Study on Utilization of Paper Sludge as a Sustainable Construction Material

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Abstract:

Growth of any country remains in utilization of industrial and agro waste for infrastructure of facilities. Developing country like India certainly needs utilization of industrial waste like paper sludge 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 the 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 paper sludge obtained from local paper industry is used with cement mortar for preparation of insulating roof tiles and light weight bricks. The addition of paper sludge has been varied from 0% to 150% by weight of cement. 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 this paper sludge in construction industry.

Key words: Paper sludge, cement mortar, insulating tiles, light weight bricks.

1. Introduction:

In India more than 300 million tons of industrial and agro wastes are produced [1] and are partially used in construction industry due to the fact that some of these waste materials are hazardous and may cause health problems [2-4].The quantity of sludge varies from mill to mill, and the quantity produced in greatly dependent on the type of furnish being used and the process.

About 300kg of sludge in produced for every ton of recycled paper in the paper mills [5, 6].The paper sludge mainly composed of calcium oxide, and partly Al_2O_3 and SiO_2 etc. Utilizing this paper sludge in concrete a construction industry will certainly cause reduction in environmental pollution, and as pozzolonic material this will lead to reduction in producing cement [7, 8].Utilization of such sludge in construction industry in of greater importance for a nation's development.

Table 1: Table Showing the Oxide Composition of Paper Sludges

S.No	Elements	Mass	Oxides	Mass
1	Na	0.000	Na_2O	0.000
2	Mg	4.030	MgO	6.682
3	Al	2.358	Al_2O_3	4.455
4	Si	8.032	SiO_2	17.181
5	S	0.121	SO_3	0.303
6	K	0.012	K_2O	0.014
7	Ca	49.816	CaO	69.702
8	Ti	0.270	TiO_2	0.450

In earlier days few attempts have been made to utilize paper sludges to in brick making and in concrete [9.10].Although many researches are going an global wide, an attempts is made to prepare paper sludge with cement mortar with various percentages as added material to the mortar up to 150% by weight of cement to made roof tiles and study the thermal insulation values by exposing to open sky on a specially fabricates wooden room model. The details of physical, mechanical and insulation properties are discussed.

2. Materials and Methods

2.1 Materials Used:

For preparation of specimens ordinary Portland cement of Ultra Tech brand conforming to IS 12260 of 53 grade and washed river sand passing 600 micron with fineness modulus 2.15 was used. 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 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 necessary quantity of water was added as indicated in Table 2.

Table 2: Table showing the Composition paper sludge mortars.

S.No	Designation	Composition				
		OPC (kg)	Sand (kg)	Slurry (g)	Percentage of Paper Sludge (%)	Water (ml)
1	C	1.33	4.00	-	-	600
2	S1	1.33	4.00	220	10%	600
3	S2	1.33	4.00	440	20%	1100
4	S3	1.33	4.00	660	30%	1000
5	S4	1.33	4.00	880	40%	950
6	S5	1.33	4.00	1100	50%	950
7	S6	1.33	4.00	1320	60%	850
8	S7	1.33	4.00	1540	70%	850
9	S8	1.33	4.00	1760	80%	850
10	S9	1.33	4.00	1980	90%	850
11	S10	1.33	4.00	2200	100%	850
12	S11	1.33	4.00	2420	110%	850
13	S12	1.33	4.00	2640	120%	750
14	S13	1.33	4.00	2860	130%	750
15	S14	1.66	5.00	3788	140%	850
16	S15	1.66	5.00	4000	150%	850

2.2 Experimental:

For determination of cube compressive strength (f_{cu}) cast iron moulds of size 100x100x100mm were used to cast triplicate specimens. Testing of specimen is shown in fig1.

Fig 1: Showing the Compressive Strength Test

Specimens for examining split tensile strength, cylinder specimens of 100mm dia and 200 mm long specimens were used in triplicate. The value split tensile strength was deduced using the relationship,

Split tensile Strength (fsp) $= \frac{2P}{\pi Dl}$ -------- **(1)**

Where, P= Max.load at failure (N)

D=diameter of the specimen.

l =length of the specimen.

To determine dry density (ρ_d), again 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 105°c for 48 hours. So that the specimens get constant mass. The dry density for each mix was calculated with the relationship.

Dry density (ρ_d) = (Dry mass of specimen / Volume of specimen) ----- (2)

Cylindrical specimens of size 45x90mm were used for determination of sorptivity and Coefficient of water absorption (k). Quantity of water absorbed by capillary action(wick action) against gravity from a 5mm depth water containing dish as shown in fig2.

Fig 2: Sorptivity Test

Mass of the specimen with time interval was measured with digital balance and recorded to a period of 60 minutes.

The coefficient of water absorption was computed using the relationship.

$$\mathbf{k} = \left(\frac{Q}{A}\right)^2 X \left(\frac{1}{t}\right) \text{ ---------- (3)}$$

Where, k = coefficient of water absorption.

Q = quantity of water absorbed up to 60minutes (ml).

A = Cross sectional area of specimen (mm^2).

t = duration of test (sec).

Tiles of size 230x230x20mm thick were cast for determining thermal insulation value. These tiles were exposed to direct sunlight for heating top surface over a specially fabricated wooden box with door opening as shown in fig3

Fig 3: Field exposure study with fabricated Wooden box

And the temperature of top and bottom surfaces are measured with laser torch temperature measuring instrument shown in fig4. Temperatures are measured from 9.00A.M to 5.00P.M at every one hour interval.

Fig 4: Temperature Measuring on Top Surface with Laser Torch

3. Result and Discussion:

The paper sludge mortars of fifteen different compositions with one control mortar specimen as indicated in Table2 are tested for dry density, water absorption, coefficient of water absorption, cube compressive strength and also for thermal insulation characterization Table3 shows these values expect thermal insulation values.

a) Dry density:

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 Table3. The dry density of control mix in 2130 kg/m³ and for 10% sludge added mixture showed the value of 2189 kg/m³ and gradually it is reduced to 1963 kg/m³ for 150% added sludge mortar specimen. The variation in dry density in shown in fig5. However upto 50% sludge additions, the dry density in slightly higher than the control mix. Thin indicates the compacters of the mortar and used hydrated samples and thus higher dry density.

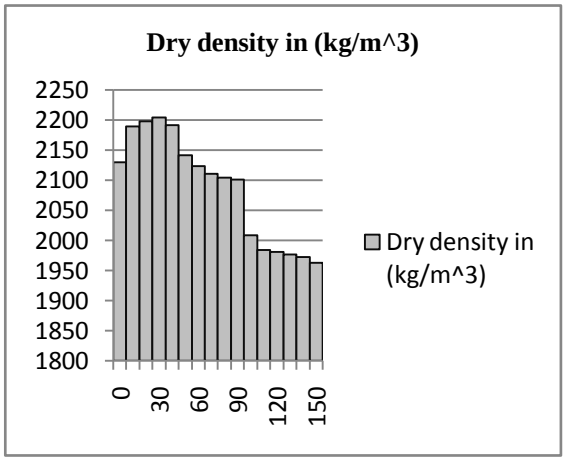


Fig 5: Variation in Dry Density

b) Water absorption :(ASTM C 642-97)

Percentage of water absorption is carried out on all specimens and the results are presented in Table 3. Lowest water absorption was found as 9.69% for control mix and as the percentage of sludge content in increased this can be seen from fig.6.A maximum value of 19.21% for 150% sludge added mixture showed.

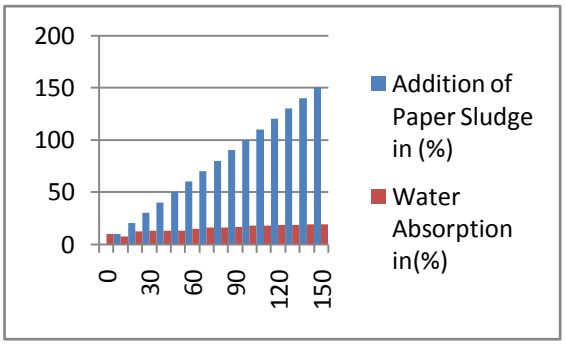


Fig 6: Graph showing the water absorption results

a) Coefficient of water absorption:

Coefficient of water absorption was computed from the results of sorptivity test and the results are presented in Table3.It can be seen that this coefficient values are gradually increased from the control values. This can be attributed to the fact that this increase is due to absorption of water by the micro fibers of cellulose materials coated with cement material and this prevents the entry of water in capillary direction. The values are shown in fig.7 and Table 3

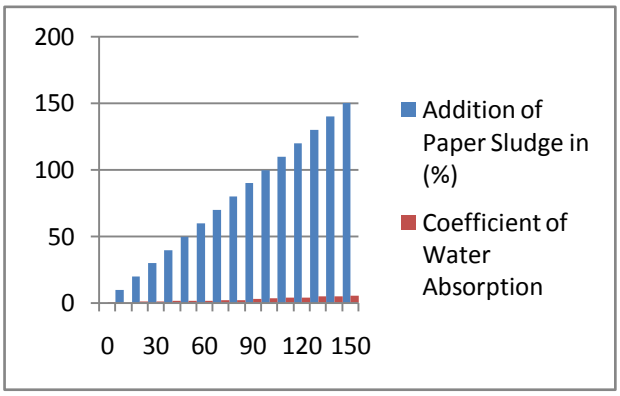


Fig 7: Graph showing the results of coefficient of water absorption

b) Cube Compressive Strength (f_{cu}) (ASTM C 109/C109M):

Cube specimens were subjected to uniaxial compression in compression testing machine of AIMIL make, 1000KN capacity. Average of these values of each category of mix was taken as final value. The value are presented in Table3.The corresponding figure in fig.8.The variation follows the curve fitting=$0.0412x^2$-$0.2724x+23.339$ ($R^2=0.9086$).The control mix has the cube compressive strength of 19.63N/mm² and a max. Cube compression strength was obtained to 30% sludge added mix, although the strength is increased up to 50% sludge addition which has this 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, SiO_2 and Al_2O_3 present in the sludge. CaO in the main reason for formation of excess calcium silicate which imparts strength. After 50% sludge addition ,the strength gradually reduced because excess lime remain in the mixture and does not allow the formation of calcium silicate/calcium aluminate or Calcium ferrite, and therefore the reduction in compressive strength after 50% sludge addition.

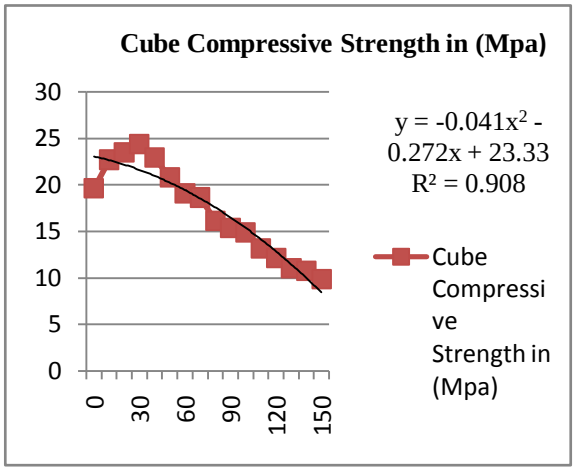


Fig 8: Graph showing the results of Cube Compressive Strength

c) Split tensile strength(f_{sp}) (ASTMC 496-90):

Table 3: Physical Properties and Mechanical strength of paper sludge mortars

S. No	Designation	Dry density Kg/m³	Coefficient of Water Absorption (%)	Water Absorption (%)	Cube Compressive Strength (MPa)	Split Tensile Strength (MPa)
1	C	2130	$1.69x10^{-8}$	9.69	19.63	2.36
2	S1	2189	$1.13x10^{-9}$	7.52	22.68	2.89
3	S2	2193	$0.93x10^{-9}$	12.14	23.49	3.03
4	S3	2204	$1.22x10^{-9}$	12.65	24.36	3.12
5	S4	2191	$1.43x10^{-9}$	12.86	22.94	3.08
6	S5	2142	$1.51x10^{-9}$	12.65	20.78	2.91
7	S6	2123	$1.74x10^{-9}$	14.55	19.09	2.61
8	S7	2111	$1.83x10^{-9}$	15.75	18.63	2.23
9	S8	2104	$2.10x10^{-9}$	16.21	16.11	1.97
10	S9	2101	$3.01x10^{-9}$	16.53	15.34	1.93
11	S10	2009	$3.25x10^{-9}$	17.69	14.86	1.88
12	S11	1984	$3.77x10^{-9}$	18.03	13.15	1.63
13	S12	1981	$4.02x10^{-9}$	18.11	12.11	1.55
14	S13	1977	$4.84x10^{-9}$	18.42	11.03	1.41
15	S14	1972	$5.02x10^{-9}$	18.73	10.73	1.32
16	S15	1963	$5.63x10^{-9}$	19.21	9.86	1.30

The split tensile strength test values are presented in Table3 and variation in shown in fig9. It follows the equation

$y=-0.0065x^2-0.0164x+2.945$ ($R^2=0.8486$). The control specimen has the split tensile strength of 2.36N/mm² was obtained 30% sludge addition. Upto 60% sludge addition the strength was 60% sludge addition the strength was above control value. This indicates that the cellulose micro fibers are highly cohesive and after higher tensile strength. After 60% sludge addition, the tensile strength value was gradually reduced.

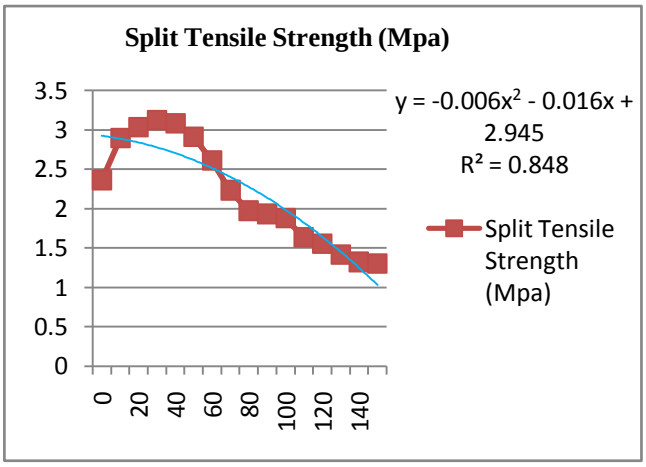


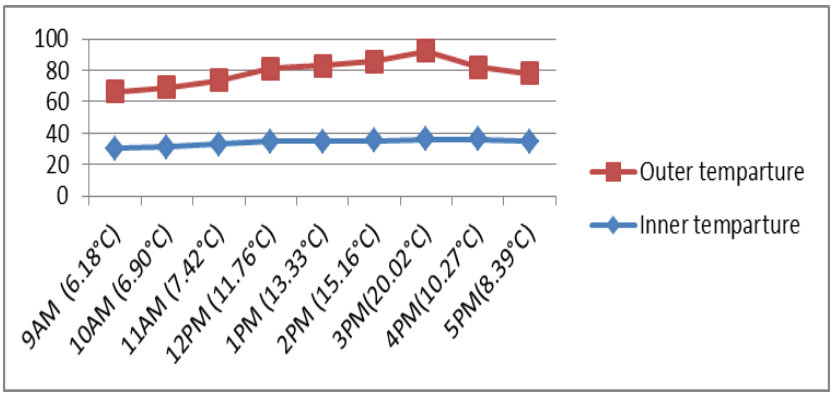
Fig 9: Graph showing the results of split Tensile strength tests

f) Exposure Study:

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.3 and fig.4 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 variation in the temperature is shown in fig.12.

It can be seen from the fig.12 that the temperature swing of 20.02°C was obtained at 3.00PM which in the largest swing and lowest of 6.18°C at 9.0AM. 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.



Temperature Swing

Fig 9: Figure showing the top and bottom surface temperature of S15 tile with due corresponding temperature swing

4 .Conclusion:

- The Paper Sludge has highest value of Calcium Oxide and which provides most beneficial strength values when added with cement mortar up to 50% and 60% by weight of cement for Cube compressive and split tensile strength.
- The dry density value slightly increased up to 60% addition of paper sludge and then gradually the density is reduced as sludge component is dominated.
- Highest Cube compressive strength was obtained for S3 in 30% addition of sludge up to 50% addition of sludge, cube compressive strength was higher than the control mixture.
- Highest split tensile strength of 3.12 N/mm2 was obtained for S3 mix, which has sludge. However, the split tensile strength was higher than the control mix up to 60% sludge addition. The role of microfibers enhanced both cube and split tensile strengths.
- Coefficient of water absorption was higher for control mix and as the sludge was added with increasing percentage, the Coefficient of water absorption was reduced
- The field exposure study reveal, maximum temperature swing of 20.02°C was obtained for S16 mix, in which 150% of paper sludge is added, i.e for maximum paper sludge addition the insulating property was achieved maximum

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