing and becoming concave and exhibiting signs of bleeding. Holes filled with coarse, self-locking aggregate are not dishing nearly as much but do suffer from bleeding. The high ambient temperatures at Burbank seem to promote both effects more than the low ambient temperatures of the other sites.

Supplemental field testing was done by the Public Works Department of the City of Burbank. This testing consisted of using the two standard binders and a binder consisting of a 20% weight modification of 40-50 penetration asphalt with Elvax 420 as a crack filler. Both dry cracks and cracks wet with water were filled with each material, dusted off with sand, and opened to traffic immediately. The initial adhesion to wet cracks was not good but by the next day, it was excellent for all materials. After approximately one month's testing, the 20% weight modification of 40-50 penetration asphalt with Elvax 420 continues to perform well. The standard Elvax 420 binder is satisfactory over cracks that were dry when filled but is opening up along the length of the crack that was wet when filled. The standard Elvax 150 binder has failed over both wet and dry cracks.

In addition to crack filling, an experimental heater/mixer was evaluated. This device is a small concrete mixer fitted out with a ring of propane burners around the bottom. In one experiment, aggregate was charged to the heater/mixer and within a half hour or so, the temperature was 300°F (149°C). Preheated binder was then charged to the hot aggregate and mixed with it until uniform and of good appearance, a process which required seven to ten minutes time. A rectangular saw-cut hole 1' x 2' x 1/2' (30 1/2 cm x 61 cm x 15 cm) was patched with the freshly made material using techniques described earlier.

Another experiment was conducted using the heater/mixer to bring up to application temperature the standard Elvax 150-based premixed material. This material was first crushed in a press to reduce it to small lumps and then charged to the mixer. The time required to reach 300°F was on the order of one hour, which is almost twice as long as the aggregate alone. The large size of the lumps (approx. 2" or 5cm) may well have impeded the heat transfer. A hole identical to the first one was filled with the material using the same techniques.

APPENDIX B

THERMOPLASTIC STREET MAINTENANCE MATERIAL

USER DESIGN COMMITTEE MEETING REPORT
SOUTH LAKE TAHOE, CALIFORNIA
JUNE 21-22, 1973

The User Design Committee concerned with the development of an all-weather thermoplastic street patching material convened in South Lake Tahoe to discussthe results of the field tests to date, and to determine the proper course of action to be pursued in the future. Attending this meeting were:

Mr. Ed Aeck, Department of Public Works, Burbank, California

Mr. Joseph Amstock, Vice President, Products Research and Chemicals Corp., Burbank, California

Mr. Richard Anderson, Assistant Manager, City of Ft. Lauderdale, City Hall, Ft. Lauderdale, Florida

Mr. Joseph N. Baker, City Manager, City of Burbank, City Hall, Burbank, California

Mr. Roy Bivins, NASA TU, Washington, D.C.

Mr. Ed Brauner, Public Works Foreman, South Lake Tahoe, California

Mr. Keith C. Brinker, Technical Supervisor, ELVAX Vinyl Resins, Dupont Corporation, Wilmington, Delaware

Mr. Edward Clarke, Superintendent of Streets, Department of Public Works, City of Burbank, City Hall, Burbank, California

Mr. John T. Frawley, Public Services Director, City of Bangor, City Hall, Bangor, Maine

Mr. Bob Gallaway, Texas Transportation Institute, College Station, Texas

Mr. Robert Griffin, Boeing Construction Co., Seattle, Washington

Mr. Carl Kay, Senior Chemist, Products Research and Chemicals Corp., Burbank, California

Mr. Ed Koonce, Manager, Maintenance and Operations Division, City of Anchorage, City Hall, Anchorage, Alaska

Mr. Charles H. McDonald, Department of Engineering, Materials Testing Section, Phoenix, Arizona

Mr. John A. Teipel, Director, Department of Streets and Sanitation Services, City of Dallas, City Hall, Dallas, Texas

As a summary statement of the meeting, it was clear that all User Design Committee members present, and industrial representatives, felt that the directions taken to date were satisfactory, and that a potentially superior material for street patching operations has been developed. What remains is to optimize some of the technical parameters to further prove the material in high-stress applications and to more definitively assess the cost benefit characteristics of implementation.

Following the introductory statements, and a summary of program developments to date, Mr. Ed Clarke of Burbank presented a report of the thermoplastic street patching experiment which was held in Burbank as a result of earlier User Design Committee meetings, and decisions on techniques of field test applications procedures. A copy of that report is attached for your information. The Committee felt that Mr. Clarke's observations and conclusions were valid and very well presented.

The Committee did express a concern with the shortcomings of materials that can be affected adversely by careless handling. The suggestion for the possibility of use of the thermoplastic as a sealer over cold mix was rejected for the reason that, given in-field application, the cold mix itself will not adhere to the surrounding asphalt. This was felt to be as much a problem of application as of material. The Committee stressed the need for a material whose properties can overcome the careless handling that is generally encountered.

An overview of the cost analysis prepared by Public Technology was presented, and copies of the complete cost analysis report were distributed. The initial reaction to the cost analysis was favorable; however, several Committee members expressed their belief that looking at the total cost of the emergency patching material was potentially misleading. They felt that the labor cost associated with cold mix applications would be less per ton than that associated with hot mix procedures. This, since there is less crew interest in doing a good job, since the patch "is not going to last anyway". Another question concerned the social costs associated with potholes. The city of Dallas, for example, received a significant number of claims for damages to vehicles from citizens due to roadway hazards.

At this point, the discussions among the Committee began to focus on the area of greatest concern; that of in-service use and durability of the material under all weather conditions. There was a distinct concern voiced about the summer/winter properties of the material. The Burbank experience would lead one to the conclusion that the current material does not have satisfactory high-temperature properties. Although it was stressed that low-temperature susceptibility was the single most important factor in the ultimate acceptance of the material, the high temperature properties should not be overlooked. Suggestions were made as to the feasibility of investigating two separate products; one for hot, and one for cold weather conditions. The current asphalt hot mix penetration value decreases with time (i. e., hardens) with exposure to air. The tests conducted in Burbank seem to indicate that the addition of Elvax to the asphalt actually tends to increase the penetration (i. e., softens). One of the problems in dealing with this sort of question is that current tests are not specific for a thermoplastic material. Current methods of measuring penetration are not necessarily applicable, and it was suggested that durometer measurements be made in parallel with penetration measurements, to determine whether correlations can be made.

Similarly, due to the fact that the thin-film-coated aggregate exhibits properties different than laboratory scale quantities of material, the physical properties must be looked at after coating. Penetration drops quickly when the material exists as a film on the aggregate.

As was mentioned before, the most important physical property is that of low temperature susceptibility and penetration. The optimum value for low temperature penetration is considered to be sixty, but this should be in an as-coated situation. A pen. of twenty at 32^{o}F would be considered adequate if the pen. was no more than one hundred at 77^{o}F. The ideal performance curve would be a pen. of sixty flat from 32^{o}F to 77^{o}F.

Since current needle-penetration tests introduce uncertainty into the data, a sliding plate micro-viscometer was suggested as an alternative, particularly since it would simulate the thin-film characteristics of the coated aggregate.

The User Design Committee developed a research and development requirement definition by which a determination of temperature susceptibility curves would be made for both the 150 and 420 grades of Elvax, involving three penetration grades of asphalt for each grade of Elvax, and parallel penetration, and thin-film viscometer measurements taken.

It is important to note, however, that we must be able to test the material that goes into the pothole; it is insufficient to merely test one component of that material, e.g., the thermoplastic asphalt.

One useful test that was suggested involves the coring of potholes along the side of the pothole to check the bond between the implanted material and the existing pavement. Problems will be encountered in that very small deviations in the structure of the patch or base can throw the findings off. It was suggested that a simple test such as either "bonded" or "not bonded" be performed. Numbers associated with the bond will be relatively meaningless because of the deviations that can occur. On a large number of corings, the qualitative judgments of "better" or "worse" would be adequate.

The discussions concerning equipment were predicated upon two criteria; first, the equipment must allow the material to be used when the local hot mix plant is shut down; and second, the equipment must maximize worker productivity, optimizing local hauls, and minimizing travel time.

The various alternatives described in the cost report require different equipment to make them feasible. The various equipments required were discussed, from a central mixing plant, such as could be provided by Boeing, to individual heated pug mills which could be attached to the back of existing trucks. The representative from the Boeing Construction Company who was present at the meeting agreed to take these requirements back to his firm, and to attempt to design a unit which would meet the requirements and both performance and cost, as laid down by the User Design Committee.

The discussions returned to a consideration of the cost analysis. There were questions of validity raised concerning the data obtained from the cities.

Based on some of these questions, it was decided to reconsider the cost analysis with several important changes. Labor will be calculated as direct labor only, since the overhead rates vary so appreciably from city to city. Only direct costs will be considered in arriving at a total figure. PTI will work with Burbank and Dallas to develop detailed cost figures, with which to validate the economic model. The other cities of the User Design Committee agreed to introduce their own numbers into the economic model to determine its applicability for their need. One of the most important changes to the model is that direct labor will be calculated as a function of the "road life" of the patch. Currently, the model visualizes direct labor as a function of volume of material used.

The "road life" factor is another quantity which requires further investigation. The patches laid down to date have been in relatively straight stretches, with very little change in either acceleration, deceleration, or lateral stress. Valid "road life" factors can only be obtained by installing test patches in areas where these stresses do occur, in order to develop a direct comparison of effectiveness between the thermoplastic material and existing techniques.

A summary of the future directions recommended by the User Design Committee are as follows:

1. Continued research and development on temperature susceptibility of the material, with particular emphasis on the low temperature properties. Investigations should determine whether it will be possible for a single material to suit both winter and summer conditions, or if two products will be necessary.

2. Continued field testing. The material should be made available to at least twenty selected cities by next fall, for application during the winter months. The application procedure should be sufficiently defined to lead to installation in high-stress areas, such as curbs, bus stops, etc.

3. Refine the quality of the input data on cost. Develop a more accurate model for a city to use in making the determination of whether or not introduction of the thermoplastic street patching material would be cost-effective.

The summary statements of each of the attending members of the User Design Committee provide a good indication of their attitudes towards the development efforts to date. These statements have been noted and are presented as follows:

John Teipel: We have found a material with promise for the peculiar needs of street patching; a material which appears to have more benefits than drawbacks. There are still some things that have to be done as outlined in the statement of recommended future directions. It is particularly important to field test the material at "bad" locations, and to develop a good measure for the life of the patch. Another thing to consider is the opportunity to increase productivity by incorporating improved management methods into the system using the new material.

Keith Brinker: A more definitive optimization of the formulation in the laboratory is still required. The main emphasis, of course, should be on field testing. As a potential manufacturer of one of the raw input materials, I am very encouraged at the way the cities want to use it, and towards their progressive attitudes. From everything we have seen, it will be the asphalt that will be the limiting factor; not the Elvax. It appears that the Elvax is actually more stable thermally than the asphalt, and should be able to stand the long-term heat required.

John Frawley: The test samples run to date have been encouraging, and point out the value of the primer for this application. The "road life" factor will be important, if only applicable to a part of the country. Tests should be related to poor subgrades, high water table, etc., in addition to the freeze-thaw considerations. I think it would also be valuable to look into a cut-back material for true cold application. Any improvement in the current cold patch would be welcome.

Bob Griffin: The street patching problem seems to be very well represented geographically on the User Design Committee, but will there really be that much use of the material? How great will be the demand, and how long until it will be accepted? Because of the wide disparity of city needs, one type of mixer probably will not meet everyone's needs. A family of mixers will have to be developed. In that regard, Boeing will require more information on the details for mixer design. We will continue to work on this with individual members of the UDC, with PTI, and with PRC.

Joe Baker: I have seen exceptional progress over the last six months, and I am well encouraged with the results to date. The research and field testing that was outlined previously are absolutely needed, and we will continue to provide whatever assistance and cooperation is required in that regard. The material should be made available to selected cities for use under existing conditions, and provide reports and/or inspections made concerning the installations. Concerted efforts should be made for additional funding from DOT.

Dick Anderson: I don't believe that you'll have any difficulty in convincing management or elected officials as to the potential cost-benefits of this new material. There might be some problem, however, in cities of less than 25,000 people, because of their limited financial resources for capital investment. I would suggest that efforts be made to try to develop a very simple and inexpensive piece of equipment for their needs, even though it may be more labor intensive than the more sophisticated systems developed for the larger cities' needs.

Joe Amstock: From what we've seen to date, I think there's no question but that we should try to keep this project alive and begin to publicize it. Perhaps a joint committee presentation to the Highway Research Board or to the Department of Transportation is called for at the present time. Time, of course, is a factor. Any decisions have to be made soon so that the work can be done to get the new field tests underway at the beginning of next winter's cycle.

Charles McDonald: I still feel that the most important thing to be done at the present time is additional testing on the temperature susceptibility of the material. Even though the main thrust is towards hot mix, there should be a parallel effort, at least on the side, on other methods and approaches. This will be necessary for those areas where they don't have the facilities for hot mix. Another big problem, too, is standing water on stressed areas.

Ed Clarke: On a projection, for applications where the surface temperature's 75^{o} and less, this material is probably a good thing already. It has shown a superior patch in those conditions, particularly in moist or wet applications. Now we have to find something for those situations where the surface temperature goes above 75^{o}. Crack filling is equally important, and should be pursued. One of the problems that will be encouraged is a consistency of thought on the evaluation of patch appearance. Perhaps a series of standard photos could be used for comparative evaluation.

Ed Aeck: One thing we haven't talked about here is the fact that we're all involved with serving the public. In that regard, we have to think about the time required for the patching operation, and how long it takes for that patch to bear traffic. These figures should be interjected in the cost-benefit evaluation, particularly since it results in good public relations for the city. It may even offset the increased cost required in the materials and equipment.

Ed Koonce: If this patch really does work as well as we think in cold and wet weather, fine. There's no need to go any further. I would like to try a primer-coated hole with our current hot patch, during our cold season. Speaking for Anchorage, the city wants end results; we're not that interested in the money.

Bob Gallaway: The prices of current commercially available material, both standard and special material, vary widely. I've seen figures ranging from \$9/ton to \$65/ton just within the Texas area alone. It is a very large market which should be looked into, in terms of combining state, county, and local markets. The marketing approach should be different in each case; the small buyer versus the large buyer. Implementation training will be needed, and should be provided along with the materials. Based on current information, it should be possible to write specifications for the material that can be applied.

The meeting was adjourned with the understanding that Public Technology would continue to work with individual cities to develop a more precise cost analysis model. Based on the general satisfaction with the performance of the material, it was decided that we would continue to pursue outside sources of funding to continue the efforts of laboratory research and development and field testing as outlined previously.

BURBANK REPORT

By Ed Clarke

On April 10, 1973 the following tests were conducted in Burbank under the guidelines of PTI and PRC. The street used for the test was one of a relatively heavy flow of traffic and also 6 inches thick. A total of 14 test holes, each 18 inches in diameter and 6 inches deep and pot-shaped were cut in the existing asphalt. These holes were placed 10 feet apart and 15 feet off the east curbline of the northbound lane. This put the left wheels of the traffic over the test holes.

The test consisted of 4 holes using 20% Elvax 420 and 80% 85-100 penetration asphalt primed and 4 holes using 20% Elvax 150 and 80% 85-100 penetration asphalt pre-mix. Two tests used Elvax 420 85-100 penetration asphalt for layered dry high density aggregate, both hot and cold, and 3 layered test holes using 20% Elvax 150 and 80% 85-100 penetration asphalt using high density aggregate, both hot and cold, and one using 3/4" large cold aggregate. One test hole was for control using 85-100 penetration commercial hot mix.

A 5% binder was used in all cases of pre-mix material.

The material was heated in a gas-fired oven to 300 degrees and then delivered to the job site approximately 2 miles distant.

The ambient temperature was around 75 degrees. The first 4 pre-mix tests consisted of one wet hole with primer, one wet hole without primer, one dry hole with primer and one dry hole without primer. The second 4 pre-mix tests were prepared the same way, that is, one wet hole with primer, one wet hole without primer, one dry hole with primer and one dry hole without primer. The material was placed in 2-3 inch layers, hand tamped, then topped off and compacted with a hand-held heated roller.

The next 2 tests consisted of a dry hole with primer and high density cold aggregate compacted in layers of 2-3 inches deep and then a 1/4" layer of Elvax 420 another 2-3 inch layer of aggregate and Elvax, etc., until the hole was full, and one dry hole without primer and high density hot aggregate was applied as above.

The next 3 test holes used Elvax 150 consisting of one dry hole with primer and high density cold aggregate and one dry hole without primer and high density hot aggregate.

The last dry hole test was with primer and cold 3/4 inch large aggregate. In this case the aggregate was applied to the hole and keyed as above and the voids were filled using Elvax 150.

On April 24, two weeks after installation, the 2 holes using Elvax 420, both wet and dry, without the use of primer, showed some signs of small chipping around the edges. All the wet of the test of the pre-mix patches were holding good.

All of the layered holes showed signs of dishing. On June 12 it was necessary to remove all of the layered holes because of excessive dishing. Parts of this material will be on display in the field. This was not a coring procedure because of the nature of the materials. They were removed by hand as is.

There was some scaling of the material using the Elvax 420 and the holes using Elvax 420 both with and without the primer, continued to break out around the edges, but not on as large a scale as the first.

Both the wet and dry holes using Elvax 150 seemed to be holding OK; however, there is some scaling at the edge on top of the dry hole without primer using Elvax 150.

On May 10 a test was made using a machine which we designed in Burbank and which you will see today. It is essentially a small cement mixer with a manifold and shield placed around the drum and heated by butane. The dense aggregate was heated to 300 degrees in the machine and the Elvax 420 with 40-50 penetration was heated in an oven. The aggregate batch weighed 190 pounds and the Elvax 420 with 40-50 penetration weighed 10 pounds. As soon as the Elvax was introduced to the aggregate a smooth material was obtained in about 4 minutes time.

Two rectangular holes, each 1' x 2' x 6" thick were used in this test because it was felt this would more truly show the utility type of cut in the street. To date there is no failure in these patches.

Three crack filling tests were made using Elvax 420 40-50 penetration asphalt and Elvax 420 85-100 penetration asphalt and one test using Elvax 150 85-100 penetration asphalt. The cracks were about 20 feet long and blown out with air and half the crack was filled with water and half left dry in each case. The Elvax was introduced at about 300 degrees. In all cases immediately after application there was no apparent bonding where the crack was moist. However, the next day all 3 patches seemed to bond well. One month later on June 11, the Elvax 420 with 40-50 penetration asphalt was firm and showed no signs of failure. The testing using Elvax 420 85-100 showed the dry application as OK and the wet application a failure, as a crack appeared. The testing using Elvax 150 85-100 penetration asphalt was a complete failure, both wet and dry.

An unusual occurrence appears in that in using the pre-mix material, the Elvax 150 is harder to use whereas the 420 is easier and does not appear as good a binder. However, in the crack filling, the 150 was a complete failure and the 420 40-50 penetration was holding up real well.

Essentially the same test that was performed in Burbank was performed in South Lake Tahoe on April 11, 1973 under a combination of rain, sleet and snow except that there was no crack filling test or rectangular test made. Thirteen test holes were made. A copy of the test results will be given to each of you.

Essentially the same results were obtained from South Lake Tahoe tests as those in Burbank.

On May 2, 1973 the last field test was performed in Anchorage, Alaska with essentially the same results. A copy of this will be given to you. The layering techniques, because of all previous tests in South Lake Tahoe and Burbank, was not made in Anchorage, Alaska.

CONCLUSION

The adding of the EVA resins to asphalt apparently changes the characteristics tremendously. As an example, both 85-100 penetration asphalt and 40-50 asphalt, when combined with EVA resins, seem to lose their body cement characteristics in that at around 75 degree ambient temperature, both become very soft to the extent that you can make a deep penetration with your finger. It appears to be a form of thermoplastic in that it does not become liquid but under pressure does allow the aggregate to move, thus accounting for the dishing in the layering technique. This movement is not apparent in the pre-mixed materials, possibly because of a lesser amount of Elvax asphalt.

In my opinion, the net result of this test with the pre-mix material cannot be final until temperatures of at least 100-110 degrees ambient has occurred over a period of several days because of some surface scaling noted in Burbank.

It appears that under ideal conditions it is questionable whether Elvax additive asphalts are equal to conventional asphalts. However, this is probably reversed under cold or moisture conditions.

Two of the big problems became very apparent in our field test, one being the lack of machinery available to mix the material under field conditions and the other the uncontrolled conditions in heating. As an example, while trying to heat in a heater drum and stir manually, our temperatures varied from 300 degrees to as high as 600 degrees, in one case.

One of the advantages of the Elvax additive to asphalt is that it appears possible to reheat many times without apparent detrimental effects to the cement qualities.

The results in Burbank indicate that no patches should be made unless a primer is used and the feather edges should be as deep as possible.

Elvax 150 seems to be harder to handle and appears to be holding up better than the Elvax 420.

Our minimal testing of Elvax additives to asphalt indicates there possibly is potential as a crack filler in that it seems that this might do the job and can be easily applied with equipment available on the market.

APPENDIX C

LABORATORY TEST METHODS

Viscosity	-----	HBF Brookfield Viscosimeter; Spindle 3 @ 10 rpm. Termperature of material: 300^{o}F (149^{o}C)
Hardness	ASTM D2240	
Penetration	ASTM D5--	Penetration @ 100^{o}F (38^{o}C); 50gms weight, 5 seconds Penetration @ 77^{o}F (25^{o}C);100gms weight, 5 seconds Penetration @ 32^{o}F (0^{o}C);200gms weight, 5 seconds
Tensile Strength	ASTM D638	
Elongation	ASTM D638	
Tear Strength	ASTM D638	
100% Modulus	ASTM D638	
Interfacial Adhesion	-----	As described in body of report
Uniformity	-----	As described in body of report

APPENDIX D

STREET PATCHING COST ANALYSIS

- A CASE STUDY -

BURBANK, CALIFORNIA

by

K. W. Lentz

PTI TECHNICAL REPORT SP-2

2 July, 1973

ACKNOWLEDGEMENT

PTI would like to express their sincere thanks to Burbank City Manager, Joe Baker for his cooperation in this effort.

Also deserving similar thanks are Superintendent of Streets, Ed Clarke, and his assistant, Ed Aeck, without whose assistance, cooperation, and accurate record keeping, the data base for this report could not have been obtained.

Further, PTI would like to express its gratitude to the National Aeronautics and Space Administration, Technology Utilization Office, for its support of this project through contract NASW-2388.

STREET PATCHING COST ANALYSIS

- A CASE STUDY -

BURBANK, CALIFORNIA

1.0 Introduction

Public Technology, Inc. has been working with NASA to develop an improved thermoplastic street patching material for approximately two years. As the material itself was developed and finally field tested, it became increasingly obvious that the new material was superior to conventional street patching hot and cold asphalt mixes. At this point, however, it became necessary to ask the question:

> "Does the improved performance gained from using the thermoplastic material justify the added cost of the new material over conventional hot or cold mix patching materials?"

In order to establish a standardized method of evaluating the cost effectiveness of using the thermoplastic material in various locations throughout the country, PTI devised a "per ton" analysis technique.[1] This analytical method allows total street patching costs to be expressed on a "per ton" of material used basis, as well as allowing for incorporation of relevant labor costs, equipment costs, and the increased "road life" to be gained from using the new material.

In order to test the feasibility of using this analysis technique, PTI, in conjunction with several cities, attempted to extract the required data from municipal records and perform a street patching cost analysis. This report describes such a study and analysis performed using data supplied by the city of Burbank, California.

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[1] "Cost Benefit Analysis of the Thermoplastic Street Patching Material" by K. W. Lentz. PTI Technical Report SP-1. Presented at Street Patching User Design Committee Meeting, South Lake Tahoe, California, June 21-22, 1973.

2.0 Background -- Burbank Street Patching Operation

Burbank, California is a city enclosing 17 square miles, and possessing 222 miles of paved streets. Because the weather is generally conducive to street patching operations year-around, street repair patches are considered permanent, i.e., they will last as long as the parent street. This is understandable since Burbank only patches under ideal conditions. During wet weather, the hot mix plants close, so Burbank suspends patching operations until conditions improve.

Burbank has one two-man street patching crew. This particular crew remains on street patching except on rainy days, at which time they are assigned to flood control duties. The crew always uses the same truck and roller.

The crew picks up anywhere from 1-10 tons (see Table XIII of hot mix daily from the local hot mix plant. The same plant is used over a given year's time. since Burbank contracts to purchase hot mix for one year periods (at a fixed price). The crew receives an invoice from the hot mix plant for the amount of hot mix received on a daily basis. Table XIII is derived from these invoices.

The daily load of hot mix is kept warm by covering it with a dark canvas tarp. It usually remains pliable enough for usage throughout the day.

3.0 Detailed Costs -- Burbank Street Patching

3.1 Material Costs

Hot mix is currently purchased by the city at a rate of $4.95 per ton plus 5% tax. The total cost is thus $5.20 per ton.

As is generally the case, prices are rising, and it is anticipated that the lowest bid in the coming fiscal year will be closer to $6.10 per ton plus tax, or $6.40 per ton.

3.2 Labor Costs

Both patching crew men are paid at a rate of $4.11 per hour. Furthermore, all public works employees are allocated fringe benefits at 38% of direct labor.

Two men, working eight hours per day patching streets, thus cost (including benefits) the city $90.97 per day.

3.3 Equipment Costs

The particular truck and equipment used for street patching is costed in an equipment sinking fund-type arrangement at a rate of \$2.50 per hour.

This comes to a daily street patching equipment cost of \$20.00 per day.

4.0 Cost Analysis

4.1 General

The PTI analysis technique requires material, labor, and equipment costs to be expressed on a per-ton basis.

The Burbank data as presented in Section 3.0, is easily converted to a per ton basis using the daily tonnage figures of Table XIII.

A conflict does, however, arise in considering the extraordinary hot mix volume days. We can speak of normal, everyday spot-patching operations, which consume 1.49 tons per day (see Table XIII) and arrive at a much higher per ton cost of patching than we do if we include the extraordinary patching day tonnages. In the analysis that follows, the costs will be split up between "spot patching" and overall patching. It should be noted that overall patching is probably more representative for considering long term costs. Large tonnage days are a fact of life and must be included. The "spot patching" costs are useful, however, in comparing per ton costs from other jurisdictions where daily patching tonnage is relatively constant, and is in fact only "spot patching".

4.2 Total Cost Equation

As derived in "Cost Benefit Analysis of the Thermoplastic Street Patching Material", the expression for total patching costs is:

$$TC = V\frac{1}{n}\left\{r_1c_1 + s + L/T + E/T\right\}$$

where: V = volume of street patching material used.

n = "road life" factor = 1.0 for conventional hot mix patching operations.

r_1c_1 = material cost per ton of patching material used.

s = storage cost per ton of patching material used.

L/T = Labor Cost per ton of patching material used.

E/T = Equipment Cost per ton of patching material used.

For the Burbank example, n=1.0 since we are evaluating patching costs of conventional hot mix methods. The material cost is that of hot mix, storage costs are zero, since hot mix is picked up at the plant. The labor and equipment costs per ton are yet to be derived. The simplified equation is thus:

$$TC = V \left\{ r_1 c_1 + L/T + E/T \right\}$$

4.3 Evaluation of Current Patching Costs

4.3.1 Material Cost per Ton

As stated in Section 3.1, current hot mix cost is \$5.20 per ton.

4.3.2 Labor Cost per Ton

As stated in Section 3.2, labor plus benefits amounts to \$90.97 per day. From Table VIII it can be seen that for overall patching operations, 2.46 tons of hot mix are used per day on the average. This results in an overall patching labor cost of \$36.98 per ton.

Similarly, the total "spot patching" labor cost per ton is \$90.97/1.49 or \$61.05 per ton.

4.3.3 Equipment Cost per Ton

From Section 3.3, the daily equipment cost is \$20.00. The overall equipment cost at 2.46 tons of hot mix per day is \$8.13 per ton.

The "spot patching" equipment cost at 1.49 tons per day is \$13.42 per ton.

4.3.4 Total Patching Costs per Ton

Adding the unit costs as in our equation, we arrive at total per ton patching costs as follows:

Overall patching effort:	\$50.31 per ton of patching material.
"Spot patching effort":	\$79.67 per ton of patching material.

5.0 Conclusions

Utilizing current methods and materials, it costs the city of Burbank $50.31 to lay down one ton of hot mix in its patching operation. This total represents a mix of 10% material cost, 74% labor cost, and 16% equipment cost.

The "spot patching" cost to lay down one ton of patching material is $79.67. This figure represents 6% material cost, 77% labor cost, and 17% equipment cost.

Since normal hot mix patches in Burbank last as long as the parent road, it is not meaningful to compare similar costs using the thermoplastic material. Although the thermoplastic material will in theory outlive the hot mix patch, the opportunity to do so does not exist.

The Burbank patching costs are extremely useful as baseline figures for comparison to cities of similar size, in similar climates, and with similar operations.

TABLE XIII

Typical Hot Mix Usage in Street Patching Operations[1]

- City of Burbank -

Date	Tons of Hot Mix
5-8-73	1.55
5-9-73	1.42
5-10-73	1.05
5-11-73	1.50
5-15-73	1.48
5-16-73	1.47
5-17-73	1.49
5-18-73	13.58[2]
5-21-73	1.55
5-22-73	1.55
5-23-73	1.57
5-24-73	1.56
5-25-73	1.55
5-29-73	1.55
5-31-73	1.45
6-1-73	1.51
6-4-73	1.55
6-5-73	1.53
6-7-73	1.55
6-11-73	8.75[2]
TOTAL	49.21
AVE/DAY	2.46
TOTAL[3]	26.88
AVE/DAY[3]	1.49

[1]Based on daily hot mix plant invoices.

[2]Large values indicate major patching jobs, such as utility cuts, etc.

[3]Total and daily average based on typical daily tonnage for small patching operations. Items in 2 above have been omitted.

APPENDIX E

STREET PATCHING COST ANALYSIS

- A CASE STUDY -

DALLAS, TEXAS

by

K. W. Lentz

PTI TECHNICAL REPORT SP-3

5 July, 1973

STREET PATCHING COST ANALYSIS

- A CASE STUDY -

DALLAS, TEXAS

1.0 Introduction

Public Technology, Inc. has been working with NASA to develop an improved thermoplastic street patching material for approximately two years. As the material itself was developed and finally field tested, it became increasingly obvious that the new material was superior to conventional street patching hot and cold asphalt mixes. At this point, however, it became necessary to ask the question:

> "Does the improved performance gained from using the thermoplastic material justify the added cost of the new material over conventional hot or cold mix patching materials?"

In order to establish a standardized method of evaluating the cost effectiveness of using the thermoplastic material in various locations throughout the country, PTI devised a "per ton" analysis technique.[1] This analytical method allows total street patching costs to be expressed on a "per ton" of material used basis, as well as allowing for incorporation of relevant labor costs, equipment costs, and the increased "road life" to be gained from using the new material.

In order to test the feasibility of using this analysis technique, PTI, in conjunction with several cities, attempted to extract the required data from municipal records and perform a street patching cost analysis. This report describes such a study and analysis performed using data supplied by the city of Dallas, Texas.

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[1] "Cost Benefit Analysis of the Thermoplastic Street Patching Material" by K. W. Lentz. PTI Technical Report SP-1. Presented at Street Patching User Design Committee Meeting, South Lake Tahoe, California, June 21-22, 1973.

2.0 Background — Dallas Street Patching Operation

Dallas, Texas has 4,600 miles of streets, approximately 80% paved, and 20% penetration asphalt. The city is divided into four districts for street maintenance purposes.

Street Patching takes place year-around. Patching crews start falling behind (i.e., potholes occur at a faster rate than crews can patch them) in October, and do not really "catch up" until July. At this time, the emergency aspect of patching operations is alleviated, and crews can concentrate on permanent repairs or replacement of particularly bad streets.

Dallas has nominally, 8 five-man crews and 8 three-man crews known as "Emergency Response Crews". Each crew has a radio-equipped truck, and is capable of being dispatched remotely, in order to handle called in emergency requests. As will be seen in the following analysis, some crews are not fully complimented, and a nominal three man crew may become a two man crew. Likewise, a four man crew is a nominal five man crew which, for one reason or another, has not been replenished in terms of manpower.

The typical day starts at 8:00 am with each crew proceeding from the District yard to the closest hot-mix plant. Depending on wait times at the hot mix plant, the crews, on the average, begin patching operations between 9:30 am and 10:00 am.

Patching operations are begun on major thoroughfares if the rush hour traffic has subsided. Other wise, work begins on lesser used side streets, residential areas, etc. Operations similarly shift to side streets when the pm rush traffic begins. All crews are, however, on call for emergency situations.

If a crew runs out of hot mix, they may return to the hot mix plant for more hot mix, or they may return to the District yard for a load of hot mix--cold lay material, and use this for the rest of the day. Driving time is a factor here in determining the course of events.

During rainy weather, the hot mix plants close, and patching crews must use hot mix--cold lay from District yards.

3.0 Detailed Costs -- Dallas Patching Operations

3.1 Material Costs

Hot mix cost per ton varies with hot mix plant, and presumably with time of year. Present data shows a range of $5.58 to $7.55 per ton of hot mix. Hot mix - cold lay was costed at $5.58 per ton.

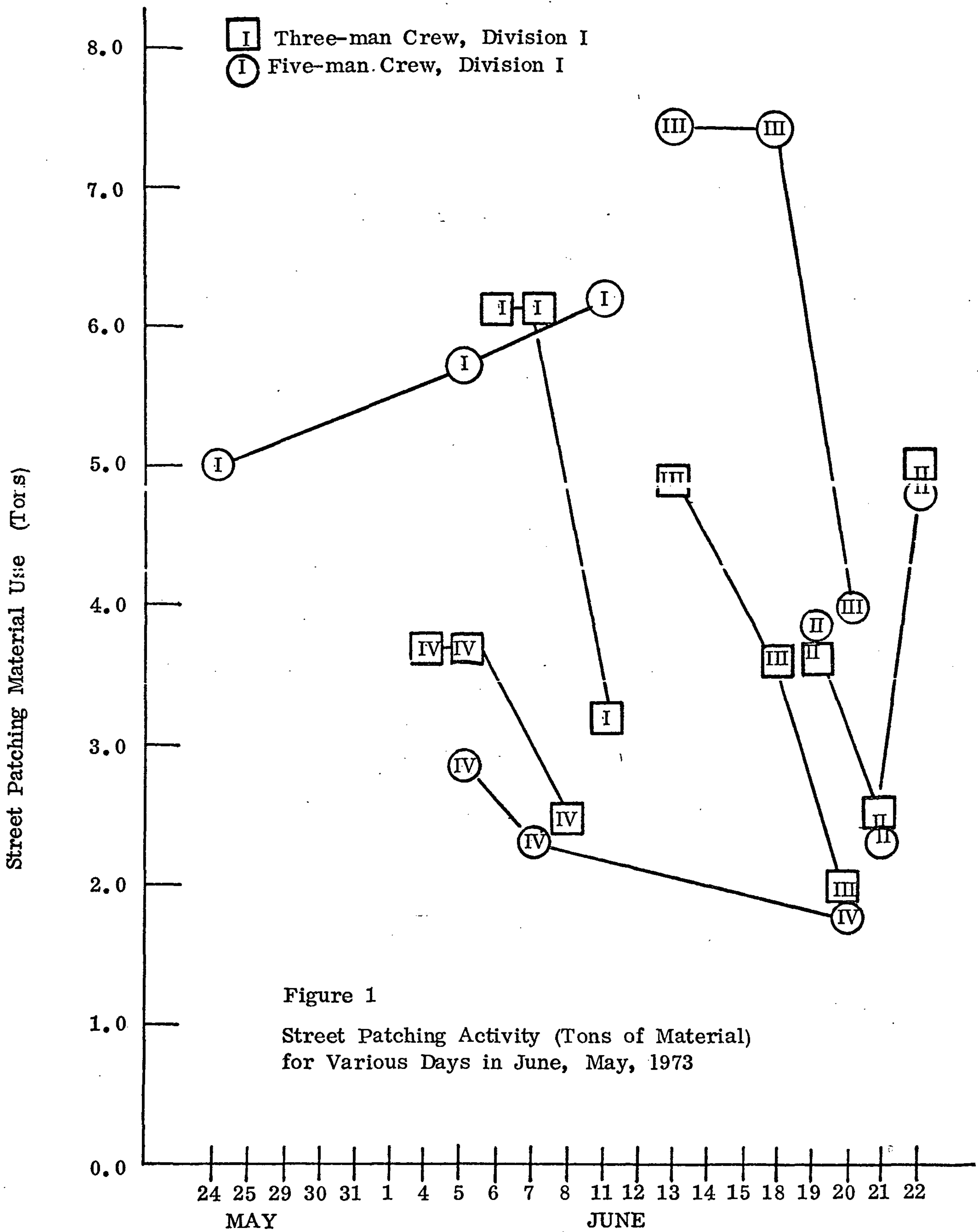
For the purposes of this analysis, an average cost per ton will be calculated using the data of Table XIV. This average cost of $5.83 per ton is representative of the material cost per ton for Dallas over a long period of time.

The material cost data appearing in Table XIV was derived from daily work reports, in which the foreman accounts for all labor, equipment, and material costs incurred during a given day.

Based on the data used for this report, a typical three-man crew uses an average of 4.07 tons per day and a typical five-man crew uses 5.23 tons of patching material per day. The total amount of patching material used depends on the particular crew, the type of patching being done, and naturally, on the weather. A previous investigation by Dallas Street Department officials found that the average patching crew used about five tons per day. This is in line with the findings of this study. This figure is corroborated further by the fact that Dallas uses a total of 20,000 tons of street patching material per year. Assuming 250 working days in a year, and 16 patching crews, the volume of material used per day per crew, figures out to 5 tons. (20,000/250 x 16 = 5)

The fact that the data in this report reflects a slightly lower average material usage per day (an overall average of 4.22 tons per day versus the 5 tons per day generally accepted) may be explained by the fact that many of the data points represent days with adverse weather conditions Figure 1 shows the daily usage of patching material as a function of data. Note that all of the crews used less material on the 20th and 21st of June -- known to be rainy, stormy days.

In order to maintain a consistent data base, the daily tonnage figures as recorded in Table XIV may be used, keeping in mind the fact that they may be slightly



Daily Tonnage Use of Street Patching Material in Dallas, Texas, During May and June, 1973 understated due to the weather factor. To reiterate, a three-man crew will be assumed to use 4.07 tons of patching material per day, and the average five-man crew will be assumed to use 5.23 tons of material per day.

3.2 Labor Costs

Labor costs vary, depending on crew size, but are readily accessible from daily work sheets. From Table XIV, the average daily three-man crew labor cost is $67.22 and the average five-man crew labor cost is $108.95 per day.

These labor costs are exclusive of fringe benefits and overhead, which amount to approximately 30% of direct labor. Overhead at a rate of 27.5% is charged to the Streets and Sanitation cost center, and an additional 2.5% is charged to the general city budget.

3.3 Equipment Costs

Equipment is charged on a per-mile basis at a rate of $0.23 per mile. The data presented in Table XIV indicates an average daily mileage figure of 70.75 miles per crew. This compares favorably with a previous study which arrived at a daily mileage figure of 69 miles per day per crew.

The value of 70.75 miles per day will be used in this study, yielding an average daily equipment cost of $16.25.

4.0 Current Cost Analysis

4.1 Total Cost Equation

As derived in "Cost Benefit Analysis of the Thermoplastic Street Patching Material" the expression for total street patching costs is:

$$TC = V\frac{1}{n}\left\{r_1c_1 + s + L/T + E/T\right\}$$

where:
- V = Volume of street patching material used (Tons)
- n = "Road Life" factor = 1.0 for comparative purposes of this report
- r_1c_1 = material costs per ton
- s = storage costs per ton of patching material used
- L/T = Direct Labor Cost per ton of patching material used
- E/T = Equipment Cost per ton of patching material used.

For evaluating current patching costs, the road life factor n will be assumed to be 1.0. [APPENDICES F&G discuss the make-up of the road life factor in detail.] Storage costs are zero for hot mix taken directly from the plant. Storage costs are finite for hot mix-cold lay stored at district yards, but this value is unknown at this time. For this example, we will assume s = 0. The equation thus simplifies to:

$$TC = V\left\{r_1c_1 + L/T + E/T\right\}$$

4.2 Evaluation of Current Patching Costs

4.2.1 Material Cost per Ton

As stated in Section 3.1, the average cost of $5.83 per ton of patching material will be used.

4.2.2 Labor Costs per Ton

For material comparison purposes, labor costs will be calculated without overhead charges included. For purposes of actual total costs, and for comparison of Dallas costs with those of other cities, the 30% overhead figure will be figured into the labor cost.

Three-man crew labor cost per day = $67.22. Average tons of material used by a three-man crew in one day = 4.07 tons (See Section 3.1). Thus the average labor cost per ton for a three-man crew is $16.52 per ton.

Five-man crew labor cost per day = $108.95. Average tonnage for a five-man crew is 5.22 tons per day yielding a five-man crew labor cost per ton of $20.87 per ton. It becomes immediately obvious that the extra labor cost incurred by a five-man crew is not matched by proportional increases in amount of material used.

Since the Dallas street patching labor force is equally composed of five-man and three-man crews (8 each), we can take the average of their respective labor costs and arrive at an overall labor figure of $18.70 per ton.

If the 30% overhead figure is attached, the actual total labor cost per ton of patching material used is $24.31.

4.2.3 Equipment Cost per Ton

Equipment costs per ton will differ with crew size, since there is a distinct difference in tons used between three- and five-man crews, with no significant difference in actual equipment costs. For a five-man crew, the equipment cost per ton is $3.11. For a three-man crew, the equipment cost is $3.99 per ton.

Again, assuming an equal number of three- and five-man crews, we will use the average value of $3.55 per ton as indicative of equipment costs per ton of patching material used.

4.2.4 Total Cost per Ton

The Dallas street patching operation costs $28.08 for each ton of patching material used. This figure does not include overhead. The total amount represents 20% material costs, 67% labor costs, and 13% equipment costs.

The total patching cost including overhead charges is $33.69 per ton with a breakdown of 17% material, 72% labor, and 11% equipment costs.

5.0 Use of the Thermoplastic Street Patching Material in Dallas

Dallas intends to use the thermoplastic material in a manner similar to Case II as outlined in "Cost Benefit Analysis of the Thermoplastic Street Patching Material". In this case, the city purchases the Elvax-asphalt mixture and mixes it with aggregate to produce the patching material.

Thermoplastic material will replace all hot mix and hot mix-cold lay street patching operations. The actual patching material will be mixed at each of the district yards, and stored in heated bins.

The patching material will be heated up prior to 8:00 AM in the bins, which will be started and watched by an existing yard man. The crews will load enough material for 1/2 day in insulated bed trucks, and proceed directly to the work site.

In the process of instituting use of the thermoplastic material, patching crew site will be reduced from three- and five-man crews to two-man crews. While this labor savings is not a direct consequence of the material itself, use is being made of the major change in operations (i.e., the material change) to set the stage for a smooth transition in labor allocation.

Dallas intends to increase the number of crews from sixteen to twenty, but these will all be two-man crews. The net labor saving will be a recuction in patching personnel of twenty-four (24) men, or 37.5%. The existing crews will be allowed to dwindle in size by attrition to the desired two-man status.

Since the crew size change is not a direct result of the material change, although it is important, the cost analysis will be performed in two stages. First, the benefits to be gained from going to the new material alone will be calculated. Secondly, the cost effect of changing crew sizes will be evaluated.

6.0 Cost Analysis - Thermoplastic Material

6.1 Total Cost Equation

As in Section 4.1, the total cost equation is:

$$TC = V\frac{1}{n}\left\{r_1c_1 + r_2c_2 + s + L/T + E/T\right\}$$

where: V = Volume of thermoplastic patching material used.

n = "Road Life" factor. For thermoplastic material, it will be greater than 1.0

$r_1c_1 + r_2c_2$ = Material costs per ton for the multi-component thermoplastic material

s = Material storage costs per ton for Elvax-asphalt and aggregate

L/T = Labor cost per ton of thermoplastic material used. Will be a function of the manner in which the material is produced and used

E/T = Equipment cost per ton of material used. Not included are capital outlays for new equipment.

The road life factor will be left in the equation, as it will be a number greater than 1.0. A theoretical road life factor of 6 has been calculated in APPENDIX G, although in actual practice, it will be somewhere between 1.0 and 6.0.

Storage costs will be ignored here under the assumption that they will be negligible with respect to material, labor, and equipment costs. The effect of storage costs on the total should be investigated, however, as cost data becomes available.

6.2 Evaluation of Projected Thermoplastic Material Patching Costs

6.2.1 Material Costs

Assuming Dallas will purchase Elvax-asphalt compound and subsequently hot-mix it with aggregate presents a situation referred to as "Case II" in "Cost Benefit Analysis of the Thermoplastic Street Patching

Material". The Elvax-asphalt compound represents 5% of the overall material, and costs \$800 per ton. ($r_1 = .05$, $c_1 = \$800$). The major constituent, aggregate, makes up 95% of the mixture and costs \$4.50 per ton in Dallas. ($r_2 = .95$, $c_2 = \$4.50$)

Calculating the patching material cost per ton,

$$r_1c_1 + r_2c_2 = \$44.28 \text{ per ton.}$$

6.2.2 Labor Costs

As stated in Section 5.0, the labor cost calculations will be made in two steps. First, just the effect of changing material will be considered. Second, the added impact of re-structuring the work force will be analyzed.

The labor benefits to be realized by changing to the new material will be increased productivity because patching crews will start patching earlier in the morning. The two hour wait in line at the hot mix plant will be avoieded since the thermoplastic material will be ready to go at the District yards at 8:00 AM.

Under present conditions, patching crews are actually patching only about 4 1/2 hours a day. The breakdown is typically:

Wait at Hot Mix Plant	-- 2 hours
Patching Activity	-- 4 1/2 hours
Driving Time	-- 1 hour
Breaks	-- 1/2 hour
TOTAL	8 hours

Under the proposed arrangement, the two hour plant wait will be realized almost entirely in added patching activity. To be conservative, assume an additional 1 1/2 hours of patching, bringing activity up from 4 1/2 hours to 6 hours, a 33% increase in work. This is equivalent to a 33% decrease in cost to get the same amount of work. As derived in Section 4.2.2, current labor costs are \$18.70 per ton (excluding overhead).

Under the proposed arrangement, more tons of material will be used per day, thus the labor cost per ton should decrease by 33% to $12.35 per ton.

If 30% overhead is included, the labor cost will be $16.29 per ton.

The foregoing cost calculations represented labor savings to be derived just from the direct effect of material change alone. If we now consider the effects of re-structuring the work force, further savings will be realized.

The proposed re-organization of patching activity calls for a change to twenty (20) two-man crews from an existing eight (8) five-man crews and eight (8) three-man crews. We are assuming that the two-man crews will be just as effective as the three- and five-man crews were previously. Table XV bears this out, as it can be seen that the two-man crew for which data exists was more effective (in terms of cost per ton) than six of the seven remaining crews.

The labor saving here is a 37.5% reduction in work force, thus labor cost per ton of material. This brings direct labor (exclusive of overhead) down to $7.83 per ton.

Including overhead (30%), the cost is $10.18 per ton.

6.2.3 Equipment Costs

For the first step of material change alone, no equipment impact will be realized. The crew deployment is assumed to be the same, thus the same equipment. A mileage savings may occur since trips to the hot-mix plant are no longer necessary, but it is difficult to put a number on this savings. Assume, as in Section 4.2.3, that equipment cost will be $3.55 per ton.

For our second step, we are reducing overall labor, but are increasing the number of crews 25%, from 16 to 20. We must figure an equivalent increase in equipment cost, bringing the cost to $4.44 per ton.

6.2.4 Total Costs

Total thermoplastic material patching costs are shown in Table XVI along with current patching costs.

7.0 Discussion of Results

Since it is the intent of Dallas to go to the crew reorganization (i.e., twenty (20) two-man crews) discussion will center on these appropriate costs. Further, since the overhead and benefits allocation is in fact a cost element, and since it varies in proportion and total effect on conventional versus thermoplastic costs, these costs will be considered.

Given the aforementioned stipulations, total patching costs can be written:

$$TC = 33.69\,V \qquad \text{(Current Method)}$$

and

$$TC = 58.90\,\frac{V}{n} \qquad \text{(Thermoplastic Material)}$$

If the thermoplastic patching material exhibits a road life factor of 1.75 (which is not at all unreasonable) the proposed method of patching with thermoplastic material will be equivalent to current methods in terms of cost.

Table XVII shows per ton savings and total dollar savings to be expected if Dallas uses 20,000 tons of patching material annually. (This number was determined by street officials to be the total annual tonnage used in street patching operations.) Various road life factors up to 6.0 are assumed.

As demonstrated in APPENDIX G, the theoretical road life factor of 6.0 is a possibility. The assumptions upon which the number was derived are based on estimates by street department officials, thus are not arrived at by wild speculation.

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TABLE XIV

Typical Hot Mix Usage and
Costs[1] in Daily Street Patching Operations

- City of Dallas -

	DISTRICT I					
	Three-man Crew			Five-man Crew		
Date	6/6/73	6/7/73	6/11/73	5/24/73	6/5/73	6/11/73
Labor[2]	$66.31	$66.31	$69.87	$110.40	$110.40	$110.40[5]
Equipment[3]	$21.62	$20.47	$17.71	$13.80	$17.25	$23.69
Material[4]	$35.27	$34.50	$17.86	$28.00	$35.61	$31.93
Volume (tons)[4]	6.17	6.18	3.20	5.00	5.73	6.23
Total Cost	$123.20	$121.28	$105.44	$152.20	$163.26	$166.02
Total Cost per Ton	$19.97	$19.62	$32.95	$30.44	$28.49	$26.65

	DISTRICT II					
	Three-man Crew			Five-man Crew		
Date	6/19/73	6/21/73	6/22/73	6/19/73	6/21/73	6/22/73
Labor	$64.38	$64.38	$64.38	$97.71	$96.92	$97.71
Equipment	$11.96	$12.42	$ 9.66	$35.45	$15.18	$11.27
Material	$21.22	$15.01	$29.88	$23.04	$15.67	$29.59
Volume (tons)	3.68	2.48	4.93	3.88	2.48	4.88
Total Cost	$97.56	$92.81	$103.92	$156.20	$127.77	$138.57
Total Cost per Ton	$26.51	$37.02	$21.08	$40.26	$51.52	$28.40

(1) Costs derived from daily crew work reports chosen at random.

(2) Direct labor exclusive of 27.5% overhead package.

(3) Equipment cost calculated at a rate of $0.23 per mile driven.

(4) Material costs include both hot mix, and hot mix-cold lay. Hot mix cost per ton varies depending on plant purchased from.

(5) Includes sick pay for man out. Crew operated with four men.

TABLE XIV
(Cont'd.)

	DISTRICT III					
	Two-man Crew[6]			Five-man Crew		
Date	6/13/73	6/18/73	6/20/73	6/13/73	6/18/73	6/20/73
Labor	$41.72	$39.60	$41.72	$118.99	$118.99	$118.99
Equipment	$14.49	$20.93	$15.87	$ 25.10	$ 21.27	$ 14.03
Material	$28.57	$20.59	$11.16	$ 44.04	$ 41.40	$ 22.32
Volume (tons)	4.91	3.69	2.00	7.44	7.42	4.00
Total Cost	$84.78	$81.12	$68.75	$188.13	$181.66	$155.34
Total Cost per Ton	$17.27	$21.98	$34.38	$ 25.29	$ 24.48	$ 38.84

	DISTRICT IV					
	Three-man Crew			Four-man Crew[6]		
Date	6/4/73	6/5/73	6/8/73	6/5/73	6/7/73	6/20/73
Labor	$69.79	$69.79	$69.79	$84.83	$83.82	$84.47
Equipment	$13.35	$11.73	$19.32	$ 9.66	$ 9.89	$ 4.38
Material	$23.81	$20.86	$14.71	$21.37	$13.59	$10.49
Volume (tons)	3.73	3.74	2.49	2.83	2.30	1.88
Total Cost	$106.95	$102.38	$103.82	$115.86	$107.30	$99.34
Total Cost per Ton	$28.67	$27.37	$41.69	$40.94	$46.65	$52.84

(6) The two-man and four-man crews were originally three-man and five-man crews respectively. As the man was lost through attrition, he was not replaced. However, the crew continued to operate a "man short".

TABLE XV

Summary of Daily Patching Costs
and Average Daily Patching Costs
per ton of Material Used

	DISTRICT I					
	Three-man Crew			Five-man Crew		
Date	6/6/73	6/7/73	6/11/73	5/24/73	6/5/73	6/11/73
Total Cost per Ton	$19.97	$19.62	$32.95	$30.44	$28.49	$26.65
Average Cost per Ton	$24.18			$28.53		

	DISTRICT II					
	Three-man Crew			Five-man Crew		
Date	6/19/73	6/21/73	6/22/73	6/19/73	6/21/73	6/22/73
Total Cost per Ton	$26.51	$37.02	$21.00	$40.26	$51.52	$28.40
Average Cost per Ton	$28.20			$40.06		

	DISTRICT III					
	Two-man Crew			Five-man Crew		
Date	6/13/73	6/18/73	6/20/73	6/13/73	6/18/73	6/20/73
Total Cost per Ton	$17.27	$21.98	$34.38	$25.29	$24.48	$38.84
Average Cost per Ton	$24.54			$29.54		

TABLE XV
(Cont'd.)

	DISTRICT IV					
	Three-man Crew			Four-man Crew		
Date	6/4/73	6/5/73	6/8/73	6/5/73	6/7/73	6/20/73
Total Cost per Ton	$28.67	$27.37	$41.69	$40.94	$46.65	$52.84
Average Cost per Ton	$32.58			$46.81		

TABLE XVI

Summary of Patching Material and Operations

Cost per Ton of Material

(Road Life Factor is Not Considered)

	Current		Material Change Only		Material Change and Crew Reorganization	
Material	$5.83	20%	$44.28	73%	$44.28	78%
Labor(1)	$18.70	67%	$12.53	21%	$ 7.83	14%
Equipment	$3.55	13%	$ 3.55	6%	$ 4.44	8%
TOTAL	$28.08	100%	$60.36	100%	$56.55	100%

	Current		Material Change Only		Material Change and Crew Reorganization	
Material	$5.83	17%	$44.28	69%	$44.28	75%
Labor(2)	$24.31	72%	$16.29	25%	$10.18	17%
Equipment	$3.55	11%	$ 3.55	6%	$ 4.44	8%
TOTAL	$33.69	100%	$64.12	100%	$58.90	100%

(1) Benefits and overhead not included.

(2) Benefits and Overhead included.

TABLE XVII

Annual Savings Realized
by Using Thermoplastic Material
Assuming Various Possible
Road Life Factors

Annual Volume = 20,000 Tons

Road Life Factor	Savings per Ton of Material	Annual Savings on Patching Operation
1.75	0	0
2.0	$4.24	$84,800
3.0	$14.06	$281,200
4.0	$18.96	$379,200
5.0	$21.91	$438,200
6.0	$23.87	$477,400

APPENDIX F

Calculation of Baseline Road Life Factor for Existing Street Patching Operations

The following percentages of types of road patching activity, as well as re-patch cycles were estimated by Dallas Streets and Sanitation Department personnel.

The patching activity was first divided arbitrarily into two geographic categories:

1. "Tough" locations which see repeated wear and tear such as bus stops, etc. About 10% of the overall patching effort is concentrated on these areas.
2. "Easy" or straightaway locations which receive minimal usage, see little start-stop activity, and which are not within the normal driving tire tread zones. This type of patch accounts for 90% of the overall activity.

The next patching activity categorization took place with respect to type of patching material and environmental conditions during patching. Four major divisions were chosen.

1. Hot mix repairs under ideal weather conditions. Potholes are prepared properly, and the hot mix adequately rolled. This condition was ascertained to exist 60% of the time.
2. Hot mix repairs under non-ideal conditions. Weather cold or slightly damp, pothole cursorily prepared, and hot mix hand tamped. These conditions will exist 20% of the time.
3. Hot mix-Cold lay repairs under ideal conditions as in (1.) above. Since hot mix is usually available under good weather conditions, this type of activity occurs only 4% of the time.
4. Hot mix-Cold lay repairs under non-ideal conditions. This is the true "temporary" patch, and this type of activity occurs 16% of the time.

In order to get a feel for re-patching activity, the same group of street maintenance experts estimated the number of times a typical pothole would be re-patched during any given year. Under the best of all possible combinations of conditions, i.e., hot-mix, ideal conditions on a straightaway; a patch was assumed to last for the life of the road. A typical road life of four years was chosen. Thus, on the average, an ideal patch would be replaced 1/4 time per year.

The following chart summarizes the "number of repatches" for a typical pothole, under each of the aforementioned conditions:

Number of Times a Typical Pothole Must Be Re-patched in a Year

PATCH LOCATION	TOUGH LOCATIONS (10%)	STRAIGHTAWAYS (90%)
Patching Conditions		
1. Hot Mix - Ideal Conditions (60%)	2	1/4
2. Hot Mix - Non-Ideal Conditions (4%)	4	1
3. Cold Mix - Ideal Conditions (4%)	6	2
4. Cold Mix - Non-Ideal Conditions (16%)	12	12

All of the preceding information may be combined to yield a "weighted average" number of times any single pothole will be re-patched during a given year:

TOTAL	PATCH LOCATION	PATCHING CONDITION	WEIGHTED PERCENTAGE OF TOTAL	X	REPATCH FACTOR	=	WEIGHTED REPATCH FACTOR
Patching Activity (100%)	Tough (10%)	(60%) Hot Mix, Ideal	6%	x	2	=	0.120
		(20%) Hot Mix, Non-Ideal	2%	x	4	=	0.080
		(4%) Cold Mix, Ideal	0.4%	x	6	=	0.024
		(16%) Cold Mix, Non-Ideal	1.6%	x	12	=	0.192
	Straightaway (90%)	(60%) Hot Mix, Ideal	54%	x	1/4	=	0.135
		(20%) Hot Mix, Non-Ideal	18%	x	1	=	0.180
		(4%) Cold Mix, Ideal	3.6%	x	2	=	0.072
		(16%) Cold Mix, Non-Ideal	14.4%	x	12	=	1.728

WEIGHTED REPATCH FACTOR FOR ALL CONDITIONS FOR ONE YEAR = 2.531

The result is simply, given all of the above assumptions as to repatching, that Dallas, on the average, repatches a pothole 2.5 times a year.

APPENDIX G

Calculation of Road Life Factor for Street Patching Operations Using the Thermoplastic Material

The assumption made as to the performance of thermoplastic material is as follows:

> A pothole patched with thermoplastic material under <u>any</u> conditions will be at least as good as a pothole patched with hot mix under ideal conditions. This is due to its superior ability to set up under wet conditions.

We may then summarize the required number of pothole repatches in a chart identical to that used in APPENDIX F. The above assumption is used. Note, however, that the case of "cold mix" is a misnomer, since it is assumed that the thermo-plastic material is being used.

PATCH LOCATION	TOUGH	STRAIGHTAWAYS
Patching Conditions		
1. Hot Mix, Ideal	2	1/4
2. Hot Mix, Non-Ideal	2	1/4
3. Cold Mix, Ideal	2	1/4
4. Cold Mix, Non-Ideal	2	1/4

TOTAL	PATCH LOCATION	PATCHING CONDITION	WEIGHTED PERCENTAGE OF TOTAL	X	REPATCH FACTOR	=	WEIGHTED REPATCH FACTOR
Patching Activity (100%)	Tough (10%)	(60%) Hot Mix, Ideal	6%	x		=	0.120
		(20%) Hot Mix, Non-Ideal	2%	x		=	0.040
		(4%) Cold Mix, Ideal	0.4%	x		=	0.008
		(16%) Cold Mix, Non-Ideal	1.6%	x		=	0.032
	Straightaway (90%)	(60%) Hot Mix, Ideal	54%	x		=	0.135
		(20%) Hot Mix, Non-Ideal	18%	x		=	0.045
		(4%) Cold Mix, Ideal	3.6%	x		=	0.009
		(16%) Cold Mix, Non-Ideal	14.4%	x		=	0.036
		WEIGHTED REPATCH FACTOR				=	0.425

Using the results of APPENDIX F, i.e., Factor = 2.531 along with the current result, we see that the improvement to be realized by going to the thermoplastic material is 2.531: 0.425 or 5.95:1.

The road life factor, n, as used in our equation is thus 5.95. This savings is realized because repatching activity has been drastically reduced.