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Contribution to the development of tiles made of paper board sludge

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Abstract. Growth of any country rest in the consumption of industrial wastes for its infrastructure amenities. Countries like India positively desires a vital utilization of industrial waste resembling paper sludge in the construction industry to make various building materials. Also, it is the duty of all civil engineers or researchers to attach them in mounting new materials from the waste dumped as land fillings. In every construction project, about 70% of cost accounts for the procurement of materials. If this, can be minimized consequently the cost of construction will certainly be condensed. Research has established that the waste paper sludge can be reused in the construction field for a probable scope. The construction diligences munch through a massive quantity of non-renewable resources. On the additional dispense, more waste paper board sludge ends up in landfills or dumpsites than those recycled. Consequently, waste paper sludge for use as a construction material composes a step towards sustainable development. Keeping this in mind an endeavor has been made to utilize paper board sludge acquired from the paper board industry and used with several pozzolanic and cementitious materials for a specific purpose. The addition of paper sludge has been varied from 0% to 20% by weight of cement. The tests done with the samples expose that four samples showed significant outcomes with remarkable strength and durability properties which guide to move for the next phase of research for producing lightweight tiles.

Keywords: waste management; paper board sludge; sustainable materials

1. Introduction

The treatment process of any system (water supply, wastewater, industrial wastewater treatment, etc.) needs a stringent plan, design, construction and implementation for its efficient outcome. The end process of these treatment processes leads to the generation of sludge due to the addition of chemical, organic and mineral ingredients. The reaction between the source water to be treated and the ingredients added for its treatment as per the design will decide the quantity of sludge generated in the respective treatment plant. The sludge generated in the treatment plants was stored in the sludge yard. Moreover, the accumulation of sludge over the periods in the sludge yard leads to a concrete solution for its disposal. The disposal system of the generated sludge

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varies according to its characteristics.

The improper organization of sludge and its dumping on the ground leads to many adverse effects. It may contaminate the surface and groundwater, affect public health, pollute the atmosphere due to the odor problems and can also cause land degradation. Therefore, keeping in view the hazardous nature and large quantity of sludge, the management of chemical sludge (handling, treatment and disposal) faces a huge problem. Cost-effective and environmentally safe sludge management and disposal methods are required to address this crucial issue. Many numbers of studies have been carried out by the researchers for the effective disposal of different types of sludge.

Aukour (2009) investigated the possibility of recycling the marble sludge in house building materials. It satisfied the objective of saving natural resources and reducing their consumption. He concluded that the incorporation of marble sludge in 15 cm blocks resulted in satisfactory properties concerning water absorption and compressive strength. Jamshidi *et al*. (2011) studied on dry sewage sludge in concrete by replacing fine aggregate. They optimized the water-cement ratio as 0.45 and replacement of 10% of dry sludge for fine aggregate and were used in paving and flooring concretes. Alqam *et al*. (2011) investigated the use of water treatment plant sludge to substitute cement in the production of paving tiles for outdoor use. The study showed that all the manufactured tiles exhibited a water absorption ratio of around 10%. The study accomplished that produced tiles, except for 50% sludge-cement replacement, complied with the breaking strength chucks of 2.8 MPa for tiles for external application. Durante Ingunza *et al*. (2011) assessed the use of sewage sludge as a raw material in the ceramic industry, specifically in the manufacturing of soft-mud bricks, to find out the maximum incorporation of sludge that results in technically sound and eco- friendly bricks. For the specified conditions of this study, it was concluded that 20% was the maximum proportion of sludge that was incorporated into a ceramic mass and still meet technical and environmental requirements.

Patel and Pandey (2009) reported the reuse of the chemical sludge (considered as hazardous waste as per Indian Government Hazardous Waste Management Rules) originated from the combined effluent treatment in textile clusters. Based on various tests, they suggested that the use of sludge was explored for various structural and nonstructural relevances depending upon the requirement of strength. It was used for applications such as load-bearing and non-load bearing walls. Negligible concentrations of heavy metals were identified in the TCLP leachate. Therefore, the chemical sludge from textile wastewater treatment plants had the potential for reuse as construction materials for different applications. Raghunathan *et al*. (2010) performed a non-dissolving composite of mix 1:1.7 (cement:sludge). The composite was used for manufacturing bricks in the first phase of the research. The bricks were found to be economical and the compressive strength of bricks was similar to the second class bricks as per the BIS standards. In Phase II of the research, bricks were broken down to obtain Synthetic Sludge Aggregate (SSA) and the SSA was used as the replacement for sand in concrete mixes M20, M30 and M40. The compressive strength of all the concrete mixes showed a decline in strength with an increase in the percentage of SSA.

Pitroda (2015) ascertained the rewarding utilization of the fly ash (Class-F) and hypo sludge in concrete production as a half-done replacement of cement with weight. The cement was replaced with fly ash (Class-F) and hypo sludge consequently in the series of 0% (without fly ash and hypo sludge), 5% + 5%, 10% + 10%, 15% + 15% and 20% + 20% by the weight of cement for M-40 mix. Concrete mixtures were produced, tested and compared regarding compressive strength and flexural strength of the conventional concrete. These tests were performed to evaluate the mechanical properties of the test results for compressive strength and flexural strength up to 90 days.

Ma *et al*. (2013) studied the comprehensive utilization of Propylene Oxide Sludge (POS). The results obtained in this study were particularly encouraging as non-hazardous shell-aggregate from propylene oxide sludge could satisfactorily be produced with relatively low density, low water absorption and high cylinder compressive strength under the hydrothermal synthesis and autoclave curing process. Ranjani and Ramamurthy (2012) reported the effects of variation in density, concentration, and type of cation associated with sulphate on the expansion, mass and strength loss of foam concrete produced with two synthetic surfactants. Comparisons were made between the behavior of foam concrete of various densities and that of corresponding base mixes of a mortar without foam. The investigations indicated that the expansion in the sodium sulphate environment was up to 28% higher than that of magnesium sulphate environment which attributed to a greater quantum of ettringite formation in the sodium sulphate environment.

De Azevedo *et al.* (2018) analyzed the sustainability of incorporating such waste into cement-based mortars. Tests were conducted, replacing lime, one of the most expensive mortar components with high environmental impact, with waste sludge in contents of 5%, 10%, 15% and 20%. The results showed that for use in wall and ceiling mortar coatings, the level of incorporation should not exceed 10%, because higher levels yield lower values of mechanical strength resistance, incompatible with market requirements. This result is probably due to the low heat of hydration of the waste material which generates slower reactions. On the other hand, higher levels of waste material content, above 10%, are appropriate convenient for mortar used to fill small repairs in masonry that do not require control of properties.

Othman and Rahmat (2019) had investigated the potential of using Wastewater Treatment sludge (WWTs) from the oil-based industry as a target material for sustainable construction component. The influence of the waste addition on the compressive strength and water absorption test was investigated on brick specimens. The unfired brick was fabricated in the factory environment. The bricks that cast were wrapped in cling film and air-cured for 7 and 28 days before testing. The results obtained show that the measured strength properties and water absorption of the stabilized WWTs are comparable to conventional bricks. The results suggest there is a potential of using sludge from the oil-based industry because of economic and environmental concerns.

De Azevedo *et al*. (2019) had performed a chemical, mineralogical, thermal, morphological, physical and environmental characterization of the paper and pulp industry wastes, to assess alternatives for their adequate disposals, such as controlled landfills, sanitation, incineration and sea dumping. It was observed that the material presents physical, chemical and morphological features that indicate the possibility of reusing it in other production chains, such as the ceramic industry, besides being classified as non-hazardous wastes. Furthermore, disposal in sanitary landfills presents advantages in environmental and technological terms.

Bhushan *et al*. (2020) had performed a study on stabilization and solidification of industrial sludge and then studied the engineering behavior of brick made from it. They presented an experimental investigation performed to check the feasibility of using paper sludge waste to reduce the quantity of clay, as there is a greater shortage of clay in many parts of the world. To begin, XRF characterization of paper sludge has been carried out. The bricks were prepared by paper sludge with varying compositions, with a reduced quantity of clay from 10 to 50%. After performing various tests, it has been observed that these waste material bricks are lightweight, sound, corrosion-resistant and strong in compression.

Table 1 Properties of ordinary Portland cement

S. No.	Properties	Test results
1	Specific gravity	3.12
2	Fineness	8%
3	Initial setting time	29 min
4	Consistency	33%

Fig. 1 Paper board sludge

The review of works of the literature reveals that the sludge from any treatment plant or the industries can be reused in various forms according to the characteristics of the sludge generated. In this work, paper board sludge was taken for the study generated from a paper board mill SPAK, (Sri Pariyur Amman Kraft) located at SIPCOT, Perundurai, Erode, Tamilnadu, India. An attempt has been made to utilize the paper board sludge as one of the raw materials for casting of floor tiles for light use in the day to day use as a building unit. Cement, fly ash and bentonite materials along with the intrusion of foam to make the tile light in weight were considered for the proportioning of the floor tile specimens. The physic-chemical and engineering properties of the sludge and the other materials were analyzed and discussed. A group of tests was done for the newly developed tile as per the Bureau of Indian Standards (BIS).

2. Materials

2.1 Cement

Ordinary Portland cement (53 grade) confirming to the standards of IS: 12269-2013 was used throughout the experimental investigation. Table 1 shows the properties of OPC cement.

2.2 Fine aggregate

River sand was used as fine aggregate in this investigation by IS 383-1970. River sand having a bulk density of 1700 kg/m^3 and a specific gravity of 2.71 was used and belongs to grading zone II.

2.3 Water

Potable drinking water was used for mixing purposes.

Table 2 Properties of paper board sludge

S. No.	Properties	Test result
1	Silica	18.18%
2	Calcium oxide (CaO)	21.46%
3	Magnesium oxide (MgO)	2.38%
4	Iron oxide (Fe_2O_3)	1.20%
5	Aluminum oxide (Al_2O_3)	0.14%

Table 3 Properties of fly ash

Parameter	Value
Silica (SiO_2)	58.12%
Alumina (Al_2O_3)	24.44%
Calcium oxide (CaO)	8.04%
Magnesium (MgO)	4.22%
Iron (Fe_2O_3)	4.12%
Phosphorous	0.30%
Sulphur trioxide (SO_3)	0.76%

2.4 Paper board sludge

The paper board sludge was collected from SPAK (Sri Pariyur Amman Kraft) paper mill. The factory was located in the SIPCOT industrial estate established in Perundurai, Erode District, Tamilnadu. The color of the sludge is brownish grey. The sludge was collected from the industry in wet form, dried and finely ground. Paper board sludge contains a considerable amount of aluminum oxide and calcium oxide. Fig. 1 shows the paper board sludge collected. Table 2 shows the properties of the paper board sludge.

2.5 Fly ash

Fly ash (Class F) was collected from the source thermal power station, Mettur, Tamilnadu. The specific gravity and pH of fly ash were found to be 2.40 and 10.40 respectively. The properties of fly ash were shown in Table 3.

2.6 Bentonite

Bentonite is a pozzolanic material obtained from volcanic ash. This material has a good binding property with clay particles. Bentonite is light brown in color and size less than 200 microns. The properties of bentonite were listed in Table 4.

2.7 Sodium lauryl sulphate

Sodium Lauryl Sulphate (SLS) is a foam generating chemical. The foam generating compound is stable under normal condition and it is added in concrete. Its color is white and easily soluble in

Table 4 Properties of bentonite

Property	Value
Specific gravity	2.66
SiO_2	60.85
Al_2O_3	14.82
Fe_2O_3	4.38
CaO	3.67
Na_2O	3.13
MgO	3.09
K_2O	0.79
TiO_2	0.61
Other	0.44
Heat loss	8.22

Fig. 2 Sodium lauryl sulphate in its form of powder and foam

water. The pH value and specific gravity are found to be 9 to 10 (Aq. sol) and 1.05 respectively. Fig. 2 shows the sodium lauryl sulphate in its form of powder and foam.

3. Methodology

3.1 Prologue study

The raw materials were collected; properties were studied and proportioning for casting the tile was formulated as shown in Table 5.

3.2 Formation of tile specimen

For the casting of tile specimens, initially, the foam was generated by mixing sodium lauryl sulphate with water. 3 g of sodium lauryl sulphate is mixed with 84 ml of water, and it is well mixed until it attains foam for a single sample. The same procedure is repeated for all other proportions. Moulds were fabricated for the size of 150 × 150 × 25.4 mm. Nine different types of

Table 5 Mix combinations for the casting of tiles

Sample id	OPC (g)	Sand (g)	PBS (g)	Fly ash (g)	Bentonite (g)
S_{00}	200	1000	0	-	-
S_{11}	180	1000	10	10	-
S_{12}	160	1000	20	20	-
S_{13}	140	1000	30	30	-
S_{21}	180	1000	10	-	10
S_{22}	180	1000	20	-	20
S_{23}	140	1000	30	-	30
S_{31}	180	1000	20	-	-
S_{32}	160	1000	40	-	-
S_{33}	140	1000	60	-	-

Fig. 3 Preparation of foam and mixing of foam with a wet mix for tile specimen

the proportion of the sample are prepared as per specification shown in Table 5 along with the foaming agent. The ratio of mix proportion is 1:5 (cement:sand) with a water-cement ratio of 0.5. Fig. 3 shows the foam generation and mixing of the wet samples of tile specimen proportions with foam.

The slurry mixed wet mix proportions were poured into the mould of size 150 × 150 × 25.4 mm. Then it is kept undisturbed for a period of 24-48 hours. Fig. 4 shows the fresh cast sample. After 24 hours, the mould is removed and allowed for a curing period of 28 days.

3.3 Testing of tile specimen

The cast specimens for the respective proportions were cured for 28 days and tested for its compressive strength, flexural strength, water absorption and abrasion for wear. The specimen densities were also computed by observing the weights of the specimens and listed. Table 6 shows the results for compressive strength, flexural strength, dry density and water absorption. Fig. 4 shows the strength variations of the tile specimens.

4. Results and discussion

Based on the raw materials collected, the mix proportions for the specimen samples were

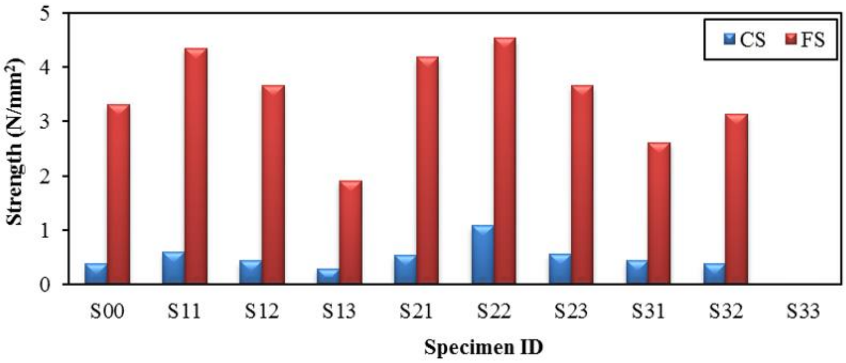

Fig. 4 Strength variations of the tile specimens

Table 6 Test outcomes of the tile specimen

Sample id	Compressive strength (N/mm^2)	Flexural strength (N/mm^2)	Dry density (kg/m^3)	Water absorption (%)
S_{00}	0.38	3.31	1850.87	12.3
S_{11}	0.60	4.35	1578.94	11.8
S_{12}	0.44	3.66	1703.51	12.1
S_{13}	0.29	1.91	1675.44	12.3
S_{21}	0.54	4.18	1771.93	11.8
S_{22}	1.08	4.53	1789.47	11.9
S_{23}	0.57	3.66	1800.00	12.4
S_{31}	0.45	2.61	1775.44	12.9
S_{32}	0.38	3.13	1794.74	13.5
S_{33}	Disintegrated	Disintegrated	Disintegrated	Disintegrated

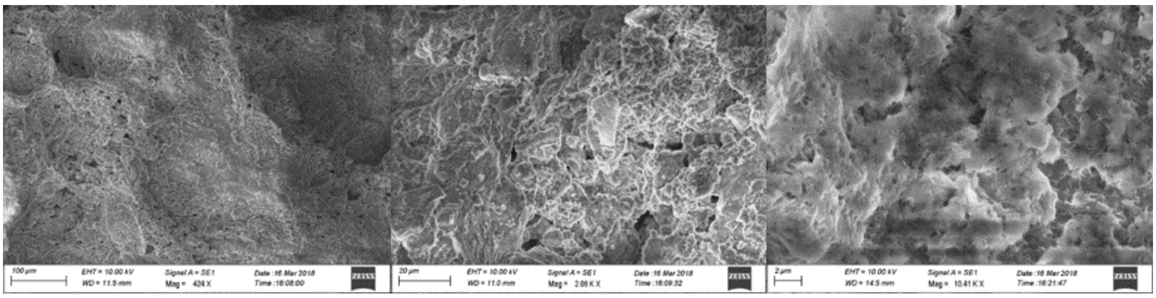

Fig. 5 Microstructure of controlled tile specimens of 424X, 2kX and 10kX magnification

designated with different mix proportions. Tile specimens were cast according to the mix proportions designated and cured for 28 days. After 28 days, the tile specimens were tested for its compressive strength, flexural strength, dry density, and water absorption. The compressive strength for the sample's conventional sample (S_{00}) and other proportioned samples were found to be varied from 0.3 N/mm^2 to 1.08 N/mm^2. The flexural strength for all the sample specimens was above 2 N/mm^2 except S_{13} which attains 1.9 N/mm^2 which were found to be satisfactory as per the

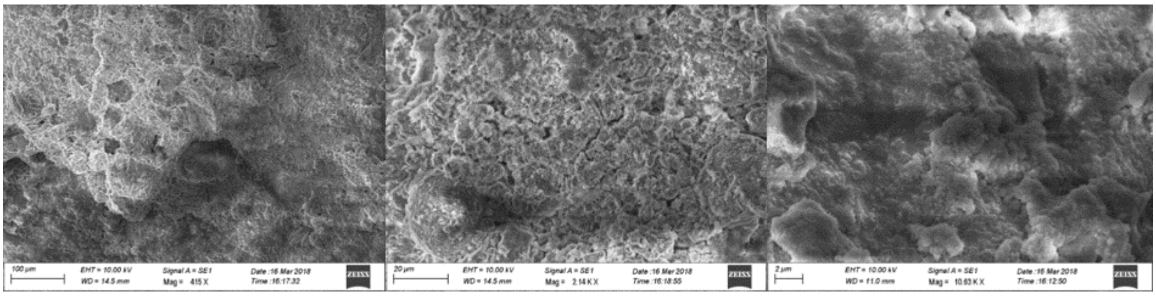

Fig. 6 Microstructure of S_{22} specimens of 424X, 2kX and 10kX magnification

recommendations of IS 2690.1.1993. The water absorption is about 11%-14% for all the samples, which is not more than 15% as per the recommendation of IS 2690.1.1993. The dry density of the specimens varies from 1650 kg/m^3 to 1850 kg/m^3 which also satisfy as a normal weight material. It was observed that specimen samples with paper board sludge, fly ash and bentonite (S_{22}) prepared with foaming agent hold reasonable compressive strength, flexural strength, and water absorption characteristics as per the BIS standards and above. Based on the above outcomes, the microstructure of the controlled specimen and sample S22 were studied for their microstructure using SEM analysis and shown in Figs. 5 and 6. From SEM analysis for sample S_{22}, the minute pores were filled up by the paper board sludge and bentonite particles. It is dense porous when compared with the controlled sample.

5. Conclusions

The utilization of paper board sludge form the paper board industry to produce tile specimens has been studied and evaluated for its performance. Hence, it is concluded that the tile specimen S_{22} gains strength and durability when compared to other specimen combinations. There could be cost-effective disposal of 10% of paper board sludge as a substitute for cement along with bentonite. In general, the tile specimen S_{22} may be recommended for terracing tile and further studied for its thermal characteristics as the future phase of work.

References

Alqam, M., Jamrah, A. and Daghlas, H. (2011), "Utilization of cement incorporated with water treatment sludge", *Jordan J. Civ. Eng.*, **159**(2980), 1-10.

Aukour, F.J. (2009), "Incorporation of marble sludge in industrial building eco-blocks or cement bricks formulation", *Jordan J. Civ. Eng.*, **3**(1), 58-65.

Bhushan, B., Grover, U., John, S. and Kanwar, V.S. (2020), *Advances in Sustainable Construction Materials and Geotechnical Engineering*, Springer, Singapore.

De Azevedo, A.R., Alexandre, J., Pessanha, L.S.P., Da ST Manhães, R., De Brito, J. and Marvila, M.T. (2019), "Characterizing the paper industry sludge for environmentally-safe disposal", *Waste Manage.*, **95**, 43-52. https://doi.org/10.1016/j.wasman.2019.06.001.

De Azevedo, A.R., Alexandre, J., Xavier, G.D.C. and Pedroti, L.G. (2018), "Recycling paper industry effluent sludge for use in mortars: A sustainability perspective", *J. Clean. Prod.*, **192**, 335-346.

https://doi.org/10.1016/j.jclepro.2018.05.011.
Durante Ingunza, M.P., Duarte, A.C. and Nascimento, R.M. (2011), "Use of sewage sludge as raw material in the manufacture of soft-mud bricks", *J. Mat. Civ. Eng.*, **23**(6), 852-856. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000239.
IS 2690 (1993), Indian Standard Specification for Burnt Clay Flat Terracing Tiles, Bureau of Indian Standards, New Delhi, India.
Jamshidi, A. Mehrdadi, N. and Jamshidi, M. (2011), "Application of sewage dry sludge as fine aggregate in concrete", *Asian J. Civ. Eng.*, **37**(59), 7-14.
Ma, H.L., Cui, C., Li, X. and Hu, S.L. (2013), "Study on mechanical properties of steel fiber reinforced autoclaved lightweight shell-aggregate concrete", *Mater. Des.*, **52**(1), 565-571. https://doi.org/10.1016/j.matdes.2013.05.086.
Othman, U.M. and Rahmat, M.N. (2019), "Utilization oil based industrial sludge as potential construction components", *Proceedings of the Sriwijaya International Conference on Science, Engineering, and Technology*, Palembang, Indonesia, October.
Patel, H. and Pandey, S. (2009), "Exploring the reuse potential of chemical sludge from textile wastewater treatment plants in India-A hazardous waste", *Am. J. Environ. Sci.*, **5**(1), 106.
Pitroda, J. (2015), "Gainful utilization of fly ash and hypo sludge in concrete", *Int. J. Constr. Res. Civ. Eng.*, **1**(1), 1-7.
Raghunathan, T., Gopalsamy, P. and Elangovan, R. (2010), "Study on strength of concrete with ETP sludge from dyeing industry", *Int. J. Civ. Struct. Eng.*, **1**(3), 379-389.
Ranjani, G.I.S. and Ramamurthy, K. (2012), "Behaviour of foam concrete under sulphate environments", *Cement Concrete Compos.*, **34**(7), 825-834. https://doi.org/10.1016/j.cemconcomp.2012.03.007.

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