EVALUATION OF THERMOPLASTIC ASPHALT COMPOSITIONS FOR STREET PATCHING

Warren D. Siemens, Public Technology, Inc.,
Washington, D. C.; and
Joseph S. Amstock, Products Research and Chemical Corporation,
Burbank, California

An investigation of a family of thermoplastic asphalt compositions for all-weather permanent street patching applications was conducted by Public Technology, Inc., and Products Research and Chemical Corporation under contract to the National Aeronautics and Space Administration. Ten ethylene-vinyl acetate copolymers were laboratory-tested in different ratio combinations with various penetration-grade asphalts. The physical properties of these compositions were related to the functional requirements for a street patching material established by Public Technology's User Requirements Committee composed of street superintendents, public works directors, city administrators, and others. Two formulations were selected for preliminary field-testing at 3 sites: Burbank, California; South Lake Tahoe, California; and Anchorage, Alaska. The field-test results (after 2 months) indicate considerable promise for the material for emergency patching. A cost-effectiveness analysis indicates that if the new material has a road life twice that of current emergency patching materials then it is as cost-effective as current materials. This is calculated on the basis of total costs (materials, equipment, and labor) averaged from data for 12 cities.

•PREVIOUS work by Jet Propulsion Laboratory and 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, Inc., under contract to the National Aeronautics and Space Administration, employed the services of Products Research and Chemical Corporation to perform the necessary laboratory development work and to provide the pilot-scale materials for field testing EVA-asphalt compositions.

Accordingly, development work was conducted to determine the most promising combinations of EVA resins with asphalt and aggregate for this application. A typical paving asphalt, 85-100 penetration, was combined with 10 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 5 resins of the first 10 that exhibited the best properties were retested at an 80/20 weight ratio of 85-100 penetration asphalt to EVA resin. These 5 resins were Elvax 150, 240, 420, 4320, and 350. Of these, the Elvax 150 and 420 asphalt combinations were chosen to undergo field testing as the binder for aggregate-filled patching compositions for potholes. These 2 resins tend

Publication of this paper sponsored by Committee on Pavement Maintenance.

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 percent by weight or greater resulted in the imparting of significant elastomeric qualities to the asphalt.

Field test applications were conducted in 3 locations: Burbank, California; South Lake Tahoe, California; and Anchorage, Alaska. The last 2 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. At each site, dish-shaped potholes 16 to 18 in. (41 to 46 cm) in diameter and from 4 to 6 in. (10 to 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 percent by weight Elvax 150 or 420 binder (80/20 85-100 penetration asphalt/EVA resin) and 95 percent dense-graded aggregate. At each test site, the premixed materials were supplied cold in 5-gallon pails and had to be heated to 260-300 F (127-149 C) before using.

With each premixed composition, 4 types of potholes were patched: dry, wet with water, dry and primed, and wet and primed. The primer used was a 60 percent 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 problem. Only the Department of Public Works at Burbank, which happened to have a large walk-in oven, was suitably equipped for heating the material in the form supplied. At the other sites, considerable improvisation was necessary.

The premixed material, when heated to the proper temperature, was applied in much the same manner as conventional hot-mix asphalt. As many 2-in (5-cm) courses as required to patch the hole were hand-tamped 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 hot-mix patching material is performing as well as the Elvax 150-based composition and slightly better than the Elvax 420-based composition. The most significant mode of failure to date has been a raveling 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 significantly less edge raveling than unprimed holes. These results, however, are based on a test period of only 2 months.

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; 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 percent weight modification of 40-50 penetration and 200-300 penetration asphalt so that regional variations in grade of available asphalt and in 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 comparably weak, soft, sticky elastomeric material of little utility.

Elvax 150, 350, and 420 were also evaluated as a 10 percent 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 combination with asphalt (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 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 2 possible routes for the large-scale production and distribution of EVA-modified asphaltic materials was made. Material 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.

SPECIFICATION OF THE PROBLEM

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 further failure in the roadbed. These failures are known as "chuckholes" or "potholes". Beyond being an irritant or nuisance to drivers, they can be a hazard to vehicular traffic. 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 cycles, which also accentuate 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 inasmuch as there is very little call for the material because it cools so much during shipment to the repair site.

The cold-mix materials that 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 must 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 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 activity, with most of the total cost of maintenance being devoted to labor. The bulk of the $800 million 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 cost data for these operations at the various local governmental levels and the consequent requirement for estimates based on sampled city, county, and state cost data.

The development of an effective, all-weather street patching material not only would provide benefits to the cost of street maintenance but also would be a public service in that fewer streets and roads would be closed to traffic and for less time. The requirement to redo emergency repairs (as many as 15 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.

The performance requirements for an all-weather, permanent street patching material for flexible and rigid pavements were developed by a User Requirements Committee convened by Public Technology, Inc. The scope of the requirements definition included 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 that 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 that can be applied more productively, i.e., the material should require less 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 Requirements Committee agreed that current asphalt tests are inadequate and in some cases inappropriate for rubberized asphalts. This statement is corroborated by a recent report (1) in which it is recommended that new test procedures be developed for rubberized asphalts and in which several improved tests are suggested.

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 the 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 the ability to remain in the pothole a minimum of 2 seasonal cycles. However, the exact duration required will depend on total cost/performance trade-offs.

Operational Requirements

3. Material application should minimize traffic disruption. Therefore, procedures at the scene should be simple, not involving complex application methods or more total pieces of equipment than current procedures, and time-to-bear-traffic should be minimized. Barricades should be required only when the crew is at work at the scene. This implies that material should bear traffic in about 10 to 20 minutes.
4. The material should be easy to store and packaged in reasonably sized, easy-to-handle configurations.
5. The material should have a sufficient shelf life—a minimum of 1 seasonal cycle.
6. The material should be applicable in ambient temperature ranges from -20 to 120 F (-29 to 49 C).
7. The material should be applicable to wet potholes, with little or no pothole preparation required.
8. Material application should not be potentially dangerous to crew in terms of toxic fumes, flash point, or other dangers to health and safety.
9. The material and its application should not cause significant air pollution or water pollution from leachate runoff.
10. The material should not require elaborate mixing and heating procedures at the scene, and, if possible, the process should use commercially available equipment.

Material Requirements

11. The material should be less susceptible than currently available materials to temperature variations for a number of properties such as flexibility, ductility, penetration, and viscosity.
12. The 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. The materials should have increased adhesion and bonding to edges of pothole or surface of pavement (in surface patching) and to aggregate and chips.

14. The material should have comparable resistance to both abrasion and penetration.

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

16. The material should be resistant to deicing chemicals and at least as resistant to petrochemicals as surrounding pavement.

17. The material should not degrade under sustained heating for at least 1 work shift; similarly, material should not degrade significantly upon reheating the material at least once prior to application.

LABORATORY DEVELOPMENT

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 called) are divided into 5 main groups, 4 of which differ primarily in their acetate content. The fifth group differs from the others 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. Previous development work in the area of EVA-asphalt compositions by the Stanford Research Institute employed the Elvax series of EVA resins. For comparative purposes, the Elvax resins were used in this development work. Keith Brinker and George Rears of E. I. du Pont de Nemours and Company, specialists in the ethylene-vinyl acetate copolymers used, gave us the technical insight into thermoplastic asphalt that permitted a successful material to be developed. Their contributions were all donated to the project by Du Pont.

Four grades of paving asphalt from the Newhall Refinery at 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, which conducted earlier research in this area.

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 to 12 minutes at a speed of 800 to 1,000 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).

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 16 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 percent) 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 10 asphalt-Elvax resin blends were 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 percent modulus, and tear strength. Table 1 gives the results of these tests. Testing methods used were ASTM except as otherwise noted in Table 2.

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 2 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 with hot aggregate resulted in a material with much the same handling characteristics and appearance of conventional hot-mix asphalt. A 5 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 5 percent addition of 85-100 penetration asphalt to the same aggregate.

Based on 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), which is related to low-temperature susceptibility and handling properties based on phase separation tendencies, ease of mixing, and tractability.

Using these key performance parameters, one of each of the 5 groups of Elvax resins was selected for further testing at a 20 percent 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 3 summarizes these physical properties.

The 5 Elvax resins that were rejected were done so 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; and
5. Elvax EP-4824—poor handling and application properties due to very high melt viscosity, material very difficult to mix.

Because 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 $1\frac{1}{2} \times 1\frac{1}{2} \times 3$ in. ($38 \times 38 \times 76$ mm), from a slab of asphalt pavement. A thin layer of hot liquid EVA-modified asphalt was spread across the center half of each of the rectangular faces of 2 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 24 hours before testing. Once stabilized, the blocks were placed in an Instron tester and pulled apart at a crosshead speed of 0.05 in. per minute (0.127 mm per minute). 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 percent Elvax resin modifications of 85-100 penetration asphalt were tested in this manner with the results given in Table 4; 85-100 pene-

Table 1. Physical properties of 40 percent weight modifications of 85-100 penetration grade asphalt with Elvax resins.

Elvax Resin	Viscosity at 300 F (149 C), poises	Hardness, Shore A	Penetration at 77 F (25 C)	Tensile Strength, psi (kg/cm^2)	Tear Strength, lb/in. (kg/cm)	100 Percent Modulus, psi (kg/cm^2)	Elongation, percent
40	208	20	41	158 (11.06)	24 (4.29)	28 (2.0)	1,150
150	272	25	33	204 (14.28)	35.5 (6.34)	35.5 (2.49)	1,175
220	101	35	29	94 (6.58)	32.5 (5.70)	54.5 (3.82)	900
240	144	41	26	260 (18.20)	52.2 (9.32)	69.6 (4.87)	1,000
310	69	27	42	3 (2.17)	16.5 (2.95	30 (2.10)	175
350	544	48	23	269 (18.83)	62 (11.07)	94 (6.58)	975
420	208	48	24	98 (6.86)	41.4 (7.39)	88 (6.16)	250
4310	91	27	41	52 (3.64)	12.3 (2.20)	52 (3.64)	100
4320	208	38	30	62.3 (4.36)	26.8 (4.78)	57 (3.99)	350
EP-4824	880 at 400 F (204 C) only	72	11	207 (14.49)	72.3 (12.91)	179 (12.53)	250

Table 2. Laboratory test methods.

Property	Method	Remarks
Viscosity	—	HBF Brookfield Viscosimeter; spindle 3 at 10 rpm; temperature of material: 300 F (149 C)
Hardness	ASTM D 2240	
Penetration	ASTM D 5	Penetration at 100 F (38 C); 50 g weight, 5 seconds Penetration at 77 F (25 C); 100 g weight, 5 seconds Penetration at 32 F (0 C); 200 g weight, 5 seconds
Tensile strength	ASTM D 638	
Elongation	ASTM D 638	
Tear strength	ASTM D 638	
100 percent modulus	ASTM D 638	
Interfacial adhesion	—	As described in report
Uniformity	—	As described in report

Table 3. Physical properties of 20 percent weight modifications of 85-100 penetration grade asphalt with Elvax resins.

Elvax Resin	Viscosity at 300 F (144 C), poises	Hardness, Shore A	Penetration			Tensile Strength, psi (kg/cm^2)	Tear Strength, lb/in. (kg/cm)	100 Percent Modulus, psi (kg/cm)	Elongation, percent
			100 F (38 C)	77 F (25 C)	32 F (0 C)				
150	14.4	15	127	95	9	32 (2.24)	10.2 (1.82)	10 (0.7)	1,550
240	16.0	22	76	61	9	35.8 (2.50)	13.8 (2.46)	22 (1.54)	1,250
350	21.6	30	50	42	9	155 (10.9)	13.0 (2.32)	48 (3.36)	1,050
420	19.2	35	56	32	8	28 (1.96)	10.5 (1.88)	—	90
4320	22.4	17	123	57	11	18 (1.26)	8 (1.43)	17 (1.19)	500

Table 4. Interfacial adhesion of 20 percent weight modifications of 85-100 penetration grade asphalt with Elvax resins using Burbank pavement blocks.

Elvax Resin	Force Required to Separate Blocks, psi (kg/cm^2)	Nature of Failure
150	19 (1.33) at 77 F (25 C)	100 percent cohesive failure in binder
	124 (8.68) at 0 F (-18 C)	85 percent cohesive failure in binder, 15 percent cohesive failure in pavement
240	44 (3.08) at 77 F (25 C)	95 percent cohesive failure in binder, 5 percent adhesion failure to pavement
	156 (10.92) at 0 F (-18 C)	90 percent cohesive failure in binder, 10 percent adhesion failure to pavement
350	34 (2.38) at 77 F (25 C)	98 percent cohesive failure in binder, 2 percent adhesion failure to pavement
	96 (6.72) at 0 F (-18 C)	95 percent cohesive failure in binder, 5 percent adhesion failure to pavement
420	20 (1.40) at 77 F (25 C)	100 percent cohesive failure in binder
	180 (12.60) at 0 F (-18 C)	85 percent cohesive failure in binder, 15 percent cohesive failure in pavement
4320	12 (0.84) at 77 F (25 C)	100 percent cohesive failure in binder
	156 (10.92) at 0 F (-18 C)	100 percent cohesive failure in binder
Control	22 (1.54) at 77 F (25 C)	100 percent cohesive failure in binder
	90 (6.30) at 0 F (-18 C)	100 percent cohesive failure in binder

Note: All specimens pulled at a crosshead speed of 0.05 in. (0.127 cm) per minute.

tration asphalt was used as a control. As can be seen, the modified asphalts exhibited superior adhesion. 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. Figure 1 shows that considerably more work is required to separate blocks bonded together 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 5 seconds each. Figure 2 shows that the modified asphalts have much flatter penetration curves or profiles than 85-100 penetration asphalt, which indicates lower temperature-susceptibility.

Based on the various test results, cost considerations, and handling properties, it was decided that a 20 percent 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 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 percent weight modification of 85-100 penetration asphalt by Elvax 40 with the combination reduced to 60 percent 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 6-gallon (22.7-litre) container fitted with a 3,000-watt snap-on band-type pail heater. The asphalt temperature was brought up to 300 F (149 C) with a slow stirring. When the temperature was reached, the Elvax resin pellets were added slowly while mixing at 400 to 500 rpm. After all the resin was added, the mixing speed was increased to 700 to 800 rpm and maintained until results of the uniformity test discussed earlier were satisfactory. Typical mixing times at the higher speeds ranged from 5 to 10 minutes.

For mixing the modified asphalt with aggregate, a steam-jacketed rotating vertical blade mixer of 80-gallon (303-litre) capacity proved satisfactory. The aggregate could be preheated to 300 F (149 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 F (149 C) and added to the hot aggregate while mixing. Within 7 to 10 minutes, the binder had completely and uniformly wetted out the aggregate.

The aggregate/binder mix ratio was 19/1 by weight. Before filling into 5-gallon pails at 60 lb (132 kg) each, the mixed material was checked for appearance and uniformity and was satisfactory. In this manner, 1,500 lb (3300 kg) of each Elvax resin-asphalt-aggregate composition was made in 500-lb (1100-kg) batches.

Additional development work of a supplementary nature was conducted. This consisted of evaluating Elvax 150 and 420 as 20 percent 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. Table 5 shows that the lower penetration grade asphalt

Figure 1.
Comparative interfacial adhesion curves at 77 F.

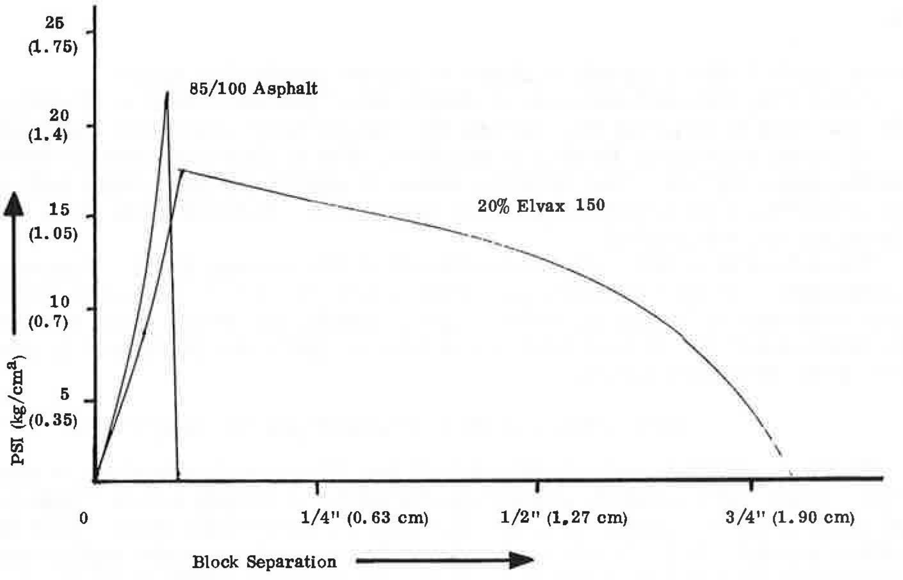
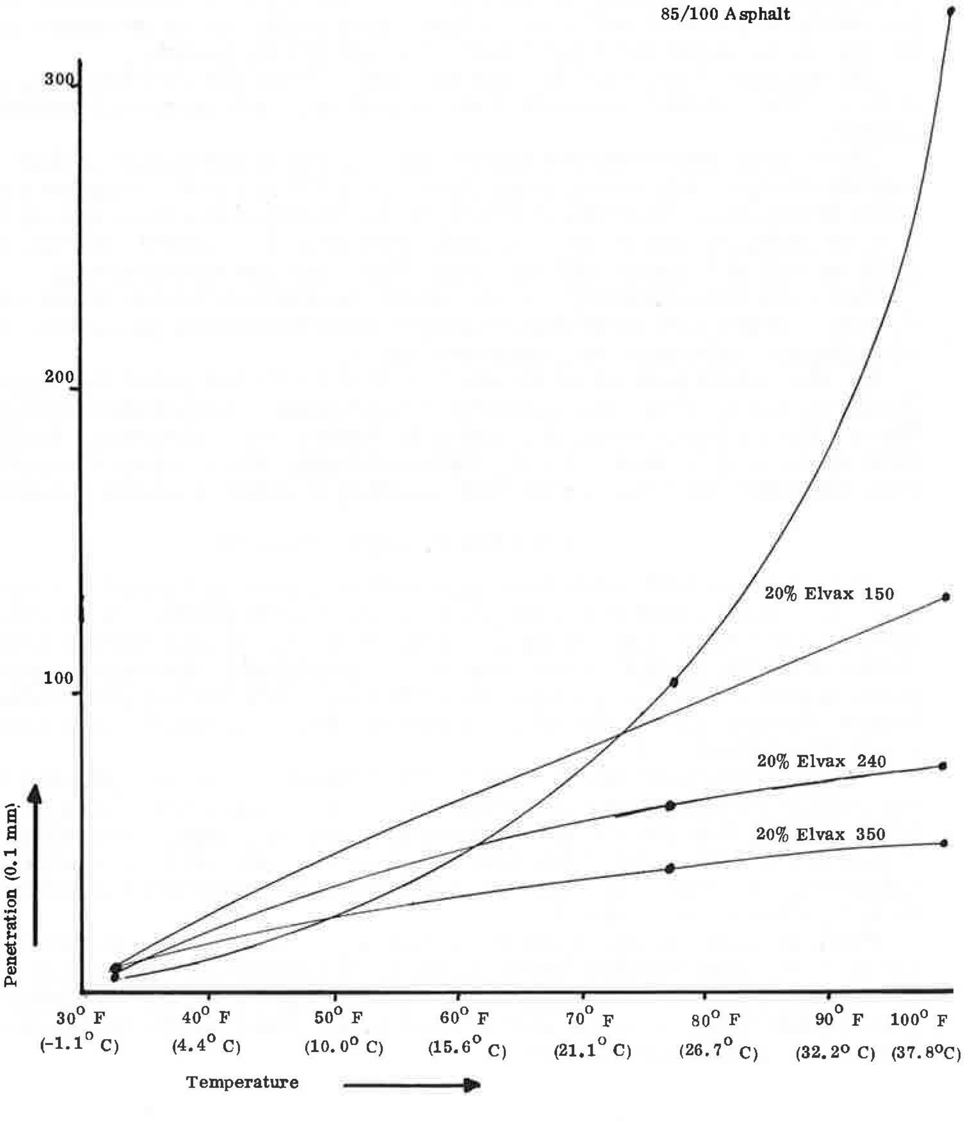


Figure 2.
Comparison of penetration profiles of EVA-modified asphalt with unmodified asphalt.



gives much better properties than the higher penetration grade.

Elvax 150, 350, and 420 were evaluated as 10 percent 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 2 standard modified asphalt compositions (20 percent 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 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 the EVA resin, available from Du Pont, asphalt, available from the refinery, and aggregate, available from local sources.

The kinds of equipment necessary to produce the binder portion include mixers capable of vigorously mixing large quantities of 200 to 10,000 centipoise viscosity material at temperatures of 300 to 325 F (149 to 163 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 suited to local producers and the latter to regional producers. Incorporation of aggregate would use conventional equipment.

Quality control procedures involve testing at 3 different points during manufacture. First, all raw materials are checked for conformance with published specifications. Second, the EVA-asphalt blend is tested for hardness or 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 on the end use. As a premix with aggregate, it can be supplied as precast blocks or as ¼ to ½-in. (0.63 to 1.27-cm) 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 material 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 the proper temperature is reached, 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.

Table 5. Physical properties of 20 percent EVA modifications of different grades of asphalt.

Elvax Resin	Asphalt Grade	Viscosity at 300 F (149 C), poises	Hardness, Shore A	Penetration 100 F (38 C)	Penetration 77 F (25 C)	Penetration 32 F (0 C)	Tensile Strength, psi (kg/cm²)	Tear Strength, lb/in. (kg/cm)	100 Percent Modulus, psi (kg/cm²)	Elongation, percent
420	40-50	37	53	62	28	13	66 (4.62)	20 (3.57)	66 (4.62)	1,200
150	40-50	35	16	176	58	22	37 (2.59)	7.55 (1.35)	9.4 (0.658)	1,500
420	200-300	14.8	23	131	57	26	20 (1.4)	6.32 (1.16)	20 (1.4)	600
150	200-300	21	1		98	45	—[a]	—[a]		—[a]

[a]Unable to fabricate specimens; material extremely soft and tacky.

Table 6. Results of field test application at Burbank.

Hole No.	Hole Type	Patch Composition	Appearance[a] 24 Hours	48 Hours	1 Week	2 Weeks	1 Month	2 Months
1	Wet with primer	Elvax 420 premix at 285 F (141 C)	NC	NC	NC	NC	NC	S-SR
2	Wet without primer	Elvax 420 premix at 290 F (143 C)	NC	NC	NC	S-ER	S-ER	S-ER
3	Dry with primer	Elvax 420 premix at 285 F (141 C)	NC	NC	NC	NC	NC	NC
4	Dry without primer	Elvax 420 premix at 280 F (138 C)	NC	NC	NC	S-ER	S-ER	S-ER
5	Dry layer with primer, cold aggregate	Elvax 420 premix at 280 F (138 C)	NC	NC	S-D	B, D	B, D	Replaced
6	Dry layer without primer, hot aggregate	Elvax 420 premix at 280 F (138 C)	NC	NC	S-D	B, D	B, D	Replaced
7	Wet with primer	Elvax 150 premix at 285 F (141 C)	NC	NC	NC	NC	NC	NC
8	Wet without primer	Elvax 150 premix at 285 F (141 C)	NC	NC	NC	NC	NC	NC
9	Dry with primer	Elvax 150 premix at 290 F (143 C)	NC	NC	NC	NC	NC	NC
10	Dry without primer	Elvax 150 premix at 290 F (143 C)	NC	NC	NC	NC	NC	NC
11	Dry layer with primer, cold aggregate	Elvax 150 premix at 280 F (138 C)	NC	NC	D	H-B, H-D	H-B, H-D	Replaced
12	Dry layer without primer, hot aggregate	Elvax 150 premix at 280 F (138 C)	NC	NC	D	S-B, S-D	B, D	Replaced
13	Dry layer with primer, cold ³/₈-in. rocks	Elvax 150 premix at 280 F (138 C)	NC	NC	SR	D	D	Replaced
14	—	Standard hot mix	NC	NC	NC	NC	NC	NC

[a]NC = no change, ER = edges raveling, SR = surface raveling, D = dishing, B = bleeding, H = heavy, S = slight.

Table 7. Results of field test application at South Lake Tahoe.

Hole No.	Hole Type	Patch Composition	Appearance[a] 24 Hours	48 Hours	1 Week	2 Weeks	1 Month	2 Months
1	Wet with primer	Elvax 420 premix at 270 F (132 C)	NC	NC	S-SR, S-ER	S-SR, S-ER	S-SR, S-ER	S-SR, S-ER
2	Wet without primer	Elvax 420 premix at 280 F (132 C)	NC	NC	S-SR, S-ER	S-SR, S-ER	S-SR, S-ER	S-SR, S-ER
3	Dry with primer	Elvax 420 premix at 280 F (132 C)	NC	NC	S-ER	S-ER	S-ER	S-ER
4	Dry without primer	Elvax 420 premix at 275 F (135 C)	NC	NC	S-ER	S-ER	S-ER	S-ER
5	Dry layer with primer, hot aggregate	Elvax 420 premix at 240 F (116 C)	NC	NC	D	D	D	D
6	Dry layer without primer, hot aggregate	Elvax 420 premix at 240 F (116 C)	NC	NC	D, S-ER	D, S-ER	D, S-ER	D, ER
7	Wet with primer	Elvax 150 premix at 300 F (149 C)	NC	NC	NC	NC	NC	NC
8	Wet without primer	Elvax 150 premix at 300 F (149 C)	NC	S-ER	S-ER	S-ER	S-ER	S-ER
9	Dry with primer	Elvax 150 premix at 290 F (143 C)	NC	NC	NC	NC	NC	NC
10	Dry without primer	Elvax 150 premix at 290 F (143 C)	NC	S-ER	S-ER	S-ER	S-ER	S-ER
11	Dry layer with primer, hot aggregate	Elvax 150 premix at 220 F (104 C)	NC	D	D		D	D
12	Dry layer without primer, hot aggregate	Elvax 150 premix at 200 F (93 C)	NC	D	D		D	D
13	—	Standard hot mix	NC	NC	NC		NC	NC

[a]NC = no change, ER = edges raveling, SR = surface raveling, D = dishing, B = bleeding, H = heavy, S = slight.

Table 8. Results of field test application at Anchorage.

Hole No.	Hole Type	Patch Composition	Appearance[a] 24 Hours	48 Hours	1 Week	2 Weeks	1 Month	2 Months
1	Wet without primer	Elvax 420 premix at 265 F (129 C)	NC	S-ER	S-ER	S-ER	S-ER	S-ER
2	Wet with primer	Elvax 420 premix at 265 F (129 C)	NC	S-ER	S-ER	S-ER	S-ER	S-ER
3	Dry without primer	Elvax 420 premix at 265 F (129 C)	NC	S-ER	S-ER	S-ER	S-ER	S-ER
4	Dry with primer	Elvax 420 premix at 265 F (129 C)	NC	NC	S-ER	S-ER	S-ER	S-ER
5	Wet without primer	Elvax 150 premix at 300 F (149 C)	NC	NC	NC	NC	NC	NC
6	Wet with primer	Elvax 150 premix at 280 F (138 C)	NC	NC	NC	NC	NC	NC
7	Dry without primer	Elvax 150 premix at 290 F (143 C)	NC	NC	NC	NC	NC	NC
8	Dry with primer	Elvax 150 premix at 290 F (143 C)	NC	NC	NC	NC	NC	NC
9	—	Standard hot mix	NC	NC	NC	NC	NC	NC

[a]NC = no change, ER = edges raveling, SR = surface raveling, D = dishing, B = bleeding, H = heavy, S = slight.

When 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-in. (5-cm) courses of patching material as necessary are hand-tamped into place, the final course being finished off with a few passes from a heated roller.

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, preliminary field test applications were conducted in Burbank, South Lake Tahoe, and Anchorage. The last 2 sites were chosen for the severe freeze-thaw temperature variations that occur.

At each test site, dish-shaped holes 16 to 18 in. (41 to 45 cm) in diameter by 4 to 6 in. (10 to 15 cm) in depth were cut into existing pavement in a wheelpath. These potholes were then swept free of debris in a cursory manner. Four basic types of potholes were filled at each site: dry with and without primer applied to the sides and wet with and without primer applied. The materials used at each site were aggregate-filled patching compositions using the 20 percent weight modification of 85-100 penetration asphalt with Elvax 150 and with Elvax 420 as the binder. Thus, 2 different patching compositions were tested in 4 different types of holes.

At Burbank and at South Lake Tahoe, additional holes of the 4 types were patched using a layering technique consisting of pouring alternate 2-in. (5-cm) layers of aggregate, ¼ to ⅜ in. (0.63 to 0.95 cm) in size, and hot binder in primed and unprimed holes for both material compositions.

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 5-gallon pails and had to be heated to 275 to 325 F (135 to 163 C) before applying. The same requirement held for the straight binder that was supplied in 1-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. In Burbank, the pails were heated to 325 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 to be very slow. The premixed material was finally brought up to application temperature at the site by charging 2 pails of the material at a time to 2 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, a large electric oven was made available by 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 F (204 C) that was part of a truck-mounted small asphalt hot-mix plant. Obviously, equipment requirements need further evaluation.

At each site, the premixed material, when heated to application temperature, was put down in 2-in. (5-cm) courses and hand-tamped until the hole was filled. The top surface was then finished off by passing a heated roller across it several 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 2 binders were observed when holes were patched using the layering technique described earlier.

The performance results of the test patches at each site were monitored and evaluated. Tables 6, 7, and 8 give the results of 2 months' 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 slight raveling at edges and on surfaces. 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 are not doing well and have been replaced in Burbank after about 2 months. Holes filled using dense-graded aggregate dished and became concave and exhibited 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 2 standard binders and a binder consisting of a 20 percent 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 2 months' testing, the 20 percent weight modification of 40-50 penetration asphalt with Elvax 420 continued 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, the aggregate was charged to the heater-mixer and within ½ 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 7 to 10 minutes. A rectangular saw-cut hole 1 × 2 × ½ ft (30.5 × 61 × 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 1 hour, which is almost twice as long as the aggregate alone. The large size of the lumps—approximately 2 in. (5 cm)—may well have impeded the heat transfer. A hole identical to the first one was filled with the material using the same techniques. Both test patches are holding up well.

COST-EFFECTIVENESS ANALYSIS

A cost-effectiveness analysis was conducted comparing total street patching costs (materials, equipment, and labor) using standard patching materials with total costs using the thermoplastic asphalt material. This analysis was based on cost data collected from 12 cities from various regions of the country and of various population sizes. The analysis is reported in detail elsewhere (2).

The relative cost benefits of 3 alternative cases for processing the material are analyzed: case 1, where the city purchases the EVA, the asphalt, and the aggregate and performs all material processing; case 2, where the city purchases the EVA-asphalt binder and mixes it with the aggregate; and case 3, where the city purchases the material ready-made.

The cost analysis shows that, assuming equal road life of the current and new materials, the costs are as follows:

Method	Annual Total Recurring Cost Per Ton ($)	Initial Equipment Outlay ($)
Current	47.30	None
Case 1	51.94	10,000 + 2,750 per crew
Case 2	81.63	2,750 per crew
Case 3	95.83	2,750 per crew

The road life factor required of the thermoplastic material to be as cost-effective as current materials is as follows:

Method	Required Road Life Factor
Current	1.0
Case 1	1.1
Case 2	1.7
Case 3	2.0

In other words, if the road life of patches using the new material is twice that of current materials, then the new material is as cost-effective as current materials or more cost-effective, depending on the case.

CONCLUSIONS AND RECOMMENDATIONS

Based on the laboratory development work and field test applications done to date, the User Requirements Committee reached the following conclusions:

1. Significantly improved physical properties can be imparted to asphalt by mixing with EVA resins in amounts of 20 percent 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 1 to 2 months' testing. No empirical data have been obtained regarding cold patch material, since the committee 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 condition. The potential savings of increased road-life over emergency patches offsets equipment expense.
6. Preliminary results indicate that a premixed material, pelletized by cooling under noncompacted 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 argues 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 to 325 F (127 to 163 C) at the time of application.

12. EVA-modified asphalt patching compositions can be reheated and reused several times without significant loss of properties.
13. EVA-modified asphalt has considerable potential as a crack filler.

Based on observation of thermoplastic street maintenance material developed, applied, and tested to date, the following recommendations for directions to be pursued to ultimately create a marketable, cost-effective product are proposed:

1. Research and development on temperature-susceptibility of the material, with particular emphasis on the low-temperature properties, should be continued. Investigations should determine whether it will be possible for a single material to suit both winter and summer conditions or if 2 products will be necessary.
2. Field testing should be continued and expanded. The material should be made available to at least 10 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, and turning and stopping zones.
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. The quality of the input data on cost should be refined, and a more accurate model for a city to use in determining whether or not introduction of the thermoplastic street patching material would be cost-effective should be developed.
5. Testing of patching compositions already in place at the 3 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.

ACKNOWLEDGMENTS

Carl Kay and Leandro Rodrieguez of Products Research and Chemical Corporation and Miles Greenbaum of Public Technology, Inc., had significant responsibilities for the work reported here.

The contribution of the members of the User Requirements Committee is gratefully acknowledged. Members of the committee were Richard Anderson, Deputy Assistant City Manager, Ft. Lauderdale, Florida; Joseph N. Baker, City Manager, Burbank, California; Charles W. Beagle, Director of Public Works, Woodbridge, New Jersey; Edward Clarke, Superintendent of Streets and Sanitation, Burbank, California; John T. Frawley, Public Service Director, Bangor, Maine; Bob Gallaway, Texas Transportation Institute, College Station, Texas; Allan F. Hendrickson, Public Works Director, South Lake Tahoe, California; William D. Hurst, Consultant, Winnipeg, Canada; Edward Koonce, Manager, Maintenance and Operations Division, Anchorage, Alaska; John T. Kyle, Commissioner of Operations, Winnipeg, Canada; Charles H. McDonald, Engineering Supervisor, Phoenix, Arizona; James C. Smith, City Manager, New Carlisle, Ohio; H. James Spelman, Engineer of Street Construction and Maintenance, District of Columbia; Donald H. Swets, Director of Public Works, Kalamazoo, Michigan; and John A. Teipel, Director, Department of Streets and Sanitation Services, Dallas, Texas.

REFERENCES

1. Rostler, F. S. An Annotated Bibliography on Use of Rubber Asphalt Pavements. Materials Research and Development, Inc., Oakland, Calif., May 1971. NTIS PB 206 965.
2. Development and Evaluation of Thermoplastic Street Maintenance Material. Submitted by Public Technology, Inc., to the National Aeronautics and Space Administration, July 1973.