RECYCLING OF RUBBER TIRES
IN
ASPHALT PAVING MATERIALS

by
M. R. Piggott, R. T. Woodhams
March 1979

A special report prepared for Environment Canada

Contract Serial No. OSU78-00103

Pollution Control Branch
Environmental Protection Service
Environment Canada
2 St. Clair Avenue West
Toronto, Canada M4V 1L5

Department of Chemical Engineering and Applied Chemistry
University of Toronto, Toronto, Canada M5S 1A4
ABSTRACT

A relatively small proportion of asphaltic bitumen comprises the average road surface in North America, and yet it is sufficient to consume nearly 75% of the more than 60 billion pounds of bitumen sold annually in Canada and the United States. Although this proportion of asphaltic binder is small [about 6%] its function is critical to the performance of the road surface. Despite the effort that has gone into developing better road surfacing materials, the quality of asphalt binders has not improved significantly over the last 5,000 years. It has been known for at least 50 years that the addition of rubber to asphalt will produce markedly superior road surfaces, some of which are still in use since they were first laid. Partly because of cost and partly because of nonconventional paving techniques rubber has been largely ignored as a practical additive except in special cases. Today there is a large accumulation of old tires which if ground into a fine powder can be mixed in a conventional pug mill along with sand, crushed stone and hot asphalt to produce a hot mix which can be applied in the normal manner without any specialized knowledge or techniques. The extra cost of such modification is only 1% of a typical paving contract whereas the advantages include lower maintenance costs and a more durable road surface that is likely to last well into the next century. This report, specially prepared
for Environment Canada, is designed to assist civic, provincial and federal authorities in the development of improved road surfacing formulations through the reuse of old tires.
# INDEX

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2. Reclaim Rubber from Discarded Tires</td>
<td>4</td>
</tr>
<tr>
<td>3. Initial Paving Trials in Metro Toronto</td>
<td>7</td>
</tr>
<tr>
<td>4. Laboratory Evaluations</td>
<td>9</td>
</tr>
<tr>
<td>6. Viscosity of Bitumen Containing Powdered Reclaim Rubber</td>
<td>15</td>
</tr>
<tr>
<td>7. Low Temperature Performance</td>
<td>17</td>
</tr>
<tr>
<td>8. Retention of Wet Strength</td>
<td>20</td>
</tr>
<tr>
<td>9. Cost of Rubber Modification</td>
<td>23</td>
</tr>
<tr>
<td>10. Conclusions</td>
<td>24</td>
</tr>
<tr>
<td>11. Acknowledgement</td>
<td>25</td>
</tr>
<tr>
<td>12. References</td>
<td>26</td>
</tr>
<tr>
<td>13. Tables and Figures</td>
<td>28</td>
</tr>
</tbody>
</table>
RECYCLING OF RUBBER TIRES IN ASPHALT PAVING MATERIALS

INTRODUCTION

Rubber, in the form of latex or vulcanized scrap, has long been used as an additive to improve the toughness of asphaltic road surfacing materials although it has not achieved widespread usage either because of cost or because the added complexity of the process has deterred would-be users. Recently, however, the growing problems of tire disposal have caused many municipalities to reconsider the use of powdered reclaim rubber, particularly as an additive in hot mix asphalts. To attain general acceptance any new paving material must use conventional mixing and paving equipment, must be simple and forgiving, must not involve substantially longer mixing times or slower paving rates, and lastly, should not be too expensive. The cost of adding rubber to asphaltic paving materials is particularly critical for widespread acceptance. To offset this added cost there must be compensating advantages in terms of greater road durability, increased lifetime, better performance and reduced maintenance. The University of Toronto, aided by a contract from Environment Canada and financial and technical assistance from the Metro Toronto Roads and Traffic Department have examined the feasibility of adding powdered reclaim rubber directly to hot mix asphalt and then evaluating the cost and performance in several road laying trials in Toronto. Five
major arteries have now been repaved with rubber modified asphalt mixtures without encountering any serious difficulties. The additional cost for rubber modification was a modest 1% of the total contract price in each case. Two years later the experimental roads are still in excellent condition with noticeably fewer cracks than the HL-1 control. Laboratory tests confirm that reclaim rubber reduces the brittle temperature of asphalt by nearly 20°C [or minus 10°C for each added part of rubber per 100 parts of bitumen] thereby preserving pavement flexibility at low temperatures.

At the other end of the temperature spectrum, during the hot summer period, the thickening behaviour of the added rubber tends to reduce rutting, distortion, sagging and creep. Rubber also prevents the excretion of bitumen in hot weather, a phenomenon referred to as "bleeding". There is also evidence to indicate that rubber helps to prevent water stripping or debonding in the presence of moisture. Since moisture is responsible for most forms of pavement distress, the surprising effectiveness of reclaim rubber in this respect is encouraging. It is possible that the rubber additives [sulfur compounds, zinc stearate, etc.] promote better adhesion between the asphalt and the aggregate whereas the antioxidants and antiozonants help to retard oxidative hardening and aging of the bitumen. It is apparent, therefore, that the benefits of added reclaim rubber extend beyond just the flexibilizing
effect of the rubber component and may help to protect the asphaltic binder from the adverse effects of weathering and oxidative degradation throughout its lifetime.

"We conclude from these investigations that the addition of reclaim rubber to asphaltic paving materials is likely to double the lifetime of road surfaces and perhaps reduce the overall costs of road building and maintenance by half". Since the current road expenditure in Canada is approximately 1.5 billion dollars annually, the anticipated savings are potentially enormous and would easily justify the trivial premium [about 1%].

This report summarizes the results of a four year evaluation program and discloses the recommended formulations and paving procedures employed in Toronto for road surfaces containing reclaim rubber.
RECLAIM RUBBER FROM DISCARDED TIRES

The techniques for shredding and grinding worn tires to a fine powder are well known. Both Union Carbide and Air Products offer cryogenic grinding units that permit almost any tire to be finely pulverized using liquid nitrogen as a refrigerant. Goodyear, in Bowmanville, Ontario, have been producing powdered reclaim for several years using a mechanical process. After the shredded tires are reduced to a fine powder with a hammer mill, the loose tire cord fibers are removed by air entrainment. Typical sieve analyses are shown in Table 1 for the powdered reclaim rubbers used in these investigations. Note that the Union Carbide cryogenic process produces a finer particle size range than the Goodyear shredding method although presumably the size reduction equipment can be altered to produce larger or smaller ranges. The limited evidence so far suggests that an average particle size near 30 mesh [0.59 mm] is preferred for best results. Reclaim rubber contains special chemical additives which are necessary in the manufacture of high performance tires, such as for example, antioxidants, antiozonants, vulcanization accelerators, extending oils, tackifiers, zinc oxide, stearic acid, sulfur and carbon black. The elastomer component may comprise styrene-butadiene copolymers [SBR], butyl, EPDM, cispolybutadiene, natural rubber or neoprene which originates from the tread, sidewall, carcass or inner liner. The carcass, which contains the tire cord may consist of rayon, nylon 66, polyester, glass fibers, steel or
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.19</td>
<td>16</td>
<td>---</td>
<td>1.0</td>
<td>11</td>
</tr>
<tr>
<td>0.84</td>
<td>20</td>
<td>1.5</td>
<td>4.5</td>
<td>29</td>
</tr>
<tr>
<td>0.71</td>
<td>25</td>
<td>12.0</td>
<td>8.0</td>
<td>52</td>
</tr>
<tr>
<td>0.59++</td>
<td>30</td>
<td>65.5</td>
<td>9.5</td>
<td>70</td>
</tr>
<tr>
<td>0.30</td>
<td>50</td>
<td>79.0</td>
<td>37.5</td>
<td>--</td>
</tr>
<tr>
<td>0.21</td>
<td>70</td>
<td>88.5</td>
<td>69.5</td>
<td>--</td>
</tr>
<tr>
<td>0.15</td>
<td>100</td>
<td>95.5</td>
<td>91.0</td>
<td>--</td>
</tr>
<tr>
<td>0.11</td>
<td>140</td>
<td>97.0</td>
<td>98.0</td>
<td>--</td>
</tr>
</tbody>
</table>

+Goodyear Tire and Rubber Co., Bowmanville, Ontario
*Union Carbide Corp., Linde Division, Tarrytown, N.Y. 10591
**US Rubber Reclaiming Co., P.O. Box 365, Buffalo, N.Y.
++Optimum size
aramid. In the Goodyear hammer mill process the tire cord is usually recovered as a loose floc which is then compressed and baled prior to disposal. The recovered rubber powder is sold as a cheap extender for low quality rubber goods [e.g., rubber mats, underlays] for which there is a small but steady market. Some reclaim rubber is devulcanized with chemical peptizers so that it can be blended with virgin material in the manufacture of lower quality rubber goods such as rubber tires, hose, belts, etc. Devulcanized rubber is sold in crumb form with a coating of talc to prevent the crumb particles from adhering to one another. Attempts to dissolve devulcanized rubber in hot asphalt were unsuccessful, and since the resulting swollen mass was difficult to disperse, the powdered vulcanized reclaim was preferred for modification of asphaltic paving materials. The vulcanized particles readily disperse in hot asphalt and fairly substantial amounts can be added [20 parts] before the increased viscosity begins to impede the mixing and paving stages. Such large concentrations of rubber would not be possible if the rubber dissolved, since the viscosity would then be so large that mixing would be impossible.
INITIAL PAVING TRIALS IN METRO TORONTO

Extensive work has been carried out both in the United States and in Europe on the utilization of reclaim rubber in paving materials. Perhaps the most successful previous method was developed under the supervision of Charles H. McDonald of Phoenix, Arizona, in cooperation with State and Federal authorities. In this process old pavement was revitalized by scarifying and applying a rubberized chip seal coat. Rubber latex is still widely used as an additive although its use is restricted to critical locations such as airport runways, bridge decks and elevated highways. Polysar, Dunlop, U.S. Rubber and Firestone have demonstrated the superiority of rubberized asphalts in paving materials since many of the experimental roads laid down in the past are still in service after more than 20 years. In most of these trials, rubber latex was used which required non-conventional paving methods. The use of commercial latices usually implied a prohibitive price and special paving techniques so that their widespread use has remained dormant.

The approach described in this report avoids earlier difficulties and permits the direct addition of powdered reclaim rubber to the pug mill together with the aggregate. Slightly longer mixing times may be desirable to ensure complete dispersion of the asphalt-rubber mixture. The hot sand and crushed traprock are added to the pug mill in the
usual manner followed by the powdered reclaim. After 5 or 10 seconds the hot asphalt is introduced at 170°C and the mixing continued for 45 seconds. Shorter mixing times may be possible if the temperature is increased to 190°C. The hot mix is applied in the normal fashion although it has been found desirable to allow the pavement to cool to at least 100°C before rolling and to flush the roller with aqueous detergent to minimize "lifting". Temperatures at the paver were 175°C.
LABORATORY EVALUATIONS

The preferred paving material for the Metro Toronto Roads and Traffic Department, designated as HL-1, is an asphaltic concrete which is designed for long wear and good skid resistance. It contains a high proportion of traprock [orthoclase, $K_2Al_2Si_6O_{16}$] instead of the usual crushed limestone or gravel. The proportions of sand, traprock and bitumen are shown in Table 2 for the HL-1 control and several paving trials carried out in 1977 [14]. In order to conduct laboratory testing of rubber modified hot mixes, supplies of the necessary components were obtained directly from Repac Construction and Materials Ltd. in Toronto. A Hobart mixer was modified as recommended by the asphalt testing laboratories at the Ministry of Transport and Communication [MTC], in order to simulate the mixing conditions in a pug mill as closely as possible. A photograph of the mixer is shown in Figure 1.

The components, including the heavy cast iron mixing bowl, were preheated in an oven at 170°C just prior to blending. The hot aggregate was mixed for 15 seconds, and then the heated asphalt [Shell Venezuelan 80-100 penetration] was poured into the bowl and mixed for a further 45 seconds before pouring the contents into a rectangular metal tray. A specially designed roller with a hydraulic stage permitted the hot mix to be compressed into rectangular slabs 30 cm long, 19 cm wide and 5.2 cm thick. A photograph of the Metro Toronto Roller is shown in Figure 2. After allowing the slabs to cool for
24 hours, they were cut into six rectangular beams 19 cm long, 4.5 cm wide and 5.2 cm thick. These beams were tested to failure in a three point bending test using an Instron Tester with an environmental chamber [Figure 3]. Since the test beams were relatively short, the bending force contained a fairly large shear contribution so that the resulting stress-strain data was only useful for comparative purposes in this study.

The fracture toughness was measured by a modified double cantilever beam method [11] illustrated in Figure 4. Two rectangular beams were separated at each end by a brass rod, one rod having an attached razor blade to act as a crack starter for the rubber-asphalt mixture which was sandwiched between the two aluminum beams. The beams were cooled to -20°C and pulled apart in an Instron Tester at a crosshead speed of 0.5 cm/min. The purpose of conducting fracture tests at -20°C was to discover whether the presence of reclaim rubber influenced the resistance to crack growth at this temperature. As is evident from Figure 5, the particle size of the reclaim rubber is an important factor since larger particles were considerably more effective than the smaller ones. The data suggests that the average particle size should not be less than 0.5 mm [or smaller than 35 mesh screen size] for best results. This may be fortunate since it is more costly to grind to small particle sizes and such finely
divided powders are more difficult to disperse and increase the viscosity of the mix to a greater extent. The conclusion is that a coarser grade than is now commercially available would be more effective. Although most of the laboratory investigations and paving trials used Goodyear powdered reclaim, there are several other sources, two of which are listed in Table 1.
<table>
<thead>
<tr>
<th>Code No.</th>
<th>% Reclai m Rubber</th>
<th>% A.C. Bitumen</th>
<th>% Sand</th>
<th>% Traprock Screenings</th>
<th>% 3/8&quot; Traprock</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>HL-1</td>
<td>0</td>
<td>6</td>
<td>38.8</td>
<td>12.9</td>
<td>42.3</td>
<td>control</td>
</tr>
<tr>
<td>RA1</td>
<td>1.2</td>
<td>6</td>
<td>34.0</td>
<td>17.0</td>
<td>41.8</td>
<td>powdered reclaim added</td>
</tr>
<tr>
<td>RA2</td>
<td>1.2</td>
<td>6</td>
<td>38.2</td>
<td>12.8</td>
<td>41.8</td>
<td>directly to aggregate in pug mill</td>
</tr>
<tr>
<td>RA3</td>
<td>1.4</td>
<td>7</td>
<td>37.8</td>
<td>12.6</td>
<td>41.2</td>
<td></td>
</tr>
<tr>
<td>RA4</td>
<td>1.4</td>
<td>7</td>
<td>61.0</td>
<td>30.6</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>RA5</td>
<td>1.6</td>
<td>8</td>
<td>60.3</td>
<td>30.1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>RH1</td>
<td>1.2</td>
<td>6</td>
<td>34.0</td>
<td>17.0</td>
<td>41.8</td>
<td>powdered reclaim predispersed in bitumen and heated at 200°C for 30 min.</td>
</tr>
<tr>
<td>RH2</td>
<td>1.2</td>
<td>6</td>
<td>38.2</td>
<td>12.8</td>
<td>41.8</td>
<td></td>
</tr>
<tr>
<td>RH3</td>
<td>1.4</td>
<td>7</td>
<td>37.8</td>
<td>12.6</td>
<td>41.2</td>
<td></td>
</tr>
<tr>
<td>RH4</td>
<td>1.4</td>
<td>7</td>
<td>61.0</td>
<td>30.6</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>RH5</td>
<td>1.6</td>
<td>8</td>
<td>60.3</td>
<td>30.1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>RH6</td>
<td>1.6</td>
<td>8</td>
<td>36.5</td>
<td>12.5</td>
<td>41.4</td>
<td></td>
</tr>
</tbody>
</table>

S: 0, 8  slag as aggregate
SR: 1.6, 8  slag as aggregate
rubber added to pug mill
MARSHALL STABILITY TESTS

The Marshall Stability Test is an ASTM procedure which is used to specify the plasticity of a fresh paving mixture after compaction. For the HL-1 hot mix control, which is a formulation widely used in Ontario, the Marshall Stability curve follows the pattern shown in Figure 6 for several concentrations of bitumen [Shell Venezuelan, penetration 85-100]. The normal bitumen content is 6% although each paving mixture is subject to slight alterations of the formula due to differences in aggregate packing efficiencies from various sources. If the bitumen content is increased beyond a critical limit [about 7%] then the excess bitumen may "bleed" in the hot summer months and create a sticky surface. When rubber is present in the formulation, however, the mix is able to tolerate a much higher concentration of bitumen [about 8%] without causing bleeding. It is apparent from Figure 6 that the Marshall Stability is reduced by half compared to HL-1, and yet road tests have shown that even 8% bitumen will produce a satisfactory surface with no sign of distress after 2 years of service. Therefore, rubber modified mixes perform well even when Marshall values are well below the normally accepted minimums. If it is necessary to increase the Marshall Stability, then this may be easily accomplished by changing the weight ratio of sand to traprock screenings; for example, at a 1:1 ratio the Marshall Stability is equal to
that of an HL-1 mix as shown in Figure 7. Notice that the void content is also drastically reduced at a 1:1 sand to screenings ratio [Figure 8].

These results may be compared with the void content of an RA3 mix compared with the HL-1 control in Figure 9. Obviously the void content of rubber modified mixes can be reduced by increasing the bitumen content or altering the sand/screenings ratio.

These preliminary results do indicate that further research is needed to optimize the formulations with reclaim rubber. If a higher Marshall Stability with a low void content is to be preferred then a 1:1 sand to screenings ratio appears necessary. To date, however, the RA3 formula shown in Table 2 has been rated excellent after two years of service [14].
There is a marked increase in the viscosity of bitumen as the proportion of powdered reclaim [Goodyear] is increased. Figure 10 indicates that at 20 parts rubber there has been a tenfold increase in the viscosity at 95°C. As a result of this increase in viscosity it can be expected that the rate of mixing of asphalt with the aggregate will be slower unless the temperature in the pug mill is increased from the usual 170°C to 190°C [or about 1°C for each part of rubber added]. Furthermore, a slow thickening reaction occurs after the rubber has been dispersed, probably due to the gradual attainment of equilibrium swelling. While the extent of post thickening is not great [the viscosity is approximately doubled], the swelling process may account for the ability of rubber modified paving compositions to accept larger amounts of asphalt without causing problems with bleeding or distortion. The Marshall Stability measures the flow properties of the compacted mix at an early stage after the mixing so that the dispersed rubber particles have not yet had an opportunity to reach their fully swollen equilibrium state. After a longer period of time the viscosity would increase to nearly double its initial value as indicated from Figure 11. Here it is observed that the viscosity of the bitumen containing 10 phb reclaim rubber slowly increases during prolonged heating at 200°C. This post thickening process may account for the ability of rubber modified hot mixes to accept greater
concentrations of bitumen without bleeding.

Viscosity measurements were determined with a rotating cylinder viscometer of the Brookfield or Haake type [Model VT 23].
**LOW TEMPERATURE PERFORMANCE**

Pavement cracking usually occurs at low temperatures when the asphalt binder becomes brittle. The addition of reclaim rubber lowers the brittle point approximately 1°C per added part of rubber. In the case of Shell Venezuelan asphalt the brittle point is near 0°C whereas when 20 parts of reclaim rubber are added the brittle point is nearer -20°C. Typical flexural stress-strain curves for HL-1 mix and a rubber modified mix [RA3] are compared in Figure 12 at three different temperatures. Note that the elongation is greater when rubber is present although the flexural strength is nearly the same. The increased elongation is quite important since it allows the pavement to yield without fracturing in the cold weather. In some trials the rubber was added to the heated asphalt and allowed to attain equilibrium swelling at an elevated temperature before being mixed with the hot aggregate. Usually the toughness was increased by this preliminary heat treatment as shown in Figure 13. The toughness, as measured by the area under the stress-strain curve in flexural testing, increased by 25 to 50% compared to the HL-1 control, an increase which was attributed to partial swelling of the rubber particles and chemical grafting as a result of residual sulfur vulcanization or oxidative coupling. The rubber additives will slowly diffuse out of the particles and become dispersed in the bitumen where they influence the
mechanical properties and adhesion characteristics. Such changes occur more slowly at a lower temperature in the solid state. The diagram in Figure 14 illustrates these changes and indicates that the rubber particles become chemically bound to the bitumen phase. These grafting reactions at a rubber particle interface are known to enhance fracture toughness in plastics technology viz., ABS. That some toughening does occur after prolonged contact of the rubber and bitumen is evident from Figure 13. The experimental points represent the percentage increase in area under the stress-strain curve when compared with an HL-1 control. The open circles show a slight increase in toughness when the rubber particles are simply dispersed during the mixing stage. When preheated in bitumen at 200°C, however, the same formulation was much tougher as indicated by the black [closed] circles. No tests were carried out to confirm whether a corresponding increase in toughness occurred after a pavement had been exposed to weathering for several months. It is probable that some interaction would occur and may accomplish this extra toughening without the necessity of special heat pretreatment. If toughening does occur spontaneously after paving has been completed then direct addition of powdered reclaim rubber to the pug mill is to be preferred.

The Rheovibron has been employed to measure the viscoelastic response of rubber modified bitumen over the temperature range from -40°C to +20°C [6, 10]. The results
showed that at a frequency of 35Hz the brittle temperature of bitumen was reduced by only 5°C when 20 parts of rubber were added whereas Penetrometer readings indicated that the brittle temperature was reduced by 20°C! This large difference reflects the pronounced dependence of the viscous response of bitumen on the strain rate. For slow thermal contractions that occur frequently due to changes in the weather, the viscous response is probably comparable to Penetration values whereas at the Rheovibron frequency of 35Hz the response may simulate vehicular traffic.
RETENTION OF WET STRENGTH

The low surface energy of bitumen implies that in the presence of moisture the adhesion of bitumen to most inorganic surfaces will be near zero. This phenomenon is well known in the paving industry and is referred to as "water stripping" [1]. Antistripping agents are commercially available, but the consensus indicates that they are not particularly effective and may even accelerate water damage after a short delay. The loss of adhesion is particularly serious since the tensile and flexural strengths may decrease to a small fraction of their original dry strength thereby exacerbating the effects of weathering, cracking, spalling, ravelling, general deterioration and pothole formation. The damage is usually most noticeable in the Spring when the roads are generally in their weakest condition due to prolonged contact with ground moisture. If amine type antistripping agents are not effective in protecting the pavement from the harmful effects of water, then it is essential that alternative techniques be developed to help retain pavement strength when exposed to moisture.

It has been demonstrated that chemical modification of asphalt by sulfonation or maleation may be used to promote better adhesion and impart full retention of the wet strength for prolonged periods of time [8, 9]. This disclosure emphasizes the advantage of incorporating ionic surface active...
materials in the bitumen in order to maintain adhesion in the presence of water and maintain the tensile strength during seasonal changes when the imposed stresses due to thermal contraction and embrittlement are likely to be most severe.

There is also an alternative solution to this persistent problem. Although results are still preliminary, tests have shown that reclaim rubber modified asphalt concretes actually become stronger and tougher when fully immersed in water as indicated in Figure 15. The reasons for this unusual strength retention are not clear, but one possibility attributes the effect to the presence of rubber additives [sulfur accelerators, zinc compounds] which may promote better adhesion with the aggregate through slow migration of surface active components to the interface. The interesting feature of this gradual enhancement is the lack of a similar improvement in a sample exposed to air for the same period of time.

Therefore, the addition of reclaim rubber contributes several other benefits in addition to increased toughness which include

[a] improved low temperature flexibility;
[b] strength retention when wet;
[c] resistance to flow or creep at elevated temperatures;
[d] greater resistance to oxidative hardening due to the presence of rubber antioxidants.

From these investigations it is apparent that the addition
of reclaim rubber is advantageous whenever asphalt paving materials are to be used and that a doubling of the road service lifetime would be a conservative estimate.
COST OF RUBBER MODIFICATION

A partial breakdown of reconstruction costs for a typical paving contract has been presented for six Metro Toronto paving contracts by George [14]. At the time this report was written the HL-1 hot mix was $23/ton and that of RA3 mix containing 28 lbs [12.7 kg] of reclaim rubber was $29/ton. Since the estimated density of an RA3 mix is about 2.4% less than an HL-1 mix, the additional cost of rubber modification on a typical contract was a modest 1% despite the surcharge. As further experience and confidence in the use of reclaim rubber is gained the extra cost should decrease to about half, i.e., 0.5% of the contract price.

The current [1979] selling price of powdered reclaim is about 11¢/lb. Since it is apparent that the current Goodyear grade of reclaim is too fine for optimum performance, a slightly coarser grade would be cheaper to produce and might lower the selling price.

Whereas the Goodyear shredding process for reclaiming tires has been in commercial operation for many years, the cryogenic processes being promoted by Air Products and Union Carbide are still in the development stage. The cryogenic process has the advantage that steel belted tires can be handled, but the energy costs appear to be greater than those of the Goodyear process. The question of which process is cheaper will not be resolved until a commercial cryogenic plant is in operation.
CONCLUSIONS

The addition of powdered reclaim rubber to asphaltic paving materials markedly improves the durability and crack resistance particularly at low temperatures. The optimum concentration appears to be in the neighborhood of 20 phb* although greater or lesser quantities may be preferred in special cases. An unexpected benefit is the presence of rubber additives such as antioxidants and vulcanization agents which impart exceptionally good strength retention in the presence of moisture. The toughness increases with age due to a slow interaction of the rubber with the asphalt which is accompanied by an increase in viscosity. As a result the performance of the rubber modified paving mixture is also enhanced at elevated temperatures and helps to minimize pavement distortions due to hot weather and traffic.

While it may be too early to estimate the increased lifetime due to rubber addition in this particular process, numerous paving trials with rubber in various forms over the past 50 years have generally performed well and indicate a probable doubling of lifetime. Therefore, the added cost of rubber addition becomes trivial in comparison with the cost of reconstruction.

* phb - parts per hundred bitumen
ACKNOWLEDGEMENT

Particular appreciation is accorded Mr. R. A. Findlay of Environment Canada who participated in the planning sessions and was responsible for obtaining financial assistance for this project.

This project was initiated by Mr. Joseph D. George, now retired, of the Toronto Metro Roads and Traffic Department who dedicated most of his career to improving the quality of Metro roads and making roadways safer for the motorist.
REFERENCES


Figure 1. A view of the Hobart Mixer which was modified for laboratory mixing of asphalt compositions.
Figure 2. The Metro Toronto Roller was designed to permit the preparation of laboratory samples of experimental hot mixes containing reclaim rubber. A hydraulic stage permitted the rolling to be carried out at high pressures [up to 20 MN] comparable to actual conditions during paving.
Figure 3. The Instron tester was used extensively for evaluating the performance of rubber modified mixes in three point bending measurements. An insulated cabinet allowed testing to be carried out at temperatures as low as -40°C.
The double cantilever beam was employed to measure the crack resistance of rubber modified asphalts at low temperatures.

Figure 4.
Figure 5. Surprisingly, large rubber particles are more effective than small ones for imparting toughness and crack resistance. These studies indicate that the rubber particles should not be less than 0.5 mm in diameter.

[phb = parts per hundred bitumen]
Figure 6. The addition of 20 phb reclaim rubber to the HL-1 mix lowers the Marshall Stability. Surprisingly, such pavements have given good performance, an indication that the rubber-modified mixtures do not conform to normal expectations on the basis of Marshall Stability measurements.
Fig 6
Figure 7. The Marshall Stability can easily be increased to normal level by altering the ratio of sand to traprock screenings. In this series the bitumen contained 20 phb reclaim rubber.
Figure 8. The void content can also be regulated by adjusting the ratio of sand to traprock screenings. In most paving compositions the void content should be less than 2%. At a 3:1 ratio the bitumen content can be increased to 8% without bleeding if 20 phb reclaim rubber is added.
Sand: Screenings

Voids (%) vs. Bitumen Content, phb

- ○ 3:1
- ◊ 2:1
- □ 1:1
Figure 9. The addition of 20 phb reclaim rubber to the HL-1 formulation increases the void content. By adjusting the sand/screenings ratio the void content and the Marshall Stability can be optimized.
Fig 9
Figure 10. The addition of Goodyear powdered reclaim produces an increase in the viscosity at 95°C. For this reason slightly longer mixing times are needed in the pug mill to ensure adequate dispersion of the rubber particles and the aggregate.
Fig 10
Figure 11. Prolonged contact of the reclaim rubber with hot bitumen produces an increase in the viscosity. This post thickening effect helps to raise the heat distortion temperature of the pavement.
The flexural tests clearly indicate the difference in behaviour between a regular HL-1 mix and a reclaim rubber modified mix. Greater elongation usually implies fewer cracks. However, the rubber modified mix becomes tougher with time whereas the HL-1 mix loses strength and age hardens.
Fig 12
Figure 13. The addition of 20 phb reclaim rubber to the aggregate produces a moderate increase in toughness compared to an HL-1 control. After heating the powdered rubber with bitumen for 30 minutes at 200°C there is a marked improvement.
Fig 13
Figure 14. After prolonged heating the rubber additives tend to disperse in the bitumen and there is some chemical grafting at the surface of the rubber particles. The result is a much tougher composite.
DISPERSED RUBBER PARTICLES IN ASPHALT

AFTER HEATING FOR PROLONGED PERIOD

Fig. 14
Figure 15. The long term immersion of a rubber modified paving sample in water shows a gain in strength after 8 months compared to a sample stored in air.
Fig. 15

RUBBER MODIFIED ASPHALT CONCRETE AFTER 8 MONTHS IMMERSION

STRESS, MPa

STRAIN
Figure 16. A closeup view of the paver applying the final topcoat on Lakeshore Boulevard, October, 1978.
Figure 17. A view of Dixon Road during the paving of six lanes with the rubber modified asphalt mix, August, 1978.
Figure 18. The final topcoat of rubber modified mix being applied to Lakeshore Boulevard, October, 1978