A New Patching Material for Pavement Failures

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The increasing volume of traffic, and particularly heavy traffic, has created a severe problem on many roads and streets in the country. This problem has resulted from elastic type failures in a "chicken wire," or "alligator" pattern cracking. The cracking is caused by fatigue of the surface from repeated deflection. Repairs by overlaying are usually effective for a short period only and many other more drastic measures are too expensive and often also ineffective.

This paper is about the successful search for a material which can be used for repairing this type of failure at reasonable cost. It involves a thin application of a hot compound of asphalt and rubber that has high elasticity and flexibility together with low temperature susceptibility. The use of aggregate is not the dominant feature in this process as it is used only to prevent pick up and excessive wear. As far as the author has been able to determine, the use of the material in this manner is unique. The experiment involved has been in place long enough to demonstrate its worth, and it should prove to be a new weapon in the hands of maintenance forces against the ever-increasing deterioration of our roads and streets.

THE so-called "flexible-type pavement" is actually not a particularly flexible structure; there are occasions when it could be classed as very brittle, particularly in cold weather or when the surface has suffered a long period of embrittlement from oxidation and age. The cracking caused by this lack of flexibility has created a tremendous problem, when considered on a nationwide scale. In traveling over the streets and highways of this country, one can seldom go more than a few miles without finding distressed pavement that is basically caused by a repeated flexing of the surface under the traffic loads.

This type of failure has been variously defined as flexure cracking, elastic-type failure, and fatigue failure. It is characterized by multiple cracking of the "chicken wire," or "alligator," type pattern without plastic deformation of the surface. The cracking is due to fatigue of the bituminous mixture from repeated deflection under load and subsequent recovery of the surface, which in turn is caused by elasticity of some member of the substructure. It is the most prevalent of the three most common types of failure occurring in flexible-type pavements. The others are the following.

1. The plastic type, which is manifested by cracking of the same character as the elastic-type of failure, but is also accompanied by plastic deformation of the surface. The surface is depressed under the loaded area and usually slightly raised at one or both sides of the loaded area. This type is usually caused by inadequate thickness of base material and is no longer a serious problem on highways or streets built under modern design criteria.

2. The surface-type failure, which is characterized by attrition, or stripping and emulsification of the asphalt in the surface of the pavement. There is raveling and loss

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of material from the surface but no significant amount of cracking. Although this type of failure is very common, it is not as serious as it can be corrected by the application of a seal coat.

Fatigue cracking resulting from the elastic-type failure is entirely different, and solutions have not only been difficult and expensive, but in many cases quite uncertain in their results because there is resilience in some member of the substructure. This resilience must be counteracted by either making the substructure or the surface so rigid that it cannot bend, or by making the surface so flexible that it will take the bending. Part of the problem lies in the fact that the deflections required to produce the elastic-type failure are so small that almost complete elimination of the resilience is required. Repeated deflections of a very small order are sufficient to produce this type of failure. Various authorities (2, 3), have given figures for a critical deflection which range from 0.010 to 0.050 in. with the certain probability that the critical deflection would vary considerably for pavements of different thickness, composition (7), asphalt grade, asphalt content, asphalt quality, prevailing temperatures, and radius of the deflection curve.

Complicating the problem is the fact that the source of such a small magnitude of elasticity may be difficult to determine. It may be either in the subgrade, subbase, or base course. An increase in the normal moisture content of even a good subgrade (for instance, by frost action) may cause it to become "quickie," resulting in a condition where the load is borne by hydrostatic pore pressure. Although such a condition does not ordinarily last for a long time, there is almost no reasonable thickness of overlying material that will prevent the deflection. The surface of a 4-ft fill over a quickie soil has been observed to visibly deflect under load. This condition also develops in densely graded base courses through frost action.

Certain materials present in soils, such as mica, have elasticity within themselves, and the economic necessity of using local materials may require that these materials be incorporated in the substructure. Such materials are often the only ones available in the particular area without incurring excessive cost. Perhaps the most common cause is entrapment of minute quantities of air (1) in fine-grained subgrade soil. Any soil which is capable of moderate capillary pressure can entrap air under certain moisture conditions by holding it in pores which are sealed on all sides by capillary moisture. The capillary pressure is sufficient to prevent the air from being expelled under traffic loading. If enough of these entrapped air cells are involved, the structure has a pneumatic character. In extreme cases such soils have an almost rubber-like elasticity when pressed between the fingers. The moisture content need only be slightly above optimum to entrap air. This type of soil is surprisingly prevalent throughout the United States.

The increasing use of cement-treated bases is, I believe, whether recognized or not, an attempt to overcome this problem of substructure elasticity by stiffening that structure. The so-called "up-side-down" method of construction in which the subbase is cement-treated, rather than the base, is a quite obvious attempt to stiffen the substructure against resilience from an underlying member. This is practiced rather commonly in New Mexico (4) and Arizona (5). Incidently, I have observed that this type of treatment has been quite successful.

The use of rigid portland cement concrete pavements has also been quite effective; however, the cost is generally prohibitive for indiscriminate use. Again, the obvious motive is to make the structure so rigid that it will not be affected by resilience of the substructure.

An attack against this type of failure has also been mounted from the other standpoint of attempting to make the bituminous mixture more flexible (6). This has been done by the use of open-graded plant mixes employing very heavy asphalt films on each particle. These mixes have large void spaces so that the high asphalt content, in relation to surface area, will not cause distress. This type of design has helped to ameliorate the situation but has not been a cure all.

Similarly, small percentages of rubber incorporated in mixes have also been used. These small percentages of rubber have undoubtedly been beneficial, although information on the degree of success obtained with these mixes for this purpose appears to be

somewhat limited. It is also my opinion that the cost of these materials has prevented the use of rubber in the amounts necessary to give the pavement true elasticity.

EXPERIMENTAL APPROACH

An entirely new approach was needed, and the approach employed in the experiments described in this paper is completely different in its use of rubber from anything which I have read. This approach embodies the use of a relatively high percentage of rubber, combined with asphalt, in a relatively thin application. The purpose is to keep the overall cost in bounds but still obtain maximum elasticity of the patching material. Although this approach may be unique, it is to this date completely successful in some extremely difficult situations. The cost is not out of line with heavier overlays which are commonly used, generally unsuccessfully, in combating this problem. It must also be remembered in maintenance repair work that the cost of the materials is a relatively minor item. The big cost is the labor involved, and anything that will eliminate repeated repairs to the same distressed area is cheap.

We found in the laboratory that a rubber-asphalt material could be made that had a consistency of thick slurry when hot. By experimentation it was found that the best consistency for our purpose was obtained by heating 85-100 penetration grade asphalt to approximately 420 deg and then stirring into it partially devulcanized reclaimed rubber (a commercial product) in the proportion of 2 parts of asphalt to 1 part of rubber. Copies of this series of laboratory tests are attached in the Appendix. These tests show that the consistency depends not only on the rubber content, but also on the degree of the solution, or "jelling," of the rubber. The higher the temperature of the mixing, the greater the degree of the solution of the rubber in the asphalt and the more nearly the end product resembles the properties of rubber rather than asphalt. In other words, when the material is mixed at a temperature of 350 F it is quite fluid and has the consistency of a thin slurry. This would be very convenient for placing; on the other hand, it would be more temperature susceptible so that it would tend to bleed more readily in the summer, and it would have less elasticity than the thicker product. The same may be said for reducing the rubber content. In other words, it can be made at any consistency desired but it must be remembered that in doing so the properties of the final product will be changed. The thinner the product, the more nearly its properties will resemble those of asphalt; the thicker the product, given the same proportions, the more they will resemble those of rubber.

Other laboratory mixes were made using synthetic rubber latex mixed with emulsified asphalt and sand in various proportions so as to form a slurry seal type of material. The mixture of this type considered best for the purpose of the experiment consisted of 2 parts of SS-1H emulsified asphalt to 1 part of synthetic rubber latex emulsion, with concrete sand added in sufficient quantity to make a slurry consistency. The details on this are also given in the Appendix.

At a later date it was decided to experiment with a mixture of 85-100 penetration grade asphalt and ordinary reclaimed rubber obtained from a local vulcanizing shop. This was a finely granulated product obtained from the buffing of tires for recapping. This material was also mixed in the proportion of 2 parts of 85-100 penetration grade asphalt to 1 part of reclaimed rubber. Experiments indicated that when this material was heated over 440 F the final product was softened to an undesirable extent. This was contrary to what we had found with the partially devulcanized product. Heating to approximately 420 F produced the most desirable results (see Appendix).

FIELD SURVEY

After studying the results of this work, a field survey was made to determine the location of the most severe test conditions that could be found so that the answers to the experimental work would be quickly forthcoming. The criteria were to locate pavements where the traffic was heavy, preferably with a high percentage of heavy truck traffic, and severe elastic-type failure had already occurred. An area where poor drainage was involved was also desirable for our purpose and one of the test areas did have exceedingly poor drainage (Fig. 1).

Figure 1. General area occupied by test panels Nos. 4,5,6, and 10, showing poor drainage.

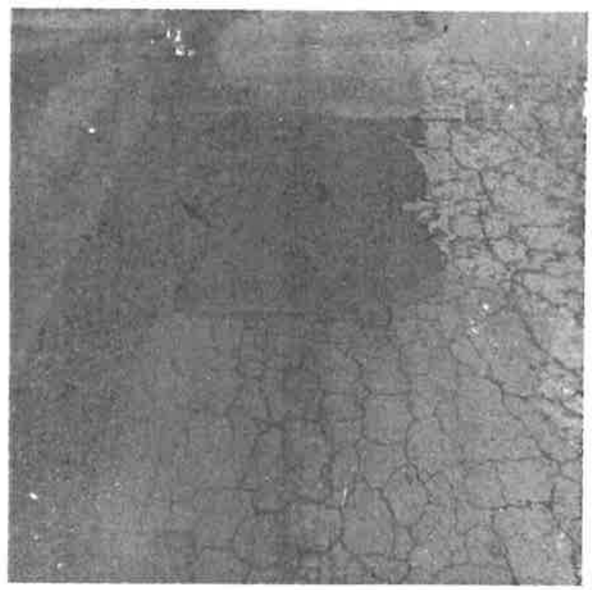

Figure 2. Test panel No. 11, showing reclaimed rubber asphalt still in good condition, whereas sand-asphalt patch is failing.

The locations, all in the city of Phoenix, selected for the various test panels were as follows.

1. Test panels Nos. 1, 2, 3, 4, 5, 6, 7, and 10 were on Seventh Street just south of Jefferson Street where the traffic volume numbered 13,200 veh/day, a large proportion of which were trucks as this street serves an industrial area. The pavement

Figure 3. Test panel No. 9 showing superior condition of rubber-asphalt repair.

Figure 4. Test panel No. 9 (in background) showing arrest of cracking.

surface was generally covered by alligator-pattern cracking in an advanced state and the drainage was extremely poor. The cracking pattern was similar to that shown in Figure 2, and Figure 1 shows the poor drainage.

2. Test sections Nos. 8 and 9 were located on north Central Avenue with daily traffic volumes of 30,800 and 38,400, respectively. Most of this traffic is of passenger type. There was severe alligator-type cracking in the wheel tracks but it was not spread as generally over the street as in the previous case. Test panel No. 9 (Fig. 3) shows par-

tially devulcanized rubber-asphalt patch in foreground and slurry seal patch, made approximately one week later, in background. The rubber-asphalt repair is clearly superior. In Figure 4 test panel No. 9 shows the arrest of cracking with less than a ¼-in. thickness of partially devulcanized rubber-asphalt compound.

3. Test panel No. 11 was placed on Washington Street which has a traffic count of 18,500 veh/day. Many of these vehicles are of the commercial and industrial type. This section was in an area which had given continuous trouble for some time. Figure 2 shows test panel No. 11 in upper center and hot mixed sand-asphalt patch in lower half; both were placed the same day but the reclaimed rubber asphalt is still in good condition whereas the sand asphalt patch is failing.

Details on all of the foregoing test panels are given in Appendix A; however, a brief resume of their performance is related here. Test panel No. 1 consisted of ½ gal/sq yd of a 50-50 mixture of SS-1H emulsified asphalt and rubber latex emulsion sanded to prevent pickup. The panel was lost due to insufficient curing time before the entry of traffic which destroyed it. It was replaced by a conventional sand asphalt mix placed by maintenance crews on the following day.

Test panel No. 2 consisted of 1 gal/sq yd of a 50-50 mixture of SS-1H asphalt emulsion and synthetic rubber latex emulsion mixed with sand to slurry consistency. Here again the panel was torn up by traffic before it could properly set. Maintenance crews placed a conventional sand asphalt mix over this patch area the following day.

Test panel No. 3 directly adjoined the first two to the south and consisted of 1 gal/sq yd of a mixture composed of 2 parts of 85-100 penetration grade asphalt and one part partially devulcanized reclaimed rubber. One-quarter inch maximum-sized, clean-cover aggregate was spread over the surface and tamped into the material. Approximately three weeks after placement the area was subjected to 58 hr of steady rain and partial inundation while being pounded by traffic. The test section was unaffected; however, the conventional sand-asphalt mixes which had been placed over the adjoining panels, Nos. 1 and 2, were cracking. They were also raveling due to partial emulsification of the asphalt. A few months later these patches were almost completely destroyed, but the rubber asphalt mixture on test panel No. 3 showed no reflection cracking from the underlying cracks or any other distress.

Test panel No. 4 consisted of the same material as No. 3 and was subjected to the same conditions. It is still in good condition. Traffic can be allowed on these materials as quickly as they have cooled—quite an advantage on a heavily traveled city street.

Test panel No. 5 consisted of 1 part of synthetic rubber latex emulsion, 2 parts of SS-1H emulsified asphalt and 6 parts of slurry sand placed at the rate of 1 gal/sq yd. Traffic was permitted to use it after 2 hr of curing. This panel failed approximately 2 weeks after placement after being under constant rain and partial inundation for 40 hr while subjected to heavy traffic. It appeared that the asphalt component had re-emulsified, leaving a porous skeleton of rubber strands which were destroyed by the traffic. The failure of the SS-1H and synthetic rubber latex with slurry sand in test panel No. 5 is not believed to be significant insofar as a normal condition is concerned. This material had very good elasticity, and, had the drainage situation been normal, there is little doubt that it would be in service today and probably resisting flexure cracking as well as the other rubber-asphalt panels. That experiment should be repeated at another location.

Test panel No. 6 was made from a proprietary emulsion of latex and asphalt (Indaco 200) applied at the rate of 1 gal/sq yd and cover aggregate was added. It was allowed to cure for 2 hr before being subjected to traffic. It shows no distress.

Test panel No. 7 consisted of the same material as test panels Nos. 3 and 4. However, it was spread at a different rate than the foregoing panels which would average approximately 0.18 in. in thickness for a rate of 1 gal/sq yd. This panel was spread to a depth of ¼ to ½ in. thick and followed with ¼-in. cover aggregate rolled with a steel roller. This panel is also in good condition as of this writing.

Test panel No. 8 was similar to test panel No. 7 as it was made of the same material and was spread to the same thickness but in an entirely different location area. It is in fair condition but shows some distress. While rolling it with a steel roller to set the

cover aggregate, some of the hot mixture was squeezed up through the cover aggregate and the roller picked it up, creating a bald spot or two. This did not appear to affect the properties of the patch, but rolling the material when it was too hot caused uneven penetration into the cover aggregate, resulting in a certain roughening of the surface texture. This roughness eventually ironed out under traffic.

Test panel No. 9 again consisted of 2 parts of 85-100 penetration grade asphalt and 1 part of partially devulcanized reclaimed rubber, a commercial product, spread at the rate of 1 gal/sq yd of mixture followed by a cover aggregate. This was placed over a portion of a long strip of failed area. The remaining portion of this strip was repaired by a conventional maintenance slurry seal patch approximately a week later. The slurry seal patch had already shown distress only a week after replacement, and had completely failed after a few months (Fig. 3). It was replaced April 14, 1965, by maintenance forces with a hot asphaltic-concrete mix. However, the rubber-asphalt test panel was still in good condition except for a few spots which had been "picked up" by the roller during placement. One of these spots is right of center, on the lower edge of Figure 3. Maintenance had also placed some slurry seal patches nearby which contained 2 percent synthetic latex emulsion but these also failed early as the rubber content was insufficient to give it the required elasticity. All of the slurry seal patches had to be completely replaced approximately three months after placement. The test panel was in good condition except for a small exceptionally thin spot where reflection cracking showed up to a minor degree (Fig. 5). The ¼-in. cover aggregate as used in these tests was completely covered by the rubber-asphalt mixture after a few days under traffic. In the spot where the cracking occurred the aggregate had not been covered as there was insufficient material to squeeze up around it. Where normal thickness was obtained, there was no reflection cracking.

Test panel No. 10 consisted of 2 parts of 85-100 penetration grade asphalt and 1 part of locally obtained, unprocessed, shredded, reclaimed rubber from a local tire shop. The asphalt was heated to a temperature of 440 F before being mixed with the rubber and the mixture was rather soft on curing. It was also covered with ¼-in. cover aggregate and is in good condition.

Test panel No. 11 was the same as test panel No. 10 except it was placed in a different location and the asphalt was heated to a temperature of 420 F. This mixture was

Figure 5. Test panel No. 9, showing slight reflection cracking.

not as soft as that in test panel No. 10. At the same time that this panel was being placed, a maintenance crew was placing adjacent hot mix sand-asphalt patches. After approximately one month of service, these conventional patches were beginning to show reflection cracking. After another month, the reflection cracking was quite pronounced (Fig. 2). There has been no reflection cracking in the rubber-asphalt mixture to date.

A tack coat was used before placement of the experimental materials on all except the first three panels. It is deemed desirable for the best results.

Experimentation on other test panels was continued in the summer of 1965 for the purpose of observing the effects of placement of the material at elevated summer temperatures and to try out other rubber compounds. These panels (see Appendix) have not been in place a sufficient length of time to warrant conclusions.

Insofar as we have been able to judge there is no apparent difference in the performance of the panels made with the partially devulcanized reclaimed rubber, a commercial product, and the ordinary reclaimed shredded rubber obtained from a local vulcanizing shop. There is, however, a difference in the reaction of the two to the asphalt. The partially devulcanized reclaimed product seems to make a stiffer product when mixed at higher temperatures, whereas the reverse is true with the conventional reclaimed rubber (Appendix C). The ideal asphalt temperature for mixing either of these products appears to be approximately 420 F.

The temperature susceptibility of this rubber-asphalt material is far less than with asphalt alone. This is, of course, a tremendous advantage in achieving control of reflection cracking. It retains some flexibility down to approximately freezing temperatures and although it does soften under summer heat, it apparently does not pick up. The material will be quite soft to the touch when warm and show tracking under truck tires, but instead of shoving and rolling, it rebounds and tends to resume its original location. A somewhat leathery skin develops on the surface which is dry and resists pick up. It will pick up, however, if a tacky material such as asphalt is applied to this dry surface, because the bond with the underlying surface is not unduly strong due to the softness of the material.

Patching by this process is actually almost comparable to that of the manufacture and placing of slurry seal, in that a finely divided material is added to a liquid. The only difference between this process and the slurry seal is that the liquid must be hot; otherwise, it is the same. The material is smoothed out with a rubber squeegee in the same manner on the street. Although ours was strictly a hand operation, the mechanization would be similar to that used for slurry seal. The similarity, however, ends after smoothing with the squeegee. In the case of a rubber-asphalt compound, a cover aggregate surface is added to prevent traffic pick up and traffic may be allowed on it as soon as it cools which is almost immediately. Whereas, with the slurry seal a considerable curing time must elapse before traffic can be permitted to use it; otherwise it will be destroyed.

In conclusion, it appears that the use of either the partially devulcanized reclaimed rubber, a commercial product, or the conventional reclaimed rubber derived from the buffing of tires for recapping, together with 85-100 penetration grade asphalt in the proportions developed by these experiments, will prevent reflection cracking from elastic-type failures caused by fatigue cracking at very nominal cost. It is thought that this has never been achieved by skin patching with any other material. This should prove to be a boon to maintenance forces throughout the country who are plagued with repairing this type of failure.

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Appendix A

TEST PANELS OF EXPERIMENTAL PATCHING MATERIAL

<u>Test Panel No. 1</u> Placed: Dec. 16, 1964

This panel, located on 7th St. south of Jefferson, consisted of ½ gal/sq yd of a mix consisting of 1 part SS-1H (40 percent H_2O) and 1 part latex emulsion (33 percent H_2O).

Sanded to prevent pickup; traffic turned on it within ¾ hr after placing which was insufficient for curing as they promptly tore it up. A conventional mixed sand-asphalt skin patch was placed Dec. 17, 1964. Heavy rain Dec. 18, 1964.

Observed July 1, 1965. Sand-asphalt patches put in by street maintenance have completely failed and have been repatched with the same material. Some cracking is beginning to appear in the new patches.

<u>Test Panel No. 2</u> Placed: Dec. 16, 1964

This test panel, located on 7th St. south of Jefferson, consisted of 1 gal/sq yd of a mixture consisting of 1 part SS-1H (40 percent H_2O) and 1 part latex emulsion (33 percent H_2O) and concrete.

Sand added to a slurry consistency. Traffic turned on test panel within ¾ hr after placing, which was insufficient time for curing. Traffic promptly tore it up. A conventional mixed sand-asphalt skin patch was placed by street maintenance, Dec. 17, 1964. Heavy rain Dec. 18, 1964 (0.5 in.).

Observed July 2, 1965. Sand-asphalt patch placed by maintenance has been completely destroyed. This area has been repatched and some cracks are beginning to appear.

<u>Test Panel No. 3</u> Placed: Dec. 16, 1964

This panel, located on 7th St. south of Jefferson, consisted of 1 gal/sq yd of a mix consisting of 2 parts 85-100 penetration asphalt and 1 part partially devulcanized reclaimed rubber.

The mixture was applied at a temperature of 420 F and cover aggregate was spread over the surface to prevent pickup. Traffic was turned on it within ¾ hr. This was sufficient time for curing as the material set up on cooling. Test panel was in good condition 1 day later (Dec. 17, 1964). Heavy rain (Dec. 18, 1964) and traffic caused the test panel to loosen at the edges, indicating the need for a tack coat.

Observed Jan. 8, 1965. Unaffected by 58 hr of steady rain and partial inundation under heavy traffic. At this time the conventional sand-asphalt patch that had been placed over the site of test panels No. 1 and No. 2 were cracking and raveling out due to partial emusification of the asphalt.

Observed April 9, 1965. Excellent condition but adjoining conventional patches were almost completely destroyed.

Observed July 1, 1965. Panel in excellent condition. Material appears to be hardening. Moderate abrasion has occurred on west edge about 1 ft in width, no cracking visible.

<u>Test Panel No. 4</u> Placed: Dec. 23, 1964

This test panel, located on 7th St. south of Jefferson, was tacked with MC-250 liquid asphalt. The test panel consisted of 1 gal/sq yd of a mixture of 2 parts 85-100 penetration grade asphalt and 1 part partially devulcanized reclaimed rubber.

The mixture was supplied at a temperature of 420 F and cover aggregate was spread over the surface. It would have been ready for traffic as soon as it cooled but it was held off for 2 ± hr to allow adjoining sections containing emulsion to cure. Rained (Dec. 28, 1964, 0.25 in.).

Observed Dec. 28, 1964. Condition good.

Observed Jan. 8, 1964. Unaffected by 58 hr of steady rain and partial inundation under heavy traffic.

Observed July 2, 1965. Test panel in excellent condition; no stripping has occurred; no cracking present. Material is harder than more recently placed test panels. Test panel has spread to a small extent in the direction of traffic.

Test Panel No. 5 — Placed: Dec. 23, 1964

This test panel, located on 7th St. south of Jefferson, was tacked with MC-250 liquid asphalt. The test panel consisted of 1 gal/sq yd of a mixture consisting of 1 part latex emulsion (33 percent H_2O), 2 parts SS-1H emulsified asphalt (40 percent H_2O), and 6 parts slurry sand.

Latex emulsion was mixed into the SS-1H mixture. It was the consistency of slurry. Traffic was turned on it after 2 hr of curing. Rained Dec. 28, 1964 (0.25 in.). Observed Dec. 28, 1964, condition ok.

Jan. 7, 1965. This panel partly failed this morning after being under constant rain and partial inundation for 40 hr while subjected to heavy traffic. It apparently partially re-emulsified the asphalt as pieces scattered about showed a porous skeleton of rubber strands.

Observed July 2, 1965. This test panel has stripped about 75 percent. Remaining material is in excellent condition.

Test Panel No. 6 — Placed: Dec. 23, 1964

This panel, located on 7th St. south of Jefferson, was tacked with MC-250 liquid asphalt. This test panel consisted of 1 gal/sq yd of a proprietary asphalt-latex emulsion mixture (Indaco 200) normally used as an elastic joint sealer. Cover aggregate was added. Traffic was turned on it after 2 hr of curing. Rained Dec. 28, 1964 (0.25 in.).

Observed Dec. 28, 1964. Condition good.

Observed Jan. 8, 1965. Unaffected by 58 hr steady rain and partial inundation under heavy traffic.

Observed July 2, 1965. Excellent condition. Test panel has spread in the direction of traffic; no cracking present. Somewhat softer than test panel No. 4. Resembles a rubber mat.

Test Panel No. 7 (4- by 8-ft) — Placed: Jan. 5, 1965

Two hundred to 208 ft south of fire hydrant at the southeast corner of 7th Street and Jefferson, and 9 to 13 ft west of the west edge of sidewalk on 7th Street. Tacked with 4 parts of 85-100 penetration grade asphalt to 5 parts of kerosene.

This panel consisted of 5 gal of 85-100 penetration grade asphalt and 21 lb of partially devulcanized reclaimed rubber (2 parts of 85-100 penetration grade asphalt to 1 part rubber by weight). Temperature of the asphalt was 420 F when mixed with the rubber. The mixture was spread to an area of $3\frac{1}{2}$ sq yd and about $\frac{1}{4}$ to $\frac{1}{2}$ in. thick. The entire test panel was completely covered with aggregate and rolled with a steel roller.

Observed July 2, 1965. Excellent condition. Test panel feels quite soft due to thicker mat than others. Some spreading has occurred in the direction of traffic.

Test Panel No. 8 ($3\frac{1}{2}$- by $13\frac{1}{2}$-ft) — Placed: Jan. 5, 1965

Turney Avenue and center lane of the west half of Central Avenue 19 ft east and 1 ft north from the drop inlet at the northwest corner of Central Avenue and Turney Avenue to the southwest corner of the test panel. Tacked with 4 parts of 85-100 penetration grade asphalt and 5 parts of kerosene.

This test panel consisted of 5 gal of 85-100 penetration grade asphalt and 21 lb of partially devulcanized reclaimed rubber (two parts of 85-100 penetration grade asphalt to 1 part rubber and cover aggregate). Temperature of the 85-100 penetration grade asphalt was 430 F, when mixed. The mixture (rubber and asphalt) was spread to an area of 5.30 sq yd and about ¼ to ½ in. thick. The test panel was then rolled with a steel roller after placing cover aggregate.

Observed July 8, 1965. Condition fair. Test panel very soft and spreading in the direction of traffic and to the side causing thin spots with some minor resultant reflection cracking. This test panel appeared to be softer than the other panels. This is probably due to a combination of an excess of tack coat and greater thickness of the rubber-asphalt material resulting in slower curing. Ideal average thickness seems to be 0.18 in. ±, obtained by spreading 1 gal/sq yd of the combined materials. The entire street was recently fog sealed and this seems to have had an adverse sealing effect on the rubber-asphalt. After the fog seal cured, it could not respond to elastic movements of the rubber and cracked badly tending to propagate cracking downward over the areas where the rubber-asphalt overlaid cracked and moving areas in the original pavement.

Test Panel No. 9 (3½- by 51-ft) Placed: Jan. 8, 1965

East half of Central Avenue south of Indian School Road west lane 1 ft east of east face of median curb, 210 ft south of south curb on Indian School Road to 261 ft south (opposite 4041 North Central Avenue).

Work was done by 3-man maintenance crew.

Tacked at 11:45 A.M., with 4 parts of 85-100 penetration grade asphalt and 5 parts of kerosene. Asphalt was heated before arrival on the job.

85-100 penetration grade asphalt, 400 F
Mixed and was spread at 11:55 A.M.
Cover aggregate applied at 12:10 P.M.
Rolled at 12:15 P.M.

Consisted of 15 gal of asphalt and 62 lb of partially devulcanized reclaimed rubber = 20 sq yd. Material cost $12.00 ± or $0.60/sq yd. 1 gal/sq yd of a mixture applied and followed by a cover aggregate which was applied.

January 21, 1965. A conventional slurry seal patch was placed January 17, 1965, extending south from test panel No. 9. It had already failed by the time of this observation and test panel No. 9 was ok. Photos taken. Slurry seal patches containing 2 percent latex, placed Jan. 17, 1965, on opposite side of median had also failed.

April 14, 1965. The slurry seal patches extending south from panel No. 9 were replaced with conventional hot mix. Some hot mix placed in a few spots on test panel where "pulling" had occurred, probably by roller at time of placement. Test panel showed no cracking except for a small spot where it was so thin that the cover aggregate was exposed in relief. Generally, the cover aggregate normally becomes buried under traffic action in this process.

May 17, 1965. Test panel was inadvertently destroyed by maintenance force. It was still functioning perfectly in preventing crack reflection.

Test Panel No. 10 (3- by 6-ft) Placed: Mar. 2, 1965

Location: 75 to 81 ft south of fire hydrant at the southeast corner of 7th Street and Jefferson Street, and 9 to 12 ft west of the west edge of sidewalk on 7th Street (adjacent to test panel No. 6).

Tacked with 4 parts of 85-100 penetration grade asphalt to 5 parts of kerosene.

This test panel consisted of an application of 1 gal/sq yd of a mixture of 2 parts of 85-100 penetration grade asphalt to 1 part of locally obtained, unprocessed, shredded, reclaimed rubber by weight. Temperature of the asphalt was 440 F, when mixed with the rubber. The mixture was spread over an area of 2 sq yd and at an average thickness of 0.18 in. This material was then completely covered with ¼ in. seal coat aggregate and turned over to traffic.

Observed July 2, 1965. Excellent condition. Some spreading has occurred in the direction of traffic. No cracking has occurred. Test panel resembles rubber mat. No stripping has occurred. More elastic than test panels Nos. 3, 4 and 6.

Test Panel No. 11 (3- by 6-ft) Placed: Mar. 2, 1965

Location: 61 to 67 ft west of east end of median curb on east Washington at 26th Street and 8 to 11 ft north of north edge of median curb.

Tacked with 4 parts of 85-100 penetration grade asphalt to 5 parts of kerosene.

This test panel consisted of an application of 1 gal/sq yd of a mixture of 2 parts of 85-100 penetration grade asphalt to 1 part of locally obtained, unprocessed, shredded, reclaimed rubber by weight. Temperature of the asphalt was 420 F, when mixed with the reclaimed rubber. The mixture was spread over an area of 2 sq yd and at an average thickness of 0.18 in. This material was then completely covered with 1/4-in. seal coat aggregate.

March 9, 1965. An observation made this date showed the test panel to be in good condition but hot mix sand-asphalt patches adjacent to the test panel, and applied the same day, showed the beginning of crack reflection. Photos taken.

Observed July 8, 1965. Test panel is in excellent condition except for an 8-in. hole in the center that was dug for test purposes. The test panel is not as soft as some others nor is there any spreading or cracking evident.

Test Panel No. 12 (3- by 6-ft) Placed: June 22, 1965

Location: 208 to 214 ft south of fire hydrant at the southeast corner of 7th Street and Jefferson Street, and 10 to 13 ft west of the west edge of sidewalk on 7th Street (adjacent to test panel No. 7).

No tack was applied.

This test panel consisted of an application of approximately 1 gal/sq yd of a mixture of 2 parts of 85-100 penetration grade asphalt to 1 part of partially devulcanized reclaimed rubber by weight. Temperature of the asphalt was 430 F, when mixed with the rubber. The mixture was spread over an area of 2 sq yd. This material was then completely covered with 1/4-in. seal coat aggregate and turned over to traffic.

The atmospheric temperature was 101 F, and the pavement temperature was 138 F at the time of application.

June 23, 1965. Heavy thunder showers on this date resulted in nearly an inch of rain. The test panel showed no sign of damage, although it was subjected to traffic in a completely submerged condition for many hours.

Observed July 2, 1965. Excellent condition. No stripping or cracking. No spreading, and the surface is smooth.

Test Panel No. 13 (3- by 6-ft) Placed: June 22, 1965

Location: 214 to 220 ft south of fire hydrant at the southeast corner of 7th Street and Jefferson Street, and 10 to 13 ft west of the west edge of sidewalk on 7th Street (adjacent to test panel No. 12).

No tack was applied.

This test panel consisted of an application of approximately 1 gal/sq yd of a mixture of 2 parts of 85-100 penetration grade asphalt to 1 part No. 9306 company designation No. 30 mesh ground whole tire rubber (a commercial product of U. S. Rubber Reclaiming Company) by weight. Temperature of the asphalt was 450 F, when mixed with the rubber. The mixture was spread over an area of 2 sq yd. This material was then completely covered with 1/4-in. seal coat and turned over to traffic. The atmospheric temperature was 101 F, and the pavement temperature was 138 F, at the time of application. Consistency was too thick for proper spreading. It shows disconnected areas. It appears that the mixture should consist of a relatively greater amount of 85-100 penetration grade asphalt for best workability with this material.

June 23, 1965. Heavy thunder showers on this date resulted in nearly an inch of rain. The test panel showed no sign of damage, although it was subjected to traffic in a completely submerged condition for many hours.

Observed July 2, 1965. Condition excellent. Surface is a little rough but seems to be ironing out under traffic.

Test Panel No. 14 (3- by 6-ft) Placed: July 2, 1965

Location: 220 to 226 ft south of fire hydrant at the southeast corner of 7th Street and Jefferson Street and 10 to 13 ft west of the west edge of sidewalk on 7th Street (adjacent to test panel No. 13). No tack was applied. This test panel consisted of an application of approximately 1 gal/sq yd of a mixture of 3 parts of 85-100 penetration grade asphalt to one part company designation No. 9306, No. 30 mesh ground whole tire rubber (a commercial product of the U. S. Rubber Reclaiming Company) by weight. Temperature of the asphalt was 400 F, when mixed with the rubber. The mixture was spread over an area of 2 sq yd. This material was then completely covered with concrete sand and turned over to traffic. The official atmospheric temperature was 107 F, the atmospheric temperature 3 ft above the pavement was 114 F, and the pavement temperature was 156 F, at the time of application.

Test Panel No. 15 (3- by 6-ft) Placed: July 2, 1965

Location: 226 to 232 ft south of fire hydrant at the southwest corner of 7th Street and Jefferson Street and 10 to 13 ft west of the west edge of sidewalk on 7th Street (adjacent to test panel No. 14). No tack was applied. This test panel consisted of an application of approximately 1 gal/sq yd of a mixture of 2 parts of 85-100 penetration grade asphalt to one part company designation No. V-17 asphalt soluble rubber (a commercial product of the U. S. Rubber Reclaiming Company) by weight. Temperature of the asphalt was 410 F when mixed with the rubber. The mixture was spread over an area of 2 sq yd. This material was then completely covered with concrete sand and turned over to traffic. The official atmospheric temperature was 107 F, the atmospheric temperature 3 ft above the pavement was 114 F, and the pavement temperature was 156 F, at the time of application.

Appendix B

TEST A

CONSISTENCY EXPERIMENT FOR PARTIALLY DEVULCANIZED RECLAIMED RUBBER - 85-100 PENETRATION GRADE ASPHALT MIXTURE

One hundred grams of 85-100 penetration grade asphalt were weighed into each of 4 beakers. The beakers were labeled No. 1, No. 2, No. 3, and No. 4, and the contents were heated to 350 F, 400 F, 450 F, and 500 F, respectively. Fifty grams of partially devulcanized reclaimed rubber were mixed with the contents of each beaker containing the 85-100 penetration grade asphalt at their respective temperatures.

1. Temperature at time of mixing - 350 F.
   Consistency - thin slurry.
   Mixed for 2 min before observing consistency.
   Consistency after 16 hr curing at 140 F - soft, sticky, and stringy.
   Consistency after 4 hr curing at 250 F - soft.
2. Temperature at time of mixing - 400 F.
   Consistency - slurry.
   Mixed for 2 min before observing consistency.
   Temperature after mixing - 300 F.
   Consistency after 16 hr curing at 140 F - soft, sticky, and stringy.
   Consistency after 4 hr curing at 250 F - soft.
3. Temperature at time of mixing - 450 F.
   Temperature after mixing - 330 F.
   Mixed for 2 min before observing consistency.

Consistency - thick slurry.
Consistency after 16 hr curing at 140 F - semi-soft, not sticky.
Consistency after 4 hr curing at 250 F - soft.

4. Temperature at time of mixing - 500 F.
   Temperature after mixing - 350 F.
   Consistency - very thick slurry.
   Mixed for 2 min before observing consistency.
   Consistency after 16 hr curing at 140 F - spongy, not sticky.
   Consistency after 4 hr curing at 250 F - soft.

General notes. Elasticity of the cold material was better with samples mixed at the higher temperatures and best with sample mixed at 500 F, but hot workability was poor at that temperature. The best compromise would seem to be a mixing temperature of 400 to 450 F.

Material was somewhat brittle at 190 F, but ductile at 36 F.

TEST B

FLOW TEST OF PARTIALLY DEVULCANIZED RECLAIMED RUBBER - 85-100 PENETRATION GRADE ASPHALT MIXTURE

The four samples from test A were cooled to room temperature. A portion of mixture, the size of a pea, was taken from each of the four samples. This pea-sized sample was placed on a shiny piece of tin plate, 1 in. apart and in a line on the upper $^2/_3$ of the tin plate. The tin plate was placed in the oven at an angle of 30 deg. The amount of flow for each pea-sized sample was observed under various temperatures.

The following data were obtained.

Flow at 170 F for 2 hr

Sample No.	Flow
1 (350 deg)	very small
2 (400 deg)	none
3 (450 deg)	none
4 (500 deg)	none

Flow at 210 F for 4 hr

Sample No.	Flow
1 (350 deg)	very small
2 (400 deg)	none
3 (450 deg)	none
4 (500 deg)	none

Flow at 330 F for 2 hr

Sample No.	Flow
1 (350 deg)	4 in.
2 (400 deg)	2 in.
3 (450 deg)	3 in.
4 (500 deg)	none

Appendix C

TESTS ON COMPRESSION AND RECOVERY OF RUBBER-ASPHALT MIXTURE FOR THE PURPOSE OF DETERMINING ELASTICITY

On March 2, 1965, two additional test panels, Nos. 10 and 11, were placed consisting of 2 parts of 85-100 penetration grade asphalt and 1 part by weight of shredded scrap reclaimed rubber obtained from a local tire recapping shop.

When placing test panel No. 10, the temperature of the 85-100 penetration grade asphalt was 440 F just before mixing in the rubber, and 420 F for test panel No. 11.

Approximately 1 gal of rubber-asphalt mixture from each test panel was molded into a concrete cylinder can. After the mixture had cooled, the concrete cylinder can was removed and two test specimens 6 in. in diameter and 7 to 8 in. in height were obtained.

The test specimen molded from material from test panel No. 10 (on 7th St. south of Jefferson) was designated test specimen A, and the other test specimen molded with material from test panel No. 11 (east Washington and 26th Street) was designated test specimen B.

The test for elasticity (compression and recovery) was performed as follows. The height of each test specimen was determined. Each test specimen was compressed by applying a vertical load until a 2-in. displacement was observed. The load was removed in one test immediately, and after 5 min in another. The height of each test specimen was measured at intervals of immediately, 1 hr, and 12 hr, after the load had been removed. The recovery in height of each test specimen was determined as an indication of the elastic properties of the material. The recovery in inches, as a percentage of 2 in. (the length of displacement), was designated as the percent of recovery of the material.

The following results were obtained.

Test Specimen A

Mixing temperature of asphalt: 440 F.
Height of test specimen before loading: 7.75 in.
Height of test specimen with load: 5.75 in.
Height of test specimen 1 hr after immediate release of load: 7 in.
Percent recovery = 1.25/2 = 63 percent.
Height of test specimen before loading: 6 in.
Height of test specimen when loaded for 5 min: 4 in.
Percent recovery (1 hr after removing load) = 0.5/2 = 25 percent
Height of test specimen 12 hr after removing load: 5 in.
Percent recovery 12 hr after removing load = 1 in./2 in. = 50 percent.

Consistency Test

Cured for 24 hr at 140 F.
Observation: sticky and soft.

Test Specimen B

Mixing temperature of asphalt: 420 F.
Height of test specimen before loading: 7 in.
Height of test specimen with load: 5 in.
Height of test specimen 1 hr after immediate release of load: 6.75 in.
Percent recovery 1 hr after release of load = 1.75/2 in. = 88 percent.
Height of test specimen when loaded for 5 min: 4.75.
Height of test specimen 1 hr after release of load: 6 in.
Height of test specimen 12 hr after removing load: 6.50 in.
Percent recovery 1 hr after removing load applied for 5 min = 1 in./2 in. = 50 percent.
Percent recovery 12 hr after removing load applied for 5 min = 1.5 in./2 in. = 75 percent.

Consistency Test

Cured for 24 hr at 140 F.
Observation: gummy and firm.

<u>Summary</u>

It appears that the temperature of the 85-100 penetration grade asphalt just before mixing with the shredded reclaimed rubber is important. Test specimen B showed more resiliency and elasticity than did test specimen A indicating some damage to the rubber at the higher temperature.