THE STIFFNESS MODULUS OF ASPHALT CONCRETE FOR DESIGN LIFE PREDICTION OF PAVEMENT UNDER TROPICAL CONDITION

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Abstract : Stiffness modulus of asphalt mixture is one of key parameters for analytical design of flexible pavement that it is very susceptible against temperature and time loading, meanwhile mostly monographs of flexible pavement design based on the temperature standard of about 25 ^{o}C.
The objective of this research is to know influence of tropical condition especially in Indonesian temperature and time loading against stiffness modulus value of asphalt concrete mixes and design life. Analysis of Indonesian temperature condition for 10 years and indirect tensile modulus test by using UMATTA (Universal Material Testing Apparatus) were carried out to determine stiffness modulus of asphalt concrete mixture on optimum asphalt content with temperature variation at 25 ^{o}C, 37.5 ^{o}C and 50 ^{o}C and time loading variation.
From analysis results of indirect tensile modulus test program, they were found that the temperature and time loading variation have an influence on stiffness modulus, loading period of elastic condition and design life.

Key Words : Stiffness Modulus, Loading Period, Design Life

1. INTRODUCTION

During the last two decade, it has been developed flexible pavement design method that its based on analysis of structural. One of required parameters in analytical design method of flexible pavement is stiffness modulus of Asphalt mix.

Stiffness modulus of Asphalt mix is very influenced by loading time and temperature (TRB, 1975), especially the temperature is increased over the working range of below 0^0 C and above 40^0 C will cause decreasing stiffness modulus of bituminous road surfacing (CRONEY, 1991). Meanwhile, mostly monographs of flexible pavement design based on the standard temperature of about 25^0 C and the reference conditions that are used in many countries to select the design stiffness of asphalt are about 15 to 25^0 C, as is shown in Table 1 ; whereas, Indonesia as climatic conditions are much warmer than in the United Kingdom and the United State of America which the pavement temperature that occurred in Indonesia higher than 25^0 C, so that the asphalt mix will perform differently under different climatic condition like that of Indonesia in contrast to that of the United Kingdom or the United State of America.

The objective of this research is to know influence of temperature in Indonesian condition and loading period to stiffness modulus value of Asphalt Concrete (AC) and design life of pavement.

Table 1 : Design Reference Conditions for Asphalt Stiffness. (M.E. Nunn, 1997)

Country/Method	Temperature (^{o}C)	Frequency (Hz)	Traffic Speed (km/h)	Loading Time (ms)
Asphalt Inst.	*	10	-	-
Austria	18	-	40	-
Belgium	15	27	60	-
Croatia	-	10	55	20
Denmark	25	-	60	-
Finland	20	-	-	-
France	15	10	-	-
Germany	20	10	70	-
Greece	20	10	50	20
Italy	20	25	10	-
Netherlands	20	8	50	20
Nottingham U.	¤	-	80	20
Norway	25	-	-	-
Portugal	25	-	60	-
Romania	-	-	-	100 (#)
Spain	20	10	-	-
Shell	*	-	-	20
UK	20	5	50	-

* Variable – dependent on location and determined from MMAT
¤ Separate Values for fatigue and structural deformation
Dependant on vehicle speed and thickness of asphalt

2. AIR AND PAVEMENT TEMPERATURE IN INDONESIA

2.1. Air Temperature in Indonesia

The Data of average temperature during 10 years (1987 – 1997) including 27 province in Indonesia from Meteorology and Geophysics Agency – Transportation Department can be used as air temperature representation in Indonesian temperature. The monthly air temperature in Indonesia was fluctuation, it is presented in Figure 1 which maximum of the monthly air temperature rose from (30.7^{o} C – 32.0^{o} C: deviation standard (SD) 0.32^{o}C – 0.47^{o} C) and minimum of the monthly air temperature had range between (21.7^{o} C – 22.9^{o}C; deviation standard (SD) 0.45^{o} C – 0.95^{o} C).

Difference of air temperature from several places in Indonesia, between maximum and minimum air temperature were 2^{o} C with average maximum air temperature value in ten years was 31.4^{o} C and average minimum air temperature 22.4^{o} C. So, it can be concluded that the mean monthly maximum air temperature in Indonesia is 31 ± 2^{o} C, minimum is 22 ± 2^{o} C and middle value was 26.5 ± 2^{o} C.

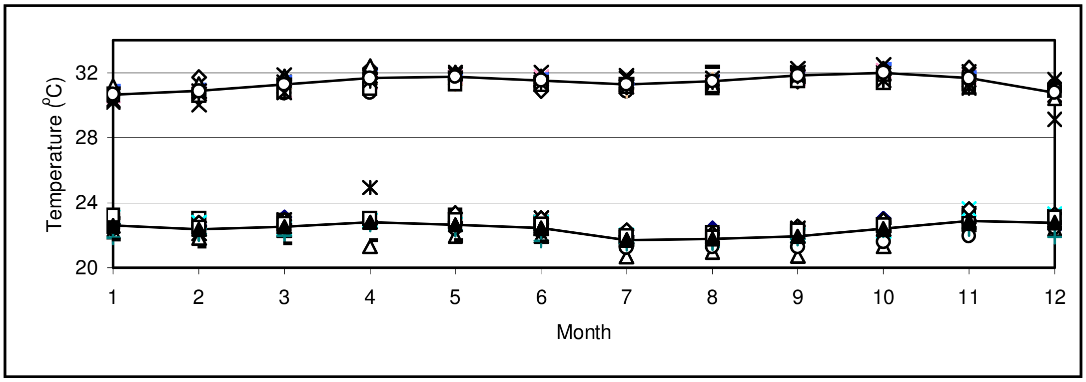

Figure 1 : Maximum and Minimum Monthly Air Temperature throughout the year in Indonesia

According to Shell (1978), the air temperature value of region has to be expressed in Weighted-Mean Annual Air Temperature (W-MAAT). Determination of W-MAAT value in a region can be conducted to Mean Monthly Air Temperature (MMAT) by using temperature weighted factor developed by Shell (1978).

2.2. Pavement Temperature.

Many previous studies conducted to look for relationship between air temperature and pavement temperature in a region related to mean weekly temperature or mean monthly temperature in certain range of time.

In program of DAMA, TAI (1982) determines that the pavement temperature of Monthly Mean Pavement Temperature (MMPT) at deepness of Z (cm) related to mathematical model which developed by WITCZAK (1972), is :

$$MMPT = MMAT\left(1 + \frac{1}{Z+4}\right) - \frac{34}{Z+4} + 6 \qquad (1)$$

Ahmed (1995) also carried out research investigating the relationship between air temperature and pavement temperature and from measurement results in five locations at one road segment, the author concluded that the highest temperature of road pavement was occurred at 2 cm from surface layer of pavement. Results of this research indicated that the relationship between air temperature and pavement temperature was represented by the equation :

$$MMPT(^{o}C) = MMAT\ (^{o}C) + 5^{o}C \qquad (2)$$

In regard to Indonesian condition, SOEDJATMIKO (1999) has carried out measurement of air temperature and pavement temperature during the hottest climate in three months in Jakarta with measurement interval of 3 hours on variation of pavement deepness. The author proposed that regression equation of the relationship between pavement temperature and air temperature, is :

$T_{p15} = 2.9726\ T_u - 45.377$

$R^2 = 0.7752$ (3)

$T_{p75} = 1.1107\, T_u + 6.705$

$R^2 = 0.2625$ (4)

$T_{p150} = 0.2683\, T_u + 28.003$

$R^2 = 0.0348$ (5)

Where :

T_u = Air Temperature (°C)

T_p = Pavement Temperature (°C)

3. RESILIENT STIFFNESS MODULUS

Elastic modulus is sometimes called Young's modulus after Thomas Young who published the concept back in 1807 which used with elastic theory. The elastic modulus based on the recoverable strain under repeated loads is called the resilient modulus M_R, defined as

$$M_R = \frac{\sigma_d}{\varepsilon_r} \quad (6)$$

in which σ_d is the deviator stress, which is the axial stress in an unconfined compression test or the axial stress in excess of the confining pressure in a triaxial compression test.

Mostly, pavement materials are not elastic because they under repeated load will cause permanent deformation. However, if the load is small compared to the strength of the pavement materials and is repeated for a large number of times, the deformation under each load repetition is nearly completely recoverable and proportional to the load and can be considered as elastic. The strains of under repeated load test can be illustrated in Figure 2.

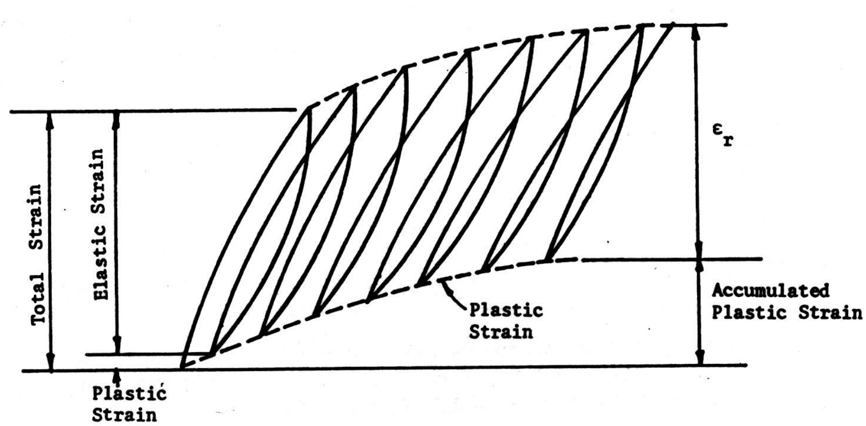

Figure 2. Strains under repeated loads (Huang,1993)

4. RELATIONSHIP BETWEEN STIFFNESS MODULUS, STRAIN AND LOADING REPETITION

BROWN et.al (1982) have developed relationship curve between Asphalt thickness and vertical strain that happened on the subgrade (ε_v) and tensile strain at the bottom of asphalt layer for various of subgrade modulus (E_3) and Base layer (E_1) with typical curve such as those which illustrated in Figure 3 and 4. Constructively, this curve shows the level of critical strain that occurred on the subgrade and bottom of base layer can be predicted.

Additionally, the authors have also developed models to determine the number of loading repetition ($N_{deformation}$ and $N_{fatigue}$) which can be supported by pavement referred to strain that occurred on the subgrade and bottom of asphalt layer. Shell (1978) and NAASRA (1987) also developed more simple model, as follows :

$$N_{deformtion} = \left(\frac{8511}{\varepsilon}\right)^{7.14} \quad (7)$$

$$N_{fatigue} = \left[\frac{6918(0.856V_b + 1.08)}{S_{mix}^{0.36}.\varepsilon}\right]^5 \quad (8)$$

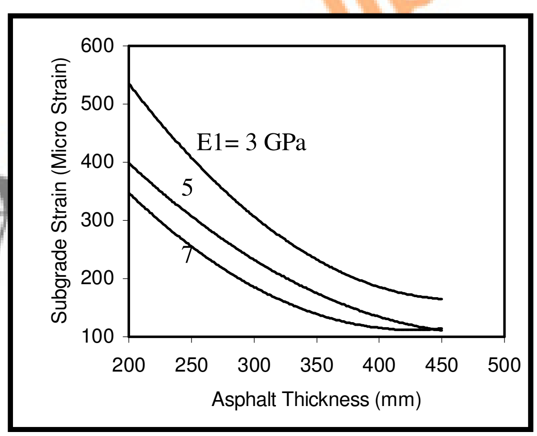

Figure 3 : Critical Strains (Subgrade Strain) as Function of Stiffness and Asphalt Thickness (Brown et al. 1982)

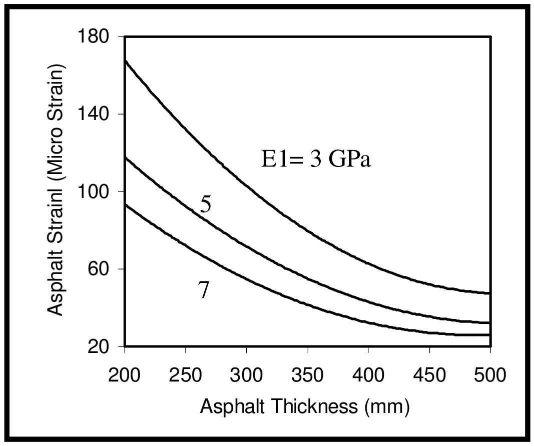

Figure 4 : Critical Strains (Asphalt Strain) as Function of Stiffness and Asphalt Thickness (Brown et al. 1982)

5. DATA PRESENTATION

5.1. W- MAAT Indonesia

W-MAAT value for the mean monthly temperature in Indonesia (see Figure 1.) which is calculated by using weighted factor developed by Shell (1978), given in Table 2.

Table 2 : W-MAAT(Maximum and Minimum) in Indonesia Based On Air Temperature Data During 10 Years

Month	MMAT (^{o} C)		Weighted Factor (Shell, 1978)	
	Max	Min	Max	Min.
January	31	23	4.62	1.58
February	31	22	4.62	1.40
March	31	23	4.62	1.58
April	32	23	5.28	1.58
May	32	23	5.28	1.58
June	32	22	5.28	1.40
July	31	22	4.62	1.40
August	31	22	4.62	1.40
September	32	22	5.28	1.40
October	32	22	5.28	1.40
November	32	23	5.28	1.58
December	31	23	4.62	1.58
Total of Weighted Factor			59.4	17.88
Avarage Weighted Factor			5.0	1.5
W-MAAT (^{o}C) in Indonesia			31.5	22.5

From this table, it can be seen that in the reality W-MAAT value for Indonesia, maximum 31.5^o C and minimum 22.5^o C is relative equal to Mean Monthly Air Temperature value (maximum 31 ± 2^o C and minimum 22 ± 2^o C). It can be assumed that air temperature in Indonesia can be based on the W-MAAT value.

5.2. Pavement Temperature in Indonesia

The calculation of maximum and minimum pavement temperature are based on the W-MAAT value in Indonesian condition by using equation 3 is 48 ± 2^o C and 22 ± 2^o C. Approximately, they can be said that the maximum, mean and minimum pavement temperature Indonesia are 50^o C; 37.5^{o}C and 25^{o}C.

5.3. Samples and Testing of Stiffness Modulus.

- **Samples.**

In regards to asphalt concrete as wearing course mix which has been widely used in Indonesia, for that the samples used in this research were Asphalt Concrete (AC). Samples were made by referring BINA MARGA specification (BM, 1987) and they were made at optimum asphalt content which have been determined previously. Sample characteristics at optimum asphalt content, this is illustrated in Table 3.

Table 3 : Asphalt Mixture Characteristics at Optimum Asphalt Content Condition

Parameters	AC	Specification AC
Optimum Asphalt (%)	6.5	-
Density (grm/cc)	2.240	-
VIM (%)	6.677	3 – 8
VMA (%)	16.8	-
VFB (%)	66.3	> 65
Stability (kg)	1300	> 550
Flow (mm)	3.9	2 – 4
M.Q (kg.mm)	322.83	200 – 500
Residual Stability (%)	93.7	> 75

Source : Bina Marga (1996)

- **Stiffness Modulus Test in Laboratory.**

Stiffness modulus test in this research was carried out by using UMATTA equipment for 120 samples with asphalt content 6.5%. This test was conducted at temperature variation referred to pavement temperature fluctuation in Indonesia, such as those which have been elaborated previously (25^o, 37.5^o and 50^{o}C). Relationship between loading time period and stiffness modulus as function pavement temperature are demonstrated in Figure 5 to 7.

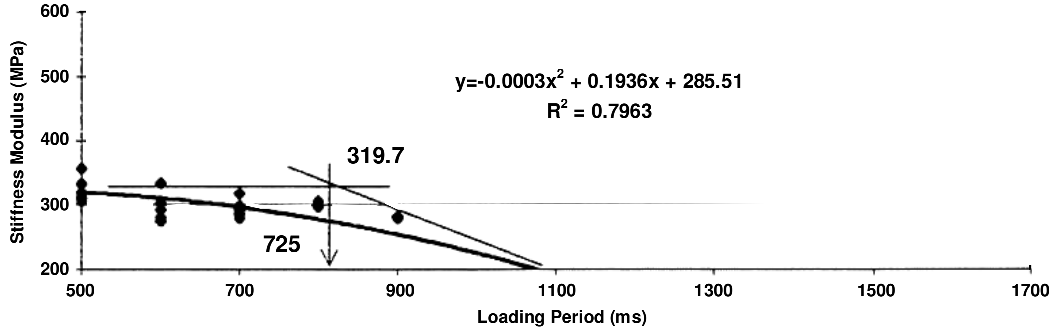

Figure 5 : Relationship Between Loading Period and Stiffness Modulus at Temperature 50°C

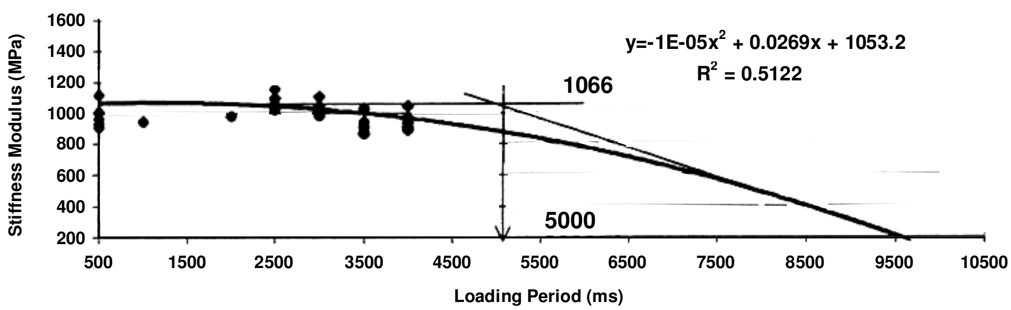

Figure 6 : Relationship Between Loading Period and Stiffness Modulus at Temperature 37.5°C

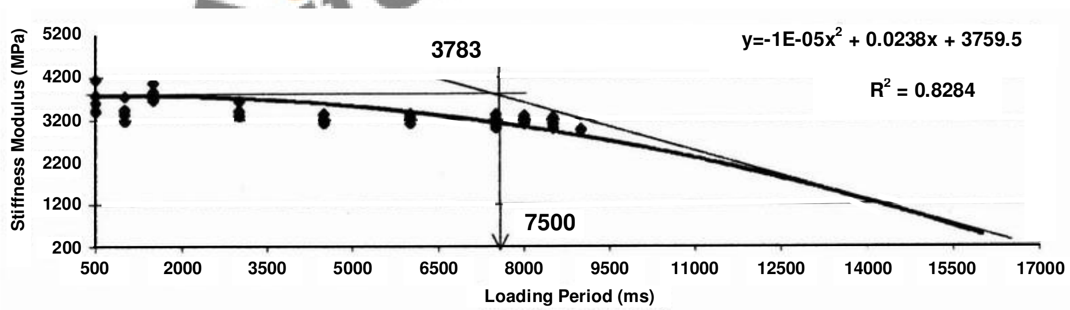

Figure 7 : Relationship Between Loading Period and Stiffness Modulus at Temperature 25°C

6. DATA ANALYSIS

6.1. Stiffness Modulus

From Figure 5 to 7, stiffness modulus value of Asphalt mixture are obtained from the relationship curve between loading period and stiffness modulus for temperature 25° C, 37.5° C and 50° C on inflection point of stiffness modulus curve. The stiffness modulus value and loading period on temperature 25° C, 37.5° C and 50° C are illustrated in Table 4.

Table 4 : Stiffness Modulus and Loading Period for Temperature 25^o C, 37.5^o C and 50^o C

Temperature	Loading Period at Inflection Point (ms)	Stiffness Modulus of Asphalt Mixture (Mpa)
25^0 C	7500	3783
37.5^0 C	5000	1066
50^0 C	725	319.7

From data at Table 4 can be analyzed as follows :

1. The Asphalt concrete wearing course decrease in stiffness modulus value as the temperature is increased
   a. The temperature increase from 25^o C become 37.5^oC caused decreasing in stiffness modulus of asphalt mixture to 71.8 %.
   b. The temperature increase from 25^o C become 50^o C caused decreasing in stiffness modulus of asphalt mixture to 91.5 %.

2. The Asphalt mix shows elastic behavior at short loading period in line with increasing pavement temperature, the range of elastic behavior on temperature and time loading variation as follows :
   a. 500 ms up to 7500 ms for temperature 25^0 C.
   b. 500 ms up to 5000 ms for temperature 37.5^0 C.
   c. 500 ms up to 725 ms for temperature 50^0 C.

6.2. Design Life Analysis

In determination of the design life, data are conducted with the assumption that thickness of asphalt layer is assumed of 300 mm and volume of bitumen of 14.5% on optimum asphalt content of AC 6.5% , then asphalt strain and subgrade strain can be predicted by using Figure 3 to 4 and also design life is based on fatigue criteria and deformation criteria can be calculated by using Equation 7 and 8. The results are illustrated in Table 5 and Figure 8.

Table 5 : Influence of Stiffness Modulus and Temperature to Strain and Design Life

Temperature	S_{mix} (Mpa)	Asphalt Strain (ms)		Design Life (N)	
		(ε_v)	(ε_t)	$N_{deformation}$	$N_{fatigue}$
25^0 C	3783	275	80	$4.398 . 10^{10}$	$7.85 . 10^8$
37.5^0 C	1066	590	150	$2.134 . 10^8$	$3.3. 10^8$
50^0 C	319.7	>600	> 180	$2.134 . 10^8$	$< 3.3 . 10^8$

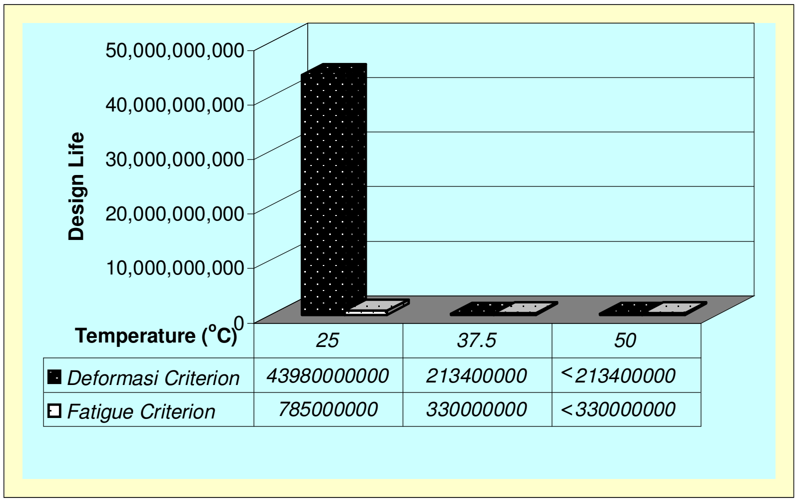

Figure 8 : Relationship Between Temperature and Design Life Based on Deformation and Fatigue Criteria

The Design life results are based on deformation and fatigue criteria on temperature variation as shown in Table 5, they can be seen that the temperature will have a significant influence on determination of the design life value of road pavement. These values will significantly decrease with increasing temperature.

7. CONCLUSION

Through calculation and analysis in this research, the following conclusions are obtained:

1. Maximum and Minimum of W-MAAT value for Indonesia are 31.5°C and 22.5°C.
2. The maximum temperature, mean and minimum of pavement temperature in Indonesia are 50°, 37.5° and 25°C
3. Determination of The stiffness modulus of asphalt mix is significantly influenced by pavement temperature and time loading period
5. The Asphalt mix shows elastic behavior at short time loading period in line with increasing pavement temperature
6. Determination of the stiffness modulus of asphalt mix must be done carefully because it will significantly influence the design life prediction

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