EFFECT OF CONCRETE PROPERTIES ON THE DESIGN CRITERIA OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

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Abstract

The effect of indirect tensile strength, dry shrinkage and compressive strength by using various types of concrete, coarse aggregate, water to cement ratio and mix proportion on the design of continuously reinforced concrete pavements (CRCPs) are evaluated in this study.

Results of 144 specimens with different shapes which represented concrete specimens having compressive strength ranging from (21.5 MPa to 75.4 MPa), W/C raining from (0.355 to 0.65) and cement contents ranging from (331 Kg /m^3 to 6oo Kg /m^3) are reported. The results are compared with the results adopted from AASHTO Guide -1986 for design of structure pavements.

The results showed that the use of high strength concrete is not satisfactory in CRCPs design, where lead to increase in the crack spacing, crack width, steel stress, and then the amount of steel that require, therefore lead to increase in the pavement construction cost. The use of light weight Porcelinite concrete was inadequate and not lie in the limited range for the design criteria of CRCPs. Also there is a different between the local results of indirect tensile strength and the corresponding values of dry shrinkage and the results adopted from AASHTO.

Introduction

The concrete properties consider a significant factor in the design of continuously reinforced concrete pavements (CRCPs).The design concept for continuously reinforced concrete pavement is to force cracks to form at relatively close interval, thus controlling the lightness of the crack to provide good load transfer and prevent excessive water percolation. The frequency of cracks and the final crack width depend on a complex interaction of environmental variables, material properties, and the magnitude of applied loads [1, 2].

Initial cracks are primarily caused by critical stresses induced by the initial temperature drop and drying shrinkage of the concrete. Additional cracks may develop during application of an external load when the combined stresses of the internal and external forces exceed the concrete tensile strength [2].

The crack pattern will eventually reach a stabilized condition when the pavement has experienced the minimum temperature during the cold season and when most of the drying shrinkage in the concrete has occurred [2].

Three main input data of concrete properties related to the design of CRCPs. These are indirect tensile strength, concrete shrinkage, and concrete thermal coefficient. It is necessary to identify the material quality that required in the design.

Elkins et.al [3] reported that the control on the design criteria provides satisfactory performance for 20 years with out maintenance and satisfactory performance 10-20 years with normal maintenance.

Research significance

The principle goals of the work reported in this paper are to gain better understanding of the effect of concrete properties on the design of continuously reinforced concrete pavements, to better understand the behavior of normal and light weight Porcelinite concrete over the different mix proportion and W/C ratios now used in practice, to compared between the results of indirect tensile strength and the corresponding values of dry shrinkage obtained in this study with these reported from AASHTO, to observation the influence of superplasticizer on the strength and dry shrinkage of concrete, and to knowledge the behavior of concrete at earlier ages (7 days).

Experimental Program

In this research, locally available materials were used to produce two types of concrete which are normal weight (NW) and light weight Porcelinite (LW)concretes. Superplasticizer admixture was added to fresh concrete mixes to obtained high rang water reduced – normal weight (HRWR- NW) and high rang water reduced - light weight Porcelinite (HRWR- LW) concretes . All specimens are cured in water and tested for compressive strength, indirect tensile strength and dry shrinkage at ages (7) and (28) days , then calculated the design parameters (crack spacing , crack width and steel stress) for the CRCPs from the following equations(4) :

$$x' = \frac{1.32\left[1+\frac{ft}{1000}\right]^{6.7} \times \left[1+\frac{\alpha s}{2\alpha c}\right]^{1.15} \times (1+\phi)^{2.19}}{\left[1+\frac{\sigma w}{1000}\right]^{5.2} \times [1+P]^{4.6} \times [1+1000z]^{1.79}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$Cw = \frac{0.00932\left[1+\frac{ft}{1000}\right]^{6.53} \times (1+\phi)^{2.22}}{\left[1+\frac{\sigma w}{1000}\right]^{4.91} \times [1+P]^{4.55}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$\sigma s = \frac{43700\left[1+\frac{D_{TD}}{100}\right]^{0.425} \times \left[1+\frac{ft}{1000}\right]^{4.09}}{\left[1+\frac{\sigma w}{1000}\right]^{3.14} \times [1+P]^{2.74} \times [1+1000z]^{0.494}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where:

x^- = Crack spacing (ft)

Cw= Crack width (in)

σs = Steel stress (psi)

θ= Reinforcing bar diameter (in)

z= Concrete shrinkage (in / in)

ft= Indirect tensile strength of concrete (psi)

D_{TD}= design temperature drop (F^o)

αs= Thermal coefficient of steel (in/in/ F^o)
αc= Thermal coefficient of concrete (in/in/ F^o)
p= Steel percent
σw = Wheel load tensile stress (psi)

Data used

The following data [(5)], which listed in Table (1), were used in this study.

Table (1) Data used

Name of parameter	*Value of parameter*
θ	No.6 (3/4 (in))
D_{TD}	(107.6 F^o)
αs	$5*10^{-6}$ (in/in/ F^o)
αc	$6.5*10^{-6}$ (in/in/ F^o) for normal concrete $3*10^{-6}$ (in/in/ F^o) for lightweight concrete
p	6%
σw	170 (psi)

Design criteria for crack spacing

Crack spacing should be between the limits of a maximum value and a minimum value. The minimum crack spacing is used to prevent punchout failure .AASHTO Guide-1986 [(6)] used a value of 3.5 ft (1.067 m) as a minimum crack spacing to represents a more safely design. Therefore, a value of 3.5 ft (1.067 m) is recommended to use in this study.While the maximum crack spacing used to minimize the crack spalling. AASHTO Guide-1986 [(6)] suggested the value of 8 ft (2.45 m) as a maximum crack spacing.

Design criteria for crack width

The limiting criteria for crack width are based on a consideration of spalling and water penetration. In general, crack width is directly proportional to the magnitude of horizontal stresses. Since crack width and degree of spalling correlate highly with the horizontal stresses, they should theoretically also correlate with each other. The penetration of water through the pavement may leads to steel corrosion and subgrade erosion. AASHTO Guide-1986 [(6)] suggested using a value of 0.04 inch (1.04 mm) as a maximum crack width.

Design criteria for steel stress

Limiting criteria placed on steel stress are due to guard against steel fracture and excessive permanent deformation. AASHTO Guide-1986 [(6)] reported Table (2) to identify the allowable steel stress depending on indirect tensile strength of concrete.

Table (2) Allowable steel stress, ksi [(6)]

Indirect tensile strength (psi)	*Reinforcing bar size*		
	No.4	*No.5*	*No.6*
300 (or less)	65	57	54
400	67	60	55
500	67	61	56
600	67	63	58
700	67	65	59
800 (or greater)	67	67	60

Materials Used in This Research

1. Cement

Ordinary Portland cement manufactured by Kufa cement factory was used in this study. The chemical and physical properties of this type of cement were conformed to the Iraqi specifications No.5- 1984[7].

2. Fine Aggregate

Normal weight natural sand was used as a fine aggregate. Before its incorporation into concrete mix, sand was sieved on 4.75 mm sieve, and used with a saturate surface dry condition. The grading of sand was conformed to the requirement of BS.882-1992 [8] as shown in Table (3). Physical and chemical properties of sand used throughout this study are shown in Table (4).

3. Coarse Aggregate

Two type of coarse aggregate were used in this research. First one was normal weight crushed gravel with a maximum size of (10 mm), its grading is shown in Table (5), and the specific gravity, sulfate content and absorption are (2.57), (0.05) and (0.5) respectively. While the other type was local naturally –occurred lightweight aggregate of Porcelinite stone, grading of this type falls in the size designation of 9.5-2.36 mm of ASTM C330-87 [9], as indicated in Table (6).

4. High Rang Water-Reducing Admixture (HRWRA)

A sulfunated melamine formaldehyde condensate based superplasticizer (commercially named as Melment L 10) was used as high rang water-reducing admixture while maintaining equal workability to the reference mixture (without admixture), table (7) show the technical description of superplasticizer.

Table (3) Grading of sand and the requirement of BS 882: 1992

Sieve size	% passing	% passing of the overall limit of BS 882:1992[8]
4.75	100	89-100
2.36	92.2	60-100
1.18	84.8	30-100
0.60	70.1	15-100
0.30	33.2	5-70
0.15	9.6	0-15
Fineness modulus = 2.1		

Table (4) Chemical and physical properties of sand

Property	Specification	Result	Limit of I.O.S. NO.45/ 1984[10]
Bulk specific gravity	ASTM C128-88[11]	2.53	_
Absorption %	ASTM C128-88[11]	2.14	_
Dry-loose unite weight Kg/m^3	ASTM C29-89[12]	1582	_
Sulfate content (as SO_3 %)	I.O.S. NO.45-84[10]	0.08	0.5 (maximum)
Materials finer than 75-µm sieve %	I.O.S. NO.45-84[10]	4.1	5 (maximum)

Table (5) Grading of crushed gravel

Sieve size (mm)	*Cumulative passing %*	*Limit of Iraq specification NO.45-1984*[10]
14	100	100
10	98.9	85-100
4.75	17.4	0-25
2.35	0.45	0-5

Table (6) Selected grading of coarse lightweight aggregate

Sieve size (mm)	% passing ASTM C330-87[9]	Selected % passing	% retained
12.5	100	100	0
9.5	80-100	95	5
4.74	5-40	10	85
2.36	0-20	0	10
1.18	0-10	0	_

Table (7) Technical description of superplasticizer

Main action	Concrete super-plasticizer
Subsidiary effect	Hardening accelerator
Solids in aqueous solution	20%
Density	1.11g/cm^3
Chloride content	Less than 0.005%
PH value	7-9

Test Procedures

1. Compressive Strength

The compressive Strength test was determined according to BS.1881-part 116 -1989[13]. A cube specimens with dimensions 100 mm were tested by using standard tasting machine with a capacity of 2000 kN . The test was conducted at ages of 7, 28 days and the average of three cubes was adopted at each test.

2. Indirect tensile strength

Depending on the ASTM C_{496-86} [14] specification the test of indirect tensile strength was done. Cylinders of 100 × 200 mm were used and the load was applied continuously up to failure by using standard tasting machine with a capacity of 2000 kN, and the average of three cubes was adopted at each test with a testing age of 7 and 28 days . The indirect tensile strength can be evaluated by using the following equation:

$$ft = \frac{2p}{\pi DL} \qquad \text{.......} (4)$$

Where:
ft = Indirect tensile strength (N/mm^2)
p=applied load (N)
D=diameter of cylinder (mm)
L= length of cylinder (mm)

3. Dry shrinkage

The dry shrinkage test was carried out according to ASTM C_{157-86} [(15)] by using prism specimens with 100×100×400 mm. The change in length was measured depending on mechanical strain gauge. Two points were defined with demec points on each of the two opposite sides of specimen.

Results of Tests and Discussion

The results of the experimental work of this research are listed in the Table (8), after that the design parameters of CRCPs (crack spacing, crack width and steel stress) were calculated for the results adopted from AASHTO and for these obtained from this study and then illustrated in Table (9).

AASHTO suggested the following approximate values of shrinkage depending on the strength of Portland cement concrete. The values of shrinkage were (0.0008), (0.0006), (0.00045), (0.0003) and (0.0002), for values (300 psi or less), (400 psi), (500 psi), (600 psi) and (700 or grater psi) of indirect tensile strength respectively [(6)].

Figures (1) and (2) represents the effect of indirect tensile strength and corresponding concrete shrinkage on the crack spacing for various W/C ratios and mix proportions for normal weight and lightweight Porcelinite concretes.

It can be noticed from these Figures, that when the indirect tensile strength between 580 psi (4 MPa) and 690 psi (4.75 MPa), the criteria of crack spalling will be satisfactory according to AASHTO results, while the allowable range according to results obtained in this research lies between 577 psi (3.97 MPa) and 702 psi (4.81 MPa) for the normal weight concrete. For a values less than 577 psi (3.97 MPa), the cracks become closer spacing and this lead to punchout failure. For a values greater than the 702 psi (4.81 MPa), cracks developed at a wider spacing than the maximum criteria and this lead to increase in crack spalling. On the other hand, all values of crack spacing for the light weight Porcelinite concrete were less than the lower limit of crack spacing for all different W/C and mix proportions. As a general, crack spacing increased as the concrete shrinkage decreased and as the concrete strength increased.

Figures (3) and (4) represent the effect of indirect tensile strength on the crack width for normal and light weight concretes respectively. It can be noticed from the above Figures the conform between the results adopted by AASHTO and research results , this is apparently attributed to finding one effected factor which is indirect tensile strength and the other factors have no effect on the crack width according to Equation (2). The values of indirect tensile strength are greater than 565 psi (3.9 MPa), the criteria of crack width will become unsatisfactory. As a general, crack width increase as the concrete strength increase. This is due to the direct relationship between crack spacing and crack width as reported by Elkins et.al [(3)].

Figures (5) and (6) represents the effect of indirect tensile strength and corresponding concrete shrinkage on the steel stress for bar size No.6 for normal weight and lightweight Porcelinite concretes respectively. It can be noticed from these figures, that when the indirect tensile strength values are equal or below 580 psi (4 MPa) and 650 psi (4.48 MPa), the criteria of the design will be satisfactory according to AASHTO and research results respectively. In a general, the increase in concrete strength will cause an increase the steel stress because of the increase in the crack width. An increase in concrete shrinkage makes the pavement to contract more, and this leads to an increase in steel stress.

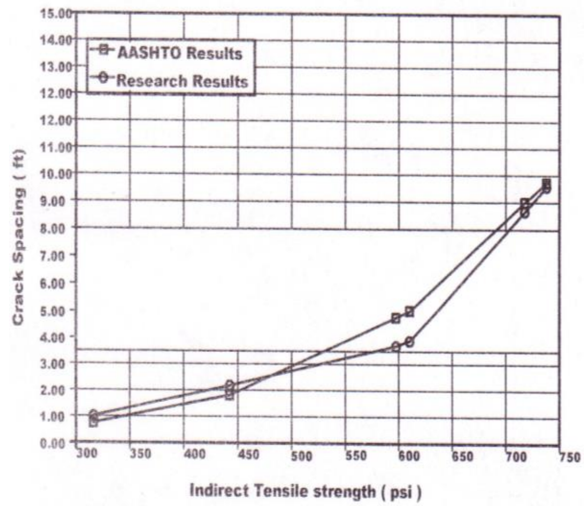
From the Table (9), we can be noticed that all type of light weight concrete consider a structure light weight concrete as CEB/FIP Manual of LWAC Design and Technology (16) reported, where all magnitudes of compressive strength greater than 15 MPa. The dry shrinkage values for all types of lightweight concrete are below $8 * 10^{-4}$, a value beyond which the concrete is usually considered to be undesirable for most structural applications (17). Despite, all specimens of light weight Porcelinite concrete were not satisfactory the limits of Design criteria for CRCPs because the low strength of this type of concrete.

The effect of superplasticizer on all types of concrete was apparently, where it was leads to an increase in indirect tensile strength and to decrease in dry shrinkage of concrete. This behavior may be ascribed to a significant water reduction, as well as, to dispersion of the cement agglomerates into individual particles, thereby a greater rate of cement hydration can be achieved in the well dispersed system (17).

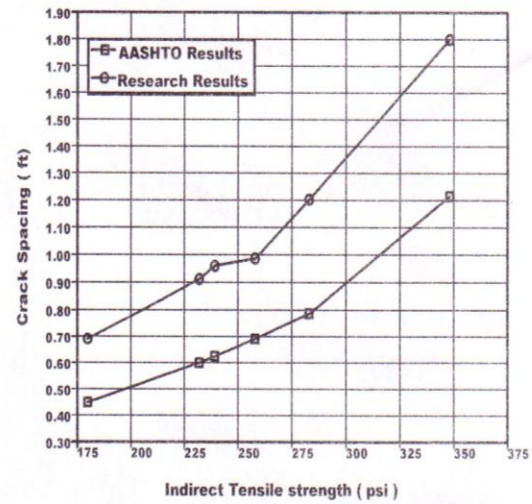
The indirect tensile strength is directly related with the compressive strength of concrete as shown in the Table (8) for all type of concrete and at any testing age. The indirect tensile strength increase with the increase of compressive strength, and the strength of all types of concrete increase with the increase of concrete age, this is due to continuous of cement hydration processes and achieve mix with dense mass that contributes in increase of concrete strength .

Finally, the set of concrete properties that is recommended to use with the common minimum steel percent of steel in the world (0.6%) in the design of CRCPs are indirect tensile strength between (577 psi -615 psi) (4 MPa- 4.25 MPa) and the dry shrinkage between (4.75-5). While the concrete properties according to recommendation of AASHTO are indirect tensile strength between (530 psi -580 psi) (3.65 MPa- 4 MPa) and the dry shrinkage between (3.5-3.75).

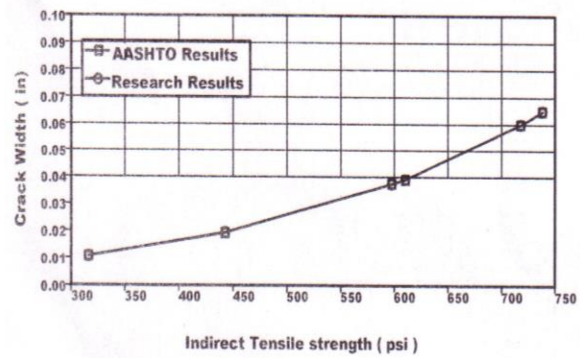
It can be concluded that the use of high strength concrete that has an indirect tensile strength more than 615 psi (4.25 MPa) in the design of CRCP will not satisfy the CRCP design criteria. When the high strength concrete is used, the steel percent may be above the maximum percent (0.9 percent) since the use high strength concrete will increase the crack spacing, crack width, steel stress, and then the amount of steel that require.



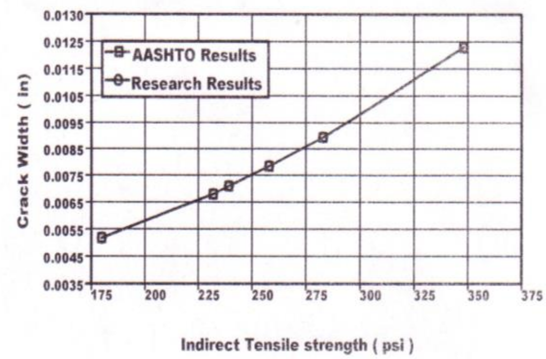
Figure(1): Relationship Between Indirect tensile Strength and Crack Spacing For the Normal Weight Concrete



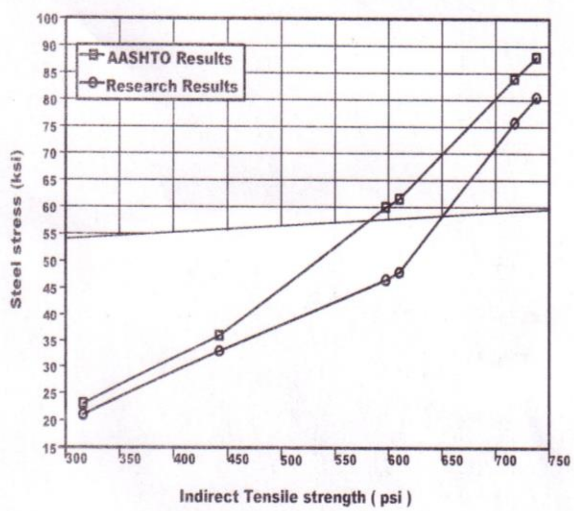
Figure(2): Relationship Between Indirect tensile Strength and Crack Spacing For the Lightweight Porcelinite Concrete



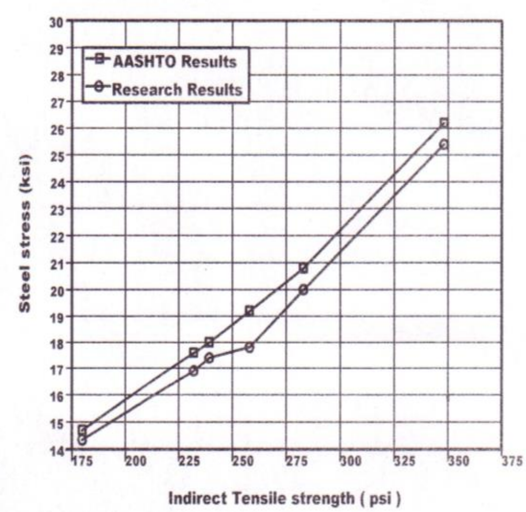
Figure(3): Relationship Between Indirect tensile Strength and Crack Width For the Normal Weight Concrete



Figure(4): Relationship Between Indirect tensile Strength and Crack Spacing For the Lightweight Porcelinite Concrete



Figure(5): Relationship Between Indirect tensile Strength and Steel Stress For the Normal Weight Concrete



Figure(6): Relationship Between Indirect tensile Strength and Crack Spacing For the Lightweight Porcelinite Concrete

Conclusions

The following points are fixed depending on the analysis of the results obtained from this study.

1. There is apparently different between the results adopted from AASHTO and the locally results, especially in the light weight Porcelinite specimens concretes.
2. All type of light weight Porcelinite concrete mixtures can not be used in CRCP design, due to the having lower values of indirect tensile strength.
3. The use of superplasticizer leads to significant increase in concrete strength and decreasing in the concrete shrinkage for all types of concrete.
4. The use of high strength concrete that has an indirect tensile strength more than 615 psi (4.25 MPa) not required in CRCP design.
5. The properties of concrete that is recommended to use with the common minimum steel percent of steel in the world (0.6%) in the design of CRCPs are indirect tensile strength between (577 psi -615 psi) (4 MPa- 4.25 MPa) and the dry shrinkage between (4.75-5). While the concrete properties according to AASHO are indirect tensile strength between (530 psi-580 psi) (3.65 MPa-4 MPa) and the dry shrinkage between (3.5-3.75).

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تأثير خواص الخرسانة على المعايير التصميمية للطرق الخرسانية المستمرة التسليح

الخلاصة:

تأثير مقاومة الشد و انكماش الجاف و مقاومة الانضغاط للخرسانة على المعايير التصميمية للطرق الخرسانية المستمرة التسليح تم دراستها في هذا البحث باستخدام أنواع مختلفة من الخرسانة, الركام الخشن, نسبة السمنت الى الماء و نسب المواد في الخلطة.

نتائج 144 نموذج ذات أشكال مختلفة و التي تمثل نماذج خرسانية ذات مقاومة انضغاط تتراوح بين (21.5– 75.4)MPa ,نسبة الماء / السمنت تتراوح بين (0.355– 0.65)و محتوى سمنت يتراوح بين (331– 600)Kg/m^3 تم احتسابها. بعد ذلك تم مقارنة النتائج التي توصل إليها البحث مع النتائج المعتمدة في دليل ال (AASHTO) سنة 1986 لتصميم الطرق الإنشائية.

النتائج بينت إن استخدام خرسانة عالية المقاومة غير ملائم في تصميم الطرق الخرسانية المستمرة التسليح حيث تؤدي الى زيادة في مسافة التباعد بين الشقوق و عرض الشق و اجهادات حديد التسليح و بالتالي فان كمية الحديد المطلوبة سوف تزداد, حيث يؤدي ذلك الى زيادة كلفة إنشاء الطريق.

إن استخدام الخرسانة ذات الركام الخفيف الوزن كان غير ملائم حيث لم يقع ضمن المديات المحددة للمعايير التصميمية الخاصة بالطرق الخرسانية المستمرة التسليح.

بالإضافة الى ذلك فان هنالك اختلاف بين نتائج مقاومة الشد و قيم انكماش الجفاف المناظرة لها التي تم الحصول عليها في هذه الدراسة مع ما هو معتمد من قبل ال (AASHTO).