USE OF ASPHALT RUBBER

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ABSTRACT

An assessment of Ontario scrap tire crumb rubber modified (CRM) hot-mix demonstration projects indicated the wet process (rubber modified asphalt cement - AR) can surpass conventional mixes in performance with favourable life-cycle costs. These findings, and development of improved AR mix design procedures and terminal blended AR with a minimum storage stability of 24 hours, resulted in three AR projects in 1994. A modified dry process project was also successfully completed using finer CRM (30 mesh). The specific project studied involved resurfacing a pavement in Brantford with two lifts of hot mix incorporating AR (about 15 percent 40 to 60 mesh CRM by mass of asphalt cement). This hot mix (about 6 percent AR by mass of mix) was designed, produced, placed and compacted without any problems. During the Marshall mix design, it is important to allow mix conditioning prior to briquette compaction and place a surcharge on the compacted briquette to prevent rebound during cooling. During field compaction, it is necessary to use a soap solution with all rollers (sticky mix) and continue finish rolling until the AR mix has cooled. There were no perceived environmental problems. Overall project monitoring involved mix compliance, compaction, smoothness, friction and resilient properties.

Key Words: asphalt; rubber; scrap tire; wet process; dry process; design; production; placement; monitoring.

1. INTRODUCTION

The Ontario Ministry of Environment and Energy (MOEE) has funded about thirty demonstration projects to evaluate the use of processed scrap tire crumb rubber modifier (CRM) in hot-mix asphalt (HMA). These rubber-modified asphalt demonstration projects had focused on rubber-modified asphalt concrete (RUMAC) where the CRM behaves essentially as rubber aggregate. Typically, one to three percent, relatively coarse (4 or 10 mesh) CRM is proportioned into a batch or drum hot-mix plant and incorporated during mixing of the HMA (termed dry process). There is little CRM modification of the asphalt cement with dry process RUMAC [1-3]. Only one rubber-modified asphalt cement (AR) demonstration project was completed prior to the 1994 paving season [4]. With asphalt rubber (AR), typically 10 to 20 percent, fine (40, 60 or 80 mesh) CRM is blended with asphalt cement at a central terminal or at the hot-mix plant. This stable, uniform, reacted blend of CRM and asphalt cement, with reduced temperature susceptibility, is then incorporated as an asphalt-rubber binder during HMA production (termed wet process) [1-3]. A material, process, technology and product schematic for CRM use in RUMAC and AR is shown in Figure 1 [3].

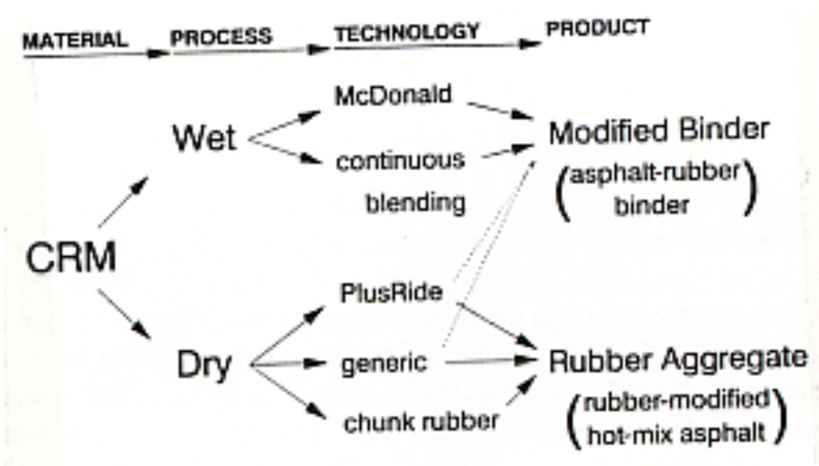

FIGURE 1 USE OF PROCESSED SCRAP TIRE CRUMB RUBBER MODIFIER (CRM) IN HOT-MIX ASPHALT (HMA) [3].
(There is some dry process interaction to modify the binder, as indicated by the dotted arrow lines, particularly for finer CRM, extended mixing times or elevated mixing temperatures.)

An independent technical, economic and environmental assessment of the first eleven Ontario rubber-modified asphalt demonstration projects was completed in late 1993. This comprehensive assessment indicated [1,2]:

1. The pavement performance of dry process RUMAC can be equivalent to conventional HMA, provided care is taken with: CRM incorporated (quality, size and quantity); mix design procedure; and mix production, placement and compaction.
2. The life-cycle cost of RUMAC is not favourable compared to HMA.
3. The pavement performance of wet process AR hot-mix asphalt can surpass HMA.
4. The life-cycle cost of AR appears to be favourable compared to HMA for surface course mixes.
5. The environmental impacts of rubber-modified asphalts are similar to HMA.

A United States Federal Highway Administration/Environmental Protection Agency (FHWA/EPA) study of recycled paving materials, completed in 1993, came to similar conclusions concerning the potential performance of RUMAC and AR [5].

The Ontario short-term experience with rubber-modified asphalt was rather negative for continuing with RUMAC, but fairly positive for further AR technology demonstration projects [1]. It should be noted that there were Ontario trial sections of fine CRM (30 to 40 mesh) rubber-modified asphalt concrete (modified RUMAC or MRUAC) placed as early as 1976

[6,7]. With finer CRM added during mix production, there is some interaction to modify the asphalt cement in the mix (termed moist process), particularly with an extended mixing time or elevated mixing temperature. The trial sections placed in Metropolitan Toronto between 1977 to 1980 appear to have performed similar to, or somewhat better than, the overall pavement system [8].

The fairly positive wet process AR experience, coupled with the development of improved CRM mix design procedures and terminal blended AR, made AR the preferred CRM technology for Ontario in 1994. Three wet process AR demonstration projects were completed during the 1994 paving season: Park Road North, City of Brantford; Armour Road, City of Peterborough; and County Road 9, Grey County. A moist process MRUAC demonstration project was also completed on Main Street in the Town of Kirkland Lake [9]. The City of Brantford AR project is described in following sections. An overview of the Town of Kirkland Lake MRUAC project is also given.

2.0 ASPHALT RUBBER (AR) TECHNOLOGY

2.1 Asphalt-Rubber Binder (ARB)

The McDonald and continuous blending method technologies for asphalt-rubber binder (ARB) are considered wet processes, as the CRM is pre-blended with the asphalt cement before AR use in the hot-mix plant. This involves reaction of the CRM with the hot asphalt cement. An extender oil or catalyst is typically added to ensure CRM dispersion and AR stability against separation or settlement [10-12]. The AR can be produced at a central terminal or at the hot-mix plant. United States proponents of AR technology have favoured using ambient process CRM [11,13]. Ontario experience has been quite satisfactory with cryogenic process CRM [1]. The wet processes are well suited to all hot-mix plant operations since the AR can be readily added using the plant's asphalt cement system. Adequate storage stability of the AR is imperative.

There is now an ASTM proposed standard specification for asphalt-rubber binder [14]. This comprehensive specification describes asphalt rubber (AR) as a blend of asphalt cement, ground recycled tire rubber (CRM) and other additives. The CRM component must be at least 15 percent by mass of the total blend and `interacted' in the hot asphalt cement sufficiently to cause swelling of the rubber particles. The proposed physical requirements for Type III asphalt-rubber binder (ARB) are given in Table 1 [14].

The use of AR in HMA requires about 20 percent more ARB than is used in comparable conventional HMA. However, the thicker films of ARB in the mix do contribute to improved durability, particularly for open-graded mixes. The AR’s lower temperature susceptibility provides increased resistance to permanent deformation and thermal cracking. From an engineering and applications viewpoint, it appears that the wet processes are more economical, practical and predictable than the dry processes [1,2]. The design, production and placement requirements for asphalt mixes incorporating AR have generally been established for some time and can be considered fairly standard [11].

2.2 Dura-Tirephalt® Rubber-Modified Asphalt Cement

Dura-Tirephalt® rubber-modified asphalt cement (termed AR throughout) was developed by McAsphalt Engineering Services in response to the growing Ontario interest in AR technology. This terminal

TABLE 1
PRODUCT DATA SHEET FOR DURA-TIREPHALT®

ASPHALT-RUBBER (AR) BINDER DESIGNATION TESTa.	PROPOSED ASTM TYPE III REQUIREMENTSb.	TYPICAL TEST RESULTSc.
Apparent Viscosity, 175°C:cP (ASTM D2196)d.	1500-6000	5750
Penetration, 25°C, 100 g, 5 s:dmm (ASTM D5)	50-100	79
Penetration, 4°C, 200 g, 60 s:dmm (ASTM D5)	Minimum 25	38
Softening Point:°C (ASTM D36)	Minimum 51.7	55.8
Resilience, 25°C:% (ASTM D5329)	Minimum 10	20
Flash Point:°C (ASTM D93)	Minimum 232.2	240
TFOT Residue (ASTM D1754)		
Penetration Retention, 4°C:% of Original	Minimum 75	90
Brookfield Viscosity, 135°C:cPe.	___ f.	3000g.
Elastic Recovery, 10°C, 10 cm:%e.	___	80
Force Ductility Ratio, 4°Ce.	___	0.47
Separation After 24 Hours, 175°Ce.	___	Pass

a. ASTM Subcommittee D04.05, Proposed Standard Specification for Asphalt-Rubber Binder (Version No.1.4, December 1993) [14].
b. Type III asphalt-rubber binders are generally recommended for use in cold climate areas defined as:
average monthly maximum ambient temperature is 27°C or lower; and
average monthly minimum ambient temperature is -9°C or lower [14].
c. For testing and mix design purposes, asphalt rubber (AR) should be heated to 175°C, and well stirred prior to each pouring. McAsphalt Engineering Services test data.
d. Modified ASTM D2196, Method A per 4.2.3.1 [14].
e. Additional asphalt rubber (AR) tests.
f. A dash indicates not specified.
g. Brookfield Thermosel System, RV Series, Spindle Number 21.

blended AR had a minimum storage stability of 24 hours for the 1994 paving season. Its storage stability has now been enhanced to 72 hours. The AR is a stable, uniform, reacted blend of compatible paving grade asphalt cement, a minimum of 15 percent Ontario manufactured 40 to 60 mesh CRM and proprietary additive for rubber dispersion and stability. The asphalt cement is typically selected to be one grade softer than would be used in conventional HMA in the area.

As indicated in Table 1, the AR meets the ASTM physical requirements for Type III asphalt-rubber binder [14]. These physical requirements are appropriate for most of Ontario. The benefits of using such AR in hot-mix asphalt can be summarized as:

1. Increased durability - the AR is more resistant to oxidation due to thicker binder films. The anti-oxidants and carbon black contained in the rubber also contribute to aging resistance.
2. Increased resistance to rutting - the higher viscosity and softening point of the AR compared to conventional asphalt cements results in increased resistance to permanent deformation.
3. Increased resistance to reflective and thermal cracking - the decreased temperature susceptibility and `elastic' characteristics of the AR contribute to increased resistance to cracking.

3.0 MIX DESIGN PROCEDURES FOR AR AND MRUAC

Practical AR and MRUAC mix design experience in the laboratory has shown the conventional Marshall method of HMA mix design [15], with two straightforward modifications, to be quite appropriate. During the laboratory AR mix preparation stage, the properly heated (typically 175°C) and well stirred asphalt-rubber binder is added in the same way as conventional asphalt cement. During the laboratory MRUAC mix preparation stage, the fine CRM (typically 30 mesh) is added during the dry mixing and the subsequent wet mixing is extended by 30 seconds. The AR or MRUAC mix is then oven retained for one hour, at a temperature 5 to 10°C lower than the initial mixing temperature, in a covered container prior to compaction of the briquettes. This is done to simulate the typical project mixing, transporting and placing (conditioning) time involved. A surcharge (7.8 kg) is placed on the compacted briquette in the mould to prevent `elastic' rebound as the briquette cools from the compaction temperature to the laboratory temperature. This simulates the project compaction procedure of continuing the finish rolling until the mat temperature is below 45 to 50°C in order to reduce any rebound effects.

4.0 CITY OF BRANTFORD ASPHALT RUBBER DEMONSTRATION PROJECT

4.1 Project

The October 1994 City of Brantford asphalt rubber demonstration project involved resurfacing a
500 m section of Park Road North from Dunsdon Street to Powerline Road. This two lane section of roadway carries about 9500 vehicles per day with 4.3 percent commercial (heavy) traffic. Two 65 mm lifts of HMA (HL 4AR binder course and HL 3AR surface course) incorporating AR were placed over the pulverized existing asphalt concrete. A small binder course (HL 4) control area was also placed.

The HL 4AR and HL 3AR mixes incorporated AR (`ASTM Type III') supplied from the McAsphalt Industries Limited terminal. These AR mixes required 0.8 percent (HL 4AR) and 0.7 percent
(HL 3AR) additional asphalt cement (ARB) for the same aggregate gradation as the conventional mixes.

The production, placement and compaction of the AR mixes was specified to be the same as for conventional mixes [16,17] with the following supplementary requirements:

1. The wet mixing time must be increased by 10 seconds over conventional mixes.
2. The production and application temperature recommendations are:

AR storage temperature	160 to 175°C
Mixing temperature	160 to 170°C
Compaction temperature	Minimum 150°C.

3. Truck boxes must be clean and a non-solvent release agent must be used.
4. Steel drum rollers must have a water/soap solution used on their drums.
5. Rubber tired rollers must have a water/soap solution sprayed on the tires.
6. Compaction must be continued until the mat temperature has dropped to at least 50°C. Care must be taken during compaction to ensure that shoving, checking or pushing of the mat does not occur.

No difficulties were experienced in completing the demonstration project paving.

4.2 Testing

The acceptance testing and initial pavement monitoring for the Park Road North AR demonstration project were completed in accordance with an Ontario Ministry of Transportation (MTO) experimental plan [18]. This testing and monitoring included: Marshall compliance testing of the AR mixes; testing the asphalt cement and AR; compaction testing (nuclear density and cores); pavement profile measurements; pavement structural capacity testing; and pavement surface frictional testing.

The material descriptions and test results for the binder course (HL 4 and HL 4AR) and surface course (HL 3AR) mixes placed on Park Road North are summarized in Table 2. Nuclear density gauge quality control compaction levels achieved were similar to those for cores given in Table 2. These compaction levels are considered to be satisfactory and reflect the care taken with finish rolling. The test data indicate fairly good compliance with the JMF and specification requirements, except for the asphalt cement (ARB) content of the AR mixes.

Asphalt cement (ARB) contents were found to be 0.37 to 0.67 percent higher than the JMF for the HL 4AR and HL 3AR mixes, respectively. There have been no signs of high asphalt cement (ARB) content (flushing or bleeding) in the field. It is considered likely that there is some AR (reacted CRM) adhesion with the very fine aggregate in the mixes that results in apparently high extracted asphalt cement contents. It was shown during the Town of Kirkland Lake MRUAC demonstration project that the use of a calibrated nuclear asphalt cement content gauge minimized this testing problem.

The test results for the asphalt cement and AR are summarized in Table 3. These results indicate the ARB met the project requirements, with the exception of one somewhat low flash point (AR Blend No.1). The rotational (Brookfield) viscosity tests indicated the ARB is stiffer than conventional asphalt cement. Based on the force ductility tests, the ARB also has better fracture resistance.

Pavement structural capacity testing (deflection testing) was completed using a Dynatest 8081 High Capacity Falling Weight Deflectometer (FWD). The normalized dynamic deflections prior to placing AR mixes (i.e. on pulverized old pavement) ranged from 0.21 to 0.39 mm with a mean of 0.32 mm. The surface resilient modulus values ranged from 379 to 711 MPa which indicate generally fair to good support. The normalized dynamic deflections after placement of the HL 4AR and HL 3AR mixes ranged from 0.17 to 0.34 mm with a mean of 0.25 mm. The corresponding surface resilient modulus values ranged from 441 to 875 MPa indicating generally good to very good support.

Pavement surface profile measurements were taken using a Digital Incremental Profiler (Dipstick®). A pavement surface profile was established for the northbound lane immediately after paving was completed.

The International Roughness Index (IRI) of this section was 2.48 mm/m. The specified range for new construction based on World Bank requirements is 2 to 4 mm/m. A further profile evaluation was made two weeks later as the pavement ride was reported as being `wavy' by the City of Brantford. A visual inspection indicated some localized depressions (roller marks) caused by the compaction equipment. Further surface profile measurements were taken. Some deviations (depressions) were found, but no definite pattern was evident. The deviations were generally about 1.0 mm with the maximum deviation measured over 3 metres calculated to be 1.7 mm. This is well within the pavement smoothness specification. Regardless, it is important that rollers not stop (`park') on the hot mat as this can cause localized depressions.

Pavement frictional properties testing was completed using a British Portable Pendulum (BPP) Tester in accordance with ASTM E303. The average British Pendulum Number (BPN) of the HL 3AR pavement surface was 64. This is significantly higher than the recommended minimum value of 45 for urban pavements. The BPN of an existing HL 3 pavement surface adjacent to the trial section was 54. It is considered that the HL 3AR pavement surface has very good frictional (skid) properties.

4.3 Long-Term Performance

The surface of the completed asphalt rubber (AR) asphalt concrete on Park Road North has a good
appearance. Long-term performance monitoring of this AR demonstration project, as part of the overall MOEE program, will provide valuable information on the service life and economics of such AR mixes. With larger scale use of AR mixes, and growing contractor experience, it is anticipated that the initial cost of AR mixes will be about 20 percent greater than for conventional mixes. However, if the anticipated increase in service life of AR mixes is achieved (reduced rutting and cracking), these mixes will be economically attractive on a life-cycle costing basis [1,2].

TABLE 2
MATERIAL DESCRIPTIONS AND TEST RESULTS FOR THE BINDER COURSE (HL 4 AND HL 4AR) AND SURFACE COURSE (HL 3AR) MIXES PLACED ON PARK ROAD NORTH

DESCRIPTION OR TEST	HL 4	HL 4ARa.	HL 3AR
Materials			
- Aggregates: % Of Aggregate			
Crushed Gravel, minus 19.0 mm, plus 4.75 mm	45.2	45.2	
minus 13.2 mm, plus 4.75 mm	b.		48.2
screenings, minus 4.75 mm	9.1	9.1	8.6
Screened Asphalt Sand, minus 4.75 mm	45.7	45.7	43.2
- Asphalt Cement:Penetration Grade	85/100	150/200 (AR)	150/200 (AR)
- Crumb Rubber Modifier (CRM) in AR:%		15	15
Property Testedc.			
- Asphalt Cement Content:% of Mix	5.37	6.37	6.77
- Passing 4.75 mm Sieve Size:%	57.3	53.9	53.7
- Passing 75 mm Sieve Size:%	5.3	3.8	2.9
- Recompacted Bulk Relative Density (BRD)	2.445	2.404	2.375
- Maximum Relative Density (MRD)	2.514	2.493	2.490
- Air Voids:%	2.7	3.6	4.6
- Voids Mineral Aggregate:%		15.6	17.4
- Stability, 60°C:N	14193	12676	9515
- Flow:0.25 mm	11.3	11.4	12.4
- Compaction, of MRD:%	94.2	93.7	91.8
- Recovered Penetration:dmm	58	68	96

a. AR — Asphalt rubber. The crumb rubber modifier (CRM) content of the AR is by percent of asphalt cement.
b. Empty Space — No relevant information or test data.
c. — One test for HL 4 and average of four tests for HL 4AR and HL 3AR, with the exception of compaction (average of five tests) and recovered penetration (one test).

TABLE 3
ASPHALT CEMENT AND ASPHALT RUBBER (AR) TEST RESULTS

TEST	ASPHALT CEMENT 85/100	ASPHALT RUBBER (Blend No. 1)	ASPHALT RUBBER (Blend No. 2)
Penetration, 25°C, 100 g, 5 s:dmm (ASTM D5)	89	90	101
Flash Point:°C (ASTM D93)	306	212	238
Rotational Viscosity (Brookfield), 135°C:cP	356	1213	1250
Force Ductility			
Elongation at Peak Load:cm	0.98	1.58	1.35
Peak Load:kg	7.06	2.69	3.06

5.0 TOWN OF KIRKLAND LAKE MRUAC DEMONSTRATION PROJECT

The September 1994 Town of Kirkland Lake fine CRM (30 mesh) rubber-modified asphalt concrete (MRUAC) moist process demonstration project provides an interesting comparison to the City of Brantford AR technology.

A 300 metre section of Main Street was surfaced with two 40 mm lifts of HL 4MRUAC. This previously unpaved road section is mainly used by large haul vehicles carrying scrap wood chips used for power plant fuel.

The moist process HL 4MRUAC binder course and surface course mix contained 1.2 percent CRM (30 mesh) by mass of mix (20 percent by mass of asphalt cement). Binder course and surface course dry process RUMAC mixes were to have been used for the Main Street demonstration project in 1993. However, given the 1993 evaluation findings for the asphalt-rubber demonstration projects, the Main Street demonstration project was deferred and changed to the moist process MRUAC technology in 1994.

There was some concern with the low stability of laboratory MRUAC mixes. This low stability undoubtedly reflects both the incorporation of fairly fine CRM and the use of a softer grade of asphalt cement (300/400) for reduced mix temperature susceptibility. It was found that oven conditioning of the mix during the Marshall mix design was important to achieving realistic laboratory stabilities. The test results for the binder course and surface course HL 4MRUAC mix for Main Street, summarized in Table 4, indicate the actual production mix stabilities are still somewhat higher than those achieved in the modified laboratory procedure. The use of the nuclear asphalt cement content gauge was proven to be effective on this project (Table 4). Test results for the HL 4MRUAC met the project specification requirements.

TABLE 4
TEST RESULTS FOR BINDER AND SURFACE COURSE MIX (HL 4MRUAC) PLACED ON MAIN STREET

PROPERTY TESTED	HL 4MRUACa.
Asphalt Cement Content	
Extraction Test (average of 3):% of Mix	6.64
Nuclear Test (average of 4):% of Mix	5.90
Crumb Rubber Modifier Content,	
CRM (average of 3):% of Mix	1.6
Passing 4.75 mm (average of 3):%	56.6
Passing 75 mm (average of 3):%	2.6
Marshall Properties (average of 2)	
Recompacted Bulk Relative Density (BRD)	2.358
Maximum Relative Density (MRD)	2.438
Air Voids:%	3.3
Voids Mineral Aggregate:%	18.6
Stability, 60°C:N	7228
Flow:0.25 mm	15.6
Compaction, of Recompacted BRD:%	95 to 98

a. HL 4MRUAC is rubber modified hot-mix asphalt (modified dry process) incorporating fairly fine crumb rubber modifier (CRM).

The Town of Kirkland Lake MRUAC demonstration project was completed without any significant problems and is considered to be a technical success. Early heavy truck usage was not harmful to the fresh HL 4 MRUAC mat.

There is a significant additional initial cost of about 40 percent with MRUAC technology over conventional HMA. Long-term monitoring of the pavement’s performance is required to determine if the MRUAC technology is economically viable.

6.0 CONCLUSIONS

The practical experience with asphalt rubber (AR) technology during 1994 was most positive. There were no materials, mix design, production, placement or compaction problems with the binder course and surface course AR mixes. While hot-mix plant emissions testing was not involved for either demonstration project, there were no perceived environmental problems with the wet process AR technology or moist process MRUAC technology. The terminal blended AR met all of the technical and handling requirements. The City of Brantford AR demonstration project was an overall technical success. Long-term pavement performance monitoring and life-cycle costing will determine if AR technology is economically viable, as anticipated.

The Town of Kirkland Lake fine CRM rubber-modified asphalt concrete (moist process MRUAC) was also a technical success. The life-cycle costs of MRUAC technology are probably not favourable. However, MRUAC can provide a logical alternative to CRM use in hot-mix asphalt if terminal blended AR is not available.

The views and ideas expressed are those of the authors and do not necessarily reflect the views and policies of the Ontario Ministry of the Environment and Energy or Ontario Ministry of Transportation.

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