An Experimental Study on the Reduction of Temperature of Cool Pavement Specimens

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Abstract

Cool pavement is a pavement that reduces pavement temperature by increasing pavement reflectivity or controlling temperature, thereby reducing urban heat island effects.The study was conducted in PES College of Engineering, Mandya for conventional pavement specimens & cool pavement specimens to determine the temperature variations & strength comparison between them. The comparisons are as follows: Under the tree shade: In CCP-CCP 1L there is reduction of 1°C, in CCP – CCP 2L reduction of 1.2°C, in CCP-CCP porous reduction of 2.5°C, in bitumen-bitumen 1L reduction of 2.9°C. Direct exposure to sun: In CCP-CCP 1L there is reduction of 1.9°C, in CCP – CCP 2L reduction of 3.2°C, in CCP-CCP porous rise of 0.1°C, in CCP-CCP porous 1L reduction of 3.0°C, in bitumen-bitumen 1L reduction of 3.9°C, in bitumen-bitumen 2L reduction of 5.0°C.The compressive strength of porous concrete is 73.96 % lesser than that of conventional concrete. The split tensile strength of porous concrete is 50.46 % lesser than that of strength of conventional concrete. The flexural strength of porous concrete is 48.99% lesser than that of strength of conventional concrete.

Keywords: Solar Reflectance Index (SRI), Solar heating reflective coating layer (SHRCL), Solar radiation

1. Introduction

The cool pavement is a road surface that makes use of reflective coatings to mirror solar radiation in contrast to the conventional dark pavement. Conventional darkish pavements make contributions to city warm islands as they take in eighty to ninety-five percent of daylight and heat the local air.

By altering land surface, pavements have important localized environmental effects in urban regions. This report focuses on the contributions pavements make to the city heat island. As with roofing substances, paving substances can reach 150°F in the daytime, radiating away from this extra heat throughout both day and night time into the air inside the urban canopy layer (as properly heating typhoon water that reaches the pavement floor). Due to the big place blanketed by means of pavements in urban areas, they're a critical element to don't forget in warm island mitigation.

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This contribution can be reduced by using the usage of "cool pavements." Cool pavements may be completed with existing paving technology and do not require new materials. Their "cool" nature comes approximately via the attention given to the choice of substances and engineering layout. The use of cool pavements is meant to reduce pavement temperature with the aid of increasing pavement reflectivity or controlling temperature by means of other means, with the selected approach(s) applied as appropriate for the duration of the urban area. Specific pavement technologies with cool attributes will no longer be suitable for all uses; some may be better appropriate to mild traffic areas, for example; others to areas wherein noise control is taken into consideration crucial. In addition, positive paving technology might not constantly be appropriate or viable in a specific place of a region – whether technically, economically, organizationally, or institutionally – and nearby pavement engineers and owner corporations may not be sufficiently acquainted with cool pavements to use them confidently.

1.1 Objectives

1. To reduce the temperature of the pavements and thereby reducing the urban heat island effects in the city.
2. Shading of the pavement surface with reflective colour paint (light-coloured material) which are having higher solar reflectance index (SRI).
3. Modification of aggregate arrangement – Increasing the number of voids and hence creating the permeable pavements (mix design of porous pavements).
4. Comparison of cool pavement with respect to conventional pavements with respect to temperature reduction.
5. To study the possible applications of cool pavements.

2. LITERATURE REVIEW

The vital overall performance makers of Urban Heat islands results are Lee et al (2010) who studied at the effect of use of air conditioning which puts pressure and as a result emit greater carbon. Therefore, the urban heat island effect contributes to environmental issues inclusive of air quality and weather change. Dark impervious pavements cover a large amount of urban floor vicinity, generally 30–45%. They identified the solution to this problem with the aid of the implementation of cool pavement technologies in pavement areas of less stringent structural requirements along with parking lots and less volume roads. Cool pavements are a

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class of materials that showcase more desirable cooling via improved reflectivity or elevated convection. This has a look at correlates heat island impact to weather change as well as outlining the exclusive cool pavement technology which can also help to mitigate weather change consequences. Tran et al (2009) studied on specific high-reflectance asphalt materials and pavement surface treatments that are suitable for use in parking lots and other large paved surfaces, have a minimal SRI of 29, and are affordable. In this look at, six technologies exhibited SRI values of 29 or greater: E-Krete micro-surfacing, Street-Bond coating, artificial binder, Densiphalt, and chip and sand seals the use of mild-colored aggregates. Another technology is by the use of surface gritting having light-colored aggregate mixture, maximum possibly might have exhibited SRI values of at the least 29 if the mixture had adhered properly to the asphalt mat.

Boriboonsomsin et al (2007) work focus on creating excessive-albedo concrete for use in pavement programs. Fly ash and slag are used as the primary constituents due to the fact they may be environmentally friendly, quite simply to be had and already known with the concrete sector. Compared with a traditional concrete mix, concrete mixes containing fly ash have a lower albedo, while concrete mixes containing slag have higher albedo. Of all mixes tested, the mixture with 70% slag as cement alternative achieves the very best albedo of 0.582, which is seventy-one % higher than the traditional mix. It additionally has better compressive power as examined at 7 and 28 days and modulus of rupture as examined at 7 days. Cao et al (2011) proposed a warmness-reflective coating (HRC) which turned into performed to the floor of asphalt pavement. The coating temperature discount principle and the mechanism to mitigate the urban heat island impact (UHI) have been explored via analyzing the abilities of the atmospheric absorption spectrum. Also, they studied exceptional HRC functions and it is having a good water-resistant capability, sturdy oil resistance, and abrasion resistance. When it has become painted on the ground of the dense-graded asphalt concrete, the pavement temperature can be decreased by about 9°C in hot seasons. The comprehensive pavement overall performance was evaluated via the following tests: antiskid, expanded abrasion, freeze-thaw cycle, and permeability. The results display that asphalt concrete pavement with adopting HRC has robust abrasion resistance, first-rate resistance to temperature fluctuation, and considerably reduces water harm. The skid-resistant ceramic granular need to be delivered within the dense-graded asphalt pavement with HRC, which become proven to have extensively more suitable antiskid capability.

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3. Materials and Methodology

The materials which used for the present study was acquired from the local area and their basic properties were studied to check its suitability according to codal specifications.
The first step of the present study was to select conventional flexible and cement concrete pavement to measure the pavement temperature at regular intervals of time.
For the present study the reduction in pavement temperature was carried out by using two different techniques that is by using a cool paint and to design porous pavement to infiltrate the water to keep pavement cool. For the first method a cool paint was selected and applied on the conventional pavement and also on casted conventional and porous specimens to measure the reduction in pavement temperature. For the present study, MAGIC COAT Heat Reflective Paint having high SRI value which makes it more suitable for pavement application was selected as a cool paint. The characteristics of porous pavement was studied by conducting permeability test and the mix design proportion of pervious concrete pavement was carried out for 43 grade of OPC as per Indian specifications IRC44-2017 and obtained a mix proportion of 1:0.4:7.6. The specimens were prepared to measure the temperature at different intervals of time and also to measure its strength characteristics. Different samples prepared above are kept under direct sunlight and under tree shade. The samples were denoted as C1, C2, C3, C4, C5 and C6 which was kept under tree shade and D1, D2, D3, D4, D5, D6, D7 and D8 which was exposed to direct sunlight. The temperature readings were recorded at fixed interval of time that is in morning, afternoon and evening.
The prepared specimens was tested for compressive strength and split tensile strength to know its structural characteristics and compared with the conventional pavements.
The following are the specimens whose surface temperature is measured at regular interval of time under different conditions:

Under Tree Shade

Table 3.1: Designations of specimens kept under tree shade

Designation	Pavement type
C1	Conventional Cement Concrete Pavement(CCP)
C2	Cement Concrete Pavement Painted (1 Layer)

C3	Cement Concrete Pavement Painted (2 Layer)
C4	Porous Pavement
C5	Conventional Bituminous Pavement
C6	Bituminous Pavement Painted 1 Layer (Existing)

Direct Exposure:

Table 3.2: Designations of specimens kept under direct exposure

Designation	Pavement type
D1	Conventional Cement Concrete Pavement(CCP)
D2	Cement Concrete Pavement Painted (1 Layer)
D3	Cement Concrete Pavement Painted (2 Layer)
D4	Porous Pavement
D5	Porous Pavement Painted 1 Layer
D6	Conventional Bituminous Pavement
D7	Bituminous Pavement Painted 1 Layer (Existing)
D8	Bituminous Pavement Painted 2 Layer (Existing)

Fig 3.1: Porous concrete specimen

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4. Analysis of Results

Results of Tests on Concrete

Table 4.1: Comparison of Strengths of Conventional and Porous Concrete

	Compressive Strength(N/mm^2)	Split tensile strength in N/mm^2	Flexural Strength in N/mm^2
Conventional Concrete	24.618	3.222	3.47
Porous Concrete	6.409	1.598	1.77
Percentage Variation in Strength	73.96 %	50.403 %	48.99%

Pavement Surface Temperature Variations

The variations of temperature readings are shown between conventional and cool pavement at morning, afternoon & evening and also average of these:

Average Pavement Surface Temperature Variations:

Fig 4.1: Variation of temperature readings under tree shade

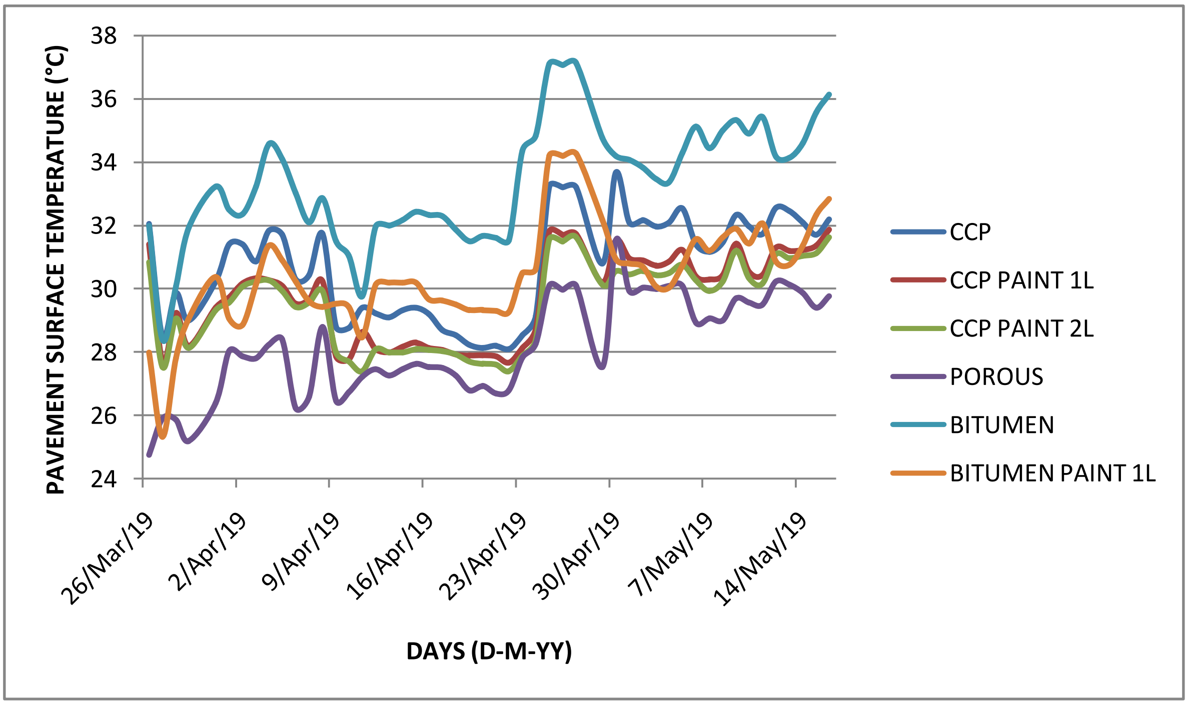

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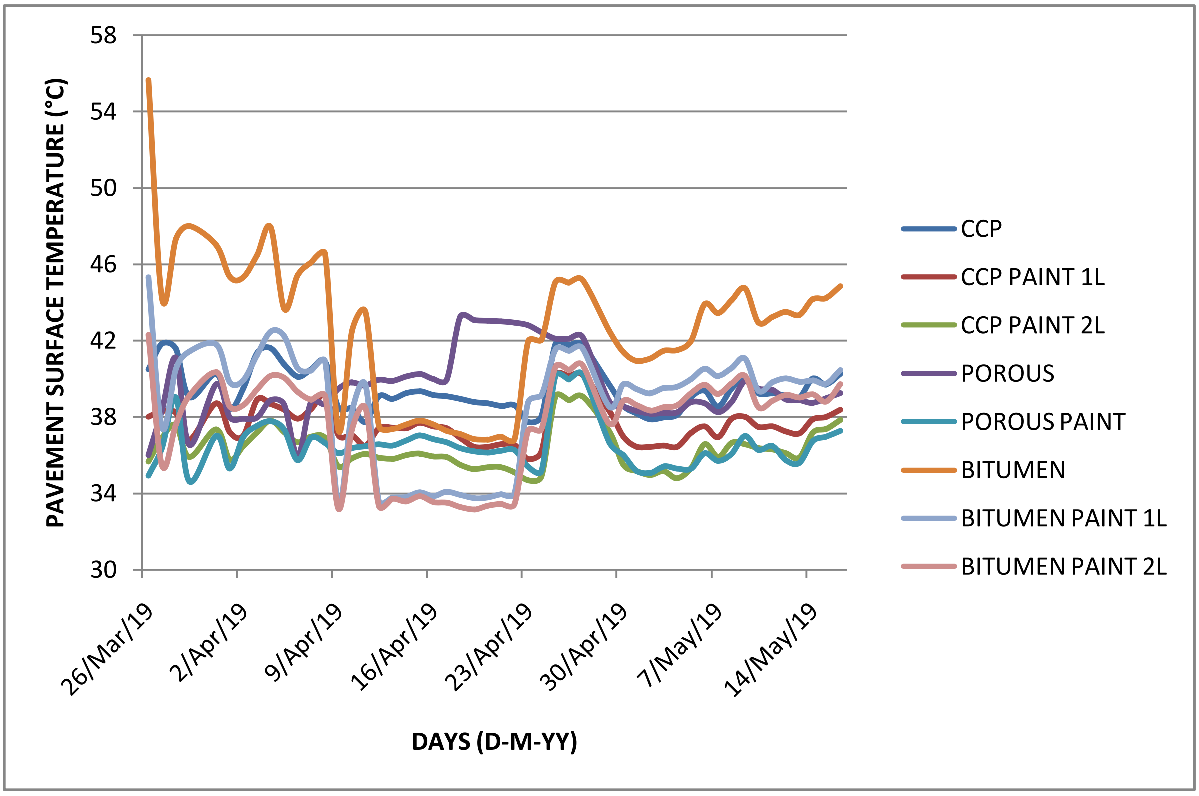
Fig 4.2: Variation of temperature readings under Direct exposure



Statistics of pavement temperature variations.

The temperature data collected from different specimens were statistically analyzed using Easy Fit software and the characteristics for each type of category was obtained. Results shows that temperature of bituminous pavement is more compared to other types of pavement and also it was observed that the temperature of pavements which was exposed to direct sunlight was much higher than the specimens which was kept under tree shade.

Since the Skewness is positive the mass of the distribution is concentrated on the left of the figure. This shows the temperature readings are less than average value is more. The Kurtosis value indicates that the values has peakness more than normal distribution curve indicating that more values are scattered near the mean value.

Table 4.2: Statistical Analysis of specimens in Morning under Tree Shade

		C1	C2	C3	C4	C5	C6
N	**Valid**	49	49	49	49	49	49
	Missing	0	0	0	0	0	0
Mean		26.355	25.308	25.084	26.092	26.286	25.645
Std. Deviation		2.851	2.212	2.287	2.861	1.059	1.103
Variance		8.133	4.895	5.234	8.187	1.122	1.218
Skewness		0.673	0.379	0.303	0.688	-0.055	-0.153

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Kurtosis	-0.447	-1.306	-1.429	-0.326	-1.047	-1.220
Range	11.7	7.3	6.8	11.9	3.8	3.8
a. Multiple modes exist. The smallest value is shown						

Table 4.3: Statistical Analysis of specimens in Morning under Direct Exposure

		D1	D2	D3	D4	D5	D6	D7	D8
N	**Valid**	49	49	49	49	49	49	49	49
	Missing	0	0	0	0	0	0	0	0
Mean		33.49	31.51	30.21	37.02	33.92	30.08	28.78	28.55
Std. Deviation		2.032	1.928	1.794	2.361	2.429	3.044	2.800	2.900
Variance		4.132	3.717	3.220	5.575	5.902	9.269	7.845	8.415
Skewness		-1.901	-1.153	-0.694	-3.211	-1.328	0.312	0.223	0.185
Kurtosis		6.395	2.817	1.587	15.012	4.233	-1.312	-1.381	-1.412
Range		11.4	10.6	9.5	15.0	13.3	9.1	8.8	9.0
a. Multiple modes exist. The smallest value is shown									

Table 4.4 : Statistical Analysis of specimens in Afternoon under Tree Shade

		C1	C2	C3	C4	C5	C6
N	**Valid**	50	50	50	50	50	50
	Missing	0	0	0	0	0	0
Mean		34.89	33.37	33.03	29.46	39.88	34.29
Std. Deviation		1.419	1.163	1.134	2.101	4.395	3.508
Variance		2.014	1.354	1.286	4.415	19.35	12.31
Skewness		-0.510	-1.621	-1.943	-2.022	-1.969	-2.746
Kurtosis		2.021	5.026	6.045	4.921	5.020	8.993
Range		7.5	6.4	6.3	11.0	23.5	19.4

Table 4.5: Statistical Analysis of specimens in Afternoon under Direct Exposure

		D1	D2	D3	D4	D5	D6	D7	D8
N	**Valid**	50	50	50	50	50	50	50	50
	Missing	0	0	0	0	0	0	0	0
Mean		50.54	46.96	44.76	48.09	43.74	59.38	49.98	47.84
Std. Deviation		3.032	3.095	3.009	4.314	3.621	5.933	4.884	3.781
Variance		9.198	9.581	9.055	18.615	13.113	35.203	23.859	14.301
Skewness		-0.965	-1.294	-1.847	-0.774	-0.324	0.352	-0.105	-0.107
Kurtosis		2.568	4.775	7.584	1.921	0.122	-1.076	-0.857	-0.214

Range	17.0	18.2	19.0	21.5	16.4	19.4	16.9	17.2
a. Multiple modes exist. The smallest value is shown								

Table 4.6: Statistical Analysis of specimens in Evening under Tree Shade

		C1	C2	C3	C4	C5	C6
N	**Valid**	50	50	50	50	50	50
	Missing	0	0	0	0	0	0
Mean		30.808	30.434	30.330	29.104	33.756	31.310
Std. Deviation		1.9354	1.8093	1.8745	1.1981	3.2893	2.8111
Variance		3.746	3.274	3.514	1.435	10.819	7.903
Skewness		-0.360	-0.384	-0.539	-0.455	0.125	0.335
Kurtosis		-0.883	-1.123	-0.016	0.877	-0.401	0.041
Range		7.0	6.4	8.8	5.8	14.4	12.7

Table 4.7: Statistical Analysis of specimens in Evening under Direct Exposure

		D1	D2	D3	D4	D5	D6	D7	D8
N	**Valid**	50	50	50	50	50	50	50	50
	Missing	0	0	0	0	0	0	0	0
Mean		34.24	34.10	33.82	33.72	31.89	38.77	37.15	36.36
Std. Deviation		3.902	3.644	3.120	3.818	3.588	5.000	3.563	3.418
Variance		15.22	13.28	9.737	14.58	12.88	25.00	12.70	11.68
Skewness		0.558	0.521	0.512	0.198	0.600	0.176	0.162	0.046
Kurtosis		-0.721	-0.596	-0.797	-1.192	-0.718	-0.965	-1.002	-1.131
Range		14.1	13.6	10.3	12.4	12.5	18.5	12.9	11.8
a. Multiple modes exist. The smallest value is shown									

Table 4.8: Under Tree Shade (daily)

		C1	C2	C3	C4	C5	C6
N	**Valid**	50	50	50	50	50	50
	Missing	0	0	0	0	0	0
Mean		30.724	29.746	29.520	28.211	33.348	30.431
Std. Deviation		1.6495	1.4185	1.3748	1.5719	1.8757	1.6143
Variance		2.721	2.012	1.890	2.471	3.518	2.606

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Skewness	-0.142	-0.142	0.173	-0.084	-0.090	0.057
Kurtosis	-1.347	-1.503	-1.436	-0.845	0.057	1.872
Range	5.6	4.2	4.2	6.8	8.7	8.9
a. Multiple modes exist. The smallest value is shown						

Table 4.9: Statistics Direct Exposure (daily)

		D1	D2	D3	D4	D5	D6	D7	D8
N	**Valid**	50	50	50	50	50	50	50	50
	Missing	0	0	0	0	0	0	0	0
Mean		39.47	37.56	36.30	39.60	36.52	42.68	38.75	37.67
Std. Deviation		1.180	1.014	1.072	1.835	1.225	3.871	3.045	2.624
Variance		1.393	1.029	1.149	3.370	1.502	14.990	9.277	6.888
Skewness		0.658	0.863	0.854	0.515	1.489	0.354	-0.661	-0.741
Kurtosis		-0.482	0.692	0.478	-0.154	2.856	1.143	-0.548	-0.808
Range		4.1	4.4	4.4	7.3	5.6	18.9	11.9	9.2

Surface Temperature Comparison

After analysis of surface temperature readings of each specimen we obtained a temperature reduction of cool pavement specimen compared with conventional pavement specimen. The results indicate that there is higher reduction of temperature by using cool paints compared to porous pavements. Also the results indicate that the temperature can be reduced by painting the existing bituminous pavement by two layer which has more effect than coating with single layer. The comparisons are as follows.

Table 4.10: Comparison of temperature readings between conventional and cool pavement specimens at Morning

UNDER TREE SHADE(°C)		DIRECT EXPOSURE(°C)	
CCP- CCP 1L	-1.1	CCP- CCP 1L	-2.0
CCP- CCP 2L	-1.3	CCP- CCP 2L	-3.3
CCP- POROUS	-0.3	CCP- POROUS	+3.5
BITUMEN- BITUMEN 1L	-0.6	CCP- POROUS PAINT	+0.4
		BITUMEN- BITUMEN 1L	-1.3
		BITUMEN- BITUMEN 2L	-1.5

(Here, - is decrease in temperature & + is increase in temperature compared to conventional)

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Table 4.11: Comparison of temperature readings between conventional and cool pavement specimens at Afternoon

UNDER TREE SHADE(°C)		DIRECT EXPOSURE(°C)	
CCP- CCP 1L	-1.5	CCP- CCP 1L	-3.6
CCP- CCP 2L	-1.9	CCP- CCP 2L	-5.8
CCP- POROUS	-5.4	CCP- POROUS	-2.5
BITUMEN- BITUMEN 1L	-5.6	CCP- POROUS PAINT	-6.8
		BITUMEN- BITUMEN 1L	-9.4
		BITUMEN- BITUMEN 2L	-11.5

(Here, - is decrease in temperature & + is increase in temperature compared to conventional)

Table 4.12: Comparison of temperature readings between conventional and cool pavement specimens at Evening

UNDER TREE SHADE(°C)		DIRECT EXPOSURE(°C)	
CCP- CCP 1L	-0.4	CCP- CCP 1L	-0.2
CCP- CCP 2L	-0.5	CCP- CCP 2L	-0.4
CCP- POROUS	-1.7	CCP- POROUS	-0.5
BITUMEN- BITUMEN 1L	-2.5	CCP- POROUS PAINT	-2.4
		BITUMEN- BITUMEN 1L	-1.6
		BITUMEN- BITUMEN 2L	-2.4

(Here, - is decrease in temperature & + is increase in temperature compared to conventional)

Table 4.13: Comparison of Average temperature readings between conventional and cool pavement specimens

UNDER TREE SHADE(°C)		DIRECT EXPOSURE(°C)	
CCP- CCP 1L	-1.0	CCP- CCP 1L	-1.9
CCP- CCP 2L	-1.2	CCP- CCP 2L	-3.2
CCP- POROUS	-2.5	CCP- POROUS	+0.1
BITUMEN- BITUMEN 1L	-2.9	CCP- POROUS PAINT	-3.0
		BITUMEN- BITUMEN 1L	-3.9
		BITUMEN- BITUMEN 2L	-5.0

(Here, - is decrease in temperature & + is increase in temperature compared to conventional)

Strength Comparison

After analysis of strength of each specimen, we obtained a strength difference of porous concrete compared with conventional concrete. The comparisons are as follows:

- **Compressive strength:** The compressive strength of porous pavement specimen (6.41) is 18.208 N/mm^2 lesser than the strength of conventional pavement specimen (24.618) i.e. compressive strength of porous concrete is **73.96 %** lesser than that of conventional concrete.

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- **Split tensile strength:** The strength of porous pavement specimen (1.60) is 1.63 N/mm^2 lesser than the strength of conventional pavement specimen (3.23) i.e. strength of porous concrete is 50.46 **%** lesser than that of strength of conventional concrete.
- **Flexural strength:** By using (0.7*fck^0.5), the strength of porous pavement specimen (1.77) is 1.7 N/mm^2 lesser than the strength of conventional pavement specimen (3.47) i.e. strength of porous concrete is **48.99%** lesser than that of strength of conventional concrete.

Conclusions

- Cool pavements lower the outside air temperature, allowing air conditioners to cool buildings with less energy.
- White topping the existing dark pavement reflects the sunlight and there by reduces the surface temperature of pavement and increases albedo. It also saves energy by reducing the need for electric street lighting at night.
- Porous pavement reduces the surface temperature and therefore, the heat island effect. And also it eliminates runoff and recharges ground water table. Porous pavements cannot be used for major works such as roads and highways but it can be used in parking plots and for foot paths such that it reduces the temperature of the area.
- MAGIC COAT Heat Reflective Paint has been designed to give relief from pavement heat as it is a high albedo paint having high SRI value which makes it most suitable for pavement insulation.

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