JOURNAL OF BASIC SCIENCE AND ENGINEERING

Study on influence of temperature in Pavement Quality Concrete for single and composite sections with admixed concrete of M-40 Grade

Sagar Y Kamble[a*] , H S Jagadeesh[b] , Raghavendra C R[c]

[a] Department of Civil Engineering, BMS College of Engineering Bengaluru, Karnataka, India
Visvesvaraya Technological University, Belagavi, Karnataka.

[b] Department of Civil Engineering, BMS College of Engineering Bengaluru, Karnataka, India

[c] Department of Mechanical Engineering, Government Engineering College, Haveri, Karnataka, India.

ABSTRACT:

In the present study is concentrated on the two-pavement quality of concrete. The single layer of concrete mix and two dissimilar layers of composite sections were considered for the study. The concrete mix is designed on M40 grade as per IRC:44-2017. Admixtures viz., steel fibre, glass fibre, marble powder, dolomite powder, and ground granulated blast furnace (GGBS) are used in the mixture. Normal cement concrete is reinforced with alkali resistant glass fibres with an optimum dosage of 0.5 % vol. of concrete. Normal cement concrete is reinforced with hooked end steel fibres with an optimum dosage of 1.5 % to the vol. of concrete and 10% marble powder and dolomite powder each. The 40% GGBS is used to replace cement partially in the GGBS admixed concrete. The temperature is recorded for every one hour over a period of seven days during hot conditions of the season. It is observed that the temperature is more at the top of the slab during daytime when compared to the bottom of concrete slab, this is attributed by the exposure of the top surface to sun light adequately. On the other hand, the temperature is more at the bottom of the slab during night time. Rigid pavement is evaluated for the Cumulative Fatigue Damage Analysis (CFD) as per IRC:58-2015. The experimental results suggest that, the maximum temperature differential value for single and composite concrete slab sections is less than pavement quality of concrete. Composite sections are referred for future traffic over the Normal concrete pavement sections.

Key words: Pavement quality of concrete, Cumulative Fatigue Damage Analysis, Composite sections, Concrete.

1. Introduction

Highway construction requires a significant financial investment. Environmental conditions like temperature significantly influence the strength of the concrete pavement. As the concrete pavement is restrained by its weight, warping, or a difference in temperature between the top and bottom surfaces, it causes strains inside the pavement. Portland cement concrete (PCC) pavement can be classified into two types- curling stress and thermal expansion stresses. Curling stresses result observed from temperature differential between the top and bottom of a pavement quality concrete pavement. This tendency to curl induces stress in the pavement as the pavement is restrained by its weight and support pressure from the sub-grade layer. Depending on the external position of applied load and the time, curling stresses may be sufficiently high causing failure of the slab. Temperature is an important environmental factor that influences the performance of concrete pavements [1]. The inclusion of fiber like steel and glass fiber help in transferring the load to internal micro crack fibers also help in fatigue strength, impact strength, pre-crack tensile strength, post peak ductility and prevent temperature and shrinking cracks. [2] The temperature variations mainly depend upon the material characteristics, the thickness of the slab and the atmospheric conditions.[3] Nowadays many researchers have been carried out to reduce the CO2. The effective way of reducing CO2 emission from the cement industry is to use the industrial by products or use of supplementary cementing material such as ground granulated blast furnace slag (GGBS), marble powder and dolomite powder[4] replacing ordinary portland cement (OPC) with industrial waste like GGBFS has been proven to have remarkable benefits regarding the mechanical properties of concrete and the environment.[5] The utilization of industrial by- products and agricultural waste as potential cement alternatives has gained attention in recent years[6] GGBFS in concrete increases the strength and durability of the concrete structure[7] It was discovered that the utilization of GGBS in concrete will be eco-friendly.[8] GGBS also is a good mineral admixture.[9] The GGBS and slag re-cycling of these slag's will become an important measure for the environmental protection. Iron and steel are basic materials that underpin modern civilization[10]The waste marble powder (WMP) was used to replace cement of concrete in specific amounts[11] Over the past few years, research on marble powder has attracted a significant amount of interest from a variety of fields, including civil engineering and building materials. During production, the marble sector is responsible for around 30–40% of the total waste, which results in severe environmental dust concerns.[12] Dolomite is an anhydrous carbonate mineral composed of calcium magnesium carbonate, ideally $CaMg(CO_3)_2$. The term is also used for a sedimentary carbonate rock composed mostly of the mineral dolomite. [13]Dolomite acts as cement when replaced at low percentage, while at higher dosage, increased the hydration products as a result of crystallization and better water absorption[14] Using dolomite powder in concrete can reduce the cost of concrete and increase the strength to some extent.[15] Dolomite has different grades and is available in different mesh sizes[16] For the low tensile strength of plain concrete, steel fiber-reinforced concrete (SFRC) is becoming widely adopted to improve the performance of this joint type.[17] The use of hooked-end steel fibers in conventional fiber-reinforced concrete has proven to improve its crack resistance, and thus, positively influence the durability properties of concrete structures.[18] The incorporation of short discrete steel fibers can lead to useful improvements in the mechanical behavior of tension weak concrete[19]Thus addition of steel fibers in concrete in uniform order will attain more strength.[20] Around the world, massive amounts of waste glass powder (WGP) are produced, there was about 200 million tons of solid waste and about 7% of it was glass waste[21]. glass fiber was added to enhance the flexural and tensile strength of concrete[22]

2. Materials

The strength of concrete depends on the properties of the materials used in the study. Fig. 1 shows the materials used samples. The Materials used in the present work were: coarse aggregates with 20 mm down and 10 mm down, fine aggregates (M sand), cement (OPC 53), admixtures, glass fibre, steel fibre, marble powder, dolomite powder, GGBS, water, and superplasticizers.

Fig. 1 Materials used for the study

a) Cement

The grade of the cement is OPC-53 grade is used, as shown in Fig.1. According to IS 16415:2015[23], the minimum 40% of cement is to be used in concrete. According to the IS16353 & IS 12269[24], we had taken the cement specifications. The specific gravity of cement is 3.15. The Chemical compositions are mention in Table 1.

b) Coarse Aggregate

20 mm & 10 mm aggregates were used as coarse aggregate specified as per IS 383:2016 [25], as given in Fig.1

c) Fine aggregate

Fine aggregate (FA) M sand is used as FA, as shown in Fig.1. FA which passes through 4.75 mm sieve is used. Grade of fine aggregate conforming to IS 383:2016[25].

d) GGBS

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GGBS According to the IS 16714:2018,[26] we had taken the GGBS. The specific gravity of GGBS is 2.66, as given in Fig 1. The chemical composition of GGBS is taken from supplier Bengaluru Infratech PVT LTD Bangalore and its compositions are mention in Table 1.

e) Marble powder

Marble powder was mainly composed of calcium carbonate and classified as limestone grade. The colour of the marble powder can vary depending on its purity, as given in Fig.1. The chemical composition of marble powder is taken from supplier Mangala Stones Bangalore and its compositions are mention in Table 1. The specific gravity of marble powder was 2.7 and its fineness was 3350 cm^2/g. It is used as a 10% of the cement is replaced by dolomite powder in the pavement quality concrete.

f) Dolomite Powder

The properties of dolomite powder are remarkable due to its composition of calcium magnesium carbonate $CaMg(CO_3)_2$, as given in Fig.1 commonly referred to as a carbonate material. The chemical composition of dolomite powder is taken from supplier Good Earth Mineral and Chemical Bangalore and its compositions are mention in Table 1. The specific gravity of dolomite powder was 2.7. It is used as a 10% of the cement is replaced by dolomite powder in the pavement quality concrete.

Table 1. Chemical composition of Cement, Marble Powder, Dolomite Powder and GGBS

Ingredients	Cement Concentration (%)	Marble Powder Concentration (%)	Dolomite Powder Concentration (%)	GGBS Concentration (%)
Lime(CaO)	65.9	55.6	32.24	40.52
Silica (SiO_2)	21.9	0.6	0.41	35.43
Alumina(Al_2O_3)	4.8	0.4	0.03	13
Iron Oxide(Fe_2O_3)	3.5	0.2	-	0.37
Magnesia(MgO)	1.6	0.1	-	8.0
Potassium oxide(K_2O)	0.5	-	-	-
Sulfur trioxide(SO_3)	0.48	-	-	-
Manganese Monoxide(MnO)	-	-	-	0.55
Calcium	-	90	-	90

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carbonate($CaCO_3$)				
Titanium dioxide (TiO_2)	-	-	<0.01	0.5
0.5	-	-	-	0.5
Brightness	-	76	76	-
Cl	0.1	0.1	-	-
Loss on ignition (LOI)	1.2	43	46.25	0.88
Glass Content	-	-	-	92

g) Glass Fibres

In the present Study, M-40 grade concrete is reinforced with alkali resistant glass fibre with an optimum dosage of 0.5% to the volume of concrete is used to minimize the heating and cracking of the concrete as given in Fig.1, The physical properties of glass fibres is taken from supplier Bauenguru Infratech PVT LTD Bangalore and are mention in Table 2.

h) Steel Fibre

A steel fibres include various aspect ratios and diameters ranging from 30 to 150, ranging from 0.25 mm to 0.75 mm. High structural strength helps reduce the width of the crack and prevents it from growing wider, a stainless-steel fibre with a hooked end steel fibre of 1.5% to the volume of pavement quality concrete is used and as given in Fig.1 to enhance the initial and post-break strength, and The physical properties of steel fibres is taken from supplier Bauenguru Infratech PVT LTD Bangalore and are mention in Table 2.

Table 2. Physical Properties of Steel Fibres and Glass Fibres

Physical Properties	Steel Fibres Specification	Glass Fibres Specification
Length (mm)	30	12
Specific gravity	7.85	2.68
Tensile Strength (MPa)	>1100	-
Elastic Modulus (MPa)	$2x10^5$	72
Poisson‟s ratio	0.28	-
Aspect ratio	54	-
Diameter (mm)	0.60	-

i) Superplasticizers

Fosroc Conplast SP430 DIS" (Super plasticizing admixture for concrete) given in Fig.1. Which improves the rheological behaviour & mechanical properties of concrete. The quantity of admixture is followed as per the IS 456 (clause 5.5) [27].

j) Water

Water Potable water is used concrete. The water should contain permissible limits of organic and inorganic solids as per IS 456, (table1) [27]. The water used in curing shouldn't contain tannic acid & ironic compounds.

3. Methodology

3.1 Different Pavement Sections Considered for the Study

1) Pavement Quality Concrete (PQC)
2) Steel Fibre (SF)
3) Glass Fibre (GF)
4) Marble Powder admixed concrete (MP)
5) Dolomite Powder admixed concrete (DP)
6) Ground Granulated Blast Furnace (GGBS)
7) Composite section of Steel Fibre admixed concrete and Pavement Quality Concrete (SF+PQC)
8) Composite section of Glass Fibre admixed concrete and Pavement Quality Concrete (GF+PQC)
9) Composite section of Steel Fibre admixed concrete and Glass Fibre admixed concrete (SF+GF)
10) Composite section of Marble Powder admixed concrete and Pavement Quality Concrete (MP+PQC)
11) Composite section of Dolomite Powder admixed concrete and Pavement Quality Concrete (DP+PQC)
12) Composite section of Marble Powder admixed concrete and Dolomite Powder admixed concrete (MP+DP)
13) Composite section of Ground Granulated Blast Furnace admixed concrete and Pavement Quality Concrete (GGBS+PQC)

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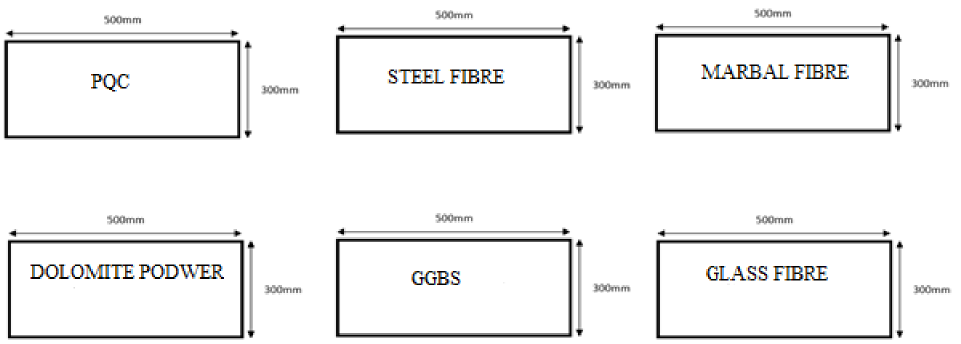

Fig. 2 Concrete Slab of Single Section

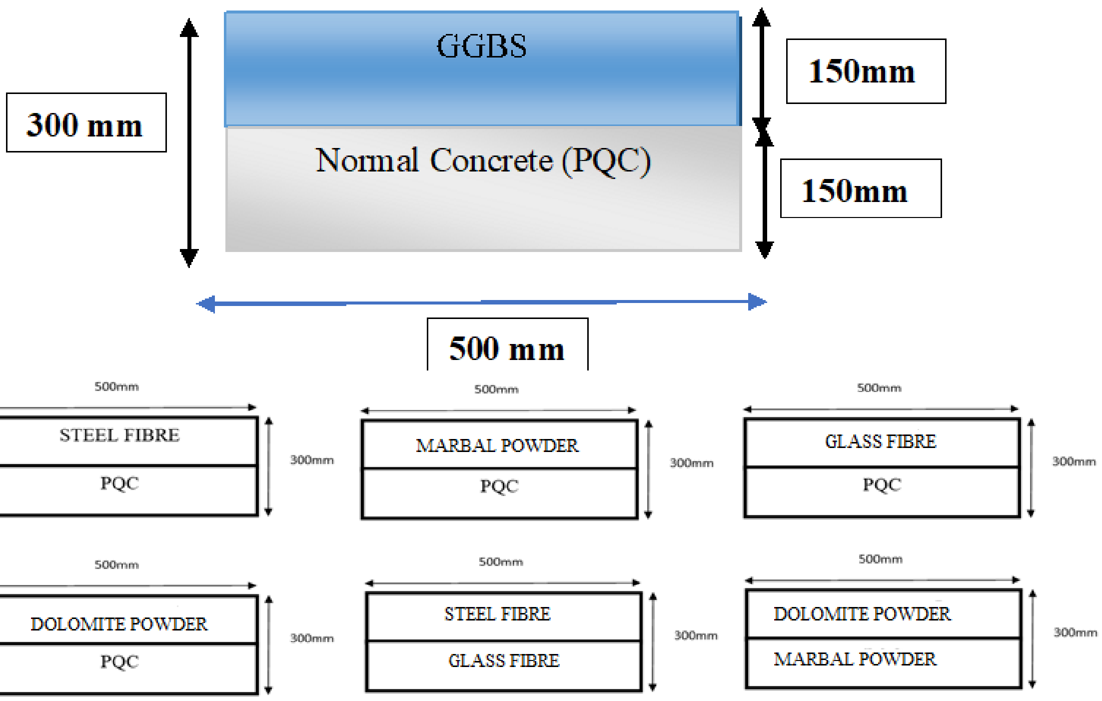

Fig. 3 Concrete Slab of Composite Section

3.2 Mix Design of M40 Grade Concrete

The proportion of all the essential materials used to make a concrete mix, such as cement, water, coarse aggregates, fine aggregates and admixture should be made economical and workable, a concrete mix design is carried out of M40 grade pavement quality concrete (PQC), M40 grade of marble and dolomite powder by 10% cement replacement and glass and steel fibres added by percent by volume of concrete as per IS: 10262-2019[28] and IRC: 44-2017[29].

Table 3. Quantities for one cubic meter

Material (kg/m3)	PQC (M40)	Glass and Steel Fibre (M40)	Marble and Dolomite Powder (M40)
Cement	379.831	379.831	376.033
Water	144.336	144.336	144.336
Fine aggregates	674.758	674.758	649.953
Coarse aggregates 20 mm	735.173	735.173	730.203
Coarse aggregates 10 mm	490.115	490.115	486.802
Admixture	-	-	41.781
Superplasticizer	1.899	1.899	1.880
Water-cement ratio	0.38	0.38	0.35
Glass Fibres (0.5% By volume of Concrete)	-	1.96	-
Steel Fibres (1.5% By volume of Concrete)	-	5.88	-

3.3 Thermal Differential Analysis

- The temperature difference between a concrete surface's top and bottom can be used to determine the effects of curl stress on the structure. Due to the varying weather conditions, the temperature difference between a concrete surface's top and bottom can vary throughout the day.
- Temperature differentials can affect the design of concrete pavement surfaces by causing slab corners to curl upward or downward. The concept of negative temperature differential curls the corner upward, and the concept of positive temperature differential might cause the edges to curl downward.

3.4 Casting of Prototype Slabs:

Since temperature stresses in cement concrete pavements are of great significance, this investigation was undertaken to ascertain how the temperature of a pavement slab of 500 X 500 X 300 mm prototype mould is shown in Fig.4. Total of 13 different combinations of slabs are cast. The final results are compared to existing concrete structures of similar size.

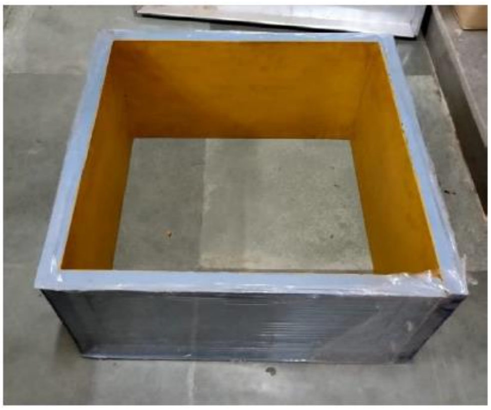

Fig. 4 Prototype Mould

3.5 Subgrade Preparation:

A trench was dug up to 25cm deep, and 10cm of M Sand mixed with aggregate was laid on top of it, which was well-consolidated. Above that, a 15cm M10 grade DLC was laid, resulting in a prepaid base area, as shown in Fig.5

Fig. 5 Base Preparation for Casting Area

Procedure

- The base is prepared before placing the mould.
- Mix proportion of single and composite materials sections: Cement, Fine aggregates, Coarse aggregates, water, and admixture are mixed in proportion, laid, and well compacted.
- A prototype mould of conventional M40 grade concrete slabs of 500 x 500 x 300 mm was cast according to the designed mix proportion.
- The location for the slab's Casting is identified so that it is exposed to sunlight.
- The ready mix is transferred into the mould in three layers & Thermocouple is attached to wooden strips (10 cm from top, 10 cm from bottom & at the middle of the strip), and it is well compacted and levelled.
- After 24 hours, the mould can be demoulded and cured for 28 days.

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- After curing, take temperature readings for the top, middle, and bottom layer every 1 hour for 7 days and are recorded using a digital temperature indicator.
- Using temperature differential, analyse it by Cumulative fatigue damage study using IRC 58-2015 Code.[30]

3.6 Recording of Temperature

In the present case, a type-K thermocouple is used to measure the temperature variation in a slab. It can be used to record the variation in temperature from -25^0 to 400^0 Celsius. The source of the voltage is the junction between two metals. A type-K thermocouple is usually made from two metals, namely nickel-chromium and aluminium, and the K type generates voltage through these two alloys. The device is shown in Fig.6

Fig. 6 K type Thermocouple and Temperature Reading Meter

4 RESULTS AND DISCUSSION

4.1 Tests on Hardened Concrete

In the study cube mould of 150X150X150mm are used for compression strength for 7 and 28 days curing strength are given in table 4. and compression strength test is carried out according to IS: 516 – 1959, “Methods of Tests for Strength of Concrete”[31] and the. Comparison of the results with the different mix proportions to PQC for M40 as shown in Fig. 7

Table 4. Results of Compression Strength Test

Compression Strength (MPa)		
Type of concrete	**7 days**	**28 Days**
PQC	32.15	48.59

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SF	36.25	56.30
GF	35.90	54.75
SF+PQC	36.27	57.67
GF+PQC	36.59	57.15
SF+GF	37.99	58.65
MP	33.79	51.45
DP	34.37	52.40
MP+PQC	34.24	51.98
DP+PQC	36.83	56.69
MP+DP	36.56	55.95
GGBS	32.89	50.46
GGBS+PQC	34.27	53.29

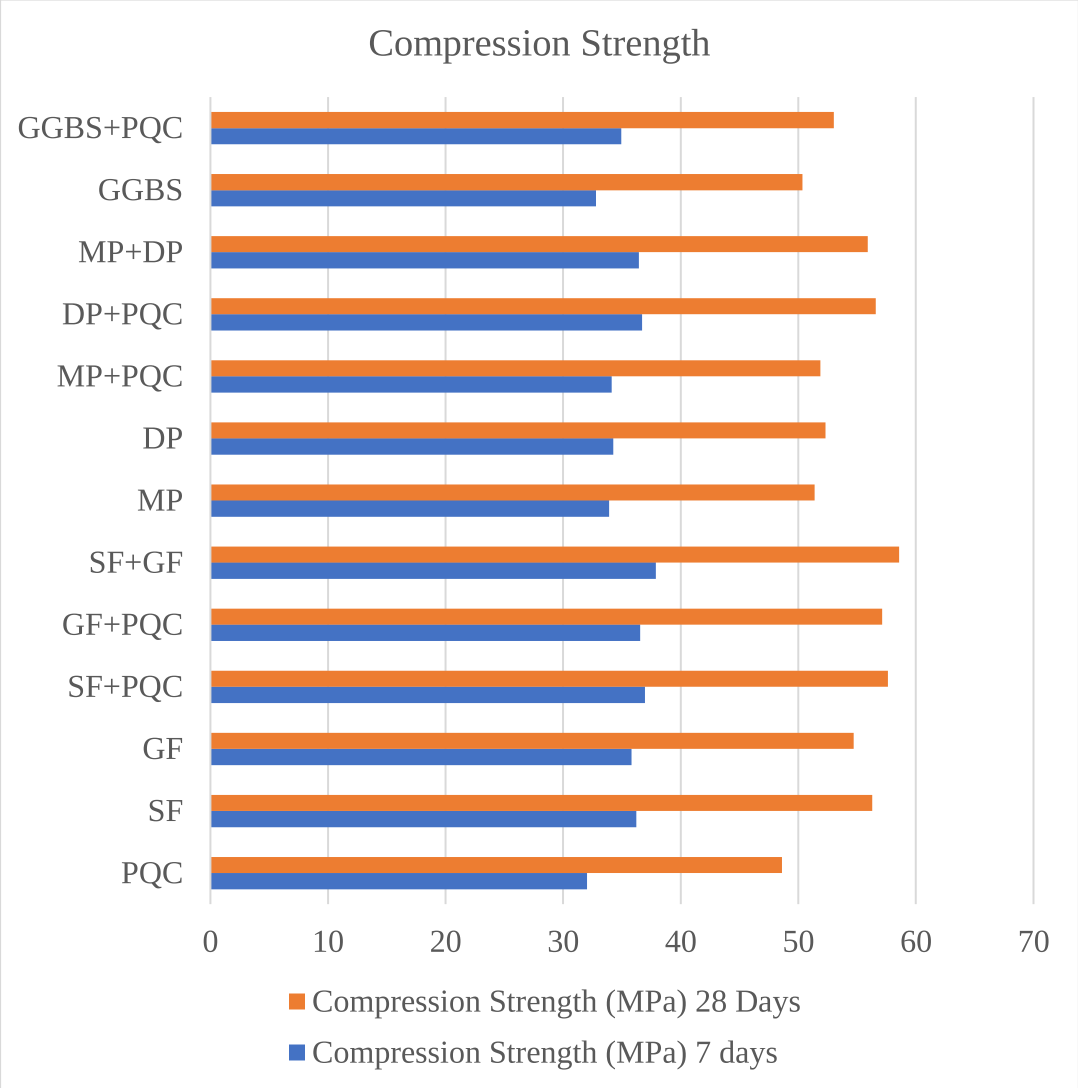

Fig. 7 Compression Strength Test Results of all the Concrete Mixes

Discussion

- All the single and composite sections resulted in better compression strength after 28 days of the curing process.
- Among all, the composite section of SF+GF has the highest compression strength of 58.58 MPa and lowest is the PQC with a compression strength of 48.62 MPa. This shows that using of admixtures can increase the compression strength properties of the concrete mix.
- Compression strength of composite sections like SF+PQC, GF+PQC, SF+GF, MP+PQC, DP+PQC, MP+DP, GGBS+PQC have more strength i.e., 57.62MPa, 57.13MPa, 58.58MPa, 51.87MPa, 56.58MPa, 55.9MPa and 53.03MPa respectively than their respective single admixed concrete sections like SF, GF, MP, DP and

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GGBS having compression strength of 56.28MPa, 54.72MPa, 51.38MPa, 52.3MPa and 50.35MPa.

- Compared to PQC, there is 15.75% increase in the compression strength of SF admixed concrete, 12.54% increase in the compression strength of GF admixed concrete, 18.51% increase in the compression strength of SF +PQC composite section, 17.5% increase in the compression strength of GF+PQC composite section, 20.48% increase in the compression strength of SF+GF composite section, 5.67 % increase in the compression strength of MP admixed concrete, 7.56 % increase in the compression strength of DP admixed concrete, 6.68 % increase in the compression strength of MP+PQC composite section, 16.37 % increase in the compression strength of DP+PQC composite section, 14.9% increase in the compression strength of MP+DP composite section, 3.55% increase in the compression strength of GGBS admixed concrete and 9.07% increase in the compression strength of GGBS+PQC composite section.

4.3 Flexural Strength Test

Beam mould of 100X100X500mm are used for flexural strength for 7 and 28 days curing strength are given in table 5. and compression strength test is carried out according to IS: 516 – 1959, “Methods of Tests for Strength of Concrete”[31]. Comparison of the results with the different mix proportions to PQC for M40 as shown in Fig. 8

Table 5. Results of Flexural Strength Test

Flexural Strength (MPa)		
Type of concrete	**7 days**	**28 Days**
PQC	3.41	5.32
SF	4.56	6.98
GF	4.16	6.56
SF+PQC	4.59	7.45
GF+PQC	4.78	7.23
SF+GF	5.17	7.90
MP	3.67	5.57
DP	3.77	5.79
MP+PQC	4.19	6.63
DP+PQC	4.54	6.87

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MP+DP	4.19	6.47
GGBS	3.57	5.44
GGBS+PQC	3.97	5.93

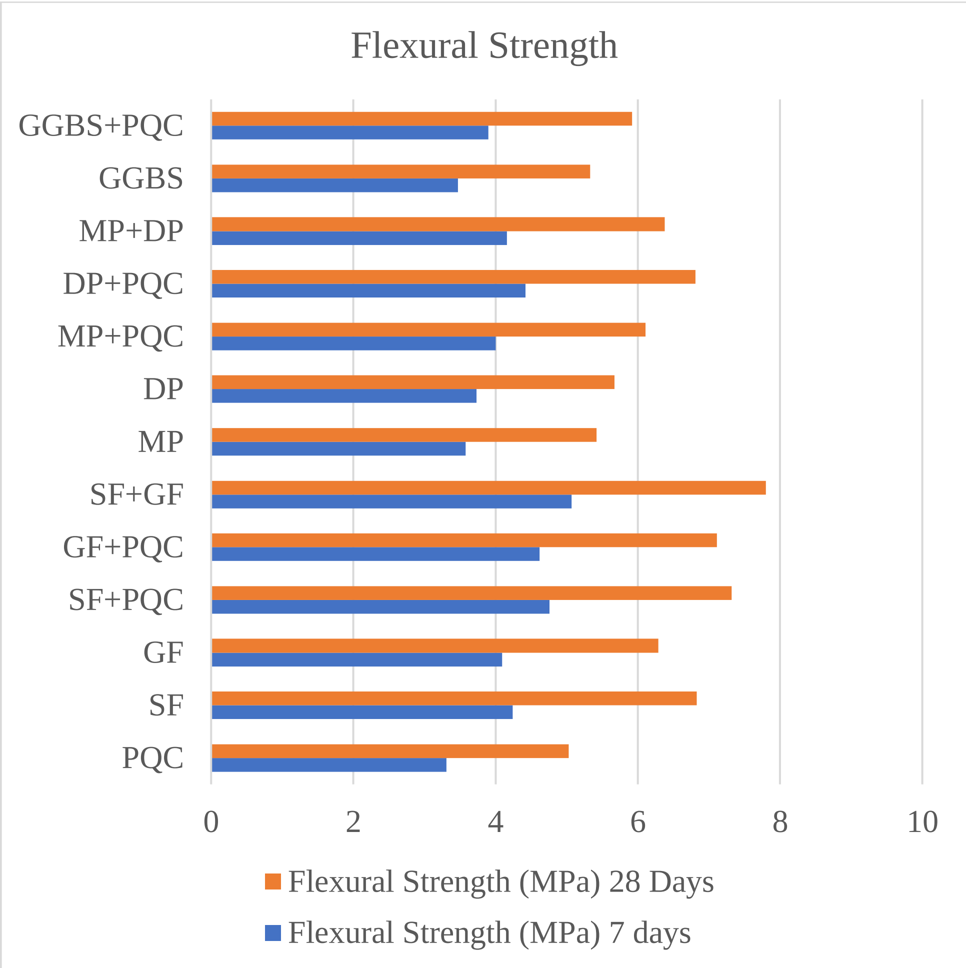

Fig. 8 Compression Strength Test Results of all the Concrete Mixes

Discussion

- All the single and composite sections resulted in better Flexural strength after 28 days of the curing process.
- Among all, the composite section of SF+GF has the highest Flexural strength of 7.8MPa and lowest is the PQC with a Flexural strength of 5.03MPa. This shows that using of admixtures can increase the Flexural strength properties of the concrete mix.
- Flexural strength of composite sections like SF+PQC, GF+PQC, SF+GF, MP+PQC, DP+PQC, MP+DP, GGBS+PQC have more strength i.e., 7.32MPa, 7.11MPa, 7.8MPa, 6.11MPa, 6.81MPa, 6.38MPa and 5.92MPa respectively than their respective

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single admixed concrete sections like SF, GF, MP, DP and GGBS having Flexural strength of 6.83MPa, 6.29MPa, 5.42MPa, 5.67MPa and 5.33MPa.

- Compared to PQC, there is 35.78% increase in the Flexural strength of SF admixed concrete, 25.05% increase in the Flexural strength of GF admixed concrete, 45.52% increase in the Flexural strength of SF +PQC composite section, 41.35% increase in the Flexural strength of GF+PQC composite section, 55.06% increase in the Flexural strength of SF+GF composite section, 7.75% increase in the Flexural strength of MP admixed concrete, 12.72% increase in the Flexural strength of DP admixed concrete, 21.47% increase in the Flexural strength of MP+PQC composite section, 35.38% increase in the Flexural strength of DP+PQC composite section, 26.83% increase in the Flexural strength of MP+DP composite section, 5.96% increase in the Flexural strength of GGBS admixed concrete and 17.69% increase in the Flexural strength of GGBS+PQC composite section.

4.4 Temperature Differentials

The temperature data collected during the hot condition for every 1 hour for 7 days to all the concrete section. The difference between the bottom and top temperature in the slab is referred to as the temperature differential. The maximum positive temperature difference between PQC and composite slab sections made of cement concrete during the hot season is given in Table 6, and its graphical representation is shown in Fig.9, also maximum negative temperature differential values for PQC and composite sections of cement concrete slabs during the hot condition are given in Table 7.

Table 6. Maximum positive day time temperature difference between PQC and composite slab section made of cement concrete during the summer season (From day 1 to 7*)*

Slab	Day1	Day2	Day3	Day4	Day5	Day6	Day7
PQC	15	14	14	13	15	15	14
GF	8	8	7	7	8	7	7
SF	9	9	8	8	9	9	8
PQC+GF	7	6	7	7	7	7	6
PQC+SF	8	7	8	7	7	8	7
GF+SF	6	5	6	6	6	5	6
DP	11	11	11	11	10	10	11
MP	11	12	11	11	12	11	11
PQC+DP	10	10	10	9	9	10	10

PQC+MP	11	11	11	11	10	10	11
DP+MP	9	9	8	9	9	9	8
GGBS	9	11	9	10	9	10	8
PQC+GGBS	9	10	10	9	9	10	10

Table 7. Maximum Negative night time temperature differential of PQC and composite sections of Cement concrete slabs during the summer season (From day 1 to 7)

Slab	Day1	Day2	Day3	Day4	Day5	Day6	Day7
PQC	-11	-12	-11	-11	-12	-10	-12
GF	-7	-6	-6	-5	-7	-6	-6
SF	-7	-6	-7	-7	-7	-7	-6
PQC+GF	-6	-4	-6	-5	-6	-5	-5
PQC+SF	-7	-6	-6	-5	-5	-6	-6
GF+SF	-4	-4	-4	-5	-4	-4	-5
DP	-9	-10	-10	-9	-9	-8	-9
MP	-10	-10	-9	-9	-10	-10	-9
PQC+DP	-8	-8	-9	-8	-8	-8	-9
PQC+MP	-9	-8	-9	-9	-8	-8	-9
DP+MP	-7	-7	-6	-7	-7	-7	-6
GGBS	-7	-9	-7	-8	-8	-9	-7
PQC+GGBS	-7	-8	-8	-7	-8	-8	-9

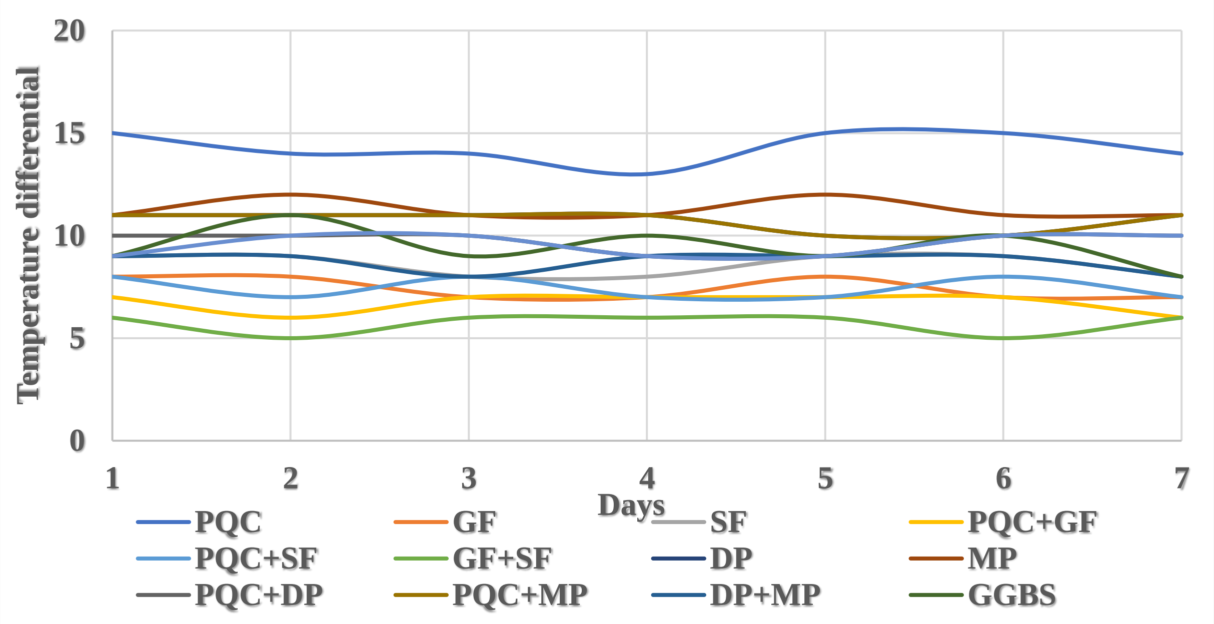

Fig. 9 Variation of maximum positive temperature differential of PQC and composite sections of cement concrete slabs during summer season (From day 1 to 7)

Table 8. Comparison of Maximum temperature Differential values with Codal Provision.

Slab	Thickness, mm	Maximum temperature Differential ^{0}C	Maximum temperature Differential, ^{0}C as per IRC-58-2015 for PQC
PQC	300 mm	15	• Hilly regions of West Bengal, Uttaranchal, Jammu & Kashmir, Arunachal Pradesh and Himachal Pradesh, U.P., Punjab, Uttaranchal, Rajasthan, Gujarat, North M.P and Haryana - **15.8^{0}C** • Jharkhand, Bihar, Assam, West Bengal, and Eastern Orissa - **16.8^{0}C** • South Tamil Nadu and Kerala- **18.1^{0}C** • South M.P., Maharashtra, Chattisgarh, **Karnataka**, Western Orissa, Andhra Pradesh, and North Tamil Nadu - **21** ^{0}C
GF		8	
SF		9	
PQC+GF		7	
PQC+SF		8	
GF+SF		6	
DP		11	
MP		12	
PQC+DP		10	
PQC+MP		11	
DP+MP		9	
GGBS		11	
PQC+GGBS		10	

Table 8 shows that the temperature differential obtained in the present study is lesser than the temperature differential values of PQC recommended by IRC 58-2015[30]. GF+SF slab have the least maximum temperature difference of 6^0, which is the better composite section compared to other sections. PQC slab have the high maximum temperature difference of 15^0. The maximum temperature difference for single and composite sections is well within the limit for the states mentioned above. Whereas the values mentioned in IRC 58-2015 are for particular states or regions, which includes other areas also, and for all three seasons, that is summer, Rainy, and winter season.

4.5 Cumulative Fatigue Damage Analysis (CFD)[30]

The analysis of cumulative fatigue damage is performed on the pavement to determine the damages caused by the combination of top-down and bottom-up fatigue damage conditions. The flexural stress at the edge caused by the combined action of a single or tandem rear axle load and a positive temperature difference is evaluated for bottom-up cracking. This stress can be determined using the stress charts and the regression equations in IRC-58:2015. The interaction of various factors such as the temperature differentials, the modulus of subgrade responses, and the thickness of the components can be shown in detail. Flexural stress analysis can also be performed using the equation in IRC-58:2015 to determine the top-down fatigue damage produced by repeated cycles of axle loads and negative temperature differences.

The pavement is considered safe if the total cumulative fatigue damages caused by

i. wheel load and curling stresses at the bottom and
ii. Wheel load and curling stresses at the top are less than one.

In other words, a pavement is considered to have failed if the total of its accumulated damages exceeds one.

Thus, if CFD (BUC) + CFD (TDC) <1, the pavement is safe from large-scale cracking

$$\left\{ \begin{array}{c} \text{CFD (Cumulative Fatigue Damage) BUC (Bottom-up Cracking Case)} \\ + \\ \text{CFD (Cumulative Fatigue Damage) TDC (Top-down Cracking Case)} \end{array} \right\} < 1$$

The design thickness may be increased by 10 mm to

(i) to permit two retexturing and
(ii) Grinding to rectify faulting during the service life.

Expressions for Maximum Tensile Stress at the Bottom of the Slab (Bottom-up Cracking Case):

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ISSN: 1005-0930

Single axle - Pavement without concrete shoulders:

K > 150 MPa/m

$S = -0.238 + 7.02\ (\gamma h^2/kl^2) + 2.41\ Ph/(kl^4) + 0.0585\ \Delta T$

Single axle – Pavement with tied concrete shoulders

k > 150 MPa/m

$S = 0.042 + 3.26\ (\gamma h^2/k/^2) + 1.62\ Ph/(kl^4\ ) + 0.0522\ \Delta T$

Tandem axle - Pavement without concrete shoulders:

K > 150 MPa/m

$S = -0.3 + 9.88\ (\gamma h^2/kl^2) + 0.965\ Ph/(kl^4) + 0.0543\ \Delta T$

Tandem axle – Pavement with tied concrete shoulders

k > 150 MPa/m

$S = -\ 0.210 + 3.88\ (\gamma h^2/kl^2) + 0.73\ Ph/(kl^4) + 0.0506\ \Delta T$

Expression for Maximum Tensile Stress at the Top of the Slab (Top-down Cracking Case):

$S = -0.219 + 1.686BPh/kl^4 + 168.48h^2/kl^2 + 0.1089\ \Delta T$

The following symbols are used in the equations:

S = Flexural stress in slab, MPa

ΔT = Maximum Temperature differential in ºC

h = Thickness of slab, m

k = Effective modulus of subgrade reaction of foundation, MPa/m

l = Radius of relative stiffness = {Eh3/(12k(1-μ2)}0.25

E = Elastic modulus of concrete, MPa

μ = Poisson’s ratio of concrete

γ = Unit weight of concrete (24 KN/m^3, density = 2400 kg/m^2)

Assumption based on IRC 58-2015 (Annexure VII)

- Cumulative modulus of subgrade reaction of foundation, k = 275 MPa/m
- Elastic modulus of concrete, E = 30,000 MPa
- Poisson’s ratio of concrete, μ = 0.15
- Unit weight of concrete = 24 KN/m^3
- Thickness of slab = 0.3 m
- Radius of relative stiffness, $l = \{Eh^3/(12k(1-\mu^2)\}0.25 = 0.70789$
- P = For Bottom-up cracking analysis: - single/tandem rear axle load (kN). No fatigue damage is computed for front (steering) axles for bottom-up cracking case.

For Top-down cracking analysis: - 100% of rear single axle, 50% of rear tandem axle, 33% of rear tridem axle.

- B = 0.90 for transverse joint without dowel bars and 0.66 for transverse joint with dowel bars.
-

Table 9. Cumulative fatigue damage values of single and Composite sections (Without shoulders)

Slab	CFD for BUC case			CFD for TDC case				Sum of BUC and TDC CFD without shoulder	Remarks
	Due to Rear single axles	Due to Tandem axles	Total CFD	Due to Rear single axles	Due to Tandem axles	Due to Tridem axles	Total CFD		
PQC	5.820	0.061	5.881	0.000	0.000	0.000	0.000	5.881	Unsafe
GF	0.073	0.000	0.073	0.000	0.000	0.000	0.000	0.073	safe
SF	0.205	0.000	0.205	0.000	0.000	0.000	0.000	0.205	safe
PQC+GF	0.022	0.000	0.022	0.000	0.000	0.000	0.000	0.022	safe
PQC+SF	0.073	0.000	0.073	0.000	0.000	0.000	0.000	0.073	safe
GF+SF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	safe
DP	0.866	0.000	0.866	0.026	0.079	0.002	0.107	0.973	safe
MP	1.529	0.000	1.529	0.093	0.204	0.007	0.304	1.833	Unsafe
PQC+DP	0.449	0.000	0.449	0.006	0.021	0.000	0.027	0.476	safe
PQC+MP	0.866	0.000	0.866	0.000	0.000	0.000	0.000	0.866	safe
DP+MP	0.205	0.000	0.205	0.000	0.000	0.000	0.000	0.205	safe
GGBS	0.866	0.000	0.866	0.026	0.079	0.002	0.107	0.973	safe
PQC+GGBS	0.449	0.000	0.449	0.006	0.021	0.000	0.027	0.476	safe

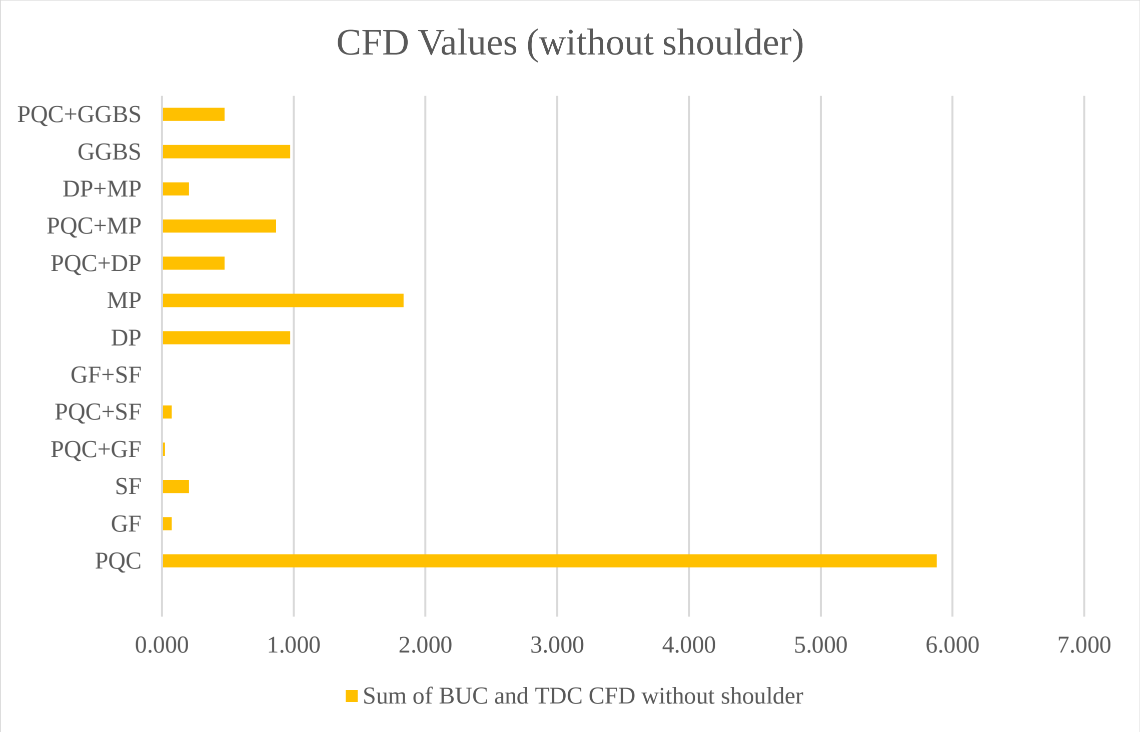

Fig. 10 Graphical representation of Cumulative fatigue damage values of single and Composite sections (without shoulders)

Table 10. Cumulative fatigue damage values of single and Composite sections (With shoulders)

Slab	CFD for BUC case			CFD for TDC case				Sum of BUC and TDC CFD with shoulder	Remarks
	Due to Rear single axles	Due to Tandem axles	Total CFD	Due to Rear single axles	Due to Tandem axles	Due to Tridem axles	Total CFD		
PQC	0.310	0.000	0.310	0.044	0.098	0.003	0.145	0.455	safe
GF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	safe
SF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	safe
PQC+GF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	safe

PQC+SF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	safe
GF+SF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	safe
DP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	safe
MP	0.013	0.000	0.013	0.000	0.000	0.000	0.000	0.013	safe
PQC+DP	0.000	0.000	0.000	0.006	0.021	0.000	0.027	0.027	safe
PQC+MP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	safe
DP+MP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	safe
GGBS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	safe
PQC+GGBS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	safe

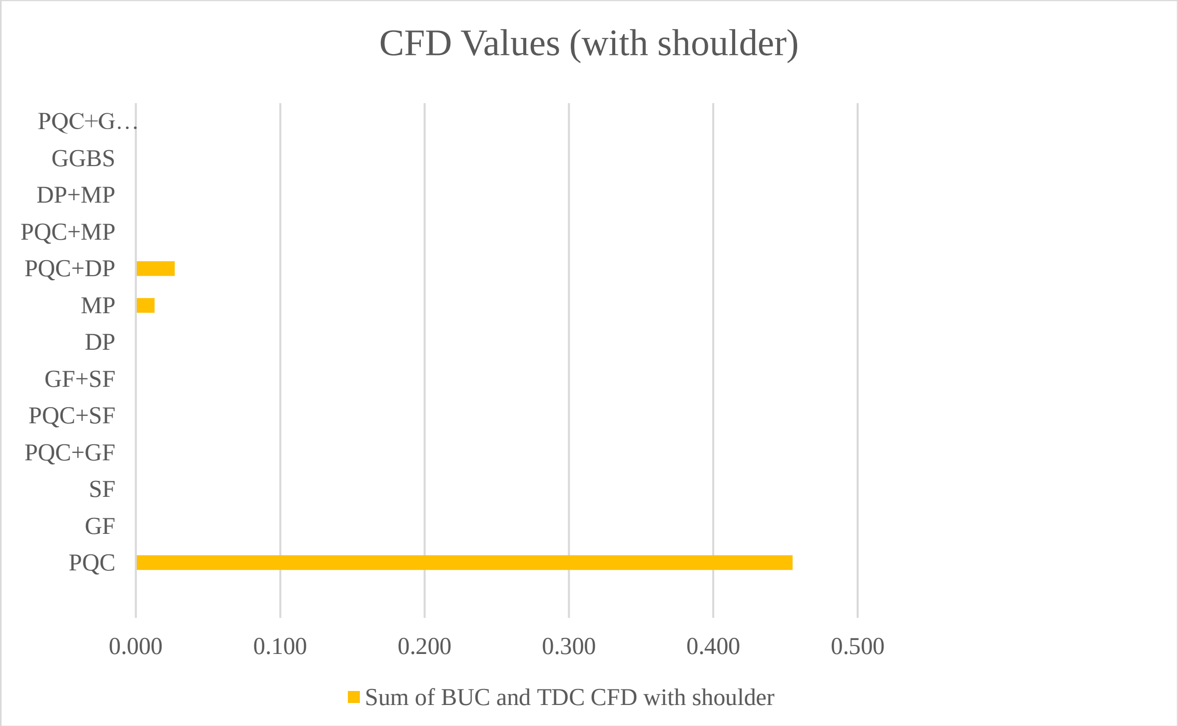

Fig. 11 Graphical representation of Cumulative fatigue damage values of single and Composite sections (with shoulders)

Discussion

- The single and composite sections resulted in less temperature differential values when compared with PQC during the summer season.
- When compared with single and composite section, composite section of the GF+SF slab has less temperature differential value of 6^0, and PQC has a high-temperature differential value of 15^0, it shows that using admixtures will reduce the temperature differential values.

- Compared to GF+SF slab, the positive temperature difference is 60% more for PQC slab, 25% more for GF slab, PQC+SF slab, 34% more for SF slab and DP+MP slab, 14% more for PQC+GF, 45% more for DP slab, PQC+MP slab and GGBS slab, 50% for MP slab, 40% more for PQC+DP slab and PQC+GGBS slab.
- Maximum temperature difference for PQC in Karnataka as per IRC 58-2015 is 21^0, and the obtained maximum temperature difference of admixed cement concrete is within the limit.
- The temperature differential values obtained from the present study for 300 mm slab are within limits for the pavement with tied concrete shoulders as per code IRC 58-2015.
- The temperature differential values obtained from the present study for the 300 mm slab are within limits for the pavement without tied concrete shoulders as per code IRC 58-2015, except for PQC and MP for the summer season.
- For CFD analysis, the data is constant for all the single and composite section admixed cement concrete as per Appendix – VII in IRC 58-2015 for PQC slab.
- For cumulative fatigue damage analysis as per IRC: 58-2015, it was found that the stresses at BUC and TDC for all the single and composite sections of the slab are less than one, and hence it is safe for the pavement with tied concrete shoulder and without concrete shoulder, except for MP and PQC.
- MP and PQC pavement are more likely to fail as CFD is greater than 1 for pavement without concrete shoulder.

5 CONCLUSION

- Using admixtures in the concrete mix can be sustainable and economical. So, using 0.5% to the volume of concrete of Alkali Resistant Glass Fibres and 1.5 % to the volume of concrete of Hooked End Steel Fibres. 10% replacement of cement by marble powder, 10% replacement of cement by dolomite powder, and 40% replacement of cement by GGBS have reduced the temperature differential value.
- Strength properties of the composite pavement sections are better than those of the single admixed sections and normal PQC concrete. There is a considerable increase in the compression and flexural strengths of the composite sections.
- Out of all the concrete sections, composite section of SF+GF could withstand more compression and flexural load.
- The maximum temperature differential value for all the single and composite concrete sections is less than PQC.
- Composite section of GF+SF slab has less temperature differential value than all other single and composite sections.
- For cumulative fatigue damage analysis as per IRC: 58-2015, it was found that the stresses at BUC and TDC for all the single and composite sections of the slab are less than 1. Hence, the pavement is safe against fatigue cracking with tied concrete shoulders for high volume roads.
- From the present study it is concluded that the composite sections have less temperature differential value when compared to single admixed concrete and standard concrete sections. So, heavy traffic composite sections can be a better solution for temperature stresses.
- The study revealed that the various characteristics of composite sections, such as their low-temperature stress and resistivity, can be beneficial for high traffic conditions. They offer better resistance to multiple loads and lower temperature differential values than single-admixed concrete and standard concrete.

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