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Stiffness and Creep Properties of HRS-BC Powered by Palm Shell Gasification in Dryer Unit

Intan Devi Nataliasari[1,*], Sunu Herwi Pranolo[2], Florentina Pungky Pramesti[1] & Ary Setyawan[1]

[1]Departement of Civil Engineering, Faculty of Engineering, Sebelas Maret University, Jalan Ir. Sutami 36, Surakarta 57126, Indonesia
[2]Department of Chemical Engineering, Faculty of Engineering, Sebelas Maret University, Jalan Ir. Sutami 36, Surakarta 57126, Indonesia
*E-mail: intandevinataliasari@gmail.com

Highlights:

- Stiffness and creep properties of an HRS-BC powered palm shell gasification dryer unit were investigated for resistance to damage.
- HRS-BC produced by a palm shell AMP was compared with HRS-BC produced by a diesel AMP.
- Both the HRS-BC produced by the palm shell AMP and the HRS-BC produced by the diesel AMP were not deformed given a standard load (100 kPa).

Abstract. Roads are infrastructure that is very important in supporting people's daily lives. With the high growth rate of traffic, the traffic load will cause damage to the road pavement in the form of deformation (rutting) and fatigue. The performance of an HRS-BC asphalt mixture was investigated to determine the asphalt's resistance to damage. HRS-BC asphalt mixture specimens were produced by a palm shell AMP and by a diesel AMP. The performance of the HRS-BC asphalt mixture was tested in the laboratory with indirect tensile stiffness modulus (ITSM) and dynamic creep test. The results showed that the HRS-BC asphalt mixture sample produced by the palm shell AMP had better stiffness than the HRS-BC asphalt mixture produced by the diesel AMP. Both the samples of the HRS-BC asphalt mixture produced by the palm shell AMP and by the diesel AMP were not deformed when given a standard load of 100 kPa and 3,600 load repetitions.

Keywords: *asphalt mixing plant; deformation; HRS-BC; palm shell; stiffness.*

1 Introduction

Infrastructure development is an important aspect of economic development in Indonesia. For example, the development of road infrastructure is an important factor for advancing the economy, because the roads are part of inter-regional linkages along with ports, airports, railways, and waterways [1,2]. With the increasing amount of road construction in Indonesia, the demand for hot rolled

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sheet base course (HRS-BC) as supporting material for road construction is increasing [3]. HRS-BC is a hot mix asphalt (HMA) and is widely used as supporting material for road construction in Indonesia [4].

As the demand for HRS-BC increases, so do asphalt mixing plants (AMPs) to produce HRS-BC. This means that more energy is needed to heat the aggregate in the AMPs. Unfortunately, the Indonesian government regulation in the Ministry of Public Policy No.10/SE/M/2011 only covers diesel, natural gas, and coal gasification as fuels for AMPs [5]. There are about 300 to 350 asphalt mixing plants in Indonesia that operate using diesel as fuel to heat the aggregate [3]. The use of diesel as a direct combustion fuel in the engine produces emissions that have a negative impact on the environment [6]. One of the efforts that can be done to reduce emissions is to develop innovations by replacing fossil fuels with abundantly available renewable energy sources such as palm shells. Palm shells can be a viable alternative energy source because Indonesia has a large number of palm oil plantations, which produce around 2.6 million tons of palm shell waste yearly [7,8]. Replacement of fuel sources with renewable energy sources is important to reduce the use of fossil fuels. Besides that it can reduce pollution, it is more effective, more efficient, and also cheaper.

The criteria for HRS-BC to be used as a supporting material for road construction is that it has to be able to withstand fatigue and rutting. Fatigue is the phenomenon of the emergence of cracks due to repeated stresses or strains whose limits are still below the material strength limit [9]. Cracks start either under or above the asphalt layer, then propagate throughout the asphalt pavement [10]. Rutting is one of the main stresses produced on the pavement, and is caused by the horizontal and lateral displacement of the asphalt mixture [11]. The occurrence of rutting can be attributed to the mixing of asphalt, subgrade, or other structural layers, or a contribution of all of them [12]. The repeated traffic load gradually increases the permanent strain on the flexible pavement, which eventually causes rutting [13].

To find out whether HRS-BC produced by a palm shell AMP is able to withstand fatigue and rutting, several tests were carried out to determine the stiffness and deformation properties of the HRS-BC. The stiffness modulus is a measure of the stiffness of a material. The greater the stiffness modulus, the smaller the elastic strain that occurs, i.e., the material becomes stiffer [14]. To determine how well a pavement performs and the pavement response to traffic loads, the stiffness of the asphalt mixture is used [15]. A dynamic creep test can be performed for the assessment of the deformation properties and evaluation of the fatigue life is based on increasing deformation binders and mixtures or decreasing resistance [16].

A previous study reported that palm shell gasification as a substitute for diesel fuel can significantly reduce CO_2 emissions, because palm shell gasification is considered a carbon-neutral resource [3]. The use of palm shells as raw material for updraft gasifiers to produce gas in an AMP gave promising results from the point of view of cold gas efficiency (CGE) and carbon conversion efficiency (CCE), because it could produce 70% CGE lower than rubber wood (75%) and 55% of CCE [17]. Gasification of palm shells produces 18.6% less residu than the use of diesel [18]. As for the stiffness and permanent deformation, Briliak, *et al.* [19] evaluated the effect of asphalt mixture aging on the stiffness modulus. The results showed that aged mixtures had an increased stiffness modulus. As we know, aging causes the asphalt mixture to become stiffer and more brittle, which causes a greater potential for cracking of the pavement [20]. Xu, *et al.* [21] evaluated the permanent deformation of asphalt mixtures. The results showed that the greater the load, the faster permanent deformation of the asphalt mixtures occurs and the smaller the fatigue life. The asphalt mixtures with greater shear strength had greater resistance to shear deformation.

Figure 1 Palm shells.

The present study evaluated the performance of HRS-BC produced by a palm shell AMP and compared it with HRS-BC produced by a diesel AMP. Samples of the HRS-BC were prepared in a road pavement laboratory. The influence of stiffness and deformation resistance on the performances of the HRS-BC produced by a palm shell AMP and of the HRS-BC produced by the diesel AMP were tested and evaluated. This evaluation showed whether palm shells can be used as a substitute for diesel as fuel for heating the aggregate of an AMP.

2 Materials and Methodology

2.1 Materials

For this research, bitumen of penetration grade 60/70 was used for sample preparation, as suggested by the Directorate General of Bina Marga, Indonesia [5]. The bitumen's conventional properties were determined based on preliminary standard tests conducted in the laboratory, as presented in Table 1.

Table 1 HRS-BC mixture conventional properties.

Properties	Unit	Specification	Standard Limits	Results
Specific Gravity	gr/cc	SNI 2441:2011	>1.00	1.032
Penetration	mm	SN 2456:2011	55-68	63.2
Softening Point	°C	SNI 2434:2011	50-58	51
Flash Point	°C	SNI 2433:2011	>232	341
Ductility at 25 °C	cm	SNI 2432:2011	>100	150

After doing preliminary standard tests on the bitumen, samples were produced with the HRS-BC mixture. The HRS-BC mixture was prepared by mixing the aggregate with asphalt at a constant temperature (160 °C). Then the HRS-BC mixture was compacted in five intervals (fifteen collisions at each interval). After that, the sample was cooled at room temperature for two to three hours. The sample was removed from the mold and let to set for 24 hours. Each test sample was given the code 'PS' for HRS-BC produced by the palm shell AMP and 'DS' for HRS-BC produced by the diesel AMP.

Figure 2 Test samples.

2.2 Methodology

2.2.1 Indirect Tensile Stiffness Modulus (ITSM)

The stiffness of the asphalt mixture has always been viewed as a synthetic indicator of structural properties and is related to the capacity of the mixture to transmit traffic loads [22]. Stiffness is defined as the ability of the load to respond to repeated traffic loads without significant cracks and being able to return to normal. The ITSM test is widely used to determine the strength and stiffness in terms of the elastic modulus. Asphalt will behave elastically at certain traffic speeds and pavement temperatures. To measure the resistance of asphalt mixtures to bending and their ability to spread the load, the ITSM test can be used [23]. In this study, the test was carried out following the Standard EN 12697:26-2018 [24].

To investigate the temperature sensitivity of the asphalt, the test was conducted at 20 °C and 40 °C, respectively. Three specimens of the HRS-BC mixture produced by the palm shell AMP and three specimens of the HRS-BC mixture produced the diesel AMP were used for the test. The physical properties of the specimens are presented in Table 2.

Table 2 Physical properties of HRS-BC for ITSM testing.

Test Type	Sample Name	Thickness (mm)	Diameter (mm)
Indirect tensile stiffness modulus (ITSM)	PS-1	53.5	100.0
	PS-2	57.0	100.0
	PS-3	57.0	100.0
	DS-1	67.5	100.0
	DS-2	51.5	100.0
	DS-3	53.0	100.0

The stiffness modulus can be calculated using the following Eq. (1):

$$E = \frac{F\ (v+0{,}27)}{z\ x\ h} \quad (1)$$

where:

E = measured stiffness modulus, MPa
F = the peak value of the applied vertical load, N
z = deformation in the horizontal direction, mm
υ = Poisson's ratio (= 0.35)
h = the thickness of the specimen, mm

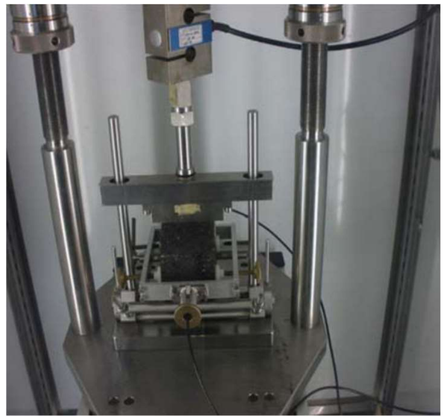

Figure 3 Indirect tensile stiffness modulus (ITSM) test set-up.

2.2.2 Dynamic Creep Test

Various test methods have been developed to investigate resistance to deformation (rutting). One of the best methods to evaluate the resistance of asphalt mixtures to permanent deformation is the dynamic creep test method [25]. The creep curve is one of the main results of the dynamic creep test, showing permanent deformation versus loading cycle [26]. The deformation resistance of the mixture is related to the stiffness of the mixture and is significantly affected by loading time and temperature. The test temperature used was 20 °C. In addition to these factors, several other variables play a role, including asphalt penetration, aggregate gradation, aggregate texture shape, aggregate locking, and compaction level. In this study, the test was carried out following Standard EN 12697:25-2016 [27].

The specimen was given a load of 100 kPa and the number of repetitions of the load was 3,600 times. This refers to Standard EN 12697:25-2016, which says that the standard load for creep testing is 100 kPa and totally 3,600 cycles must be applied (total time for the test is about 2 h) [27]. A specimen of the HRS-BC mixture produced by the palm shell AMP and a specimen of HRS-BC mixture produced by the diesel AMP were used in the test. The physical properties of the samples are presented in Table 3.

Table 3 Physical properties of HRS-BC for dynamic creep testing.

Test Type	Sample Name	Thickness (mm)	Diameter (mm)
Dynamic creep test	PS-4	54.5	100.0
	DS-4	53.0	100.0

The dynamic creep modulus can be calculated using the following Eq. (2):

$$E = \frac{\sigma}{\varepsilon n}\, x\, 1000 \tag{2}$$

where:

E_n = creep modulus after *n* load applications, MPa
σ = applied stress, kPa
ε_n = cumulative axial strain of the specimen after *n* load applications (%)

Figure 4 Dynamic creep test set-up.

3 Results and Discussion

3.1 Indirect Tensile Stiffness Modulus (ITSM)

In this study, the indirect tensile stiffness modulus test was carried out following BS EN 12697:26-2018 [27]. The stiffness moduli of the HRS-BC mixture produced by the palm shell AMP and HRS-BC mixture produced by the diesel AMP at temperatures of 20 °C and 40 °C are presented in Table 4.

Table 4 Indirect tensile stiffness modulus (ITSM) test results.

Sample	***Stiffness Modulus (MPa)***	
	20 °C	**40 °C**
PS-1	4436	3272
PS-2	4536	3025
PS-3	4964	4042
Average	4645	3446
DS-1	3923	1588
DS-2	2505	1052
DS-3	2140	814
Average	2856	1151

As can be seen in Table 4, the stiffness modulus of the HRS-BC mixture produced by the palm shell AMP was higher than that of HRS-BC mixture produced by the diesel AMP at both temperatures. The value of the stiffness modulus decreased as the temperature increased. This is according to the nature of asphalt, which becomes stiffer at lower temperatures. When the HRS-BC mixture has low stiffness at high temperature, plastic deformation is more likely to occur, whereas when the HRS-BC mixture has high stiffness at low temperature, premature fatigue crack failure can occur [28].

A graph of the relationship between temperatures and stiffness modulus can be seen in Figure 5.

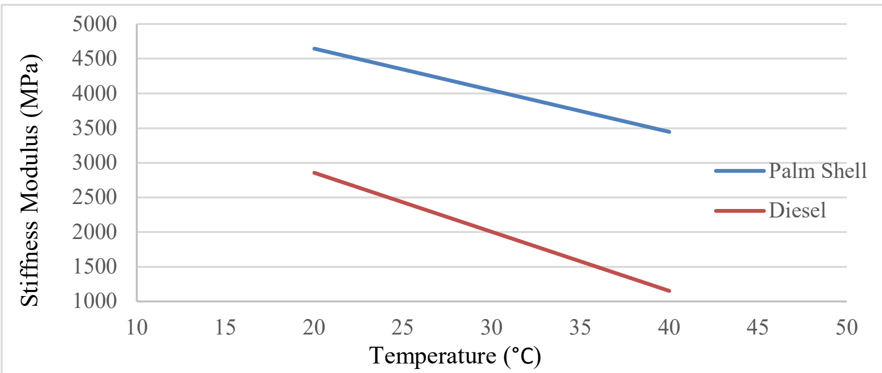

Figure 5 Stiffness modulus test results.

Figure 5 shows that the stiffness modulus of the HRS-BC mixture blends decreased significantly with increasing temperature. This trend in line with the results obtained by Moreno, *et al.* [28] and Guo, *et al.* [22]. In this case, plastic deformation is possible due to the bearing and stress dissipation capacities of the HRS-BC mixture produced by the palm shell AMP and the HRS-BC mixture produced by the diesel AMP at a limited high temperature. On the other hand, the HRS-BC mixture had a high stiffness, which could lead to premature fatigue cracking when service temperatures are very low [28]. The results obtained in the tests carried out at different temperatures show that the HRS-BC mixture produced by the palm shell AMP was more resistant to tensile and temperature changes when compared to the HRS-BC mixture produced by the diesel AMP.

3.2 Dynamic Creep Test

The dynamic creep test results are presented in Tables 5 and 6.

Table 5 Results of dynamic creep test of HRS-BC mixture produced by palm shell AMP (PS-4).

Cycle	Seating stress (kPa)	Cyclic stress (kPa)	Stress (kPa)	Total permanent strain (με)	Stiffness (MPa)
a	b	c	d = (b+c)	e	f = (d/e)*10^3
1	4.5	59.1	63.6	0	0
5	4.5	100.6	105.1	1,825.688	57.567
9	4.6	100.1	104.7	2,834.862	36.933
45	4.6	99.9	104.5	7,146.789	14.622
85	4.6	100.1	104.7	9,761.468	10.726
125	4.6	100.1	104.7	11,706.422	8.944
385	4.7	100.1	104.8	19,477.064	5.381
745	4.5	100.3	104.8	26,137.615	4.009
1585	4.6	99.9	104.5	38,183.486	2.737
2725	4.6	99.8	104.4	58,211.009	1.793
3325	4.7	100.1	104.8	74,091.743	1.414
3600	4.6	100.2	104.8	74,330.275	1.409

Table 6 Results of dynamic creep test of HRS-BC mixture produced by diesel AMP (DS-4).

Cycle	Seating stress (kPa)	Cyclic stress (kPa)	Stress (kPa)	Total permanent strain (με)	Stiffness (Mpa)
a	b	c	d = (b+c)	e	f = (d/e)*10^3
1	4.7	58.4	63.1	0	0
5	4.6	100.1	104.7	1,264.151	82.822
9	4.6	100.1	104.7	1,877.358	55.769
45	4.6	100.2	104.8	4,226.415	24.796
85	4.6	99.9	104.5	5,481.132	19.065
125	4.6	100.2	104.8	6,330.189	16.555
385	4.6	100.2	104.8	9,452.83	11.087
745	4.6	99.9	104.5	12,141.509	8.607
1585	4.6	100.1	104.7	16,981.132	6.166
2725	4.6	99.9	104.5	23,226.415	4.499
3325	4.5	100.2	104.7	27,726.415	3.776
3600	4.6	100.3	104.9	30,254.717	3.467

The sample was tested with standard provisions of BS EN 12697-25:2016 [27] and it was found that the total permanent strain was 74,330.275 με and the stiffness value was 1.409 MPa, as can be seen in Table 5. From these results, it can be seen that given a standard load of 100 kPa and 3,600 load repetitions, the sample of the HRS-BC mixture produced by the palm shell AMP showed no deformation. The sample was tested with standard provisions from BS EN 12697-25:2016 [27] and it was found that the total permanent strain was 30,254.717 με and the stiffness value was 3.467 Mpa, as can be seen in Table 6. From these results, it can be seen that given a standard load of 100 kPa and 3,600 load repetitions, the sample of the HRS-BC mixture produced by the diesel AMP showed no deformation.

A graph of the relationship between strain and number of load repetitions and the graph of the relationship between stiffness and number of load repetitions can be seen in Figures 6 and 7.

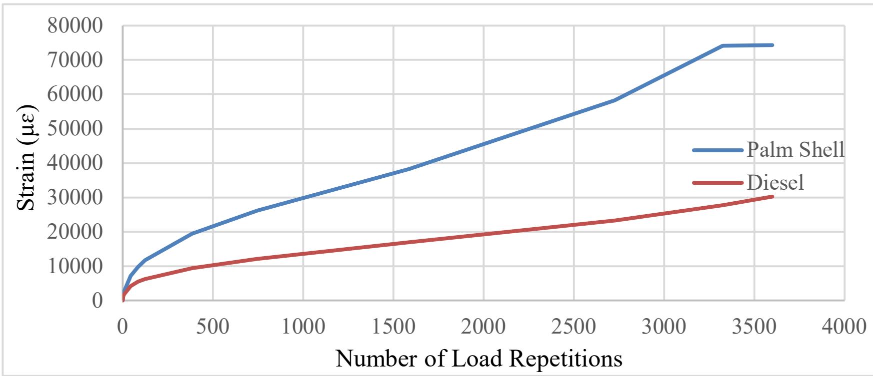

Figure 6 Graph of the relationship between strain and number of load repetitions.

Figure 6 shows the dynamic creep strain on the HRS-BC mixture produced by the palm shell AMP and the HRS-BC mixture produced by the diesel AMP at 100 kPa loading, up to 3,600 load repetitions. The HRS-BC mixture produced using diesel AMP displayed a smaller strain, which means it had better deformation resistance.

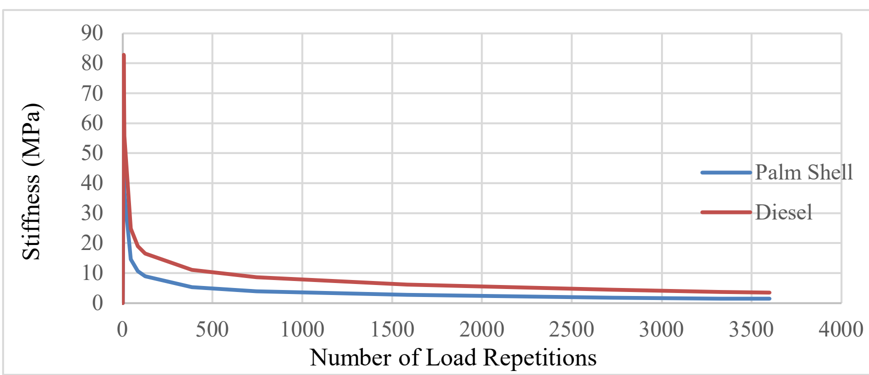

Figure 7 Graph of the relationship between stiffness and number of load repetitions.

Figure 7 shows the dynamic creep stiffness of the HRS-BC mixture produced by the palm shell AMP and the HRS-BC mixture produced by the diesel AMP at 100 kPa loading, up to 3,600 load repetitions. The HRS-BC mixture produced by the diesel AMP displayed slightly greater rigidity when compared to the HRS-BC mixture produced by the palm shell AMP. This is in line with the smaller strain according to Figure 6.

Figures 6 and 7 show that under dynamic loads, the HRS-BC mixture produced by the palm shell AMP experienced greater strain, so that its stiffness was smaller when compared to the HRS-BC mixture produced by the diesel AMP. Since all specimens were tested at the same loading level, it appears that at a loading rate of 100 kPa, the behavior of the sample approached the elastic rate. The accumulation rate of permanent strain was very low, i.e., close to zero. Therefore it can be concluded that a loading rate of 100 kPa is not high enough for the evaluation of permanent deformation behavior [25].

4 Conclusion

From the test results, the HRS-BC mixture produced by the palm shell AMP could withstand two times the load at low or high temperatures when compared to the HRS-BC mixture produced by the diesel AMP. This may indicate that the risk of permanent deformation due to traffic load can be avoided.

The samples of the HRS-BC mixture produced by the palm shell AMP and the samples of the HRS-BC mixture produced by the diesel AMP did not deform at 3,600 load repetitions when the test was carried out using standard loads (100 kPa).

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