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Replacing Fibre Reinforced Concrete with Bitumen Asphalt in Airports

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Abstract**—**Concrete pavement has superior durability and longer structural life than asphalt pavement. Concrete pavement requires less maintenance compared to asphalt pavement which requires maintenance and major rehabilitation. Use of the concrete pavement has been grown over the past decade in developing countries. Fibre reinforced concrete (FRC) has been successfully used in design of concrete pavement in past decade. In this research, the effect of fibre volume fraction in modulus of rupture, load-deflection, equivalent flexural strength ($f_{e,3}$) and the equivalent flexural strength ratio ($R_{e,3}$) has been used in different fibre volume fraction. Crimped-type flat steel fibre of size 50 x 2.0 x 0.6 mm was used with 1.0%, 1.5% and 2.0% volume fraction. Beam specimens of size 500 x 100 x 100 mm were used for flexural as well as with JCI method for analysis flexural toughness, equivalent flexural strength. It was obtained as the 2% fibre volume fractions; reduce 45% of the concrete pavement thickness.

Keywords**—**Concrete pavement, Equivalent flexural strength, Fibre, Load-deflection curves.

I. INTRODUCTION

WITH increasing traffic volumes and an increased demand for innovative rehabilitation and repair of the aging transportation infrastructure, the growth of the concrete pavement product usage in would has been continuous over the past decade. Transportation departments and municipalities are continuously looking for timely and cost effective renovation, repair and rehabilitation technologies to effectively manage this massive investment including new asphalt and concrete pavement products.

Plain concrete is an inherently brittle material with low tensile strength and strain capacity.The use of steel fibres considerably improves its structural characteristics such as static flexural strength, impact strength, tensile strength, ductility and flexural toughness, the cracking performance of concrete pavements and reduce the required slab thickness. But the most important improvement imparted by steel fibres is the ability to control crack widths and carry significant stresses after the initial cracking of the concrete. This improvement in post-cracking behavior gives the concrete a pseudo-ductility that is known as toughness. The degree of improvement depends upon many factors such as size, type, aspect ratio and volume fraction of fibres.

The use of discrete fibres in concrete slabs on ground (or concrete pavement) application has been reported in the literature for over 40 years [1]-[5]. Mindess et al. reports that 60 percent of fibre applications are for concrete slabs on ground for which they have been used as secondary reinforcement [6], [7].FRC pavements have been successfully designed and constructed with also some premature failures as reported in the literature. Overall, the failures of FRC pavement were related to insufficient thickness design especially for overlays and/or the use of large joint spacing (>30ft.).

Studies have shown that steel fibres increase the flexural and ultimate load carrying capacity of concrete slabs and the magnitude of the increase is related to the fibre volume and aspect ratio. Beckett concluded that as the steel fibre content increased from 20 to 30 kg/m^3 for an aspect ratio of 60 (fibre length divided by diameter), the increase over plain concrete first flexural crack strength of the slab went from 11 to 33 percent [8]-[10].

Tatnall and Kuitenbrouwer concluded that the theoretical results based on Westergaard elastic analysis did not accurately predict the flexural cracking loads of slabs (based on concrete beam flexural strengths) [11], [12]. Similarly, Roesler et. al.[13] showed that concrete slabs under monotonic loading had an increased flexural strength over companion beam specimens by as much as 30 percent, while the calculated Westergaard stress resembled the concrete beam flexural strength. Roesler et al. analyzed the flexural resistance of beams and large-scale slabs on ground using different type of fibres and concluded that discrete fibres contribute to the flexural strength of concrete slabs beyond what is predicted by beam tests [13]. The slabs' flexural strengths were 1.8 to 2.2 times greater than the beam flexural strengths for the fibre-reinforced concrete and 1.4 times greater for the plain concrete. The flexural cracking load of the fibre-reinforced slabs was 25 to 55 percent higher than the plain concrete slab. The addition of synthetic fibres at 4.4 kg/m^3 and hooked end steel fibres at 27.3 kg/m^3 increased the flexural cracking load relative to plain concrete slabs by 30 percent. The crimped steel fibres at 39 kg/m^3 showed the greatest increase to the flexural strength (55%), which was primarily attributed to its higher concrete flexural strength. Results of large-scale slab tests and beam toughness tests have shown that structural synthetic and steel fibres increase the

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flexural capacity of plain concrete slabs. The equivalent flexural strength ratio ($R_{e,3}$) obtained from flexural beam toughness tests predicted the increase in the flexural capacity of steel and synthetic fibre-reinforced concrete slabs over plain concrete slabs. Fibrous concrete with an $R_{e,3}$ of 30 percent can reduce the required slab thickness on an airfield rigid pavement by 17 percent [14].

II. ALTOUBAT SIMPLIFIED DESIGN METHOD

Altoubat et al. proposed a new approach to design pavements with FRC, using the equivalent flexural strength of the FRC material [14]. The main reason for this method is that flexural strength results obtained from beam tests have not been consistent with the large-scale experimental results showing considerable difference in the load carrying capacity between fibrous and plain concrete slabs. Since the MOR does not characterize the difference in strength between plain and FRC slabs, an alternative strength measure is required to demonstrate the toughness benefit of FRC over plain concrete. This method uses the equivalent flexural strength ($f_{e,3}$), which was developed in Japan and can be obtained from bending of beams under third-point loading. This parameter uses the residual strength or the post-cracking strength of fibre reinforced concrete. The equivalent flexural strength is proportional to the area under the load-deflection curve up to a central beam deflection of 3 mm (for a 450 mm span) and is calculated as follows:

$$f_{e,3} = \frac{1000TL}{3bh^2} \tag{1}$$

where, T is the area under the load-deflection curve (in N-m) up to a central beam deflection of 3 mm, L is the span between the supports (mm), b is the width of the beam (mm) and h is the depth of the beam (mm). The equivalent flexural strength ratio, $R_{e,3}$, is defined as the ratio between the $f_{e,3}$ value and the concrete MOR:

$$R_{e,3} = \frac{f_{e,3}}{MOR} \times 100 \tag{2}$$

The $R_{e,3}$ has been positively correlated to the increase in flexural and ultimate load capacity of the fibre-reinforced concrete SOG over plain concrete slabs.

The effective modulus of rupture (MOR') is based on proportionally increasing the concrete beam MOR by the $R_{e,3}$ value to account for the contribution of fibres to slab flexural capacity in existing rigid pavement design procedures.

$$MOR' = MOR\,(1 + \frac{R_{e,3}}{100}) \tag{3}$$

This effective MOR' approach allows for the benefits of fibres, which is primarily thickness reduction, to be realized in existing concrete pavement design procedures. The proposed method targets fibre reinforced concrete pavement with low volume fraction (~0.5%) in which the equivalent flexural strength ratio ($R_{e,3}$) varies between 20 and 50 percent. This residual strength capacity offered by fibres can be achieved without modifying conventional concrete paving mixtures for workability and constructability. The ration of thickness is obtained from the eq. 4.

$$\sqrt{\frac{MOR'}{MOR}} = \frac{h}{h'} \tag{4}$$

h and h' is the thickness of plain concrete and fibrous concrete, respectively.

III. BENEFITS OF CONCRETE PAVEMENT

1) Concrete pavement lasts twice as long: One of the most well known advantages of concrete is its superior durability and longer structural life. The expected life of an asphalt road is 17 years compared to 34 years for concrete [15].
2) Concrete pavement eliminates spring load restrictions: A study by the AASHTO Road Test showed that 61% of asphalt roads fail during spring conditions compared to 5.5% for concrete [16].
3) Concrete pavement does not rut, washboard or shove: Heavy loads can create ruts in asphalt roadways, while the stopping and starting motion can create a washboarded surface. The rigid surface of concrete, however, prevents these types of deformation from occurring in concrete roads.
4) Concrete pavement provides fuel savings for heavy vehicles: Heavy vehicles cause greater deflection on flexible pavements than on rigid pavements. This increased deflection of the pavement absorbs part of the vehicle energy that would otherwise be available to propel the vehicle, thus, the hypothesis can be made that more energy and therefore more fuel, is required to drive on flexible pavements. Concrete's rigid design reduces road deflection and corresponding fuel consumption. In 1982, Dr. Zaniewski reports that the savings in fuel consumption for heavy vehicles travelling on concrete versus asphalt pavements was up to 20% [17].

IV. EXPERIMENTAL PROGRAM

The concrete mix used for casting the test specimens is shown in Table 1. Ordinary Portland cement, crushed stone coarse aggregates having maximum size 12.5 mm and river sand were used. The specimens incorporated corrugated steel fibres, namely aspect ratio of 40 (fibre size 0.6 x 2.0 x 50 mm) of the fibre volume fractions of 1.0%, 1.5% and 2.0% by weight. The tensile strength of fibre was 801 MPa. The compressive strength test was conducted on concrete cubes of size 150 mm x 150 mm x 150 mm to obtain the 28-days compressive strength of concrete. The load was applied at a rate of 14 $N/mm^2/min$.The static flexural strength of concrete was obtained by testing 100 mm x 100 mm x 500 mm size test specimens under three point flexural loading on a simply supported span of 450 mm at a constant of 0.1 mm/minute [18]. All the static flexural tests were conducted on a 100 kN INSTRON close loop electro-hydraulic Universal Testing Machine. The complete load deflection curve was obtained for each specimen tested. The first crack load, defined as the point at which the load deflection curve first deviates from linearity and the maximum load attained was noted for each test specimen. The flexural strength for each specimen was calculated using standard procedure. The compression and static flexural strength of plain concrete is shown in Table1.

TABLE I
CONCRETE MIXTURE PROPORTIONS AND COMPRESSIVE STRENGTH OF PLAIN CONCRETE

Water/ Cement ratio	Sand/ Cement ratio	Coarse Aggregate/ Cement Ratio	f_{cu} (MPa)
0.35	1.35	2.12	57.82

A. Flexural toughness

Flexural toughness is an important parameter in assessing the influence of fibres on the post-peak response of the concrete composites. The flexural toughness was determined using the JCI methods. The JCI method, toughness TJCI, is defined as the area under the load-deflection curve up to a deflection of 1/150 of span (δ150, Fig.1) [19]. By accounting for the beam size and span, T_{JCI} is presented using the toughness factor, σ_b as follows:

$$\sigma_b = \frac{T_{JCI} L}{\delta_{150} b h^2} \tag{5}$$

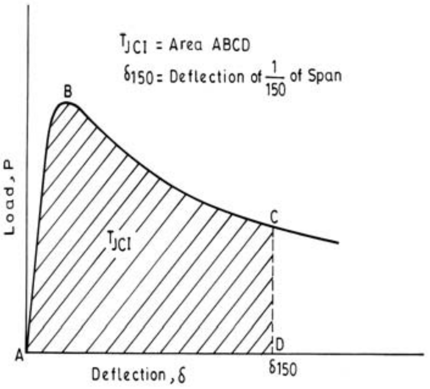

Fig. 1 Definition of flexural toughness (JCI method)

V. RESULTS AND DISCUSSION

A. Static flexural strength test results

The static flexural strength test results corresponding to different fibre volume fractions used in this investigation is presented in Table 2. The maximum increase in static flexural strength, taken as average of 12 beams, varied from 34% - 100% for concrete mixes having 1.0%, 1.5% and 2.0% volume fractions of fibres. The maximum increase in static flexural strength of 100% was observed for concrete with 100% at fibre volume fraction of 2.0%.The peak loads, first crack loads and the corresponding centre-point deflections, taken as average for the 12 beams, with different volume fractions of fibres are listed in Tables 2 and 3. The increase in centre point deflection corresponding to ultimate load, taken as average of 12 beams, was observed to vary between 61-167% for concrete mixes having 1.0%, 1.5% and 2.0% fibre volume fractions. The maximum increase in ultimate load deflection of 167% with respect to plain concrete was observed in case of fibrous concrete specimens having 2.0% volume fractions of fibres. Similarly, it can be observed from Table 3 that there is an increase in first crack load of the order of 16–34% for concrete mixes having 1.0%, 1.5% and 2.0% fibre volume fractions. The maximum increase in first crack load of 16%, 26% and 34% with respect to plain concrete was observed at all the three fibre volume fractions tested in this investigation. The maximum increase in first crack deflection of 14–21% with respect to plain concrete specimens was observed for fibrous concrete specimens with fibre volume fraction of 1.0–2.0%, respectively. The load deflection curves for steel fibrous concrete specimens for different fibre volume fraction is presented in Fig. 2. It can be observed from the static flexural test results obtained in this investigation that the fibres have greater influence on the peak load and deflection at peak load. The comparison of first crack and ultimate loads presented in Table 2 and 3 show that fibre reinforcement exercises greater influence on the ultimate load of the composite than on the first crack load. From a perusal of the results of this investigation, it can be concluded that in general, up to a fibre content of 2.0%, the first crack load and the ultimate load were found to increase with increase in the volume fraction of fibres in the concrete mix. The fibre volume fraction is more effective in influencing the ultimate load and deflection than the first crack load and the corresponding deflection.

TABLE II
LOAD AND DEFLECTION WITH DIFFERENT FIBRE VOLUME FRACTIONS

Fibre Volume Fraction (%)	MOR (MPa)	Maximum Load and Deflection	
		Deflection (mm)	Load (kN)
0	5.35	0.3383	11.88
1.0	7.50	0.5453	16.68
1.5	9.44	0.6610	20.98
2.0	10.72	0.9020	23.83

TABLE III
FIRST CRACK LOAD AND DEFLECTION WITH DIFFERENT FIBRE VOLUME FRACTIONS

Fibre Volume Fraction (%)	MOR ((MPa)	First Crack Load and Deflection	
		Deflection (mm)	Load (kN)
0	5.35	0.3383	11.88
1.0	7.50	0.3977	13.76
1.5	9.44	0.3997	15.19
2.0	10.72	0.4053	15.89

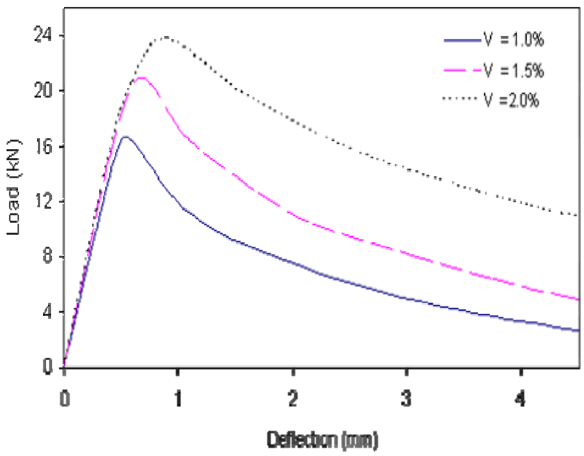

Fig.2 Load deflection curves for fibrous concrete at different fibre volume fractions

B. *Flexural toughness and equivalent flexural strength of FRC*

The results of the toughness indices using the JCI methods, the equivalent flexural strength ($f_{e,3}$) and $R_{e,3}$ values for concrete mixes with three volume fractions of steel fibres as obtained from the corresponding load deflection curves are presented in Table 4.

From perusal of the test results, it is evident that the T_{JCI} indices increase with increasing fibre content in the concrete mix. The equivalent flexural strength and $R_{e,3}$ values increase with increasing fibre volume fraction in the concrete mix. The maximum values of T_{JCI}, ($f_{e,3}$) and $R_{e,3}$ varied from 52.306, 7.846 and 73.19 at fibre volume fraction of 2.0%, respectively.

TABLE IV
EQUIVALENT FLEXURAL STRENGTH

Fibre Volume Fraction (%)	T_{JCI} N-m	$f_{e,3}$	MOR	$R_{e,3}$
0	2.010	0.301	5.35	5.63
1.0	27.102	4.065	7.5	54.20
1.5	36.89	5.534	9.44	58.62
2.0	52.306	7.846	10.72	73.19

The results of the MOR, MOR', h/h' and thickness reduction values for concrete mixes with three volume fractions of steel fibres is presented in Table 5. It was observed that MOR' varied from 5.65 to 18.57 at fibre volume fraction of 0-2.0%. The reduction of thickness varied from 30%, 39% and 45% for fibre volume fraction of 1%, 1.5% and 2%, respectively.

TABLE V
AVERAGE OF THICKNESS REDUCTION

Fibre Volume Fraction (%)	MOR	MOR'	h/h'	Thickness Reduction (%)
0	5.65	5.65	1.00	0
1.0		11.57	0.70	30
1.5		14.97	0.61	39
2.0		18.57	0.55	45

VI. CONCLUSION

Fibrous concrete in pavement with different fibre volume fractions have been investigated. The present result is obtained.

- The static flexural strength test results increase 100% for concrete at fibre volume fraction of 2.0%
- The fibre volume fraction is more effective in influencing the ultimate load and deflection than the first crack load and the corresponding deflection.
- Toughness indices using the JCI methods increase significantly with increasing fibre volume fractions.
- The equivalent flexural strength and *Re*,3 values increase with increasing fibre volume fraction in the concrete mix.

Concrete pavement thickness reduced with increasing fibre volume fraction in the concrete mix. This reduction is 45% with 2% fibre volume fraction.

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