A STUDY OF CHUNK RUBBER FROM RECYCLED TIRES AS A ROAD CONSTRUCTION MATERIAL

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ABSTRACT

The feasibility of using large rubber chunks from shredded tires as aggregates in cold-mixes for road construction was investigated in this study. The research was directed toward development of a chunk rubber asphalt concrete mix design for low volume road construction using local aggregate, shredded tire rubber chunks and a cationic emulsion. A set of mixes using different combinations of chunk rubber content, emulsion content and fly ash content were tested. Marshall stability results of mixes with 10% Type C fly ash showed optimum emulsion contents of 6.8, 7.3 and 7.8% for 2, 4 and 6% rubber, respectively. The Marshall stability values decreased for increasing rubber contents. The target Marshall stability value of a suitable cold mix at 43ºC was required to be 2225 N. A mix with 10% Type C fly ash, 2% rubber and 7% emulsion showed an average Marshall stability value of 1600 N. Based on the Marshall stability results, some of these mixes appeared to be suitable as binder courses or stabilized drainable bases for low volume roads. If 9 kg of chunk rubber equivalent is produced per tire, then a one km long and 7.3 m wide low-volume road with a 100 mm thick base built with this mix can incorporate approximately 3350 tires. This application can minimize the scrap-tire waste problems of rural communities.

KEY WORDS

chunk rubber, cold mix, low-volume roads, mix design, scrap tires

INTRODUCTION

Each year approximately 285 million tires are added to stockpiles, landfills or illegal dumps across the United States [1]. The EPA estimates that the present size of the scrap tire problem is two to three billion tires. If the national rate of tire generation is used, it is estimated that on the average, one scrap tire per person per year is generated in Kansas. This translates to approximately 2.4 million tires per year in Kansas. The current estimate of the number of accumulated scrap tires in the state is between 4.3 and 5.5 million [2]. Cloud, Coffey, Leavenworth and Sedgwick Counties have the most scrap tires, totalling over 3.3 million. The case of Cloud County, a rural county with approximately 11,000 people, is particularly interesting. The estimated number of accumulated tires is slightly over half a million [2]. The large number of tires accumulated over the years and currently being generated creates a disposal problem in the rural areas of Kansas.

Introduction of scrap tire rubber into asphalt concrete pavement has the potential to solve this waste problem. It has been estimated that if only 10% of all asphalt pavement laid each year in the United States contained 3% rubber, all the scrap tires produced for that year in this country would be consumed [2]. The potential benefits of a cost-effective product has kept interest in asphalt-rubber high throughout the world. The use of scrap tire rubber as an additive for asphalt concrete has been developing for over 30 years. Recently, however, it has attracted attention all over the United States because of enactment of the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) which mandates the use of scrap tires in hot mixes for asphalt concrete pavements.

Problem statement

The use of rubber as an additive in asphalt has been discussed and researched for the past 30 years. Although the use of asphalt-rubber is attractive from the viewpoint of environmental preservation, it is not widely used because its performance and cost effectiveness have not been conclusively proved.

The asphalt-rubber production can be broken down into the "wet" process and the "dry" process. The “wet” process uses the rubber as an additive to the asphalt binder. In this process, anywhere from 10% to 30% rubber, by weight, can be introduced into the binder at a high temperature, and the rubber is allowed to react with the binder. The reaction time is usually recommended by the rubber supplier. The resulting asphalt-rubber binder is typically used in hot-mix hot-laid asphalt concrete but can also be used in stress absorbing membranes (SAM) or stress absorbing membrane interlayers (SAMI) where spray-type applications are common.

The "dry" process uses rubber as an aggregate. Usually 2% to 3% rubber is added, as a solid, with coarse and fine aggregates to a pure asphalt binder. The most popular mix design for this product has been patented under the trade name "PlusRide" [1]. A generic system, called the TAK system, has been developed recently and used on a few construction projects [1].

Most of the asphalt-rubber research work done in the past concentrated on roads with hot-mix asphalt concrete with finely ground rubber, commonly known as crumb rubber. This crumb rubber is expensive, and would not be cost-effective for low-volume roads. An alternative to the crumb rubber studied by the CRREL [3] was the use of larger rubber particles, or chunk rubber, as aggregates in a hot-mix. However, no research has been done about the feasibility of using larger rubber chunks as aggregates in cold-mix. This was the major objective of this project. The results of this study should benefit the rural counties in Kansas. For example, Lincoln County, Kansas, had a tire pile consisting of approximately 8,000 car, truck and tractor tires. It would be beneficial to Lincoln County, and of course to other counties in Kansas with tire piles, if these tires were shredded and the resulting rubber chunks were incorporated cost-effectively into low-volume county roads using cold-mix.

Objectives

The major objective of this research project was to formulate a Chunk Rubber Asphalt Concrete (CRAC) mix to be used on low-volume roads. CRAC is a rubber-modified asphalt concrete which is produced by the so-called "dry process"—a mixing process where rubber particles are used as aggregates with sizes between 2 mm and 600 μm, as in "PlusRide," or with sizes plus 4.75 mm to 9.5 mm, as studied by the CRREL and Oregon State University. However, the CRAC studied in this project was a cold-mix in contrast with the "dry process" hot-mixes researched earlier. It also contained rubber chunks of up to a maximum of 12.5 mm.

RECYCLED RUBBER IN COLD MIX

The MSO Construction and T.J. Pounder, Ltd., in Ontario, Canada, are believed to be the first agencies who have studied recycled shredded tires in the Cold In-Place Recycling (CIR) process of deteriorated pavements. The method of formulation used was a compendium of in-house knowledge of material behavior and resulted from engineering achievement and experimentation. From the results of laboratory testing and based on the experiences of MSO and Pounder in the CIR process, it was determined that a feasible, stable and durable binder course asphalt mix can be produced from cold mixes with crumb rubber in it. The thrust of this initial examination was to find a maximum significant amount of recycled rubber tire crumbs that could be mixed with Recycled Asphalt Pavement (RAP) as an aggregate and used in the CIR process. An emulsified asphalt was used as a recycling agent in the mix along with ambient ground recycled tire crumb produced by the cryogenic process. The addition of rubber in RAP reduced the compressive strength by about 25%. However, it contributed to the flexibility. This lent itself to the weather conditions in Ontario. The idea was to find an acceptable compromise point between the two characteristics—strength and flexibility. The best results were found in a mix containing 7000 tires/km [4].

RESEARCH ACCOMPLISHED

Research approach

Although the research was planned to have both laboratory and field studies of CRAC as an alternative cold-mix, it was confined to laboratory studies of CRAC cold mix. Lack of a construction project hindered the effort to build a road with the cold-mix incorporating chunk rubber.

Project scope

The purpose of this part of the research was to develop a CRAC mix for use on a low volume road in Miami County (potential test site) using an asphalt emulsion. The goal was to develop a mix using the "dry" process or the chunk rubber as an aggregate, which would achieve a Marshall stability value of 2225 N, a value that seemed to be acceptable by KDOT for a cold-mix.

Materials used

Aggregates

The aggregates were supplied by Fogle Quarry of Ottawa, Kan. This source was chosen because of its close proximity to Miami County. The aggregates supplied consisted of 12.5 mm bedding, 6.4 mm chips, 6.4 mm screening and a manufactured sand.

Rubber

The chunk rubber used in this study was supplied by Mid-Continent Resource Recovery, Inc., of Wichita, Kan. The rubber was produced through a series of stationary scrap tire shredders and nearly 100% of it passed through a 9.5 mm sieve, with the majority retaining on a 4.75 mm sieve. The supplied chunk rubber had steel and fibers in it. Some of the fibers were removed by sieving.

Emulsion Content (%)	Avg. Air Voids (%)	Avg. VMA (%)	Corrected Stability (N)	Flow (mm)
5	9.85	17.4	4625	1.93
6	8.83	17.55	4580	1.93
7	6.88	17.40	4000	1.93
8	4.32	16.56	4000	1.75
9	1.89	16.50	4715	2.03

Table 1. Emulsion mix Marshall test results.

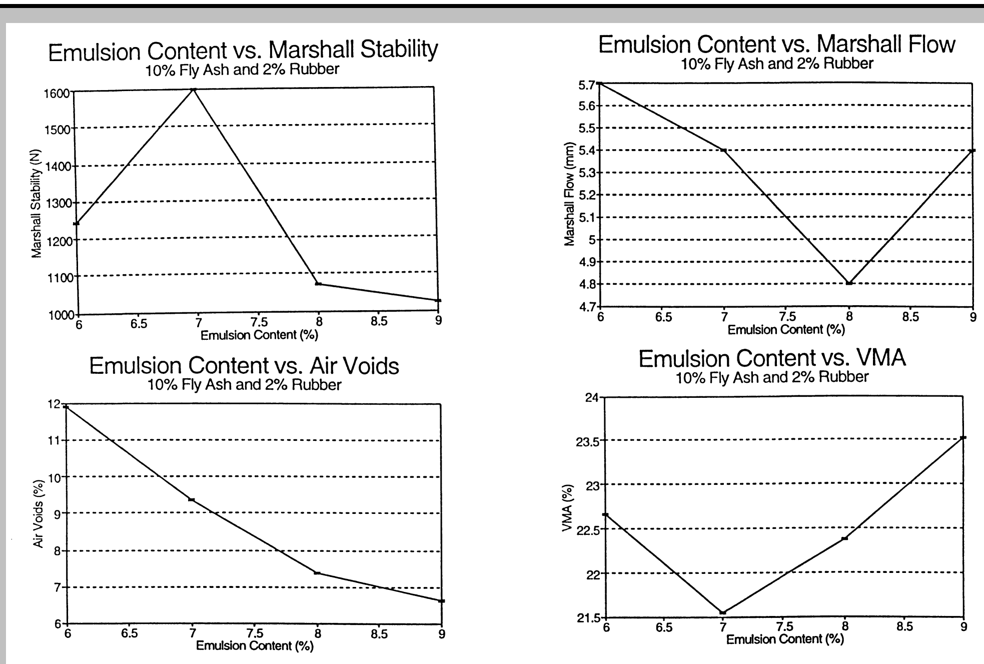

Figure 1. Marshall stability, flow, air voids, VMA and unit weight of CRAC mixes with 10% fly ash and 2% rubber for different emulsion contents.

Asphaltic materials

Two different asphaltic materials, a medium curing cutback (MC-800) and a cationic medium setting emulsion (CMS-1), were investigated in this project. The MC-800 cutback was provided by Coastal Derby Corp. of El Dorado, Kan., and the CMS-1 emulsion was provided by Koch Industries, Salina, Kan.

Fly Ash Content (%)	Moisture Content (%)	Avg. Corrected Stability (N)
2	2.5	18,500
	5.0	46,260
	7.5	30,800
4	2.5	25,130
	5.0	70,280
	7.5	29,140
6	2.5	34,250
	5.0	84,510
	7.5	46,130
8	2.5	39,230
	5.0	84,510
	7.5	54,710

Table 2. Marshall stability values of aggregate-fly ash combinations at different moisture contents.

Fly ash

Due to the low stability characteristics of chunk rubber cold mix and following KDOT practice of using fly ash in cold mixes, an ASTM Type C fly ash was used in the chunk rubber cold mix. The ash was provided by W. Handy Co. of Mission, Kan. Another Type C fly ash from Jefferie Energy Center in St. Marys, Kan., also was studied for comparison. A set retarding admixture was used to prevent flash-setting of the ash in the mix.

MIX GRADATION

The mix was designed as gap-graded with nearly 100% passing the 12.5 mm sieve. The control mix, with no fly ash, was designed to have 94% retaining on the 75 µm (No. 200) sieve. As the fly ash content increased, the combined aggregate gradation was changed and, consequently, the percentage of aggregate retained on the 75 µm sieve decreased. A mineral filler was used in the control mix and in the test mixes containing low fly ash percentages.

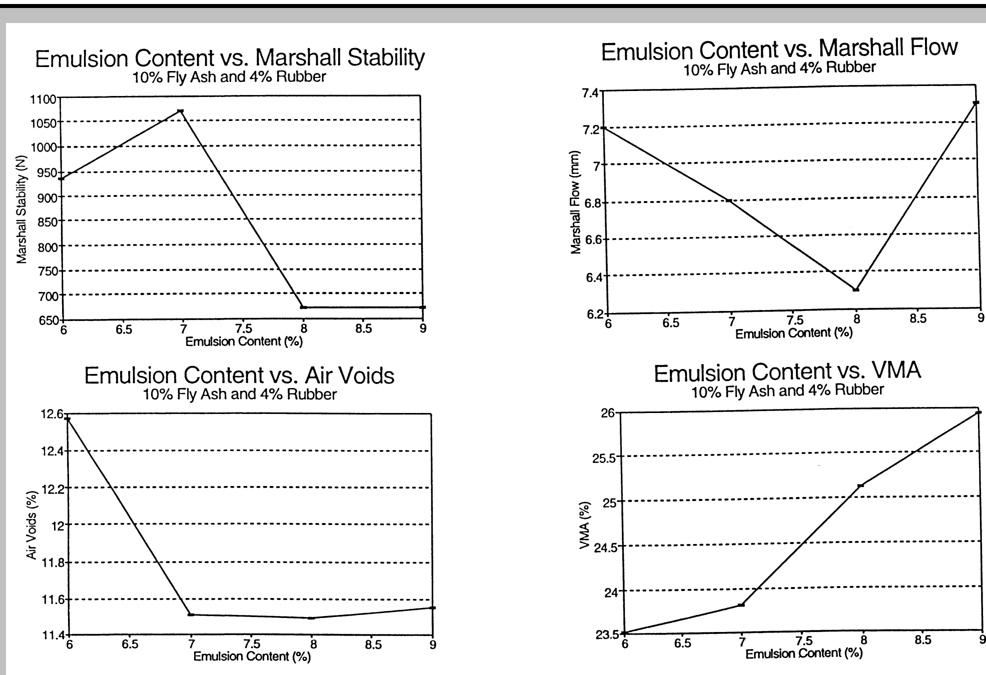

Figure 2. Marshall stability, flow, air voids, VMA and unit weight of CRAC mixes with 10% fly ash and 4% rubber for different emulsion contents.

Test mixes contained 2%, 4% and 6% rubber, as determined by weight.

SAMPLE PREPARATION

The mix design was planned to be developed based on the Marshall stability and flow tests. The aggregate and asphalt emulsion were heated to 66-71ºC for mixing. In samples containing fly ash, the asphalt was mixed with water and retarder before mixing with the aggregate. The mixes were cured and compacted at 52-55ºC. The loose mix was placed in a mold and rodded 15 times before compacting. Compaction consisted of 50 blows per side using a Marshall compactor.

All samples were tested for the Marshall stability and flow after being submerged in a 43ºC water bath for about 30 to 40 minutes. The samples were tested approximately 24 hours after mixing. Bulk (Saturated Surface Dry) densities of the samples were determined before the Marshall stability and flow tests. Rice tests (ASTM D D2041) were done to determine the theoretical maximum density (TMD) of the samples.

Binder Type	Binder Content (%)	Corrected Stability (N)	Flow (mm)
Emulsion	7	620	6.9
Cutback	6	600	7.6
Cutback	7	535	8.9
Cutback	8	310	7.6

Table 3. Marshall stability values for the mixes with cutback and emulsion.

PARAMETRIC STUDY

At the beginning of this research program, Marshall samples of the control mix (no fly ash, no rubber) were made at 5, 6, 7, 8 and 9% (by weight of the total mix) emulsion contents. Three samples at each emulsion content were tested for the Marshall stability and flow. Density and void analyses were also done. Table 1 summarizes the results of this preliminary test program. From the results of this test program, the optimum emulsion content (corresponding to the maximum Marshall stability, air voids of 3-5%, maximum density, minimum VMA and allowable flow values) for the mix was determined to be about 7%. This design allowed a parameter (emulsion content) to be fixed as other parameters were investigated. Those parameters include: moisture content, cutback asphalt vs. emulsified asphalt, fly ash content, rubber content, retarder content and curing time before compaction.

Moisture content

The first parameter evaluated was moisture content needed for hydration of the fly ash in the cold mix. Marshall test-size samples were made by compacting the aggregate-fly ash mix only, excluding the rubber and asphalt emulsion, at five fly ash levels. Two samples were made at 2.5, 5 and 7.5% moisture contents for fly ash levels of 2, 4, 6, 8 and 10% (by weight of the total aggregate). The samples were tested for Marshall stability, and the results were plotted as a function of the moisture contents. Table 2 summarizes the results of this experiment. The optimum moisture content was determined corresponding to the highest stability in the graph. The graphs showed that the optimum moisture contents for 2, 4, 6, 8 and 10% fly ash were 5.2, 5.1, 5.2, 5.3 and 5.5%, respectively. These moisture levels dictated how much water needed to be added to the asphalt emulsion and retarder before mixing with the aggregate.

Cutback asphalt vs. asphalt emulsion

Cutback and emulsified asphalts were compared at 4% fly ash and 4% rubber content to determine which one would give the higher stability values. It had been decided that unless cutback showed a significant benefit, emulsified asphalt would be used due to health concerns and more

Curing Time (hr)	Retarder Content (%)	Corrected Stability (N)	Flow (mm)
0.0	1	1470	7.4
	2	1425	8.1
0.5	1	*	*
	2	800	9.4
1.0	1	*	*
	2	*	*
2.0	1	800	8.4
	2	625	7.1
4.0	1	800	8.6
	2	1070	9.9
24.0	1	755	9.1
	2	890	7.6

* disintegrated during handling

Table 4. Effect of curing time and retarder content on Marshall stability.

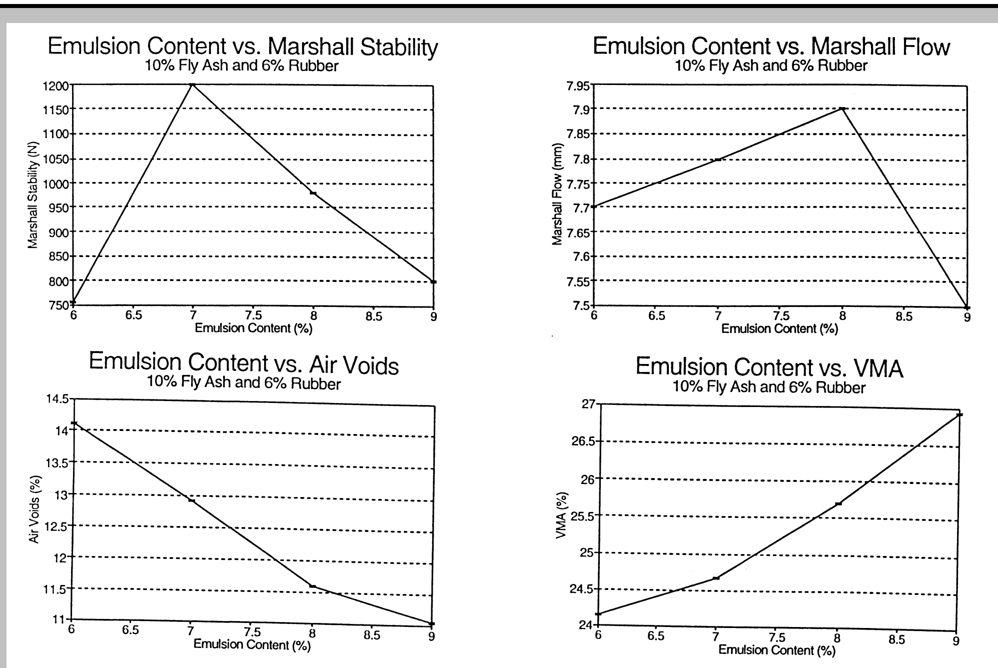

Figure 3. Marshall stability, flow, air voids, VMA and unit weight of CRAC mixes with 10% fly ash and 6% rubber for different emulsion contents.

widespread use for cold mixes in Kansas. Two Marshall samples were made using 7% emulsified asphalt. Since the optimum asphalt content had not been determined for the cutback asphalt, two Marshall samples were made at each of the 4, 5, 6, 7 and 8% cutback contents. The samples were tested for Marshall stability values at 43ºC. The samples at 4 and 5% were too weak to be tested. The maximum Marshall stability value for the cutback samples was 620 N and was found at 6% oil content (the stability was 600 N at 7%) as shown in Table 3. The emulsion mixes also showed a maximum stability of 620 N and was, therefore, chosen as the asphalt binder of choice. The fact that the maximum stability occurred at only 6% for cutback was deemed inconsequential because of lack of data needed to determine overall optimum asphalt content.

Retarder content/cure time

The retarder content and curing time were investigated at the same time because of their dependency on each other. KDOT typically uses 1% retarder (as a percentage by weight of the fly ash), but has, on occasion, used 2%. After mixing 1% retarder with the fly ash-aggregate-emulsion mix at the optimum moisture content, the loose mix was observed to be very wet. Thus it was apparent that some curing period was needed before compaction to allow for evaporation and for initial reaction of the fly ash with water. To evaluate the conditions which would produce maximum Marshall stability, curing times (before compaction) of 0, ½, 1, 2, 4 and 24 hours were combined with 1% and 2% retarder contents. The total curing time before testing for Marshall stability was fixed to be 24 hours. The highest stability was observed when the sample was compacted immediately after mixing as shown in Table 4. However, as mentioned earlier, this mix would be impractical for actual construction conditions because of its saturated state. Based on the trend of the data, it was decided to use 2% retarder content and begin compaction after 2 hours of cure.

Fly ash/rubber contents

The most important parameters of this research were the fly ash and rubber contents. Unlike asphalt rubber hot mix, no reaction between the rubber and emulsion can be expected in the cold mix. However, the economics of using this scrap material while satisfying some minimum engineering criteria is largely the reason for its potential use on low volume roads. The use of rubber for this project is a replacement for traditional larger aggregates. Since chunk rubber is not as strong as the crushed stone aggregate, it follows that the stability of an asphalt-aggregate-chunk rubber mix would be lower than a mix without rubber. However, it was also surmised that the larger rubber chunks tend to absorb some of the energy imparted to compact a CRAC sample resulting in a weaker aggregate structure than a mix without chunk rubber. This was evidenced by the lower stability values of the CRAC samples.

To increase the stability of CRAC samples and following KDOT practice of using Type-C fly ashes in cold mixes, it was decided to add fly ash to the mix. Since the parameters, rubber content and fly ash, have overwhelming effects on the performance of CRAC mix, the major part of this research justifiably focused on finding the ideal fly ash-rubber combination. It stands to reason that as more fly ash is added to a mix, the Marshall stability increases and, in fact, this is what indeed happened up to a point. However, the addition of fly ash also changes the gradation of the mix and can "choke" a mix by altering the matrix of the aggregates.

RESULTS AND DISCUSSIONS

Knowing that 10% fly ash produced the highest stability, a new set of samples were made at 6, 7, 8 and 9% emulsion and 2, 4 and 6% rubber for Marshall stability and flow test. Density and void analyses were also conducted for these samples. Table 6

Fly Ash Content (%)	Rubber Content (%)	Bulk (SSD) Density	TMD	Avg. Air Voids (%)	Avg. VMA (%)	Avg. Corrected Stability (N)	Avg. Flow (mm)
2	2	2.08	2.40	13.27	24.59	1155	5.8
2	4	2.04	2.34	12.97	24.55	800	6.8
2	6	1.97	2.31	14.33	25.36	710	8.1
4	2	2.12	2.42	12.08	23.12	1200	6.4
4	4	2.04	2.36	13.22	24.35	625	6.9
4	6	1.96	2.3	14.76	25.87	800	8.3
6	2	2.14	2.41	11.18	22.59	1380	6.4
6	4	2.04	2.35	13.15	24.32	890	7.6
6	6	1.99	2.30	13.43	24.75	845	7.3
8	2	2.13	2.41	11.53	22.86	1245	6.6
8	4	2.02	2.37	14.68	25.11	755	6.8
8	6	1.99	2.32	14.25	24.74	935	7.5
10	2	2.18	2.40	9.03	20.97	1870	5.9
10	4	2.06	2.35	12.33	23.49	1335	9.7
10	6	2.01	2.30	12.63	24.08	1470	10.5

Table 5. Chunk Rubber Asphalt Concrete (CRAC) test results at different fly ash and rubber contents.

tabulates the results. Figures 1, 2 and 3 illustrate the results. The optimum air void content was set at 11%. From the graphs of Marshall stability vs. emulsion content, bulk (SSD) density vs. emulsion content, percent air void vs. emulsion content, and percent VMA vs. emulsion content, optimum asphalt contents of 6.8, 7.3 and 7.8% were calculated for 2, 4 and 6% rubber contents, respectively. The optimum emulsion content was taken to be the average of emulsion contents corresponding to the maximum Marshall stability, maximum unit weight and 11% air void. A check was made to ensure that the optimum emulsion content satisfied the criteria for VMA set by the Asphalt Institute [5]. It was noted that there was a linear relationship between increasing emulsion content and increasing rubber content. Since the air void content was most affected by varying emulsion levels, the required emulsion content could be significantly reduced if a 12% or higher air void content was allowed. The high flow values of the mixes may mean better flexibility in the field in terms of higher deformation capabilities, but may also indicate the potential for rutting.

The results show trends that would be expected for nearly all properties. A notable exception is the flow at 10% fly ash and 6% rubber. The plotted curve is concave although it should be convex. However, scattered data at 7% and 8% emulsion cause the average to be skewed. The VMA values also show an interesting trend. However, the average air void value peaks at about 6% emulsion content and decreases with increasing emulsion content.

CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn:

- The use of rubber chunks (up to a maximum size of 12.5 mm) in CRAC as a replacement for traditional large aggregates results in a weaker mix than without rubber. Since rubber is not as hard as the crushed stone aggregates, it follows that the Marshall stability of an asphalt-aggregate-chunk rubber mix would be lower than a mix without chunk rubber. However, it was also

Rubber Content (%)	Emulsion Content (%)	Bulk (SSD) Density	TMD	Avg. Air Voids (%)	Avg. VMA (%)	Avg. Corrected Stability (N)	Avg. Flow (mm)
2	6	2.12	2.39	11.88	22.66	1245	5.7
2	7	2.17	2.39	9.37	21.55	1600	5.4
2	8	2.16	2.34	7.38	22.37	1070	4.8
2	9	2.16	2.31	6.62	23.52	1025	5.4
4	6	2.04	2.34	12.57	23.51	935	7.2
4	7	2.06	2.32	11.51	23.82	1070	6.8
4	8	2.05	2.31	11.49	25.14	670	6.3
4	9	2.04	2.28	11.55	25.94	670	7.3
6	6	1.98	2.30	14.10	24.14	755	7.7
6	7	1.99	2.28	12.94	24.67	1200	7.8
6	8	1.98	2.24	11.60	25.70	980	7.9
6	9	1.97	2.21	11.03	26.93	800	7.5

Table 6. Chunk Rubber Asphalt Concrete (CRAC) test results at 10% fly ash.

surmised that the larger rubber chunks tend to absorb some of the energy imparted to compact a CRAC sample, resulting in a weaker aggregate structure than a mix without any chunk rubber.

- The addition of type C fly ash results in higher Marshall stability of a chunk rubber asphalt concrete. A gap-graded CRAC cold-mix with 2% chunk rubber and 10% fly ash with an optimum emulsion content of 7% showed the highest average Marshall stability of 1600 N. However, this value is much lower than the KDOT accepted 2225 N Marshall stability for a suitable cold mix.

- If 9 kg of chunk rubber equivalent is produced per tire, then a one km long and 7.3 m wide low-volume road with a 100 mm thick base built with this mix can incorporate approximately 3350 tires.

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