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Experimental Investigation on Fibre Reinforced Concrete Pavement Slabs Subjected to Temperature Gradient

Nandini Nair[1], Priya Grace IttiEipe[2]
[1]PG Scholar, Civil Engineering Department, Mahaguru Institute of Technology, Mavelikara, India
[2]Professor and Head of the Department, Civil Engineering Department, Mahaguru Institute of Technology, Mavelikara, India

Abstract**: *A long lasting, reliable and economical transportation system is a critical component for the continuous movement of heavy traffic. Rigid pavements are made of concrete are widely for land transportation used because of its increased life, strength and it provides efficient movement of heavy traffic. Concrete is a brittle material and its low tensile strength leads to the formation of cracks, which is one of the main reason of concrete failure. Addition of fibre prevents the crack formation because fibres are crack arresters. Fibre addition increases the structural integrity of the pavement. Concrete slab in pavement structure experiences daily temperature fluctuations and results in the formation of temperature gradients in the slab. The objective of this study is to investigate the material properties of the three different fibres used in pavement slabs subjected to temperature gradient and the fibres used is coir fibre. Reduced cracks ensure pavement durability, reduced maintenance, improved performance, improved performance and ride quality.***
Keywords: Rigid pavements, Fibre Reinforced Concrete (FRC), Coir Fibre, Temperature Gradient, Pavement Slab.

I. INTRODUCTION

For the continuous movement of goods and services, a long lasting, reliable and economic transportation system is a critical component. A pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. Pavements are of two types: flexible pavement and rigid pavements.

Rigid pavements are made from cement concrete and are widely used in land transportation because of its increased life and increased strength. Cement concrete pavements offer long service life and provides efficient movement of heavy traffic. In India, traditional system of bituminous pavements is used. Bitumen has been widely used in the construction of flexible pavements for a long time.

However, due to high temperature in summer season, the bitumen becomes soft resulting in bleeding, rutting and segregation finally leading to failure of pavement. In winter season, due to low temperature, the bitumen becomes brittle resulting in cracking, ravelling and unevenness, which makes the pavement unsuitable for use. In rainy season, water enters the pavement resulting in potholes and sometimes total removal of bituminous layer. In hilly areas, due to sub-zero temperature, the freeze and thaw cycle takes place. Due to freezing and melting of ice in bituminous voids, volume expansion occurs. This leads to pavement failure.

Cement concrete is a better substitute to bitumen. However, concrete is a brittle material when subjected to normal stress and impact loading and low tensile strength of concrete creates formation of cracks, which is a main reason of concrete failure. Addition of fibre reduces the crack formation because fibres are crack arresters. So Fibre Reinforced Concrete (FRC) is a better option to eliminate this kind of concrete failure.

A. Fiber Reinforced Concrete (FRC)

Fiber Reinforced Concrete (FRC) is a concrete containing fibrous material which increases its structural integrity. The usage of fibers in combination with concrete also results in a mix with improved early resistance to plastic shrinkage cracking and thereby protects the concrete from drying shrinkage cracks. It accomplishes improved durability and reduced surface water permeability of concrete.

Fiber Reinforced Concrete (FRC), some of them are steel fibers, glass fibers, synthetic fibers such as polypropylene, polyester and nylon, natural fibers such as coir and jute. Coir fibers are used for this experimental work.

B. Behaviour of Concrete Pavement

Concrete slab in the pavement structure is exposed to different temperature at the surface as compared to the bottom. Since at the top the slab is directly exposed to the atmosphere and subjected to temperature fluctuations. This results in the formation of temperature gradients in the pavement slab. Temperature gradients play a significant role with regards to the performance of the pavement during its design life.

C. Temperature Stress

Temperature gradients develop through the depth of the concrete pavement slab due to the daily variation in temperature. This results in a unique deflection behaviour which has been recognized as curling of pavement. During day time, positive temperature difference between the top and the bottom surfaces of the concrete slab in day time causes the slab corners to curl downwards, while a negative temperature gradient difference during night time results in the upward curling of concrete slab.

When a positive temperature gradient exists in the slab, the slab expands more on top when compared to the bottom of the slab and therefore curls downwards as shown in Fig. 1. When a negative temperature gradient exists in the slab, the slab contracts at the top more than the bottom and hence curls upward. In this case, the slab loses support from the base layer at the edges as shown in Fig. 2. The self-weight of the slab exerts tensile stress at the top of the slab and compressive stress at the bottom of the slab.

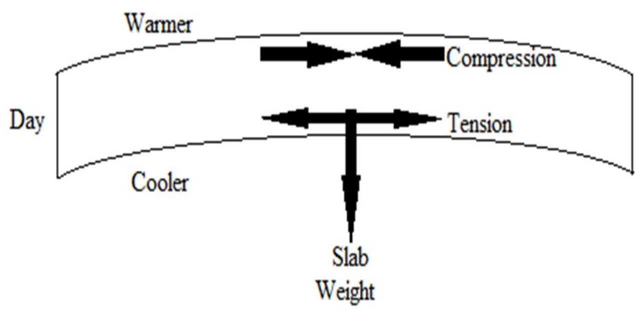

Fig.1 Downward Curling of Corners of the Slab

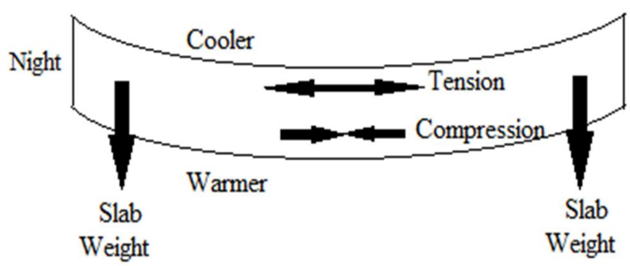

Fig.2 Upward Curling of Corners of the Slab

D. Scope and Objectives

The main objective of the project is

1) To compare the mechanical properties of Coir Fiber Reinforced Concrete used in pavements along with that of conventional concrete.
2) To conduct an effect of Fiber reinforced concrete (FRC) pavement slabs subjected to temperature gradient.

II. MATERIALS

The materials required for this experimental investigation are cement, fine aggregate, coarse aggregate, coir fibre and potable water. Different tests were conducted for each material as specified by relevant IS codes. The detailed properties are given in subsequent contents. M30 mix proportion was selected for this work. The data required for mix proportioning are obtained from the laboratory tests conducted on the materials used. Mix design was done as per IS: 10262-2009 guidelines for concrete mix design proportioning.

A. Cement

Ordinary Portland Cement (OPC) of 53 grade confirming to IS 12269 was used in the investigation. Table 3.1 shows the physical properties of OPC used in this study.

TABLE I
PROPERTIES OF CEMENT

Fineness	Standard Consistency	Initial Setting Time	Final Setting Time	7 Day Compressive Strength
7%	32%	47 minutes	330 minutes	29

B. Fine Aggregate

Dry river sand was used as fine aggregate. Laboratory tests were conducted on fine aggregate to determine the different physical properties as per IS 2386 (Part III) 1963.

TABLE II
PROPERTIES OF FINE AGGREGATE

Specific Gravity	Fineness Modulus	Water Absorption
2.58	5.8	2.9

C. Coarse Aggregate

Crushed granite stone obtained from local quarries were used as coarse aggregate. Laboratory tests were conducted on coarse aggregates to determine the different physical properties as per IS 2386 (Part III)-1963.

TABLE III
PROPERTIES OF COARSE AGGREGATE

Specific Gravity	Fineness Modulus	Water Absorption	Bulk Density (Kg/m3)	Void Ratio	Porosity
2.9	6.05	3.44	1.66	0.729	0.43

D. Coir Fibre

Coir fibre is a natural fibre extracted from the outer husk of coconut. The coir reinforced concrete is strong, flexible and may be less expensive to produce than other reinforcement methods.

TABLE IV
PROPERTIES OF COAIR FIBRE

Diameter (mm)	Aspect Ratio	Specific Gravity
0.4	50	1.15

The weight of coir fibre to be used for preparing the specimen depends on the required volume fraction, the dimension of the mould and on the specific gravity of the fibre itself. Volume fraction of fibre is the ratio of the volume of fibre to gross volume of compacted concrete, expressed in percentage. According to IRC: SP: 462013 fibre dosages by volume fraction is determined by equation 1.

*Dosage in kg/m3 = 10 * fibre volume in % * specific gravity of fibre material*….(1)

The optimum dosage of coir fibre is 0.5% and the specific gravity of the coir fibre is 1.15. So the required dosage of coir fibre is 5.75kg/m3.

E. Water

Potable water was used as mixing water. It is drinkable, clear and apparently clean, and does not contain any substances at excessive amounts that can be harmful for making concrete and was conformed to IS: 456-2000 recommendations.

III.EXPERIMENTAL STUDY

A. *Field Experiment*

Concrete specimens of size 100x15x15 cm cast at different times of a day were used for this study. Temperature at different points across the cross-section and deflection at top surface of the specimen were measured. Dial gauges and thermocouples were installed over specimen. Specimen cast at early morning and late afternoon were used for this study.

Specimens of fibre reinforced concrete and conventional concrete were prepared. Mixing was done in a laboratory type pan mixer. Wooden moulds of inside dimensions 100x15x15 cm were used for casting the specimens. Also cubes were prepared to test the compressive strength. Standard moulds of 150mm size were used for cube casting. Thoroughly mixed concrete was filled into the mould in three layers of equal heights followed by tamping. Excess concrete was removed with trowel and top surface was finished to smooth level. The samples prepared were cubes and beams.

After casting the mould specimens were stored in the laboratory at room temperature for 24 hours from the addition of water to dry ingredients. After this period the specimens were removed from the moulds, immediately submerged in the clean and fresh water.

TABLE V
DETAILS OF SPECIMEN

Specimen	Size	Time of Casting	Atmospheric Temperature (ºC)
Specimen cast at morning	100x15x15 cm	8:00 AM	29
Specimen cast at afternoon	100x15x15 cm	12.00 PM	32

B. *Instrumentation*

The key objective of this experimental work is to investigate the fibre reinforced concrete pavement slab subjected to temperature gradient. So it is important to measure the temperature. When the pavement slab is subjected to continuous temperature variations, it may deflect and it is also critical to measure the deflection. For measuring the temperature and deflection of the specimen, thermocouples and dial gauges are installed.

Thermocouples were installed at specific depths. Three thermocouples are installed at three depths and the thermocouples are installed in such a way that the sensor is fully embedded in the concrete. Thermocouples are installed at three depths which include top surface of the specimen, middle portion of the specimen and bottom surface of the specimen. After casting the beam specimen dial gauges were installed on the top surface. The points where the deflection is to be measured were marked. It should be ensured that the needle of each dial gauge should touch the specimen surface. Deflection was read from dial gauges. The whole arrangement of this experimental setup is shown in the fig. 3. And the arrangement consists of three thermocouples and two dial gauges with a wooden frame. The values obtained from the total arrangements are temperature and deflection.

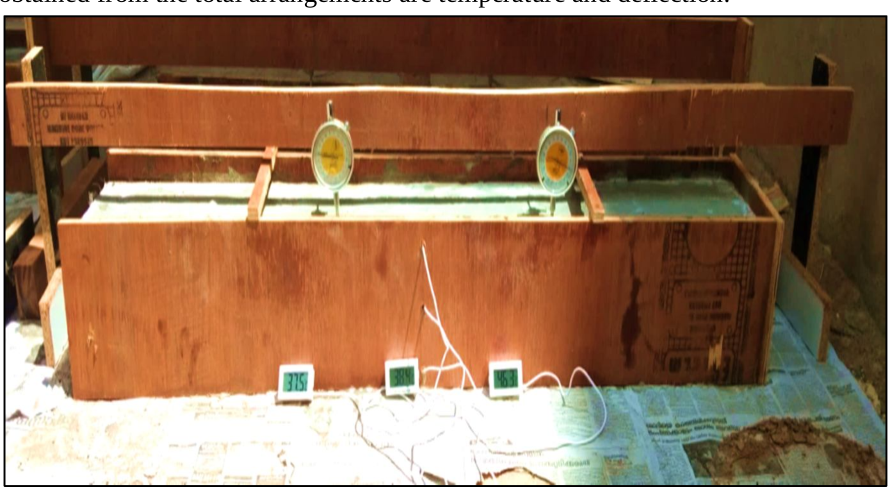

Fig. 3 Experimental Arrangements

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IV. RESULTS AND DISCUSSION

A. Strength Properties of Concrete

1) *Compressive Strength of Concrete:* Compressive strength was determined for mix prepared for specimen cast at morning (B1) and specimen cast at afternoon (B2).

TABLE VI
COMPRESSIVE STRENGTH OF CONCRETE

Mix Designation	Average Cube Compressive Strength (N/mm2)	
	5 day	7 day
B1	22.7	26.8
B2	24.9	28.4

2) *Flexural Strength of Concrete:* The flexural strength (fcr) was obtained from the compressive strength (fck) of the concrete cube using the formula.

$$fcr = 0.7 \sqrt{fck}$$

TABLE VI
FLEXURAL STRENGTH OF CONCRETE

Mix Designation	Average Cube Flexural Strength (N/mm2)	
	5 day	7 day
B1	3.33	3.62
B2	3.49	3.73

3) *Modulus of Elasticity of Concrete:* The approximate value of modulus of elasticity (E) was obtained from the formula

$$E = 5000 \sqrt{fck}$$

TABLE VI
MODULUS OF ELASTICITY OF CONCRETE

Mix Designation	Modulus of Elasticity (GPa)	
	5 day	7 day
B1	23.8	25.9
B2	24.9	26.6

B. Temperature Measurements

1) *Specimen cast at Morning:* Temperature gradient for specimen cast at morning for 48 hours was measured and plotted.

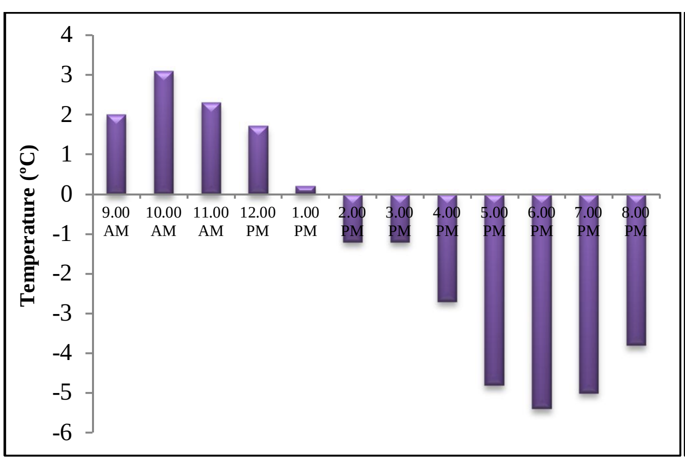

Fig. 4 Temperature Gradient at One Hour Interval (9 AM to 8PM)

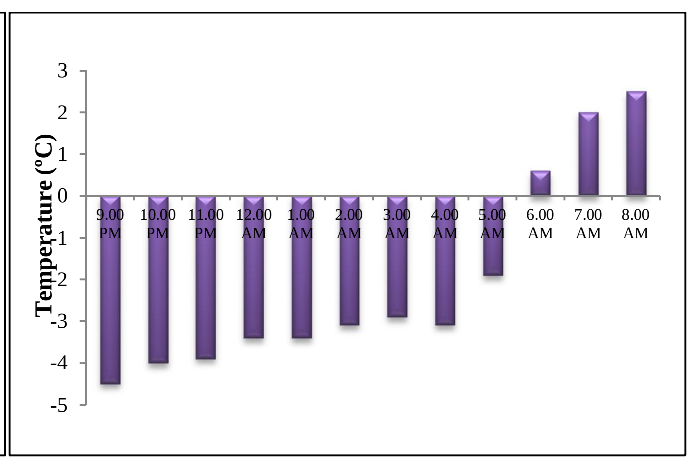

Fig. 5 Temperature Gradient at One Hour Interval (9 PM to 8AM)

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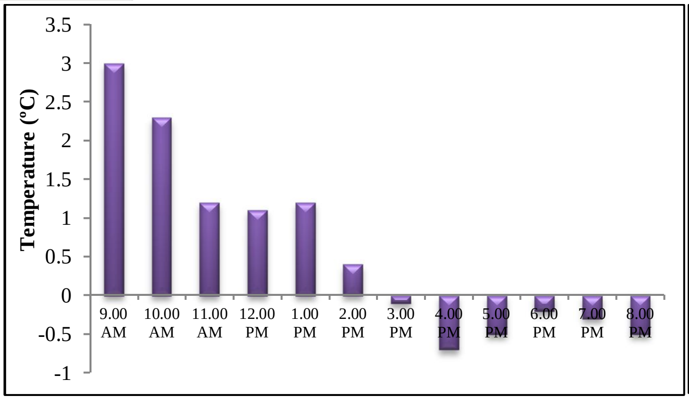

Fig. 6 Temperature Gradient at One Hour Interval (9 AM to 8PM)

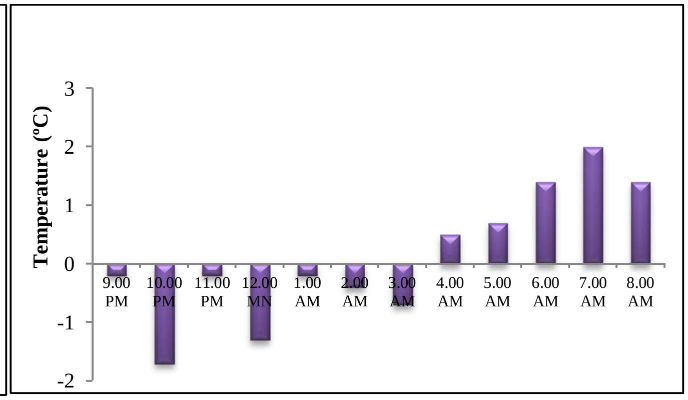

Fig. 7 Temperature Gradient at One Hour Interval (9 PM to 8AM)

2) *Specimen cast at Afternoon:* Temperature gradient for specimen cast at afternoon for 48 hours was measured and plotted.

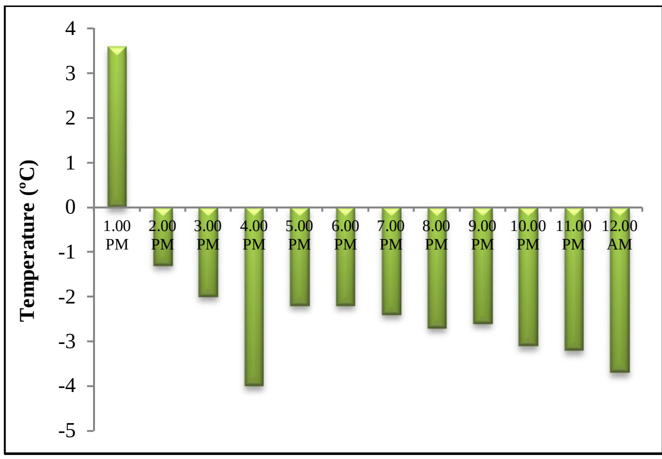

Fig. 8 Temperature Gradient at One Hour Interval (1 PM to 12 AM)

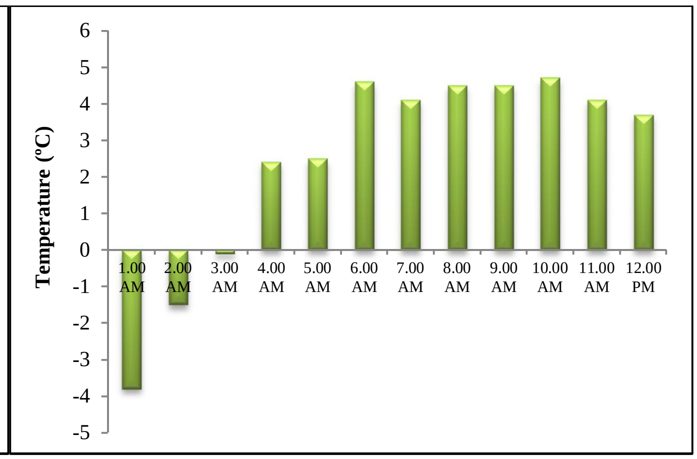

Fig. 9 Temperature Gradient at One Hour Interval (1 AM to 12 PM)

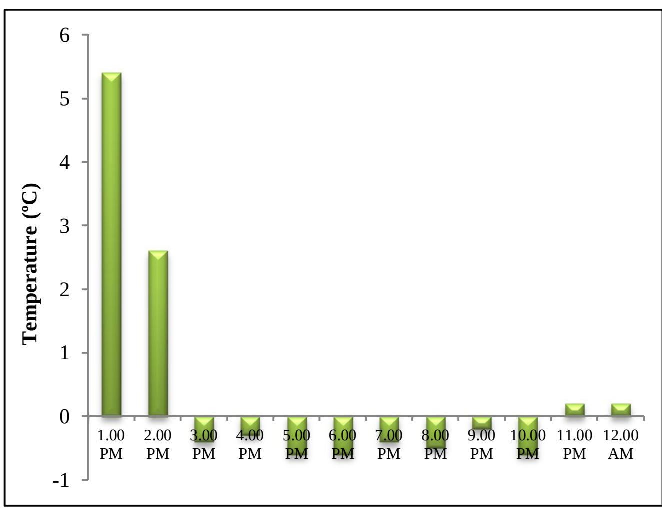

Fig. 10 Temperature Gradient at One Hour Interval (1 PM to 12 AM)

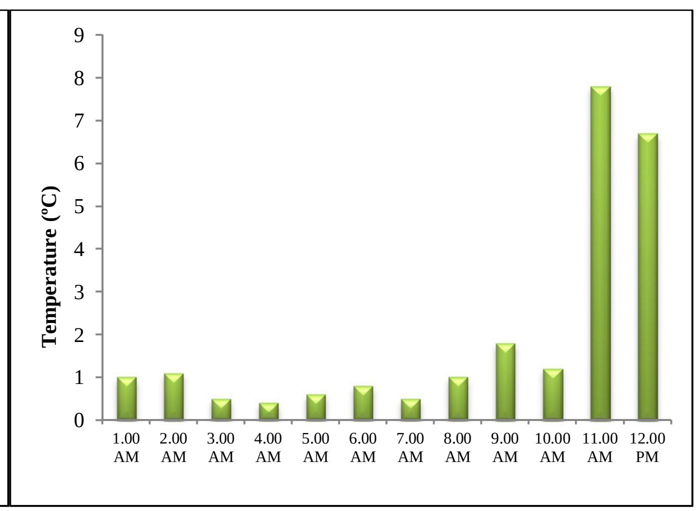

Fig. 11 Temperature Gradient at One Hour Interval (1 AM to 12 PM)

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C. Deflection Measurements

The deflection measurements for specimen cast at morning and afternoon was measured and plotted

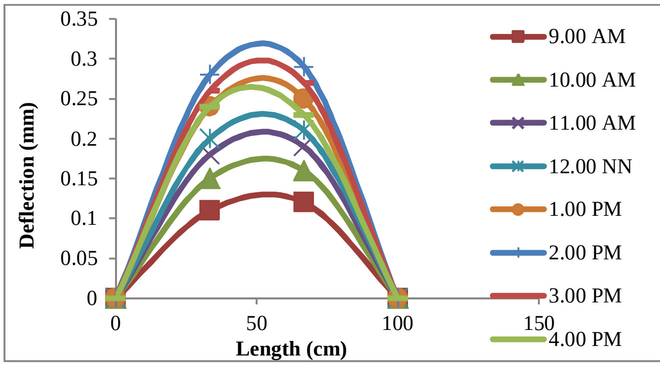

Fig. 12 Deflection at One hour Interval at Specimen cast at Morning (9.00AM to 4.00 PM)

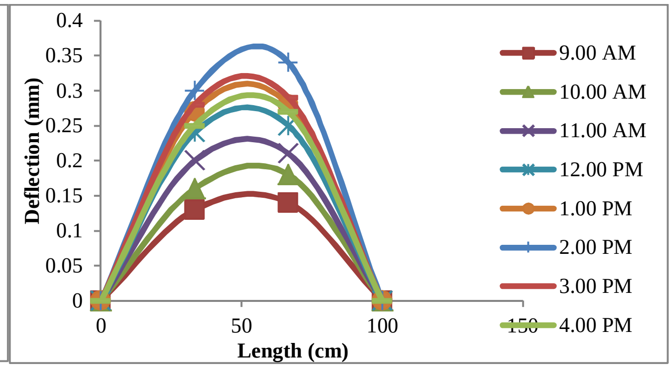

Fig. 13 Deflection at One hour Interval at Specimen cast at Afternoon (9.00AM to 4.00 PM)

V. CONCLUSIONS

The conclusions obtained from this experimental investigation are summarized below,

A. Temperature has a non-linear variation throughout the pavement slab across the depth
B. During the initial hours, the temperature gradient of the specimen is due to heat of hydration of concrete
C. During day time, the specimen cast at morning and afternoon shows downward curling
D. Mechanical properties such as compressive strength, flexural strength and modulus of elasticity gets improved due to the addition of fibres
E. Adding fibre to a concrete mix can reduce cracks, increases concrete strength and there by increases the service life
F. Compressive strength of specimen cast at afternoon is higher than that cast at morning

VI. ACKNOWLEDGEMENT

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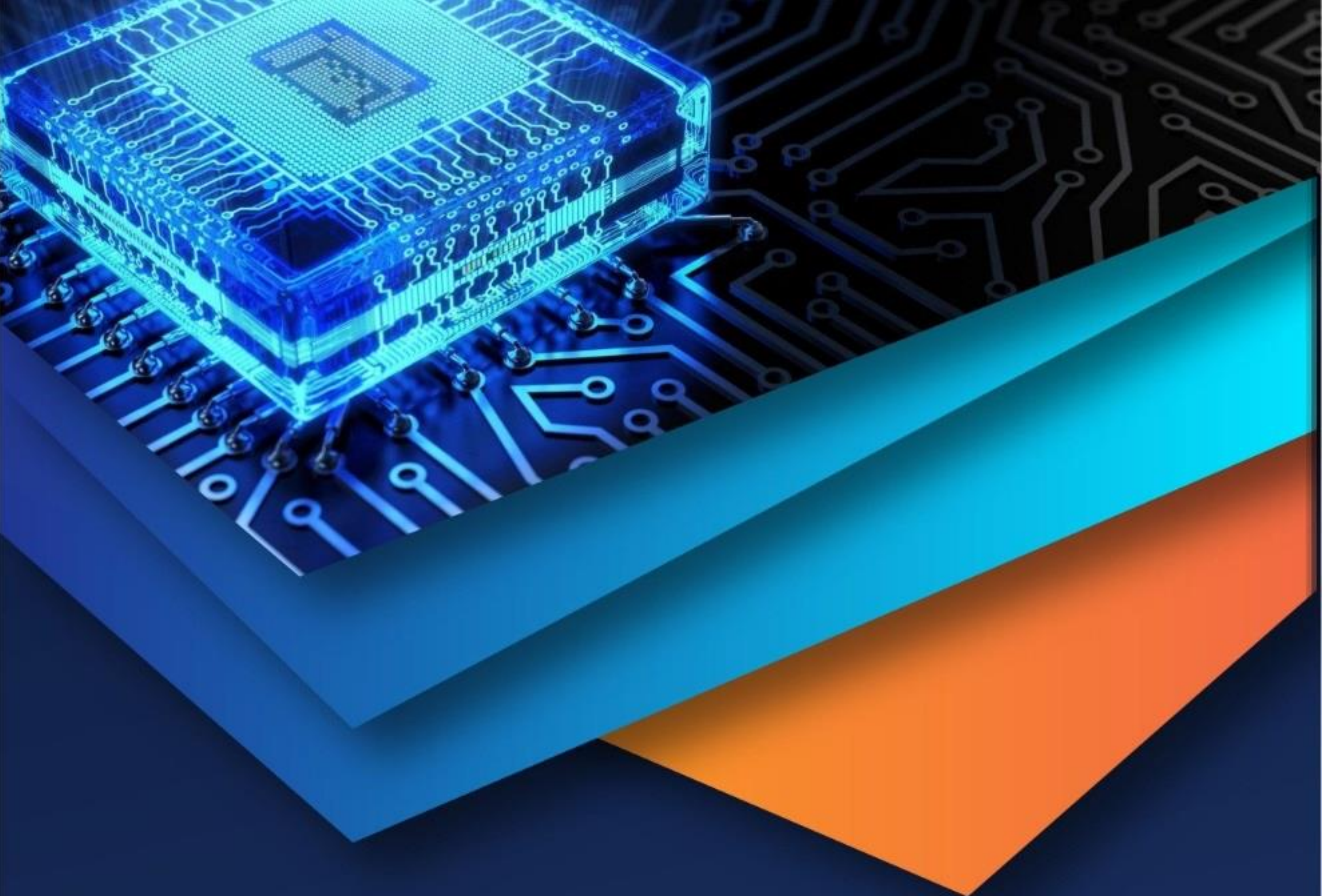

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