CONSTRUCTION MATERIALS INCORPORATING DISCARDED TIRES

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CONSTRUCTION MATERIALS

INCORPORATING DISCARDED TIRES

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ABSTRACT

Majority of discarded tires generated in the USA are either landfilled or stockpiled. This results in increased environmental and health problems, and lost resources and energy recovery. These problems have forced researchers and scientists to develop constructive use options for discarded tire as alternatives to landfilling or stockpiling. There are several reuse options for scrap tires. This paper presents the state-of-the-art information on the use of tires in roadway construction work as well as other low-cost construction material which have high potential to consume most of the tires produced in the country.

INTRODUCTION

One of the most challenging problems of today is the need to find environmentally and economically sound solutions to tire disposal/utilization. In the U.S.A., nearly 300 million tires are generated each year. Wisconsin alone produces nearly 5 million tires per year. Due to low reuse of tires (about 25%), a large number of tires are either stockpiled, landfilled, or destroyed in environmentally unacceptable manner. Stockpiled tires create an ideal atmosphere for breeding mosquitoes and a habitat for vermins. At present landfills restrict the burial of whole tires due to: (1) tires are not biodegradable and cannot be easily compacted, resulting in more space requirements, and, (2) tires float and rise to the surface due to buoyancy effects of gases trapped by them. This, in turn, exposes landfill to insects, rodents, and birds, and also permits landfill gases to escape.

Due to the aforementioned problems and in order to recover resource and energy from used tires, a great deal of research has been conducted and much is still in progress to establish large scale tire utilization technologies [1-12]. A recent study has found that approximately 57 million tires generated during the year 1990 - 1991 were reused, recycled, or recovered [4].

A number of uses for discarded tires presently exist [2,3,4]. These include: (1) use of discarded tires in tire retreading, (2) use of tires in the manufacture of gaskets, seals, automotive tailpipe insulators, mats, etc., (3) use of tires as reclaimed rubber, (4) use as a fuel through burning, (5) use of tires in the production of chemicals and raw materials such as gas, oil, char, carbon blacks, etc. by the use of destructive distillation technique, (6) miscellaneous use of tires in the
manufacture of erosion control structures and artificial reefs, (7) use of tire as rubber in pavements, and, (8) use of tires in low-cost construction materials and sound absorbing products.

The largest potential outlet for discarded tires is rubberized roads and construction materials. A federal law, the intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), mandates the use of scrap tire material in federally funded state roads [1,4]. This law requires that beginning in 1994, 5% of all the federally funded state roads must contain a minimum of 20 lbs of ground rubber per ton of paving material applied. This percentage will be increased to 10% for 1995, 15% for 1996, and 20% for 1997. The law further requires that EPA and DOT carry out investigations to evaluate performance, health impact, and recyclability of rubber containing asphalt, and the results of these investigations should be reported to congress by the middle of 1993 [1].

In the light of the above, it appears highly essential to generate performance data on materials involving the use of discarded tires. The results of such investigation would help increase utilization of discarded tire rubber in construction materials, especially in pavements.

This paper primarily addresses the innovative uses of tires in road construction and the manufacture of low-cost materials. The secondary objective is to study the economic impact of using scrap tires as ingredients of highway materials.

SIZE REDUCTION OF TIRES

Waste tires are processed by either mechanical or cryogenic processes to produce rubber of various sizes. The latter technique generates relatively small particles, whereas the former technique produces a range of shredded particles [2]. Size produced by mechanical shredder is found to vary down to 100 mesh powder. Tire processing by cryogenic means involves cooling of the whole scrap tire or coarse shreds below the glass transition temperature -80°F. Consequently, tires becomes brittle, and are easily shattered in a hammermill to 16 - 24 mesh pieces [8].

RUBBERIZED ASPHALT PAVEMENT SYSTEMS

Various terms have been used to describe rubberized paving materials. A common terminology is described in Figure 1 [6]. The most commonly used terms are asphalt-rubber and rubber-filled treatments. Asphalt-rubber refers to paving grade asphalt blended with rubber, whereas rubber-filled treatment refers to the addition of dry scrap rubber to the asphalt concrete mixtures. Asphalt rubber is produced by wet process while rubber filled treatment is produced by dry process.

Tire rubber is premixed with liquid asphalt at an elevated temperature to form a new asphalt-rubber binder, and used in a similar manner as conventional liquid asphalts. When such a binder is sprayed onto the surface and followed by distribution and rolling of a cover aggregate, the resulting material is called a seal coat, chip seal or surface treatment. An application of this type of treatment between layers of pavement is termed as interlayer. This type of treatment is used to
retard reflective cracking. In asphaltic concrete, asphalt-rubber liquid binder is mixed with fine and coarse aggregates. This is called an asphalt concrete friction course when used in the surface to increase friction.

Rubber-filled systems are cheaper compared to asphalt-rubber systems. This system is used in asphaltic concrete and friction courses only.

Rubber-Filled Systems (Dry Process)

Two different systems, namely, the PlusRide System and generic system fall under rubber modified asphaltic concrete manufactured by dry process.

PlusRide

PlusRide process was developed in the 1960's by the Swedish Companies Skega AB and AB Vaegfoerbaettringar (ABV). This process involves the use of relatively large particles of tire rubber (1/16 - 1/4") as a partial replacement of aggregates in an asphaltic concrete mixtures, and it is marketed by PaveTech Corporation of Seattle, Washington. The mix contains about 3 to 4 percent rubber by weight of the total mixture, and requires the amount of asphalt to be increased from 4 to 6 percent in a conventional mixture to 7 to 9 percent for the PlusRide mix [7]. This system also requires a gap grading of aggregate (Figure 2).

Generic System

This system was developed by H.B. Takallon in 1989 [5]. The mix design of this system is very similar to that for conventional asphalt concrete. The amount of rubber used can be 1, 2, or 3 percent of total mixture, which translates to 20, 40, or 60 lb per ton of total mixture. This system employs a dense graded aggregate gradation, and therefore does not need any special aggregate gradation as required for the PlusRide System.

Construction Practice for Dry Process

For production of rubber-modified asphalt concrete, mixtures have been made using batch, continuous, or drum-dryer plants. In the case of batch plants, the required quantities of rubber, asphalt, and aggregates are measured prior to adding to the plugmill mixing chamber. Whereas in both continuous and drum-dryer plants mixing is performed continuously, and rubber is fed from a separate bin to the midentry (recycle fit opening) [5]. The equipment required for rubber-filled systems is essentially the same as used for conventional asphalt concrete production.

In order to produce asphalt-rubber binder, temperature of the asphalt cement is kept between 350 and 400 °F at the time of the addition of ground rubber. The asphalt and crumb rubber is mixed in a blender unit and pumped into agitated storage. Reaction between these materials is completed in a minimum of 45 minutes from the time crumb rubber is added to the asphalt [5]. The resulting binder is metered and fed into the mixing chamber of an asphalt concrete mixers.
production plant. The laydown and compaction equipment and procedures used in the asphalt-rubber binder process are primarily the same as that described above.

PERFORMANCE OF RUBBERIZED MATERIAL SYSTEMS

The earliest use of asphalt-rubber in Arizona began in 1964 [7]. In the mid 1960’s, the city of Phoenix pioneered the use of asphalt-rubber binder in chip seal treatments. This binder is composed of 70 to 80 percent hot asphalt cement and 20 to 25 percent ground recycled rubber [7,8].

Asphalt-rubber uses in Arizona have been mainly in two different types of surface treatments [7]. These include: (1) stress absorbing membrane (SAM); a hot-asphalt-rubber chip seal is applied to the distressed crack surface, and, (2) stress absorbing membrane interlayer (SAMI), this system involves the use of a hot-asphalt-rubber chip seal to the surface, followed by a 1-1/2 to 2-in asphaltic concrete overlay. Pavements treated with asphalt-rubber binder have been found to last 2 to 5 times longer than conventional asphalt sealer [8,9]. A pavement constructed with an asphalt-rubber layer of 0.11-in plus 2-in of asphalt concrete showed durability equivalent to a 7-in asphalt concrete overlay [8].

The rubber-filled asphaltic concrete concept was developed in 1960’s in Sweden. The PlusRide mixture in Sweden is reported to have better durability and skid resistance relative to comparable conventional asphaltic concrete mixtures. The use of the PlusRide mixture in the USA began in the late 1970’s. Addition of this material in pavements provides improved performance in regards to fatigue properties, skid resistance, noise reduction, reduction in reflection of cracking in resurfaced asphalt pavements, etc. [2,3].

Tests conducted by the Alaska Department of Transportation and Public Facilities showed a substantial reduction in stopping distances under icy road conditions compared to conventional pavements [10]. Besides, this material provides a mechanism to reduce formation of ice layers on the road surface. The mechanism primarily results from increased flexibility of the rubberized materials and poor bond between the road surface and ice, causing disintegration of the ice deposited on the road surface.

A study conducted by the Texas Transportation Institute for the Federal Highway Administration provides exhaustive analysis of performance data on rubber-modified asphalt paving materials used in various projects in the USA. Data obtained in this work has been summarized by Chamberlin and Gupta [6]. This study involved 210 experimental rubber modified pavements built during the year 1977 to 1984, and their performance was compared to the control pavement containing no rubber using eight different measures of pavement distress types [6]. The results are summarized in Figure 3. This figure shows the performance of rubberized pavements compared to conventional asphalt mix. The results reported show no definite conclusion about the performance of rubberized pavements relative to conventional asphalt mixture. However, the performance of about 95% of rubber-filled asphalt concrete was either equal to or better than the performance of conventional materials.

A number of recent investigations have been directed toward evaluation of rubberized
pavements. Lundy et al. [11] investigated performance of rubberized asphaltic concrete pavement as well as conventional asphaltic concrete pavement under both laboratory and field conditions. Their test result showed: (1) increase in modulus of elasticity of both the rubber-modified and control mixtures with time, (2) higher tensile strength for control mixtures relative to the rubberized systems, (3) roughness of the rubberized systems was slightly higher; and (4), 25 to 75% higher fatigue strength of the rubberized materials relative to control mixtures. Based on the fatigue tests, for rubber modified materials layer equivalency values were reported to be 1.2 to 1.8 times that for the conventional asphalt concrete.

Doty [12] compared performance of a number of rubber-modified paving materials with conventional asphaltic materials. Those were rubberized dense-graded asphalt concrete overlays with or without a SAMI, PlusRide dense-graded AC overlays, and four thicknesses of conventional dense-graded AC overlays, and single and double stress absorbing membrane interlayers (Figure 4). Table 1 shows properties of the various materials tested in the study [11]. The results showed the lowest permeability for the PlusRide DGAC. The permeability of the ARS DAGAC was substantially lower than that for the conventional DGAC. These results reveal that rubberized pavements have greater resistance to surface water (rainfall) intrusion. Similar trends were noted in regards to abrasion resistance Table 1. Test data showed adequate skid resistance for the PlusRide pavement, but very good results were obtained for the other surfaces. The results indicated that the initial stiffening effect of the asphalt-rubber overlays is equal to or greater than that for the equivalent thickness of conventional DGAC. The tolerable deflection of the rubberized asphalt overlays is greater than that for equivalent thickness of conventional DGAC. The amount of cracking in the various paving materials is shown in Table 2. This would provide a measure of remaining life of the pavements. In general, author reported that rubberized paving materials performed either equal or better than equivalent or greater thickness of conventional dense-graded concrete with respect to resistance to cracking.

Rubberized chip seal coats (SAM's and SAMI's) used in Arizona have shown numerous benefits as described below [7].

(1) The asphalt-rubber seal coats retard reflective cracking in the pavement with less than 0.25 in. cracks for 8 to 12 years. They tend to stop secondary cracks up to 15 years.

(2) They seal and preserve the in-situ original quality of asphaltic material.

(3) They act as excellent crack filling materials and joint sealer.

(4) Their service life is approximately 2 to 5 times greater than for most standard seals.
In spite of the above favorable properties of the rubberized materials (seals) and economics, this system has posed some problems to motorists. The rubberized systems often exposed loose chips which are scattered by moving cars. This has caused damages of numerous windshields and made unhappy to motorists. As a result, the city was forced to develop, another rubberized material as an alternative to chip seals. The developed material was asphalt-rubber hot concrete mix consist of a gap gradation incorporating large amount of asphalt binder (8 to 10% asphalt-rubber). The results showed that 1-in. asphalt rubber-concrete overlay will be adequate to resist reflective cracks [7]. This treatment have shown improved riding surface and decreased in traffic noise.

It is well known that rubber has high capacity to absorb shock and vibrations. In general, addition of tire rubber should help increase vibration and shock absorbing capacity of materials. Due to this reason, in general, rubberized materials are expected to have increased service life.

In the past rubber has been used in asphalt for manufacturing of asphaltic materials for tennis courts, basements, floors, tiles, roofs, adhesives, waterproofing, expansion joints, etc. [2].

Naik and Singh [2,3] summarized potential uses of tires in new materials. Those include: (1) the use of tire rubber in manufacture of protective barrier for highway bridges, (2) asphaltic blocks for construction of slope pavements under highway bridges and other similar uses, (3) crash barrier on highways, (4) railroad crossing ties, (5) elastic foundations for railroads, highways, airport structures, and other foundations where vibrational damping is required, and, (6) low-strength concretes for construction of parking lots and other cementitious materials requiring low-strength.

**ECONOMIC IMPACTS OF USING DISCARDED TIRE RUBBER IN PAVING MATERIALS**

In general rubber-modified asphaltic materials are costlier compared to conventional asphaltic materials due to additional cost of ground rubber and processing involved, and cost of royalty fee if any [6,13]. In a study [6], based on national pooled data, it was determined that service life of rubberized materials must be significantly higher than conventional materials in order to recover the first cost. To accomplish this, the increase in life of rubberized systems relative to conventional materials should be 100 to 200% for asphalt-rubber seal coat, 50 to 100 percent for asphalt-rubber interlayer, and 100 to 150 percent for asphalt-rubber concrete [6]. This cost is expected to decrease with increased uses of rubberized materials, improvement in tire processing technology, experience gained in the use of tire rubber in construction materials.

Increase in cost for the PlusRide process are bid on per ton basis. Additional costs for the PlusRide mixture relative to conventional asphalt mixtures include: (1) cost for higher amounts of asphalt, that is, about 2 to 2.5% higher than for the conventional mix, (2) cost incurs due to change in aggregate grading requirements, (3) cost of tire rubber, and, (4) cost of the Royalty fee [5].
The cost increase for the generic system relative to the conventional mix include: (1) cost of additional asphalt used, about 1 to 1.5 higher amount of asphalt is used, and (2) the cost of tire rubber.

The cost increase of the asphalt-rubber binder compared to conventional asphalt binder, includes the cost of rubber, cost of blending, on-site support, and a special mixture design.

The details of increase in cost of rubberized systems relative to conventional materials are shown in Table 3. The net cost increase would be slightly reduced because of increased yield that occurs due to addition of tire rubber. A comparison of installation cost of rubber-modified pavements with conventional pavement revealed that cost of paving with materials containing tire rubber is significantly higher compared to the conventional asphalt mix (Table 4).

As expected, cost of rubber-filled asphalt mixtures are lower as compared with asphalt-rubber binder system. The generic mix system is the most cost-effective system of all the material systems incorporating scrap tire rubber. Therefore, it has a very high potential for use in actual construction of roads. Besides, this system does not require any technological changes in the conventional construction practices. However, since this system is relatively new, more research is needed relative to other rubberized systems before it can be recommended for a wide range of conditions.

**SUMMARY**

A number of technologies exist for utilization of scrap tires. Due to lack of acceptable markets, a large volume of discarded tires are either landfilled, stockpiled or destroyed. Attempts are being made to develop economically and environmentally sound technologies for large scale uses of scrap tires. Based on the analysis of information available, it was determined that the greatest amount of scrap tire can be utilized in construction of roads and low-cost construction materials.

This paper provides the state-of-the-art information on scrap rubber use technologies in asphaltic concrete pavements and other asphaltic materials.

Scrap tire use in pavement involves both rubber-filled and asphalt-rubber (binder) systems. The rubber-filled system is a dry process in which dry crumb and/or ground tire rubber is added to asphaltic concrete mixtures. The rubber-filled systems include the PlusRide and generic mixtures. Whereas asphalt-rubber systems is wet process which involves blending of tire rubber to asphalt at an elevated temperature. The resulting binder is used in the same fashion as conventional asphalt. In general, a well designed rubberized pavement is expected to perform better than conventional asphaltic concrete mixtures.

Economic analysis has shown that installation cost of rubberized pavements are 1.5 - 3 times that of comparable conventional asphaltic mixtures. However, this cost differential is expected to decrease with increased utilization of tire rubber in pavements, and improved tire
processing technologies, and increased experience in the use of this materials. In general, rubber-filled concrete mixtures are economically attractive relative to asphalt-rubber binder systems. The generic rubberized material is the least cost material system and does not require much change in either mix design or equipment requirement from the conventional systems. Therefore, it is concluded that this system is most appropriate for use of tire in paving work. However, due to relatively new type of materials, this material needs to be evaluated before commercial application of this technology.

Scrap tire rubber has been used in numerous asphaltic materials. The potential applications of tire rubber are in roofs, basements, waterproofing expansion joints, etc., elastic foundations, railroad crossing ties, crash barriers, etc.

REFERENCES


FIGURE 1: CLASSIFICATION OF RUBBER-MODIFIED ASPHALT PAVING MATERIALS [6]
FIGURE 2: SCHEMATIC OF RUBBER GRANATES IN RUBBER-MODIFIED ASPHALT [5]
FIGURE 3: PROJECT PERFORMANCE BY APPLICATION TYPE, IN THE NATIONAL POOLED FUNDS STUDY [6]
FIGURE 4: TEST SECTION LAYOUT [12]
<table>
<thead>
<tr>
<th>Materials</th>
<th>Segment Number</th>
<th>Overlay Thkn(^1) (ft)</th>
<th>% Comp.</th>
<th>Permeability(^2) (ml/min)</th>
<th>Surface Abrasion(^3) (gms loss)</th>
<th>Skid(^4) No. (SN(_{40}))</th>
<th>Deflection(^5) (0.001&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-Built</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>As-Built</td>
<td>Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARS DGAC</td>
<td>1</td>
<td>0.27</td>
<td>0.28</td>
<td>93.3</td>
<td>36.3</td>
<td>17.1</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.17</td>
<td>0.18</td>
<td>91.7</td>
<td>22.3</td>
<td>17.6</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.12</td>
<td>0.15</td>
<td>92.8</td>
<td>--</td>
<td>18.7</td>
<td>54</td>
</tr>
<tr>
<td>PlusRide DGAC</td>
<td>4</td>
<td>0.19</td>
<td>0.15</td>
<td>97.1</td>
<td>--</td>
<td>9.7</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.21</td>
<td>0.18</td>
<td>98.4</td>
<td>11.0</td>
<td>14.8</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.28</td>
<td>0.28</td>
<td>96.1</td>
<td>6.8</td>
<td>11.4</td>
<td>44</td>
</tr>
<tr>
<td>Conv. DGAC</td>
<td>7</td>
<td>0.20</td>
<td>0.15</td>
<td>91.7</td>
<td>177.0</td>
<td>47.8</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.18</td>
<td>0.20</td>
<td>91.2</td>
<td>--</td>
<td>48.2</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0.32</td>
<td>0.30</td>
<td>91.4</td>
<td>--</td>
<td>32.5</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.52</td>
<td>0.50</td>
<td>92.1</td>
<td>--</td>
<td>35.1</td>
<td>67</td>
</tr>
<tr>
<td>Double SAM</td>
<td>11</td>
<td>0.10</td>
<td>0.04</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>62</td>
</tr>
<tr>
<td>SAM</td>
<td>12</td>
<td>0.13</td>
<td>0.04</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>59</td>
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<tr>
<td>SAM</td>
<td>13</td>
<td>0.14</td>
<td>0.03</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>57</td>
</tr>
</tbody>
</table>

Notes: 1. Includes SAMI, segments 1, 2, 5, and 6
2. Per Calif. Test 341
3. Per Calif. Test 360, Method B
4. Per ASTM E274, Meas 10/83
5. 80th percentile deflections per Calif. Test 356 (Dynaflect Method)
TABLE 2: ESTIMATE OF PAVEMENT CRACKING [12]

<table>
<thead>
<tr>
<th>Material</th>
<th>Segment Number</th>
<th>Estimated Percent Cracked (May 1987)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARS DGAC</td>
<td>1</td>
<td>&lt;5%</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>&lt;5%</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5-10%</td>
</tr>
<tr>
<td>PlusRide</td>
<td>4</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>DGAC</td>
<td>5</td>
<td>5-10%</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>5-10%</td>
</tr>
<tr>
<td>Conv. DGAC</td>
<td>7</td>
<td>70-75%*</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>75-80%*</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>10-15%</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>Double SAM</td>
<td>11</td>
<td>60-65%</td>
</tr>
<tr>
<td>SAM</td>
<td>12</td>
<td>65-70%</td>
</tr>
<tr>
<td>SAM</td>
<td>13</td>
<td>85-90%</td>
</tr>
</tbody>
</table>

* Failed
TABLE 3: COMPARATIVE SCHEDULE OF INCREASES IN COST OF ASPHALT MIXES USING USED-TIRE RUBBER TO CONVENTIONAL ASPHALT MIX [5]*

<table>
<thead>
<tr>
<th></th>
<th>Conventional Asphalt (Control)</th>
<th>Increases In Cost Beyond Conventional Asphalt - Standard (Control)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Asphalt/Binder Arizona Process dollars</td>
</tr>
<tr>
<td>Asphalt Binder</td>
<td>2.40</td>
<td>1.80</td>
</tr>
<tr>
<td>Asphalt/Rubber Binder</td>
<td>23.10</td>
<td></td>
</tr>
<tr>
<td>Aggregate</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Contractor Overhead</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>Royalty</td>
<td>4.50</td>
<td></td>
</tr>
<tr>
<td>Rubber (60 lbs. dry) @ .12/#</td>
<td>7.20</td>
<td>7.20</td>
</tr>
<tr>
<td>Total Increase Per Ton in Dollars</td>
<td>26.10</td>
<td>20.10</td>
</tr>
</tbody>
</table>

* Assumptions:

Percentage of Asphalt Binder:
- Conventional A/C: 5.5%
- Asphalt/Rubber Binder: 7.0%
- RUMAC - PlusRide: 7.5%
- RUMAC - Generic: 7.0%

Binder Cost: $120.00 per ton
Asphalt/Rubber Binder Cost: $450.00 per ton

Maximum Specific Gravity of Mix:
- Conventional A/C: 150 pounds per cubic foot
- Asphalt/Rubber Binder: 148 pounds per cubic foot
- RUMAC - PlusRide: 140 pounds per cubic foot
- RUMAC - Generic: 142 pounds per cubic foot
### TABLE 4: COMPARATIVE PROJECT COST OF ASPHALT MIXES USING USED-TIRE RUBBER TO CONVENTIONAL ASPHALT MIX [5]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost/ton ($)</td>
<td>$28.00</td>
<td>$54.10</td>
<td>$48.10</td>
<td>$40.00</td>
</tr>
<tr>
<td>Tonnage required per mile, 36 feet wide, 3” thick, (Tons)</td>
<td>3,564</td>
<td>3,516</td>
<td>3,326</td>
<td>3,374</td>
</tr>
<tr>
<td>Cost/mile ($)</td>
<td>$99,792</td>
<td>$190,216</td>
<td>$159,981</td>
<td>$134,960</td>
</tr>
<tr>
<td>Number of tires Recycled/mile</td>
<td>--</td>
<td>5,274</td>
<td>16,630</td>
<td>16,630</td>
</tr>
<tr>
<td>Difference in paving Costs/recycled tire</td>
<td>--</td>
<td>$17.14</td>
<td>$3.62</td>
<td>$2.11</td>
</tr>
</tbody>
</table>