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NOTES

Note on structural strength of asphalt rubber concrete developed through the stone mastic asphalt concept

Otto Svec and Robert Veizer

Abstract: One serious environmental problem related to the transportation field is the stockpiling of old rubber tires. Several huge fires of old tires have already occurred in Canada and the United States and have caused considerable air and possibly soil pollution. Therefore it is of paramount importance to develop techniques to recycle this potentially valuable material, such as by incorporating it into asphalt concrete. The focus of current research at the Centre for Surface Transportation Technology has been to develop a high-performance rubber asphalt concrete based on the stone mastic asphalt (SMA) concept which will be flexible enough (yet strong enough) to resist differential frost heave along roadways better than standard hot-mixed asphalt. Results indicate that a special mix has been successfully developed based on the SMA aggregate concept in which all components, including 0%, 5%, 10%, 15%, and 20% of small rubber crumbs content (based on bitumen weight), are properly sized and designed.

Key words: stone mastic asphalt, crumb rubber, laboratory testing, mix design.

Résumé : Le stockage des vieux pneus pose un problème environnemental sérieux lié au domaine des transports. Plusieurs gros incendies de pneus qui se sont produits au Canada et aux États-Unis ont pollué considérablement l'air et peut-être le sol. Il est donc capital de mettre au point des techniques permettant de recycler ce matériau qui peut être précieux, par exemple en l'incorporant au béton asphaltique. À l'heure actuelle, les travaux de recherche du Centre de technologie des transports de surface portent principalement sur la mise au point d'un béton de caoutchouc-bitume haute performance basé sur le principe de l'asphalte coulé gravillonné (SMA), et sur la mise au point d'un matériau dont la flexibilité et la résistance permettront aux chaussées de mieux résister au soulèvement différentiel dû au gel, comparativement à l'asphalte mélangé à chaud utilisé couramment. Les résultats indiquent qu'un mélange spécial basé sur le principe du SMA a été mis au point, tous les constituants, dont des fragments de caoutchouc en teneurs de 0%, 5%, 10%, 15% et 20% (par rapport au poids du bitume), étant bien dimensionnés et étudiés.

Mots clés : asphalte coulé gravillonné, fragments de caoutchouc, essai en laboratoire, étude de mélange.

1. Introduction

The current global interest to recycle discarded used automobile tires is primarily related to environmental problems. A useful and economical environmentally safe method of utilizing old tires in large quantities has not been developed. The United States discards some 300 million tires annually; Canada discards about 25 million. Out of these in the United States, 33 million are retreaded and 22 million are reused. The remaining 188 million tires are added to stockpiles, landfills, or illegal dumps (Heitzman 1992). The United States Environmental Protection Agency (EPA) estimates that there are 2–3 billion used tires stockpiled in the United States.

Crumb rubber made from old tires has been used in hot-mixed asphalt (HMA) for approximately 20 years. This technology, however, has not received wide acceptance by highway agencies in the United States or Canada. Despite this, the United States government has legislated the utilization of rubber in asphalt pavements. The minimum utilization requirement is that in asphalt pavement constructed with Federal-aid funds starting in 1994, 5% crumb rubber modifier (CRM) must be incorporated. This amount will grow by 5% increments until the proportion reaches 20% in the year 1997. However, the general road-building community in North America is concerned that rubber asphalt (RA) (*i*) may pose an environmental threat greater than convention HMA, (*ii*) cannot be recycled to the same degree as HMA, (*iii*) will exhibit structural stability and performance that is of lesser

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quality than standard HMA, and (*iv*) will cost substantially more than standard HMA.

Current and potential uses of old tires include (*i*) the energy field (cement kiln; electric utilities; supplementary fuel for pulp and paper mills; and pyrolysis, resulting in gas, oil, and char (carbon black) products), (*ii*) civil engineering (light-weight embankments, drainage layers, slope-stabilizing structures, retaining walls), and (*iii*) the construction of roadways (rubber-modified asphalt).

The purpose of this study is to focus our research on the development of a mix based on the crumb rubber wet process which would attempt to satisfy the four concerns noted above. These four key conditions are hindering factors for the wide implementation of CRM asphalt. The interest of the authors of this paper is focused on the development of a new rubber crumb asphalt concrete based on HMA and stone mastic asphalt (SMA) technology by Allison (1987).

2. Background

The notion of improving viscosity properties of bituminous materials by incorporating natural rubber into bitumen was first introduced in the late eighteenth century (see Hancock 1823 and Cassell 1844). The objective of these and subsequent efforts (see Heitzman 1992 and Hughes 1993) was to improve the elastic properties of the binder through the use of natural rubber and, after World War II, synthetic rubber and other polymers. The idea of incorporating old tires into asphalt was seriously initiated around the 1960s. The details of this development can be found in Heitzman (1992) and Takallou and Sainton (1992). This process begins with three possible types of granulating rubber tires: (*i*) the cracker mill processes (most common), (*ii*) the granulator process, and (*iii*) the micromill process. More details on this technology can be found in Heitzman (1992) or other related literature. The product of these processes is then used together with asphalt cement as crumb rubber modified asphalt for road applications.

There are two ways to incorporate CRM into the asphalt, i.e., the so-called wet process, or the dry process. The wet process is defined as any method that adds the crumb rubber to the binder for heating and interacting to form a rubberized binder. The dry method was developed in Europe and is based on the concept of replacing stone aggregates with rubber crumbs. This latter process has been used in the United States, particularly in Arizona and Alaska. In this process a special mix design is used requiring a unique mineral aggregate gap gradation. Both wet and dry processes have been used elsewhere around the world and are continuing to be further developed to improve performance and effectiveness.

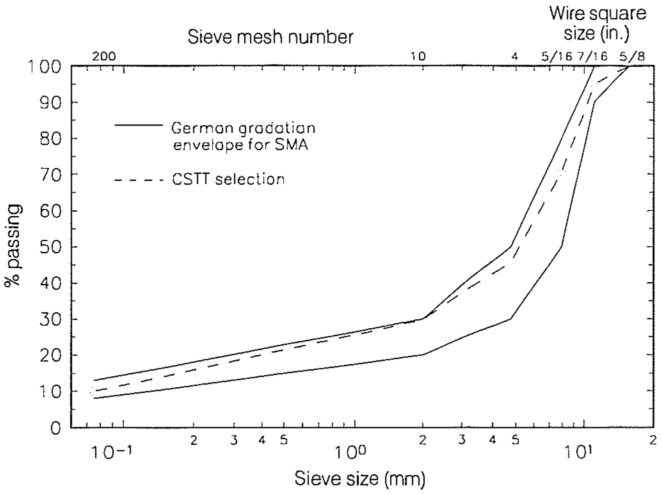
3. Mix design

Based on a literature review and our initial experiences with rubber asphalt, a decision was made to utilize a special mix, whose concept is based on a direct load transmission through stone to stone contact. The mix concept was developed about 25 years ago in Germany under the name Splittmastixasphalt, and is widely known in North America as stone mastic asphalt (SMA). SMA is gap-graded, dense, hot-mix asphalt (HMA) with a large proportion of coarse aggregate and rich asphalt cement – filler mastic. The German mix design of SMA is based on cubical-shaped, durable stone aggregate (e.g., granite), capable of withstanding heavy concentrated traffic loads. SMA has high stability to rutting due to the high shear modulus of this material and, therefore, high resistance to shear flow caused by dynamic traffic loads. A mix based on rather small size aggregates (e.g., top size aggregates 16 mm) allows its utilization in the form of thin top layers, and thus results in a relatively low cost. The SMA used in European countries has also shown good resistance to wear from studded tires (no longer permitted in Canada), good frictional properties, and good construction characteristics. This paper indicates that the use of ground rubber crumbs in an SMA mix (if properly designed as gap graded mix) can result in a high-quality asphalt pavement.

Table 1. Aggregate blend.

Sieve size (mm)	% passing
16	100
11	90–100
8	50–80
5	30–50
2	20–30
0.09	8–13

Fig. 1. Gradation specification for splittmastixasphalt (SMA) mix design. CSTT, Centre for Surface Transportation Technology.



The bulk relative density of the coarse limestone aggregate used in this project was 2.657, as determined by the Ministry of Transportation of Ontario (MTO) using the standard LS-604 test. The bulk relative density of the fine aggregates was 2.658, determined by the LS-605 test. The bulk relative density of the limestone filler passing the number 200 sieve was determined by hydrometer analysis, and is 2.76.

The aggregate gradation for this development was modelled according to SMA gradation used in Germany and reported by Bellin (1992). The aggregate blend and gradation specifications are shown in Table 1 and Fig. 1, respectively.

Table 2. Aggregate fraction gradation.

	Percent passing		
Sieve size	HL3	Crusher screening	Sand
16.0 mm	100	—	—
11.0 mm	90	—	—
8.0 mm	47	100	—
#4	4	93	100
#10	1	56	93
#20	—	34	80
#40	—	22	49
#60	—	15	21
#100	—	10	5
#200	—	5	1

To achieve this gradation, HL3 mix specified by MTO and screenings were sieved and placed into designated containers. Each stone size, defined in the aggregate blend down to 2 mm, was contained separately. Sand was used to satisfy the 0.09–2 mm fraction gradation. In this way the material between 0.09 and 2 mm was a mixture of natural and manufactured sand. Anything passing through the 0.09 mm sieve was used as the limestone filler. As the last part of this mix, 0.3% cellulose fibre by weight of the sample was added. Figure 1 shows selected gradation. The aggregate fraction gradation for the selected mix is presented in Table 2.

For the asphalt binder, 85/100 Pen asphalt cement (Case 8052-42-4) supplied by Husky Oil of Calgary, Alberta, was used. The method for crumb rubber asphalt design suggested by Chehowits (1989) was followed. Recycled and crumbed old tires free from contaminants including mineral matter, fibre, and metal were used. Furthermore, all other conditions stated by Chehowits, for example maximum moisture content (0.75%), rubber hydrocarbon content (between 40–50%), and mineral contaminants (0.25%), were satisfied. The selected crumb rubber was manufactured by Recovery Technologies Inc. of Toronto, using a cryogenic grinding process. Rubber crumbs, namely GTR-10 gradation passing the number 8 (100%), 10 (97%), and 20 (75–100%) sieves, were used for this new mix.

Five Marshall mix designs were performed for 0% (control mix), 5%, 10%, 15%, and 20% crumb rubber content related to the weight of the asphalt cement. Table 3 shows the results of optimal values for the volume of mineral aggregates (VMA), air voids, flow, density, and stability using 75 blows for Marshall compaction.

4. Laboratory testing

The testing program was designed based on three performance-related tests, i.e., indirect tensile strength test, fatigue test, and a repetitive uniaxial compression test.

4.1. Indirect tensile test

A standard indirect tensile test according to ASTM D4123 under 51 mm/min strain loading conditions was used. The resulting tensile strength (S_T) of the asphalt concrete was calculated by the following standard equation:

Fig. 2. Typical characteristics of a fatigue test. N_f, fatigue failure.

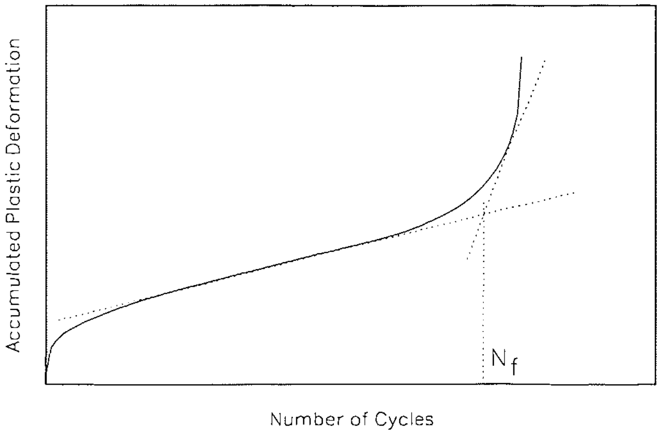


Table 3. Asphalt properties at optimum crumb rubber binder content.

	GTR-10 rubber				
Property	0%	5%	10%	15%	20%
Average optimum binder content (%)	4.6	4.6	5.0	5.6	6.0
Flow (0.01 in.)	14.5	11.0	14.5	15.0	18.0
Stability (lb)	2650	3120	3110	2400	2080
% VMA	12.5	14.0	15.2	17.4	19.25
% air voids	2.25	4.0	4.0	5.5	6.0
Bulk relative density	2.445	2.400	2.380	2.327	2.285

Note: 1 in. = 2.54 cm; 1 lb = 454 g.

$$[1] \quad S_T = \frac{P_{Fail} A_0}{h}$$

where P_{Fail} is the total load at failure, h is the height of the specimen, and A_0 is a constant dependent on the diameter of the sample. For a Marshall specimen the constant is 0.156.

4.2. Fatigue test

The fatigue testing was performed following the procedure developed by Stolle (1990). This method was selected because cylindrical specimens were used as opposed to the beam samples recommended by Strategic Highway Research Program (SHRP). The setup is identical to that of the indirect tensile strength test except that it is load controlled. A compressive haversine wave at a frequency of 1 Hz was applied to maintain uniform cyclic loading. Specimens were failed in fatigue using either 15% or 30% of the static strength determined previously. A sample fatigue test graph is shown in Fig. 2.

The fatigue failure (N_f) in this test is defined as the point at which the rate of accumulated irrecoverable displacement appeared to accelerate. This point corresponds to the intersection of the constant accumulated deformation line (slope) and the tangent to the curve at maximum curvature (Fig. 2). At the defined fatigue failure (N_f) a well-defined crack started to develop along the vertical diameter of the sample. Three fatigue tests were conducted at each load for each mix type.

Table 4. Summary of the testing program.

Test type	Temperature (°C)	No. of samples required per mix	Approximate length of test
ITS	25	3	5 min
Fatigue			
15% max load	25	3	1–4.5 h
30% max load	25	3	10–25 min
Rutting	25	3	Stopped at 3 h
	40	3	1–3 h

4.3. Repetitive uniaxial compression test

The repetitive uniaxial compression test utilized cylindrical cores and a hydraulic actuator for loading. A cylindrical plate is placed on the flat side of the specimen and a maximum load of 690 kPa is applied to the sample. A thin rubber pad is placed between the loading plate and the specimen. A minimum load of 5 kg was used during the resting period of each cycle to avoid the separation of the loading head, and generation of impact pressure. The square wave loading function was applied to simulate traffic loading. The square wave consists of a loading period of 0.2 s followed by a 1.8 s rest period. The tests were conducted at 25 and 40°C. Each mix was tested three times and a representative result was selected for comparison.

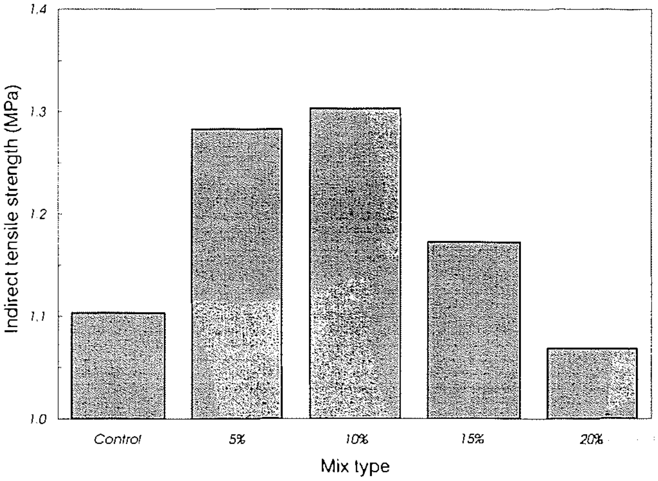
5. Results and analysis

A summary of the testing program is given in Table 4. A total of 90 samples was required to complete the testing program. Performance of asphalt rubber mixes, developed and analyzed in this study, is described below.

5.1. Indirect tensile strength test

Figure 3 indicates the average results of indirect tensile strength (ITS) tests carried out on samples of asphalt concrete with rubber crumbs. It is evident that the inclusion of 5% of rubber crumbs in the mix resulted in a significant increase in indirect tensile strength. The strength peaked for 10% crumb rubber content as well as showing improvements for the 5 and 15% crumb rubber contents. The mix containing 20% crumb rubber content had a strength approximately equal to the control mix. Therefore, the optimum crumb rubber content seems to be around 10%, as far as strength of rubber asphalt is concerned as defined by the ITS test. It is hard to believe and difficult to expect that rubber crumbs added to asphalt concrete would increase its strength. These results, however, can be explained in a different way: if the rubber crumbs were partly dissolved at high temperature during the mixing process and were well incorporated in the final mix, it can be expected that this new concrete might exhibit increased strength, as a consequence of improved rheological properties.

Fig. 3. Indirect tensile strength of optimum SMA mixes.



5.2. Fatigue test

For every set of samples, depending on different rubber content, loading limits (upper and lower) were selected. The lower loading limit was selected as 15% of the ITS test value, and the upper loading limit was selected at 30%. Therefore, the haversine loading function ranged from a minimum of 1% of the ITS test value to 15% or 30% of the ITS test value for each fatigue loading cycle, depending on the test selected. The upper limits were in the range of approximately 0.33–0.38 MPa, and the lower limits varied between 0.16 and 0.19 MPa (Fig. 4). The higher fatigue loads failed at a lower number of cycles, whereas the lower fatigue loads failed at a higher number of cycles. Interestingly enough, this test indicates behaviour similar to that of the ITS test concerning improved properties due to the addition of crumb rubber. The control samples show the lowest number of cycles to failure, whereas samples with 20% of rubber in asphalt show the highest. For comparison purposes, the results are plotted in Fig. 4 on an applied tensile stress versus cycles to failure graph. As concluded in the analysis of ITS testing, these results also indicate a higher level of elastic characteristics for rubber asphalt mixes.

5.3. Repetitive uniaxial compression test

The fatigue tests were carried out at two temperatures: at ambient 25°C in the laboratory and at 40°C in the temperature-controlled chamber. At ambient temperature (25°C), tests must be performed for an extensive period of time to achieve failure. Therefore, their evaluation was based on permanent axial strain values and the slope of resulting graphs. This slope, defined at the linear portion of the rutting graphs, is referred to as the *K* value. Figure 5 demonstrates the effect of crumb rubber content on permanent axial strain during the test. It is interesting to note that the character of these results is very similar to those obtained from all the previous cases. That is, the control samples indicate the highest deformation (strain), and samples with 5% and 10% crumb rubber the lowest. The *K* values (Fig. 7) were increasing according to the following rubber content: 10%, 5%, 15%, 20%, and 0% (control).

In the case of tests at 40°C, Fig. 6 shows similar trends to the results at 25°C, except that these tests reached the fatigue failure point. This figure clearly indicates poor behaviour of control samples, whereas specimens with 5% and 10% crumb rubber content reached the largest number

Fig. 4. Fatigue test results under 1−15% and 1−30% loading conditions based on maximum ITS results.

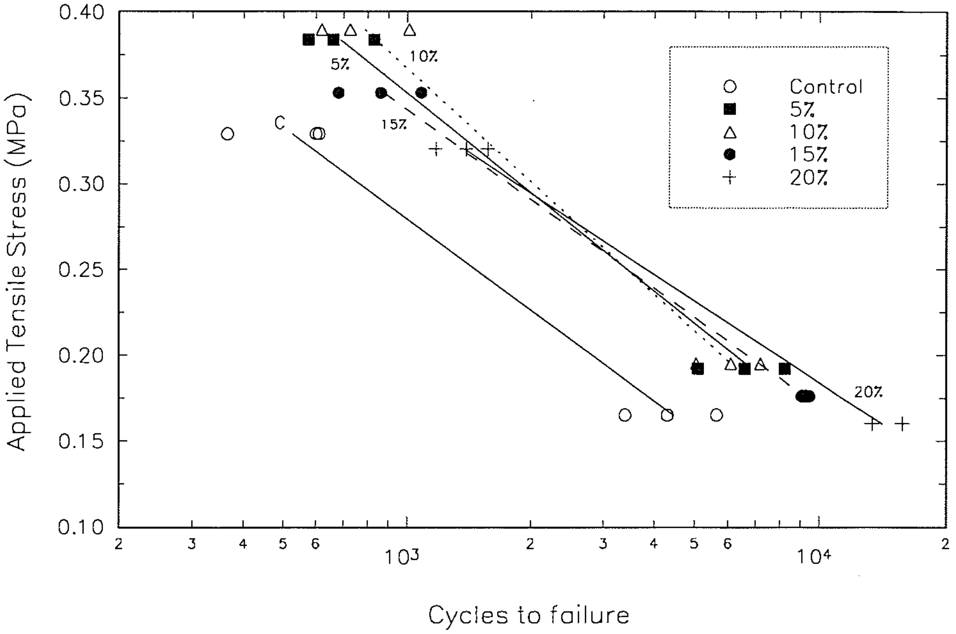
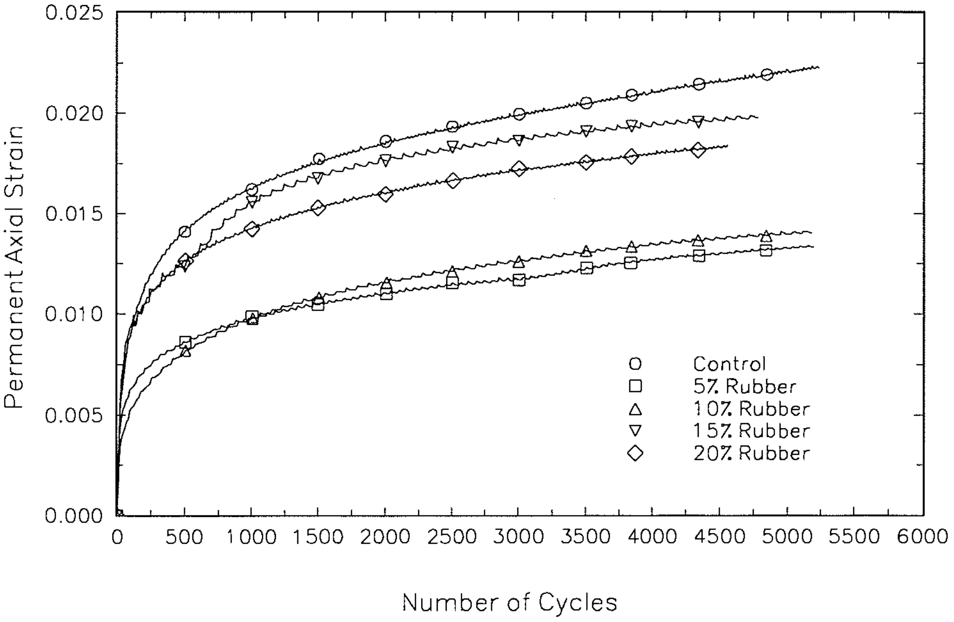


Fig. 5. Axial compression test results at 25°C.



of cycles before failure. Specimens with 15% and 20% crumb rubber content were not completed due to time restrictions. It is expected, however, that these two experiments would follow characteristics of the results shown in Fig. 5, and it is clearly evident that they outperformed the control sample before termination of the test.

The *K* values of these repetitive uniaxial compression tests are presented in Figs. 7 and 8. The results carried out at both 25 and 40°C temperatures demonstrated again the same characteristics as those obtained in previous testing: high *K* value for control specimens, and low values for crumb rubber samples. In the final analysis of the repetitive uniaxial compression testing program, 10% crumb rubber asphalt seems to be the most practical.

6. Conclusions

This paper represents preliminary research work on the development of crumb rubber asphalt based on the concept of SMA. The results obtained to date indicate an excellent future for this new technology. The presence of crumb rubber in the asphalt concrete (i.e., in the sand−dust−fibre

Fig. 6. Axial compression test results at 40°C.

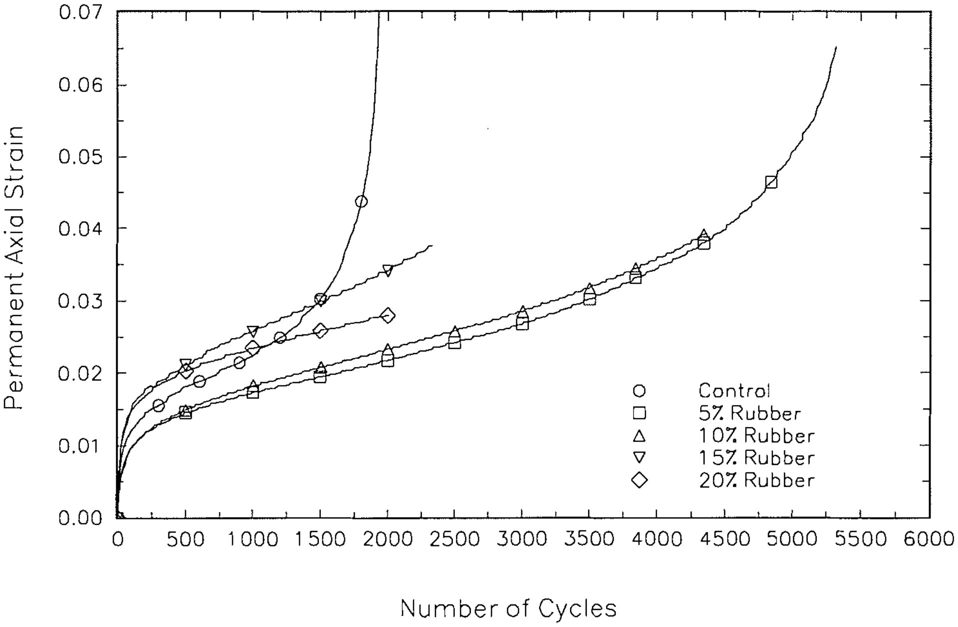
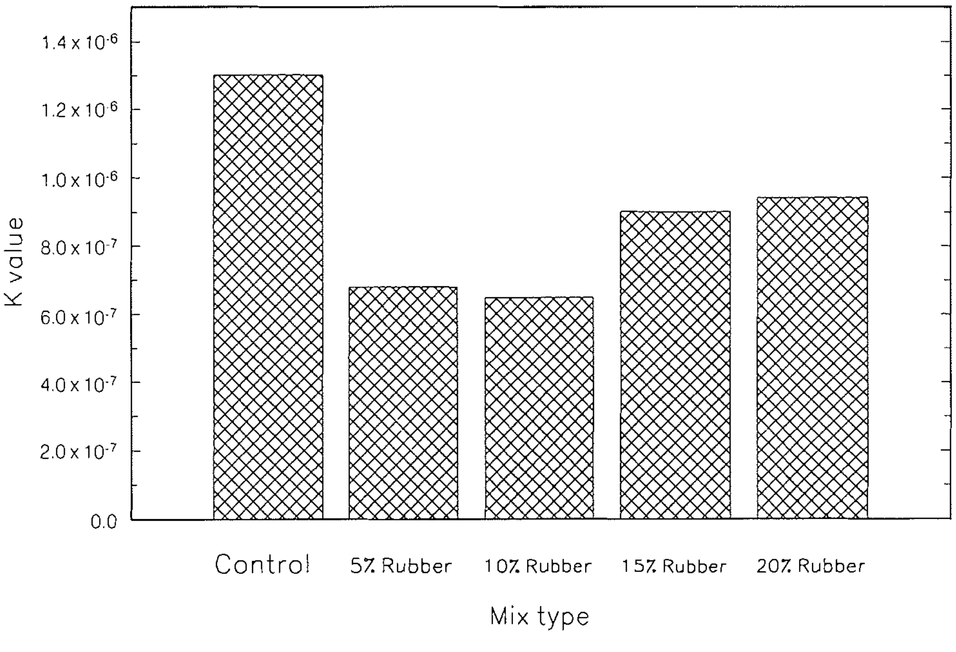


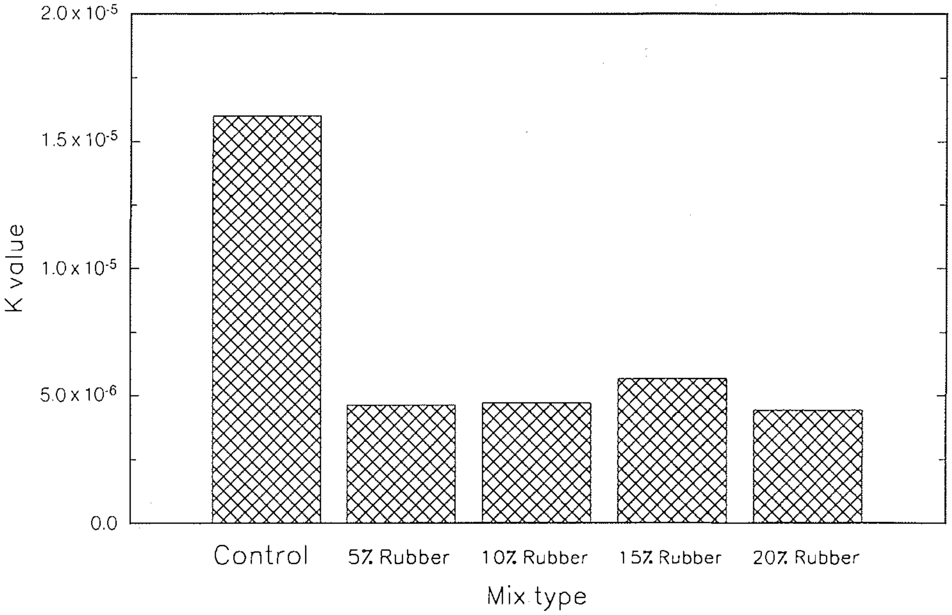
Fig. 7. Results for axial compression tests: *K* values for SMA mixes (25°C).



matrix and not in the stone to stone contact interfaces) not only increased the flexibility characteristics of the rubber asphalt, but the authors believe that it also increased resistance against cracking. The fatigue results clearly indicate that the addition of crumb tire rubber to the asphalt cement mixture improved its fatigue characteristics. However, the results did not discriminate between various percentages of CRM asphalt cement mixes. This is an interesting result which should be studied further. Increased flexibility might decrease cracking of asphalt roads during winter because of frost heaving. However, even though the repetitive uniaxial compression test indicates good resistance of this new mix against rutting, this must be further investigated under different conditions and with additional, different testing set ups.

Therefore, it should be stressed that another testing program must be carried out to answer another crucial question. Will this new mix perform in a similar way as standard mix (control) under all adverse conditions of traffic (loading and frequency), climate (temperature, moisture), rapid temperature changes, etc. The following additional testing should be performed: (*i*) rutting using a new Centre for Surface Transportation Technology rutting test or standard "Moving wheel test," (*ii*) moisture damage test, (*iii*) cold temperature damage test, and (*iv*) direct tension test and perhaps others.

Fig. 8. Results of axial compression tests: *K* value is for SMA mixes (40°C).



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