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Analysis Of Polymer Fibre Reinforced Concrete Pavements By Using ANSYS

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ABSTRACT

This paper presents an assessment of the performance of polymeric concrete with synthetic fibre reinforcement against reflective cracking in an overlay system. The performance of polymeric concrete with synthetic fibres as an overlay material is measured in terms of the load-deflection, strain-deflection and load-strain behaviour of beams of the polymeric concrete. For this purpose, five types of beams having different number of fibre wires and position are tested for flexure strength. Deflection/strains for each increment of load are recorded. In addition, cubes of plain concrete and of concrete with synthetic fibre needles were tested after 7 and 28 days for compressive strengths. Finite element models in ANSYS software for the beams have also been developed. Beams with greater number of longitudinal fibre wires displayed relatively better performance against deflection whilst beams with synthetic fibre needles showed better performance against strains. Thus, polymeric concrete overlay with fibre reinforcement will serve relatively better against occurrence of reflective cracking. Cement concrete pavements are used for heavy traffic loads throughout the world owing to its better and economical performance. Placing of a concrete overlay on the existing pavement is the most prevalent rehabilitating method for such pavements however the problem associated with the newly placed overlay is the occurrence of reflective cracking.

Keywords: Analysis, Polymer Fibre Reinforced Concrete, Pavements, Using ANSYS

1. INTRODUCTION

Concrete is weak in tension and has a brittle character. The concept of using fibres to improve the characteristics of construction materials is very old. Early applications include addition of straw to mud bricks, horse hair to reinforce plaster and asbestos to reinforce pottery. Use of continuous reinforcement in concrete (reinforced concrete) increases strength and ductility, but requires careful placement and labour skill. Alternatively, introduction of fibres in discrete form in plain or reinforced concrete may provide a better solution. The modern development of fibre reinforced concrete (FRC) started in the early sixties. Addition of fibres to concrete makes it a homogeneous and isotropic material. When concrete cracks, the randomly oriented fibres start functioning, arrest crack formation and propagation, and thus improve strength and ductility. The failure modes of FRC are either bond failure between fibre and matrix or material failure. In this paper, the state-of-the-art of fibre reinforced concrete is discussed and results of intensive tests made by the author on the properties of fibre reinforced concrete using local materials are reported. Construction of rigid pavements is essential for airports as well as for highways where weak sub grade exists or heavy traffic volume is encountered. Concrete is the most common material used in the construction of rigid pavements and overlays but the problem associated with concrete is its sensitiveness to moisture loss and shrinks whenever moisture loss occurs due to hydration of cement, evaporation, etc. If concrete member is restrained, then tensile stresses are developed in the concrete and when these stresses touch the tensile strength, cracks are formed.

Mixing of FRC can be accomplished by many methodsl21. The mix should have a uniform dispersion of the fibres in order to prevent segregation or balling of the fibres during mixing. Most balling occurs during the fibre addition process. Increase of aspect ratio, volume percentage of fibre, and size and quantity of coarse aggregate will intensify the balling tendencies and decrease the workability. To coat the large surface area of the fibres with paste, experience indicated that a water cement ratio between 0.4 and 0.6, and minimum cement content of 400 kg/m are required. Compared to conventional concrete, fibre reinforced concrete mixes are generally characterized by higher cement factor, higher fine aggregate content and smaller size coarse aggregate. Due to increasing traffic volume on existing airports and roadways, major challenges are faced by road agencies because they have to repair deteriorated pavements to maintain smooth traffic flow on these pavements. To reduce reflecting cracking, several techniques including a seal coat application to the existing pavement, saw and seal the hot-mix-asphalt (HMA) overlay, cracking and seating of concrete pavements, use of geo synthetics, etc. are used. The agency observed that none of these sections exhibited reflection cracking during the first year following rehabilitation. However, most of the reflection cracking appeared during the second year after rehabilitation. However, relatively small increase in the length of the reflection cracking over time for all of the rehabilitation techniques was noted. In addition, the amount of reflection cracking does not significantly increase after this period. However, it is expected that these cracks will continue to deteriorate.

1.1Scope
The scope of this report includes studying the effect of reinforcing rebar on shrinkage and thermal stresses in concrete by analytical and numerical methods as well as by experimental measurements, and proposing a series of designs for the reinforced CRCP based on the numerical and mechanistic results. The study also reveals some areas where further studies are recommended.

1.2Advantages
- High longitudinal strength.
- Nonmagnetic.
- Corrosion resistance.
- High fatigue endurance.
- Light weight (about one-fifth to one-fourth the density of steel).
- Low thermal and electric conductivity.

2. EXPERIMENTAL PROGRAM

To assess the performance of polymeric concrete with synthetic fibre reinforcement, a polymeric concrete mix with special additives like Styrene-butadiene co-polymer latex (SBR) and pulverized fuel ash (PFA) is prepared.

A. Beam Specimen
A special mold having six chambers was used for casting beams of 360mm x 60mm x60mm. The beam specimens are prepared according to the ASTM, C-192 test procedure. Five groups of beams designated as A, B, C, D and E are casted with different amount and position of fibres. Beam-A is casted from plain mix with no fibre wires, beam-B casted with five fibre wires, beam-C with four fibre wires, D with three fibre wires and beam-E with fibre needles @ 2kg/m3. Two beams are casted for each group. Cubes of standard size (6in3) were prepared from both plain mix and mix with synthetic fibre needles. The molds were filled in three equal layers; each layer was compacted by 35 strokes of 1in square steel punner. After 24 hours, these were unmolded and kept in water till the day of testing.

B. Reinforced Concrete
For modeling of concrete the ANSYS used an element named as Solid65 which is non linear model of brittle material similar to concrete. It was an eight node solid iso parametric element with three degrees of freedom at each node.

C. Steel Reinforcement
For the modeling of steel ANSYS provided an element named as Link180 There were two ways to use it one was smeared and the other is discrete, discrete was considered to be more convergent as it subtracts the area of steel from total concrete which was the actual scenario where as in smeared the steel was embedded in the concrete and behaved as one unit which was not the actual case.

2.1 EXPERIMENTAL DATA
The mild steel flexural reinforcements used were 2#13 bars, 2#10 hanger bars and shear reinforcement included #10 U-stirrups. Cover for the rebar was set to 40mm in all directions.
I. Volumetric Stability (Settlement)
Settlement cracking occurs in freshly mixed concrete as the concrete settles over time and encounters some restraint. The heavier particles sink due to gravity until the concrete sets. Plastic settlement cracking has been frequently observed to occur at changes in cross section. The practical significance of settlement cracking is in the construction of reinforced slabs, and bridge decks. The magnitude of tensile stress generated as a result of plastic settlement, along with the capillary stress and the autogenously effect, may be sufficient to initiate plastic cracking. The role of settlement in plastic cracking has been studied for several decades. Powers (1968) measured the settlement of cement paste by manually monitoring the displacement of a steel pin resting on the surface of fresh concrete. The amount of settlement observed was related to specimen height, water-to-cement ratio (w/c) and concrete consistency (Powers, 1968). A uniform settlement (i.e., homogenous volume contraction) in a fresh concrete mixture does not lead to plastic cracking. Differential settlement however can lead to cracking. Differential settlement can be caused by either external boundaries or embedded rigid inclusions. Simulated the settlement behavior occurring due to embedded rigid inclusions using a model where rebar was positioned in a photo elastic material (gelatin) at variable cover depths and spacing.It

was concluded that clear cover depth, rebar size and rebar spacing are the major factors affecting the magnitude of differential settlement with lager bars and smaller cover depths typically resulting in larger cracks used a non-contact laser device to quantify the amount of settlement occurring in between the time of concrete placement and setting for mortar containing chemical admixtures. It was shown that the mixing and placement time significantly influence the amount of settlement that may occur. For example, when compared with the settlement measured immediately after mixing, the settlement in a material placed 40 minutes after mixing showed nearly a 50% reduction in settlement.

3. ANALYTICAL MODEL FOR FREELY SUPPORTED REINFORCED CONCRETE SLAB

To estimate the development of shrinkage and thermal stresses in a freely supported reinforced concrete slab, a representative concrete prismatic model containing a longitudinal reinforcing rebar at its center with width (or reinforcing space in CRCP) B, height (or thickness in CRCP) H, length L, and rebar diameter 2r is considered. Then, for simplification of analysis, the model is modified into an equivalent cylinder with the corresponding equivalent diameter 2R accompanied by the same length and rebar diameter as those for the prismatic model. Adopting the shear-lag theory, there are several assumptions applied to this analysis the concrete and reinforcement exhibit elastic behavior a perfect bond between concrete and reinforcement exists at an infinitely thin interface, the stiff nesses of the concrete and the reinforcement in the radial direction are the same, the strain in the concrete ε c at a distance R from the x-axis is equivalent to the restraint-free concrete strain due to the shrinkage or temperature variation, and the temperature distribution in the concrete and reinforcement is uniform in the radial direction.(Figure.1)

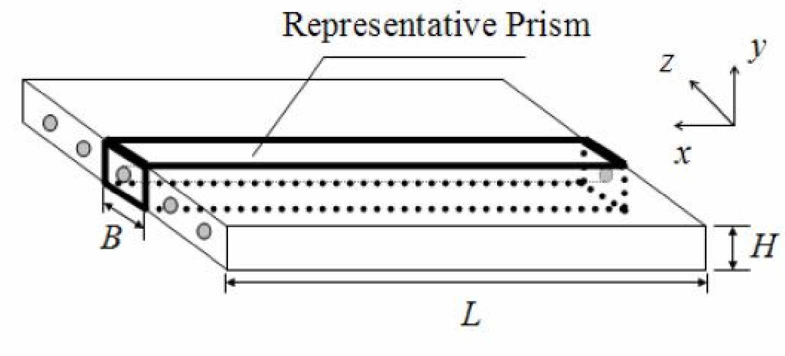

Figure.1 Schematic details of representative reinforced concrete prism.

The effects of concrete's radial shrinkage on concrete stress development in the longitudinal direction are neglected.

A. Finite Element Modeling

Experimental RC beam specimen was analyzed by using ANSYS which is an engineering simulation commercially used software offering a comprehensive suite that spans the entire range of physics, providing access to virtually any field of engineering simulation that a design process requires. The software use it s tools to put a virtual product through a rigorous testing procedure such as testing a beam under different loading scenarios before it becomes a physical object. ANSYS can carry out advanced engineering analyses quickly, safely and practically by variety of contact algorithms, time based loading features and nonlinear material models. In this study it used to carry out discrete modeling of RC beam to analyze it under static loading conditions.

B. Failure Criteria For Concrete

The model developed using ANSYS is capable of predicting failure for concrete materials. Both cracking and crushing failure modes are accounted for. The two input strength parameters i.e. ultimate uni-axial tensile and compressive strengths are needed to define a failure surface for the concrete. Consequently, a criterion for failure of the concrete due to a multiracial stress state was calculated by William and constitutive model for multiracial stresses proposed that in a concrete element, cracking occurs when the principal tensile stress in any direction lies outside the failure surface. After cracking, the elastic modulus of the concrete element is set to zero in the direction parallel to the principal tensile stress direction. Crushing occurs when all principal stresses are compressive and lie outside the failure surface, subsequently, the elastic modulus is set to zero in all directions and the element effectively disappears.

Crack Detection

Cracks may be either macro cracks, detectable by visual inspection, or micro cracks, which can be detected only with microscopes or non-destructive testing. Another distinction is between discrete cracks, for which each has to be located and counted individually, and distributed fine cracks, for which calculations of an area may be more important.

I. Discrete Crack Detection

To find an alternative to the detection of individual cracks by visual inspection, a significant amount of effort has gone into development of automated analysis software for pattern recognition of cracks in digital images. In earlier work, the digital images were obtained by scanning analog photographs. As the resolution, number of pixels, of digital cameras has improved the practice is now to take direct digital images of the area under investigation. In the image analysis process, the software examines each black pixel and its neighbors to decide if it belongs to a given crack. When a crack is detected, it is then characterized by a set of parameters including location, length, width and direction. There are two major considerations in the sensitivity of this process: one is the probability of detection and the other is the probability of false positives. An algorithm with a low probability of detection will miss a significant number of cracks. An algorithm with a high number of false positives may detect a high percentage of actual cracks, but may also mistake other features for cracks.

II. Cracking Due To Chemical Reaction

Deleterious chemical reactions may cause cracking of concrete. These reactions may be due to materials used to make the concrete or materials that come into contact with the concrete after it has hardened. Concrete may crack with time as the result of slowly developing expansive reactions between aggregate containing active silica and alkalis derived from cement hydration, admixtures or external sources (e.g. curing water, ground water, alkaline solutions stored or used in the finished structure). The alkali silica reaction results in the formation of a swelling gel, which tends to draw water from other portions of the concrete.

4. FEA STUDY OF DESIGN CONSIDERATIONS FOR CRCP

4.1 Effect Of Concrete Cte On Stress Development In Crcp

Two different types of concrete, with granite aggregate or siliceous river gravel aggregate, have been adopted in the stress analysis of the CRCP slab segment. The CTEs of granite and siliceous river gravel concrete are 10.26 με/5.7 με/ F) and 14.40 με/ C (8.0με/oF), respectively. In addition, the steel-reinforced CRCP slab segment is analyzed for comparison with the SFRP-reinforced one. The bond between the concrete and reinforcement is assumed to be perfect, and the bond-slip between the concrete slab and sub-base was represented using a spring stiffness of 236.409 kilonewton per meter (kN/m) (1,350 pounds force per inch (lbf/inch)), which is simulated for a flexible sub-base or a lime-treated clay sub-base, having the bond-slip stiffness per unit area of 40.719 MPa/m (150 lbf/in 2 /inch) with respect to the concrete slab.(Figure.2)

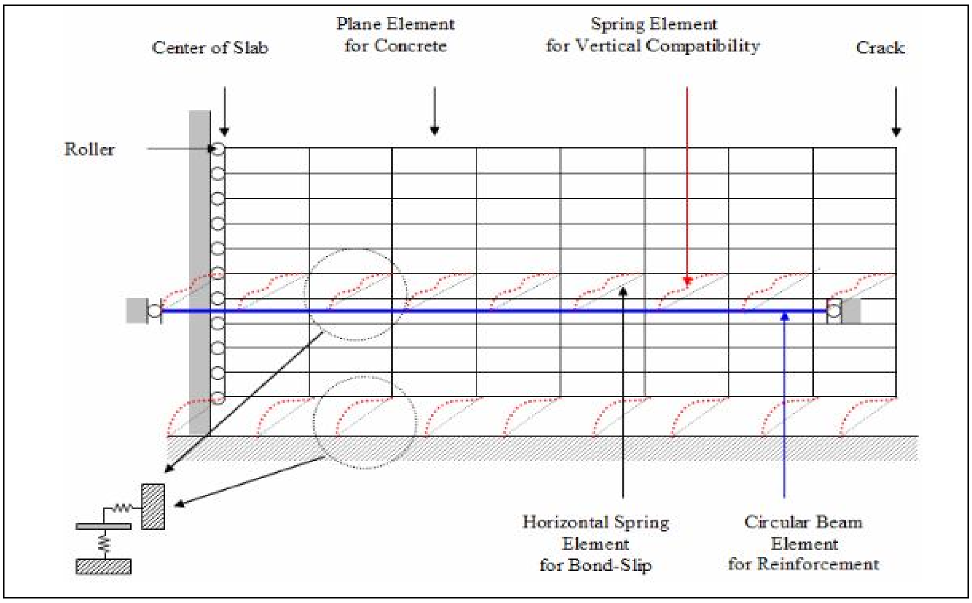

Figure. 2 Schematic details of a 2-D CRCP finite element model.

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4.2crack Development And Reinforcement Stress In Sfrp-Crcp With Varying Concrete Coarse Aggregate Type

The material properties of concrete (such as CTE and Young's modulus) are primarily a function of the type of coarse

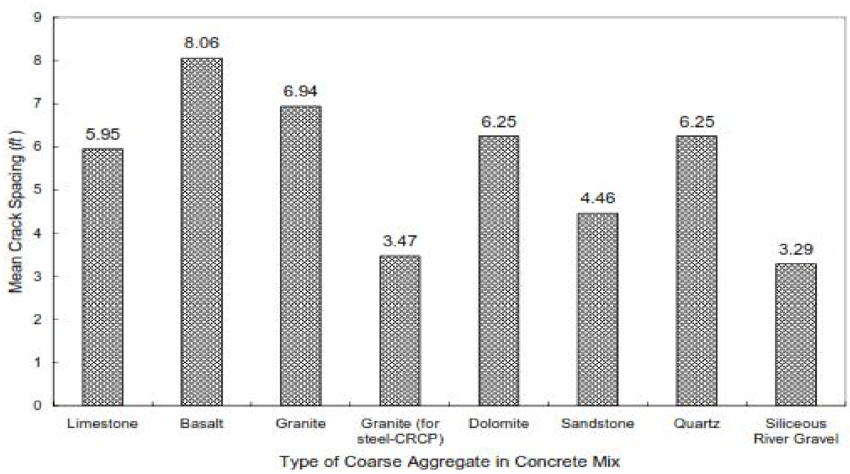
Table 1 Concrete material properties

Coarse Aggregate Type	Coefficient of Thermal Expansion ($\mu\varepsilon$/°F[1])	Compressive Strength (lbf/in^2)[2]	Young's Modulus ($\times 10^6$ lbf/in^2)	Tensile Strength (lbf/in^2)	Flexural Strength (lbf/in^2)	Drying Shrinkage ($\mu\varepsilon$)
Limestone	3.8	4,500	3.6	387	625	626
Basalt	4.8	4,500	3.8	486	992	471
Granite	5.74	4,660	4.56	560	610	394
Dolomite	5.9	4,500	4.8	495	895	458
Sandstone	6.5	4,500	3.8	468	762	498
Quartz	6.6	4,500	4.5	495	868	458
Siliceous River Gravel	8.0	4,500	5.0	419	697	572

[1] 1 $\mu\varepsilon$/°F = 1.80 $\mu\varepsilon$/°C.
[2] 1 lbf/in^2 = 0.00689 MPa.

aggregate, and since these properties are interdependent, a consistent set of properties that are representative of the concrete mixture to be used should be carefully selected for the concrete pavement design and analysis. The approximate sets of concrete material properties are listed in table 6. Except for that of granite concrete, the compressive strengths are assumed to be 31.03 MPa (4,500 lbf/in) to approximate the values of indirect tensile strength, followed by the flexural strength and drying shrinkage values.

Young's modulus of SFRP is smaller than that of steel. Among the SFRP-CRCPs, the CRCP using basalt concrete is predicted to have the largest crack spacing of 2.457 m (8.06 ft), which slightly exceeds the upper limit of allowable crack spacing of 2.438 m (8 ft). This is reasonable since the basalt concrete has a relatively low CTE and Young's modulus, which cause low tensile stress development in concrete and result in less cracks in the CRCP. On the other hand, 52 using the siliceous river gravel concrete creates the smallest crack spacing of 1.003 m (3.29 ft), which results from its high CTE, high Young's modulus, and large shrinkage; this is still acceptable, despite slightly deviating from the lower allowable limit of 1.067 m (3.5 ft).(Figure.3)



1 ft = 0.305 m

Figure.3 Mean crack spacing versus type of coarse aggregate in concrete mix

It is found in the prediction that even though the limestone concrete has the lowest CTE and Young's modulus, the crack spacing is smaller than those for the basalt, granite, dolomite, and quartz concretes (a result of this type having the lowest tensile strength and largest shrinkage). It can therefore be understood that the material properties of each type of concrete must be collectively considered and used in the CRCP design. From the comparison in crack spacing between the SFRP-CRCPs and VDOT's steel-CRCP, it is also found that the SFRP-CRCPs using the sandstone and the siliceous river gravel concretes have crack spacings comparable to that for VDOT's steel-CRCP without increasing the amount of SFRP reinforcement. In addition to the comparable SFRPCRCPs, the SFRP-CRCP using the limestone concrete has a crack spacing of 1.814 m (5.95 ft), which is within the acceptable range for the criteria of crack spacing.(Figure.4)

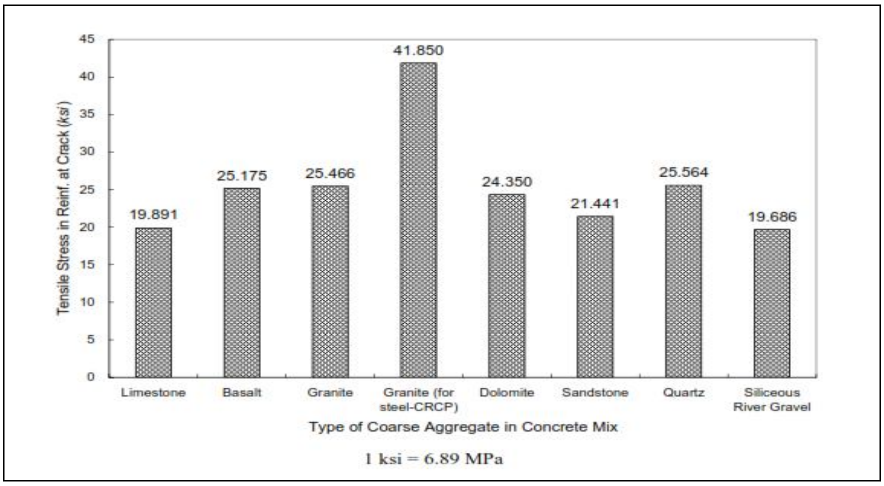


Figure. 4 Crack width versus type of coarse aggregate in concrete Mix

4.3. Crack Development And Reinforcement Stress In Sfrp-Crcp with Varying Sub-base Type

The comparison of the performances of SFRP-reinforced CRCP on various sub-base types was simulated in this section. The linear bond-slip relationships between the concrete slabs and various sub-base types, in terms of bond-slip stiffness per unit area of slab base (GPa/m (lbf/in 2 /inch)), were utilized for the simulation; the relationships were obtained experimentally by a group of researchers at the University of Texas. (33,34,35) The sub-base types considered are untreated clay, asphalt stabilized, flexible, lime-treated clay, and cement stabilized, listed in order of lowest to highest bond-slip stiffness/unit area (GPa/m (lbf/in 2 /inch)). The value of bond-slip stiffness/unit area for each type is shown in table 5. In addition to the cases of the aforementioned sub-base types, hypothetical bond-slip cases of 0.136, 0.271, 0.543, 1.357, and 2.715 GPa/m (500, 1,000, 2,000, 5,000, and 10,000 lbf/in 2 /inch, respectively) were also simulated to find the appropriate range of bond-slip for the considered CRCP that eventually satisfies the limit of crack spacing, crack width, and the reinforcement stress level at crack.

Table 2 Mechanistic prediction of crack development and reinforcement tensile stress at crack for SFRP-CRCP

Subbase Type[1]	Bond-Slip Stiffness/Unit Area ($lbf/in^2/inch$)	Mean Crack Spacing (ft)	Crack Width (inch)	Reinf. Tensile Stress at Crack (ksi)
Untreated clay	21.95	8.62	0.0478	28.501
Asphalt stabilized	55.88	6.94	0.0388	25.466
Flexible	145.45	6.94	0.0388	25.468
Lime-treated clay	154.55	6.76	0.0378	24.769
~	500	5.95	0.0334	23.255
~	1,000	5.68	0.0318	22.893
~	2,000	4.64	0.026	20.887
~	5,000	3.57	0.0201	18.256
~	10,000	2.91	0.0164	16.250
Cement stabilized	15,400	2.45	0.0139	14.871

Therefore, the asphalt-stabilized sub base appears to approximately provide the minimum allowable bond-slip (15.169 MPa/m (55.88 lbf/in 2 /inch)) necessary to avoid spalling distress of the given CRCP. The cement-stabilized sub base was found to have nearly the maximum allowable bond-slip, resulting in a mean crack spacing of 0.747 m (2.45 ft) and a crack width of 0.35 mm (0.0139 inch). The mean crack spacing for the cement-stabilized sub base is somewhat small compared with its limit of about 1.067 m (3.5 ft), having the possibility of punch-out distress. The tensile stresses in the SFRP reinforcement at cracks were also predicted over various sub-base types (figure 7.14). As can be seen in the figure, higher bond-slip causes lower tensile stress in the reinforcement at the crack since the smaller crack spacing is expected with the higher bond-slip. The tensile stresses in the reinforcement corresponding to the sub-base types range from about 103.43 to 199.96 MPa (15 to 29 ksi). The tensile stress levels for most sub-base types, except for that of the cement-stabilized, exceed the allowable tensile stress of 124 MPa (18 ksi). Only the cement stabilized sub-base meets this criterion, even though it may have some possibility of causing punch-out distress in the CRCP. In this simulation calculated by the CRCP8 program, the bond stress between the concrete and reinforcement leads to stress changes in the concrete and reinforcement, and the bond stress varies in the bond development zone; the location of this zone is determined by solving the system of governing equations with the assumed bond stress distribution function and the reinforcement boundary condition.

The performance of GFRP-CRCP in response to traffic loading is mainly dependent on the overall stiffness of the CRCP system. It is generally known that the flexural stiffness of the slab can be significantly influenced by the slab thickness rather than the reinforcement.(30) The thickness design, which determines the pavement stiffness, is accordingly dependent on load transfer 60 coefficient, so it is currently thought that as long as the load transfer capability of GFRP-CRCP is satisfactory, the thickness of GFRPCRCP may be able to remain the same, providing a pavement stiffness comparable to that of steel-CRCP. Currently, the thickness design procedure of steel-CRCP follows that of conventional jointed pavement, and the thickness of steel-CRCP is also recommended to be the same as that of conventional jointed pavement. A possible future construction of 27.94-cm- (11-inch-) thick GFRP-reinforced and steel reinforced CRCP sections are being planned in Elkins, West Virginia, in 2005. Under a given construction condition from the West Virginia Department of Transportation (WVDOT), using number 7 longitudinal GFRP rebars at 15.24-cm (6-inch) spacing on the line about 2.54 cm (1 inch) above the mid depth of the slab is predicted to be an economically applicable design for GFRP-CRCP with limestone concrete on the asphalt stabilized sub-base . In addition, number 6 GFRP rebars spaced at 1.219 m (48 inches (4 ft)) will be installed as transverse reinforcement. For the steel-reinforced CRCP, number 6 longitudinal steel rebars spaced at 15.24 cm (6 inches) will be adopted on the same sub-base along with number 5 transverse steel rebars spaced at 1.219 m (48 inches (4 ft)). After the construction, the field monitoring of both the CRCPs will be followed to compare and evaluate the performance of the GFRP-CRCP in terms of crack spacing, crack width, and the number of distresses (such as spalling and punch-out).(Figure.5)

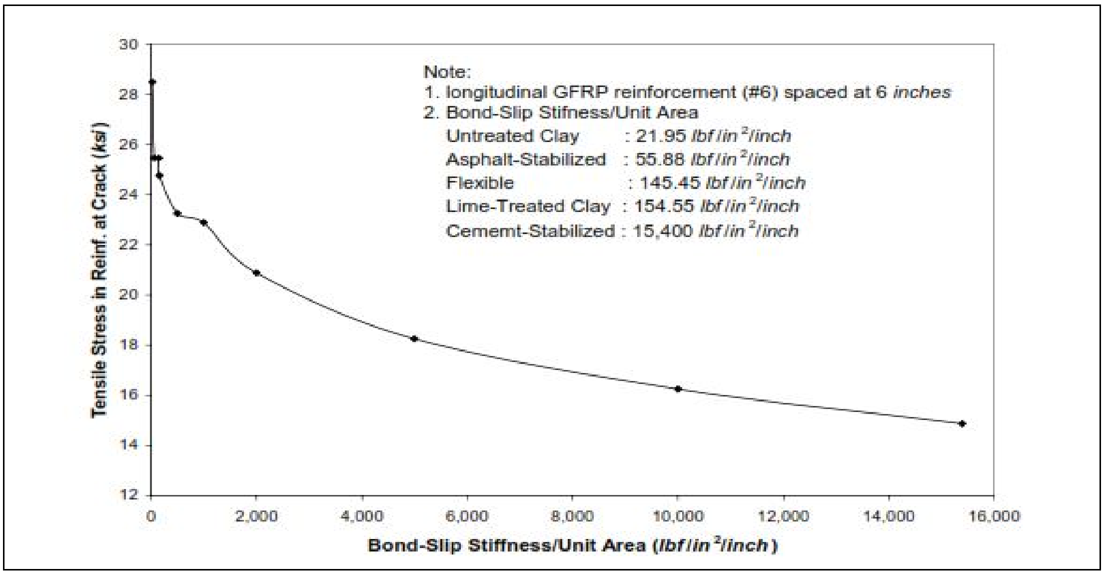


Figure. 5 Tensile stress in GFRP reinforcement at crack versus bond-slip stiffness/unit area

5. CONCLUSION

Further studies of the effect of a high transverse CTE of the GFRP rebar on its bond with concrete at various temperatures and on cracking in the GFRP-reinforced CRCP are necessary. Investigations into the effect due to the low transverse (shear) strength of the GFRP rebar on the load transfer at the cracks generated in the GFRP-reinforced CRCP should be conducted. Investigation of the relationship between the load transfer efficiency and the crack width is required. Beams with the greater number of longitudinal synthetic fibres performed better against deflection as compared to the beams of other groups. Beams with synthetic fibred needles performed better against strain as compared to the beams of other groups. The appearance of one crack at failure indicates that there is lack of bond between concrete and synthetic fibred which encourages strain softening as compared to steel reinforced beams, where the formation of multi-cracks demonstrates that the bond between the concrete and fibres is good enough and the fibres are effective in stress transformation and strain hardening occurs. If the bond prevails between them, the above mentioned cocktail can be a compatible overlay to use to retard reflective cracking. Laboratory tests indicate that a cocktail of synthetic fibres needles in the concrete mix and longitudinal synthetic fibres at the bottom of the beam will be able to control strains and deflections and hence be resistive against reflective cracking.

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