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Utilization of Sewage Dry Sludge as Fine Aggregate in Concrete

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ABSTRACT: The world needs an environmentally friendly construction materials because of the desire to reduce CO₂ emissions and at the same time minimize waste. In recent years, investigations have been carried out by many researchers on the use of waste materials as a partial replacement of sand/cement in concrete. The residue that accumulates in sewage treatment plants is called sludge. The aim of investigation is to study the behavior of concrete while adding of dry sludge with different proportions in concrete by using tests like compression strength and split tensile strength. The mix design was carried out for M25 grade concrete as per IS: 10262-2009. 5% replacement of dry sludge by cement content can be used as an additive to concrete mix without causing a significant reduction in compressive strength. One possible area of application would be in the preparation of low-strength mass concrete that could be used for bases and subbases of roads with light traffic, as filler, etc. This research had not only solved the problems of contamination caused by sludge, but also brought certain economic and environmental benefits.

KEYWORDS: Sewage sludge; Concrete; Fine aggregate; Compressive strength; Split tensile strength.

I. INTRODUCTION

The world needs an environmentally friendly construction material because of the desire to reduce CO₂ emissions, save nonrenewable energy resources, provide aesthetically pleasing and healthy surroundings and at the same time minimize waste. Portland cement is a product of an industry that is not only energy-intensive but also responsible for large emissions of CO₂ - a major greenhouse gas. The manufacture of one ton of portland-cement clinker releases a ton of CO₂ into the atmosphere. The world's yearly cement output of 1.5 billion tonnes of mostly portland cement, accounts for nearly 7 percent of the global CO₂ emissions. Blended portland cements containing fly ash from coal-fired power plants and granulated slag from the blast-furnace iron industry provide excellent examples of industrial ecology because they offer a holistic solution to reduce the environmental impact of several industries. In addition, to minimize environmental impact, engineers should try to reduce the quantity of concrete used in buildings, use alternative types of concrete (with fly ash, for example), and use that concrete wisely.

Sludge refers to the residual, semi-solid material left from industrial wastewater, or sewage treatment processes. It can also refer to the settled suspension obtained from conventional drinking water treatment, and numerous other industrial processes. The residue that accumulates in sewage treatment plants is called sludge. In recent years, investigations have been carried out by many researchers on the use of sewage sludge as a partial replacement of cement in building materials. Yague et al. (2005) found that with the addition of 10% sludge in proportion to the amount of concrete, the mechanical strength decreases significantly, making it unsuitable for medium- to high-strength reinforced concrete. Compressive strengths of mortars containing 25% and 50% of sewage sludge ash are always lower than those of reference mortars. Cyr et al. (2007). Liu et al. (2011) explored the feasibility of using the sludge derived from dyestuff-making wastewater coagulation for the preparation of unfired bricks with four typical cements including portland cement, ground silicate cement clinker, alumina cement and slag cement. The experimental results showed that the cement solidified sludge was capable of reaching all performance criteria for unfired bricks at a cement/dry sludge/water ratio of 1:0.5–0.8:0.5–0.8. The compressive strengths of alumina cement solidified sludge overpass 40 MPa, higher than those of other cement solidified sludges. Vichaphund et al. (2011) have tested the possibility of utilization of the sludge waste obtained from the natural rubber manufacturing process as a raw material for producing clay ceramics and found that up to 30% of sludge waste can be added into the clay ceramics, and the sintered samples showed good properties. In another study, investigated the use of sewage sludge as a raw material in the manufacture of soft-mud bricks (Ingunza et al., 2011). The results obtained confirm that compressive strength was significantly

diminished with the addition of sludge: the bricks with 5% sludge lost an average of 45% of the strength obtained by the control brick; the bricks manufactured with 15 and 20% lost around 70% of maximum strength; however, they still met minimum strength standards. It was concluded that 20% was the maximum proportion of sludge that could be incorporated into a ceramic mass and still meet technical and environmental requirements. Shao et al. (2011) have used sewage sludge and fly ash as the main raw materials and clay as the cementing agent to prepare lightweight ceramsite. They found that lightweight ceramsite may serve as the water treatment material, the building material and the thermal insulation material and so on. This research had not only solved the problems of contamination caused by sludge and solid wastes like fly ash, but also brought certain economic and environmental benefits. The aim of investigation is to study the behavior of concrete while adding of dry sludge with different proportions in concrete by using tests like compression strength and split tensile strength.

II. MATERIALS AND METHODS

The present experimental program was conducted at the Concrete Technology & Structural Engineering Laboratory, Department of Civil Engineering, Jaypee University of Engineering & Technology, Raghogarh, Guna (MP), India from July 2011 to May 2012.

Sewage sludge

The sludge used in this study was obtained from a sewage treatment plant of National Fertilizers Limited company located in Vijaipur, Guna district of Madhya Pradesh in India. The wet digested sludge was allowed to dry under the hot sun to remove some of the moisture. The dry sludge was ground using the Los Angeles Abrasion machine. Inside the drum, there were 45 ball bearings, each of diameter 25 mm. The drum was rotated at 5000 revolutions using an electric motor at a speed of 25.7 rpm (revolutions per minute). After grinding, in ensuring fineness, the dry sludge was sieved through a 90 μm sieve in order to produce sludge powder.

Cement

Pozzolana Portland Cement (PPC) of Jaypee cement was used. Its specific gravity was 2.95.

Fine aggregate

Natural sand used as a fine aggregate in concrete mix design. The natural sand having specific gravity 2.6, Grading zone: 2 and fineness modulus: 2.8

Coarse aggregate

The maximum size of the crushed stone used for this mix design was 20 mm. The specific gravity of aggregate was 2.89, water absorption 1.96% and fineness modulus: 6.8.

Water

The potable water used in this study was satisfy the requirements of IS 456: 2000. The w/c ratio used for this mix design was 0.55.

Specific gravity and Bulk density

The specific gravity of sludge and sand was determined by the standard method according to ASTM C 127-93.

Compressive strength test

The test was performed as agreed by the IS 516 (1959). In this method, the concrete cubes of size i.e., 100mm X 100mm X 100mm were casted and cured for 7, 28 and 90 days according to ASTM C192 (2007). Later, cubes were tested under compressive testing machine. The load was applied by increasing rate of 140kg/cm²/minute till the resistance of specimen to the increasing load breaks down. The maximum load taken by specimen was noted when failure observed. Three cubes were tested in each category. The 90 days curing period was used as indication for long behavior of concrete strength.

Split tensile strength test

The test was conducted according to the procedure mentioned in IS 5816 (1999). The cylindrical concrete specimen of diameter 150mm and length 300mm was placed horizontally in the centre part of assembly by using wooden strips. The specimen loaded by equal distribution of the load. The load was applied and increased continuously at the rate of 1.2 to



2.4 N/mm²/min until failure of specimen. The Maximum load applied was recorded carefully and detect the condition of the specimen.

III. RESULTS AND DISCUSSIONS

3.1 Comparison of physical characteristics of sludge with sand

All sludge sample was passed through drying process at a temperature 105±5°C before using in concrete mixes. The drying process facilitates the sludge handling and gives them a granulometry. Table 1 illustrates comparison of physical characteristics of sludge with sand. The sludge particles were found to be porous indicated from low values of specific gravity and bulk density. The porous nature of concrete mixes containing sludge particles specifies rapid water absorption.

Table 1. Comparison of physical characteristics of sludge with sand.

S.No.	Physical property	Sludge sample	Sand
1.	Specific gravity	1.028	2.6
2.	Bulk density (kg/m ³)	1028	1650
3.	Fineness modulus	2.9	2.75
4.	Water absorption (%)	5%	0.6%
5.	Moisture content (%)	23.5%	12%

3.2. Chemical characteristics of sludge particles

The sludge produced in the plant is exposed to sun for a long period of time and then transferred to dumping sites. Table 2. Chemical characteristics properties of sludge and sand particles. The long period, which the sludge stayed in an aerobic condition, reduces the organic content due to decomposition of organic material. The organic material content (weight loss at 550°C) varied between 11 to 13%. The moisture content of sludge (weight loss at 105°C) ranges from 20 to 25%.

Table 2. Chemical characteristics properties of sludge and sand particles.

S.No.	Chemicle characteristics	Observed values in sludge sample	Permissible values
1.	Insoluble chlorides	16 mg/l	30 mg/l
2.	Carbonates	5mg/l	50mg/l
3.	Sulphtes	-	-
4.	pH	7	Should not be acidic
5.	Organic matter	11%	-

3.3. Unsoundness due to the impurities present in the sludge particles

There are two types of unsound aggregate particles, those that fail to maintain their integrity due to non durable impurities and those that lead to disruptive action on freezing or even on exposure to water i.e., due to changes in volume as a result of changes in physical conditions. Unsound impurities such as clay lumps, wood may lead to pitting and scaling. If present in large quantities may adversely effect the strength of concrete and should certainly not be permitted in the concrete to be exposed to abaration.



3.4. Properties of cement

Table 3 describes the properties of cement used in this work.

Table 3. Properties of cement used

S.No.	Property of cement	Observed value
1.	Type	PPC (Jaypee cement)
2.	Consistency	30%
3.	Initial setting time	42min
4.	Final setting time	120 min
5.	Compressive strength at 28 days	35 MPa

3.5. Mechanical properties of concrete

The grade of concrete used in this research was M25. The quantity of materials in 1 m³ was mentioned in the Table 4. The compressive strength results at 7 days, 28 days and 90 days with varying sludge content replacement viz., 0 %, 5 %, 10 % and 15 % were mentioned in Table 5. The sludge particles were coarser than sand, hence they have a small surface area and require less water to wet their surface. Hence with higher amount of sludge particles, more water will be available in the mix, henceforth would in turn decrease the strength. The weaker sludge particles tend to weaken the concrete hence produce less compressive strength. In essence the decrease in density of the concrete obtained in each case is obtained by the presence of voids, either in the aggregate or in the mortar or in the interstices between the coarse aggregate particles. It is clear that the presence of voids reduces the strength of concrete containing sludge particles compared to normal weight concrete. Table 5 indicated that the compressive strength at 7, 28 and 90 days get decreasing with increasing of sludge percent in concrete.

One possible area of application would be in the preparation of low-strength mass concrete that could be used for bases and subbases of roads with light traffic, as filler, etc. This research had not only solved the problems of contamination caused by sludge, but also brought certain economic and environmental benefits.

Table 4. Quantity of materials used.

Component	Quantity in 1 m ³
Cement	400 kg
Water	220 kg
Fine aggregates	630 kg
Coarse aggregates	1210 kg
Water cement ratio.	0.55

Table 5. Compressive strength results with varying sludge content.

S.NO.	Percentage replacement by sludge	7 days compressive strength	28 days compressive strength	90 days compressive strength
1.	0%	22.5 N/mm ²	32 N/mm ²	36.53 N/mm ²
2.	5%	21.63 N/mm ²	30.8 N/mm ²	36.12 N/mm ²
3.	10%	21.20 N/mm ²	29.63 N/mm ²	35.75 N/mm ²
4.	15%	20.30 N/mm ²	28.88 N/mm ²	35.1 N/mm ²



Table 6 gives the compressive strength values at 7 and 28 days with the same water content. At 5 % sludge replacement, slightly increased the compressive strength at 7 and 28 days. When the water content is increased, there were a decrease of compressive strength at 9.7 % and 9.75 % respectively for 7 and 28 days. When the water content is kept constant, there were a decrease of compressive strength at 4.34 % and 4.28 % respectively for 7 and 28 days.

Table 6.Strength with same water content

S.NO	Percentage replacement by sludge	7 days compressive strength	28 days compressive strength
1.	0%	23 N/mm ²	32 N/mm ²
2.	5%	23.2 N/mm ²	32.2 N/mm ²
3.	10%	22.7 N/mm ²	31.6 N/mm ²
4.	15%	22.5 N/mm ²	31.0 N/mm ²
5.	20%	22.0 N/mm ²	30.63 N/mm ²

3.6.Split tensile strength

The concrete develops cracks when tensile forces exceed its tensile strength. Thus, it is essential to determine the tensile strength of concrete to determine the load at which the concrete members may crack. Table 7 gives the results of split tensile strength test results at 28 day (N/mm²) for M25 grade concrete when sludge is added in increasing order viz., 0, 5, 10 and 15 %. The results depicts that the split tensile strength get decreasing with increasing of sludge %.

Table 7. Split tensile test for M25 grade concrete

S. No.	Sludge (%)	Spilt tensile strength at 28 days (N/mm ²)
1	0	2.10
2	5	1.98
3	10	1.69
4	15	1.24

3.7. Workability

The slump values were mentioned in Table 8. In this study, the mix prepared for medium workability thus ensuring the slump remains same. For equal workability the concrete mix containing the sludge particles register a lower slump and a lower compacting factor than the normal weight concrete because the work done by gravity is smaller in case of concrete containing sludge particles as the sludge particles have a lower density. A consequential danger is that if a higher workability is used there is a danger of segregation. The porous nature of concrete mixes containing sludge particles means that they have rapid water absorption. Thus if the aggregate is dry at the time of mixing, it will rapidly absorb water and the workability will quickly decrease. The remedy lies in mixing the aggregate with at least one – half the mixing water before adding the cement, knowing the water absorption and the effective water cement ratio.



Table 8. Slump values

S.no	Sludge as sand replacement	Slump value
1.	0% (reference mix)	5cm
2.	5%	5cm
3.	10%	5.5cm
4.	15%	6 cm

IV. CONCLUSIONS

According to the experimental results, the usage of sewage sludge in concrete mixes as an alternative of disposal for NFL sewage sludge is possible. The main conclusions, which can be drawn based on the experimental results are:

- 1) 5% replacement of dry sludge by cement content can be used as an additive to concrete mix without causing a significant reduction in compressive strength. Using higher sludge percentages than 5% decreases the workability of the mix and subsequently causes a reduction in slump.
- 2) The split tensile strength results depicts that the strength decreases with increase of sludge replacement (%).
- 3) Concrete mixes containing dry sludge can be effectively used in low load bearing structures and they provide an effective alternative for waste management, hence full filling the criteria of being known as ecofriendly concrete.

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