Effects of modifying Bitumen with Asbuton on the Mechanical Characteristics of Asphalt Mixtures

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Abstract

Given the high temperatures and heavy traffic loads, pavements in Indonesia are prone to fatigue damage and permanent deformation. Modifying the asphalt mixtures by means of polymers is an effective but costly option. This paper shows that modification of the bitumen by means of RETONA, made from asphaltic rock which is abundantly available on Buton island, is also an effective option to increase the resistance to fatigue and permanent deformation. The paper will show the results of DSR tests performed on the RETONA binder and the recovered binder of a reference base course mixture as well as the results of stiffness tests, tension and compression tests and fatigue tests. It is shown that replacing the bitumen with only 20% RETONA already greatly enhances the characteristics of the mixture.

Introduction

Because of its hot climate and heavy traffic, many roads in Indonesia suffer from extensive fatigue cracking and permanent deformation. It is obvious that modification of asphalt mixtures is needed in order to be able to cope with these harsh conditions. Modification of the asphalt mixture is possible by using polymer modifications but this is costly. Another possibility is to use RETONA which is a material produced from abundantly available natural asphalt rock resources on Buton island.

This paper describes the effects of modifying the asphalt mixture with RETONA. Although the emphasis is mainly placed on the stiffness and fatigue resistance of the modified material compared to a reference material, also conclusions with respect to the effects of the RETONA modification on the resistance to permanent deformation will be drawn.

Asphalt Buton and RETONA

Buton is an island located south east of Sulawesi (Celebes) which has abundantly natural rock asphalt usually named as Asbuton which stands for Asphalt Buton. Astuti [1] reported that about 300 million tons of deposits are spread over an area of about 70.000 ha. Meanwhile, a report from the website of the Research and Development Agency of the Ministry of Public

Work, Government of Indonesia, shows that the deposits are actually double the size of what is reported in [1]. Although the precise quantity is not exactly known, one can safely say that the potential of the available resources is huge.

On Buton this natural asphalt is found as a brownish black asphaltic porous rock which is lightweight and contains aggregates, bitumen, and water. The refinement process used to retrieve the bitumen is branded as Refined Buton Asphalt (RETONA).

The process starts with blasting the rock with dynamite which results in lumps or chunks of materials of approximately 20 mm in size. Then this material is crushed using a hammer mill which reduces the particle size to approximately 2.5 mm. This material is then delivered to a chemical plant for bitumen extraction. In this plant an acid-alkaline chemical reaction is taken place in which Asbuton is diluted with an inorganic solvent, leaving the RETONA (bitumen and natural filler) with different characteristics for different market applications. The amount of bitumen in the RETONA depends on the amount of inorganic solvent used in the process. In principle use of more inorganic solvent results in higher bitumen content but also results in higher production costs. The RETONA used in this study consists of 35% bitumen and 65% filler.

Asphalt mixtures tested

A base course mixture called gravel asphalt concrete (GAC) was used for evaluating the effects of modifying it with RETONA. Details of the mixture and why this particular was chosen are given in [2].

The reference mixture had a 40/60 pen bitumen and a limestone filler called Wigro. In the RETONA modified mixture, the gradation was kept the same but 20% of the bitumen was replaced by RETONA. The reason of choosing 20% of RETONA is because this is suggested by the producer (PT Olah Bumi Persada). In their instruction they advised the user to mix 20% (by weight) of Retona's bitumen with 80% of bitumen pen 60/70.

Since RETONA still contains aggregates of filler size, the original gradation had to be modified slightly. Table 1 shows the gradation of the reference GAC and that of the GAC modified with RETONA.

Monotonic uniaxial compression test

Specimens of both the reference GAC and the Retona modified GAC, having a diameter of 65 mm and a height of 130 mm, were tested in the monotonic compression test. The tests were performed at different temperatures and strain rates (displacement rate). These specimens were drilled from the blocks produced in the shear box compactor. The scheme of how the specimens were drilled from the blocks is explained in [3]. The results obtained from the Retona modified mixtures are shown in table 2.

Table 1. Composition of the reference and RETONA modified mixture

Sieve size (mm)	% retained by weight reference GAC mixture	% retained by weight RETONA modified GAC mixture
31.5	0	
22.4	5.22	
16	18.85	
11.1	31.28	
8	39.95	
5.6	48.52	
4	52.88	
2	54.79	
0.5	61.51	
0.18	82.89	82.89
0.09	83.49	83.35
0.063	90.63	90.44
Passing 0.063	5.53	4.29
Bitumen 40/60	3.85	3.08
Bitumen Retona		0.77
Fines coming from RETONA		1.43
Total	100.00	100.00

Table 2. Results of the monotonic uniaxial compression test for GAC 40/60+Retona

	Actual Strain Rate	E mod	Poisson's ratio	f_c
	%/s	MPa		MPa
5°C	0.010	5608.9	0.23	-12.34
	0.10	6496.9	0.18	-21.11
	0.33	6554.0	0.18	-26.09
	1.07	8019.1	0.20	-31.21
20°C	0.05	921.1	0.33	-5.66
	0.10	1231.2	0.43	-7.29
	1.03	5084.6	0.32	-14.28
	2.74	8703.6	0.48	-16.75
30°C	0.10	138.00	0.46	-1.32
	1.02	436.00	0.44	-3.13
	2.13	581.90	0.24	-4.19
	3.15	908.80	0.52	-4.99
	11.49	1593.90	0.40	-7.41

Figure 1 shows the relation between the compressive strength prediction and strain rate and temperature for both the reference and Retona modified mixture. It should be noted that this figure is based on the models developed for predicting the compressive strength. This model developed for the Retona modified mixture which is given by means of equation 1. A similar model was developed for the reference mixture.

$$f_c = -47.45\left[1 - \frac{1}{1 + \left[\dot{\varepsilon}\, e^{\left(-76.74 + \frac{21799.34}{T}\right)}\right]^{0.3662}}\right] \qquad (1)$$

Where: f_c = compressive strength (MPa)
T = temperature (^oC)
$\dot{\varepsilon}$ = strain rate (%/s)

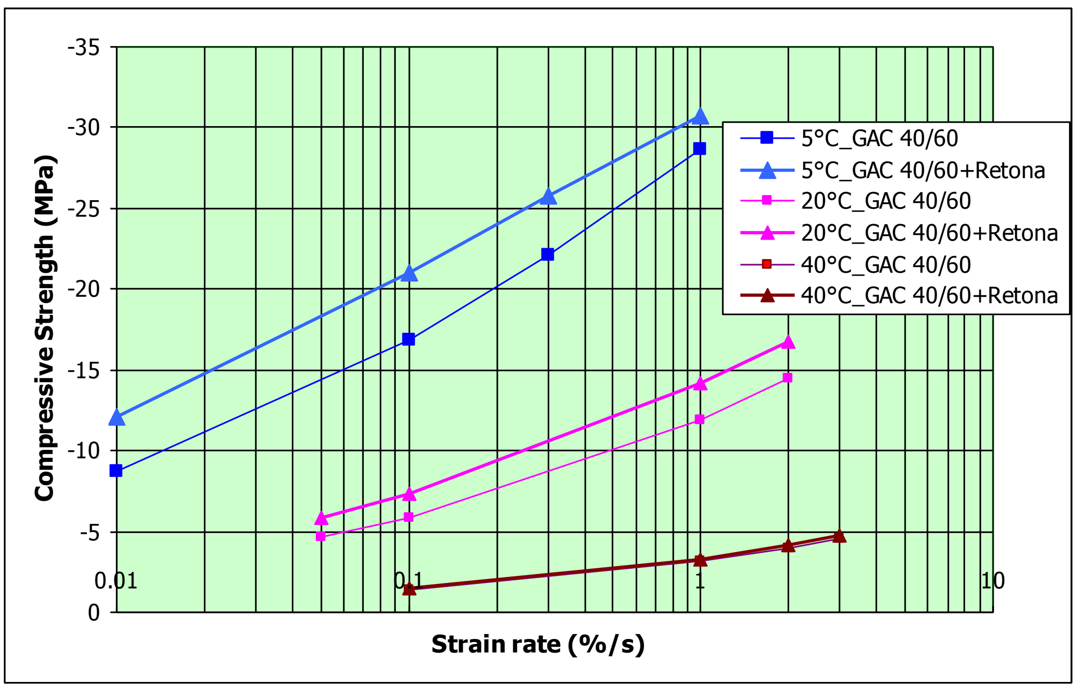

Figure 1. Compressive strength of GAC 40/60 and GAC 40/60+Retona

It can be seen that the addition of Retona increases the compressive strength of the mixture especially at low temperatures and low strain rates. At high temperatures Retona doesn't give a significant improvement on the strength of the mixture. However, in general the addition of 20% Retona to the mixture can improve the compressive strength on average with a factor of 1.2.

Monotonic Uniaxial Tension test

Also monotonic tension tests were performed on both mixtures at different temperatures and strain rates. The test set up is shown in figure 2.

Figure 2. Uniaxial tension test on GAC 40/60+Retona

The results were used to develop models that predict the tensile strength as a function of temperature and strain rate. These models were used to develop figure 3.

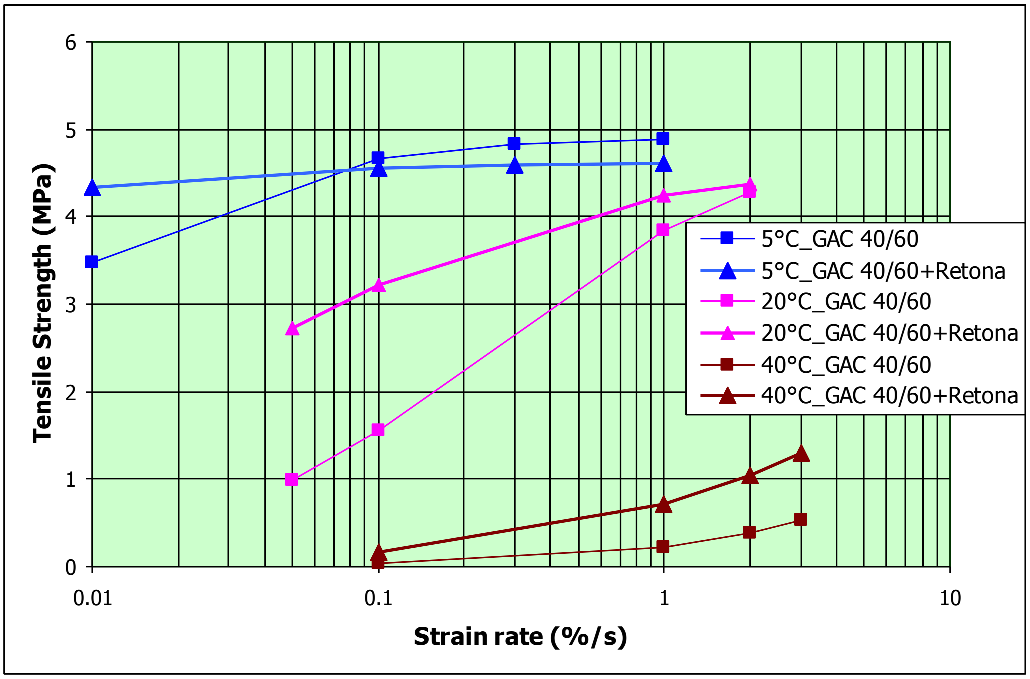

Figure 3. Tensile strength of GAC 40/60 and GAC 40/60+Retona

The figure shows that at the lower temperatures and high strain rates the tensile strength is not so much affected by the addition of Retona. Nevertheless it can be stated that in general the addition of 20% Retona to the GAC mixture did improve its tensile strength with a factor of 2.1.

Yield surface

Based on the results of the tension and compression tests, yield surfaces can be developed which indicate at which stress level the asphalt mixture will fail. Since the tensile and compressive strength of asphalt mixtures are dependent on loading time and temperature, also the yield surfaces are dependent on loading time and temperature. Figure 4 shows the yield surfaces for the GAC 40/60 mixture and the GAC 40/60+RETONA mixture. The parameters I_1 and $\sqrt{J_2}$ are defined as follows.

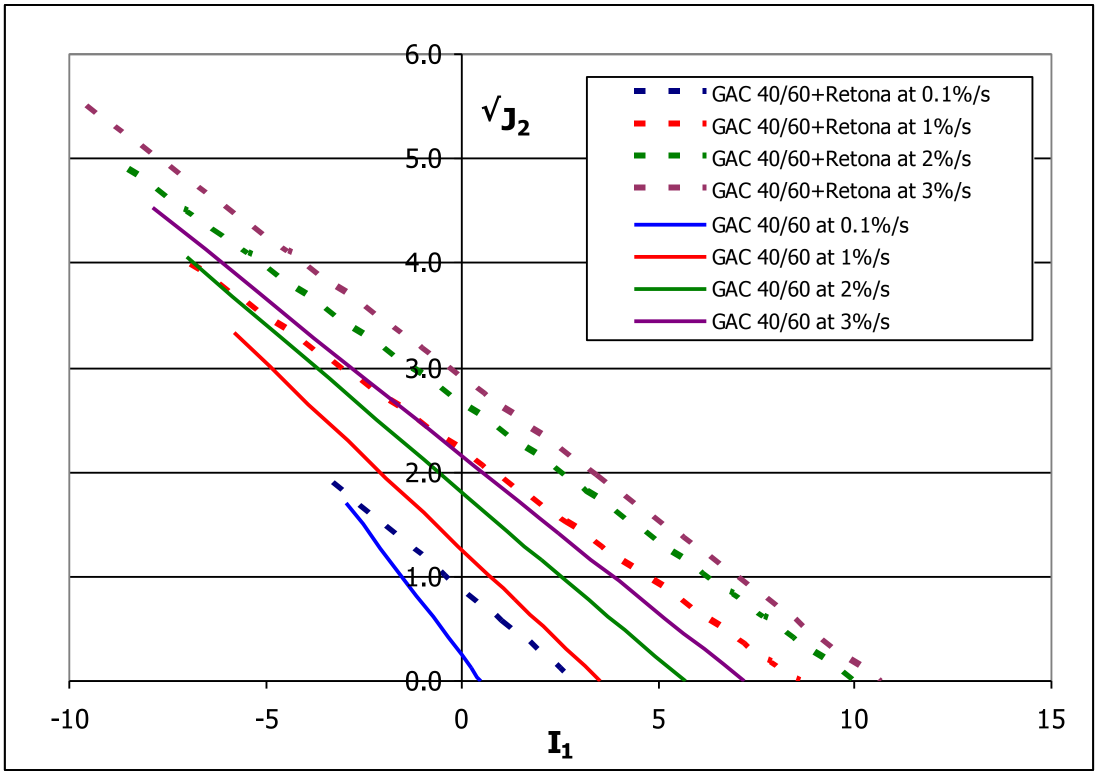

Figure 4. Yield surfaces of GAC 40/60 and GAC 40/60+Retona, at 30 °C and different strain rates

$I_1 = \sigma_1 + \sigma_2 + \sigma_3$ (2)

$J_2 = [(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2]/6$ (3)

Where: σ_i = principal stress

The tension and compression tests are uni-axial tests and therefore σ_2 and σ_3 are equal to zero. σ_1 is equal to the tensile resp. compressive strength. Figure 4 clearly shows that the yield surfaces of the RETONA modified mixture are well above the yield surfaces of the reference mixture indicating that the RETONA modified mixture has a higher resistance to 3D stress conditions and a higher resistance to permanent deformation. This will be described in more detail later on.

Binder stiffness

In order to determine the bitumen content and to further characterize RETONA, an extraction of the natural rock asphalt has been carried out. The bitumen recovery process, based on NEN-EN 12697-3[4], was performed using a Centaur 2 MSE® centrifuge, a vacuum pump, microfiber filter paper (with 1.6 μm particle retention in liquid), and dichloromethane as a solvent. The results indicate that the bitumen content of the granular Retona is on average 35% by weight. Figure 5 shows the results obtained at different stages of the extraction process.

(a) **(b)**

Figure 5. (a) From left to right are the dichloromethane after 1st, 4th and 7th centrifuge rotation. (b) From left to right are the granular RETONA in original form, the filler, and the bitumen extracted.

Dynamic shear rheometer (DSR) measurements were done on the bitumen recovered from the RETONA and the 40/60 bitumen that was recovered from the reference mixture. The results are shown in figure 6.

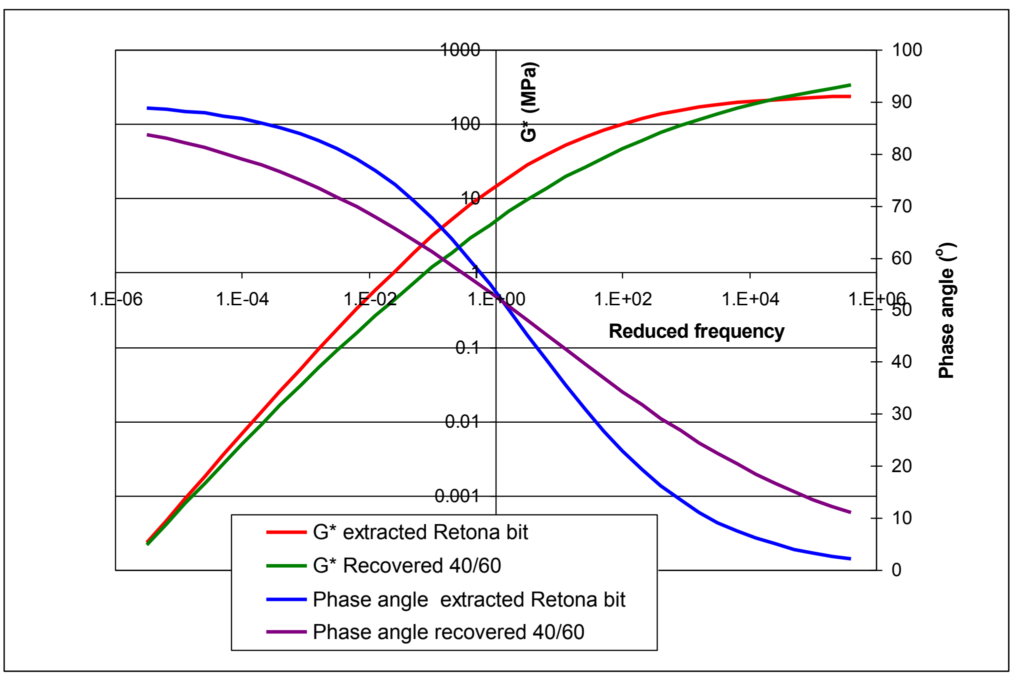

Figure 6. Master curve of extracted Retona bitumen and recovered 40/60 bitumen

The figure shows that in the frequency range which is relevant for pavements ($10^{-2} < f < 10^{2}$), the RETONA bitumen is stiffer and has a lower phase angle than the recovered 40/60 bitumen. This indicates that the RETONA modification is helpful in reducing permanent deformation.

Mixture stiffness

The mixture stiffness was determined by means of the 4 point beam bending test at temperatures ranging from 5°C to 40°C and frequencies ranging from 0.5 Hz to 8 Hz. The tests were carried out in strain control using a peak to peak strain level of 100 μstrain.

The test results at various temperatures were shifted to the selected reference temperature of 15°C. A master curve for the mixture stiffness was developed based on this shifted data. The results are shown in figure 7.

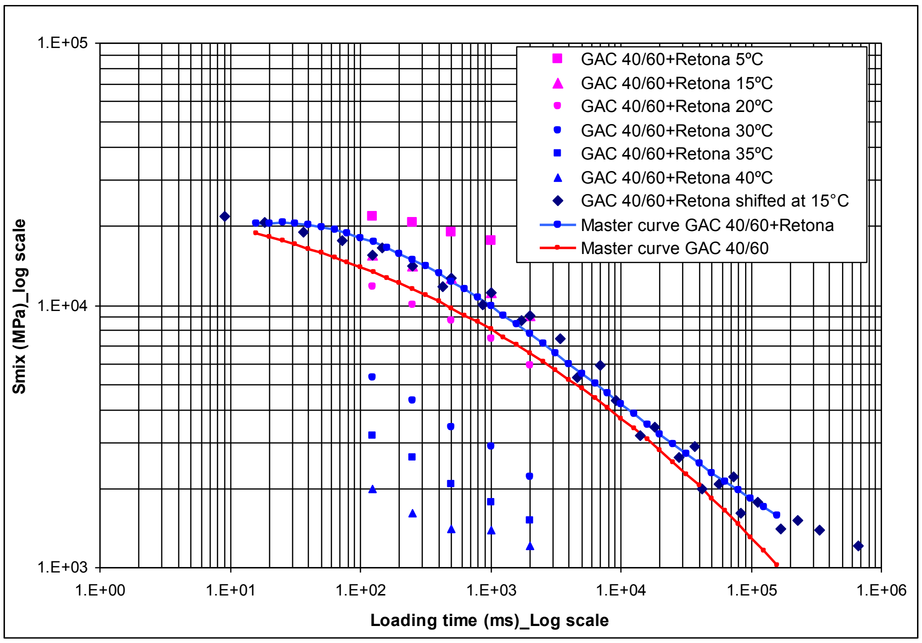

Figure 7. Master curve of gravel asphalt concrete with and without RETONA at a reference temperature of 15°C

As can be seen in figure 6 the addition of Retona in the mixture only slightly increases the stiffness of the GAC. This is due to the fact that only 20% of the reference bitumen is replaced by RETONA bitumen.

Four point bending fatigue tests

The objective of this test was to obtain a fatigue relation for the GAC 40/60+Retona and the GAC 40/60 mixtures. The tests were carried out at a temperature of 30°C and a frequency of 8 Hz . Nine beams of 50 x 50 x 400 mm of each mixture have been tested.

Figure 8 shows the fatigue line of GAC 40/60 mixture and GAC 40/60+Retona mixture. From the figure it can be seen that the slope of the two lines are almost the same but the GAC 40/60 modified with 20% Retona shows a bit higher intercept than the GAC 40/60's line. On average the fatigue life of the RETONA modified mixture is 1.3 higher than the fatigue life of the unmodified mixture.

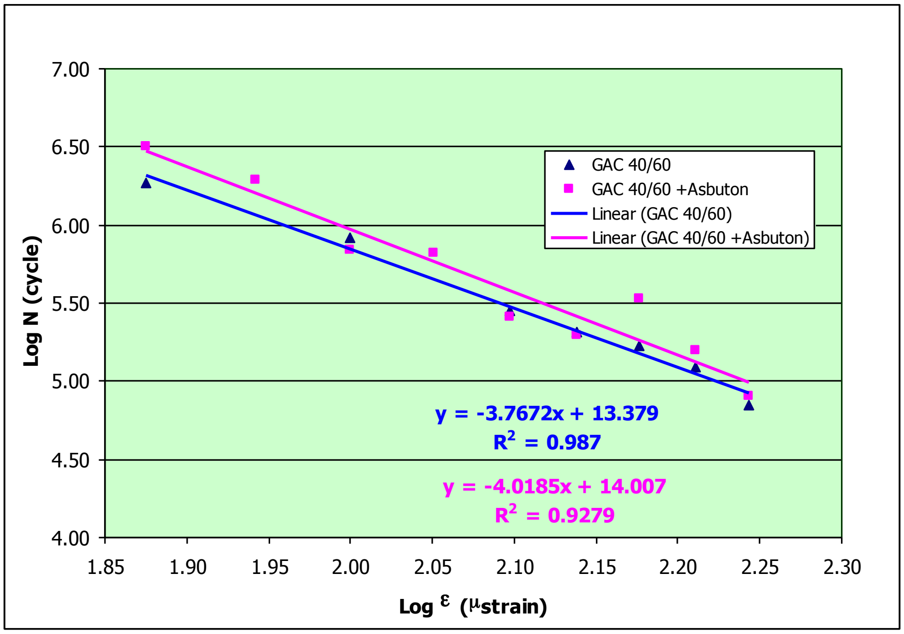

Figure 8. Fatigue line of GAC 40/60 and GAC 40/60+Retona

Since at 30°C the GAC mixture modified with RETONA has a higher fatigue life than the unmodified mixture, it is beneficial to implement RETONA modified mixtures in hot tropical countries like Indonesia.

Resistance to permanent deformation

Although no specific tests were done to determine the resistance to permanent deformation, some conclusions with respect to it can be drawn given the fact that information about the mixture stiffness of the reference mixture and the RETONA mixture are available as well as the yield surfaces.
Given the fact that the stiffness of both mixtures is approximately the same, the same stresses will occur in an asphalt pavement made with reference and RETONA modified asphalt provided that the loads are the same and the pavement structures are similar. This means that at similar locations, the I_1 and $\sqrt{J_2}$ value will be the same. The distance of this stress point relative to the yield line is however much larger for the pavement with RETONA modified mixture than for the pavement with the reference mixture. This implies that failure and permanent deformation is less likely to occur in the RETONA modified mixture than in the reference mixture. The principles behind this reasoning are also schematically outlined in figure 9.

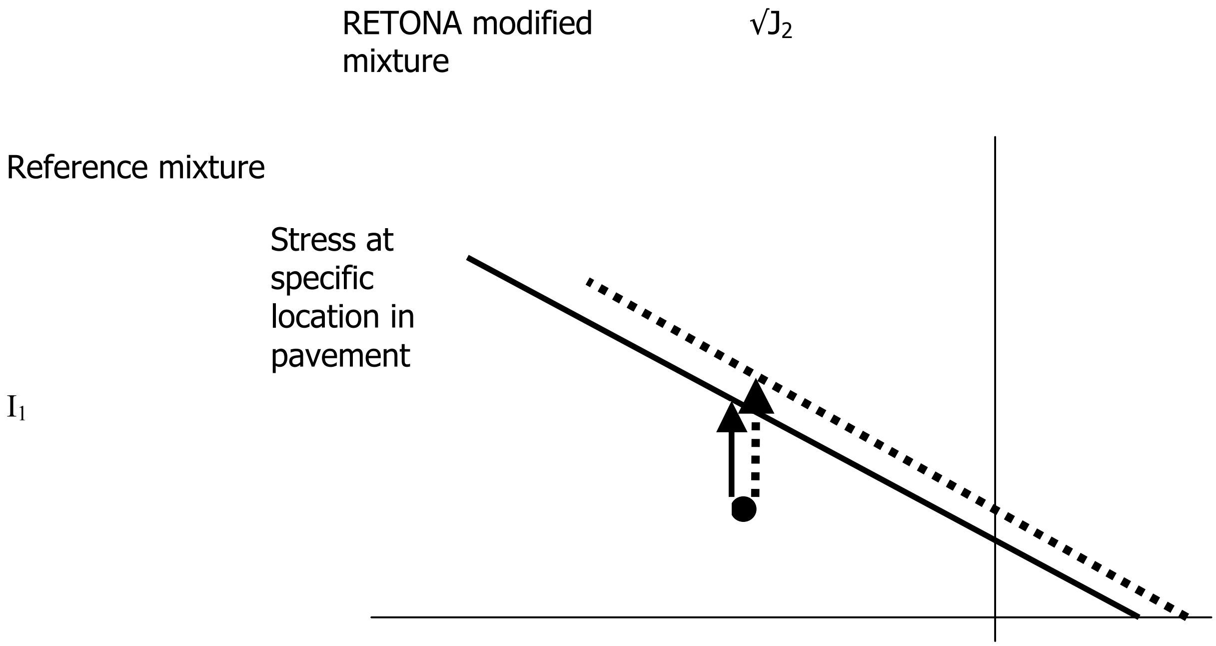

Figure 9. Principle of using yield surface in determining resistance to failure and permanent deformation.

Conclusions

The results of this study have shown that modifying the bituminous binder with RETONA (the RETONA used contained 35% bitumen and 65% filler) enhances the characteristics of the asphalt mixture. Both the resistance to fatigue and permanent deformation will increase by using this modifier.

In this research only 20% of the bitumen was replaced with RETONA. It is expected that even better results will be obtained when higher amounts of RETONA are being used.

References

[1] T. Astuti, "Study of Resistance to Fatigue Cracking of Asphalt Mixes with Refined Buton Natural Asphalt (Retona)," Master Thesis, International Institute for Infrastructutal Hidraulic & Environmental Engineering, IHE, Delft, The Netherlands, 2002.

[2] F. P. Pramesti, A. A. A. Molenaar, and M. F. C. v. d. Ven, "Fatigue Cracking of Gravel Asphalt Concrete: Cummulative Damage Determination," in *7th RILEM International Conference on Cracking in Pavements*, Delft The Netherlands, 2012, pp. 739 - 749.

[3] F. P. Pramesti, A. A. A. Molenaar, M. F. C. v. d. Ven, J.Qiu, and M.F.Woldekidan, "Comparison of Two Beam Fatigue Test," in *The 4th International Conference on Asphalt Materials*, Guangzhou, China, 2013.

[4] NEN-EN, "Bituminous Mixtures-Test methods for hot mix asphalt," in *Part 3; Bitumen recovery: Rotary evaporator*, ed: Comite European de Normalisation, 2005.