Evaluation of Japanese Asphalt Binders and Asphalt Mixtures After Mixing Ground Rubber

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Synopsis

This paper presents an evaluation carried out for Japanese asphalt-rubber binders and asphalt-rubber mixtures. At first, ground rubber 0.2mm and 0.4mm from passenger car tires was mixed separately to straight asphalt 60/80 (grade of penetration) at rates of 0%, 9%, 12%, 15% and 18% by total asphalt-rubber weight. Conventional tests (penetration and softening point temperatures) and Superpave tests (dynamic shearing, flexural creep stiffness and apparent viscosity) evaluated the binder's properties. Ground rubber at rate of 15% mixed to asphalt produced the best behavior for both rubber sizes. Considering this, dense-graded asphalt-rubber mixtures as well as conventional mixtures were prepared. Laboratory tests performed included the Marshall Stability, flow value, residual stability, wheel tracking and static bending. Mixing ground rubber improved significantly the mechanical properties of dense-graded asphalt mixtures.

Evaluation of Japanese Asphalt Binders and Asphalt Mixtures After Mixing Ground Rubber

Worldwide studies evaluating the mixing of polymers (for instance, SBS, SBR, EVA) with asphalt have shown significant improvements on asphalt binders as well as on asphalt concrete mixtures properties. Researches performed have also included the mixing of ground rubber to asphalt. The evaluation of asphalt-rubber binders proved that the presence of rubber particles increase the apparent viscosity, the resistance to dynamic shearing and reduces the flexural creep stiffness. Considering the asphalt-rubber concrete mixtures, they present enhanced performance, especially related to permanent deformation and fatigue life.

This paper evaluates Japanese asphalt-rubber binders and asphalt-rubber mixtures. At first, ground rubber 0.2mm and 0.4mm from passenger car tires was mixed separately to straight asphalt 60/80 (grade of penetration) at rates of 0%, 9%, 12%, 15% and 18% by total asphalt-rubber weight. Conventional and Superpave tests evaluated the behavior of original (unaged) and short-term aged binder's. Conventional tests included the penetration and softening point temperatures. Superpave tests evaluated at high temperatures the apparent viscosity using the Brookfield viscometer. In addition, the Complex Shear Modulus ($|G^*|$) and phase angle (δ) using the Dynamic Shear Rheometer (DSR) were also analyzed. At low temperatures, the study comprised the flexural creep stiffness and slope of response using the Bending Beam Rheometer (BBR). Ground rubber at rate of 15% mixed to asphalt produced the best properties for both rubber sizes. Considering this, dense-graded asphalt-rubber mixtures as well as conventional mixtures were prepared. The Marshall Design method was used to determine the optimum asphalt content (OAC). Laboratory tests performed included the Marshall Stability, flow value, residual stability, wheel tracking and static bending.

LITERATURE REVIEW

Ground rubber from scrap tires may be mixed to straight asphalt in order to improve the asphalt properties. Blending of rubber particles can be carried out using the "wet process" or the "dry process". The wet process consists to mix ground rubber to asphalt before adding the aggregates, while the dry process replaces some of the aggregate in the asphalt mixture. Considering the wet process, the asphalt and rubber blending is performed at high temperatures. Studies on asphalt-rubber binders report temperatures ranging from 150°C to 220°C, whereas, the time of reaction or time of digestion varies from ten minutes to two hours (Hicks *et al*., 1995; Roberts *et al.*, 1996; Abdelrahman and Carpenter, 1999). After mixing, rubber particles absorb the lighter fractions of asphalt and swell, decreasing the interparticles distance and increasing the viscosity (Hicks *et al*., 1995).

Laboratory analyzes for asphalt-rubber binders have shown the presence of ground rubber reduces the dependency on temperature and on frequency of loading. At high temperatures, the resistance to permanent deformation, measured by the Complex Shear Modulus ($|G^*|$) using the Dynamic Shear Rheometer (DSR), increases proportionally to the rate of rubber addition. The same behavior was found for softening point temperatures. At low temperatures, the stiffness measured with the Bending Beam Rheometer (BBR) decreases, the rate change is not as big as at high temperatures, but the reduction is still significant. Further, the temperature susceptibility becomes smaller after blending ground rubber to asphalt (Bahia and Davies, 1994; Bahia, 1995; Hanson and Duncan, 1995; Souza *et al.*, 2004; Souza *et al.*, 2004b).

Considering the asphalt-rubber mixtures, researches evaluating this kind of material show that the demand on asphalt increases when ground rubber is mixed to asphalt, either using the dry process or the wet process (Malpass and Khosla, 1995; Dantas Neto *et al.*, 2003). The resistance to permanent deformation improves compared to that observed for conventional mixtures (Olmos *et al.*, 2003; Leite *et al.*, 2003; Nourelhuda *et al.*, 2003; Gallego *et al.*, 2000). The enhancement to rutting may reach three or four times as observed by Dantas *et al.* (2003) and studies developed by Nourelhuda *et al.* (2003) found the permanent deformation was developed mostly by shoving (or lateral displacement), whereas, for conventional mixtures they were developed mostly by densification. Comparing the performance to rutting among asphalt-rubber mixtures and mixtures using polymer modifiers (SBS and EVA), rubberized mixtures showed higher increase of resistance, and such growth of resistance was independent on the binder content (Leite *et al.*, 2000). Asphalt-rubber mixtures also present larger fatigue cracking resistance, showing these mixtures can resist a larger number of load repetitions (Esch, 1982; Nourelhuda *et al.*, 2003; Gallego *et al.*, 2000; Leite *et al.*, 2000; Mamlouk and Mobasher, 2003; Antunes *et al.*, 2000). In addition, the temperature susceptibility is also improved (Takallou and Hicks, 1988; Antunes *et al.*, 2000; Mamlouk and Mobasher, 2003). As for surface evaluation, asphalt-rubber mixtures present improved skid resistance under icy conditions and significant reduction on traffic noise (Takallou and Hicks, 1988).

CHARACTERIZATION OF MATERIALS

Gradation of Passenger Car Ground Rubber

The gradation of ground rubber used here is as shows Table 1.

Table 1: Gradation of passenger car ground rubber

Sieve opening (mm)	Percent passing	
	PS0.2mm	PS0.4mm
2.36	100.00	100.00
2.00	100.00	100.00
1.70	100.00	100.00
1.18	100.00	99.50
0.60	100.00	97.40
0.425	98.42	68.80
0.30	91.80	24.10
0.25	77.61	13.00
0.15	20.14	1.25
0.075	0.67	0.03
Pan	0.00	0.00

Ground Rubber Characteristics

A chemical analysis performed for ground rubber detected the following components: 8.6% of acetone extracts; 4.8% of ash; 43.59% of natural rubber (NR) and 13.31% of styrene butadiene rubber (SBR). The specific gravity of rubber particles was 1.12.

Aggregates for Asphalt Concrete Mixtures

Considering the aggregates used for asphalt-mixtures, Table 2 presents the following grain size distribution.

Table 2: Aggregate distribution

Type of aggregate	Grade 6	Grade 7	SC	Coarse sand	Fine sand	Filler	Percent passing (%)	Percent target (%)
Design (%)	34.5	22.5	7.0	26.5	5.0	4.5		
Sieve (mm)	1	2	3	4	5	6		
19.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
13.20	90.0	100.0	100.0	100.0	100.0	100.0	96.6	97.5
4.750	1.5	83.6	100.0	100.0	99.1	100.0	62.3	62.5
2.360	0.3	5.1	89.1	96.7	96.9	100.0	42.5	42.5
0.600		1.5	39.7	53.5	85.3	100.0	26.1	24.0
0.300		1.4	29.6	30.2	47.6	99.9	17.3	15.5
0.150			21.3	12.4	4.3	98.6	9.4	11.0
0.075			15.5	3.9	0.8	87.9	6.1	6.0

Asphalt Cement Characteristics

This investigation used straight asphalt type 60/80 (grade of penetration), whose physical characteristics are: 70 (0.1mm) of penetration at 25°C; 22 (0.1mm) of penetration at 4°C; 46.8°C of softening point; 339°C of flash point and ductility bigger than 100cm.

EVALUATION OF ASPHALT-RUBBER BINDERS

At first, a mechanical mixer type Heidon BLh600 performed the mixing of straight asphalt and ground rubber. This equipment has a 50cm shaft and helix type fan measuring 80mm diameter. A mantle heater kept the temperature of asphalt-rubber constant during the mixing process. The addition of ground rubber to straight asphalt was performed at 180°C±1°C, using a rotation speed of 250RPM. After finishing rubber addition, the mechanical mixing process continued for 30 minutes at 660RPM. After mixing finished, the asphalt-rubber binder resultant was kept for one hour in oven at 180°C±1°C to perform the binder digestion. Then, samples were prepared for conventional and Superpave tests. Further, asphalt-rubber binder was poured into glass bottles for short-term aging at the Rolling Thin Film Oven-RTFO (asphalt-rubber using rubber 0.4mm), and likewise at pans for short-term aging at the Thin Film Oven-TFO (asphalt-rubber using rubber 0.2mm). Aging tests at RTOFT for binders mixing rubber 0.2mm showed these binders used to creep out the bottles and after the period of oxidation, the oven was significantly dirty and little binder was left inside the bottles to be used for conventional and Superpave tests. Because this, the short-term aging for this type of binder was performed at the Thin Film Oven machine. After oxidation, for both types of binder, samples were prepared to perform the same tests carried out for unaged binders.

Laboratory Analyzes

This study analyzed the behavior of asphalt-rubber binders using conventional and Superpave tests. The conventional tests comprised the softening point temperatures as well as the penetration at 25°C and at 4°C. Superpave tests evaluated the flexural creep stiffness with the Bending Beam Rheometer (BBR), the dynamic shearing using the Dynamic Shear Rheometer (DSR) and the apparent viscosity measured with the Brookfield viscometer.

Softening Point Test

The softening point test finds out the temperature at which asphalt cement cannot support the weight of a steel ball and starts flowing. In this way, is possible to settle the temperature at which a phase change occurs in the asphalt cement (Roberts *et al.*, 1996). This study found (Figure 1) that original and aged asphalt-rubber binders increased their softening point temperatures as the percentage of rubber became bigger and such improvement was more remarkable for binders using rubber 0.4mm. In this way, the addition of rubber enhanced the resistance to permanent deformation.

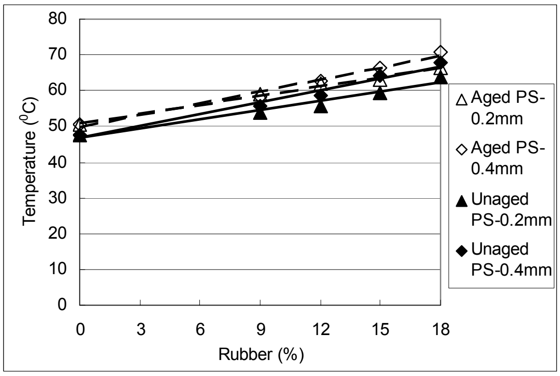

Figure 1: Softening point temperatures

Penetration Tests

The penetration test at 25°C consists to measure the displacement of a vertical standard needle, for a total mass of 100 grams, allowed to sink into a container of asphalt binder at room temperature (25°C) during five seconds. The stiffness of asphalt is expressed as the depth in tenths of millimeter (dmm) the needle penetrated it. At 4°C this test measures indirectly the performance of asphalt binders at low temperatures. A vertical standard needle mounted on a shaft, for a total mass of 200 grams, is allowed to penetrate a container of asphalt binder at a temperature of 4°C during 60 seconds. The stiffness of asphalt is expressed as the depth in tenths of millimeter (dmm) the needle penetrated it (Roberts *et al.*, 1996).

As illustrates Figure 2, the penetration at 25°C decreased when the rate of rubber mixed to asphalt became bigger. Before aging, binders using rubber 0.4mm showed lower values of penetration, proving higher consistency of these binders. After aging, both types of rubber presented similar behavior. Further, the oxidation and the increasing percentage of rubber did not influence the penetration values measured.

At 4°C (Figure 3), there was a tendency of increase the penetration values as the rate of rubber became bigger before and after aging, showing an improvement of flexibility at low temperatures. However, the data was relatively scattered.

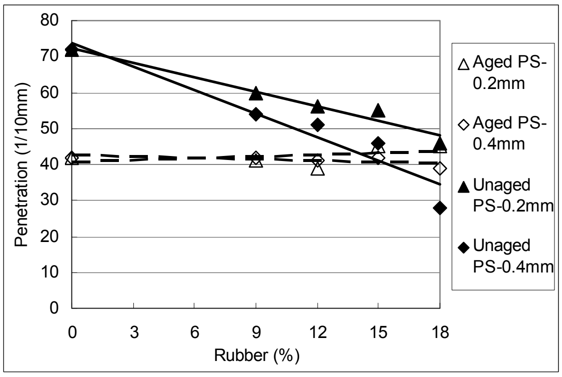

Figure 2: Penetration test at 25°C

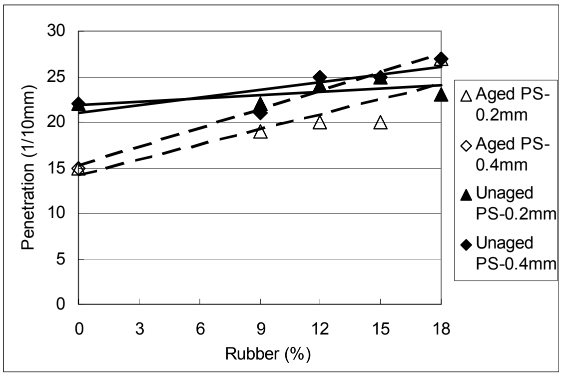

Figure 3: Penetration test at 4°C

Temperature susceptibility

The temperature susceptibility is the rate at which the consistency of asphalt cement changes with a change in temperature. Asphalts cements showing high susceptibility to temperature change may present very low viscosity, resulting in tender mix problems during asphalt mixture compaction. Further, their stiffness at the lowest service temperature is usually very high, resulting in low temperature shrinkage cracking (Roberts *et al.*, 1996). The penetration index (PI) is a quantitative estimation of the temperature susceptibility. The PI is calculated from the penetration values measured at 25°C and some other temperature for asphalt cement. The logarithm of penetration is plotted against the test temperatures in degrees Celsius. The slope of this line, is calculated as

$$\mathrm{A} = \frac{\log Pen\,at\,T_1 - \log Pen\,at\,T_2}{T_1 - T_2} \tag{1}$$

Where:
Pen = penetration of asphalt binder at T_1, T_2, in tenths of millimeter;
T_1, T_2 = temperature, in degrees Celsius.

The Penetration Index (PI) (pen/pen) is then determined using the following empirical expression

$$PI = \frac{20 - 500.A}{1 + 50.A} \tag{2}$$

The lower the PI value of an asphalt cement, the higher its temperature susceptibility.

This study evaluated the temperature susceptibility considering the penetration values of asphalt binders at 25°C and at 4°C, before and after oxidation. According to Figure 4, the penetration index (PI) increased in an expressive way after mixing ground rubber. This growth was proportional to the rate of rubber content and bigger for binders using rubber 0.4mm. Thus, asphalt-rubber binders reduced the temperature susceptibility, especially when mixing bigger particles of rubber. After oxidation (Figure 5), the same tendency could be seen; however, the difference among penetration indices using rubber 0.2mm and 0.4mm increased, showing a higher contribution of bigger particles to reduce the temperature susceptibility.

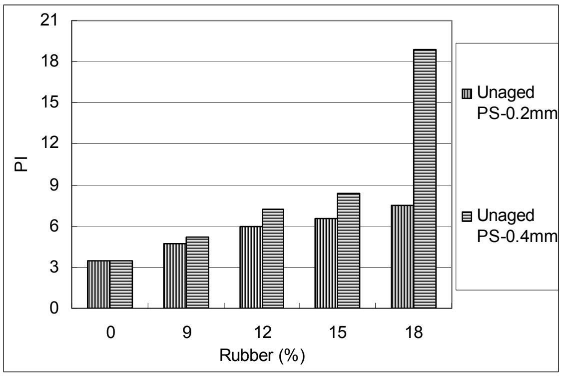

Figure 4: Penetration Index (PI) before oxidation

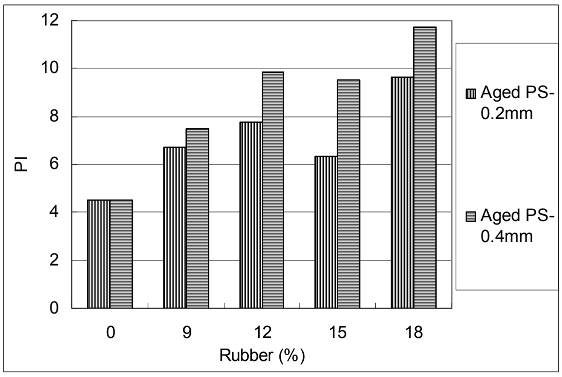

Figure 5: Penetration Index (PI) after aging

Flexural Creep Stiffness

According to the Superpave Specification, the flexural creep stiffness and the slope of response evaluate the resistance of asphalt binders to thermal cracking. Asphalt concrete pavements may develop thermal cracking when the temperature drops rapidly at cold temperatures. As the pavement contracts, stresses begin to build up within the pavement layers. If the contraction occurs very quickly, the stresses can eventually exceed the stress relaxation ability of the asphalt concrete pavement. Because this, the pavement develops cracking as a way to relieve the stresses. The BBR measures the midpoint deflection of a simply supported prismatic beam of asphalt binder that is subjected to a constant load applied to the midpoint of the beam. From this measurement two parameters are analyzed, the stiffness (S) at 60 seconds and the slope of the tangent line at this point (called "m-value" or "slope of response") (Roberts *et al.*, 1996).

This study analyzed all asphalt-rubber binders at –10°C and at –15°C. Figures 6 and 7 show when the temperature dropped, the flexural creep stiffness became higher. However, for both temperatures, as the percentage of rubber increased, the stiffness measured decreased significantly and in a similar way. Thus, the resistance to thermal cracking was improved after mixing ground rubber. Further, unaged binders presented similar tendency of decrease, whereas, after aging, binders using rubber 0.4mm tended to present slightly lower stiffness values. In addition, it could be seen the presence of rubber reduced the effect of oxidation, since the aged stiffness values present the same order of magnitude of that measured for unaged binders.

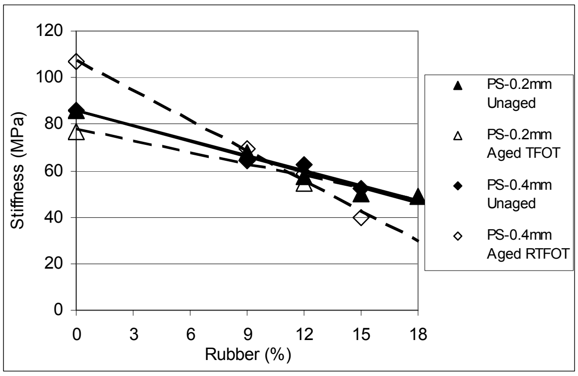

Figure 6: Flexural Creep Stiffness at –10°C

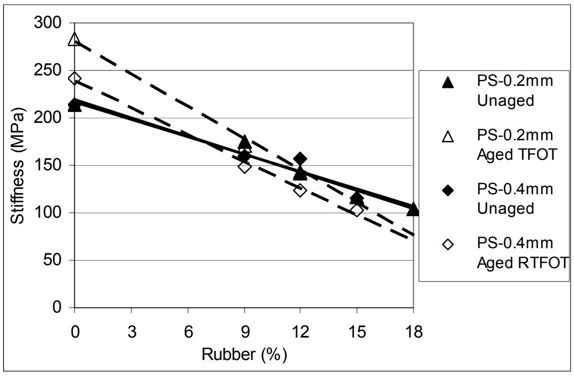

Figure 7: Flexural Creep Stiffness at –15°C

The slopes of response (Figures 8 and 9) became smaller when the temperature fell from –10°C to –15°C. For both types of rubber unaged asphalt-rubber binders showed similar decreasing values as the rate of rubber became bigger. Thus, the rate of stress relaxation became slower. After aging, binders using rubber 0.2mm presented increasing m-values as the rate of rubber enlarged. In this way, these binders tended to increase the ability to deform quickly enough to prevent cracking. Further, considering the effect of oxidation, it could be found that when the temperature decreased, the presence of rubber particles reduced the rate of change among slopes of response before and after aging.

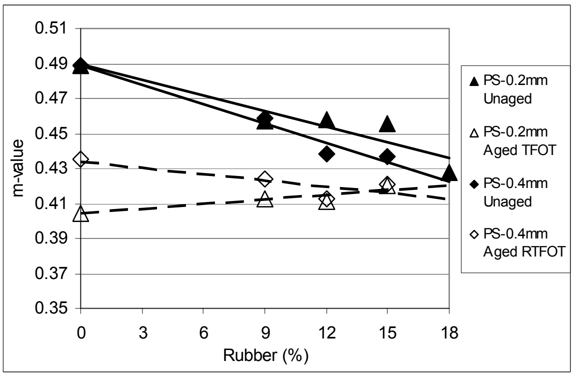

Figure 8: Slope of response at –10°C

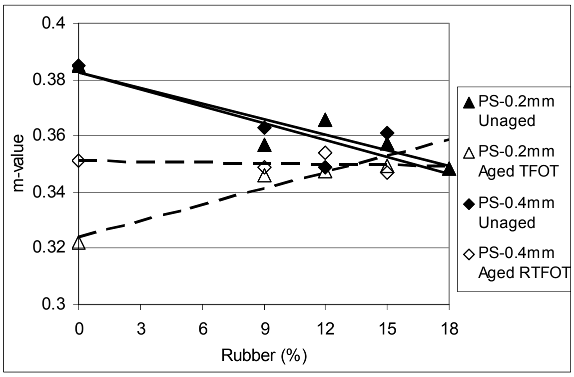

Figure 9: Slope of response at –15°C

Dynamic Shearing

The dynamic shearing performed with the Dynamic Shear Rheometer (DSR) estimates the Complex Shear Modulus (|G*|) and phase angle (δ) at high, at intermediate and at low temperatures. The Complex Shear Modulus (|G*|) is the ratio of maximum shear stress to maximum shear strain, and it represents the total resistance of the binder to deformation when repeatedly sheared. The time lag between the applied stress and the resulting strain is the phase angle (δ) (Roberts *et al.*, 1996).

This study evaluated the behavior of all samples at 45°C and at 65°C. A Dynamic Shear Rheometer (DSR) using the parallel plate configuration (25 mm diameter) carried out the test for all samples. The gap between the upper and the lower plate was defined as 2.5 times the respective size of rubber particles and all tests ran at a frequency of 1.59Hz. At 45°C (Figure 10), comparing straight asphalt and asphalt-rubber binders, the |G*| became significantly bigger when the rate of rubber increased. The same remark could be seen at 65°C (Figure 11). The presence of ground rubber probably increases the friction contact among particles, especially at higher temperatures, when straight asphalt starts flowing, improving the resistance to deformation. However, despite the increasing tendency of |G*| as the rubber content became bigger, the absolute values of |G*| fell in an expressive way at 65°C. At 45°C, before and after oxidation, binders using rubber 0.2mm showed higher values of |G*| and so, higher, resistance to deformation. At 65°C, despite the difference of rubber size, the |G*| values showed the same increasing extent for both types of rubber. In addition, after aging, the |G*| became bigger, but such increase was not so extreme, proving the presence of rubber reduced the effect of oxidation.

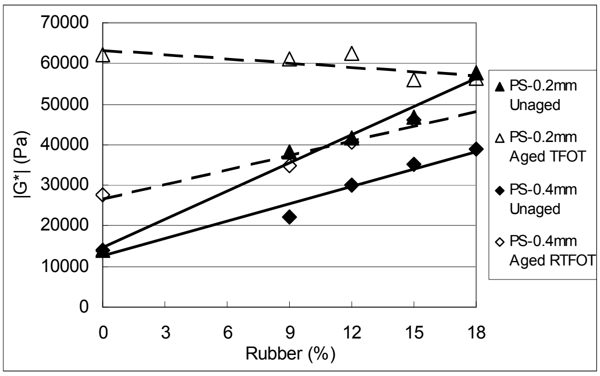

Figure 10: Complex Shear Modulus (|G*|) at 45°C

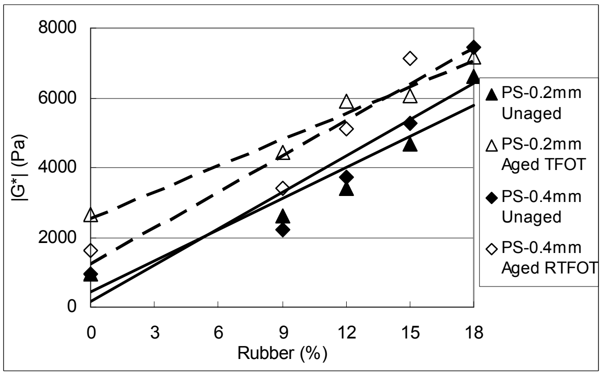

Figure 11: Complex Shear Modulus (|G*|) at 65°C

Considering the phase angles (δ) (Figures 12 and 13), it could be seen they were inversely proportional to the rate of rubber mixed to straight asphalt. This behavior was observed before and after aging, showing enhancement of binder's elasticity. Moreover, despite the difference of rubber size, the phase angles showed the same order of magnitude before and after oxidation. Again, the presence of rubber probably reduced the effect of oxidation, since the difference of phase angles before and after oxidation was not so significant.

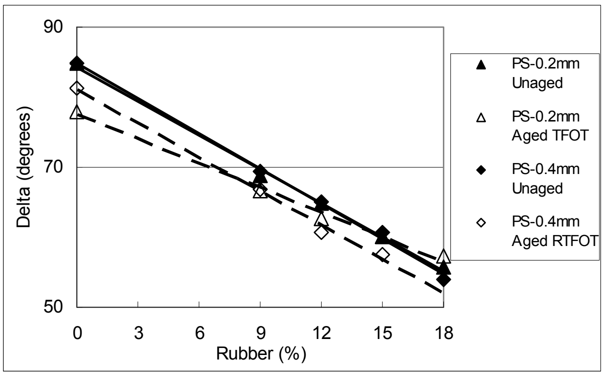

Figure 12: Phase angle (δ) at 45°C

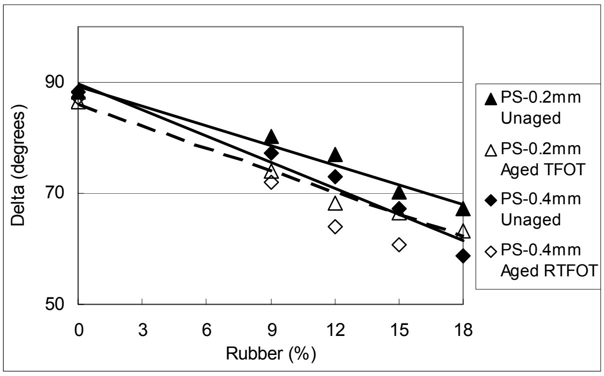

Figure 13: Phase angle (δ) at 65°C

Apparent viscosity

The viscosity requirement aims to insure that the material can be pumped and mixed with aggregate. The apparent viscosity of asphalt binders can be determined using a rotational viscometer usually known as Brookfield viscometer. The viscosity is measured through the torque required to rotate a spindle plunged into hot asphalt at a constant rotational speed (Roberts *et al.*, 1996). According to the ASTM D6114-97 (1987), the apparent viscosity of asphalt-rubber binders is determined at 175°C and the viscosity limits are 1500 cP and 5000 cP, minimum and maximum viscosities, respectively.

This study analyzed the viscosities (Figure 14) using a rotational viscometer (Brookfield) at 175°C, for a rotation speed of 20RPM. It could be seen that as the rate of rubber increased, the viscosities became significantly bigger, and this remark was more important for binders using rubber 0.4mm. In this way, the addition of 18% of rubber 0.4mm showed extremely high viscosity, what might result in pumping problems during asphalt mixture production.

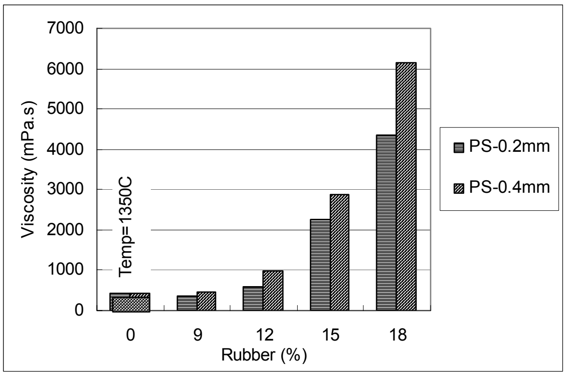

Figure 14: Apparent viscosities

Main Findings from Asphalt-rubber Binder Evaluation

This section showed that mixing ground rubber to straight asphalt improved the consistency and flexibility at high temperatures. Further, the stiffness at low temperatures reduced significantly, as well as the temperature susceptibility. Considering the overall results from conventional and Superpave tests, ground rubber at a rate of 15% mixed to straight asphalt proved the best properties at high and at low temperatures. The rate of 18% presented the highest resistance to dynamic shearing, the highest softening point temperature, the highest flexibility at low temperatures and the lowest flexural creep stiffness. However, it’s extremely high apparent viscosity makes the pumping and workability more difficult at asphalt plant mix.

EVALUATION OF ASPHALT-RUBBER MIXTURES

At first, ground rubber was mixed to straight asphalt using a mechanical mixer type Heidon BLh600. This equipment has a 50cm shaft and helix type fan measuring 80mm diameter. A mantle heater kept the temperature of asphalt-rubber constant during the mixing process. The addition of ground rubber to straight asphalt was performed at 180°C±1°C, using a rotation speed of 250RPM. After finishing rubber addition, the mechanical mixing process continued for 30 minutes at 660RPM. After mixing finished, the asphalt-rubber binder resultant was kept for one hour in oven at 180°C±1°C to perform the binder digestion.

Temperature of Mixture Production

Marshall Method was used to calculate the optimum asphalt content (OAC) of dense-graded asphalt mixtures. The mixing of straight asphalt and aggregates followed the Japanese standard temperatures, whereas, for asphalt-rubber binders, the temperatures selected represent average values used for asphalt-rubber mixtures worldwide. Table 3 presents the details about temperatures of mixture production.

Table 3: Temperatures considered during the production of dense-graded mixtures

Temperature	Straight Asphalt 60/80	AR-PS0.2mm	AR-PS0.4mm
Binder heating (°C)	150	180	180
Aggregate heating (°C)	160	190	190
Mixing binder-aggregate (°C)	145	165	165

Properties of Dense-graded Asphalt Mixtures

Since the volumetric properties of asphalt concrete mixtures affect the performance, here, despite the difference of binders used, all samples evaluated presented the same air voids percentage. The optimum asphalt content (OAC) for dense-graded mixtures using straight asphalt was determined as 5.4%. Considering the asphalt-rubber mixtures, the OAC became bigger when the rubber size increased. In addition, the voids in mineral aggregate (VMA) grew as the size of rubber increased. This fact shows that since rubber particles do not melt into the asphalt, when they swell they tend to push the aggregate particles apart, increasing in this way, the VMA. Table 4 presents the details of dense-graded mixtures evaluated.

Table 4: Properties of dense-graded asphalt mixtures evaluated

Property	Straight Asphalt 60/80	AR-PS0.2mm	AR-PS0.4mm
Optimum Asphalt Content (OAC) (%)	5.4	6.2	6.5
Apparent density (g/cm3)	2.401	2.381	2.371
Air Voids (%)	4.0	4.0	4.0
Voids in Mineral Aggregate (VMA) (%)	16.6	18.0	18.7
Voids Filled with Asphalt (VFA) (%)	75.3	78.1	78.7

LABORATORY ANALYZES

Marshall Stability, Flow Value and Residual Stability

Marshal Stability evaluates the maximum load carried by a compacted specimen tested at 60°C at a loading rate of 50.8mm/min (Roberts *et al.*, 1996). This study compacted Marshall samples at 50 blows/side and the average value of three samples was taken into account to analyze the performance of every type of mixture. As illustrates Figure 15, comparing conventional and asphalt-rubber mixtures, the addition of ground rubber 0.2mm and 0.4mm to asphalt reduced the Marshall stability, especially when using rubber 0.2mm. However, mixtures using rubber 0.4mm presented just a slight decrease, showing the resistance to deformation was not affected significantly.

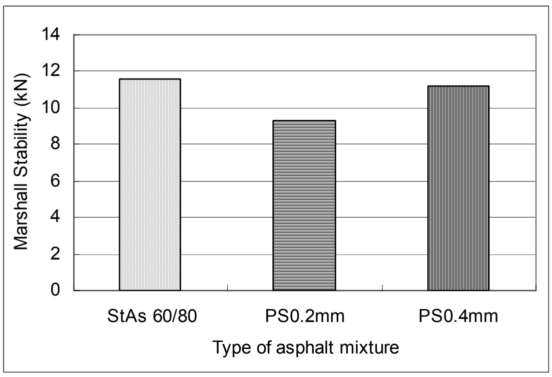

Figure 15: Marshall Stability

The flow value is the vertical deformation of the sample (measured from the start of loading to the point at which stability begins to decrease) in hundredths of an inch (Roberts *et al.*, 1996). According to Figure 16, the flow value became slightly bigger for asphalt-rubber mixtures and such increase presented the same order of magnitude despite the difference of rubber size mixed to asphalt. However, according to Japanese standards, despite such growth, the flow values are still between 20 and 40 (0.01cm), the acceptance limits used to evaluate the flow of asphalt mixtures.

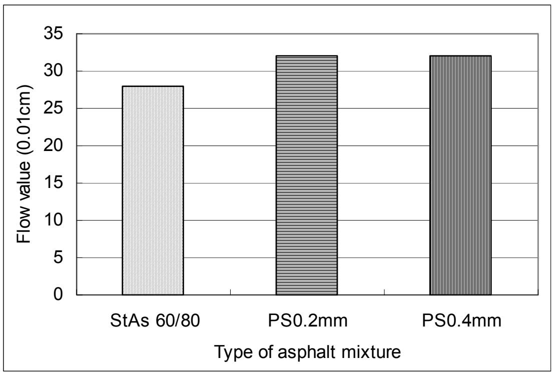

Figure 16: Flow value

The residual stability assesses the moisture susceptibility or the deterioration of an asphalt concrete mixture (Roberts *et al.*, 1996). The residual stability after 48 hours (Figure 17), proved the mixtures using rubber 0.2mm increased it by 17%, whereas, the use of rubber 0.4mm increased it by 10% compared with that seen for conventional mixtures. In this way, mixtures using smaller particles of rubber mixed to straight asphalt showed lower moisture susceptibility.

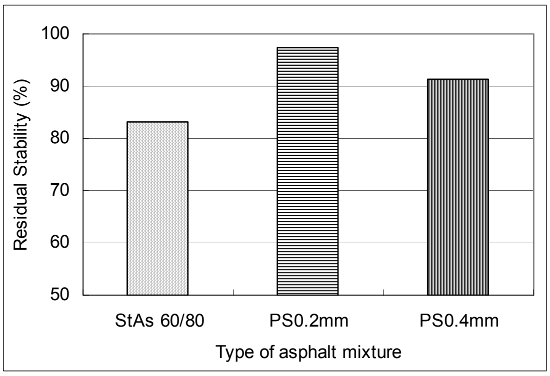

Figure 17: Residual stability

Wheel Tracking Test

The performance to permanent deformation was carried out using the wheel tracking test machine. This equipment consists of a solid and smooth tire rubber measuring 20cm diameter and 5cm wide, applying forwards and backwards, repeated loads of 686±10N at 42 passes/minute. For every type of asphalt mixture, two samples (30x30x5cm each) were compacted and tested at 60°C during 60 minutes. The vertical displacements were measured automatically at every five minutes. Using these data, the dynamic stability (DS) could be calculated according to Equation 3.

$$DS = \left(\frac{15}{d_{60} - d_{45}} \right) \times 42 \qquad (3)$$

Where:
DS = Dynamic Stability (passes/minute);
d_{45} = vertical displacement after 45 minutes loading (cm);
d_{60} = vertical displacement after 60 minutes loading (cm).

The analysis of Figure 18 shows the Dynamic Stability increased 12 times using rubber 0.2mm and 14 times mixing rubber 0.4mm compared with the value measured for conventional mixture. In this way, the resistance to permanent deformation enhanced significantly after rubber addition. Moreover, the performance of asphalt-rubber mixtures was similar regardless the difference of rubber size.

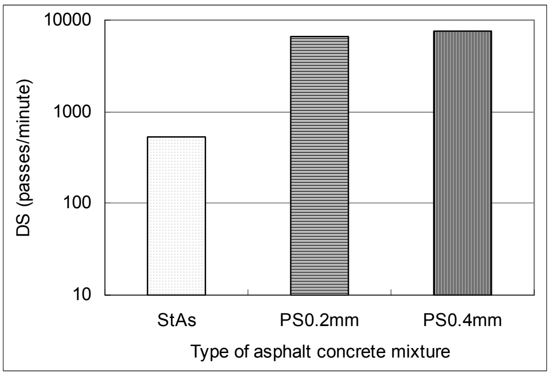

Figure 18: Dynamic Stability

The rate of deformation along the time of testing for every asphalt mixture is shown in Figure 19. From this picture, straight asphalt presents a linear increasing deformation along the time, reducing progressively the resistance to permanent deformation. On the other hand, asphalt-rubber mixtures showed very low tendency to increase the deformation along the time. Further, both types of rubber presented similar performance.

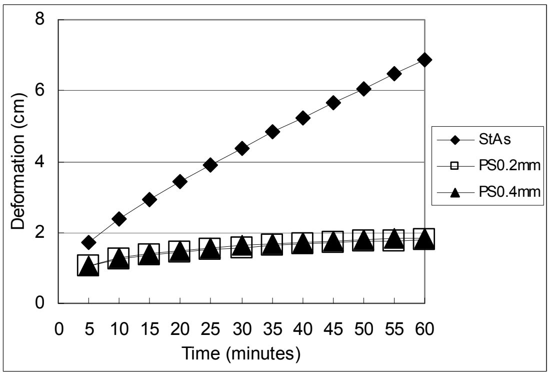

Figure 19: Rate of deformation

Static Bending

Static bending test evaluates the flexural strength and the strain at failure of asphalt mixtures. At first, asphalt mixtures were prepared and compacted on wheel tracking molds (30x30x5cm). After cooling, these asphalt blocks were cut into beams with 5cm width, 5cm height and 30cm length. The static bending test was performed for a span length of 200mm, for temperatures ranging from –10°C to 20°C. A loading rate of 50mm/min was used during testing. This experiment assessed three beams at every temperature for every type of asphalt mixture. The data here presented shows the average values calculated at every temperature.

From Figure 20, it's seen that asphalt-rubber mixtures, from –10°C to 5°C, presented higher values of flexural strength than that measured for conventional mixtures. Moreover, analyzing the breaking point, for asphalt-rubber mixtures, the region of brittleness was reduced by 5°C, compared with that seen for conventional mixtures. In this way, the resistance to cracking at low temperatures was improved. Further, despite the difference of rubber size, asphalt-rubber mixtures showed flexural values with the same order of magnitude.

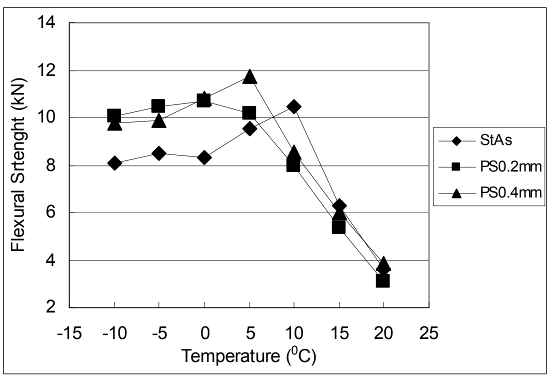

Figure 20: Flexural strength

Considering the strains at failure (Figure 21), it could be found that at low temperatures, asphalt-rubber mixtures presented higher values of strain at failure than that measured for conventional mixtures. In this way, the resistance to cracking was enhanced. In addition, despite the difference of rubber size, the strains at failure for asphalt-rubber mixtures were similar for both sizes of rubber used.

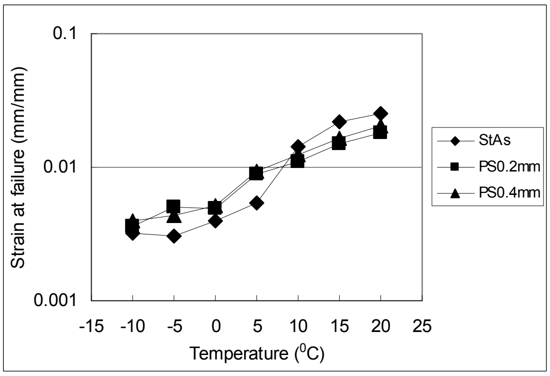

Figure 21: Strain at failure

CONCLUSIONS

This paper presented an evaluation carried out for asphalt-rubber binders and for asphalt-rubber concrete mixtures. The analysis of binder comprised mixing, respectively, ground rubber 0.2mm and 0.4mm to asphalt, at rates of 0%, 9%, 12%, 15% and 18%. Superpave and conventional tests examined the behavior of such binders. The evaluation of asphalt concrete mixtures used asphalt-rubber binder mixing 15% of ground rubber. The overall findings are:

The penetration at 25°C for unaged binders decreased after mixing ground rubber to asphalt and such decrease was directly proportional to the rubber content. After aging, both types of rubber presented similar behavior, showing penetration values with the same order of magnitude, despite the increase of rubber content.

At 4°C there was a tendency of increase the penetration values as the rate of rubber became bigger before and after aging, showing an improvement of flexibility at low temperatures.

The penetration indices (PI) after mixing ground rubber increased proportionally to the rate of rubber. This enhancement was more important when using rubber 0.4mm. Thus, the addition of rubber reduced temperature susceptibility in an expressive way.

The softening point temperatures, before and after aging, increased as the percentage of rubber became bigger, and such improvement was more remarkable for binders using rubber 0.4mm.

The flexural creep stiffness decreased significantly for both types of rubber when the rate of rubber enlarged. In addition, despite the difference of rubber size, the stiffness values before and after aging were similar for every rubber percentage.

The viscosities became significantly bigger as the rate of rubber increased, especially for binders using rubber 0.4mm.

Asphalt-rubber mixtures showed a reduction of Marshall Stability values, especially when using rubber 0.2mm. In addition, the flow value became bigger and such increase presented the same order of magnitude despite the difference of rubber size mixed to asphalt. The residual stability after 48 hours, presented an important increase for asphalt-rubber mixtures, especially for mixtures using rubber 0.2mm.

Comparing conventional and asphalt-rubber mixtures, the last ones presented significant improvement of Dynamic Stability, increasing 13 times, in average, the resistance to permanent deformation. Moreover, the performance was similar regardless the difference of rubber size. The rate of deformation along the time of testing for every asphalt mixture showed a linear increasing deformation for conventional mixtures along the time, whereas, asphalt-rubber mixtures presented very low tendency to become bigger for the same period of time. Further, for both types of rubber the rate of deformation presented similar performance.

At low temperatures, asphalt-rubber mixtures presented higher values of flexural strength than that measured for conventional mixtures. Moreover, for asphalt-rubber mixtures the region of brittleness was reduced by 5°C. Further, despite the difference of rubber size, asphalt-rubber mixtures showed flexural values with the same order of magnitude. In addition, for both types of rubber, asphalt-rubber mixtures presented higher values of strain at failure than that measured for conventional mixtures at low temperatures. In this way, mixing ground rubber to asphalt improved the resistance to cracking.

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