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Experimental Investigation on Self-Compacting Fiber Reinforced Concrete in a Rigid Pavement

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Abstract: The importance of any concrete structure is completely dependent on its strength. Hence, strength is the most important factor in the present construction world. The strength of concrete depends mainly on the factors like the type of constituents, the admixtures and the concrete chemicals used in the manufacturing of concrete. However, the water-cement ratio influences the strength of concrete and it can be verified using Abram's law. The fundamental concept behind the Abram's law is that, the capillary pores in the concrete get diminished as the time progresses. Thus, the study on porosity of concrete is necessitated. The most advanced and commonly used type of concrete for the construction to achieve high strength and more workability is Self-Compacting Concrete. Hence, it is highly essential to the study the strength and durability characteristics of Self-Compacting Concrete since, it uses mineral and chemical admixtures in Self-Compacting Concrete on the basis of the primary factor and secondary factor such as, water-absorption, compressive strength and tensile strength. The different proportions of super-plasticizer are added on trial and error basis and the proportion of VMA and AEA are based on the previous researches.

Key words: Air entraining agent (AEA) · Porosity · Self-compacting concrete (SCC) · Viscosity modifying agent (VMA)

INTRODUCTION

A rigid road pavement consists of a top concrete pavement resting on underlying courses, usually a base course and an optional sub-base layer. Several important advantages are connected to adopting rigid roadways as opposed to conventional flexible pavements. In particular, a rigid road pavement provides an efficient, comfortable, high-performance and cost effective design choice when dealing with roadways and highways subjected to heavy traffic loads. Indeed, owing to its high flexural stiffness and mechanical resistance, a rigid pavement allows to homogeneously transfer the vehicular loads to the underlying layers, preventing load and stress concentrations in the subgrade and, in turn, deflection and subsidence of the pavement structure. Moreover, through proper roughening and marking techniques, usually based on suitable floor grinders, micro and macro-texture and, in turn, friction and adherence performance (skid resistance) of the pavement surface may be accurately controlled, which is a key issue in warranting proper safety standards. The light reflectance property of Portland cement makes the concrete rigid pavement an optimal technology to guarantee suitable illumination standard at a reasonable main power cost. This issue is especially important in tunnel roadways at daytime, owing to the blinding effect of sunlight. Furthermore, concrete pavement may be recycled and reused during maintenance operations and at the servicing life end. On the overall, concrete represents an attractive energy saving as well as eco-friendly road material. On the other hand, concrete pavements may undergo rapid deterioration, in the form of micro and macro cracks, fractures and failures, which can cause loss of serviceability and unsafe driving condition. This occurrence is mainly due to the brittle behavior of cement concrete together with its low resistance to fatigue phenomena and its small toughness. However, these detrimental aspects can be mitigated through the adoption of fibers. Indeed, dispersed structural fibers can be added

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at the mixing stage of concrete in the so-called fiber reinforced concrete (FRC). Many studies have been performed in the last decades concerning the mechanical performance of FRC. It appears that fibers can significantly improve durability, tensile strength and toughness of the cement matrix, preventing the crack opening and growth in concrete members and cementitious composites, like cement-treated road materials. Recently, most attention has been devoted to the adoption of polymeric fibers, because of their advantages over the metallic ones with special regard to chemical stability, lightness and workability. It should be noted that a FRC road pavement might be realized through substantially conventional paving techniques provided some basic guidelines are followed, as explained in this paper.

Furthermore, due to their low flexural stiffness, synthetic fibers are especially suitable in the ejected concrete technology (spritz-beton), which takes a great part in the lining construction for tunnels. In addition, polymeric fibers, particularly the polypropylene-based fibers, are proved to improve the fire resistance of concrete, in what is often named the anti-spalling effect. Indeed, even if cement concrete is known as a non-combustible material and no self-propagating fire, it is prone to a pop-up like damaging phenomenon if subjected to high thermal loads. This is especially the case for high resistance concrete (HRC) and silicate added concrete. Under high temperature, polypropylene-based fibers sublimate, thus decreasing the water pressure inside the pores of the cement matrix and preventing crack and expulsion of the outermost layers. This makes the FRC a promising technology to realize roadway inside tunnels and galleries, where high safety standards as regard to fire protection are mandatory. As a result, polypropylene-based fiber reinforced concrete (PFRC) appears to be, besides an appealing building material, a very attractive rigid pavement matrix, with special regard to high performance and safety. The present work provides some basic guidelines for designing rigid PFRC pavements, as applied to the design of an actual application. Glass fiber–reinforced concrete (GFRC) consists basically of a cementitious matrix composed of cement, sand, water and admixtures, in which short length glass fibers are dispersed. The effect of the fibers in this composite leads to an increase in the tension and impact strength of the material. GFRC has been used for over 30 years in several construction elements, mainly nonstructural ones, like facade panels (about 80% of the GFRC production), piping for sanitation network systems, decorative non-recoverable formwork and other products. The lightweight characteristics and improved tensile strength of GFRC as compared with concrete led to a recent research program to study the viability of its use as a structural material. The research was developed in association with concrete precast companies for which the referred improved characteristics are especially appealing as the reduced weight of the precast elements is important for transportation and installation. To obtain a GFRC with high durability, reinforcement systems were also analyzed, considering carbon or glass strands and stainless steel bars, leading to corrosion-free solutions.

Research Objective:

- To verify whether Self-Compacting Concrete can be used in construction of rigid pavements.
- To determine the strength of hardened fiber reinforced concrete.

Scope of the Research:

- SCC with different types of fiber reinforced in it provides good compressive and tensile strength.
- This composition can be used for construction of rigid pavements.

Literature Review:

- Arabi N.S. Al Qadi&Sleiman M. Al-Zaidyeen investigated the effect of specimen shape on residual mechanical properties of polypropylene (PP) fiber self-compacting concrete (SCC) exposed to elevated temperatures from 200 to 600^{o} C. Various shaping regimes were used including cylindrical and cubical shapes for a series of durations of 2 and 4 h and air cooling to the room temperature before testing.
- Nobili, L. Lanzoni&A.M. Tarantino provided the basics for the design of a polypropylene based fiber reinforced concrete (PFRC) road pavement, as applied in an actual testing section resting inside a tunnel of the ‘‘Quadrilatero Marche-Umbria’’ road empowerment project, Italy. Results of a six-month monitoring carried out on actual traffic loads are also presented, as a feedback to the designing stage. Monitoring encompasses direct measurement of the strain level inside the cast as well as acoustic measurement. It is shown that the fiber reinforced concrete technology provides an efficient, safe as well as cost effective design solution for roadways, especially inside tunnels.
- Mounir M. Kamal, Mohamed A. Safan, Zeinab A. Etman&Bsma M. Kasem studied the major impact of the introduction of self-compacting concrete (SCC) is connected to the production process. The

productivity is drastically improved through the elimination of vibration compaction and process reorganization. The working environment is significantly enhanced through avoidance of vibration-induced damages, reduced noise and improved safety. Additionally, SCC technology has improved the performance in terms of hardened concrete properties like surface quality, strength and durability.

- Mohamed I. Abukhashaba, Mostafa A. Mostafa, Ihab A. Adam investigated Self-Compacting-Concrete, SCC containing Cement-Kiln-Dust, CKD may offer several environmental, economic and technical benefits. The use of fibers extends its possibilities since fibers arrest cracks and retard their propagation. An investigation was performed to examine the effect of reinforcing SCC with Polypropylene fiber, PPF, on its stress strain characteristics as well as fresh and mechanical properties. Six mixtures with water–binder ratio (**w**/**b**) of 0.45 were conducted.
- GritsadaSua-iam&NattMakul investigated the properties of self-compacting concrete mixtures comprising of ternary combinations of TYPE 1 Portland Cement (OPC), untreated Rice Husk Ash (RHA) and Pulverized fuel ash. The SCC mixture were produced with a controlled slump flow. The fresh and hardened properties including water requirement, workability, density, compressive strength development and ultrasonic pulse velocity were determined.
- Ali sadrmomtazi&Rominazarshinzanoosh the main objective of this study was to investigate use of rice husk in cement composite contained of waste rubber tire. Tires are discarded without control and deposited in inadequate way in the environment increasing the environmental, pollution and favouring the proliferation of insects that causes tropical diseases. Rice husk used in the present work was replaced of 10% of cement weight. And five designated rubber contents varying from 10% to 50% by volume and 0.3% polypropylene fiber were used.
- Heba A. Mohamed This study presents an experimental study on self-compacting concrete (SCC) with two cement content. The work involves three types of mixes, the first consisted of different percentages of fly ash (FA), the second uses different percentages of silica fume (SF) and the third uses a mixture of FA and SF. After each mix preparation, nine cylinder specimens are cast and cured.
- Abdulkader El Mir & Salem Georges Nehme studied that the construction industry demands more durable concrete with high performance. Self-compacting concrete (SCC) is developing gradually to meet many aspects of construction technology, especially reinforced concrete. On the other hand, durability properties still need some enhancements particularly in term of microstructure properties. Furthermore, there is a lack of research on nondestructive testing of self-compacting concrete.

Research Methodology:

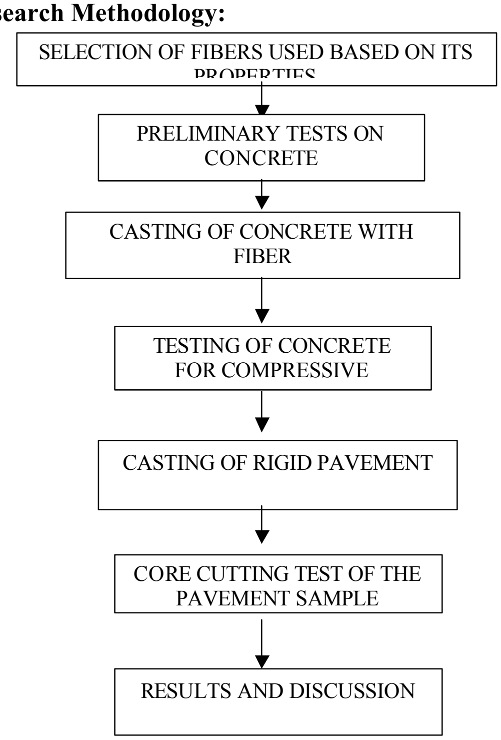

Fig. 1: FLOW CHART

Materials and Mixing

Mixture Proportioning:

Table 1: Mix Design M-30

Materials	Quantities (kg/m^3)	Ratio
Cement	576	1
Fine aggregates	918	1.593
Coarse aggregates	847	1.47
Water	173	0.3

Materials

Ordinary Portland Cement (OPC): OPC available in the local market is used in the investigation. The cement used has been tested for various proportions according to (ASTM C150-85A) the specific gravity was 3.15.

Coarse Aggregates: Crushed angular granite material of 20 mm maximum size from a local source was used as course aggregate. The specific gravity was 2.60; the absorption value was 1.5%, with a bulk density of 1480 kg/m3, which conforms to ASTM C 33-86, was used.

Fine Aggregates: The fine aggregates consisted of river sand with a maximum size of 4.75 mm, with a fineness modulus of 2–3 normal grading. The specific gravity was 2.33 and the absorption value was 4%.

Polypropelene Fibers: Short Polypropylene (PP) fibres (12 mm) are used in the experimental study, which consisted of one type of polypropylene fiber. While the addition of PP fibres varying with a mixing ratio of 0%, 0.05%, 0.10% and 0.15% (by volume) were used.

Glass Fibers: Short Glass fibers (12mm) will be used in the experimental study, which consisted of similar type of fiber throughout. 85 gms of this fiber is added to one bag of cement of 50 Kgs.

Experimental Methods: All concrete mixes were prepared in 40 L batches in a rotating planetary mixer. The batching sequence consisted of homogenizing the sand and coarse aggregate for 30 s, then adding about half of the mixing water into the mixer and continuing to mix for one more minute. The mixer was covered with a plastic cover to minimize the evaporation of the mixing water and to let the dry aggregates in the mixer absorb water. After 5 min, the cement and fly ash were added and mixed for another minute. Finally, the SP and the remaining water were introduced and the concrete was mixed for 3 min. PP fibres were added to the mix gradually and separately for each mix within 2 min. Six cubes (150 x 150 x 150 mm) in which three are with fiber and three without fiber were casted and kept in sink moist under wet conditions for each mix to determine compressive strength after 7 days and 28 days.

Design of Rigid Pavement Using Irc Method

Design Parameters: The design wheel load is taken as 5100 kg with area of 15cm and tyre pressure ranging from 6.3 to 7.3 kg/cm^2. The traffic volume for 20 years after construction is give by the relation:

$$A_d = P^/ [1+r]^{(n+20)}$$

where,

A_d = Number of commercial vehicles per day (laden weight > 3 tonnes)

$P^/$ = Number of commercial vehicles per day at last count.

r = Annual rate of increase in traffic intensity (may be taken as 7.5%)

n = Number of years between the last traffic count and the commissioning of new cement concrete pavement.

- The mean daily and annual temperature cycles are collected.
- The modulus of subgrade reaction K is determined using standard plate. The minimum K-value of 5.5 kg/cm^2 is specified for laying cement concrete pavement.

- The flexural Strength of cement concrete used in the pavement should not be less than 40 kg/cm^2. The suggested values of modulus of elasticity, E are $3*10^5$ kg/cm^2 and Poisson's ratio u is 0.15. The coefficient of thermal expansion of concrete may be taken as $10*10^{-6}$ for design purposes.

Calculation of Stresses: The wheel load stresses at edge region is calculated for the designed slab thickness as per Westergaard's analysis using stress chart given in fig.2

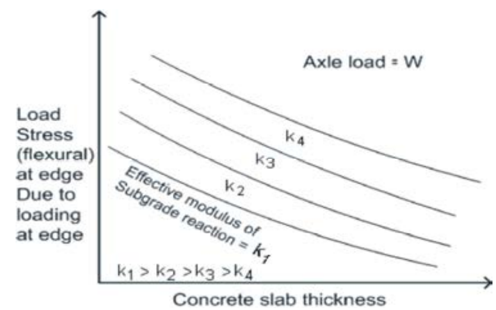

Fig. 2: Edge Load Stress Chart (IRC)

Temperature stress at edge region is calculated as per Westergaard's analysis using Bradbury's coefficient given in Fig. 3.

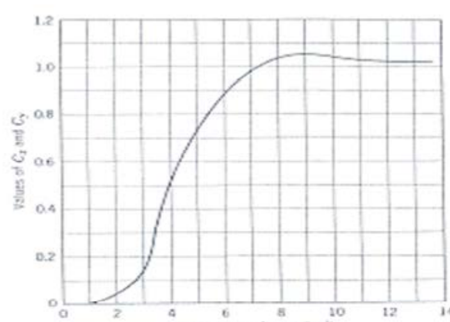

Fig. 3: Warping Stress Coefficient

Temperature stress can also be calculated using the following equation:

$S_c = 3P/h^2[1-(a*2^{0.5}/l)^{1.2}]$

where,

S_c = load stress at edge or corner region, kg/cm^2
P = Design wheel load, kg
h = Thickness of CC pavement slab, cm
a = Radius of load contact, cm
l = Radius of reltive stiffness, cm

Wheel load stress at corner region is calculated as per Westergaard's analysis and is given by the equation: -

$S = P*Q/h^2$

Design Steps for Slab Thickness:

- The width of slab is decided based on the joint spacings and lane width.
- The length of the CC slab is equal to the spacing of contraction joints, L_c. This is designed using the equation for plain CC pavements:

$L_c = 2\ S_c/W\ f*10^4$

If reinforcement is provided at the contraction joints for the assumed trial thickness of the slab the following equation is used:

$L_c = 200\ S_s\ A_s/b\ h\ W\ f$

where,

L_c = Spacing between contraction joints, m
S_c = Allowable stress in tension in cement concrete, kg/cm^2
S_s = Allowable tensile stress in steel, kg/cm^2
A_s = Total area of steel, cm^2 across the slab width
W = Unit weight of cement concrete, kg/m^3
b = Slab width, m
f = Coefficient of friction
h = Slab thickness, cm

A trial thickness value of slab is assumed for calculating the stresses. The warping stress at the edge region is calculated using the equation:

$St_{(e)} = C_x\ E\ e\ t/\ 2$ or
$= C_y\ E\ e\ t\ /\ 2$ (whichever is higher)

where,

$St_{(e)}$ = Warping stresses at edge, kg/cm^2
E = Modulus of elasticity of concrete, kg/cm^2
e = Thermal coefficient of concrete per °C
t = Temperature difference between the top and bottom of the slab in °C
C_x = Coefficient based on L_x/l in desired direction
C_y = Coefficient based on L_y/l in right angle to above direction

The load stress in edge region is found using stress chart, Fig. 2.

The total stresses at the corner due to wheel load and warping is checked using stress chart, Fig. 3.

The design thickness, h is adjusted for the traffic intensity or classification at the end of design life and using the adjustment value from table to obtain the final adjusted slab thickness.

Spacing of Joints: The maximum spacing recommended for 25 mm wide expansion joints is 140 m when the foundation is rough, for, all slab thicknesses. When the foundation surface is smooth spacing may be 90 m for slab thicknesses up to 20 cm and 120 m for slab thicknesses 25 cm, when the pavement is constructed in summer, however when pavement is constructed in winter the above spacings may be restricted to 50 and 60 m respectively.

The maximum contraction joint spacings may be kept at 4.5 m in unreinforced slabs of all thickness. In the case of reinforced slabs, the contraction joint spacing may be 13 m for 15 cm thick slab with steel reinforcement of 2.7 kg/m^2 and 14 m for 20 cm thick slabs with steel reinforcement of 3.8 kg/m^2.

Design of Dowel Bar: Dowel bars do not function satisfactorily in thin slabs and therefore dowel bars are provided in slab of thickness 15 cm or more. IRC recommends 2.5 cm diameter dowel bars of length 50 cm to be spaced at 20 cm in the case of15 cm thick slabs and spaced at 30 cm in the case of 20 cm thick slabs, the design load being 5100 kg.

Design of Tie Bars: Tie bars are designed as per the details given in the table below:

Table 2: Tie bar details

Slab thickness, cm	Tie bar details, cm Diameter	Max. Spacing	Plain bars	Deformed bars
15	0.8	38	40	30
	1.0	60	45	35
20	1.0	45	45	35
	1.2	64	55	40
25	1.2	55	55	40
	1.4	62	65	46

Design of Reinforcement: Reinforcement in CC pavements are intended to prevent deterioration of the cracks and not to increase the flexural strength of uncracked slabs. The area of longitudinal and transverse steel required per metre width or length of slab is computed from the formula:

$A = L f w / 2 S$

Work Done:

- Estimation of quantity
- M-30 SCC Mix design
- Casting of concrete cubes, cylinders, beams
- Testing of concrete for compressive strength

Test Results

Compressive Strength of Cubes:

AGE	Compressive Strength (N/mm^2)
7 DAYS	31.07
14 DAYS	43.02
28 DAYS	47.8

Compressive Strength of Cylinder:

Age	Compressive Strength (N/mm^2)
7 DAYS	29.25
14 DAYS	40.5
28 DAYS	45

Compressive Strength of Beam:

AGE	Compressive Strength (N/mm^2)
7 DAYS	28.44
14 DAYS	39.375
28 DAYS	43.75

Core Cutter Test:

AGE	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
7 DAYS	32.01	40.85
14 DAYS	43.05	
28 DAYS	47.5	

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