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Effect of Temperature Differential in HVSF Concrete Pavements

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ABSTRACT: Cement concrete pavement slabs undergo expansion and contraction due to the variation in atmospheric temperatures. The amount of expansion or contraction mainly depends upon the difference in temperatures between top and bottom surfaces (t) of the slab during day and night, thickness of the slab (h), Coefficient of thermal expansion of concrete (e), Modulus of sub grade reaction (K), Poisson's ratio (μ), and Modulus of elasticity of concrete (E). The temperature gradient between the top and the bottom surfaces induce warping stresses in the pavement slab. The warping stresses along with the wheel load stresses become the worst combination from the pavement performance point of view.

An attempt has been made in this direction to make a comparative study on the behavior of cement concrete pavement slabs with High Volume Silica Fume Concrete (HVSFC). A concrete mix for M40 is designed as per IS: 10262:2009. The trial tests resulted in mix proportioning of 60% cement, 40% Silica Fume, water/cement ratio of 0.4. Concrete pavement slabs were cast of thicknesses 100 mm, 150 mm and 200 mm. The sizes of the slabs were 750 X 750 mm. Companion specimens using conventional concrete of M40 grade were cast. The temperature variations over the depth of the slab were studied and results are presented. The study indicates that HVSFC specimens exhibit good resistance to thermal gradients.

KEYWORDS: Conventional Concrete, High Volume Silica Fume Concrete, Thermocouples, Thermal Gradient.

I. INTRODUCTION

Concrete is one of the major construction material used, which is next to the consumption of water by the mankind. It is estimated that eight billion tonnes of concrete is produced every year throughout the world. This is due to the availability of the abundance of the raw materials, low relative cost and the adoptability of concrete forming various shapes. The extraction of raw materials causes depletion of resources. In recent times, the environmentalists are more concerned regarding the cement manufacture.

Millions of tons of cement are 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, silica fumes, marble powder, GGBS etc... Favoring environment and saving cement. Large length of roads is required to be built in near future over the globe in general and India in particular.

One tonne of cement manufacture emits approximately one tonne of CO_2 in to the atmosphere. This causes green house effect and global warming of the planet. Hence an emission of 8 billion tonnes of CO_2 every year which causes an environmental impact. The way to reduce the environmental impact is the use of supplementary cementations materials one such material is silica fume obtained as a product resulting from reduction of high purity quartz with coal.

Temperature variations in the pavement slab are very important as the differential temperatures between the top and the bottom of the slab would induce the warping stresses in the slab. During the day time the temperature at the top of the slab would be higher than at the bottom. Whereas the temperature at the bottom of the slab during the night is higher compared to the top surface on account of slow cooling effect below the slab. The temperature variations mainly depend upon the material characteristics, the thickness of the slab and the atmospheric conditions. Warping stresses along with the load stresses form the critical combination of stress conditions in the pavement design and analysis.

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.

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Temperature along depth of the slab is to be recorded to determine thermal stresses. Thermocouples are used to record the temperature.

II. RELATED WORK

The analysis of rigid pavements subjected to transverse loads was first introduced in results of tests conducted on concrete pavements to study the effects of variations in temperature and moisture. Their result showed that temperature distribution through the pavement's thickness is highly nonlinear, and that measured "stresses arising from restrained temperature warping are equal in importance to those produced by the heaviest legal wheel loads". Harr and Leonards (1959), and Lewis and Harr (1969) also dealt with the problem of temperature stresses in concrete pavements. Although temperature variation through the thickness is nonlinear (e.g., Choubane and Tia 1992; Mirambell 1990; and Smith et al. 1991), the majority of the current methods of analysis, including two-dimensional (2-D) finite elements, are limited to linear temperature distribution (e.g., Ioannides and Salsilli-Murua 1989; Taheri et al. 1992; Yoder and Witczak 1975; Zaman et al. 1993). The linear distribution is derived from the temperature difference between the top and bottom surfaces of the pavement.
A temperature gradient will cause differential expansion or contraction between the top and bottom of the slab; if the slab were weightless and unrestrained it would warp in to the shape of part of spherical surface, and the only stress set up would be a small internal stress if the temperature gradient varied with depth. In fact, the weight of the slab and load transfer devices or friction at the joints will restrain free warping and these restraining forces will set up stresses whose magnitude may be determined by two methods. The first, derived by Westergaards, assumes that the temperature gradient in a slab is constant throughout its thickness; the second derived by Thomlinson, assumes that the temperature gradient at the top surface of the slab and the thermal properties of the concrete are known. The temperature gradient through the depth of the slab will only occasionally be constant; it is usually more accurate therefore to calculate the stresses by Thomlinson's method than by Westergard's, especially as the maximum stresses occur when the gradient varies with depth. Westergard's method considerably overestimates the stress if applied to non-linear temperature gradients.
Fifteen concrete slabs were instrumented with thermal resistors, allowing the monitoring of temperatures in concrete pavements slabs in sao Paulo by Jose.T. Balbo [2] where a typical tropical hot and wet environment prevails. Over the course of one year, it was sought the influence of climatic conditions such as temperature and moisture on the daily and seasonal variations of temperature differentials through the slabs' depths. Day time temperature differentials of more than 15 degree Celsius were observed during typical summer days (e.g., high air temperature of 32 degree Celsius and 7.6 hours of solar radiation). The absolute value of night time temperature differentials are not as extreme as the day time differentials, and are significant mostly during spring and summer (from September to march). Nonlinear quadratic temperature distributions through the slab thickness were evident in most cases; nevertheless, distributions that are almost linear may be present at some times during the day or even at night. Occurrences of positive temperature differentials even at night time were recorded and discussions of those particularities are addressed. The effects of tropical rains on temperature differentials are presented, and empirical models for the prediction of temperature differentials in slabs are suggested.
According to Zahidule, Mustague and Dave [12], Curling generally results from the temperature differential across the concrete slab thickness. Curling induces stresses in the pavement slab that may contribute to early-age concrete cracking. This study deals with the field measurement of temperature and curling on a newly built jointed plain concrete pavement. The pavement section consisted of a 12-inch concrete slab, 4-inch bound drainable base, and 6-inch lime- treated sub grade. Temperature data was collected at five different depth locations across the thickness of the concrete slab with the digital data loggers embedded in the slabs.

III. PRESENT INVESTIGATION

The minimum flexural strength required in cement concrete pavements to resist the load and temperature stresses under the worst exposure conditions as per literature is 40Kg/cm2. Keeping this in mind proportioning of concrete mix to get the target cube strength of 40Mpa was initially aimed to satisfy the flexural requirements of the rigid pavements.
The following materials are used in the present investigation while proportioning the materials.

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Cement: Ordinary Portland cement conforming to IS: 1269 – 1987 was used. The cement is commercially available – 53 Grade OPC.
Silica Fume: Mahavir Chemical Industries, Delhi.
Fine Aggregate: Locally available river sand free from silt, organic matter and passing through 4.75mm sieve conforming to zone II of IS: 383 – 1970.
Coarse Aggregate: Locally available crushed granite aggregate passing through 20mm & retaining on 4.75mm conforming to IS: 383 – 1970.
Water: Potable water free from injurious salts was used for mixing and curing.
Super Plasticizer: CONPLAST – SP430

Later various mix combinations were tried by changing the percentage of cement with silica fume at 20%, 30%, 40%, 50% and 60% of the total cement content. The results showed that required strength of 40 Mpa could be achieved with 40% of replacement of cement by silica fume and it was at the age of 56 days of curing. From the trial tests, it is observed that a final combination of 60% cement and 40% silica fume would form the binder content in the mix design. Considering the importance of temperature stresses in cement concrete pavements in mind, an attempt has been made to study the temperature variations in the pavement slab (size 750 X 750mm and with thickness of 100mm, 150mm and 200mm) made with HVSFC. The results are compared with the conventional concrete specimens of the same dimensions.

Fig 1: Thermocouple with Temperature Indicator


Fig 2: Moulds for Casting

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. Figure 1.
Slabs of size 500mmx500mm and thickness 100, 150, and 200mm are cast at the selected site. Marine ply wood moulds are prepared to cast the slabs. Figure 2.

IV. DATA ANALYSIS

Temperatures are recorded after 56 days of casting by using a digital temperature indicator. The temperature is recorded every hour for a period of 2-days.

Table 1: Temperature (°C) Readings in Middle of CC Slabs

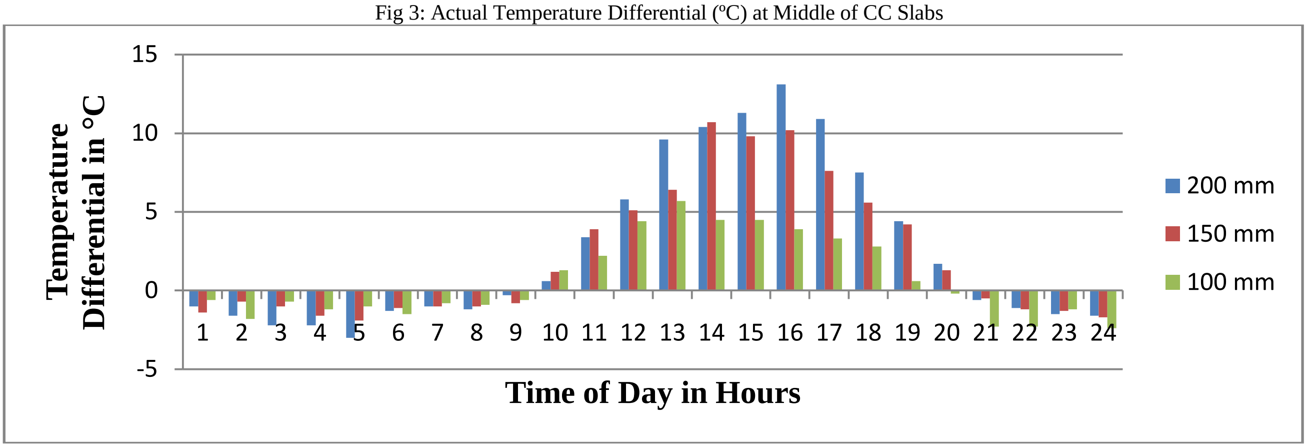
Time (Hrs)		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
20cm Thick Slab	T	27.8	26.3	28.4	25.6	28.3	25.6	25.6	26.2	27.8	30.7	33.6	37.5	38.6	39.8	43.0
	B	29.4	28.5	30.6	28.6	29.6	26.6	26.8	26.5	27.2	27.3	27.8	27.9	28.2	28.5	29.9
15cm Thick Slab	T	29.3	29.6	29.0	30.0	29.8	28.4	28.0	27.9	30.6	32.8	33.3	35.8	41.4	42.0	42.8
	B	30.0	30.6	30.6	31.9	30.9	29.4	29.0	28.7	29.4	28.9	28.2	29.4	30.7	32.2	32.6

10cm Thick Slab	T	30.2	31.6	31.6	31.8	30.4	29.4	28.4	30.2	30.9	32.4	34.8	39.4	38.0	39.8	40.8
	B	32.0	32.3	32.8	32.8	31.9	30.2	29.3	30.8	29.6	30.2	30.4	33.7	33.5	35.3	36.9

Time (Hrs)		16	17	18	19	20	21	22	23	24
20cm Thick Slab	T	39.5	35.9	33.3	31.3	29.6	29.4	27.9	26.8	28.0
	B	28.6	28.4	28.9	29.6	30.2	30.5	29.4	28.4	29.0
15cm Thick Slab	T	40.2	37.6	36.2	34.5	31.9	30.6	29.9	29.0	29.0
	B	32.6	32.0	32.0	33.2	32.4	31.8	31.2	30.7	30.4
10cm Thick Slab	T	39.2	38.4	34.4	33.4	32.6	31.5	30.6	30.9	30.2
	B	35.9	35.6	33.8	33.6	34.9	33.8	31.8	33.3	30.8

T = Top; B = Bottom

Fig 3: Actual Temperature Differential (ºC) at Middle of CC Slabs



A typical data sheet for temperature readings observed at middle for 20cm, 15cm and 10cm thick of CC slabs is shown in Table1 and figure 3 shows the actual temperature differential at middle of CC Slabs. From the above figure it is observed that the maximum positive temperature differential observed was at 4:00 PM for 20cm thick slab and the maximum negative temperature differential was observed at 05:00AM for 20cm thick slab.

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

Time (Hrs)		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
20cm Thick Slab	T	30.3	29.0	30.2	29.8	30.6	28.3	28.8	29.9	28.4	29.2	32.2	35.5	36.5	38.8	39.9
	B	29.7	31.2	30.4	29.9	29.0	27.9	28.4	30.8	28.8	31.9	30.4	34.4	36.7	38.9	42.4
15cm Thick Slab	T	30.3	31.9	31.8	30.5	30.2	28.5	29.0	30.2	28.2	30.2	28.9	30.6	31.5	32.6	33.6
	B	29.5	31.4	31.2	30.3	30.2	28.1	28.7	30.0	30.2	31.0	32.6	36.2	38.1	40.2	41.5
10cm Thick Slab	T	30.3	31.6	31.6	30.8	31.8	29.3	29.0	31.4	29.8	30.6	30.2	32.8	34.8	36.0	36.8
	B	30.3	29.0	30.2	29.8	30.6	28.3	28.8	29.9	28.4	29.2	32.2	35.5	36.5	38.8	39.9

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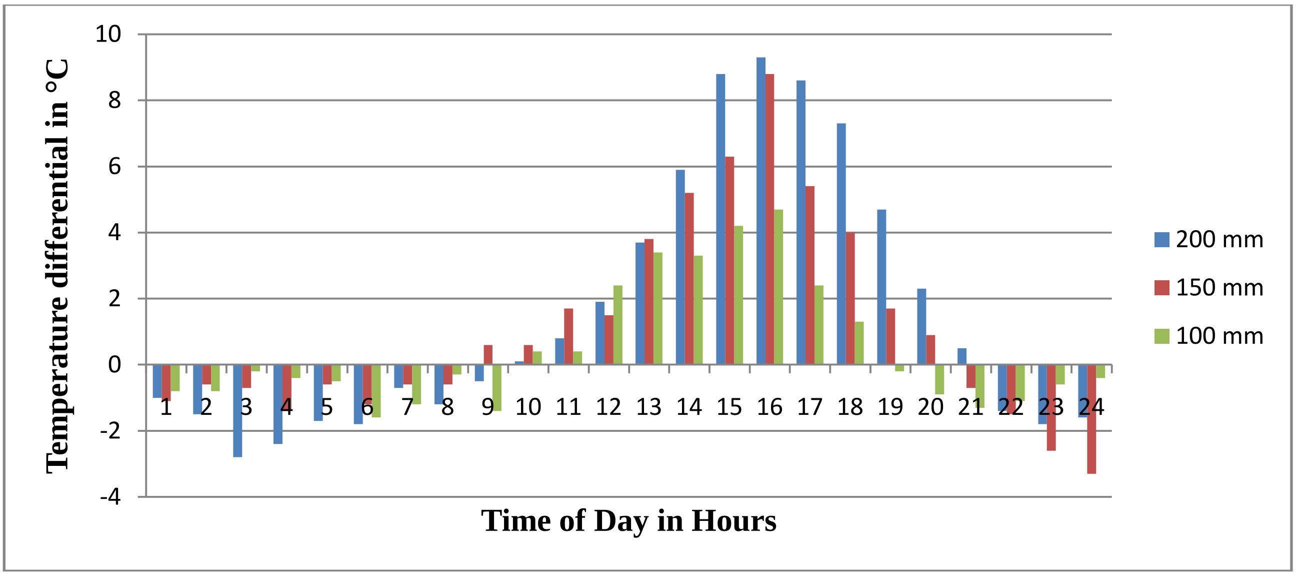
20cm Thick Slab	T	38.5	37.6	36.6	35.8	33.4	32.1	28.5	31.1	29.5
	B	39.3	37.6	35.2	33.4	32.1	31.9	31.2	30.8	28.8
15cm Thick Slab	T	33.9	33.6	33.5	32.5	32.8	33.4	33.8	34.1	29.9
	B	39.5	37.0	35.3	32.7	33.3	33.1	29.4	29.2	30.9
10cm Thick Slab	T	37.1	35.7	35.5	33.6	34.6	34.2	30.0	29.6	31.7
	B	38.5	37.6	36.6	35.8	33.4	32.1	28.5	31.1	29.5

T = Top; B = Bottom

Fig 4: Actual Temperature Differential (ºC) at Middle of HVSFC Slabs



A typical data sheet for temperature readings observed at middle for 20cm, 15cm and 10cm thick of HVSFC slabs is shown in Table2 and figure 4 shows the actual temperature differential at middle of HVSFC Slabs. From the above figure it is observed that the maximum positive temperature differential observed was at 4:00 PM for 20cm thick slab and the maximum negative temperature differential was observed at 12:00AM for 15cm thick slab.

Table 3: Temperature (°C) Readings in Edge of CC Slabs

Time (Hrs)		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
20cm Thick Slab	T	28.5	26.5	28.2	27.3	27.5	28.2	26.5	28.4	32.0	33.2	36.9	37.8	38.7	40.6	44.5
	B	28.8	28.3	29.6	28.6	28.4	29.4	27.9	26.0	27.8	27.7	28.1	28.2	28.5	29.8	32.3
15cm Thick Slab	T	27.9	29.8	30.0	30.2	29.5	28.1	28.4	30.4	32.0	33.5	34.5	37.3	40.2	42.5	44.5
	B	29.5	30.2	31.4	30.9	30.0	29.2	28.4	28.8	28.6	28.5	28.5	29.6	31.8	33.0	34.9
10cm Thick Slab	T	29.4	29.4	30.2	30.6	28.8	28.4	28.0	29.1	30.6	31.8	34.6	39.6	40.5	41.7	42.3
	B	30.6	29.8	31.6	31.8	29.9	29.0	28.9	29.3	29.4	29.4	31.5	33.8	36.3	38.2	39.0

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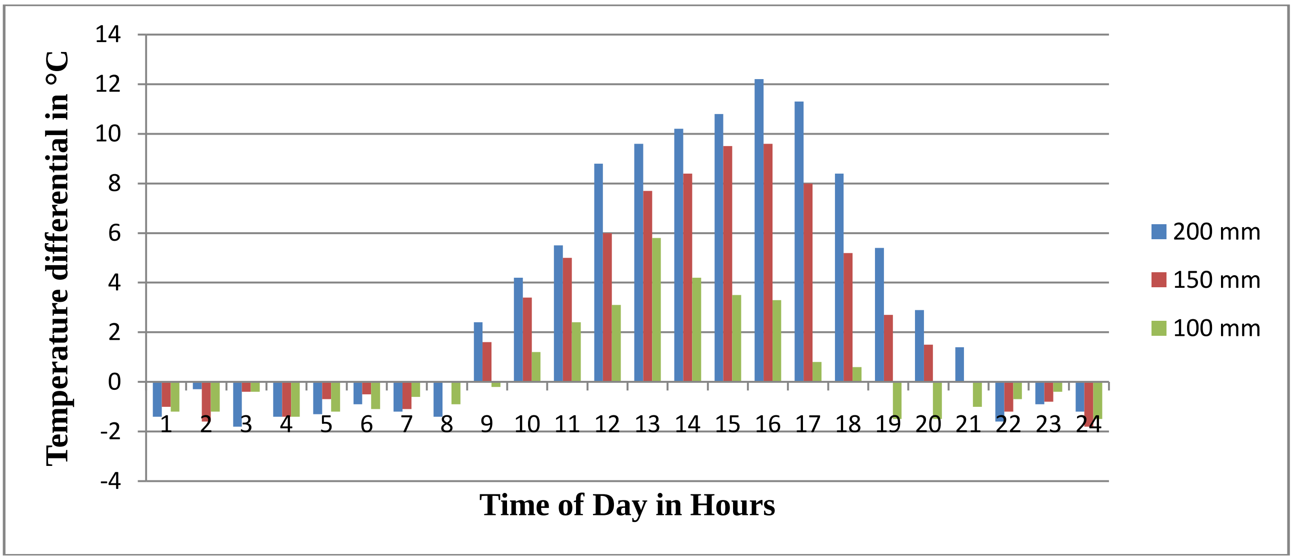
20cm Thick Slab	T	42.6	38.3	35.7	32.8	30.2	28.2	28.0	26.3	28.3
	B	31.3	29.9	30.3	29.9	28.8	29.8	28.9	27.5	29.7
15cm Thick Slab	T	42.9	39.8	36.0	33.8	33.2	31.1	29.4	28.2	29.5
	B	34.9	34.6	33.3	32.3	33.2	32.3	30.2	30.0	30.5
10cm Thick Slab	T	39.4	37.4	33.2	32.1	31.7	31.6	29.0	30.4	29.6
	B	38.6	36.8	34.7	33.6	32.7	32.3	29.4	31.9	30.8

T = Top; B = Bottom

Fig 5: Actual Temperature Differential (ºC) at Edge of CC Slabs



A typical data sheet for temperature readings observed at edge for 20cm, 15cm and 10cm thick of CC slabs is shown in Table3 and figure 5 shows the actual temperature differential at edge of CC Slabs. From the above figure it is observed that the maximum positive temperature differential observed was at 4:00 PM for 20cm thick slab and the maximum negative temperature differential was observed at 03:00AM for 20cm thick slab.

Table 4: Temperature (°C) Readings in Edge of HVSFC Slabs

Time (Hrs)		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
20cm Thick Slab	T	28.6	29.2	29.8	28.3	27.6	27.4	27.9	29.0	27.9	31.9	32.7	36.4	39.6	42.2	43.2
	B	30.0	29.6	30.7	30.0	28.4	28.1	28.3	29.4	27.2	29.5	28.9	31.3	31.9	32.6	33.2
15cm Thick Slab	T	28.6	30.1	30.4	28.8	28.8	26.9	27.5	29.6	29.1	31.6	31.9	35.2	38.8	42.0	40.7
	B	29.6	30.5	31.0	29.6	29.9	27.7	28.4	28.8	28.1	28.8	28.3	30.8	32.4	34.3	34.3
10cm Thick Slab	T	28.8	29.7	30.3	28.9	30.0	27.6	28.1	30.0	29.8	30.8	33.7	35.3	37.5	39.9	41.6
	B	30.5	30.4	32.0	30.2	30.6	28.4	28.5	30.2	29.4	30.5	32.0	32.6	34.6	36.2	37.2

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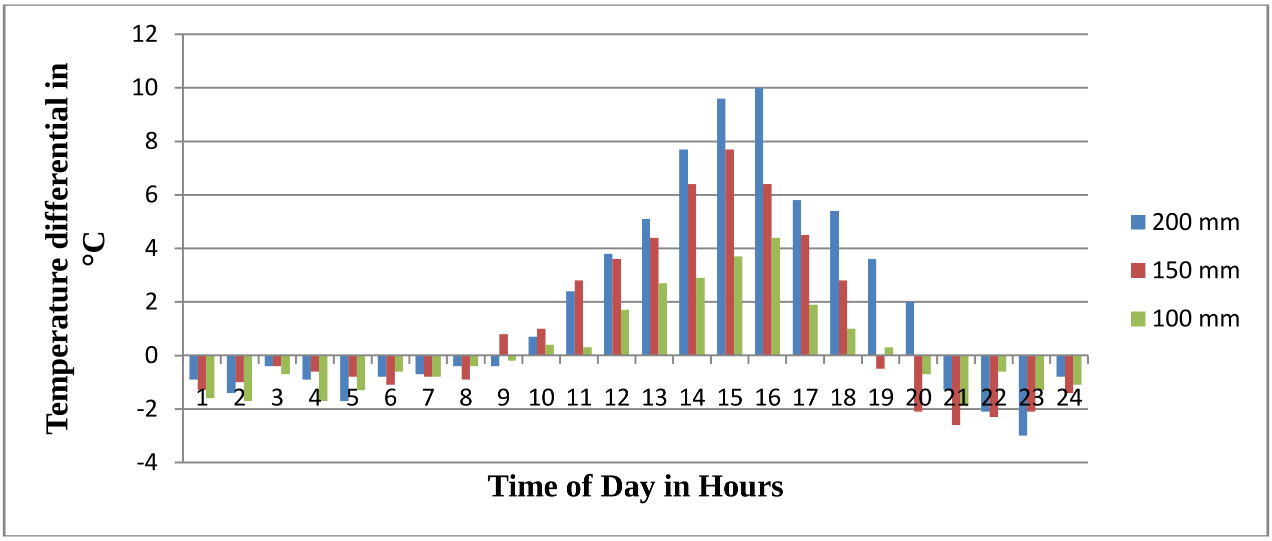
20cm Thick Slab	T	40.1	38.8	37.1	35.9	31.2	31.5	27.0	29.5	30.8
	B	34.3	33.4	33.5	33.9	32.5	33.6	30.0	30.3	31.7
15cm Thick Slab	T	39.9	37.6	33.9	30.4	30.9	29.6	27.1	29.2	30.5
	B	35.4	34.8	34.4	32.5	33.5	31.9	29.2	30.6	31.8
10cm Thick Slab	T	39.4	36.5	36.7	33.1	32.3	31.6	28.8	29.6	30.6
	B	37.5	35.5	36.4	33.8	34.2	32.2	30.1	30.7	32.2

T = Top; B = Bottom

Fig 6: Actual Temperature Differential (ºC) at Edge of HVSFC Slabs



A typical data sheet for temperature readings observed at edge for 20cm, 15cm and 10cm thick of HVSFC slabs is shown in Table 4 and figure 6 shows the actual temperature differential at edge of HVSFC Slabs. From the above figure it is observed that the maximum positive temperature differential observed was at 4:00 PM for 20cm thick slab and the maximum negative temperature differential was observed at 11:00PM for 20cm thick slab.

Table 5: Temperature (°C) Readings in Corner of CC Slabs

Time (Hrs)		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
20cm Thick Slab	T	27.4	27.5	28.2	27.5	26.8	26.7	27.6	27.6	30.1	31.9	33.8	35.6	39.4	42.0	46.2
	B	28.5	29.2	29.8	28.6	28.0	27.6	27.0	26.3	28.0	28.9	28.5	28.2	29.8	30.2	33.1
15cm Thick Slab	T	26.6	27.5	27.8	28.3	27.4	26.6	26.0	28.1	27.9	30.0	32.8	35.6	40.4	45.2	47.4
	B	28.3	28.6	29.2	29.6	28.5	27.8	26.8	28.2	27.6	28.8	28.9	29.8	32.9	35.9	36.5
10cm Thick Slab	T	29.5	28.8	30.2	29.8	29.3	27.3	28.0	28.9	29.1	30.2	34.0	35.5	40.3	43.4	43.5
	B	30.2	30.2	32.2	31.7	30.8	28.4	29.2	29.6	29.9	29.5	32.6	33.5	36.7	38.0	39.5

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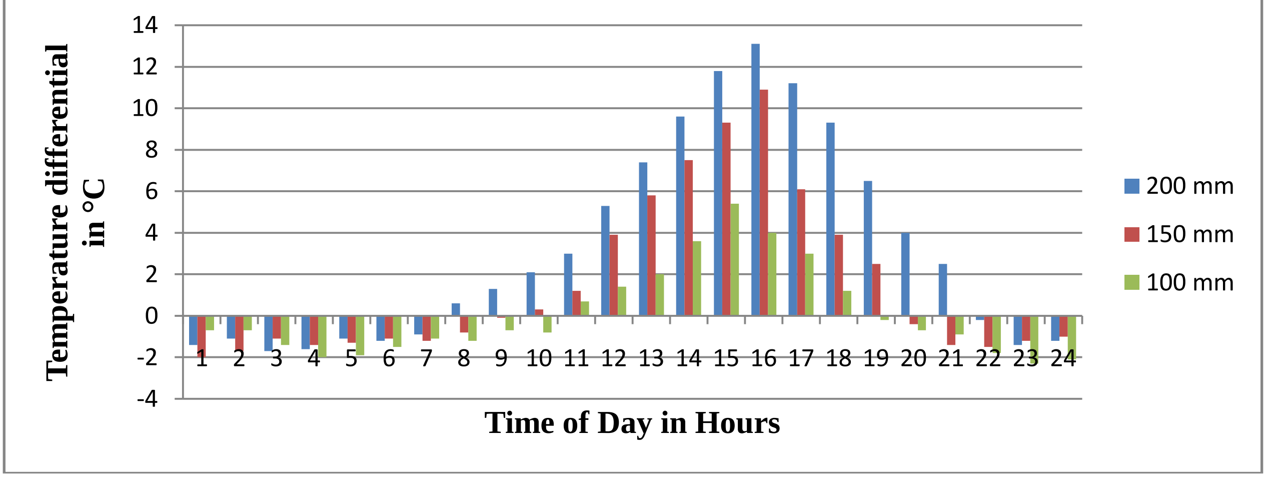
20cm Thick Slab	T	43.1	40.8	37.1	34.8	32.4	29.2	27.4	26.7	28.0
	B	31.9	31.5	30.6	30.8	29.9	29.4	28.8	27.9	29.4
15cm Thick Slab	T	42.9	39.5	34.9	31.6	31.6	29.9	27.8	28.6	28.6
	B	36.8	35.6	32.4	32.0	33.0	31.4	29.0	29.6	30.6
10cm Thick Slab	T	41.9	37.6	34.2	33.8	31.5	30.6	27.0	29.3	31.3
	B	38.9	36.4	34.4	34.5	32.4	32.4	29.3	31.4	32.0

T = Top; B = Bottom

Fig 7: Actual Temperature Differential (ºC) at Corner of CC Slabs



A typical data sheet for temperature readings observed at corner for 20cm, 15cm and 10cm thick of CC slabs is shown in Table 5 and figure 7 shows the actual temperature differential at corner of CC Slabs. From the above figure it is observed that the maximum positive temperature differential observed was at 4:00 PM for 20cm thick slab and the maximum negative temperature differential was observed at 11:00PM for 10cm thick slab.

Table 6: Temperature (°C) Readings in Corner of HVSFC Slabs

Time (Hrs)		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
20cm Thick Slab	T	28.7	28.8	29.5	28.0	28.2	26.2	27.5	28.4	31.4	33.4	33.6	37.2	39.4	43.0	43.6
	B	29.6	29.8	31.6	29.6	29.4	27.7	28.1	28.2	29.7	29.7	28.5	30.7	31.2	33.3	34.1
15cm Thick Slab	T	28.0	28.6	29.6	28.0	28.0	25.6	26.9	27.8	30.0	30.4	31.6	34.5	38.4	42.5	44.3
	B	29.7	29.9	31.8	29.6	29.6	27.0	28.3	28.8	29.9	29.9	30.4	32.4	33.4	35.8	36.3
10cm Thick Slab	T	28.8	28.8	29.6	28.4	29.2	26.9	28.0	29.2	30.2	30.6	33.7	35.5	38.2	41.5	40.7
	B	29.8	29.9	31.8	29.4	29.9	27.4	28.4	29.4	30.2	30.2	32.8	33.6	35.6	38.2	38.5

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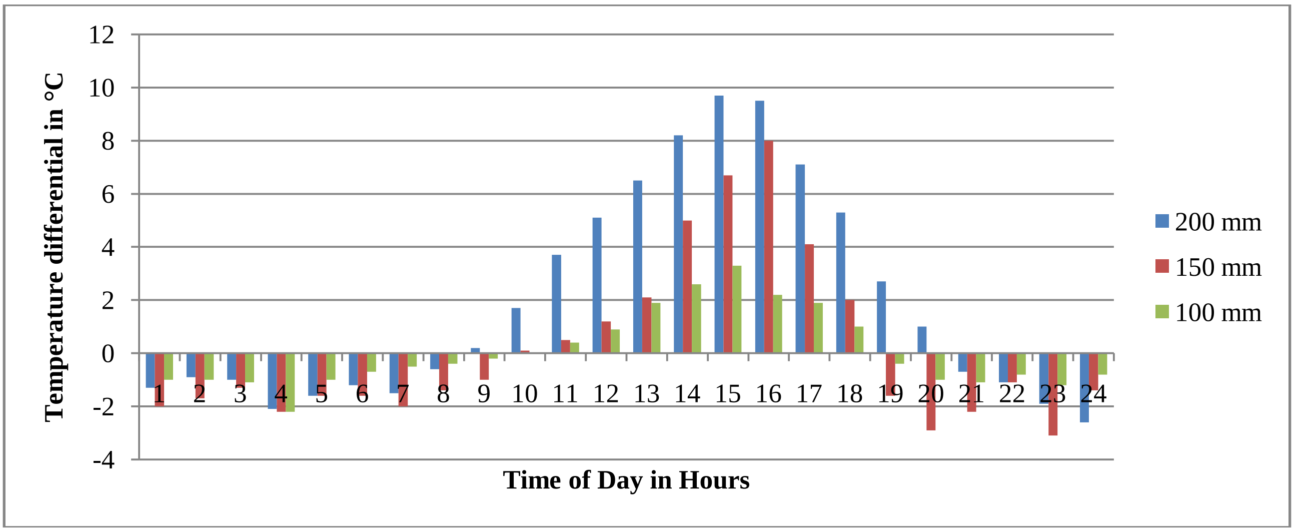
Time (Hrs)		16	17	18	19	20	21	22	23	24
20cm Thick Slab	T	41.8	39.1	36.8	33.6	32.4	30.6	26.9	28.0	30.0
	B	34.7	33.8	34.1	32.6	33.1	31.7	28.8	30.6	31.3
15cm Thick Slab	T	40.7	36.6	32.9	30.2	31.2	30.3	26.5	28.6	29.4
	B	36.6	34.6	34.5	33.1	33.4	31.4	29.6	30.0	31.4
10cm Thick Slab	T	40.3	36.4	34.4	32.6	32.6	30.3	29.3	28.6	30.5
	B	38.4	35.4	34.8	33.6	33.7	31.1	30.5	29.4	31.5

T = Top; B = Bottom

Fig 8: Actual Temperature Differential (ºC) at Corner of HVSFC Slabs



A typical data sheet for temperature readings observed at corner for 20cm, 15cm and 10cm thick of HVSFC slabs is shown in Table 5 and figure 7 shows the actual temperature differential at corner of HVSFC Slabs. From the above figure it is observed that the maximum positive temperature differential observed was at 3:00 PM for 20cm thick slab and the maximum negative temperature differential was observed at 11:00PM for 15cm thick slab.

Table 7: Comparison of observed temperature differential for CC and HVSFC slabs

SI No	**Type of Slab**	**Temperature Differential (^{o}C) on slab thickness of**		
		150mm	**200mm**	**250mm**
1	CC	5.8	10.9	13.1
2	HVSFC	4.7	8.8	10.0
3	IRC values for Karnataka (As per IRC: 58-2002)	17.3	19	20.3

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V. SUMMARY AND DISCUSSIONS

The temperature studies carried out on High Volume Silica Fume Concrete, and Conventional Concrete slab specimens of different thickness namely 150mm, 200mm and 250mm exposed to atmospheric temperature variations were compared and presented in this paper. The temperatures were recorded at top and bottom for three critical locations namely interior, edge and corner regions. The temperature data taken for 150mm, 200mm & 250mm slab of HVSFC and CC is shown in Table 1 to Table 6. The temperature differentials observed are shown graphically from Fig 3 to Fig 8 for different thicknesses of HVSFC and CC slab. The consolidated observed data for the temperature differential for slab thickness of 150mm, 200mm and 250mm are shown in Table 7. The temperature differentials noticed in the present investigation show lower values compared to the IRC values under different slab thickness. Hence this needs further attention to redefine the new temperature differentials for new pavement material as high volume silica fume concrete (HVSFC). The lower temperatures in the present study could be due to smaller size of the slab considered compared to actual slab dimensions (3500mm wide and 4500mm length). Hence further investigations are to be carried out to improve the results.

VI. CONCLUSIONS

1. The obtained temperature differentials for HVSFC are lower than suggested values by IRC 58–2002 for the design of concrete pavements.
2. Lesser the temperature difference in the HVSFC shows that warping stress in HVSFC pavement will be less than CC.
3. Thus it can be concluded that HVSFC can be used for construction of new pavements when there is no restrictions for time limits.
4. The reduction in total stresses in the pavements, hence the thicknesses will be less than CC pavements.
5. 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.

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