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Ingenious Use of Hypo Sludge in M25 Concrete

Abhinandan Singh Gill

Abstract**—**Paper mill sludge is one of the major economic and environmental problems for paper and board industry, million tonnes quantity of sludge is produced in the world. It is essential to dispose these wastes safely without affecting health of human being, environment, fertile land; sources of water bodies, economy as it adversely affect the strength, durability and other properties of building materials based on them. Moreover, in developing countries like India where there is low availability of non-renewable resources and large need of building material like cement therefore it is essential to develop eco-efficient utilization of paper sludge. Primarily in functional terms paper sludge comprises of cellulose fibers, calcium carbonate, china clay, low silica, residual chemical bonds with water. The material is sticky and full of moisture content which is hard to dry. The manufacturing of paper usually produce loads of solid waste. These paper fibers are recycled in paper mills to limited number of times till they become weak to produce high quality paper. Thereafter, these left out small and weak pieces called as low quality paper fibers are detached out to become paper sludge. The material is by-product of de-inking and re-pulping of paper. This hypo sludge includes all kinds of inks, dyes, coating etc inscribed on the paper. This paper presents an overview of the published work on the use of hypo sludge in M25 concrete formulations as a supplementary cementitious material exploring its properties such as compressive strength, splitting and parameters like modulus of elasticity, density, applications and most importantly investigation of low cost concrete by using hypo sludge are presented.

Keywords**—**Concrete, sludge waste, hypo sludge, supplementary cementitious material.

I. Introduction

ENVIRONMENTAL issues related to solid waste management is one of the most challenging issues in the world. Due to generation of huge quantities of solid waste we are facing a serious pollution problem. On an average the per capita consumption of paper in world is about 50kgs [1]**.** For each tone of recycled paper about 300kg of sludge is produced [2]. The disposal of paper waste sludge poses serious environmental problems and health hazards. The productive use of hypo sludge represents a way of solving some problems of solid waste management to some extent. Cement manufacturing on the other hand is one of the major carbon dioxide emitting sources. The global cement industry contributes more than 6% of greenhouse gas emission to the earth's atmosphere. Further they emit 1 million ton of green house gases for producing 4million tonnes of cement. [3]. The use of hypo sludge in cement industry will reduce the carbon dioxide and sulphur emission as less cement productivity and utilization will be involved thus providing a way to green technology.

Abhinandan Singh Gill is with the Guru Nanak Dev Engineering College, Luhiana, Punjab, India (e-mail: abhi_gill@hotmail.com).

The idea is to develop supplementary cementitious material in order to address environmental effects as associated with solid waste and cement manufacturing.

II. The Pozzolanic Properties of Paper Sludge Waste

Investigation was carried out to determine the pozzolanic properties by establishing optimal conditions for transforming paper de-inking sludge into pozzolanic [4]. They dry hypo sludge was burnt in an electric laboratory furnace from 600^0C to 800^0C for 2 and 5 hours. The resulting products were grounded powders and compared with results from conventional mathematical program the areas of peaks where each mineral as quantified were determined through the Gaussian adjustment and subtraction of the base line and sieved to a particle size of under $45\mu m$. The mineralogical composition by X-ray diffraction was detected where XRD patterns were accomplished in SIEMENS D-5000 diffractometer using a wolfram cathode and copper plate as anode. The semi-quantitative mineralogical components were accomplished using the method of the reflectant.

To observe and compare the pozzolanic activity of calcined sludge commercial metakaolin was used as a reference. An accelerated method by using saturated lime solution at 40^0C for 1, 7, 28, 90 days was used. CaO concentration in the solution was analyzed at the end of each period [5]. The combined lime (mmol/L) was obtained by the difference between the concentration in the control saturated lime solution and CaO present in the solution in contact with the sample. The analysis indicates that dry industrial waste is formed mainly of calcium oxide, silicates and alumina. The presence of chloride ions (0.04%) and loss on ignition (47.62%) was detected.

TABLE I
Chemical Composition of the Raw Sludge (% By Mass) [4]

Oxide (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	K_2O	P_2O_5	SO_3	Na_2O	LOI
Raw sludge	18.01	10.14	0.55	19.82	2.58	0.26	0.21	0.1	0.33	0.25	47.62

The starting sludge had an organic matter content of 29%. The mineral fraction of the dry sludge mainly consists of kaolinite (21%), calcite (35%) and other minerals such as phyllosilicates type chlorite and micas (11%), talc (2%) and quartz (2%) are also present in small amounts.

III. Mechanical Properties

A. Compressive Strength

The compressive strength of concrete by replacing hypo sludge accordingly in the range of 10 to 40% in the specified design mix was examined [6]. Total of 5 concrete cubes of

150*150*150 was prepared including the reference concrete. A table vibrator was used for compaction. The specimen was kept in water for different age of testing after 24 hours of demoulding. The compressive strength was determined at 7, 14, 28 days of M25 by using compression testing machine of capacity 200MT. The main factor responsible for the fall in strength as witnessed in mixes was due to decrease in cement content or inversely, the increase in hypo sludge percentage and this may be due to weak bonds developed due to addition of sludge content. They found out that with 10 percent addition of hypo sludge in reference sample, percent decrease of 29.96 at 7th day was observed following 26.37at 14th day and 33.55 at 28th day, with increase in proportion of paper waste sludge in cement the compressive strength reduced further.

A mix M25 grade design as per Indian Standard method to find out the ultimate compressive strength at 14 and 28 days .The concrete cubes of size 150*150*150mm were casted using M25 concrete. The ordinary Portland cement was replaced with paper waste sludge in the range from 10% to 70%. After curing and removing from mould, the specimens were calibrated on compression testing machine of 2000KN [3].

TABLE II
THE DESIGN MIX PROPORTION [3]

	Water	Cement	Fine aggregates	Coarse Aggregates
By weight (kg)	191.6	547.42	456.96	1255.475
By volume	0.35	1	0.834	2.29

TABLE III
CONCRETE DESIGN MIX PROPORTIONS [7]

Sr. No	Types of concrete	Concrete Design Mix Proportion (By Weight) in kg				Cement Replacement By Hypo Sludge
		W/C Ratio	C	F.A.	C.A.	
1	A1	0.50	372.0	558.6	1251.9	-
2	C1	0.50	334.8	558.6	1251.9	37.20
3	C2	0.50	297.6	558.6	1251.9	74.40
4	C3	0.50	260.4	558.6	1251.9	111.60
5	C4	0.50	223.20	558.60	1251.90	148.80

Mix proportions: Conventional Concrete – 1: 0.834: 2.29, 10% replacement – 0.9: 0.834: 2.29, 20% replacement – 0.80: 0.834: 2.29, 30% replacement – 0.70: 0.834: 2.29, 40% replacement – 0.60: 0.834: 2.29, 50% replacement – 0.50: 0.834: 2.29, 60% replacement – 0.40: 0.834: 2.29, 70% replacement – 0.30: 0.834: 2.29. The ultimate compressive strength of conventional concrete at 14 and 28 days was found to be 17.81N/mm^2 and 37.33N/mm^2. It was observed that the optimum compressive strength at 14 and 28 days was observed with 30% replacement with hypo sludge corresponding to 35.5 N/mm^2 and 56.11 N/mm^2 respectively.

The experiments were conducted to find out the average compressive strength by taking in account 5 different concrete cube samples with different proportion of hypo sludge used as a supplementary cementitious material. The water cement ratio was kept at 0.50 and other concrete design mix proportions are presented in Table I. The cement replacement by paper waste sludge was increased from 0, 37.20, 74.40, 111.60, 148.80 by weight in kgs and average compressive strength was noted for cubes (150*150*150) (N/mm^2) at 7, 14, 28 days for M25 [7].

It was found that the average compressive strength at 7,14,28 days for M25 with 37.20 (by weight in kgs) replacement of hypo sludge was more than that of the traditional concrete specimen, with the further addition of paper waste sludge in cement content or inversely, the increase in sludge content the compressive strength decreased.

TABLE IV
AVERAGE COMPRESSIVE STRENGTH FOR CUBE (150X150X150) AT 7, 14, 28 DAYS FOR M25 [7]

Types of concrete	Average Compressive Strength (N/mm^2)		
	7 Days	14 Days	28 Days
A1	28.76	32.00	38.52
C1	29.24	33.63	39.70
C2	22.96	23.35	25.78
C3	20.92	22.96	23.26
C4	19.47	21.04	22.96

The compressive strength of concrete cubes by preparing a trial mix proportions as shown in Table V was investigated [8]. The experiments so far conducted with cement and POFA (palm oil fuel ash) which is obtained from burning oil husk and shell and its chemical composition indicated presence of high amount of silica [9], and also it has been identified as having an active role in providing durable and strong concrete, have suggested pozzolanic properties associated with this by-product [10]. In this case, cement and POFA are considered cementitious in conformity with BS 4550 Part 3.4:1978 [11].

TABLE V
MIX PROPORTIONS OF CEMENT, POFA AND PAPER SLUDGE [8]

Mix Designation	Materials %		
	Cement	POFA	Sludge
M-1	90	5	5
M-2	80	10	10
M-3	70	15	15
M-4	60	20	20
M-5	50	25	25

The cubes of nominal size 70.7 mm were initially cured in moist conditions for the first 24 hours and then were immersed in water, both at $20 \mp 2°C$ and 85% RH until day for compression test. The compressive strength tests on all mixes were performed according to EN 12390-3:2002 [12].

The strength values were expected to decrease as the percentage of paper sludge increase but unlike what was expected there was continuous increase in strength with time. The highest compressive strength was noted at 28 days which was 26.0 N/mm^2 through M-1 mix and strength of up to 8.89N/mm^2 was observed in M-4 mix which contains 20% POFA and hypo sludge. This value was slightly more than the minimum compressive strength of 7N/mm^2 as prescribed in BS 6073 Part 2:2008 [13]. Thus the use of POFA with paper waste sludge provides an opportunity of utilizing then as supplementary cementitious material by fulfilling the strength requirement.

The compressive strength obtained with and without the use of silica admixtures was evaluated and compared [2]. About 20 cubes were casted of M25 mix design as per Indian Standard (IS 10262-1982) for conventional concrete of cube size 150mm x150mm x 150mm and 100mm x 100mm x 100mm.

Mix proportions for trial were: Cement = 281.60, Hypo sludge = 70.4 kg/m^3, Water = 140kg/m^3, Fine aggregates = 485.8 kg/m^3, Coarse aggregates = 781.3kg/m^3, Water cement ratio = 0.42

The compressive strength of concrete at 7, 14, 21, 28 days with 5% to 10% replacement with paper waste sludge were observed. The optimum compressive strength was found at 10% replacement with hypo sludge corresponding to 13.11 N/mm^2 at 7 days, 17.55 N/mm^2 at 14 days, 24.44 N/mm^2 at 21 days and 24.66 N/mm^2 at 28 days where the compressive strength for conventional concrete at flowing days was found to be 14.22N/mm^2, 17.56N/mm^2, 23.33N/mm^2, 24.88N/mm^2.

It was also found out that up to 10% of cement can be replaced by paper waste sludge. With the addition of silica admixtures, the compressive strength of concrete increases.

TABLE VI
COMPARISON OF COMPRESSIVE STRENGTH RESULTS WITH AND WITHOUT SILICA ADMIXTURES [2]

No of Days	15% Hypo sludge concrete without admixture (N/mm^2)	15% Hypo sludge concrete with silica admixtures N/mm^2)
7	10.66	12.22
14	14.22	15.55
21	18.88	20.66
28	22.00	23.33

III. SPLIT TENSILE STRENGTH

The split tensile strength of cylinder at 28 days with 0% replacement with hypo sludge was found to be 1.84 N/mm^2 which reduced to 1.56 with 10% replacement with paper waste sludge. It was found out that the split tensile strength further reduced with increase in percentage replacement of cement with hypo sludge from 0% to 70% [3].

The average split tensile strength for cube moulds (150*150*150) at 56 days was investigated [6]. It was found out that with 10% addition of paper waste sludge, the split tensile strength reduced by 5.23% that is from 3.44 N/mm^2 to 3.26 N/mm^2. There was significant decline of 29.36% in the split tensile strength with 20% addition of hypo sludge and it further reduced with decrease in proportion of cement or inversely the increase in proportion of paper waste sludge.

IV. MODULUS OF ELASTICITY

Deflection of concrete slabs and beams is common structural movement. Dead and live loads develops flexural strains which results in deflection. This may also occur in cracking in tensile zone. Modulus of elasticity of concrete is of prime importance to determine the deflection of structural elements. After 56 days of casting the testing of the resting specimen (150mm diameter and 300mm height) was carried out. The modulus of elasticity can be calculated by difference of the measured stresses and strains on an upper level (i.e. 1/3 of the value of compressive strength) and a lower level (i.e. 0.5 N/mm^2).

1. It was observed that with respect to reference specimen, with 10% addition of hypo sludge the modulus of elasticity decreased by 15.62% that is from 17777 to 15000 Mpa at 56 days and as the proportion of hypo sludge increased from 0% to 40% the modulus of elasticity further decreased. [14]
2. The modulus of elasticity of concrete was further observed with partial replacement of cement by paper waste sludge and fly ash (thermal industry waste) in M25 concrete mix [15]. It was found out that at 10% replacement with paper waste sludge and fly ash modulus of elasticity decreased by 6.24% and as the addition of hypo sludge and thermal industry waste increased the modulus of elasticity further decreased. The decrease was significantly less than that of hypo sludge concrete.
3. The modulus of elasticity for cylinder at 28 days for M25 was investigated [7]. It was found that with 37.20(by weight) in kg addition of hypo sludge the modulus of elasticity increased by 2542N/mm^2 from the reference concrete. With the further addition of paper waste sludge from 20% to 40% there was decrease in the value.

TABLE VII
MODULUS OF ELASTICITY FOR CYLINDERS (150X300) (N/MM^2) AT 28 DAYS FOR M25 [7]

Types of concrete	Modulus of elasticity (N/mm^2)
	28 Days
A1	24958
C1	27500
C2	23167
C3	17875
C4	15750

TABLE VIII
ACCEPTANCE LIMITS FOR DURABILITY INDEXES [16]

Acceptance Criteria		OPI (log scale)	Sorptivity (mm/h)
Laboratory concrete		> 10	< 6
As-built Structures	Full acceptance	>9,4	<9
	Conditional acceptance	9,0 to 9,4	9 to 12
	Remedial measures	8,75 to 9,0	12 to 15
	Rejection	< 8,75	>15

V. DURABILITY

Concrete is a tough material with great strength. Being porous material it interacts with surrounding environment. The flow of gas and water determine the durability of concrete. The main characteristic influencing the durability of concrete is its permeability. Permeability is defined as a measure of flow of water under pressure which depends on the porous structure of concrete. In other words it indicates the mechanism that uptake and transport water and gaseous substances.

Sorptivity is used to measure the response of concrete to pressure. It is defined as the ability to absorb and transmit water through it by capillary suction. In other words the

uptake of water by hardened, unsaturated concrete is characterized by sorptivity.

A. Water Absorption Test

The cylinder of 100mm dia x 50mm height cylinder was immersed in water for 90 days curing [16]. For 24 hours the specimens were oven dried at the temperature 110°C until the mass became constant. The mass was weighed again. The weight W1 was referred as dry weight of the cylinder and W2 was given to wet weight of the cylinder which was obtained after keeping specimen in hot water at 85^0C for 3.5 hours.

$$\% \text{ water absorption} = [(W2 - W1) \div W1] \times 100 \quad (1)$$

where, $W1$= Oven dry weight of cylinder in grams; $W2$= After 3.5 hours wet weight of cylinder in grams.

Based on the experiment it was found out that the water absorption of hypo sludge concrete shows higher rate of absorption at 10% replacement with paper waste sludge with M25 grade concrete corresponding to 1.13% which is a bit higher than traditional concrete at 90 days.

B. Sorptivity

It is measured as the rate of uptake of water. The action is composed of transport mechanism which depends on solid and fluid characteristics. Sorptivity is the function of pore structure (radius, continuity of capillary and tortuosity of porous sold and density, surface tension and viscosity of the liquid.

Water was used as the test fluid [16]. The cylinder specimen of size $100mm\ dia \times 50mm$ height was drowned in water for 90 days curing. The level of water was not kept more than 5mm above the base of specimen, a non-absorbent coasting was provided to seal to prevent the flow from the peripheral surface. The quantity of water absorbed was measured by weighing the specimen on a top pan balance weighting up to 0.1 mg in time period of 30 minutes. Dampened tissues were used to wipe off the surface water on the specimen. The cumulative water absorption (per unit area of inflow surface) increases as the square root of elapsed time (t)

$$I = S.t_2^1 \text{ Therefore } S = \frac{I}{t_2^1} \quad (2)$$

where S=Sorptivity in mm. and t= elapsed time in mint.

$$I = \Delta w \div Ad \quad (3)$$

$$\Delta w = \text{ Change in weight} = W2 - W1$$

A=surface area of the specimen after 30 minutes capillary suction of water in grams. D=density. W1= Oven dry weight of cylinder in grams. W2=Weight of cylinder after 30 minutes capillary suction of water in grams.

The sorptivity was found to be 2.32 mm/min$^{0.5}$ at 10% addition of paper waste sludge with concrete which was same as that of traditional or the reference concrete and there after it showed the increasing trend with increased proportions of hypo sludge.

VI. Density

The bulk density of cubes was found out after 28 days of curing. In a similar manner to strength the values were evaluated as weight per unit volume, density was noticed to decrease with increasing percentage of hypo sludge. Paper sludge in its dry and semi-dry state is quite lighter than hardened cement paste and this was considered as key factor responsible for decrease in density [8]. This result correlated to the previous findings which gives similar results, with increasing paper sludge content the bulk densities decreased [6].

VII. Economic Feasibility

Cost analysis is carried out for the optimum proportion of percentage of hypo sludge in M25 concrete mix. The cost is compared to the conventional concrete.

The test points towards developing low cost concrete by varying mix proportions from 10% replacement to 70% replacement of hypo sludge in M25 concrete mix [3]. The cost of material used in test was as follow- Cost of cement = Rs/per bag 250.00, Cost of sand per m3 =Rs 867.20, Cost of hypo sludge per kg = Rs 0.50, Cost of coarse of aggregate per m3 = Rs 561.40.

The compared values of cost show gradual decrement in total cost of per cubic meter concrete. The calculated cost of normal concrete was 3305.14, with 10% addition of hypo sludge the cost reduced by Rs 246.339. Similar with 30% replacement of cement with paper waste sludge the cost reduced by Rs 739.02. The fall in cost was witnessed with decrease in cement in M25 grade.

TABLE IX
Relative Cost of Slab for M25 [7]

Types of concrete	Slab Thickness (cm)	Cost of 1m x 1m Slab (Rs)	Relative Cost (%)
A1	19	785.67	100.00
C1	15	580.12	73.83
C2	19	680.10	86.56
C3	19	627.32	79.84
C4	20	605.17	77.02

The calculate cost of reference specimen was Rs. 4135.12. [1]. The difference in cost from normal concrete to partially replaced concrete with 10% addition of paper waste sludge was Rs.358.43. The cost further reduced with increase in proportion of hypo sludge.

The calculated cost of reference specimen was taken as Rs 4135.12 [7]. With 10% reduction of cement in designed concrete mix the difference in cost from normal concrete to partially replaced concrete was Rs.277.82 that is there was 6.71 % change in the cost and as the percentage of paper sludge waste increased to 20% the cost further reduced by Rs 555.64. The trend further decreased with decrease in proportion of cement.

The relative cost of 19cm thick slab with 20% addition of hypo sludge in M25 concrete mix was 86.56% of the reference specimen and with increased proportion of hypo sludge the cost further reduced.

VIII. Applications

A. Rigid Pavements of Rural Roads

The design of a cement concrete pavement was put forward for rural roads in Gujarat State consisting of vehicles like animal drawn vehicles, agriculture tractors, trailers, heavy trucks, motorized two-wheelers, light goods vehicle with traffic volume of up to 500 vehicles per day [7]. The soil was soaked CBR value 2%.

TABLE X
Design of Cc Pavement for Rural Design Parameters [7]

Traffic Volume (A)	=UP TO 500(Assume)
Concrete Grade (f_c)	M25
Characteristic Compressive Cube Strength	=39.70 N/mm^2 At 28 days Actual Compressive Strength
Flexural Strength (f_f)	=4.49 N/mm^2 [49.90 kg/cm^2]
90 days Flexural strength	=44.94 N/mm^2 [49.4 kg/cm^2]
Soaked CBR Value (%)	=2%
Modulus of Sub grade Reaction (K)	=21 (N/mm^2/mm)*10^{-3}
Effective K value (20% more)	=25.2 (N/mm^2/mm)*10^{-3}
Elastic modulus of concrete (E_c) (As per actual calculation	=27500N/mm^2
Poisson's ratio (μ)	=0.15
Coefficient of thermal coefficient of concrete (α)	=0.00001/°C
Design Wheel Load (P)	30kN
Tyre pressure (q)	=0.5 N/mm^2[5kg/cm^2]
Spacing of contraction Joints (L)	=3.75m[3750mm]
Width of slab	=3.75m[3750mm]
Radius of load contact (assumed circular), (a)	=13.82cm

The calculations were performed in a similar way by using various values of flexural strengths of concrete [7]. It was observed that paper waste sludge can be used in development of low cost rural roads. The checks for temperature stresses, radius of relative stiffness, edge load stress, corner stresses were performed observed after number ricks.

B. Fabrication of Bricks

The Compressive Strength of bricks fabricated by using 20% hypo sludge and 20% POFA at 7 days was 6.54 N/mm2 and 28 days was 10.84 N/mm^2 [8]. The brick strength of observations is more than the minimum recommended value of 7 N/mm^2 [13].

The Water Absorption capacity of POFA-hypo sludge bricks was found to be 39.6% which was relatively high as compared to normal concrete. The water absorption is found to be influenced by cellulose fibre [8]. Whereas other reports of autoclave aerated concrete shows higher absorption of up to 60% [17]. Therefore, as compared to aerated concrete the present material has much lower absorption capacity.

Density- Considering the average unit weight of normal concrete brick as 2.3 g/cm^3 [18], where average weight per brick is 2.44 kg and it corresponding density is 1.7 g/cm^3. The decrease of 26.1% in overall unit weight of hypo sludge-POFA brick was found out which is relatively quite significant.

IX. Conclusion

Based on limited experimental investigation concerning M25 grade concrete the following observations are made regarding the use of hypo sludge (paper industry waste) as supplementary cementitious material:

The calcined product obtained from paper waste sludge at optimal conditions of calcinations exhibits high pozzolanic property and permits its possible reuse as a pozzolanic material.

Environmental effects from wastes and those associated with the carbon dioxide emission from the production of Portland cement can be reduced.

1) As hypo sludge percentage increase in M25 grade, compressive strength and split tensile strength decreases hence up to 10% of hypo sludge can be replaced with cement and up to 15% of hypo sludge can be used with silica admixtures, POFA or other pozzolanic addition.
2) The Modulus of elasticity decreases with increased percentage of hypo sludge but the extent of decrease is less with thermal industry waste or with pozzolanic addition. Also the modulus of elasticity for cylinder increases with 10% hypo sludge replacement.
3) The hypo sludge concrete shows higher water absorption and sorptivity than traditional concrete.
4) The cost analysis indicates that with addition of paper waste sludge the cost of concrete decreases.
5) Paper waste sludge can be used as SCM for construction of rigid pavement in development of low cost rural roads
6) The bricks with adequate strength characteristics can be developed by incorporating 20% hypo sludge and 20% POFA which have potential to serve as masonry unit elements.
7) The density of cube blocks decrease with the use of hypo sludge and about 26.1% weight is reduced in comparison with normal brick by the use of 20% paper waste sludge and 20% POFA.
8) This new construction material can be used for economic feasibility in projects implemented by government for providing temporary shelters (where less strength is required) for those affected by natural disaster.
9) Paper waste sludge could be a valuable resource and will be advantageous from the standpoint of cost economy, durability, energy efficiently and overall ecological profile of concrete.

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Abhinandan Singh Gill was born in Ludhiana city on 21st July 1993. He is pursuing his Bachelor of Engineering degree in Civil Engineering from the Guru Nanak Dev Engineering College, Ludhiana, Punjab, India and is expected to graduate in June 2015. He has published paper in International Journal and National conference.