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A Novel Lightweight Phase-changing Cooling Roof Tile

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ABSTRACT

Roof tiles are the most common roof coverings in Indian buildings, especially in traditional residential buildings. Given the important role of roofing characteristics in building energy efficiency and indoor thermal comfort conditions, innovative solutions to improve the thermal energy performance of this diffused roofing element have become a key research issue. In this perspective, cool roofing applications represent an effective solution to this objective. The present work deals with the analysis of an innovative cooling roof tile manufactured using a combination of Metakaolin with different percentages, EPS, sodium silicate, and coating material. The experimental work was carried out during day and night. The thermal performance of cooling roof tiles was assessed in terms of the open-air temperature compared to the thermal performance of ordinary roofing tiles. The report discovered that using revolutionary cool roofs greatly increased thermal comfort during the daytime, and preserved thermal comfort during the night. The innovative cool roof tile is cheaper, easier to implement, and less expensive compared to other roofing technologies. The study revealed that the roof's exterior and interior surface temperature reduced about 8°C and 12°C, respectively during day time, while the roof's exterior and interior surface temperature maintain atmospheric temperature during nighttime. The compressive and transverse breaking strength was increasing about 9.1% and 39.6%.

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1. INTRODUCTION

The phenomenon of urban heat islands has caused architects, engineers, and contractors in the construction sector to employ passive design, construction, and building specification strategies. These passive design strategies involve making use of the environment in which the building is located to reduce heating or cooling. These strategies shall include; considerations of building orientation, shape, envelope; (the choice of materials), and landscape. Increasing the demand for shelter and an increase in population brought about (which is still growing), the architects, the builders, and the contractors have been forced to be more careful about the specification of the material selection of the elements used in the building roof. This is a passive design strategy for surface mitigation temperature of buildings in hot climates Various factors influence how much energy a building consumes, such as location, purpose, and the intended use. The thermal properties of the materials used for the exterior walls and roofs may have a major impact on the surface temperature and, in turn, on the amount of heat flowing through the surface of the building. A cool building surface (walls and/or roof) uses a coating with high thermal emissivity and solar reflectance properties to lower the temperature. Solar thermal load of a building reduces its energy requirements for cooling [1]. A number of experimental and modelling studies have been published which compare the energy-efficient building benefits of cooling roofing techniques [2-4]. Over the past decades, the advantages of cooling roof technologies have been thoroughly studied throughout the world [5-10]. A number of factors influence the thermal performance of materials, but the main determinants are solar reflectance and thermal emissivity. Other surface properties include the type of coating used on the surface of the material, the thickness and texture of the coating, the durability of the coating when exposed to weather elements [11].

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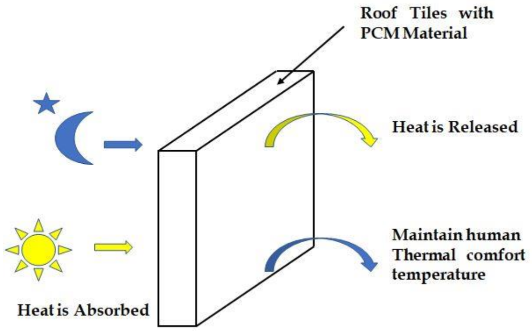

Figure 1. characteristic of PCM material

Cool roofs are a recognized passive cooling technology designed to reduce the energy consumption of buildings for cooling and to mitigate the effects of urban heat on islands [12]. High solar reflectivity and high thermal emissivity make up the cool roof. These roofs are typically light in colour and absorb less radiation, and effective at reducing the heat load on a building [13]. The temperature reached 50.6 degrees Celsius due to climate change in India, 2019 during daytime and average nighttime temperatures of 2–8 °C (36–46 °F). Low temperature can fall below freezing in the Punjab plains, falling to around −3 °C (27 °F) in Amritsar. So cool roof creates cooler the building it will affect the living people. To overcome this issue the phase change material (PCM) concept is introduced. Prior to 1980, PCMs were integrated into building materials for thermal energy storage applications and a great deal of attention was paid to the work concerned with the achievement and assessment of the application of PCMs in gypsum wallboards, plasterboards, textured finishes, etc. [10, 14-20]. The PCM has special characteristics it maintains the heating and cooling functions of the building and creates pleasant human comfort temperature [21]. The sodium silicate is used as the PCM material. Sodium Silicate is a colourless compound of oxides of sodium and silica. It has a phase-changing property [22]. Figure 1 shows the characteristic of PCM material.

In this research, a new innovative reflective roofing tile was developed using metakaolin, Expanded polystyrene sheet (EPS), and a PCM with a reflective coating material. The performance of roof tiles is measured in terms of thermal emissions, which are mainly determined by the cooling capacity of these materials. The thermal performance of the roof tile is measured during daytime and night-time at the top and bottom surface of the tile.

Metakaolin is widely used in mortar and concrete as pozzolanic material; it has a significant impact on improving the mechanical and durability properties of mortar and concrete [23-26]. Because of its highly amorphous structure, is known as the most reactive material for the geopolymerization process. It is obtained by heating kaolinite, a mineral of clay, at a high temperature and by rapid cooling afterward [27]. Metakaolin is white in colour as the heat absorption of construction material depends on the reflection of light on the surface, while whiter construction tends to remain cooler than darker materials, which provide a cooling property in concrete. Since the cost is higher in the materials than cement, the proportions are tested (15, 20 and 25%).

Expanded polystyrene sheet (EPS) is a versatile, low-weight substance with excellent energy absorption characteristics. EPS is a closed-cell polymer that does not readily retain vapor, and when exposed to sustained immersion of water, EPS can still maintain its form, scale, composition and physical appearance and maintain 80% of its thermal value. The production of EPS does not contain ozone-depleting gasses and does not use chlorofluorocarbons (CFCs). That, in addition, plays a constructive position in the elimination of carbon dioxide pollution and the impact in global warming. The EPS is a recycled plastic waste, that reduces the cost of cement mortar and saves the landfilling problem of plastic waste, which also acts as an insulation coating. This Expanded polystyrene type is fulfilling IPC Code: C04B26/02. Also using of EPS leads to a remarkable reduction in thermal conductivity [28, 29]. Hence using of EPS in tiles leads to reducing temperature.

Reflective coatings and light colour are used as an energy-saving measure for buildings, reducing the incoming solar radiation into the shell of the house [8, 22]. Light reflective paint for concrete is aimed at creating a retro-reflective impact on concrete and cement substrates that are heavily influenced by weather patterns. Reflective paint is immune to all sorts of natural environmental effects: heat, dust, wind, etc. Reflective material paint is scratch-resistant and will never crack. It also reduces the heat so, saves energy. It leads to a reduced requirement for air conditioning hence reduced electricity. It is highly reflective in the near infra-red (non-visible) portion of the solar spectrum, thus keeping interiors cool during hot summer months.

2. MATERIALS

All the materials meet up the Indian standard specification. The fine aggregate used in the mortar mix conforms to Zone-II as per IS 383-1970 [30] has a fineness modulus of 2.34. The cement utilized over the experiments is Portland Pozzolana Cement (PPC) conforming to IS (IS:269/ IS 12269: 2013) [31]. EPS sheets were obtained from the plastic waste factory, India. A type of commercially available rectangular EPS sheets which was ground in grinding machine to a maximum sieve size of 1.0 mm. The properties of various materials used in the experimental work are reported in Tables 1-3.

TABLE 1. Physical properties of Portland pozzolana cement

SI No	Characteristics	Test values	Value specified by IS:1489 (Part 1)-1991
1	Standard consistency (%)	32	-
2	Fineness of cement as retained on 90 lm sieve (%)	0.70	Maximum 10%
3	Setting times (minutes) Initial	40 minutes	Minimum 30 minutes
4	Setting times (minutes) Final	280 minutes	Maximum 600 minutes
5	7 days Compressive strength (MPa)	23.5	Minimum 22.0
6	28 days Compressive strength (MPa)	34.5	Minimum 33.0

TABLE 2. Physical properties of fine aggregate

SI No	Characteristics	Test Values
1	Specific gravity (oven-dry basis)	2.69
2	Bulk density loose (kg/l)	1.35
3	Fineness modulus	2.30
4	Water absorption (%)	2.39
5	Grading zone	II

TABLE 3. Physical and mechanical properties of EPS

SI No	Property	Average value
1	Compressive strength	0.09 MPa
2	Density	13 kg/m^3
3	Flexural strength	0.21 MPa
4	Water Vapor permeability	1.4 Perm-cm
5	Water Absorption	4 % by vol.

As cement provide heating to the tile, an alternate material metakaolin (Chinese clay) was used in different ratio, which was sieved through 2 µm sieve and weighed. The specific gravity of highly reactive metakaolin is 2.5. The white colour provides a cooling effect. To emphasis, a phase changing property to the tile an optimal 1% (of total cement) sodium silicate was added to the mix. The workability of fresh metakaolin aggregate cement mortar was determined at 20°C by the finger-touching method prescribed in Choi and Ohama.

Here metakaolin ratios, 15% (control sample), 20%, and 25% mix proportion by volume were prepared. EPS beads content for the mixtures were kept constant at $0.0001m^3$. The interfacial zone between cement paste and fine aggregate plays a critical role in determining the mechanical properties of mortar. For this reason, EPS beads were wetted finally with a part of the mixing water after mixing the remaining materials. The pre-wetting of lightweight aggregate will critically affect the strength of its mortar. A technique similar to cement-wrapping was applied on the EPS beads. The concrete mixes were prepared in a laboratory counter current mixer for a total of 5 min. Precautions were taken to ensure homogeneity and full compaction. The fresh mortar was then poured into molds and compacted by hand and leveled using a vibration table.

3. DESCRIPTION OF THE TEST SPECIMENS

In this research work, three different types of tiles were casted using different percentages of metakaolin. The other materials like sodium silicate, EPS, crack shield coat and Flexi cool paint is constant in all the tiles. These three innovative cool roof tiles are compared with ordinary roof tiles. Different cool roof tile and ordinary tile is displayed in Figure 2. To cast the tile, a mold was designed and created from a welding yard. The mold consisted of a base plate for grip and it has two shoe levers that help the mold to open into two L-shaped brackets which enable to get crack-free edges of the tile. The base and the sidewalls of the mold were greased with waste oil for easy removal of hardened tile.

For each mixture, three sets of six samples of 70.6×70.6×70.6 mm cubes and three sets of four samples of 250×250×20 mm tiles were prepared. The specimens were cured two days under wet gunny bags initially and then removed from the molds and cured in lime saturated water up to the date of testing. Two days before testing the tiles and cubes were coated with two materials. Initially to fill the voids and to provide a well-finished surface, an apex Ultima Smart care crack shield was applied. To achieve a reflective surface 2 coating of excel flexicool coat paint was painted using a brush. The mix design was done for cement mortar 1:3, from the mix design different proportion of material was calculated. Table 4 displays the Quantity of material required for one tile with different percentages of metakaolin.

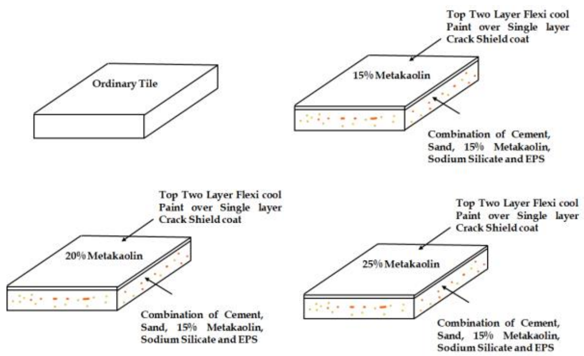

Figure 2. Cool roof tile specimens

TABLE 4. Quantity of material required for one tile with different percentage of metakaolin

S.No	Materials used	Quantity required for one Tile in kg (15%)	Quantity required for one Tile in kg (20%)	Quantity required for one Tile in kg (25%)
1	Cement	0.39	0.36	0.34
2	M sand	1.53	1.44	1.35
3	Metakaolin	0.34	0.45	0.57
4	Sodium silicate	3.8g	3.6g	3.4g
5	EPS	$0.0001m^3$	$0.0001m^3$	$0.0001m^3$
6	Crackshield	0.010	0.010	0.010
7	Flexicool paint	10ml	10ml	10ml

4. EXPERIMENTAL OBSERVATION

The experimental investigation was carried out for all four different tile specimens in the form of weight, temperature, strength, and durability.

4. 1. Weight Classification Test The weight classification of the tiles as per ASTM C1492 – 03 [33] is given in Table 5. It indicates the weight variation for the roof tiles to be classified as normal, medium, or lightweight.

4. 2. Temperature Test The temperature test was carried out on March 17, 2020 in Coimbatore, Tamilnadu, India. The rooftop surface temperature exceeds surrounding ambient air and indoor attic temperatures during hot summer days. To conduct a thermal performance study of white cement tiles four models of flat model rooftops were evaluated. The test models are shown in Figure 3.

Outdoor and indoor air temperatures near surfaces were measured using a digital thermocouple probe (model HTC IRX-64 K type range -50 to 1370˚C) and digital LCD display thermometer (model) 2040W as shown in Figure 4. The temperature was measured in two intervals as day and night for checking the phase changing property of roof tile.

Temperature probes were direct under sun and night when taking measurements. The temperatures measured

TABLE 5. Weight Classification (ASTM C1492-03)

Weight classification	Oven dry weight(lb/ft^3)
normal	greater than 125
medium	105 to 125
lightweight	less than 105

Figure 3. Test models

Figure 4. Thermometer k-type

outside and inside of the tile shown in Figure 5. At every hour from 9.00 A.M. to 7.00 P.M. Indoor and outdoor temperature during the daytime are displayed in Table 6.

During night time the temperatures were measured outside and inside of the tile at every hour from 12.00 A.M. to 4.00 A.M. Inside and outside temperature during night time are displayed in Table 7.

4. 3. Strength and Durability Test The compressive, transverse breaking strength was carried

Figure 5. Temperature testing inside and outside of tile

TABLE 6. Day time temperature comparison

Morning time	Side	15% MT (˚C)	20% MT (˚C)	25% MT (˚C)	Ordinary Tile (˚C)
09:0 0am	in	28.5	28.1	28.0	30.5
	out	27.6	27.0	27.0	37.0
10:00 am	in	32.0	31.2	31.0	34.0
	out	30.7	29.6	29.5	41.5
11:00 am	in	35.5	34.5	34.1	38.5
	out	33.7	32.7	32.5	45.2
12:00 pm	in	36.9	36.1	35.8	44.2
	out	35.1	34.8	34.7	46.6
01:00 pm	in	37.0	36.2	35.9	44.0
	out	35.3	34.8	34.8	46.2
02:00 pm	in	37.1	36.3	36.0	44.1
	out	35.6	35.0	34.9	46.3
03:00 pm	in	36.8	36.0	35.7	44.1
	out	35.0	34.7	34.5	46.4
04:00 pm	in	35.4	34.4	34.0	38.3
	out	33.6	32.6	32.4	43.0
05:00pm	in	35.2	34.0	33.8	38.0
	out	33.3	32.1	32.1	41.0
06:00pm	in	28.8	28.3	28.1	31.2
	out	27.6	27.2	27.3	35.0
07:00pm	in	27.9	27.6	27.5	30.0
	out	27.0	26.8	26.1	31.3

TABLE 7. Night time temperature comparison

Night time	Side	15% MT (°C)	20% MT (°C)	25% MT (°C)	Ordinary Tile (°C)
12:00 am	in	24.6	24.1	24.0	23.4
	out	24.2	23.9	23.7	26.1
01:00 am	in	24.4	24.0	23.9	23.2
	out	24.0	23.7	23.5	25.7
02:00 am	in	24.0	23.6	23.5	23.8
	out	23.8	23.4	23.2	25.2
03:00 am	in	23.6	23.1	23.1	22.9
	out	23.3	22.8	22.7	24.1
04:00 am	in	24.6	24.1	24.0	23.2
	out	24.1	23.7	23.5	25.1

out to find the strength of the specimen, and the impact strength test was carried out to find the durability of the specimen. The compressive test was conducted as per ASTM C270 – 14a [32], and the wet transverse breaking strength was carried out based on the standards 13801 [33] and ASTM 1167-11 [34]. From the experiment compressive strength and transverse breaking were recorded and it is summarized in Tables 8 and 9.

5. RESULT AND DISCUSSION

5. 1. Weight Calculation From the experimental investigation, it was observed that, all the tile specimen comes below the normal criteria. But an increase in the amount of metakaolin reduces the weight of the roof tile. The 20% metakaolin tile has more beneficial in terms of weight classification they are under lightweight. The EPS also contributes to lightweight. This is more clearly shown in Table 10.

5. 2. Temperature Test The temperature test was carried out on all the specimens and the temperature was taken inside and outside of the tiles during Day time and Nighttime. All the innovative tile specimens perform well in temperature compared to ordinary tile.

On March 17, 2020 the atmospheric temperatures recorded have been 37°C and 23°C during day and night, respectively. From Table 6 it was observed that the maximum temperature observed by the ordinary tile during the daytime outside of tile is 44.4°C, which is 18.9% higher compared to atmospheric temperature. However, another innovative tile (15% MT, 20% MT, 25% MT) is during the daytime outside temperature is less than one percent variation compared to atmospheric

TABLE 8. Compressive strength of the tile

Testing days	ordinary tile (N/mm^2)	15% MT (N/mm^2)	20% MT (N/mm^2)	25% MT (N/mm^2)
7 Days	10.48	11.09	12.32	11.93
14 Days	14.06	15.11	16.42	15.86
28 Days	22.27	23.1	24.3	23.61

TABLE 9. transverse breaking strength of the tile

Transverse breaking strengtl	Ordinary tile (N)	15% MT (N)	20% MT (N)	25% MT (N)
Wet	901	1153	1258	1225

TABLE 10. Comparison of the weight of tiles

Test of tile	Ordinary tile	15% MT	20% MT	25% MT
Dry weight (kg)	2.89	2.68	2.1	2.23
(lb/ft3)	143.58	133.60	104.88	111.12
weight classification	normal	normal	light weight	medium

temperature. Figure 6 shows the temperature variation outside of tile compared with ordinary tile during day time it can be observed that compared to ordinary tile in all the innovative tile the temperature reduced nearly 8°C in Noon (between 12.00 P.M. to 3.00 P.M.). compared to atmospheric temperature, 20% MT and 25% MT specimen maintain the same atmospheric temperature during day time. The maximum temperature observed by the ordinary tile during daytime inside of tile is 46.6°C, which is 22.2% higher compared to atmospheric temperature. However, the tile 15% MT, 20% MT and 25% MT the average of 8°C temperature reduced compare to ordinary tile throughout the daytime from 9.00 A.M. to 5.00 P.M. The specimen 20% MT and 25% MT temperature variation is nearly 12°C compare to ordinary tile. The higher variation of 12.2°C in 20% MT and 12.3°C in 25% MT. Figure 7 shows the temperature variation inside of tile compared with ordinary tile during daytime.

Figure 8 shows the Day time temperature variation inside and outside tile. In the ordinary tile, the temperature increases inside compare to outside. The time between 9.00 A.M. to 11.00 A.M. the temperature increases average of 7°C. In noontime, the temperature variation is average of 2.5°C between 12.00 P.M. to 3.00 P.M. After this hour again the temperature variation becomes very large. however, in 15% MT, 20% MT and 25% MT the temperature is reduced inside compare to outside. Also, the temperature is less than the atmospheric temperature. From this, it is understood that, using metakaolin and reflective Flexi cool paint, the specimens were not absorbing the temperature because of the colour of the tile and reflective material.

To find the phase changing property of tile the temperature is measured during night time between 12.00 A.M. to 4.00 A.M. The atmospheric temperature during night time is on 17th March 2020 is 23°C. The average outside temperature of the ordinary tile during nighttime is 23.5°C. However, the average outside temperature of other tiles during nighttime is 24°C equal to atmospheric temperature. The temperature variation outside of tile for innovative tile compared with ordinary tile is an increased average of 0.5°C during night time. Also, it maintains the atmospheric temperature. Figure 9 shows the temperature variation outside of tile compared with ordinary tile during night time. Also, inside of the tile the average temperature reduced 2°C compared to ordinary tile, Figure 10 displays the temperature variation inside of tile compared with ordinary tile during night time.

The temperature variation of inside and outside tile for 15% MT, 20% MT and 25% MT is less than 0.5°C. Also, it maintains the atmospheric temperature. It shows the phase-changing property of the tile. However, the tile 20% MT is having very little temperature variation compared to inside and outside of the tile. Figure 11 shows the Nighttime temperature variation inside and outside tile. In ordinary tile, the temperature increases inside compare to outside this is due to the ordinary tile absorb the temperature during the day time.

5. 3. Strength And Durability Test From the experimental investigation, it is observed that the compressive strength and transverse breaking strength is

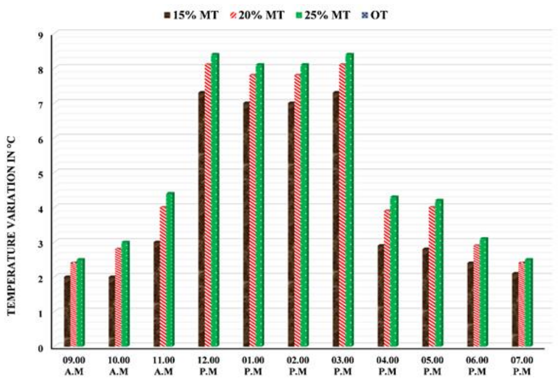

Figure 6. Temperature variation in outside of tile compared with ordinary tile- Day Time

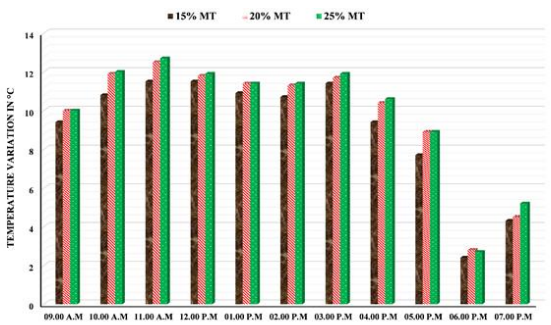

Figure 7. Temperature variation inside of tile compared with ordinary tile- Day Time

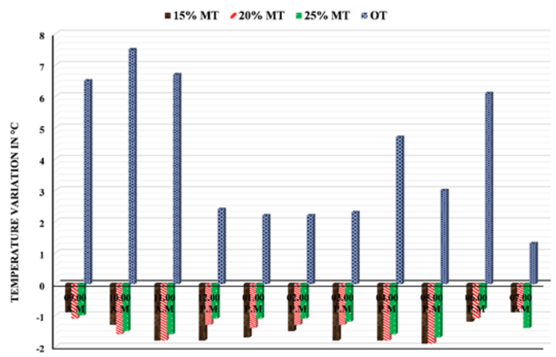

Figure 8. Day time temperature variation inside and outside tile

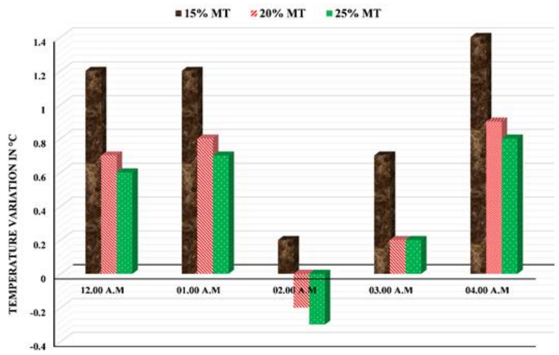

Figure 9. Temperature variation in outside of tile compared with ordinary tile- Nighttime

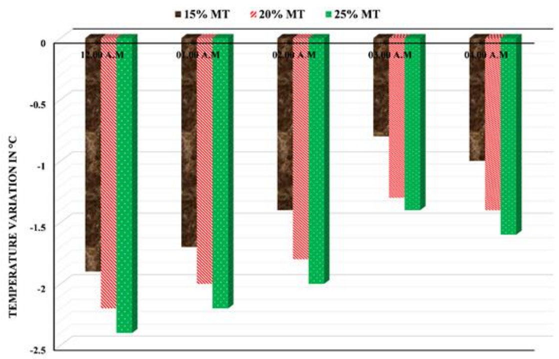

Figure 10. Temperature variation inside of tile compared with ordinary tile Nighttime

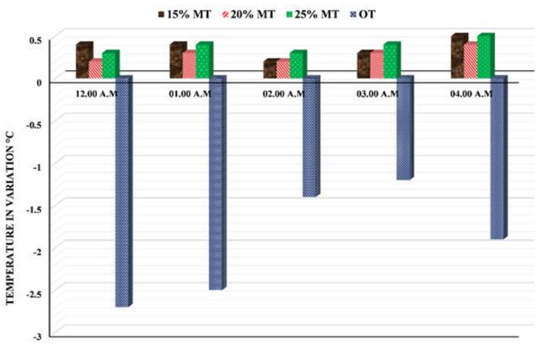

Figure 11. Nighttime temperature variation inside and outside tile

increasing in innovative tiles compared to ordinary tile. The 20% MT specimens were carrying higher compressive strength and transverse breaking strength. Compared to ordinary tile which is 9.1% higher in terms of compressive strength and 39.6% higher in transverse breaking strength. In terms of durability, after carrying out the tests, all the specimens were not breaking and free from defects such as cratering, blistering, superficial microcracking

6. CONCLUSION

In the present work, the cooling roof tile using metakaolin, sodium silicate, and Flexi cool paint has been investigated. four different specimens of tile were casted. In this three-specimen cast using cooling property and one as ordinary tile. Testing parameters considered for the study are temperature and weight. The analysis of the study led to the following conclusions:

- The proposed tile using metakaolin, sodium silicate, and Flexi cool paint specimens performed well in terms of temperature during and night time. According to the weight calculation, 20% MT is considered a lightweight tile.
- The maximum temperature observed by the ordinary tile during the daytime outside of the tile is 44.4°C, which is 18.9% higher compared to atmospheric temperature. However, another innovative tile (15% MT, 20% MT, 25% MT) is during the daytime outside temperature is less than one percent variation compared to atmospheric temperature.
- The temperature variation inside and outside during daytime, the temperature reduced nearly 8°C in Noon (between 12.00 P.M. to 3.00 P.M.) in all the innovative tile compared to ordinary tile. Compared to atmospheric temperature, 20% MT and 25% MT specimens maintain the same atmospheric temperature during day time.
- Maximum temperature observed by the ordinary tile during daytime inside of the tile is 46.6°C, which is 22.2% higher compared to atmospheric temperature. In the innovative tile, the temperature reduced the maximum of 12.2°C in 20% MT and 12.3°C in 25% MT.
- In the ordinary tile the temperature increases inside compare to outside during the daytime. The time between 9.00 A.M. to 11.00 A.M. the temperature increases average of 7°C. In noontime, the temperature variation is average of 2.5°C between 12.00 P.M. to 3.00 P.M. After this hour again the temperature variation becomes very large. however, in 15% MT, 20% MT and 25% MT the temperature is reduced inside compare to outside. Also, the temperature is less than the atmospheric temperature.
- Due to the phase changing property incorporated using sodium silicate. The temperature of the roof tile is higher than the ordinary tile. But cooling wise effective. This property helps in cold regions.
- Experimental measurements showed metakaolin type exhibit more indoor and outdoor temperature differences compared to ordinary roof tile types. The differences were lower in the forenoon, highest at noon, and between above in the afternoon.
- A comparative study was undertaken on three metakaolin type tiles to determine the relative thermal performance of specimen tiles over ordinary roof tiles. 20% and 25% type tiles gave more thermal insulation. Which will thereby lead to less usage of electricity in the buildings.

- The specimen 20% MT has higher strength compared to ordinary tile, which is 9.1% and 39.6% in terms of compressive strength and transverse breaking strength.
- Thus, by adopting the replacement method we can overcome problems such as the plastic waste disposal crisis. The utilization of EPS and its application for the sustainable development of the construction industry is the most efficient solution and also addresses the high-value application of such waste.

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Persian Abstract

چکیده

کاشی های سقفی رایج ترین پوشش سقف در ساختمان های هند، به ویژه در ساختمانهای مسکونی سنتی است. با توجه به نقش مهم خصوصیات سقف در بهره وری انرژی ساختمان و شرایط آسایش حرارتی داخلی، راه حل های نوآورانه برای بهبود عملکرد انرژی گرمایی این عنصر بام به یک موضوع تحقیقاتی اصلی تبدیل شده است. از این منظر، کاربردهای بام خنک نشان دهنده یک راه حل موثر برای این هدف است. کار حاضر به تجزیه و تحلیل یک نوع کاشی سقف خنک کننده ابتکاری ساخته شده با استفاده از ترکیبی از متاکائولین با درصدهای مختلف ، EPS ، سیلیکات سدیم و مواد پوشش دهنده می پردازد. مطالعات تجربی بر روی نمونه ها در طول شبانه روز انجام و عملکرد حرارتی کاشی های سقف خنک کننده از نظر دمای هوای آزاد در مقایسه با عملکرد حرارتی کاشی های بام معمولی ارزیابی شد. نتایج مطالعات آزمایشگاهی نشان داد که استفاده از سقف های خنک مطلوبیت حرارتی در طول روز و شب را افزایش می دهد. کاشی سقف خنک و نوآورانه در مقایسه با سایر فن آوری های مربوط به سقف ها، اجرای آسان تر و ارزان تری دارد. این مطالعه نشان داد که دمای سطح خارجی و داخلی سقف به ترتیب در طول روز حدود ۸ درجه سانتیگراد و ۱۲ درجه سانتیگراد کاهش می یابد، در حالی که سطح خارجی و داخلی سقف باعث حفظ دمای محیط در طول شب می شود. همچنین مقاومت گسیختگی فشاری و عرضی نمونه ها در مقایسه با نمونه ای مشابه حدود ۹.۱٪ و ۳۹.۶٪ افزایش داشت.