

Thermal Characteristic Study of Tiles Made from Cellulose Materials



Engineering

KEYWORDS : PaperSludge, Bagasse, Saw Dust, Coconut coir pith, Cement Mortar, Insulating Tiles

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ABSTRACT

Growth of any country remains in the utilization of industrial and agro waste for infrastructure of facilities. Developing country like India certainly needs utilization of industrial waste like paper sludge and also agro wastes like Bagasse, Coconut coir pith, Saw Dust in construction industry to produce various building materials. Also it is a duty of every Civil Engineer to engage himself in developing newer materials from the waste materials available on earth's crust, because in every construction project 70% of cost goes for these materials. If this can be reduced, subsequently the cost of construction will certainly be reduced and as a consequence, many homeless people of our country will adequately be housed. Keeping this in mind, an attempt is made to utilize these waste materials obtained from local areas in the preparation of insulating roof tiles as horizontal roof surface of the building is receiving maximum thermal energy and generates uncomforness for living, inspite of providing lime concrete weathering course. The addition of paper sludge has been varied from 0% to 150% by weight of cement and replacement of paper sludge varied from 0% to 100% and other materials like bagasse, coconut coir pith and saw dust addition varies from 0% to 20%. All required mechanical, physical, chemical and thermal insulation studies have been carried out systematically and the results are presented and discussed in detail to explore the possibility of using these materials in construction industry.

Introduction

Due to the increasing population in the last decade, there is a great shortage of construction materials like bricks, concrete, solid blocks, hollow blocks, tiles etc. In order to meet the increasing housing demand, there is an exponential need of production of these construction materials. The production of conventional building materials such as cement, bricks and steel consume a lot of thermal and electrical energy and also various toxic substances such as carbon monoxide, oxides of sulfur, oxides of nitrogen, and suspended particulate matters are emitted to the atmosphere during the manufacturing of this materials which in turn pollute air, water and land and thus also affects human health [2].

Also disposal of solid waste produced from agricultural and industrial activity is another serious problem in developing countries like India. Annually, Asia alone generates 4.4 billion tonnes of solid wastes and that of agricultural sources alone contributes more than 600 MT per year. However, it is reported that about 350 MT of wastes have been generated in India from agricultural sources alone. The major quantities of wastes generated from agricultural sources are groundnut shell, sugarcane bagasse, rice straw, rice husk, jute fibre, coconut shell, banana bark, palm leaves, paddy and wheat straw and husk, wastes of vegetables, food products, tea, oil production, jute fibre, wooden mill waste, coconut husk, cotton stalk, etc. Reuse of such wastes in construction material will be an appropriate solution not only for the pollution problem but also for the high cost of building materials and for the problem of the land-filling. Therefore, the issues related to the above have gained great importance in our society in recent years.

The cost of construction materials is increasing day by day because of high demand, scarcity of raw materials, and high price of energy. From the view of energy saving and conservation of natural resources, the use of alternative material for the manufacture of construction materials is now a global concern. For this, the extensive research and development work towards finding new ingredients are required for producing sustainable and environment friendly construction materials [1]. The present study investigates the potential use of various solid wastes and

agro wastes in the production of construction materials. Besides, this study gives several examples on the use of industrial and agro waste based construction materials in real construction.

Materials and Methods

Materials Used

For preparation of the specimens, Ordinary Portland cement of Ultra Tech brand conforming to IS 12260 of 53 grade and washed river sand passing through 600 micron sieve with fineness modulus of 2.15 was used.

Paper Sludge

The paper sludge was obtained from "Malar paper miles" near Karaikudi. The paper sludge was subjected to chemical analysis by X-ray fluorescence (XRF) technique and the oxide compositions are shown in Table -1

Paper sludge slurry was prepared to a required consistency ratio of 1:0.63. This slurry was added with cement mortar of 1:3 mix with solid paper sludge weight of 0% to 150% by weight of cement and also replaced with cement mortar by 0% to 100% by weight of cement and foam is also added and the necessary quantity of water was added to prepare the specimen.

Table 1 Oxide Composition of Paper Sludge

Sl.No	Elements	Mass	Oxides	Mass
1	Na	0.000	Na ₂ O	0.000
2	Mg	4.030	MgO	6.682
3	Al	2.358	Al ₂ O ₃	4.455
4	Si	8.032	SiO ₂	17.181
5	S	0.121	SO ₃	0.303
6	K	0.012	K ₂ O	0.014
7	Ca	49.816	CaO	69.702
8	Ti	0.270	TiO ₂	0.450

Bagasse, Coconut Coir pith, Saw Dust

This agro waste material which is to be used with cement mortar is locally available around Karaikudi region. Also these materials are directly used with cement mortar without any activation process. This is then added with the cement mortar of 1:3 ratio in the range of 5%, 10%, 15%, 20% by weight of cement. The samples of Paper Sludge, Bagasse, Coconut Coir pith, Saw Dust are shown in fig below.



Fig.1 Paper Sludge



Fig.2 Bagasse



Fig.3 Saw Dust



Fig.4 Coconut Coir Pith

Experimental

Dry Density (ASTM C 642-97)

To determine the dry density (ρ_d), 100x100x100mm cube specimens were used. After 28 days of curing, specimens were retrieved from curing tank and dried in open sky for several days and finally in oven at 110°C for 48 hours, so that the specimens get constant mass. The dry density for each mix was calculated with the relationship.

$$\text{Dry density } (\rho_d) = (\text{Dry mass of specimen} / \text{Volume of specimen})$$

Water absorption test (ASTM C 642-97)

For determination of Water absorption of the cured sample, specimen of size 100mm diameter and 200 mm length were used. The mass of Water absorbed by the dry mass of the specimen gives the capacity of water absorption. It is normally expressed in percentage.

$$\text{Percentage of Water Absorption} = (B-A)/A \times 100$$

Cube compression test (ASTM C 109/C 109M)

The cube compressive strength test was carried out with specimen of size 100 X 100 X 100 mm, which is casted in iron mould in triplicate numbers. Specimens were dried in open air after 3 days of heat curing and it is subjected to the test as per standards. The test was conducted using AIML compressive testing machine of capacity 1000 KN. The cylinder compressive strength (f_{cy}) was computed from the fundamental principle

$$f_{cy} = \text{Load at failure} / \text{Area of cross section}^2$$



Fig. 5 Compressive Strength Test

Split tensile strength(ASTM C 496-90)

Specimens for examining split tensile strength are cylindrical specimens which is of dimension 100 mm diameter and 200 mm long. The specimens were casted in triplicate. The test was carried out using compression testing machine. The value of split tensile strength was deduced using the relationship,

$$\text{Split tensile strength, } (f_{sp}) = 2P/\pi d$$

P = Maximum Load at failure (N)
 d = Diameter of the specimen (mm)
 l = length of the specimen (mm)

Steady State temperature Test

Steady state temperature test was carried out using muffle furnace with top loading attached with temperature indicator and thermocouple as shown in fig. The constant temperature ranges such as 70°C, 80°C, 90°C were arbitrarily chosen for this study. The tiles of size 230 X 230 X 20 mm to be tested will be placed horizontally over the top of the furnace and the temperature will be set by adjusting the knob located in digital temperature indicator. Initially the set temperature will be for a period of 30 min. Therefore the bottom phase of the tile is exposed to the set tem-

perature and using laser torch thermometer , the temperature of the bottom surface and top surface are measured and recorded.

The test is further carried out with 80°C and 100°C temperatures for a soaking period of 15 min. This test is carried out for 20mm and 50mm thick tiles and the temperature drop are recorded separately for each tile.



Fig.6: Steady State temperature study With muffle furnace



Fig.7: Temperature Measuring with Infrared thermometer

Open to Sky Test

For open to sky test, small wooden boxes fabricated using 15mm thick plywood also with a door at the top to represent a small room is used and it is shown in fig. Tiles of dimension 230 X 230 X 20 mm to be tested is placed on the top of the box. After exposing the tile for 1 hour to the open sky, the top and bottom surface temperature are measured by using laser torch thermometer. Temperature is measured from 9.00 a.m to 5.00 p.m at every one hour interval.



Fig. 8: Field exposure study with fabricated Wooden box



Fig. 9: Temperature Measuring on Top Surface with Laser Torch

Results and Discussion

The cement mortar with various compositions and one control mortar specimen are tested for dry density, water absorption, cube compressive strength, split tensile strength and also for thermal insulation characterization.

Dry density(ASTM C 642-97)

The dry density of mortar specimens were calculated from the principles said down in ASTM C 642-97 for all specimens and the results are presented in the tables below. The dry density of control mix is 2130 kg/m³ and for 10% sludge added mixture, it showed the value of 2189 kg/m³ and gradually it is reduced to 1963 kg/m³ for 150% added sludge mortar specimen. However upto 50% sludge addition, the dry density is slightly higher than the control mix. Also the dry density for 10% sludge replaced mix is 2012kg/m³ which decreased gradually upto 100%.The dry density for foamed concrete also decreased from 1127 to 1029kg/m³. The dry density for the various material decreased progressively as the percentage of replacement increases. The reduction in density is mainly due to the addition of these cellulose materials which has got lighter weight than OPC and increased in bulk. Similarly addition of foam has drastically reduced the density of mortar mix since air bubble is occupying the space in the mix.

Water Absorption Test (ASTM C 642-97)

Percentage of water absorption is carried out on all specimens and the results are presented in the tables below. Lowest water absorption was found as 9.69% for control mix and as the percentage of additive and replacement in cement mortar is increased, the water absorption starts increasing.A maximum value of 19.21% for 150% sludge added mixture and 17.73% for 100% sludge replaced mix and 36.18% for foamed concrete is obtained. For materials like Bagasse, Coconut Coir Pith and Saw dust, the maximum value is 32.68%,33.45% and 24.12% which is all for 20% added mix. This is due to the absorption and retention of water within the specimen. For foamed concrete, the water absorption is very high due to the presence of air bubbles within the mass.

Cube compressive strength (f_{cu}) (ASTM C 109/C109M)

Cube specimens were subjected to uniaxial compression in compression testing machine of ALMIL make which is of 1000KN capacity. Average of the values of each category mix was taken as the final value. The control mortar shows the strength of 19.63Mpa and the maximum Cube compression strength was obtained with 30% sludge added mix, although the strength is increased up to 50% sludge addition which has the value as 20.78N/mm² and there after the strength was gradually reduced till 150% addition of paper sludge. The increase in strength up to 50% sludge addition is due to the presence of CaO, SiO₂ and Al₂O₃ present in the sludge. CaO is the main reason for formation of excess calcium silicate which imparts strength. After 50% sludge addition ,the strength gradually reduces because excess lime remain in the mixture and does not allow the formation of calcium silicate/calcium aluminate or Calcium ferrite, and therefore there is a reduction in compressive strength after 50% sludge addition.In the case of replacing sludge with cement mortar, the maximum compressive strength is obtained from 30% replacement which is 27.83 Mpa but the strength continued to increase upto 60% replacement. In the case of Bagasse, Coconut Coir Pith, Saw Dust added cement mortar, the compressive strength was decreased as the percentage of the cellulose materials increased .This is due to the presence of lignin in the cellulose material which reduces the strength.

Split Tensile strength(f_{sp})(ASTM C 496-90)

The control specimen has the split tensile strength of 2.36N/mm² and maximum value was obtained for 30% sludge addition and replacement. Upto 60% sludge addition and replacement

the strength was above control value. This indicates that the cellulose micro fibers are highly cohesive and has higher tensile strength. After 60% sludge addition, the tensile strength value was gradually reduced. This is due to the lime reactivity with SiO₂ component of Sand. In Foam added paper sludge, the split tensile strength is drastically reduced due to the presence of air bubbles and voids.

Table 2 Properties of Paper Sludge Mortar (With addition of Paper Sludge)

Sl.No	Designation	Dry Density (kg/m ³)	Water Absorption (%)	Cube compressive strength (Mpa)	Split Tensile strength (Mpa)
1	C	2130	9.69	19.63	2.36
2	S1	2189	7.52	22.68	2.89
3	S2	2193	12.14	23.49	3.03
4	S3	2204	12.65	24.36	3.12
5	S4	2191	12.86	22.94	3.08
6	S5	2142	12.65	20.78	2.91
7	S6	2123	14.55	19.09	2.61
8	S7	2111	15.75	18.63	2.23
9	S8	2104	16.21	16.11	1.97
10	S9	2101	16.53	15.34	1.93
11	S10	2009	17.69	14.86	1.88
12	S11	1984	18.03	13.15	1.63
13	S12	1981	18.11	12.11	1.55
14	S13	1977	18.42	11.03	1.41
15	S14	1972	18.73	10.73	1.32
16	S15	1963	19.21	9.86	1.30

Table 3 Properties of Paper Sludge Mortar (With replacement of Paper Sludge)

Sl.No	Designation	Dry Density (kg/m ³)	Water Absorption (%)	Cube compressive strength (Mpa)	Split Tensile strength (Mpa)
1	R1	2012	12.71	24.56	2.99
2	R2	2001	12.98	26.71	3.23
3	R3	1998	13.42	27.83	3.87
4	R4	1990	13.78	25.93	3.16
5	R5	1984	14.15	22.12	2.73
6	R6	1980	15.02	20.34	2.01
7	R7	1976	15.99	17.67	1.93
8	R8	1959	16.34	15.93	1.88
9	R9	1942	16.92	14.18	1.79
10	R10	1934	17.73	14.77	1.62

Table 4 Properties of Paper Sludge Mortar (With addition of foam)

Sl.No	Designation	Dry Density (kg/m ³)	Water Absorption (%)	Cube compressive strength (Mpa)	Split Tensile strength (Mpa)
1	C	1127	17.98	8.3	2.01
2	F1	1084	21.36	7.12	1.97
3	F2	1076	27.14	7.01	1.97
4	F3	1067	32.16	6.94	1.96
5	F4	1058	34.76	6.83	1.87
6	F5	1042	35.12	5.94	1.42
7	F6	1037	36.03	5.12	1.02
8	F7	1029	36.18	4.98	0.98

Table 5 Properties of Cement Mortar with Bagasse, Coconut Coir Pith, Saw Dust

Sl.No	Designation	Dry Density (kg/m ³)	Water Absorption (%)	Cube compressive strength (Mpa)	Split Tensile strength (Mpa)
1	B1	1694	24.12	10.72	1.23
2	B2	1580	28.73	10.69	1.21
3	B3	1520	31.12	9.43	1.01
4	B4	1492	32.68	8.93	0.98
5	P1	1493	26.14	9.67	1.12
6	P2	1412	28.73	8.01	1.01
7	P3	1384	30.12	6.23	0.94
8	P4	1312	33.45	4.93	0.86
9	H1	1690	18.12	14.87	2.20
10	H2	1663	19.03	12.38	2.03
11	H3	1610	21.64	10.94	1.86
12	H4	1543	24.12	8.12	1.67

*B- Bagasse, P- Coconut Coir Pith, H-Saw Dust

Steady State Temperature Test

Steady state temperature tests were carried out on tiles of 20mm and 50mm thickness. In the 1st category of mix, the gradual addition of paper sludge increases drop in temperature for all three set of temperatures and therefore in this category S15 tile is found to give good results in both thickness. Similarly in category 2, the replacement of OPC by paper sludge increases the temperature drop and therefore R10 is found to give better results. In category 3, F7 tile is found to give better results than other mixes. Generally 20mm thick tiles is more economical than 50mm thick tiles in this case.

In steady state temperature test, when the tiles are heated at steady state temperature of 70 ° c, 80 ° c, 90 ° c, the Bagasse added tiles has performed better than other tiles. A temperature drop of 22.6 ° c was obtained when heated to 90 ° c. Next to this, the coconut coir pith added cement mortar mix showed 21.2 cat the same 90 c. As the third one, saw dust mixed cement mortar tiles showed a value of 19.6 c for 90° c. Therefore from these results, it can be concluded that Bagasse mixed cement mortar tiles performed better than other tiles in terms of drop in temperature.

The reason being, the Bagasse chips occupied much higher volume shape and also flaky structure of the com and thus it prevents the thermal gain from the heat source. The coconut coir pith and saw dust are of smaller particle size and distributed randomly giving path at many places for thermal gain.

Table 6 Performance Test Results of best Tiles based on Steady State Temperature Test (Drop in Temperature)

Type of Tile	Tile Thickness (mm)	Applied Temperature(°C)			Best Tile
		70°C	80°C	90°C	
Addition of Paper Sludge 150% with cement mortar 1:3	20	8.10	11.50	13.40	S15
	50	19.10	26.10	33.10	
Replacement of Paper Sludge with cement mortar 1:3	20	8.50	14.60	23.80	R10
	50	15.6	16.80	30.90	
Foam added Tiles	20	25.60	29.90	32.80	F7
	50	32.20	33.90	33.40	
Replacement of Bagasse with cement mortar 1:3	20	6.1	15.7	22.6	B2

Replacement of Coconut coir pith with cement mortar 1:3	20	5.4	16.5	21.2	P2
Replacement of Saw Dust with cement mortar 1:3	20	5.1	16.3	19.7	H4

Open to sky Test

All the 20 mm thick tiles were subjected to field exposure studies from 9.00AM to 5.00PM. During this test, the ambient temperature, top and bottom surface temperature of the exposed tiles were measured with the help of laser torch thermometer. The fig.7 and fig.8 shows the arrangement of tiles and the measuring techniques. The result of the test is shown for the best insulation tiles of S15 which is of 150% sludge added mixture tile. The temperature swing of 20.02°C was obtained at 3.00PM which is the largest swing and lowest of 6.18°C at 9.00AM. This test indicates the best adoptability paper sewage mortar tiles as an insulating roof tile. This S15 tile has highest paper sludge and hence highest thermal insulation property. But R10 formulations found to give better results than the category S15 mix. But the category 3.foam added mix found to give the very best mix proportion for thermal insulation. In this case also, the insulation value between 20mm and 50mm thick tile is not significant and therefore 20mm thick tile of F7 is the best insulating material.

Table 7 Performance Test Results of best Tiles in Open to Sky Test

Type of Tile	Tile Thickness (mm)	Drop in Temperature(°C)								Best Tile
		10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	
Addition of Paper Sludge 150% with cement mortar 1:3	20	5.00	5.60	8.40	11.90	12.60	12.80	9.30	8.90	S15
	50	9.70	10.20	11.40	12.10	14.90	16.90	13.70	12.20	
Replacement of Paper Sludge with cement mortar 1:3	20	8.10	8.30	9.10	9.70	10.00	11.70	9.90	16.80	R10
	50	9.90	10.10	11.70	16.30	16.80	17.40	14.30	18.20	
Foam added Tiles	20	16.10	17.90	17.90	18.40	19.70	18.40	17.60	9.40	F7
	50	16.30	20.30	20.30	21.90	22.10	22.90	18.70	13.40	
Replacement of Bagasse with cement mortar 1:3	20	6.1	6.9	10.2	12.4	12.4	12.1	11.9	11.7	B4
Replacement of Coir pith with cement mortar 1:3	20	7.1	8.9	12.1	13.5	13.1	12.9	12.1	11.7	P4
Replacement of Saw Dust with cement mortar 1:3	20	7.3	8.9	12.4	13.2	13.0	12.9	11.4	10.1	H4

In open to sky test, when the percentage of cellulose material like Bagasse , coconut coir pith, saw dust is increased, maximum drop in temperature is observed . In this test also, the maximum drop in temperature was observed at 2pm. From 10am to 2pm , it shows a gradual increase in drop . After 2pm, Drop is reduced gradually. Next to Bagasse , Coconut coir pith and saw dust has performed well as indicated in Table. 7

Conclusion

Addition of paper sludge

In general, when paper sludge is added with cement mortar of 1:3 ratios, the temperature resistance is increased. The temperature drop across the cross section was increased as the paper sludge content was increased for all temperature ranges. It also increased with the increase in the thickness of the tiles.

The temperature drop was higher at higher steady state temperature in the furnace for both the thickness.

In the case of open to sky test, as the content of paper sludge increases, the drop in temperature is increased. The drop in temperature is increased gradually from 10am to 3pm and later as the ambient temperature falls down, the drop decreases. Maximum drop in temperature for 20mm thick tile was 12.8 °C and for 50mm thick tile was 16.9 °C which is observed at 3pm.

Replacement of OPC with Paper Sludge

Tiles made with replacement of OPC with paper sludge also show the temperature drop for 50 mm thick tile which was slightly higher than 20mm thick tiles.

Similarly as the replacement value increases upto 100%, the in-

ulating value becomes very high. In this case 20mm thick tiles also perform better as compared to 50mm thick tiles with slight temperature difference.

In the case of open to sky test, as the quantity of paper sludge is increased gradually, the thermal conductivity is reduced and high drop in temperature was obtained. A drop of 11.70° C for 20mm thick tiles and 17.4° C for 50mm was observed at 3pm.

Addition of Paper sludge with Foam

In this case of steady state temperature test, F7 sample performed better compared to the other samples. The 50mm thick tiles performed better than 20mm thick tiles .However a significant remarkable temperature difference compared to 20mm thick tiles is not found. In this case, 20mm thick tile is quiet sufficient and economical from temperature drop point of view.

In the case of open to sky test, 50mm thick tiles has performed better than 20mm thick tiles. The maximum temperature drop of 19.70 ° C is obtained for 20mm thick tiles and 22.9° C is obtained for 50mm thick tiles at 2 pm and 3 pm.

Addition of Bagasse , Coir pith , Saw dust

Tiles made of Bagasse found to perform well compared to coconut coir pith and saw dust due to the high volume and flaky structure of the Bagasse material when compared to others.

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