Laboratory Investigation of Properties of Asphalt-Rubber Concrete Mixtures

TAISIR S. KHEDAYWI, ABDEL RAHMAN TAMIMI, HASHEM R. AL-MASAEID, AND KHALED KHAMAISEH

A study was undertaken to investigate (a) the effect of rubber concentration and rubber particle size on properties of asphalt cement, (b) the effect of rubber concentration and rubber particle size on properties of asphaltic concrete mixtures, and (c) the effect of rubber on water sensitivity of asphaltic concrete mixtures. Three types of materials were used: one type of rubber obtained by chopping the tread peel from scrap truck tires, one type of asphalt cement with a penetration grade of 80 to 100, and one type of crushed limestone aggregate. Four concentrations of rubber (5, 10, 15, and 20 percent by total weight of asphalt-rubber mixes) and three rubber particle sizes (Nos. 16–20, Nos. 20–50, and Nos. 50–200) were also used. Results indicated that penetration, ductility, flash point, and specific gravity were inversely related to the increase of rubber concentration in the binder, whereas the softening point was directly related to the increase of rubber concentration in the binder. Results show that asphalt-rubber concrete mixtures have lower stability and higher flow than do asphaltic concrete mixtures without rubber. The experiments also indicated that retained stability of all asphaltic concrete mixtures was acceptable, except for the retained stability of the mixture with rubber particle sizes of No. 50–200 at a 20 percent rubber concentration.

As the use of tires has increased, the growing pile of scrap tires has been eyed as a cheap source of rubber for preparing rubberized asphalt. Early experiments showed that these tires could be ground and mixed with hot asphalt in large percentages to produce a material that had properties superior to those of the base asphalt (*1*).

McDonald (*2*) called for the use of 33 percent (by weight) devulcanized rubber with the remaining proportion composed of 85 to 100 penetration-grade asphalt cement. The asphalt was heated to 420°F when rubber was added and mixed until a jell consistency was acquired. This composition was applied to the pavement in amounts of 1 gal/yd^2; then about 45 lb/yd^2 of aggregate chips were applied to complete the membrane.

Morris and McDonald (*3*) introduced the use of digestions of scrap rubber in asphalt that contained up to 25 percent by mass of comminuted tire-tread rubber; this material has been widely used in the United States. To prevent cracks in the substance from being reflected through overlays, this preparation normally is applied as a chip-seal surface treatment with approximately 20 percent rubber added to the asphalt cement.

Schnormeier (*4*) studied the conditions of a pavement in Phoenix, Arizona, composed of asphalt rubber that was laid between 1969 and 1974. Asphalt rubber used in the Phoenix pavement was produced by two methods: the McDonald process, in which hot asphalt is mixed with 25 percent ground tire rubber to establish a reaction and diluted with kerosene; and the Arizona refinery process, in which hot asphalt is mixed with 18 to 22 percent ground rubber to establish a reaction, then diluted with an extended oil. Schnormeier concludes that asphalt rubber has superior engineering properties, such as a remarkable retention of viscosity, reduction in the volume changes in the subgrade as a result of moisture changes, and a reduction in maintenance that occurs when asphalt is used, as observed in the survey of streets and roads; he recommends the use of asphalt rubber in crack filling and joint sealing.

Lalwani et al. (*5*) made a study on asphalt-rubber using rubber particles that had a gradation of two parts No. 50 (300 μm) to one part No. 30 (600 μm). The study indicated that an increase in rubber concentrations reduces the temperature sensitivity of the binder while it increases the toughness at 25°C.

Roberts and Lytton (*6*) developed a mixture design method to use asphalt-rubber binders in concrete for flexible airport pavements. Rubber from ground scrap tires was used because it is widely available. Two types of asphalt rubber were used in the study. Type A contained 25 percent rubber by weight and Type B contained 18 percent rubber. These two types were used in preparing Marshall specimens. A successful mixture design, obtained with asphalt-rubber binders, exhibited higher stabilities than do similar mixtures made with asphalt cement.

In studying the application of asphalt rubber as an asphaltic concrete crack sealant, Chehovits and Manning (*7*) found that asphalt-rubber sealants have improved temperature susceptibility characteristics and higher elasticity than the unmodified asphalt sealants. They specified that for a material to perform adequately as an asphaltic concrete crack sealant, it must have sufficient flexibility throughout the range of temperatures encountered in service to remain bonded to the crack faces.

OBJECTIVES

The objectives of this research are as follows:

- To study the effect of rubber concentration and rubber particle size on properties of asphalt cement,
- To study the effect of rubber concentration and rubber particle size on properties of asphaltic concrete mixtures, and

Civil Engineering Department, University of Science and Technology, Irbid, Jordan.

- To investigate the effect of rubber on water sensitivity of asphaltic concrete mixtures.

LABORATORY WORK

The experimental work was divided into two stages: investigation of properties of asphalt-rubber binders and determination of properties of asphalt-rubber concrete mixtures.

To evaluate the effect of rubber additives on the behavior of asphalt cement, the following variables were investigated:

- Rubber contents of 5, 10, 15, and 20 percent by total weight of asphalt-rubber mix;
- Rubber particle size passing and retained on the following sieves: No. 16–20, No. 20–50, and No. 50–200; and
- Mixing temperature of at least 160°C based on the range of 160°C to 230°C, which is found in the literature (*8*).

Materials Used

The following materials were used in this study:

- Asphalt cement—One penetration-grade asphalt cement (80–100) was used in this study. This asphalt was obtained from Jordan Petroleum Refinery. This type of asphalt was chosen because it is widely used in pavement construction. Table 1 gives a summary of the results of some tests performed on the asphalt.
- Rubber—The rubber used in the study was obtained by chopping a tread peel of scrap truck tires at ambient temperature using a special machine. The tires were produced by Dunlop Company—Japan and were manufactured with natural rubber (*9*). The specific gravity of the rubber obtained is 0.985. Tread is an external rubber layer protecting the carcass from wear and damage caused by the road surface. It is the part that comes in direct contact with the road and generates the frictional resistance that transmits a vehicle's driving, braking, and cornering forces to the road.

The rubber gradation included particle sizes between the No. 16 and No. 200 sieves. Three parts of rubber between these two sieves were used in this testing. The samples were sieved on the following sieves: No. 16–20, No. 20–50, and No. 50–200.

- Aggregate—One type of limestone aggregate was used in this study. This aggregate is the most commonly used in pavement construction in Jordan. The gradation used in this study conformed to the wearing layer specifications of the Jordanian Ministry of Public Works. This gradation is given in Table 2. Table 3 gives a summary of the properties of the aggregate.

Preparation of Asphalt-Rubber Binders

The suggested procedure for preparing asphalt-rubber binders was based largely on the experience of researchers (*6*) and included the following steps:

1. Asphalt cement was heated in an oven at a temperature of at least 160°C.
2. The stainless steel beaker used for mixing was cleaned and kept in the oven at a temperature of at least 160°C.
3. The required amount of asphalt was weighed into the beaker; then the amount of rubber required to yield the desired rubber-to-asphalt ratio was weighed.
4. The beaker was placed on a hot plate to maintain a mixing temperature of at least 160°C. The laboratory mixer used was then placed so that the propeller was about 1.5 cm above the bottom of the beaker.
5. The mixer was started, and the prepared amount of rubber was added gradually to the beaker while stirring. The speed of the mixer was increased up to 500 rpm. The mixing was continued for at least 30 min and until the homogeneous asphalt-rubber binder was obtained.
6. At the end of the mixing operation, the asphalt-rubber binder was used to prepare specimens for the penetration, softening point, flash point, ductility, and specific gravity or to mix with the heated aggregate to prepare asphalt-rubber concrete specimens.

Measurement of Properties of Asphalt-Rubber Binders

Properties of each asphalt-rubber binder were determined using ASTM standard tests. The following tests were run on each binder:

- Penetration of three specimens for each binder was determined using ASTM D5.
- Softening point of three specimens for each binder was determined using ASTM D36.
- Flash point of three specimens for each binder was done using ASTM D92.
- Three measurements of ductility for each binder were made using ASTM D113.

TABLE 1 Properties of Asphalt Cement Used in Study

Property	ASTM Test Designation	Test Result
Penetration (0.1mm) at 25°C, 100gm, 5 Sec	D 5	93
Ductility (cm) at 25°C	D 113	100
Specific gravity	D 70	1.024
Softening point (°C), ring and ball	D 36	46
Flash point (°C)	D 92	338

Note:- 1mm = 0.0394 in.

TABLE 2 Aggregate Gradation

Sieve Size	Percentage Passing	Specification*
1 in.	100	100
3/4 in.	95	90–100
3/8 in.	68	56– 80
No. 4	45.5	35– 56
No. 8	36	23– 49
No. 50	12	5– 19
No. 200	6	4– 8

Note:– 1 in. = 2.54 cm

* Jordanian Specification Limits

• Specific gravity of three specimens for each binder was performed using ASTM D70.

Measurement of Properties of Asphalt-Rubber Concrete Mixes

The variables involved for this part of the investigation are as follows.

• Rubber content: 0, 5, 10, 15, and 20 percent by total weight of binders;
• Rubber size: No. 16–20, No. 20–50, and No. 50–200; and
• Binder content: 4, 5, 6, 7, and 8 percent by total weight of mix.

To determine the properties of the asphalt-rubber concrete, the Marshall test method procedure was used as part of this study. A total of 120 specimens were prepared for this part of the study. All of these specimens were tested for Marshall stability, flow, air voids, voids in mineral aggregate, and unit weight. The tests were conducted according to MS-2 (*10*) and ASTM D1559.

Water Sensitivity of Asphalt-Rubber Concrete Mixes

The Marshall immersion test was used to evaluate the influence of rubber on moisture resistance of asphalt-rubber concrete mixes (*11*). In this test, Marshall stability is measured for wet and dry specimens at 4 percent air voids. A total of 48 specimens were prepared. The specimens were divided into two groups. One group was cured in air at room temperature for 24 hr (unconditioned) and then put in a water bath at 60°C for 30 min. The other group was immersed in a water bath at 60°C for 24 hr (conditioned).

Both groups were tested in duplicate using the Marshall apparatus. Moisture damage is evaluated on the basis of Marshall stability for conditioned and unconditioned specimens.

TEST RESULTS AND DISCUSSION

Effect of Rubber Concentration and Rubber Particle Size on Properties of Asphalt Cements

Penetration

Figure 1 presents the relationship between penetration of the binders and rubber content for the three sizes of rubber particles being used. This figure shows that the penetration decreases with the increase of the percentages of rubber in the binders. Binder with No. 20–50 rubber particle size shows higher values of penetration, whereas binder with No. 16–20 rubber particle shows lowest values of penetration.

Softening Point

Figure 2 shows that the softening points of the binders are directly proportional to the increase of rubber concentrations in the binders.

Flash Point

Figure 3 shows that flash points of the binders are inversely related to the increase of rubber concentrations in the binder. Asphalt-rubber binder with No. 20–50 rubber particles shows higher values of flash point, whereas binder with No. 16–20 rubber particles shows the lowest values of flash point.

Ductility

Figure 4 shows that ductility of binders decreases and then increases with increasing rubber content in the binder. Asphalt-rubber binders with finer rubber particles (No. 50–200) show slightly higher ductility, whereas binder with No. 16–20 rubber particles shows lower ductility.

TABLE 3 Properties of Aggregate

Type of Aggregate	ASTM Test Designation	Bulk Specific Gravity	Apparent Specific Gravity	Water Absorption (%)
Limestone coarse aggregate	C 127	2.54	2.60	3.50
Limestone fine aggregate	C 128	2.45	2.70	3.80
Limestone mineral filler	C 128	2.63	2.74	4.20

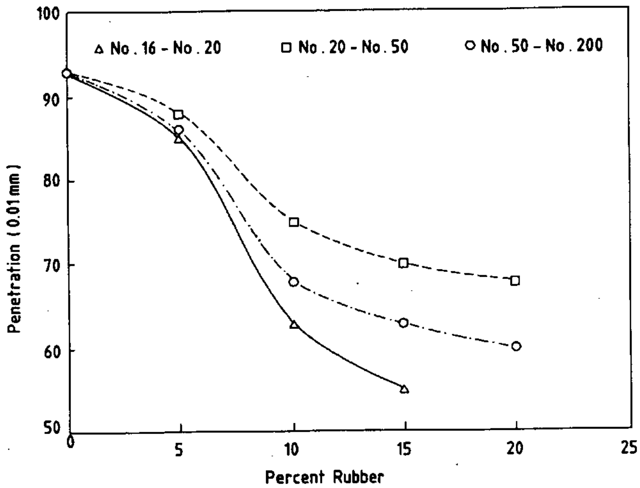

FIGURE 1 Effect of rubber content on penetration of asphalt-rubber binders.

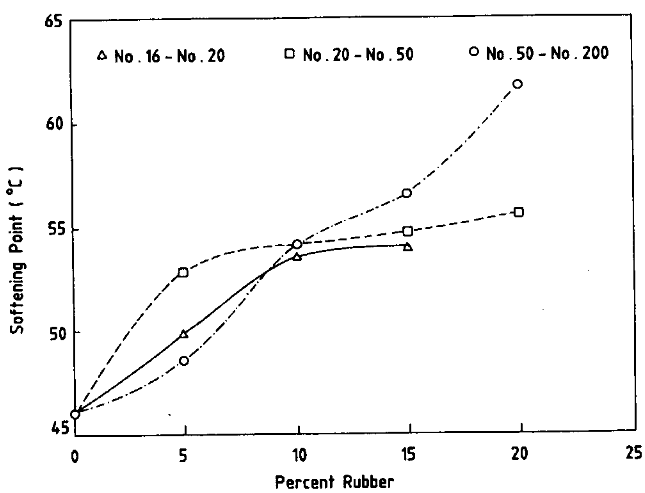

FIGURE 2 Effect of rubber content on softening point of asphalt-rubber binders.

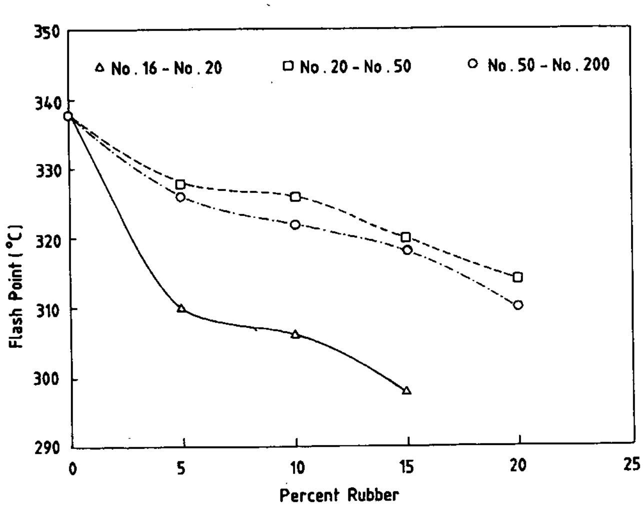

FIGURE 3 Effect of rubber content on flash point of asphalt-rubber binders.

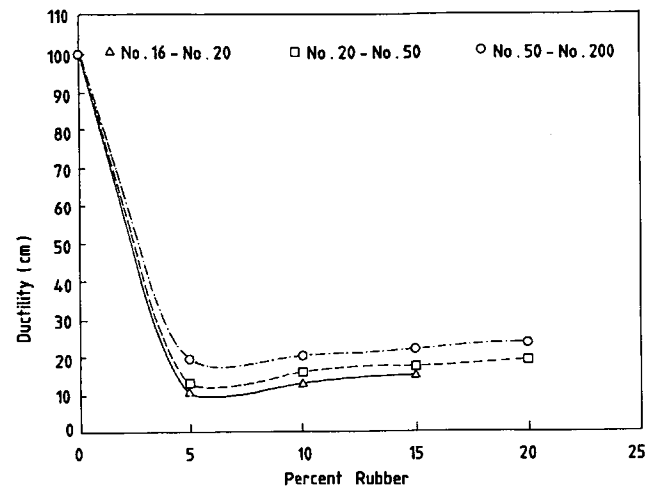

FIGURE 4 Effect of rubber content on ductility of asphalt-rubber binders.

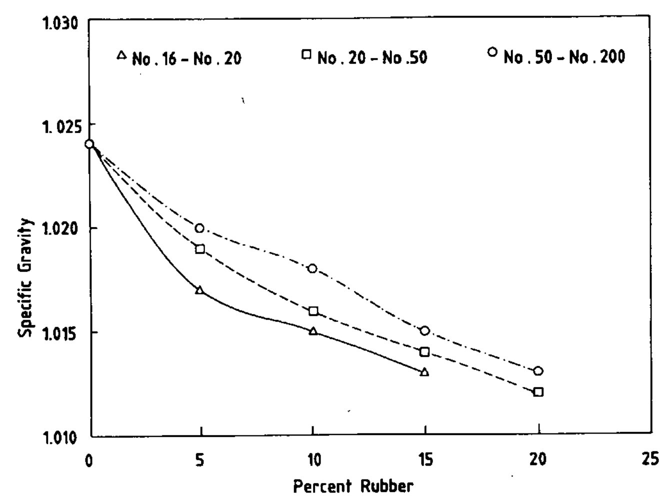

FIGURE 5 Effect of rubber content on specific gravity of asphalt-rubber binders.

Specific Gravity

Figure 5 shows the relationship between the specific gravity of the binders and rubber content for various sizes of rubber particles. Specific gravity is inversely related to the increase in the rubber content. The data collected for the specific gravity of various binders indicated that asphalt-rubber binder made up of No. 50–200 rubber particles shows higher values of specific gravity, whereas rubber-asphalt made up of No. 16–20 rubber particles shows lower values.

Effect of Rubber Content and Rubber Particle Size on Properties of Asphalt-Rubber Concrete

Table 4 and Figures 6 to 9 summarize the measured properties of asphalt-rubber concrete mixtures. The effect of rubber content and the size of the rubber particle on properties of asphalt-rubber concrete mixtures are discussed next.

TABLE 4 Properties of Asphalt-Rubber Concrete Mixture at 4 percent Air Voids

Percent of Rubber	Binder Content (%)	Marshall Stability (Kgf)	Flow (0.25mm)	VMA (%)	Unit Weight (Mg/m^3)	Ret. Stab. (%)
Asphalt-Rubber Binder Made up of No.16-No.20 Rubber Particles						
0	5.0	1560	11.0	12.7	2.314	83
5	4.8	1300	11.2	12.8	2.310	82
10	5.1	1295	12.5	13.0	2.309	78
15	5.2	1150	13.6	13.3	2.295	75
Asphalt-Rubber Binder Made up of No.20-No.50 Rubber Particles						
5	4.7	1200	13.0	12.0	2.324	82
10	5.1	1188	14.3	13.0	2.313	79
15	5.2	1146	15.1	13.5	2.304	76
20	5.5	1140	17.5	14.4	2.280	75
Asphalt-Rubber Binder Made up of No.50-No.200 Rubber Particles						
5	4.9	1470	12.5	12.3	2.333	80
10	4.7	1198	13.6	12.5	2.332	77
15	4.6	1191	13.9	12.6	2.330	75
20	4.5	1081	14.3	12.9	2.315	73

Note:- 1kgf = 2.2 lbf, 1mm = 0.0394 in., 1 Mg/m^3 = 0.01618 lb/ft^3

Marshall Stability

Figure 6 presents the relationship between Marshall stability and rubber content in the binder at 4 percent air voids for various rubber particle sizes. This figure shows that Marshall stability decreases with increasing rubber content in the binder.

Flow

Figure 7 shows that flow increases with an increase in rubber content in the binder. Bituminous concrete mixtures with No. 16–20 rubber particles show lower flow values, whereas bituminous mixtures with No. 20–50 rubber particles show higher flow values.

Voids in Mineral Aggregate

Figure 8 presents the relationship between voids in mineral aggregate (VMA) and rubber content in the binder at 4 percent air voids for various sizes of rubber particles. This figure shows that VMA increase with increasing rubber content in the binder.

Retained Stability

Evaluation of water sensitivity of asphalt concrete mixtures is mainly based on the retained stability (RS), which is the ratio between wet and dry stabilities. Most researchers indicate that this ratio should not be less than 75 percent. There-

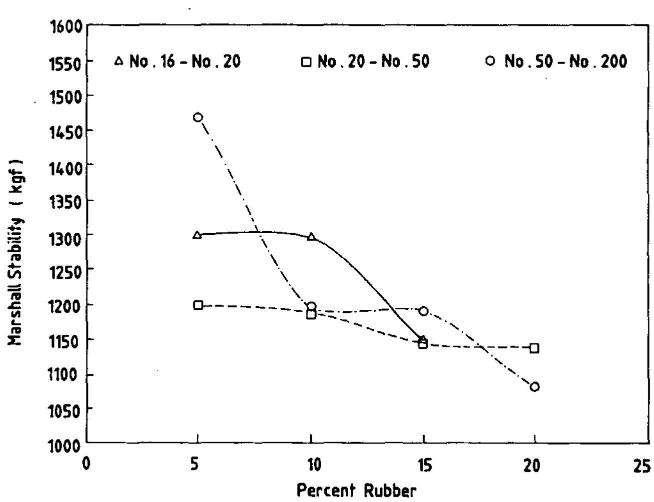

FIGURE 6 Relationship between rubber content and Marshall stability at 4 percent air voids.

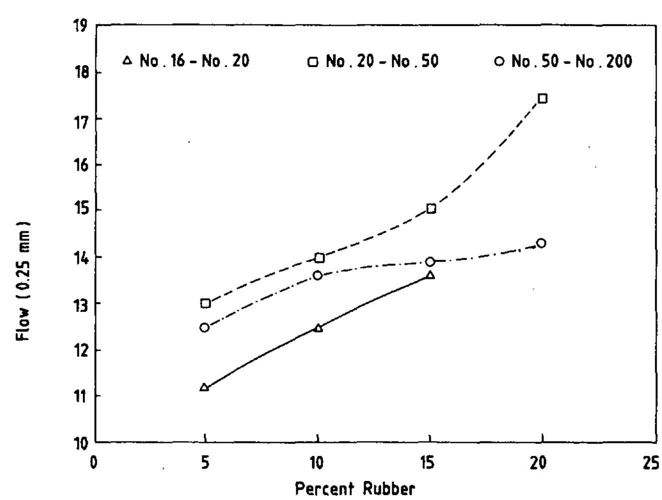

FIGURE 7 Relationship between flow and rubber content at 4 percent air voids.

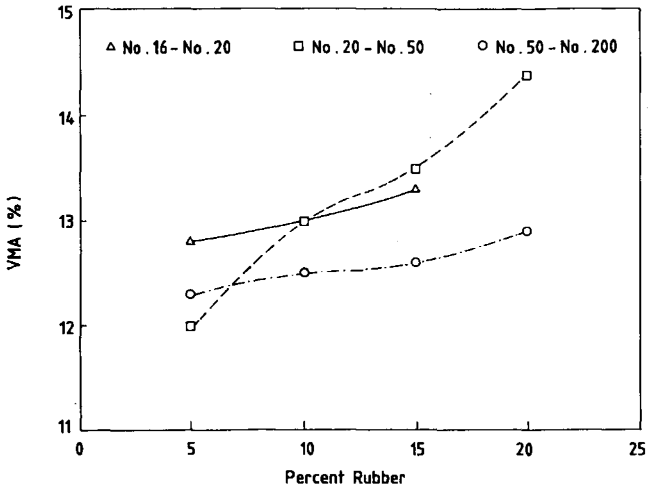

FIGURE 8 Relationship between rubber content and VMA at 4 percent air voids.

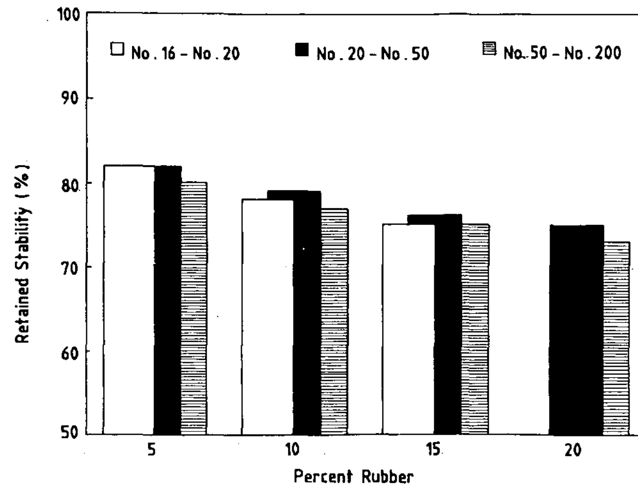

FIGURE 9 Retained stability versus rubber content at 4 percent air voids.

fore 75 percent RS was used as the acceptance-rejection criterion (*11*). Figure 9 shows the relationship between RS and rubber content for the three sizes of rubber particles used in asphalt-rubber binders. RS was inversely related to the increase in rubber content in the binder for the three asphalt-rubber concrete mixtures. The RS of all mixtures was acceptable, except for the RS of the mixture with No. 50–200 rubber particle sizes at 20 percent rubber content, which was not acceptable.

CONCLUSIONS

On the basis of the results of this study, the following conclusions are made:

- The addition of rubber to the asphalt cement changes the properties of binders. Penetration, ductility, flash point, and specific gravity of the asphalt-rubber binder are inversely related to the increase in rubber concentration in the binder. However, the softening point is directly related to the increase in the rubber concentration.
- The ductility and specific gravity of the asphalt-rubber binder decrease as the size of the rubber increases.
- Mixtures prepared with asphalt-rubber binders exhibit lower stabilities than do similar mixtures made up of asphalt cement binder. In contract, incorporating rubber into asphaltic concrete mixtures increases the flow of these mixtures.
- For mixtures made up of asphalt-rubber binders, VMA slightly increases with an increase in the rubber content in the binder.
- The retained Marshall stability of all mixtures was found acceptable, except the RS of mixtures with No. 50–200 rubber particle size at 20 percent rubber content.

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