Research Paper

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Structural Analysis and Service Life Prediction of Rubberized Thin Surfacing Hot Mix Asphalt

Sebastianus Kristianto Nugroho*, Ary Setyawan & Arif Budiarto

Department of Civil Engineering, Faculty of Engineering, Sebelas Maret University, Jalan Ir. Sutami No 36, Surakarta 57126, Indonesia

Corresponding author: sebastianknugroho@gmail.com

Abstract

Rubberized thin surfacing hot mix asphalt (RTSHMA) is a type of flexible pavement that is currently being developed. It can provide the same good performance as asphalt concrete–wearing course (AC-WC). Based on previous research, the use of crumb rubber in the asphalt mixture can provide several advantages, such as increasing the flexibility of the mix so that the pavement is more resistant to cracking. Based on research showing the advantages of rubberized asphalt, the idea emerged to apply it in the field, namely on the Palur–Sragen City Boundary section as wearing course. The method of analysis in this study was modeling the pavement structure with the KENPAVE and BISAR 3.0 programs. The analysis results showed that the AC-WC model and RTSHMA model have the same good performance because both of them have a service life of more than twenty years, which is the standard for flexible pavements. However, RTSHMA has an advantage, i.e., the thickness layer is 25% thinner than AC-WC's. With a thinner layer than AC-WC but the same good performance, RTSHMA is worth considering as an alternative pavement, especially for overlays.

Keywords: *BISAR 3.0; KENPAVE; overlay; rubberized asphalt; service life.*

Introduction

The Palur–Sragen City Boundary section is a national arterial road in Indonesia, located in the province of Central Java. This road segment is 20.01 km long and connects the cities of Solo and Sragen. The increase in vehicles passing through arterial roads is directly proportional to population growth, resulting in premature damage characterized by cracks and deformation [1, 2]. This needs to be addressed immediately to prevent further damage, and one way is to overlay it.

So far, the pavement mixtures for overlay commonly used in Indonesia are asphalt concrete–wearing course (AC-WC) and hot rolled sheet–wearing course (HRS-WC). AC-WC pavement is a type of tightly graded pavement, while HRS-WC is a type of gap-graded pavement. Both have in common that the minimum thickness is 4 cm. Apart from these two types of pavement mixtures, a different kind of pavement is now widely used in Indonesia, especially for overlays, namely thin surfacing hot mix asphalt (TSHMA).

TSHMA is a mixture that has hybrid characteristics between AC and HRS mixture. TSHMA can provide exemplary performance in terms of stability and flexibility. Therefore, this mixture generally has a long service life [3]. The main advantage of TSHMA mixture is its thin thickness. Where the mixture of AC and HRS requires a thickness of 4 to 5 cm for the surface layer, TSHMA only requires a thickness of 2 to 3 cm to provide the same good performance [4]. This offers many benefits, especially from an economic and environmental perspective [5]. Many studies on TSHMA have been carried out, one of which is known as rubberized thin surfacing hot mix asphalt (RTSHMA).

RTSHMA is a TSHMA mixture that utilizes crumb rubber as an added ingredient or as a substitute for aggregate or asphalt. Adding crumb rubber to the asphalt mixture can increase the stability, ductility, skid resistance, and softening point of the mixture [6-9]. Using crumb rubber in combination can also reduce the amount of asphalt used. By adding crumb rubber at 0.5% of the total weight of the mixture, the optimum asphalt content (KAO)

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can decrease by 29.6% [10]. In the HRA mixture, using crumb rubber as a substitute for all fine aggregates makes the mixture more flexible, durable, and impermeable [11].

So far, studies on rubberized asphalt only focused on the characteristics of the mixture. Little attention has been paid to using rubberized asphalt as a road pavement layer and how it performs under traffic loads. Therefore, this study tried to close this research gap by applying RTSHMA as a layer of the pavement structure and studying it under traffic loads. This research used modeling with the help of the KENPAVE and BISAR 3.0 programs. These are often used to evaluate the performance of pavement structures based on fatigue, rutting, and permanent deformation criteria [12, 13].

Fundamental Aspects and Research Method

Fatigue Cracking

Fatigue cracking is a type of pavement damage in the form of a series of cracks that occur in the surface layer 14, 15]. Basically, fatigue is caused by elastic and viscoelastic behaviors of asphalt mixture [16]. Various factors, including time, loading time, loading speed, loading mode, temperature, moisture, resting period, stress level, and aging, have an effect on the deformation behavior and performance of flexible pavement [17-19]. To calculate number of load repetitions that cause fatigue cracking, the following equation approach from the Asphalt Institute can be used:

$$Nfg = 0.0769(\varepsilon ht)^{-3.921}|E|^{-0.845} \quad (1)$$

where:

Nfg = number of repetitions of the fatigue criteria, ESAL
εht = horizontal tensile strain
E = modulus elasticity, kPa

Permanent Deformation

Permanent deformation is a type of damage caused by repetitive traffic loads and is characterized by a permanent decrease/deformation of the road pavement structure [20-22]. The location of permanent deformation is below the sub-base course layer or above the subgrade layer. The following equation approach from the Asphalt Institute can be used to calculate the number of load repetitions that cause permanent deformation:

$$Ndp = fa(\varepsilon vc)^{-ft} \quad (2)$$

where:
Ndp = number of repetitions of the permanent deformation criteria, ESAL
εvc = vertical compressive strain
fa = 1.365×10^{-9}
ft = 4.477

Service Life

Service life is the length of time a pavement structure can achieve in serving traffic loads until damage occurs [23]. The road pavement structure will experience a decrease in its service life along with its ability to withstand traffic loads. It is necessary to maintain the road pavement structure to achieve its planned life, as shown in Figure 1 below.

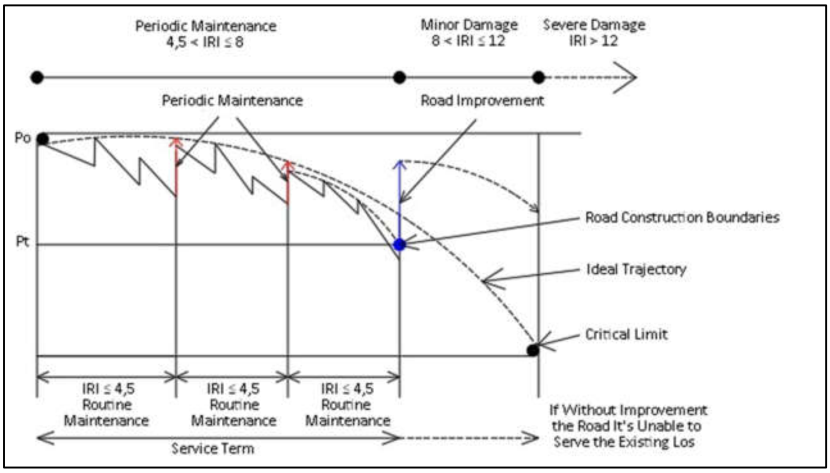


Figure 1 Graph of the relationship between pavement structural condition and service life. Source: [23]

In this study, service life was calculated by substituting the value of the number load repetitions based on fatigue (Nfg) or the number load repetitions based on permanent deformation (Ndp) as the CESAL value in Equation 3 below.

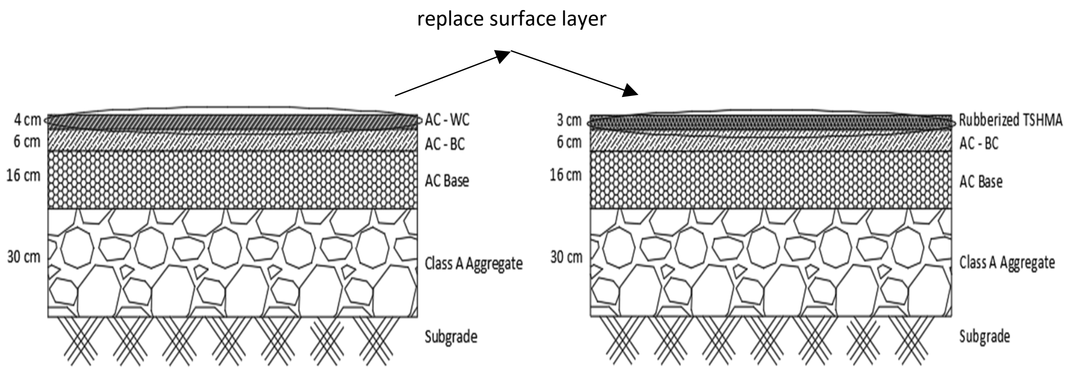
$$CESAL = \sum(\text{LHRTjk x FVD})\text{ x 365 x FL x FD x }\frac{(1+1\,(0.01)q)^{\text{SL}}-1}{1(0.01)q} \tag{3}$$

where:

CESAL = cumulative equivalent standard axle load
LHRTjk = average daily traffic in one year
FVD = factor of vehicle damage
FL = lane distribution factor
FD = directional distribution factor
q = traffic growth rate
SL = service life

Research Method

The research method used in this research was modeling by using the KENPAVE and BISAR 3.0 programs. An overview of the pavement structure model to be analyzed in this study can be seen in Figure 2.



(a) (b)

Figure 2 (a) Existing AC-WC model (b) RTSHMA model.

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KENPAVE

KENPAVE is a program that is often used in the modeling of road pavement structures. In the KENPAVE program, there are two modeling menus : KENSLABS, which is used for modeling rigid pavement structures, and KENLAYER, which is used for modeling flexible pavement structures [24]. This study focused on the KENLAYER menu because the pavement structure model to be modeled was a flexible pavement type. The steps for modeling pavement structures using KENPAVE program are:

1. Input thickness and Poisson's ratio

The first step in making a model is creating a frame, In the KENPAVE program, the frame can be described according to the thickness of each layer in the pavement structure. The thickness data are secondary data from the construction design of the Palur–Sragen City Boundary section, which were obtained from the National Road Implementation Center of Central Java – DIY. The existing AC-WC model and the RTHSMA model only differed in the thickness of surface layer, used which was 4 cm in the existing AC-WC model and 3 cm in the RTSHMA model. Apart from inputting the layer thickness, in the initial steps the Poisson's ratio value was also specified which was the typical Poisson's ratio of the materials obtained from literature. The thickness (TH) and Poisson's ratio (PR) that were used can be seen in Figure 3.

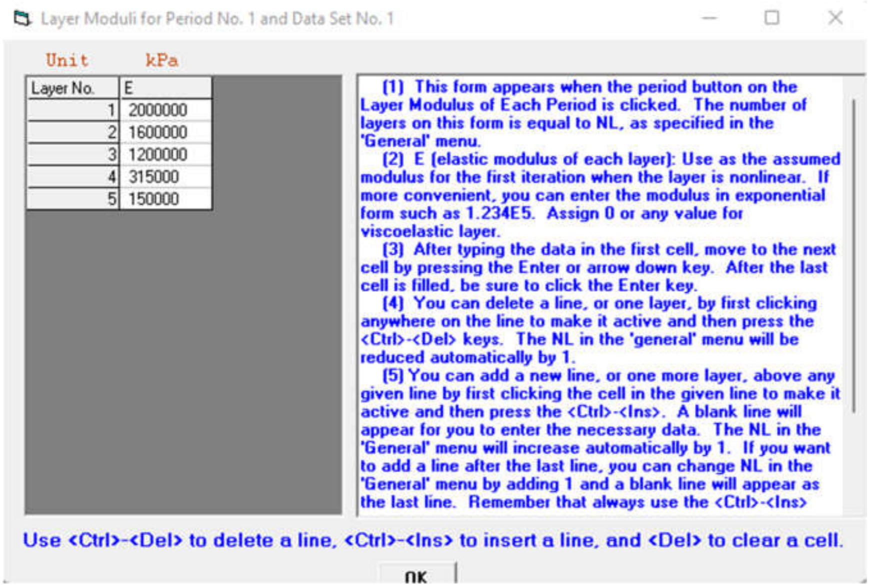
(a)

(b)

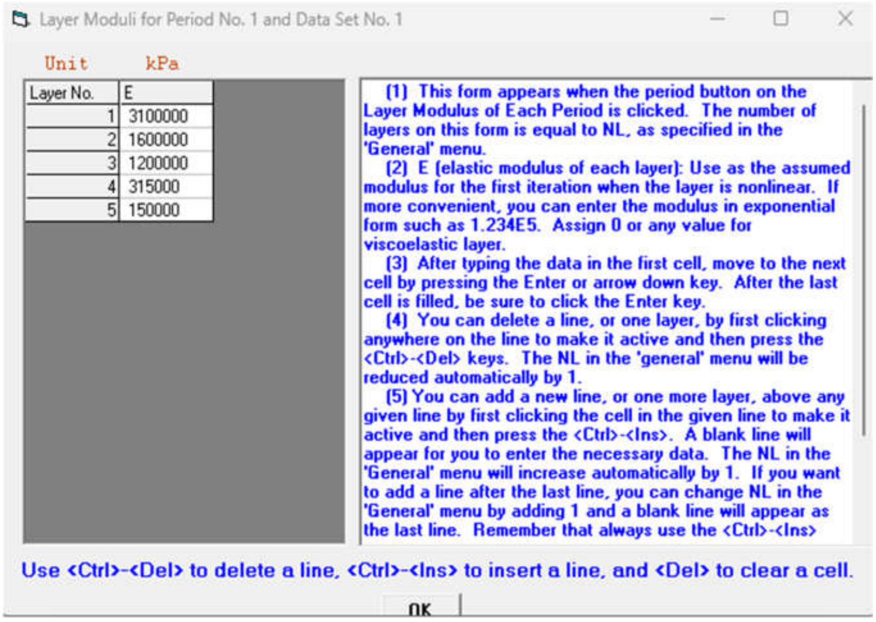
Figure 3 (a) Thickness of existing AC-WC model (b) thickness of RTSHMA model.

2. Input load and elastic modulus

As the next step after setting the thickness and Poisson's ratio, the load and elastic modulus were set. The standard axle load in the models was set to a single axle load (dual wheels of 8.16 ton). The value of the elastic modulus describes the hardness of each layer of the pavement structure. The elastic modulus in the existing AC-WC model and the RTHSMA model only differed in the surface layer, with the existing AC-WC model using 2 x 10^6 kPa based on typical data and the RTSHMA model using 3.1 x 10^6 kPa based on previous research. The elastic modulus value obtained from the literature was the typical elastic modulus of the materials. The elastic modulus value used can be seen in Figure 4.



(a)



(b)

Figure 4 (a) Elastic modulus of AC-WC model (b) elastic modulus of RTSHMA model.

3. Running the models

The last step of modeling with KENPAVE is running the models by clicking on the 'Run Analysis' command. The output of the models are strain values. Then, the strain values were used to calculate the number of load repetitions using Equation 1 and Equation 2.

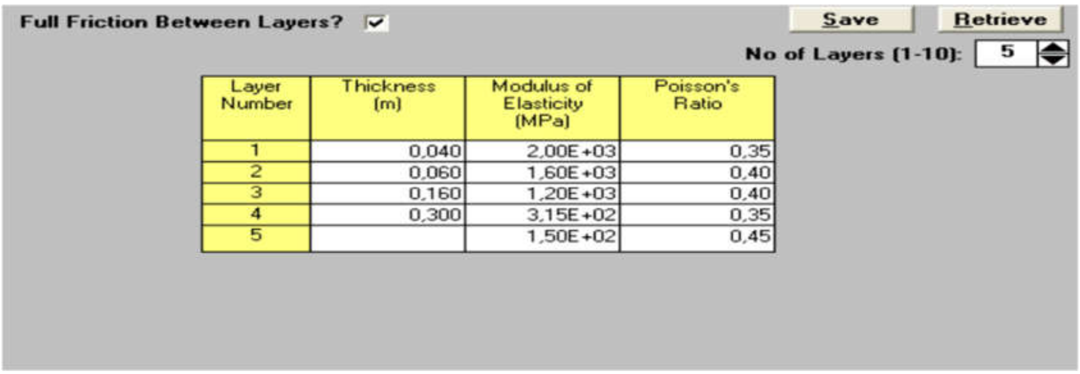
BISAR 3.0

BISAR 3.0 is a program created by Shell that is often used to analyze road pavement models. This program is very simple to use and can explore models with a multi-layer system [25]. Similar to the KENPAVE program, the

BISAR 3.0 program also needs the layer thickness, Poisson's ratio value, load, and elastic modulus to create models. The steps for modeling a pavement structure using BISAR 3.0 program are:

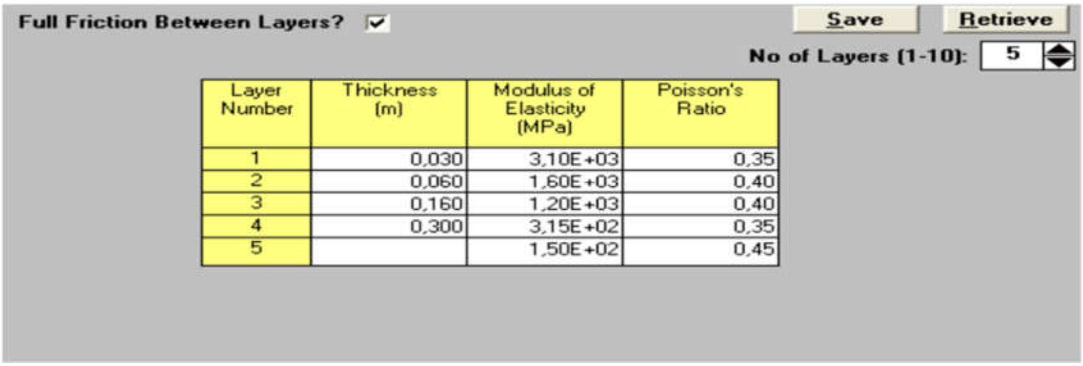
1. Input thickness, elastic modulus, and Poisson's ratio

The first step of making a model in BISAR 3.0 is inputting the thickness, elastic modulus, and Poisson's ratio of values for the model. The data required by the BISAR 3.0 program are same as for the KENPAVE program. The thickness, elastic modulus, and Poisson's ratio used can be seen in Figure 5.



Layer Number	Thickness (m)	Modulus of Elasticity (MPa)	Poisson's Ratio
1	0,040	2,00E+03	0,35
2	0,060	1,60E+03	0,40
3	0,160	1,20E+03	0,40
4	0,300	3,15E+02	0,35
5		1,50E+02	0,45

(a)



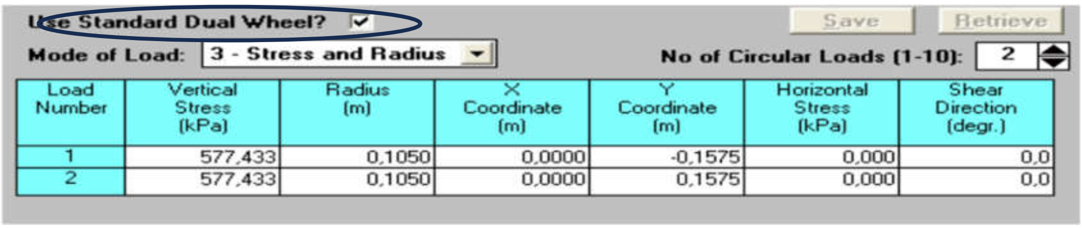
Layer Number	Thickness (m)	Modulus of Elasticity (MPa)	Poisson's Ratio
1	0,030	3,10E+03	0,35
2	0,060	1,60E+03	0,40
3	0,160	1,20E+03	0,40
4	0,300	3,15E+02	0,35
5		1,50E+02	0,45

(b)

Figure 5 (a) Frame of exisiting AC-WC model (b) frame of RTSHMA model.

2. Input load

The next step is inputting the load. The load of the models also described as the standard axle load, was defined by choosing 'Use Standard Dual Wheel', which automatically sets the load. The load used shown in Figure 6.



Load Number	Vertical Stress (kPa)	Radius (m)	X Coordinate (m)	Y Coordinate (m)	Horizontal Stress (kPa)	Shear Direction (degr.)
1	577,433	0,1050	0,0000	-0,1575	0,000	0,0
2	577,433	0,1050	0,0000	0,1575	0,000	0,0

Figure 6 Inputting the load for the models.

3. Running the models

The last step of modeling with BISAR 3.0 is the same as KENPAVE, i.e. running the models with the 'Run Analysis' command. The outputs of the models are also strain values. The strain values were used to calculate the number of load repetitions using Eqs. (1) and (2). Then, the result of the number of load repetitions were compared to the result of the number of load repetitions by the KENPAVE program.

Result and Discussion

Flexible pavement is designed to be able to carry loads for twenty years, so the pavement structure must be able to service the traffic loads without fatigue cracking or permanent deformation, occurring at least until the planned age. Therefore, it is necessary to calculate the number of load repetitions the planned age, i.e. twenty years for flexible pavements. This number of load repetitions based on planned age controlled the models in this research.

The study case in this research was the Palur–Sragen City Boundary section, which is a national arterial road with two directions. Each direction has two lanes, so based on the manual pavement design, the direction distribution factor (DD) is 50%, and the lane distribution factor (DL) is 80%. The calculation of the number of load repetitions can be seen in Table 1.

Table 1 Calculation Number of Load Repetitions Palur–Sragen City Boundary Section

Type of Vehicle	LHRT	R	DD	DL	VDF	ESA
Category 1,2,3,4,8	28,647	32.375	0.5	0.8	0	0
Category 5A	247	32.375	0.5	0.8	0	0
Category 5B	656	32.375	0.5	0.8	1	3,100,748
Category 6A	2,195	32.375	0.5	0.8	0.5	5,187,608
Category 6B	2,955	32.375	0.5	0.8	9.2	128,501,426
Category 7A	457	32.375	0.5	0.8	14.4	31,105,796
Category 7B	87	32.375	0.5	0.8	18.2	7,484,336
Category 7C	106	32.375	0.5	0.8	19.8	9,920,503
		CESAL				185,300,417

Result of KENPAVE and BISAR 3.0 Programs

The outputs of the analysis using the KENPAVE and BISAR 3.0 programs are the values of the horizontal tensile strain and the vertical compressive strain. These strain values were the basis for calculation of the service life of the two types of models studied. The model analysis results can be seen in Table 2 below.

Table 2 Output of KENPAVE and BISAR 3.0 Programs

	Horizontal Tensile Strain (εht)	Vertical Compressive Strain (εvc)
AC-WC Model with KENPAVE Program	7.894×10^{-5}	1.278×10^{-4}
AC-WC Model with BISAR 3.0 Program	8.844×10^{-5}	1.319×10^{-4}
RTSHMA Model with KENPAVE Program	8.678×10^{-5}	1.285×10^{-4}
RTSHMA Model with BISAR 3.0 Program	9.186×10^{-5}	1.330×10^{-4}

Result of Load Repetition Calculation

The strain values based on the output of the KENPAVE and BISAR 3.0 programs was then used to calculate the number of repetitions of the load. The horizontal tensile strain value (εht) was used to calculate the load repetitions based on the fatigue criteria with Equation 1. The vertical compressive strain value (εvc) was used to calculate the load repetitions based on the permanent deformation criteria with Eq. (2). The results of calculating the number of load repetitions can be seen in Table 3.

Table 3 Calculation of Number Load Repetitions

	Nfg	Ndp	Control	Note
AC-WC Model with KENPAVE Program	4,889,816,785 ESAL	368,293,470 ESAL	185,300,417 ESAL	Qualified
AC-WC Model with BISAR 3.0 Program	3,131,734,358 ESAL	319,739,802 ESAL	185,300,417 ESAL	Qualified
RTSHMA Model with KENPAVE Program	3,373,270,524 ESAL	359,396,091 ESAL	185,300,417 ESAL	Qualified
RTSHMA Model with BISAR 3.0 Program	2,698,831,852 ESAL	308,069,607 ESAL	185,300,417 ESAL	Qualified

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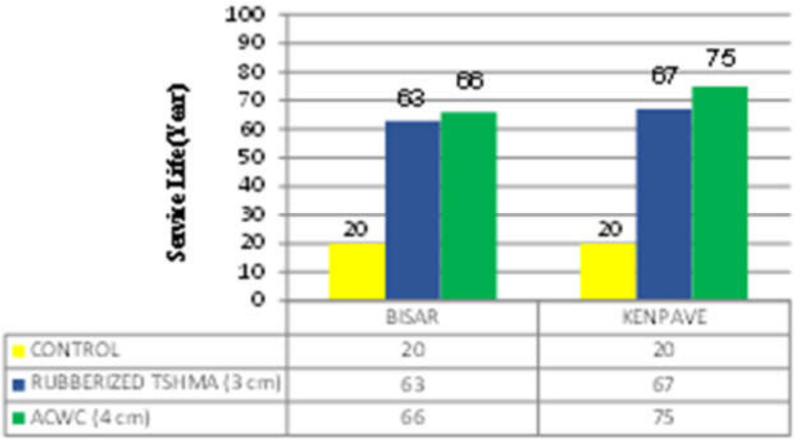
Result of Service Life Calculation

The number of load repetitions of the fatigue criteria was used to calculate the service life, while the number of load repetitions of the permanent deformation criteria measured the permanent deformation. The number of load repetitions was then used to calculate the service life with Eq. (3) by substituting the number of load repetitions with the CESAL value. The results of the calculation of the service life can be seen in Table 4 below.

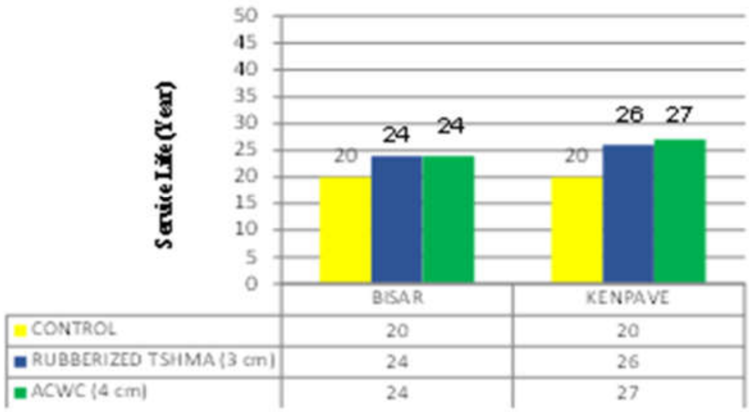
Table 4 Calculation of Service Life

	Nfg	Ndp	Control	Note
AC-WC Model with KENPAVE Program	75 Years	27 Years	20 Years	Qualified
AC-WC Model with BISAR 3.0 Program	66 Years	24 Years	20 Years	Qualified
RTSHMA Model with KENPAVE Program	67 Years	26 Years	20 Years	Qualified
RTSHMA Model with BISAR 3.0 Program	63 Years	24 Years	20 Years	Qualified

The service life calculation results are also shown in the comparison graphs in Figure 7 below.



(a)



(b)

Figure 7 (a) Criteria for fatigue (b) criteria for permanent deformation

Based on the results of the analysis and the calculations, it was found that the performance of the existing AC-WC pavement is slightly better than of RTSHMA pavement. Still, both types of pavement meet the minimum service life requirements for flexible pavement layers, which is twenty years. Therefore, with a thinner layer thickness and using waste materials and still obtaining a good performance, the RTSHMA pavement is quite feasible to be considered for overlays.

Conclusion

Based on the results of the analysis and discussion above, it can be concluded that:

1. The existing pavement on the Palur–Boundary Section of Sragen city performs slightly better than RTSHMA. Still, both types of pavement meet the minimum service life standard when applied in the field.
2. RTSHMA can reduce the layer thickness by 25% compared to the existing pavement and provides equally good performance. Therefore, RTSHMA is worth considering as an alternative pavement option.

The design of the RTSHMA structure in this research may be further developed by using variations of layer thickness and loading so that it is possible to obtain a structural design with optimal performance.

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