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Study of Thermal Gradient in Concrete Slabs through Experimental Approach

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Abstract- Millions of tons of cement is used every year that adversely affects environment. Cement is also an important building material for infrastructure development. Cement can be suitably replaced with low cost and so called waste materials like fly ash, marble powder, silica fumes etc... Favoring environment and saving cement. Large length of roads is required to be built in near future over the globe in general and in India in particular. The present technology of making flexible pavements is increasingly becoming unsustainable because of rising life cycle costs and could be suitably replaced with high volume fly ash and high volume marble powder based concrete roads.

The daily and seasonal variation in temperature is an important factor influencing cement concrete pavements. The temperature differential depends on the thickness of slab and the grade of concrete. In this study an effort is made to determine realistic temperature differential and temperature stresses in pavement quality concrete , high volume fly-ash concrete slab and high volume marble powder concrete slab of different thickness. The Concrete slabs of size 500X500 mm of different thickness are instrumented with thermocouples to record the temperature differential between top to bottom of the slabs. Also an attempt is made to Design a Controlled concrete mix and High Volume Fly Ash Concrete and High Volume Marble powder Concrete by replacing 50% of cement by fly ash and 50% of cement by Marble powder respectively, also to find Compressive strength and Static Flexural strength at different periods of curing.

Keywords: pavement quality concrete, high volume fly ash concrete, high volume marble powder concrete, thermocouples, temperature gradient, compressive strength and flexural strength.

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STUDYOFTHERMALGRADIENTINCONCRETESLABSTHROUGHEXPERIMENTALAPPROACH

Strictly as per the compliance and regulations of :

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Mr. Dhananjay M [α] & Mr. Abhilash K [σ]

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The temperature is recorded every hour for a period of two days. It was observed that the temperature is more predominate at the top of the slab during day time when compared to bottom of concrete slabs and also observed that the temperature is more at the bottom of the slab during night time when compared to top of concrete slabs. The temperature gradient in concrete slabs achieves equilibrium two times a day i.e. during morning hours and also during evening hours and also actual temperature stresses are calculated.

From these studies, it is observed that the compressive strength in Controlled concrete is higher at 3, 7 and 28 days of curing. Fly-ash admixed concrete has lower compressive strength at 3, 7, 28 days of curing when compares to Controlled concrete, but at 56days the compressive strength of High Volume fly Ash Concrete is more than that of Controlled concrete. Similarly the static flexural strength of fly ash admixed concrete mix is higher than Controlled concrete at 56 days of curing.

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Keywords: pavement quality concrete, high volume fly ash concrete, high volume marble powder concrete, thermocouples, temperature gradient, compressive strength and flexural strength.

I. Introduction

Concrete pavements by far have the best long-term value because of their longer life expectations, durability and minimum maintenance requirements. The rigidity of concrete pavements allows them to keep the riding surface in good condition. Concrete pavements can be designed to last for more than 25 years. Concrete pavements frequently outlast both their designed life expectancy and traffic loads. The durability of concrete minimizes the need for extensive repairs or annual maintenance. When repairs are necessary, they are typically smaller in scope than the asphalt pavements. Concrete's rigid surface makes it easier for wheels to roll, thus reduces operation cost of vehicles.

Pavements are generally subjected to axle loads varying from 30kN to 250kN. While designing the pavements the cumulative damage factor is taken into account in order to incorporate all categories of axle loads applications. Loads of different magnitudes cause different amount of damage to the pavement. Fatigue and fracture has become an important consideration in the design of structures subjected to repeat or cyclic loading conditions. The fatigue performance generally depends on material characteristics, geometry, stress – strain history and environment among other factors which occur at random during the intended life of the structure as a result high performance concrete (HPC) is essential for rigid pavements.

High Performance Concretes produced today contain materials in addition to Portland cement to achieve higher compressive strength and durability. The materials include fly ash, silica fume, ground-granulated blast furnace slag etc. used separately or in combination. At the same time, chemical admixtures such as high-range water-reducers are needed to ensure that the concrete is easy to transport, place and finish. For high-strength concretes, a combination of mineral and chemical admixtures is nearly always essential to ensure achievement of the required strength. The structural deteriorations in cement concrete pavements are noticed in the form of cracks due to combined effects of load stress and warping stress at critical regions.

The stresses developed in rigid pavement include load stress, shrinkage/expansion stress and temperature stress. Temperature stresses develop due to the change in temperature from top to the bottom region of the concrete slab. Temperature along depth of the slab is to be recorded to determine thermal stresses. Thermocouples are used to record the temperature.

Thermocouples are the most popular temperature sensors.

They are cheap, interchangeable, have standard connectors and can measure a wide range of temperatures. Thermocouples are available in different combinations of metals or calibrations. Because thermocouples measure in wide temperature ranges and can be relatively rugged, they are very often used in industry.

a) Need for the study

High Volume Fly ash Concrete (HVFAC) is being used for rigid pavements in recent times, the strength and durability properties of HVFAC and High Volume Marble Powder Concrete (HVMPC) are not the same as conventional Pavement Quality Concrete (PQC). The stresses induced due to temperature may very when compared to PQC. Hence there is a need to analyze the stresses induced due to temperature in HVFAC and HVMPC pavement.

b) Objective of the study

The main objectives of this study are to analyze the temperature stresses induced in CC slabs.

Specific objectives are:

- To design a Controlled concrete mix and High Volume Fly Ash and High Volume Marble powder Concrete mix by replacing 50% of cement by fly ash and marble powder.
- To study the Temperature gradient along the depth of the concrete slabs, i.e. for Pavement Quality Concrete, High Volume Fly ash Concrete and High Volume Marble powder concrete slabs of different thickness.
- To check whether maximum recommended temperature differentials within the concrete roads are as per IRC 58-2002, is within the limits for different slab thickness.
- Comparison of stresses in High Volume Fly ash Cement Concrete Pavement, High Volume Marble Powder Concrete and Pavement Quality Concrete.

II. Present Investigation

High Volume Fly Ash Concrete, High Volume Marble Powder Concrete and Conventional Pavement Quality Concrete are used in this study to determine the effect of temperature in Concrete pavement slabs. Conventional Pavement Quality Concrete is designed as per IS 10262:2009. Fifty per-cent cement is replaced with by Fly Ash and Marble Powder to get High Volume Fly Ash Concrete and High Volume Marble powder concrete.

Table 1 : Physical properties of materials used in the study

Sl.No	Material	Property	Value
1	Cement	Normal Consistency Initial setting time Specific Gravity	34% 45min 3.045
2	Fly-ash	Specific Gravity Fineness Modulus	2.10 3.325%
3	Granite powder	Specific Gravity Fineness Modulus	2.27 0%
4	Fine aggregate	Specific Gravity Fineness Modulus Water absorption	2.606 3.23% 0.45%
5	Coarse aggregate	Specific Gravity Fineness Modulus Loss Angeles Abrasion Value Aggregate Impact Value Aggregate Crushing value Water absorption	2.86 1.63% 34.96% 17.32% 26.82% 1.4%

a) Casting of Concrete Slabs

Slabs of size 500mmx500mm and thickness 150, 200, and 250mm are cast at the selected site. Marine ply wood moulds are prepared to cast the slabs. Figure 1.

Figure 1 : Moulds for Casting

The location for casting the slab is identified such that it is exposed to sun light. The slab is directly cast on earth surface. The surface is prepared before casting. Thermocouples are fixed to wooden beads of size 10x10mm at 3 levels that is 25mm from top 25mm from bot-tom and at the center of the bead as shown in Figure 2.

Figure 2 : Fixing of Thermocouple on wooden beads

The wooden bead is placed in the mould, Concrete is poured into the mould first around the thermocouple bead and then in three layers and compacted as shown in Figure 3.

Figure 4 : Compaction of Concrete in Moulds

Then all the 9 slabs are cast in a similar way. The slabs are cured for a period of 28 & 56 days by membrane curing by gunny bags.

b) Temperature Recording

Temperatures are recorded after 56 days of casting by using a digital temperature indicator. As shown in figure 5.

Figure 5 : Temperature recording at the site

The temperature indicator has two leads which are connected to the two leads of the thermo-couple. When temperature indicator is activated it displays the temperature directly in degree centigrade. The temperature is recorded every hour for a period of 2-days.

Table 2 : Temperature (°C) Readings in Middle of PQC Slabs

Hours	25 cm Thick			20 cm Thick			15 cm Thick		
	T	M	B	T	M	B	T	M	B
7:00 AM	27.2	27.4	27.6	26.1	26.3	26.5	23.5	24.4	23.8
8:00 AM	27.5	27.4	27.4	26.2	26.2	26.2	25.6	25.2	25.5
9:00 AM	29.6	28.2	27.4	28.2	26.1	25.9	28.2	27.2	26.4
10:00AM	31.6	28.5	27.3	32	29.2	27.8	31.2	28.3	27.1
11:00AM	33.2	27.9	26.5	35.3	31.2	28.1	34.5	32.2	28.2
12:00 PM	36	31.2	27.3	36.1	32	28.6	36.7	28.3	29.2
1:00PM	39.9	32.4	28.5	39.2	33.1	30.3	40.2	34.5	31.2
2:00 PM	43.9	38.6	30.7	43.1	36.8	30.7	44.8	37.2	32.9
3:00 PM	42.5	36.2	32.9	42.7	36.8	34.3	43.5	39.3	35.1
4:00 PM	41.1	38.2	33.1	40.2	36.7	32.8	43.8	40.2	37.2
5:00 PM	39.5	36.8	33.9	39.8	37.1	34.5	42.5	39.7	37.7
6:00 PM	36.2	34.2	33.9	36.1	34.2	33.9	39.3	38.1	37.2
7:00 PM	33.9	33.9	33.9	33.4	33.3	33.4	36.2	36.2	36.3
8:00 PM	32	32.5	32.8	32	32.5	32.7	32.9	33.3	33.5
9:00 PM	31	31.9	32.7	31.2	31.9	32.6	30.3	31.2	31.9
10:00PM	29.8	31.2	32.6	29.3	30.8	31.8	28.5	29.9	30.8
11:00PM	28.8	30.8	32.3	28.3	30.2	31.4	27.2	29.2	30.1
12:00AM	28.3	29.3	31.4	27.8	28.8	30.6	26.3	28.2	28.8
1:00 AM	27.3	28.3	30.1	27.4	28.3	29.9	26.2	27.9	28.5
2:00 AM	27.1	28.2	29.6	27.2	28.3	29.3	25.8	27.2	27.8
3:00 AM	26.9	27.3	29.1	26.9	27.2	28.9	25.6	26.8	27.7
4:00 AM	26.3	26.9	27.8	26.5	27	28	25.5	26.4	26.9
5:00 AM	26.1	26.8	27.1	26.2	26.9	27.1	25.2	25.6	26.1
6:00 AM	25.6	36.1	26.3	25.9	26.2	26.5	24.8	25.1	25.3

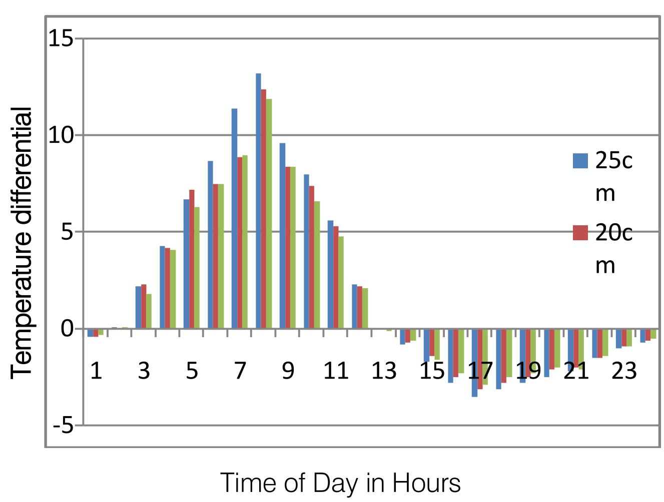

Figure 6 : Actual Temperature Differential at middle of PQC Slabs

Table 3 : Temperature (°C) Readings in Middle of HVFAC Slabs

Hours	25 cm Thick slab			20 cm Thick slab			15 cm Thick slab		
	T	M	B	T	M	B	T	M	B
7:00 AM	25.7	25.9	26.1	25.8	25.9	26.1	25.7	25.8	26
8:00 AM	25.9	25.8	26	26.9	26.9	26.9	26.4	26.3	26.3
9:00 AM	29.6	28.2	27.5	28.9	27.8	27.2	27.9	26.9	26.1
10:00AM	34.2	31.3	29.7	33.2	30.5	28.5	31.9	29.1	27.8
11:00AM	36.5	31.8	29.6	36.2	32.9	29.7	34.2	31.1	28
12:00 PM	41.2	35.4	31	41.2	35.2	32.1	37.6	33.9	30
1:00PM	41.1	35.2	30.2	41.7	36.2	31.6	38.9	35.2	30.2
2:00 PM	46.3	39	34.2	48.1	42.2	37.4	46.3	42.2	37.1
3:00 PM	45.5	37.2	33.3	45.8	40.4	35.5	43.7	39.3	37
4:00 PM	43.2	40.2	35.5	43.9	40.8	36.3	42.3	39.3	37.1
5:00 PM	41.6	38	35.1	41.6	39.1	36.2	40.4	38	36.8
6:00 PM	39.2	37.2	35.5	38.3	36.8	35.9	36.3	35.8	34.9
7:00 PM	35.3	35.4	35.4	35.4	35.4	35.4	32.8	33	32.9
8:00 PM	35.1	35.4	35.8	33.6	33	34.2	32.2	32.5	32.8
9:00 PM	33.8	33.9	35.2	32.6	33.4	33.9	31.5	32.1	32.8
10:00PM	32.5	34.2	34.8	31.3	32.8	33.2	30.4	31.9	32.1
11:00PM	31.2	33.2	34.1	31.1	32.8	33.9	29.6	30.8	31.8
12:00AM	30.9	32.3	33.4	30.7	31.2	33	28.9	30.1	31.2
1:00 AM	30.4	31.8	32.6	29.2	30.2	31.2	28.2	29.3	30.2
2:00 AM	29.8	30.8	31.7	28.8	29.6	30.5	27.9	28.9	29.5
3:00 AM	28.5	29.2	30.2	28.2	28.9	29.7	27.7	28.3	29
4:00 AM	28.3	29.3	29.5	27.9	28.5	28.9	27.2	27.2	28.2
5:00 AM	28.1	28.2	29.1	27.1	27.6	28.1	26.9	27.5	27.6
6:00 AM	27.7	27.9	28.3	26.9	27.2	27.4	26.4	26.6	26.9

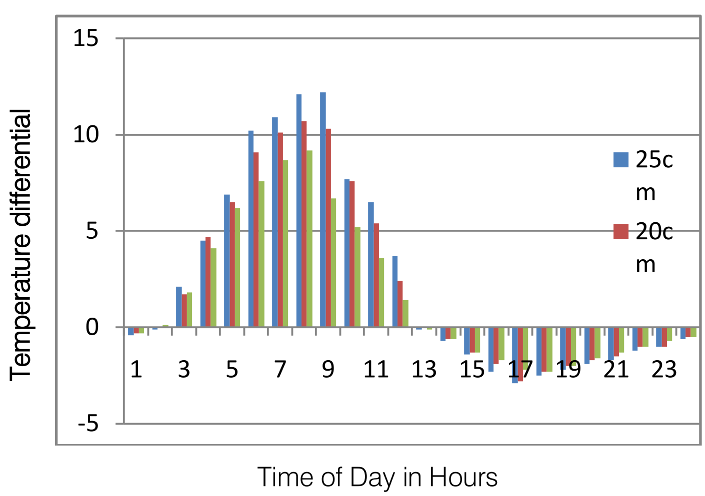

Figure 7 : Actual Temperature Differential at middle of HVFAC Slabs

Table 4 : Temperature (°C) Readings in Middle of HVMPC Slabs

Hours	25 cm Thick slab			20 cm Thick slab			15 cm Thick slab		
	T	M	B	T	M	B	T	M	B
7:00 AM	26.2	26.3	26.5	25.3	25.4	25.6	26.2	26.5	26.8
8:00 AM	26.5	26.5	26.5	28.1	28	28	27.9	27.8	27.8
9:00 AM	29	27.9	26.7	30.1	28.4	28.2	28	26.9	26.4
10:00AM	33.8	30.5	29.3	35.2	30.9	30.5	33.2	31.2	28.7

11:00AM	38.2	35.1	31.2	37.8	36.9	31.7	37.9	34.1	32.4
12:00 PM	38.8	34.3	30.1	38.8	34.3	31.2	40	36	32.3
1:00PM	41.9	37.5	32	39.9	34	31.3	44.5	38.2	35.8
2:00 PM	46.4	38.4	34.2	46.8	42.2	36.2	49.5	43	39.9
3:00 PM	45.1	39.1	35.2	44.9	41.1	36.7	46.2	41.6	38.4
4:00 PM	43.3	39.9	35.8	43.8	40.4	37.2	44.4	41.4	39.3
5:00 PM	43	40.5	36.9	42.3	40.8	37.4	42.8	41.2	39.1
6:00 PM	38.9	37.5	36.8	38.7	37.6	36.9	39.8	36.9	37.9
7:00 PM	37.5	37.5	37.5	36.3	36.3	36.4	34.3	34.3	34.2
8:00 PM	36.5	36.7	37.4	34.2	34.5	34.8	31.4	31.7	32
9:00 PM	33.8	34.8	35.3	32.7	33.2	34	30.2	30.8	31.2
10:00PM	31.9	33.2	34.3	30.1	31.2	32.3	28.5	30.3	30.4
11:00PM	30.3	32.3	33.2	28.8	30.3	31.5	27.5	29.3	29.9
12:00AM	30.3	31.3	32.8	28.5	29.3	30.7	27.5	28.9	29.4
1:00 AM	29.5	30.3	31.6	27.5	28.8	29.3	27.2	28.2	29
2:00 AM	29.2	30.1	31	27.4	27.9	28.8	26.5	27.3	28
3:00 AM	28.8	29	30.2	26.9	27.6	28.2	26.2	27.2	27.3
4:00 AM	28	28.4	29	26.5	27.1	27.4	26.2	26.8	27
5:00 AM	27.2	27.6	28	26.2	26.5	26.9	25.9	26.1	26.5
6:00 AM	26.9	27.1	27.5	26.1	26.4	26.5	25.5	25.9	26.2

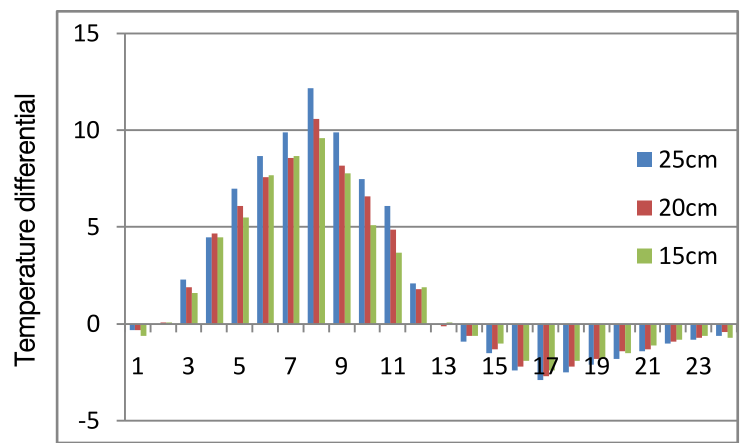

Figure 8 : Actual Temperature Differential at middle of HVMPC Slabs

Table 5 : Temperature (°C) Readings in Edge of PQC Slabs

Hours	25 cm Thick		20 cm Thick		15 cm Thick	
	T	B	T	B	T	B
7:00 AM	25.9	26.2	25.3	25.5	24.1	24.2
8:00 AM	27.2	27.2	26.6	26.7	25.8	25.9
9:00 AM	30.2	28.4	29.3	27.5	30.8	29.1
10:00AM	36.6	30.9	34.4	29.2	33.8	29.1
11:00AM	37.7	29.8	38.4	31.8	36.4	30.9
12:00 PM	40.1	32.7	40.9	33.8	38.2	31.2
1:00PM	40.9	33	42.9	35.2	39.2	32
2:00 PM	48.3	36.9	47.8	37.6	43.5	33.2
3:00 PM	44.3	35.9	44.3	36.5	41.9	34.8
4:00 PM	41.5	35.2	41.8	35.4	41.4	35.2
5:00 PM	39.3	35.2	39.4	35.3	39.7	35.8

6:00 PM	37.3	35.2	36.7	34.9	37.3	35.8
7:00 PM	34.1	34.2	33.4	33.3	33.7	33.7
8:00 PM	31.2	31.9	30.2	30.8	31.4	31.9
9:00 PM	29.8	31.5	29.3	30.8	29.6	31
10:00PM	29	31.3	28.9	30.7	28.3	30.1
11:00PM	28.5	31.5	28	30.4	27.2	29.5
12:00AM	28.2	30.7	27.8	29.7	26.4	28.4
1:00 AM	27.9	30.1	27.5	29.2	26.5	28.2
2:00 AM	27.5	29.2	27.2	28.9	26.3	27.9
3:00 AM	27.3	28.6	26.9	28.1	25.9	27
4:00 AM	26.9	27.9	26.5	27.4	25.5	26.4
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6:00 AM	26.4	27	26.1	26.6	24.9	25.4

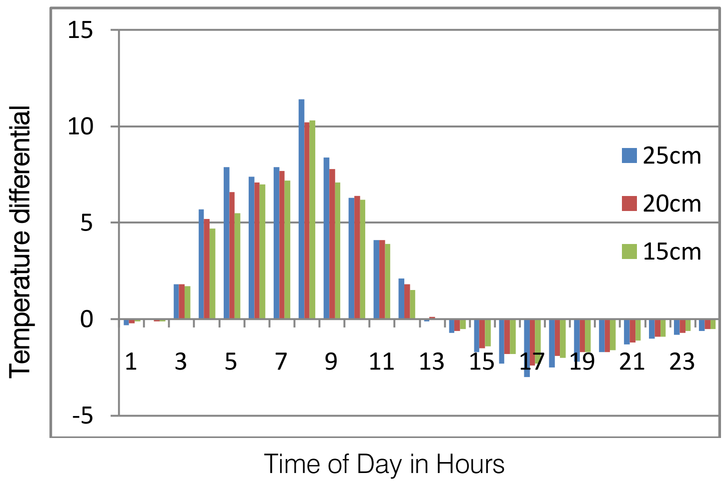

Figure 9 : Actual Temperature Differential at edge of PQC Slabs

Table 6 : Temperature (°C) Readings in Edge of HVFAC Slabs

Hours	25 cm Thick		20 cm Thick		15 cm Thick	
	T	B	T	B	T	B
7:00 AM	27.4	27.8	27.1	27.5	25.1	25.4
8:00 AM	27	27.1	27.1	27	26.3	26.3
9:00 AM	28.8	26.8	28.9	27.2	28.4	26.8
10:00AM	33.9	29.2	33.8	29.7	34.1	29.9
11:00AM	37.7	30.8	37.6	31.5	35.6	30.2
12:00 PM	42.3	33.1	42.1	33.3	38.7	30.9
1:00PM	42.5	31.9	42.4	32.4	42.2	33.1
2:00 PM	45.1	33.9	47.3	37.5	42.9	34.2
3:00 PM	44.1	34.3	45.6	36.9	43.4	35.2
4:00 PM	42.1	34.5	43.2	36.2	41.9	35.1
5:00 PM	39.1	34.1	39.7	35.1	39.4	34.6
6:00 PM	35.9	33.2	36.5	34.2	36.2	34.2
7:00 PM	33.4	33.5	33.2	33.2	33.4	33.4
8:00 PM	32.7	33.4	32.9	33.6	31.2	31.8
9:00 PM	31.3	32.8	31.4	32.8	30.2	31.3
10:00PM	30.8	32.5	30.6	31.9	29.7	30.3
11:00PM	30.2	32.7	29.2	31.4	28.7	30.8
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1:00 AM	29.3	31.2	28.2	30	28.1	29.6

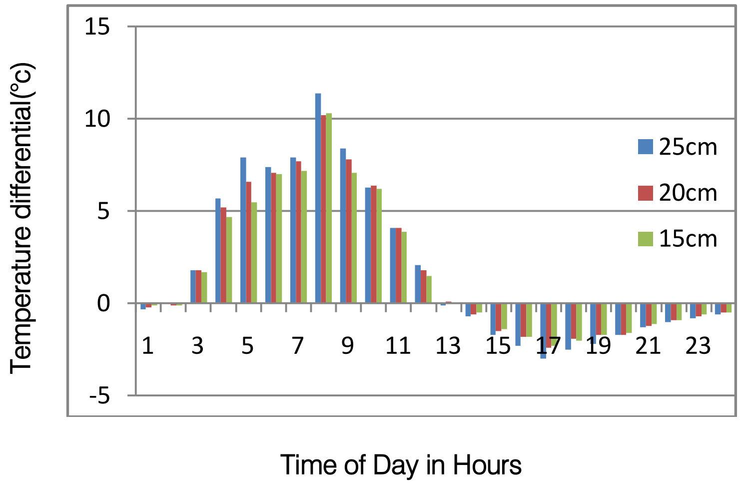

Figure VIII : Actual Temperature Differential at edge of PQC Slabs

Table VI : Temperature (°C) Readings In Edge Of HVFAC Slabs

Hours	25 cm Thick slab		20 cm Thick slab		15 cm Thick slab	
	Top	Bottom	Top	Bottom	Top	Bottom
7:00 AM	27.4	27.8	27.1	27.5	25.1	25.4
8:00 AM	27	27.1	27.1	27	26.3	26.3
9:00 AM	28.8	26.8	28.9	27.2	28.4	26.8
10:00AM	33.9	29.2	33.8	29.7	34.1	29.9
11:00AM	37.7	30.8	37.6	31.5	35.6	30.2
12:00 PM	42.3	33.1	42.1	33.3	38.7	30.9
1:00PM	42.5	31.9	42.4	32.4	42.2	33.1
2:00 PM	45.1	33.9	47.3	37.5	42.9	34.2
3:00 PM	44.1	34.3	45.6	36.9	43.4	35.2
4:00 PM	42.1	34.5	43.2	36.2	41.9	35.1
5:00 PM	39.1	34.1	39.7	35.1	39.4	34.6
6:00 PM	35.9	33.2	36.5	34.2	36.2	34.2
7:00 PM	33.4	33.5	33.2	33.2	33.4	33.4
8:00 PM	32.7	33.4	32.9	33.6	31.2	31.8
9:00 PM	31.3	32.8	31.4	32.8	30.2	31.3
10:00PM	30.8	32.5	30.6	31.9	29.7	30.3
11:00PM	30.2	32.7	29.2	31.4	28.7	30.8
12:00AM	29.6	31.6	28.9	30.7	28.3	29.9
1:00 AM	29.3	31.2	28.2	30	28.1	29.6
2:00 AM	28.2	29.8	27.3	28.8	27.3	28.6
3:00 AM	27.8	29.1	27	28.2	26.9	28
4:00 AM	27.2	28.3	26.4	27.3	26.4	27.3
5:00 AM	26.3	27.2	26.1	26.9	26.3	27
6:00 AM	25.9	26.6	25.9	26.5	26.2	26.7

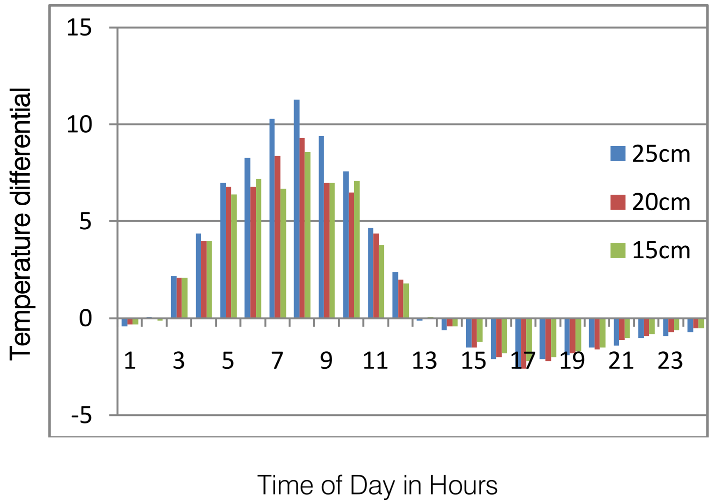

Figure 11 : Actual Temperature Differential at edge of HVMPC Slabs

Table 8 : Temperature (°C) Readings in Corner of PQC Slabs

Hours	25 cm Thick		20 cm Thick		15 cm Thick	
	T	B	T	B	T	B
7:00 AM	25.9	26.2	25.3	25.5	24.1	24.2
8:00 AM	27.2	27.2	26.6	26.7	25.8	25.9
9:00 AM	30.2	28.4	29.3	27.5	30.8	29.1
10:00AM	36.6	30.9	34.4	29.2	33.8	29.1
11:00AM	37.7	29.8	38.4	31.8	36.4	30.9
12:00 PM	40.1	32.7	40.9	33.8	38.2	31.2
1:00PM	40.9	33	42.9	35.2	39.2	32
2:00 PM	47.3	36.9	46.8	37.6	42.5	33.2
3:00 PM	44.3	35.9	44.3	36.5	41.9	34.8
4:00 PM	41.5	35.2	41.8	35.4	41.4	35.2
5:00 PM	39.3	35.2	39.4	35.3	39.7	35.8
6:00 PM	37.3	35.2	36.7	34.9	37.3	35.8
7:00 PM	34.1	34.2	33.4	33.3	33.7	33.7
8:00 PM	31.2	31.9	30.2	30.8	31.4	31.9
9:00 PM	29.8	31.5	29.3	30.8	29.6	31
10:00PM	29	31.3	28.9	30.7	28.3	30.1
11:00PM	28.5	31.5	28	30.4	27.2	29.5
12:00AM	28.2	30.7	27.8	29.7	26.4	28.4
1:00 AM	27.9	30.1	27.5	29.2	26.5	28.2
2:00 AM	27.5	29.2	27.2	28.9	26.3	27.9
3:00 AM	27.3	28.6	26.9	28.1	25.9	27
4:00 AM	26.9	27.9	26.5	27.4	25.5	26.4
5:00 AM	26.5	27.3	26.4	27.1	25.4	26
6:00 AM	26.4	27	26.1	26.6	24.9	25.4

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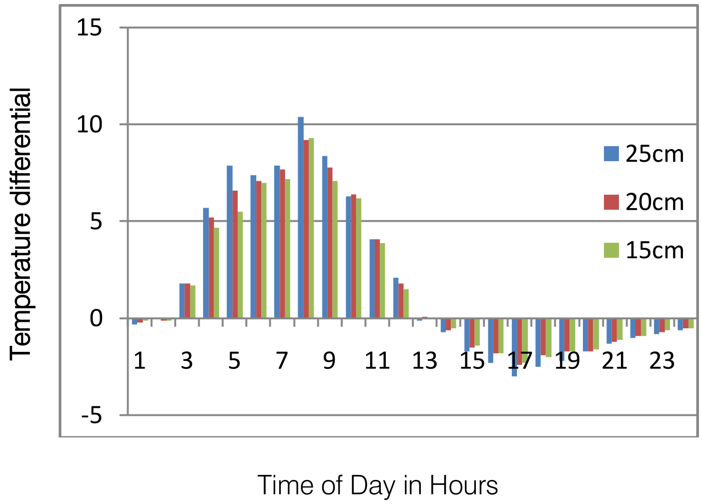


Figure 12 : Actual Temperature Differential at corner of PQC Slabs

Table 9 : Temperature (°C) Readings in Corner of HVFAC Slabs

Hours	25 cm Thick		20 cm Thick		15 cm Thick	
	T	B	T	B	T	B
7:00 AM	26.9	27.2	26.2	26.5	24.2	24.4
8:00 AM	27.1	27	26.5	26.6	26.3	26.4
9:00 AM	29.2	27.1	29.2	27.2	28.7	26.9
10:00AM	35.8	31.3	34.9	30.2	34.6	30.5
11:00AM	38.4	31.9	37.6	31.2	37.1	30.9
12:00 PM	40.1	32.4	41.9	33.7	41.9	34.5
1:00PM	42.8	33.9	42.8	34.3	43.2	35.1
2:00 PM	47.4	37.1	46.8	37.8	47.7	38.8
3:00 PM	44.6	35.9	45.5	37.4	46.1	37.8
4:00 PM	41.8	35.3	43.5	37.2	43.4	36.5
5:00 PM	39.2	35	39.2	35.3	39.9	36.4
6:00 PM	37.1	34.8	36.8	34.8	37.9	36.1
7:00 PM	34.3	34.3	34.2	34.2	34.8	34.7
8:00 PM	32.4	33.4	31.2	32	29.8	30.5
9:00 PM	29.6	31.1	30.4	31.8	28.7	30
10:00PM	28.9	31.1	29.2	31.2	27.8	29.7
11:00PM	28.2	30.8	28.9	30.9	27.6	29.6
12:00AM	28.2	30.4	28.4	30.1	27.3	28.9
1:00 AM	27.3	29.3	28.1	29.8	27.1	28.6
2:00 AM	26.9	28.7	27.8	29.3	26.9	28.9
3:00 AM	26.7	28.3	27.5	28.8	26.8	27.9
4:00 AM	26.2	27.5	26.9	28	26.3	27.1
5:00 AM	25.8	26.9	26.2	27.1	25.8	26.6
6:00 AM	25.4	26.2	25.9	26.6	25.7	26.3

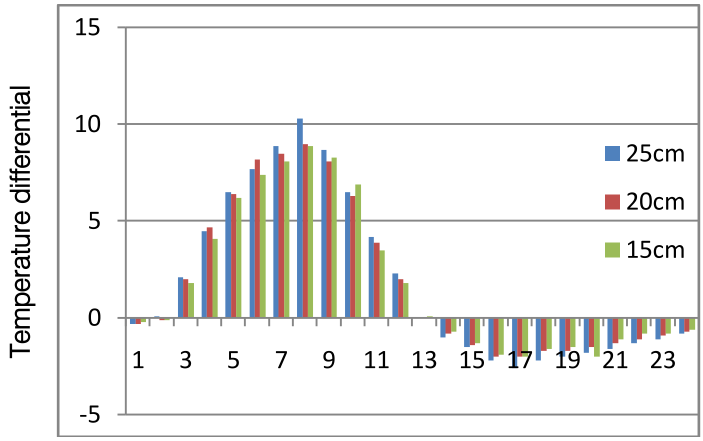


Figure 13 : Actual Temperature Differential at corner of HVFAC Slabs

Table 10 : Temperature (°C) Readings In Corner of HVMPC Slabs

Hours	25 cm Thick		20 cm Thick		15 cm Thick	
	T	B	T	B	T	B
7:00 AM	26.2	26.5	25.2	25.5	25.4	25.6
8:00 AM	27.7	27.7	28.4	28.3	27.4	27.3
9:00 AM	29.2	26.8	30.3	28.2	31.1	29.1
10:00AM	32.2	28.3	35.3	31.5	35.6	31.5
11:00AM	35.2	29.8	38.9	33	37.1	32.3
12:00 PM	39.8	32.3	41.2	34.1	40.9	34.1
1:00PM	43.9	35.3	44.3	35.2	42.3	34.2
2:00 PM	47.4	37.2	47.2	37.6	47.5	38.3
3:00 PM	45.8	37.1	46.9	38.3	46.2	38
4:00 PM	41.7	35.7	43	36.5	45.5	38.1
5:00 PM	39.6	35.5	40.2	36.2	41.9	37.8
6:00 PM	37.2	34.9	37.9	35.8	38.1	36
7:00 PM	34.3	34.3	35.2	35.1	35.2	35.1
8:00 PM	32.5	33.3	31.5	32.2	31.9	32.4
9:00 PM	31.3	32.9	29.8	31.3	29.9	31.2
10:00PM	30.3	32.3	29	30.9	29.3	30.8
11:00PM	29.3	31.7	28.1	30.3	28.5	30.5
12:00AM	28.2	30.3	27.8	29.7	28.1	29.9
1:00 AM	27.9	29.7	27.2	28.8	27.6	29.1
2:00 AM	27.3	28.8	26.8	27.9	27.2	28.8
3:00 AM	26.7	28	26.5	27.8	26.9	28.4
4:00 AM	26.4	27.6	26.1	27.2	26.8	27.8
5:00 AM	26.1	27	25.7	26.5	26.3	27
6:00 AM	25.8	26.4	25.3	25.9	26.5	26.8

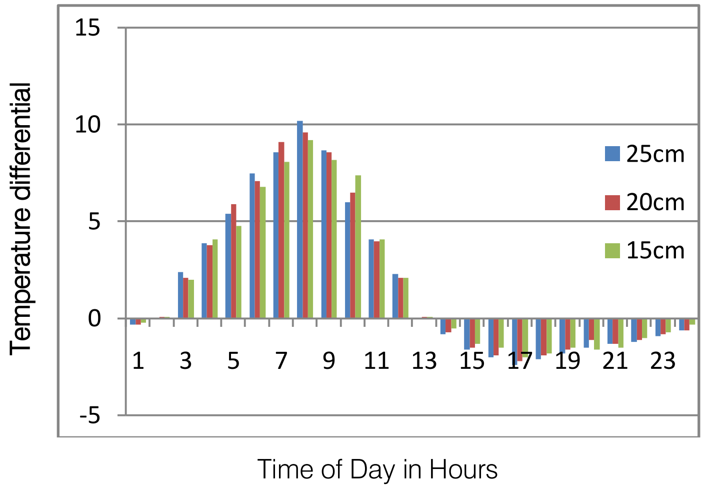


Figure 14 : Actual Temperature Differential at corner of HVMPC Slabs

III. Results and Discussion

The results obtained from the present investigation conducted on HPC slabs and discussions are presented in this chapter.

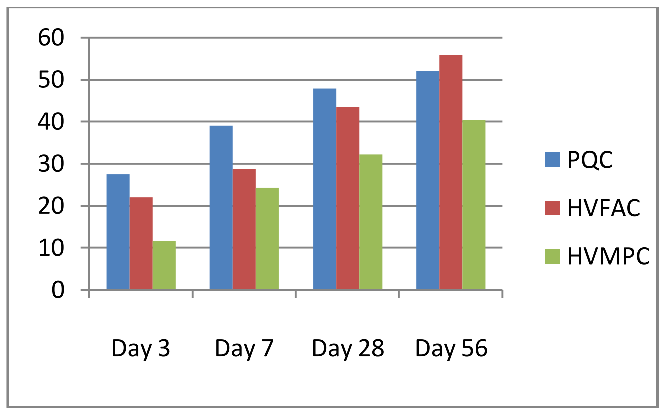
a) Cube Compressive Strength

The cube specimen of PQC, HVFAC & HVMPC mixes is tested for compressive strength at 3, 7, 28 and 56 days of curing. The cube compressive test results for all mixes are shown in Table. It observed that there is an increase in cube compressive strength with increase in number of days of curing. PQC gain early compressive strength compared to HVFAC. From test results it is observed that the compressive strength of HVMPC is lesser than that of PQC & HVFAC at 56 days of curing.

Cube Compressive Strength Test Results of Concrete slabs.

Sl. No	Number of days of Curing	Conventional PQC Mix (N/mm²)	Fly Ash Admixed concrete Mix (N/mm²)	Marble Powder Admixed Concrete mix (N/mm²)
1	3	27.48	22.07	11.70
2	7	39.11	28.74	24.37
3	28	47.41	42.96	32.59
4	56	52.00	55.70	40.44

Comparison of Compressive Strength of PQC, HVFAC and HVMPC Mixes.



Days of curing

Cube Compressive Strength Test Results of Concrete slab.

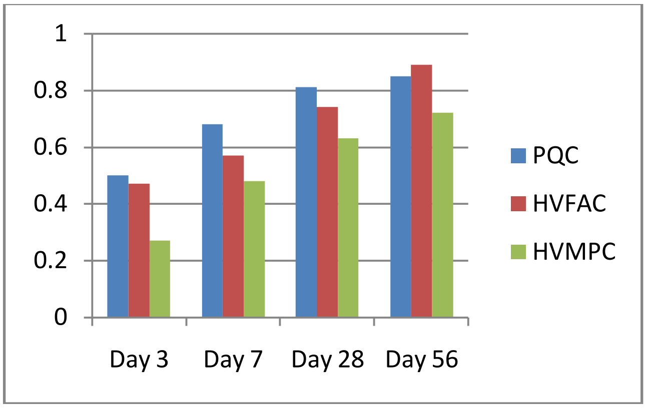
b) Static Flexural Strength

The static flexural strength of PQC and HVFAC beam specimens were determined using two point loading method and the test results are shown in Table.

Static Flexural Strength Test Results of Concrete slabs

Sl.No	Number of days of curing	PQC – Beams		HVFAC - Beams		HVMPC – Beams	
		Load KN	Fcr N/mm²	Load KN	Fcr N/mm²	Load KN	Fcr N/mm²
1	3	11.25	0.5	10.5	0.47	6	0.27
2	7	15.25	0.68	13	0.57	10.75	0.48
3	28	18.25	0.81	16.75	0.74	14.25	0.63
4	56	19.25	0.85	20	0.89	16.25	0.72

Comparison of Flexural Strength of PQC, HVFAC and HVMPC Mixes.



Days of curing

Static Flexural Strength Test Results of Concrete slabs

c) Obtained Temperature Differentials in Concrete slabs

The temperature is recorded for a period of two day in all the slabs. The maximum positive & negative temperature differential occurred during a day in each slab is shown in tables below.

Positive Temperature Differential in different types of concrete Slabs.

1. At Centre

Thickness (mm)	Maximum positive Temperature differential in °C		
	PQC	HVFAC	HVMPC
150	11.9	9.2	9.6
200	12.4	10.7	10.6
250	13.2	12.2	12.2

2. At Edge

Thickness (mm)	Maximum positive Temperature differential in °C		
	PQC	HVFAC	HVMPC
150	10.3	9.1	8.6
200	10.2	10.0	9.3
250	11.4	11.2	11.3

3. At Corner

Thickness (mm)	Maximum positive Temperature differential in °C		
	PQC	HVFAC	HVMPC
150	9.3	8.9	9.2
200	9.2	9.0	9.6
250	10.4	10.3	10.2

Negative Temperature Differential in different types of concrete Slabs

1. At Centre

Thickness (mm)	Maximum negative Temperature differential in °C		
	PQC	HVFAC	HVMPC
150	-2.9	-2.3	-2.4
200	-3.1	-2.8	-2.7
250	-3.5	-2.9	-2.9

2. At Edge

Thickness (mm)	Maximum negative Temperature differential in °C		
	PQC	HVFAC	HVMPC
150	-2.3	-2.1	-2.2
200	-2.4	-2.2	-2.6
250	-3.0	-2.5	-2.6

3. At Corner

Thickness (mm)	Maximum negative Temperature differential in °C		
	PQC	HVFAC	HVMPC
150	-2.3	-2.0	-2.0
200	-2.4	-2.0	-2.2
250	-3.0	-2.6	-2.4

d) *Maximum positive temperature differential for different thickness of CC slabs*

Thickness (mm)	Type of concrete			As per IRC:58-2002
	PQC	HVFAC	HVMPC	
150	11.9	9.2	9.6	17.3
200	12.4	10.7	10.6	19
250	13.2	12.2	12.2	20.3

e) *Obtained temperature stresses in concrete slabs Positive temperature stresses in different types of concrete slabs*

1. At Centre

Thickness (mm)	Maximum positive Temperature stresses in N/mm²		
	PQC	HVFAC	HVMPC
150	0.225	0.174	0.182
200	0.234	0.202	0.200
250	0.250	0.231	0.231

2. At Edge

Thickness (mm)	Maximum positive Temperature stresses in N/mm²		
	PQC	HVFAC	HVMPC
150	0.166	0.146	0.138
200	0.164	0.161	0.150
250	0.184	0.180	0.182

3. At Corner

Thickness (mm)	Maximum positive Temperature stresses in N/mm²		
	PQC	HVFAC	HVMPC
150	0.1095	0.1013	0.1047
200	0.094	0.0918	0.0979
250	0.098	0.0968	0.0958

Negative Temperature stresses in different types of concrete Slabs.

1. At Centre

Thickness (mm)	Maximum negative Temperature stresses in N/mm²		
	PQC	HVFAC	HVMPC
150	-0.055	-0.0435	-0.045
200	-0.059	-0.0530	-0.0151
250	-0.066	-0.055	-0.055

2. At Edge

Thickness (mm)	Maximum negative Temperature stresses in N/mm²		
	PQC	HVFAC	HVMPC
150	-0.037	-0.033	-0.035
200	-0.038	-0.035	-0.042
250	-0.048	-0.040	-0.042

3. At Corner

Thickness (mm)	Maximum negative Temperature stresses in N/mm²		
	PQC	HVFAC	HVMPC
150	-0.026	-0.022	-0.0228
200	-0.024	-0.020	-0.0225
250	-0.028	-0.024	-0.0226

f) *Maximum positive temperature stress for different thickness of CC slabs*

Maximum positive temperature stress for different thickness of CC slabs

Thickness (mm)	Type of concrete		
	PQC	HVFAC	HVMPC
150	0.225	0.174	0.182
200	0.234	0.202	0.200
250	0.250	0.231	0.231

IV. Results

1. At Centre

a) The maximum positive and negative temperature differentials in pavement quality concrete slab are +13.2 ^{0}C and -3.5 ^{0}C respectively.

b) The maximum positive and negative temperature stress in pavement quality concrete slab are 0.250 N/mm^2 and -0.066 N/mm^2 respectively.

c) The maximum positive and negative temperature differentials in high volume fly-ash concrete slab are 12.2 ^{0}C and -2.9 ^{0}C respectively.

d) The maximum positive and negative temperature stress in high volume fly-ash concrete slab are 0.23 N/mm^2 and -0.055 N/mm^2 respectively.

e) The maximum positive and negative temperature differentials in high volume marble powder concrete slab are 12.2 ^{0}C and -2.9 ^{0}C respectively.

f) The maximum positive and negative temperature stress in high volume marble powder concrete slab are 0.231 N/mm^2 and -0.055 N/mm^2 respectively.

2. At Edge

a) The maximum positive and negative temperature differentials in pavement quality concrete slab are 11.4 ^{0}C and -3 ^{0}C respectively.

b) The maximum positive and negative temperature stress in pavement quality concrete slab are 0.184 N/mm^2 and -0.048 N/mm^2 respectively.

c) The maximum positive and negative temperature differentials in high volume fly ash concrete slab 11.2 ^{0}C and -2.5 ^{0}C respectively.

d) The maximum positive and negative temperature stress in high volume fly ash concrete slab are 0.180 N/mm^2 and -0.04 N/mm^2 respectively.

e) The maximum positive and negative temperature differentials in high volume marble powder concrete slab are 11.3 ^{0}C and -2.6 ^{0}C respectively.

f) The maximum positive and negative temperature stress in high volume marble powder concrete slab are 0.182 N/mm^2 and -0.042 N/mm^2 respectively.

3. At Corner

a) The maximum positive and negative temperature differentials in pavement quality concrete slab are 10.4 ^{0}C and -3 ^{0}C respectively.

b) The maximum positive and negative temperature stress in pavement quality concrete slab are 0.1095 N/mm^2 and -0.02 N/mm^2 respectively.

c) The maximum positive and negative temperature differentials in high volume fly ash concrete slab are 10.3 ^{0}C and -2.6 ^{0}C respectively.

d) The maximum positive and negative temperature stress in high volume fly ash concrete slab are 0.1013 N/mm^2 and -0.024 N/mm^2 respectively

e) The maximum positive and negative temperature differentials in high volume marble powder concrete slab are 10.2 ^{0}C and -2.4 ^{0}C respectively.

f) The maximum positive and negative temperature stress in high volume marble powder concrete slab are 0.1047 N/mm^2 and -0.0228 N/mm^2 respectively.

V. Conclusion

- High volume fly-ash concrete slabs are found to gain compressive strength in gradual pattern. The compressive strength is more at higher curing ages i.e. 56 days & 90 days.
- The compressive strength of High Volume marble Powder Concrete is less at all curing ages i.e. 3,7,28 & 56 days when compared to PQC.
- The obtained temperature differentials for HVFAC & HVMPC are lower than suggested values and temperature difference by IRC 58–2002 for the design of concrete pavements.
- Initial cost of construction or maintenance for concrete overlays is more compared to bituminous overlays. But over a period of time concrete overlays prove more economical.
- Lesser the temperature difference in the HVFAC & HVMPC shows that warping stress in HVFAC & HVMPC pavement will be least than normal PQC.
- Since the compressive strength of HVMPC is less, therefore HVMPC is not recommended for construction of new pavements.
- Thus it can be concluded that HVFAC can be used for construction of new pavements when there is no restrictions for time limits.
- The reduction in total stresses in the pavements, hence the thicknesses will be less than conventional concrete pavements.
- Environmental parameters are to be considered to get realistic temperature differential in HPC pavements.

VI. Acknowledgment

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