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Glass Fiber Reinforced Asphalt Paving Mixture: Feasibility Assessment

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Abstract. The development of different asphalt additives and modifiers requires that pavement engineers make sound judgment regarding the effectiveness of these new products in order to justify their use. Therefore, informing the pavement engineers in recent materials development along with a method to assess the feasibility of using the new products is essential. This paper presents a performance based economical assessment regarding the feasibility of reinforcing the asphalt paving mixture using glass-fiber, taking into consideration factors such as initial construction cost, major rehabilitation, and salvage value of the pavement at the end of the analysis period. The result of this study shows that reinforcing the asphalt paving mixture with glass-fiber enhances the overall performance of the pavement structure. Such improvement would reduce future rehabilitation cost thus making the use of the reinforced paving mixture more economical.

1. Introduction

The second half of the twentieth century has seen massive construction of highways all-over the world. A good roadway infrastructure is the backbone of a strong stable economy. However, the development of modern highways has always depended upon the highway construction materials available. The early attempts to use tar and pitch as a stabilizing material led to the development of using asphalt cement as a binding material. As development continues higher quality asphalt mixture is needed due to the heavy use of such infrastructures. Consequently pavement technologists are forced to experiment with the existing materials so that it can be made to perform better and more economical. In addition, attainment of cost effectiveness in the construction and rehabilitation of the highway infrastructure has been the focal point of many research activities in recent years[1,2].

The main drawback of asphalt paving material is its weakness in tension. One of the simplest methods of improving the tensile properties of the mixture is to reinforce it, either by using long woven or grid fabric, or with randomly oriented short fiber. A number of different fiber types have been tried to reinforce the paving mixture[3-5]. The relatively high tensile property of the fiber reinforced paving mixture would improve the pavement resistance to some distresses.

In recent years, the development of different fiber types, coupled with claims by manufacturers that their products offer a solution for most pavement distresses, make it difficult for pavement engineers to make sound judgments on the effectiveness of these new products, thereby justifying their use. Consequently, given today's economic situation, and the magnitude of the work required to complete and maintain highway infrastructure, a program to evaluate the effectiveness of newly developed paving materials, along with a method of performance based economic assessment, is essential to ensure that more economic materials are used.

The purpose of this paper is to evaluate the effects of reinforcing the asphalt paving mixture on the overall pavement performance and to present means of economical assessment concerning the feasibility of using glass-fiber, taking into consideration the initial cost of construction, major rehabilitation cost, and salvage value of the pavement at the end of the analysis period.

2. Reinforced Paving Mixture

An experiment was conducted to evaluate the effects of glass-fiber reinforcement on the mechanical properties of asphalt paving mixture. The glass-fiber used is strong, durable, and exhibits a high melting point, (160-180ºC). A 25 mm fiber length was used to reinforce a paving mixture composed of a surface coarse dense graded aggregate and a typical AC-20 viscosity graded asphalt cement. The effects of fiber content on the mechanical properties of the paving mixture were evaluated at different testing temperature levels (20, 30, and 40ºC). Fiber contents of 0.17, 0.33, and 0.50 percent, by the total weight of the mixture, were used in preparing Marshall-size specimens. The properties evaluated through laboratory testing were the tensile strength, resilient modulus, permanent deformation, and fatigue life. A detailed description of the experiment is presented in reference[6].

The long-term service performance of the asphalt pavement depends on many factors, including the loading, environmental conditions, and the materials properties of the pavement layers. If these factors were kept constant and different reinforced mixture is used in the top layer then the difference in pavement performance will depend primarily on the effect of the reinforcement to paving mixture. In order to assess the influence of reinforcement on the pavement performance, a typical pavement section was used for the evaluation. A 100 mm layer thickness of conventional and reinforced paving mixtures was used as surface layer. Each surface layer (wearing course) was supported by 200 mm base course and 300 mm subbase and subjected to an average daily traffic of 1000 EAL_{18} throughout the 20 years analysis period.

The VESYS 3AM structural subsystem was used to predict the pavement performance[7,8]. The VESYS 3AM is a computer program developed by the Federal Highway Administration in the United States of America for predicting the performance of pavement based on the mechanical properties of the materials in the different layers of a flexible pavement. The VESYS 3AM predicts the performance of a given pavement in terms of rutting, cracking and present serviceability index (PSI) for a predetermined traffic volume and prevailing environmental conditions.

The mechanical properties of the paving materials required by the VESYS Model to predict the pavement performance are the resilient modulus and the permanent deformation parameters, α and μ, for the pavement materials making up the pavement layers and the fatigue coefficients K_1 and K_2 for the asphalt layer/s. The seasonal mechanical properties of the nonasphaltic materials were selected from a previous study[6]. The seasonal resilient modulus of the asphalt materials was evaluated using the diametral resilient modulus test as described in the ASTM Method D 4124-82 and presented in Table 1. The seasonal permanent deformation parameters α and μ were determined according to the VESYS Manual[8] and presented in Table 2.

TABLE 1. Seasonal resilient modulus for layer materials (MPa).

Material \ Season (Temp ºC)	Winter (20ºC)	Spring (30ºC)	Summer (40ºC)	Fall (30ºC)
Conventional W/C	4710	1570	760	1570
0.17% Reinforced W/C	4810	1670	880	1670
0.33 Reinforced W/C	4910	1700	900	1700
0.50% Reinforced W/C	4900	1700	890	1700
Base course	2948	1217	662	1217
Subbase	179	186	186	186
Subgrade	14	48	48	48

TABLE 2. Seasonal permanent deformation parameters for pavement layers.

Mixture \ Season (Temp ºC)	Winter (20ºC)		Spring (30ºC)		Summer (40ºC)		Fall (30ºC)	
	α	μ	α	μ	α	μ	α	μ
Conventional W/C	.08	.42	.12	.52	.16	.56	.12	.52
0.17% Reinforced W/C	.07	.42	.11	.53	.16	.54	.11	.53
0.33% Reinforced W/C	.07	.43	.12	.52	.15	.55	.11	.52
0.50% Reinforced W/C	.08	.42	.13	.50	.18	.58	.13	.54
Base course	.10	.75	.18	.68	.19	.56	.18	.68
Subbase	.03	.68	.03	.68	.03	.68	.03	.68
Subgrade	.04	.84	.06	.82	.06	.82	.06	.82

The fatigue characterization of the asphalt paving mixtures were determined at 21ºC using the indirect tensile fatigue test. The characterization curves of initial strain verses fatigue life in terms of the number of load applications to failure for the reinforced paving mixtures, in comparison to the conventional paving mixture, are presented in Figure (1). The fatigue analysis in the VESYS model required the determination of the fatigue coefficients K_1 and K_2 for the following equation

$$N_f = k_1 \, (1/\varepsilon)^{K_2} \tag{1}$$

where

Nf is the number of load applications to failure
ε is the initial induced tensile strain and

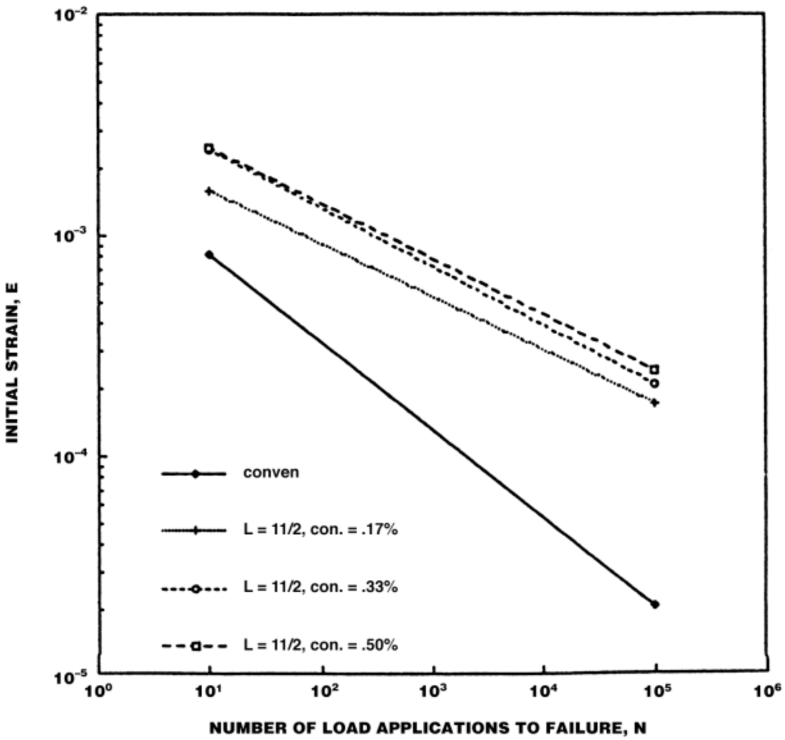


FIG. 1. Strain VS number of load applications to failure at 21ºC for conventional and reinforced paving mixtures.

K_1 and K_2 are the material constants which can be determined from regression equation.

The pertinent fatigue coefficients, K_1 and K_2, for each paving mixture are presented in Table 3.

TABLE 3. Fatigue coefficients.

Coefficient / Material	K_1	K_2
Conventional W/C	4.855 × 10-E10	2.525
0.17% Reinforced W/C	3.470 × 10-E10	4.098
0.33% Reinforced W/C	5.215 × 10-E10	4.110
0.50% Reinforced W/C	2.637 × 10-E10	4.153

2.1 Rutting

The VESYS 3AM predicts pavement rutting primarily as a function of the laboratory-determined permanent deformation parameters of the pavement layers. The predicted rut depth is based on the cumulative permanent strain damage to all the pavement layers. Table 4 presents the predicted increase in the rutting depth with time for both conventional and reinforced paving mixtures. Examination of the results indicate that the pavement section with conventional paving mixture, as a wearing course, resulted in excessive pavement rutting in 5 years. However, when reinforced paving mixtures were used the pavement rut depth was marginally decreased. Also, it was found that the change in the fiber content within the limit of the study was not significant.

TABLE 4. Predicted rut depth in the top layer (mm).

Time (Year)	EAL_{18} 1×10^3	% of fiber content in the paving mixture			
		0.0%	0.17%	0.33%	0.50%
1	36	7.3	7.0	7.0	7.0
5	182	13.2	12.5	12.5	12.5
10	365	16.8	16.5	16.2	16.3
15	547	19.5	19.0	18.8	18.9
20	730	21.8	21.2	20.5	20.5

2.2 Fatigue Cracking

The VESYS 3AM predicts a dimensionless cracking index based on Miner's damage hypothesis[8] which is an indicator of the expected fatigue cracking of the pavement. The cracking index estimates the occurrence of fatigue cracking, and for which a value of one corresponds to the time when the cracking just initiated at the bottom of the asphalt layer. It is generally believed that a value of cracking index between 1.0 and 1.5 indicates slight surface cracking, while a value of 1.5 to 2.5 represents moderate surface cracking, and a value of 2.5 to 3.5 indicates a severe surface cracking[9]. The predicted values are mainly a function of fatigue parameters K_1 and K_2, traffic loading, pavement temperature variations, and layer thickness. The predicted cracking indices are presented in Table 5. It indicates that pavement section constructed with conventional paving mixture would exhibit moderate cracking after 5 years while no cracking would appear if reinforced mixtures were used.

TABLE 5. Fatigue cracking damage index.

Time (Year)	EAL_{18} 1×10^3	% of fiber content in the paving mixture			
		0.0%	0.17%	0.33%	0.50%
1	36	0.41	0.18	0.11	0.14
5	182	2.07	0.87	0.50	0.73
10	365	4.14	1.75	1.06	1.46
15	547	6.20	2.62	1.59	2.19
20	730	8.27	3.50	2.12	2.92

2.3 Present Serviceability Index

The VESYS 3AM program predicts the overall structural adequacy of the pavement in terms of the present serviceability index (PSI). A summary of the predicted service life of the pavement sections is presented in Table 6. The data presented in the table indicates that the service life of the pavement section would be influenced by the amount of fiber used to reinforce the paving mixture. For the aforementioned loading and environmental conditions, conventional pavement would provide 5 years of service life while reinforced pavement sections would extend the pavement's service life up to 7.6 years for 33% fiber reinforced paving mixture.

TABLE 6. Predicted service life of pavement (Terminal PS I = 2.5).

	% of fiber content in the paving mixture			
	0.0	0.17%	0.33%	0.50%
Time (Year)	5.0	5.9	7.6	6.6

3. Life Cycle Cost Analysis

Often, pavement designers try to develop a pavement that is inexpensive without considering, in most cases, the resulting maintenance and rehabilitation costs. In reality, pavement rehabilitation activities have a considerable impact on the overall cost associated with maintaining the pavement at an acceptable level of service. Therefore, the economic assessment of using reinforced paving mixtures requires that both short and long term effects be ascertained. Ideally, the designers should try to select the pavement that will serve traffic needs for the least cost, while maintaining a maximum level of service over the pavement life.

In order to accurately and fairly compare the performance of the reinforced asphalt pavement with the conventional asphalt pavements, both should be evaluated based on their total cost over the analysis period. Several methods have been proposed over the last few decades for determining the cost of highway and road systems[10]. However, the life-cycle analysis method based upon the calculation of an equivalent uniform annual cost (EUAC) per kilometer per traffic lane would seem most appropriate. This method converts over time the considered cost components, such as initial construction cost, major rehabilitation cost, maintenance cost, and salvage value into a single cost per year. Comparison of alternatives is made on the basis of the difference in EUAC, the lowest annual cost being the more economic alternative.

3.1 Cost Components

The selection of the proper cost components or items is an important part of making life cycle cost analysis. Furthermore, in comparative economic analysis of different pavement types, only their different costs are relevant while similar associated costs should not be considered[11]. Therefore, costs that are not affected by using the fiber, such as design and construction cost, were not included in the evaluation. Moreover, routine maintenance, which contributes more to the safe operation of the facility and little to the pavement performance, was also omitted. Consequently in this analysis, only the initial construction cost and the cost of major rehabilitation treatments, which are considered meaningful in the context of performance and life expectancy of the pavement, were included. Furthermore, this economic assessment did not attempt to identify all the benefits or disadvantages associated with the use of fiber, but merely those which comprise the basis of traditional pavement cost analysis. Additional benefits that might be expected from using fiber reinforced paving mixture such as improved “ridability,” comfort, and reduction of accidents associated with major rehabilitation activities, among others, were also not considered.

3.1.1 Initial Construction Cost

The first primary cost associated with material selection for the construction of asphalt pavement is the initial construction cost. The primary difference in initial construction cost is the cost of fiber used to reinforce the paving mixture. The increase in cost depends mainly on the amount and the cost of fiber used to reinforce the paving mixture. The unit cost for the conventional construction materials used to construct the pavement section, have been based on the 1994 average construction cost for local projects per unit volume in Saudi Riyals, as given in Table 7. The cost of reinforced asphalt paving mixture will always be more than the cost of conventional asphalt paving mixture. The fiber cost effects on the pavement wearing course were evaluated at three different fiber contents. The unit cost of the reinforced paving mixtures at a fiber cost ranging from5 to 25 Saudi Riyals per kilogram is presented in Table 8.

TABLE 7. Average cost of conventional paving materials in Saudi Riyals, per one cubic meter.

Item	SR
Wearing course	150
Base course	140
Subbase	25
Milling	40

TABLE 8. Cost of wearing course reinforced paving mixture for different fiber cost in Saudi Riyals, per one cubic meter.

Asphalt mix	Fiber cost per kilogram				
	5	10	15	20	25
0.17% Reinforced W/C	159	167	176	184	193
0.33% Reinforced W/C	167	183	200	216	233
0.50% Reinforced W/C	175	200	225	250	275

To assess accurately the economic feasibility of reinforced asphalt mixture, identical pavement sections composed of conventional and reinforced paving mixture were evaluated for their performance. A 100 mm layer thickness of conventional and reinforced paving mixtures were used as a surface layer. As described earlier, each wearing course layer was supported by 200 mm base course and 300 mm subbase. The initial construction cost of the pavement sections, for different fiber cost per kilometer, is presented in Table 9.

TABLE 9. Initial construction cost per kilometer of pavement in Saudi Riyals.

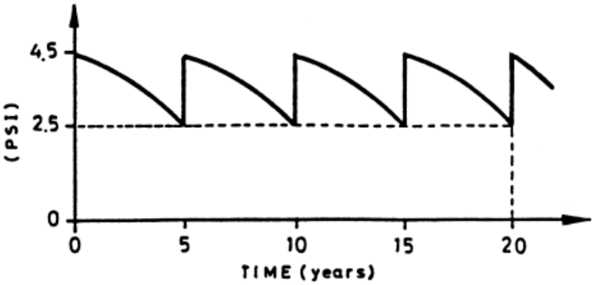
Fiber cost per kilogram	% of fiber content in the paving mixture			
	0.0%	17%	0.33%	0.50%
5	283500	288855	293895	299250
10	283500	294210	304290	315000
15	283500	299565	314685	330750
20	283500	304920	325080	346500
25	283500	310275	335475	362250

The other cost items that might be incorporated within the reinforcing process of the paving mixture are the costs associated with cutting and uniformly dispersing the fiber throughout the paving mixture (cutting the fiber and mixing time). In this economic analysis the quoted glass fiber costs include the cost of cutting the fiber at any desirable length and transportation. Furthermore, in the process of dispersing the 25 mm fiber lengths into the asphalt paving mixture, it was found that the mixing times for both the conventional and the reinforced mixtures were the same[6]. Therefore this cost item was assumed to be equal and was therefor omitted.

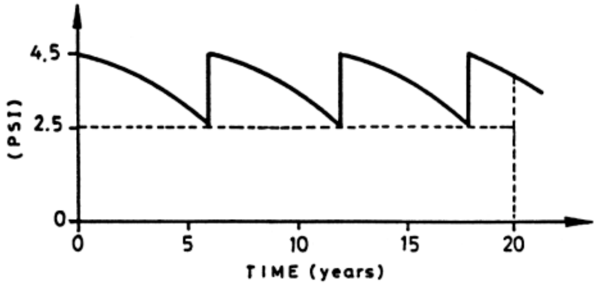
3.1.2 Rehabilitation Cost

In a life-cycle most analysis of a pavement, a key component is the assessment of the pavement service life after construction, and the subsequent major rehabilitation requirement within the analysis period. Therefore, the performance data obtained from the VESYS model, presented previously, were used to develop performance curves for both conventional and reinforced paving mixtures as shown in Figure 2. The major assumptions used in developing the performance curves are that the strategy for rehabilitating the pavement sections will be overlay. It is also assumed that the building material which will be used in overlay is similar to the material used in initial construction. The pavement is assumed to regain its original serviceability level after the construction of new overlay and the overlay will extend the pavement life another period equivalent to the original period predicted by the model.

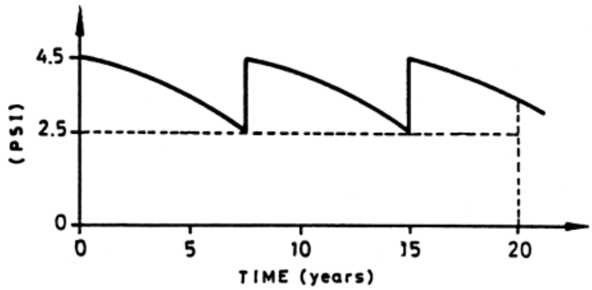
Rehabilitation cost consists mainly of the cost associated with resurfacing (overlay) of the pavement section. The thickness of the overlay is a major factor in the rehabilitation cost. In this evaluation, an overlay of 50 mm was selected. The time of the rehabilitation activities was determined based on the pavement performance curves. These performance curves indicate that, as a rehabilitation strategy, a new overlay would be constructed whenever the pavement reaches the terminal serviceability level of 2.5. Therefore, the resurfacing costs and its frequency will, of course, vary with type of the material used. Table 10 presents the rehabilitation cost per kilometer using both the reinforced and the conventional paving mixtures at different fiber costs. The rehabilitation cost consists mainly of the cost of milling 50 mm of the old pavement surface and constructing new 50 mm overlay.



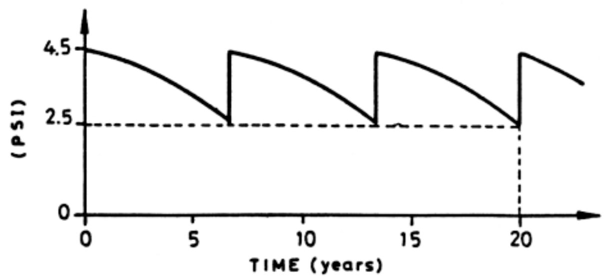
Performance Curve for Conventional Paving Mixture.



Performance Curve for 0.17 % Fiber Reinforced Paving Mixture.



Performance curve for 0.33 % Fiber Reinforced Paving Mixture.



Performance Curve for 0.50 % Fiber Reinforced Paving Mixture.

FIG. 2. Performance curves for conventional and reinforced paving mixtures.

TABLE 10. Rehabilitation cost per kilometer of pavement in Saudi Riyals.

Fiber cost per kilogram	% of fiber content in the paving mixture			
	0.0%	17%	0.33%	0.50%
5	111300	116655	121695	127050
10	111300	122010	132090	142800
15	111300	127365	142485	158550
20	111300	132720	152880	174300
25	111300	138075	163275	190050

3.1.3 Salvage Value

The salvage value refers to the remaining useful life of the pavement at the end of the analysis period. Conceptually, the salvage value is equivalent to how much the pavement is "worth" at the end of the analysis period. The salvage value was calculated as follows:

$$SV = ICC - (1 - Y/Y_E) * RC \tag{2}$$

where,

SV = salvage value
ICC = initial construction cost
Y = number of years before the next rehabilitation at the end of the analysis period
Y_E = expected useful life of pavement or expected rehabilitation useful life and
RC = rehabilitation cost of pavement

3.1.4 Analysis Period and Discount Rate

Analysis period and discount rate are two important factors which have a significant effect on the life cycle evaluation process. The analysis period is the time used for comparing the paving materials and selection of this period is an important factor in life cycle cost analysis. Generally, the analysis period should be chosen so that the cost factors involved in comparing the different paving materials can be defined with reasonable accuracy[11]. In this analysis a 20 year analysis period was selected. On the other hand, the discount rate is used as a method for reducing future costs to present costs, or equivalent uniform annual cost, taking into account the value of capital. In this analysis a discount rate of seven percent was used to reduce various costs to equivalent uniform annual cost so that the cost of different materials can be compared on a common basis.

3.2 Analysis and Results

Having established a mean of cost comparison, the intent now is to evaluate the economical feasibility of using fiber reinforced asphalt paving mixture. The idea of this evaluation is to find the break even fiber cost for the different pavement sections composed of paving mixtures with different fiber content, based on the EUAC for each pavement section. A decision can then be made on selecting the most economical fiber content.

Since each of the four pavement sections (reinforced and conventional) behaves differently and requires different pavement rehabilitation costs at different times, the associated cost for each pavement must be accumulated in a manner that keeps their cost comparable. This can be accomplished by converting all cost throughout the pavement life into the EUAC.

To calculate the EUAC, each cost item is reduced to an EUAC over the analysis period by using the appropriate factor. The initial construction cost is multiplied by the "capital recovery factor"; major rehabilitation costs are first multiplied by the "present worth factor" to reduced it to present worth, and then multiplied by the "capital recovery factor" to arrive at the EUAC; salvage value is reduced to the EUAC by application of the "positive sinking fund factor" (a negative cost)[10].

Figure 3 shows the equivalent uniform annual cost for conventional as well as the three reinforced paving mixtures as a function of fiber cost at 7% discount rate. The results indicate that the use of reinforced paving mixtures is more economical than the use of conventional paving mixture, if the cost of the glass-fiber is less than 10 SR/kg for all evaluated fiber content. Moreover, the use of reinforced paving mixtures with 0.17 and 0.33% fiber is more economical than the conventional mixture if the fiber cost is less than 15 SR/kg. Furthermore, the figure shows that the reinforced paving mixture with 0.33 percent fiber is more economical than conventional paving mixture even if the fiber cost goes up to 20 SR/kg.

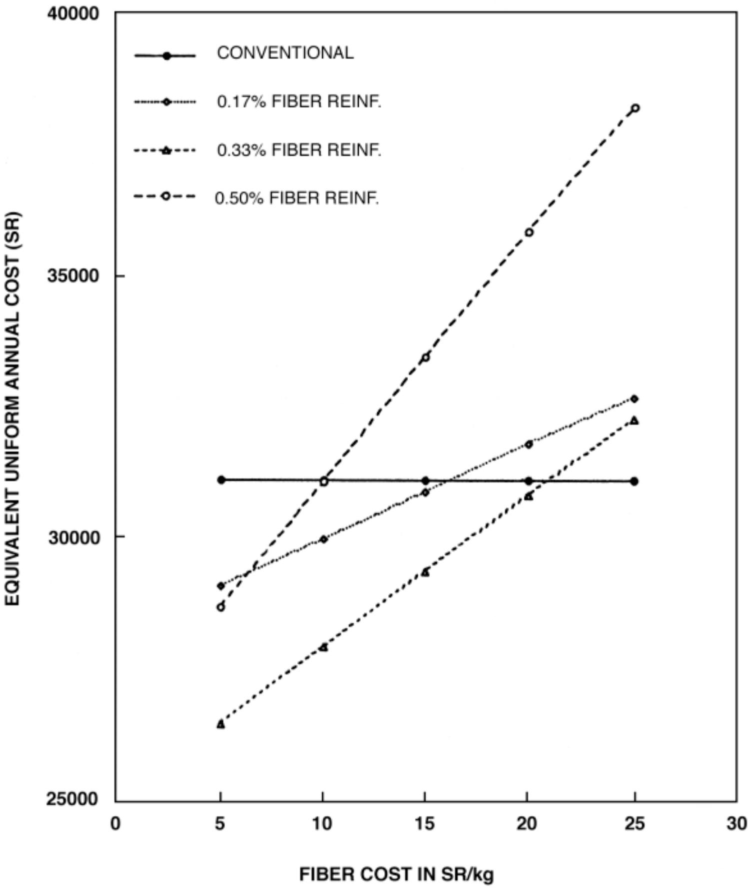


FIG. 3. Equivalent uniform annual cost for conventional and reinforced paving mixtures vs fiber cost.

4. Conclusions

Given today's economic situation and the degree to which the funds for building and maintaining highways must be stretched, it is important that pavement technologists and decision makers be aware of the recent developments in new construction materials and the effectiveness of using these materials in improving the overall pavement performance. Whereas reinforcing the paving mixture will always increase the initial construction cost of the pavement, this cost may be offset by a reduction in the associated pavement rehabilitation cost over the pavement life, thereby making the reinforcement more economical in terms of overall cost as shown by this evaluation.

The result of this evaluation shows that reinforcing the paving mixture with fiber improves the performance of the pavement structure, thereby reducing the frequency of future rehabilitation costs and resulting in a more economical pavement. Based upon the life cycle cost analysis, reinforced paving mixture appears to be more economical than the conventional paving mixture by a considerable margin especially when the actual fiber market price is considered. A market price ranging from 10 to 15 SR/kg was quoted by the fiber supplier, depending on the required amount.

Some considerations which cannot be reduced to monetary units, may yet favorably influence decision making concerning the feasibility of using reinforced paving mixture; examples are smoother "ridability" and decrease in user inconvenience and accident associated with the decrease in the frequency of pavement rehabilitation activities. These factors might result in the choice of reinforced paving mixture over conventional paving mixture even at a higher fiber cost.

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تسليح خلطات الرصف الزفتية بالألياف الزجاجية : تحليل جدوى اقتصادية

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المستخلص . يتطلب التطور السريع لمضافات ومحسنات الزفت المختلفة من مهندسي الطرق إتخاذ قرارات مناسبة حول فعالية هذه المواد لتبرير استخدامها . لذلك فإنه أصبح من الضروري وضع برنامج لتثقيف مهندسي الطرق بالتطور الحديث في مجال هذه المواد وطرق استخدامها وتقويمها . يقدم هذا البحث تقويمًا اقتصاديًا لأداء استخدام الألياف الزجاجية كعامل تسليح في خلطات الرصف الزفتية . ولقد أخذ في الاعتبار العوامل المؤثرة في ذلك مثل تكلفة التشييد الأساسية ، وتكلفة الصيانة الدورية ، وقيمة طبقات الرصف عند نهاية الفترة التحليلية . حيث أظهرت نتائج هذا البحث أن خلطات الرصف الزفتية المسلحة بالألياف الزجاجية قد حسنَّت الأداء العام لطبقات الرصف الزفتية . كما أدى هذا التحسين إلى خفض تكلفة الصيانة مما جعل تسليح خلطات الرصف الزفتية ذا جدوى اقتصادية عند الأخذ بعين الاعتبار التكلفة الإجمالية لطبقات الرصف .