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Rutting evaluation of rubberized and SBS modified porous asphalt mixtures

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A R T I C L E   I N F O

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A B S T R A C T

The aim of this research is to investigate the impact of crumb rubber and Styrene-Butadiene-Styrene (SBS) on rutting potential of porous asphalt mixtures. Optimal binder content of control mix, 5% SBS, and mixtures containing 10%, 15%, and 20% of crumb rubber were determined using Cantabro Loss test. Dynamic creep, wheel tracking, draindown, and falling-head permeability tests were then carried out on specimens to examine rutting resistance, resistant to draindown, and permeability. SBS modified and 10% rubberized asphalt satisfied all the requirements of porous asphalt design criteria. They also have similar rutting performance, permeability. Except for rutting performance, 10% rubberized asphalt has the best performance. Instead, asphalt mixture containing 20% crumb rubber was the most mixture against rutting resistance.

1. Introduction

Porous asphalt is gap-graded coarse mixture containing approximate air void content of 20%. It is mainly used for water drainage, which avoids puddle formation and improves sight vision while raining. Moreover, sound absorption property causes noise reduction and increases friction. Safety is enhanced due to drainage properties improvement and Hydroplaning phenomenon removal by porous asphalt mix (PIARC, 1993). Regarding functional properties, structural deficiency of this type of mixture increases life cycle cost compared to conventional dense-graded asphalt mix. Stone-on-stone contact of coarse aggregate skeleton bears axle loads that is not stable at higher temperature to prevent rutting (Santucci, 2001). In addition, aging intensifies as a result of larger surface exposed to air and it accelerates oxidation. Draindown is another problem of gap-graded asphalt mixtures, which is required to be controlled. In the past three decades, in order to improve the performance of asphalt mixtures polymer modifiers have been widely investigated (PIARC, 1993). Low Density Polyethylene (LDPE), which is the main element of plastic pocket, was found to have a positive effect on not only resistance properties of porous mixture such as draindown, rutting, and moisture susceptibility, but also on environment by effective recycling disposal materials (Punith & Veeraragavan, 2007). A combination

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of Cellulose fiber and Reclaimed Polyethylene Modified Binder (RPMB) was proved to improve fatigue life, rutting and moisture damages resistance of porous asphalt mix (Punith et al., 2011). SBS is recommended to decrease high temperature rutting (Akbulut & Gürer, 2007; Nielsen et al., 2005). Using waste polymer of rubber is also considered particularly beneficial since rubberized asphalt mixtures are environmentally friendly due to recycling used tire and service life increase (Oliveira et al., 2013; Takallou & Sainton, 1992).

Numerous studies have been conducted on performance of mixtures containing rubberized and SBS modified binder. All indicate its usefulness on enhancing rutting resistance, aging, fatigue behavior, and moisture susceptibility (Xiao & Amirkhanian, 2010; Xiao et al., 2009, 2010). Others have also investigated the fatigue behavior, cold cracking, durability and environmental specifications of asphalt concretes or concretes containing polymeric binders (Ameri et al., 2012; Heidari-Rarani et al., 2014; Aliha et al., 2014,2015; Sol-Sánchez et al., 2015; MansourKhaki et al. 2015) In this study, rubberized binder at different percentages and SBS modified binder at 5% were used in order to find their effect on rutting performance of porous asphalt. Moreover, influence of theses polymers on designing parameters was investigated.

2. Materials

Physical properties of used Lime aggregates are presented in Table 1. Particle size distribution is also given in Fig. 1, which falls within the upper and lower limits of the proposed gradation of Iran Highway Asphalt Paving code 234 (IHAP code, 2003). Properties of used performance grade (PG58-22) bitumen are also presented in Table 2. In addition, it is indicated in Table 3 that penetration decreases and softening point increases by crumb rubber (CR) content increase. It shows that stiffer binder is resulted using rubber.

Table 1. Aggregate Physical Properties

Measured Properties	Standard (ASTM)	value
Bulk specific gravity of coarse aggregate(gr/cm^3)	C127	2.59
Bulk specific gravity of fine aggregate (gr/cm^3)	C127	2.32
Water absorption of coarse aggregate (%)	C127	2.2
Water absorption of fine aggregate (%)	C127	2.4
Los Angeles abrasion value (%)	C131	22.3
Percentage of Fractured Particles in one side	D5821	97
Percentage of Fractured Particles in two sides	D5821	94

Table 2. Binder Properties

Measured Properties	Standard (ASTM)	Value
Penetration at 25˚C (0.1 mm)	D5-73	64
Softening point (R &B ˚C)	C36-76	53
Ductility at 25˚C (cm)	D113-79	>100 cm
Density at 25˚C (gr/cm^3)	D70-76	1.05
Flash point (˚C)	D92-78	308

Table 3. Penetration and softening point at different concentrations of crumb rubber

Properties	CR-10%	CR-15%	CR-20%
Penetration at 25˚C (0.1 mm)	40	32	30
Softening point (R &B ˚C)	58	67	71

*CR-10%, CR-15%, and CR-20% are asphalt cement samples containing 10%, 15%, and 20% crumb rubber, respectively.

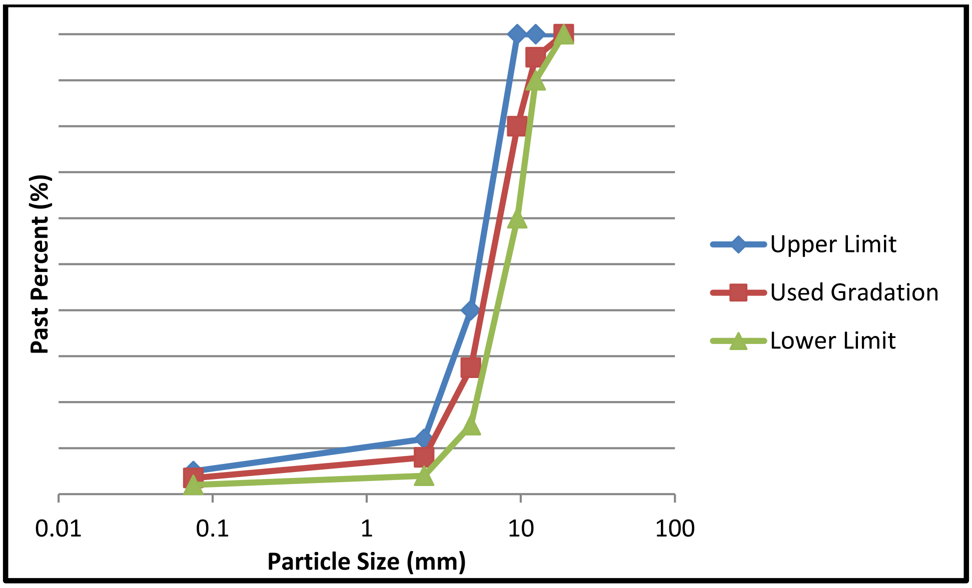

Fig. 1. Particle size distribution

3. Experimental setup and procedure

3.1 Rubberized binder preparation

In wet process, high-speed stirrer apparatus is used to blend rubberized binder. In this research, -40 mesh rubber at concentration of 10%, 15%, and 20% were added to the virgin binder at reaction temperature of 180˚C and a reaction speed of 3500 rpm for 30 minutes (Panda & Mazumdar, 2002). It was shown earlier that the blended binder properties are not affected by time after half an hour (Xiao et al. 2006). SBS was also blended as crumb rubber.

3.2 Sample fabrication

In this research, cylindrical samples with a diameter of 100 mm and approximate height of 67 mm, which weight of 1000 gr, were fabricated by Suprepave Gyratory Compactor (SGC) with setup parameters presented in Table 4 (Brown & Cooley, 1999). Control, 5% SBS modified, 10%, 15%, and 20% rubberized samples were used at binder content of 4.5%, 5%, 5.5%, and 6% to determine the optimal binder content for each type of mixture. Three identical samples were prepared for each percentage and the average was calculated as the measured value of different tests.

Table 4. Setup parameters of Suprepave Gyratory Compactor

Setup Parameters	Value
Stress level (kPa)	600
Number of Gyration	50
Angle (degree)	1.25
Rotational speed (rpm)	30

3.3 Cantabro test

This test was performed with accordance to standard ASTM C131 to determine optimal binder content of porous asphalt mix. In this test, specimens went through 300 rotations at rotational speed ranges between 30 to 34 rpm by Los Angeles Apparatus. It is carried out without steel spheres at 25˚C. The result is the weight loss calculated by Eq. (1) as follows,

$$CL = \frac{A-B}{A} \times 100 \tag{1}$$

where A is the initial weight, B is the retained weight, and CL is the Cantabro Loss (%).

Optimal binder content is the average of binder contents that relates to 18% air void content and 20% Cantabro Loss. However, any binder content that falls within these two specification limits is an acceptable optimal binder content. Mixtures at selected optimal binder content must satisfy following criteria:

(1) Minimum air void of 18%
(2) Maximum CL of 20% for un-aged specimens.

3.4 Draidown test

This test is performed on specimens to check whether they exceed the limited value of 0.3% or not (Smith, 1992). According to standard AASHTO T305-97, un-compacted mixture at optimal binder content is placed into a wire basket with a tray underneath and experiences one hour at a temperature 10˚C above the production temperature. The amount of draindown is then calculated by Eq. (2) as follows,

$$DR = \frac{D - C}{B - A} \times 100, \tag{2}$$

where DR is the amount of draindown, A is the wire basket weight, B is the sample weight plus wire basket, C is the tray weight, and D is the tray weight after an hour in the oven.

3.4 Falling-head permeability test

Permeability of porous asphalt mix is particularly important as this function is the main reason of using it. Minimum Coefficient of permeability is proposed 100 m/day with accordance to NCAT Report (Kandhal & Mallick, 1999). This coefficient is obtained by performing falling-head permeability test with accordance to ASTM D3637 on cylindrical sample with diameter of 15 (cm) and approximate thickness of 8 (cm). The used specimens were also fabricated by SGC and the test is performed three times on each specimen. Eq. (3) yields the formula that the coefficient of permeability or hydraulic conductivity is computed:

$$k = t_c \times \frac{a \times L}{A \times t} \times \ln(\frac{h_0}{h_t}) \tag{3}$$

where:

k: Coefficient of permeability (cm/s)

a: Area of pipe (cm^2) that is equal to 20.428 cm^2

L: Length of specimen (cm)

A: Area of specimen (cm^2) that is equal to 176.417 cm^2

t: Elapsed time of test (sec)

h_0: Head of beginning of test that is equal to 103.3 (cm)

h_t: Head at end of test that is equal to 29.7 (cm)

t_c: Corrective coefficient for test temperature other than 20˚C

3.5 Dynamic Creep test

The aim of dynamic creep test is to evaluate rutting resistance of asphalt mixtures. Permanent deformation versus cycle cure is the most important output of the test that is related to rutting resistance. It should be noted that the cumulative strain is not equal to measured rut depth and is considered as a criterion for rutting resistance comparison of different mixtures.

In this study, the software of UTM-5 at Iran University of Science and Technology developed according to Australian code, AS-2891.12.1 was used to carry out the test. The test specimens were kept at least 5 hours at 40˚C temperature. Setup parameters of Dynamic creep test are presented in Table 5.

Table 5. Dynamic Creep test parameters

Parameter	Value
Loading pattern	Rectangular
Loading period	500 ms
Rest period	1500 ms
Contact stress	10 kPa
Applied repeated stress	200 kPa
Termination criteria	400000 cycles of load repetition or 300000 μs

3.6 Wheel tracking test

Wheel track is a simulative test to predict measured rut depth (Stuart & Mogawer, 1997). In this research, wheel tracking test was performed to evaluate control and modified mixtures rutting resistance. The test was carried out according to BS 589-110 code. Three compacted slabs with dimensions of $300 \times 300 \times 50\ (mm)$ were prepared for each type of mixture at optimum binder content and 18% to 20% air void content. According to Hamburg test specification, the temperature for PG58-22 is performed 45ºC. Slab samples were kept in test temperature of 45˚C at least for 6 hours. Rut depth was measured after 8000 cycles.

4 Results and discussion

4.1 Mix design results

Since higher binder content increases the thickness of asphalt film on aggregate surface, increase of cementitious material, as shown in Fig. 2, results in more cohesive mixtures. Consequently, more abrasion resistant mixtures are obtained. Fig. 3 illustrates that more binder content, however, reduces the air void content which is not allowed to be less than 18%. Although, at concentrations of 15% and 20%, there are no binder contents for 18% air void, they can be computed by introduced trend lines. It can be inferred from Fig. 2 that at lower asphalt binder dosage, Cantabro Loss weights of rubberized mixtures are far greater than that of control mixture. However, they approach it at high dosage of 6%.

Fig. 4 shows that almost all mixture types satisfy minimum air void content requirement except two that are negligibly below the 18% limit. Finally, optimal binder contents are presented in Fig. 3. Rubberized mixtures do not have greater optimal binder content than control mixture up to the dosage of 10%. However, 15% crumb rubber increases optimal binder content 0.6% compared to control one. More crumb rubber results in reduction. Tables 6 and 7 present the trend lines for Cantabro test and air void content, respectively.

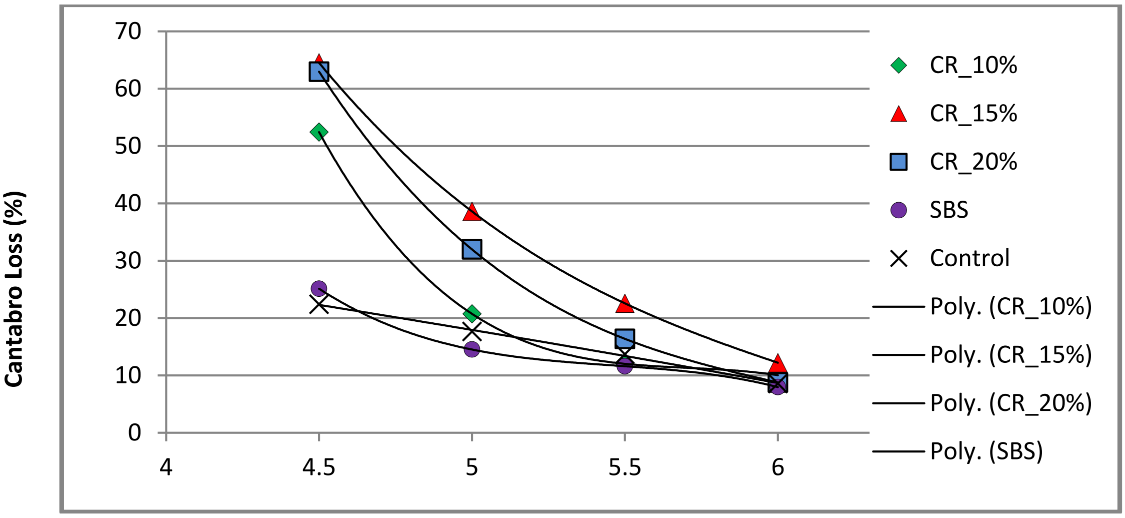

Fig. 2. Cantabro test results

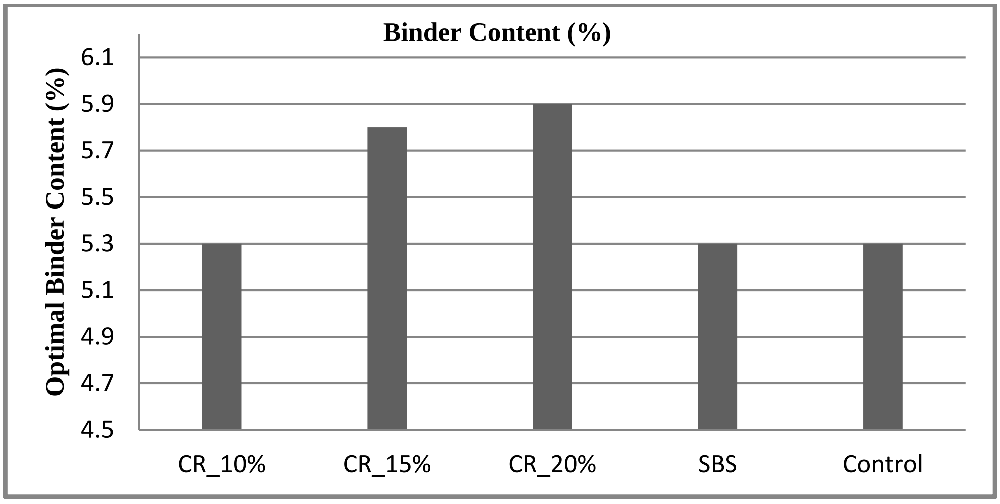

Fig. 3. Optimal Binder content

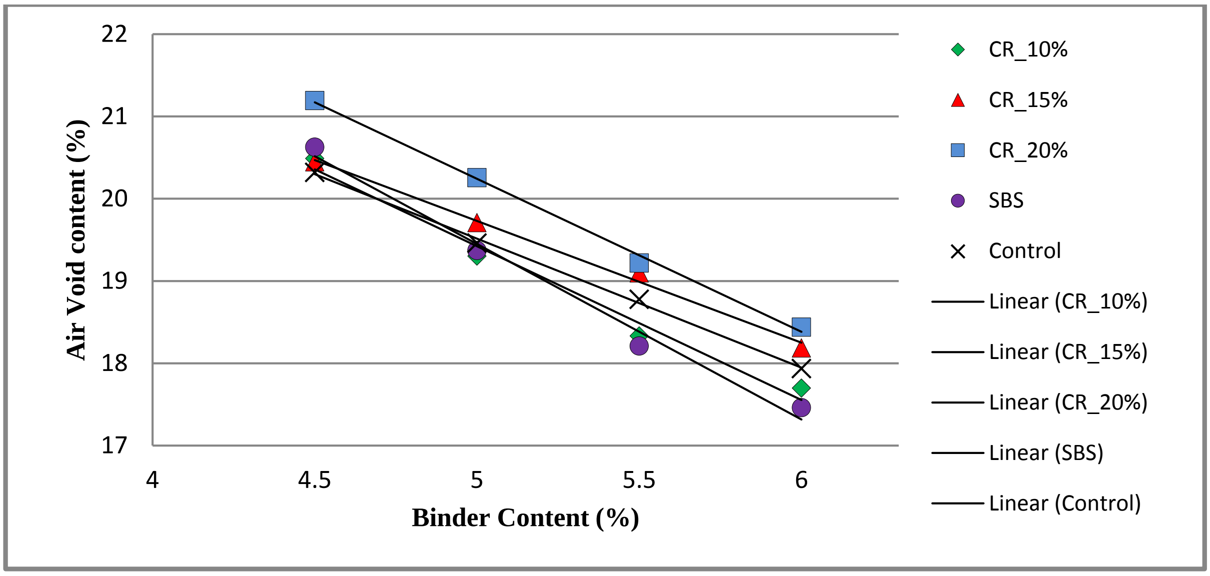

Fig. 4. Air void content results

Table 6. Cantabro test trend lines

Mixture type	Regression equation	R-squared
CR-10%	$CL(\%) = -21.655(BC)^3 + 370.77(BC)^2 - 2118.5(BC) + 4051.1$	1
CR-15%	$CL(\%)=-5.588(BC)^3 + 103.57(BC)^2 - 657.17(BC) + 1433.6$	1
CR-20%	$CL(\%) = -9.8927(BC)^3 + 179.21(BC)^2 - 1094.3(BC) + 2259.7$	1
SBS	$CL(\%) = -11.232(BC)^3 + 183.86(BC)^2 - 1006.9(BC) + 1856.6$	1
Control	$CL(\%) = = -0.3466 (BC)^2 - 5.4433(BC) + 53.82$	0.9982

Table 7. Air void Content trend line

Mixture type	Regression equation	R-squared
CR-10%	$VA(\%) = -1.8684x + 28.765$	0.9826
CR-15%	$VA(\%) = -1.4795x + 27.128$	0.994
CR-20%	$VA(\%) = -1.8594x + 29.539$	0.9971
SBS	$VA(\%) = -2.1323x + 30.111$	0.988
Control	$VA(\%) = -1.5676x + 27.353$	0.9981

4.2. Draindown test results

As shown in Fig. 5, all mixtures satisfy maximum allowable requirement of 0.3 regarding draindown. Increase of crumb rubber content decreases the amount of draindown since rubber improves thermal sensitivity of asphalt cement by increasing its viscosity.

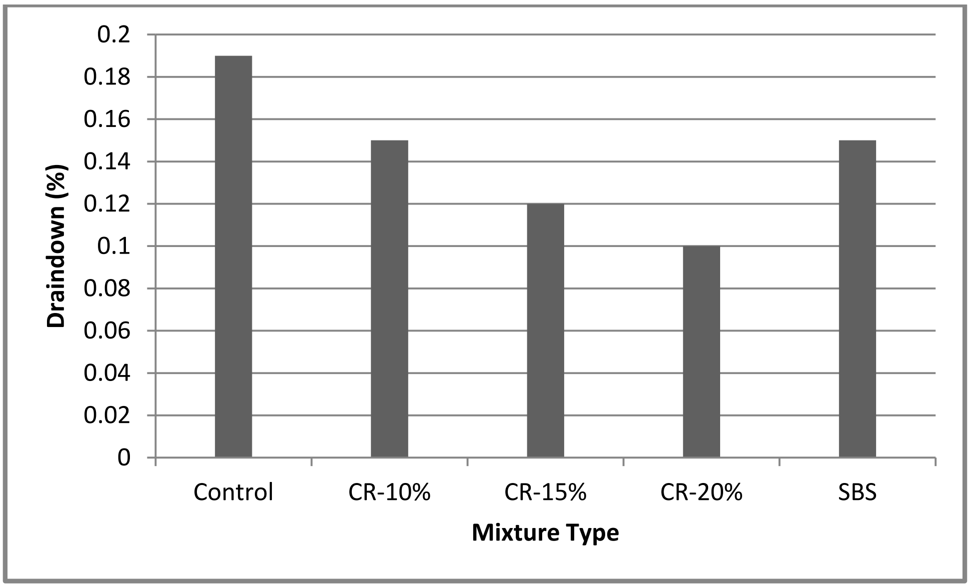

Fig. 5. Draindown test Results

4.3 Permeability test results

As shown in Fig. 6, the falling-head Laboratory permeability test results indicate that control , SBS modified, and 10% crumb rubber mixtures satisfy minimum requirement of allowable coefficient of permeability (100 m/day). Coefficient of permeability reduces with crumb rubber dosage increase at the same air void content. It shows that rubberized asphalt cement is more resistant against water flow.

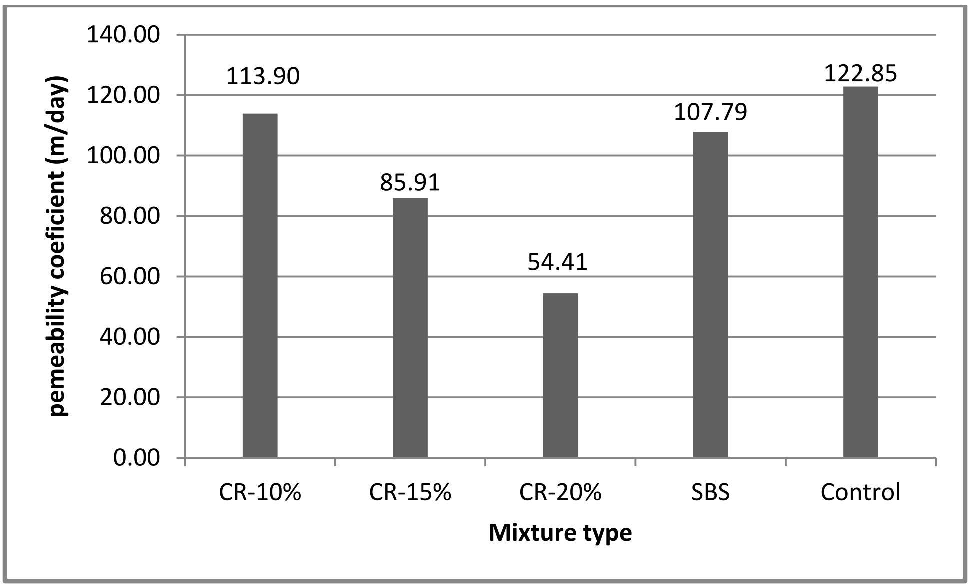

Fig. 6. Permeability test results

4.4 Dynamic creep test results

Rutting resistance is significantly improved by adding crumb rubber into asphalt cement. Fig. 7 illustrates that Flow Number (FN) increases with crumb rubber increase. Elastomeric property of rubberized porous asphalt mix is observed by Dynamic Creep test. It affects rutting performance of asphalt mixtures by modifying two properties of asphalt cement. First, greater portion of deformations become recoverable. In addition, adding crumb rubber into asphalt cement makes it less sensitive to temperature rise and its elastic property is better preserved at high temperature. SBS has the same effect on rutting performance as 10% crumb rubber.

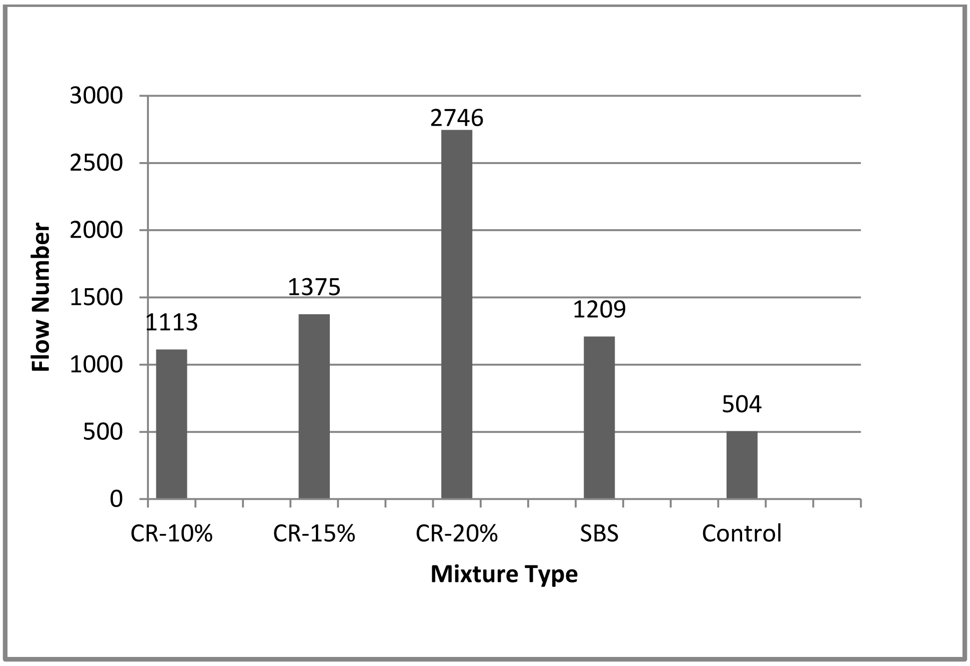

Fig. 7. Results of Dynamic Creep test

4.5 Wheel Tracking

As shown in Fig. 8, rut depth of modified porous asphalt mixtures is significantly reduced compared to control one. SBS and CR-10% have approximately the same rut depth showing they equally improve rutting performance of porous mixes. Similar to FN obtained from dynamic creep test, CR-20% is the most rut resistance mixture followed by CR-15%, CR-10%, SBS, and control mixtures.

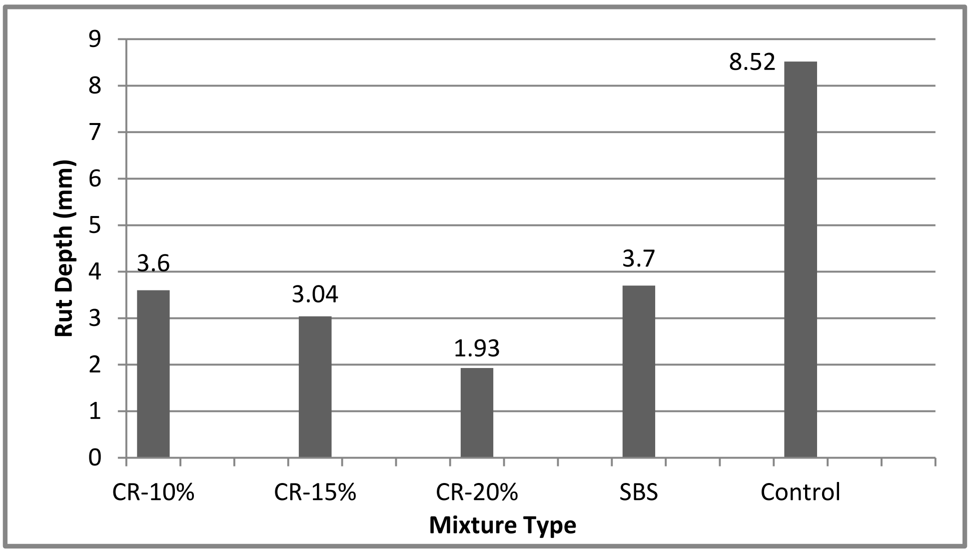

Fig. 8. Rut Depth results

5. Conclusion

This research investigated the impact of crumb rubber at different concentrations on rutting potential of porous asphalt and compared it with SBS modified porous asphalt. Both positive and negative effects were found regarding rutting performance of mixture containing Crumb rubber and SBS. The summary of tests results are as follows:

- Crumb rubber increases the amount of optimal binder content. On the other hand, SBS decreases it.
- Crumb rubber and SBS reduce porous asphalt potential of Draindown.
- Crumb rubber and SBS have negative effects on permeability of porous asphalt. They reduce the rate of permeability. However, it was found that the control, SBS, and 10% rubberized mixtures have coefficient of permeability greater than 100 m/day.
- Rutting resistance increases with crumb rubber content increase. Significant improvement is resulted by adding crumb rubber into asphalt cement. Mixture containing 20% crumb rubber has maximum FN and the least rut depth. CR-10% and SBS yield the same rutting performance.

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