Utilization of Waste Paper Pulp by Partial Replacement of Cement in Concrete

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ABSTRACT

The use of paper-mill pulp in concrete formulations was investigated as an alternative to landfill disposal. The cement has been replaced by waste paper sludge accordingly in the range of 5% to 20% by weight for M-20 and M-30 mix. By using adequate amount of the waste paper pulp and water, concrete mixtures were produced and compared in terms of slump and strength with the conventional concrete. The concrete specimens were tested in three series of test as compression test, splitting tensile test and flexural test. These tests were carried out to evaluate the mechanical properties for up to 28 days. As a result, the compressive, splitting tensile and flexural strength increased up to 10% addition of waste paper pulp and further increased in waste paper pulp reduces the strengths gradually. The research on use of paper sludge can be further carried out in concrete manufacturing as a new recycled material.

Keywords - **Compressive Strength; Flexural Strength; Paper Pulp Concrete; Split Tensile Strength.**

I. INTRODUCTION

Over 300 million tones of industrial wastes are being produced per annum by chemical and agricultural process in India. These materials possess problems of disposal, health hazards and aesthetic problem. Paper fibers can be recycled only a limited number of times before they become too short or weak to make high quality paper. It means that the broken, low- quality paper fibers are separated out to become waste sludge. Paper sludge behaves like cement because of silica and magnesium properties which improve the setting of the concrete [1]. The quantity of sludge varies from mill to mill. The amount of sludge generated by a recycled paper mill is greatly dependent on the type of furnish being used and end product being manufactured. Paper mill sludge can be used as an alternative material applied as partial replacement of fine aggregates in manufacturing fresh concrete intended to be used for low cost housing projects [2].

About 300 kg of sludge is produced for each tone of recycled paper. This is a relatively large volume of sludge produced each day that makes making landfill uneconomical as paper mill sludge is bulky. By adjusting the mixture to an equivalent density, concrete mixtures containing the residuals can be produced that are equal in slump and strength to a reference concrete without residuals [3]. In 1995, the U.S. pulp and paper industry generated about 5.3 million metric tons of mill wastewater-treatment residuals (on oven-dry basis), which is equivalent to about 15 million metric tons of dewatered (moist) residuals. About half of this was disposed in landfills/lagoons, a quarter was burned, one-eighth was applied on farmland/forest, one sixteenth was reused/recycled in mills, and the rest, one sixteenth, was used in other ways [4]. Pulp and paper mill residual solids (also called sludge) are composed mainly of cellulose fibers, moisture, and papermaking fillers (mostly kaolinitic clay and/or calcium carbonate) [5].

Utilization of the widely spread industrial wastes in the civil construction practice may lead to a real possibility of significant decrease in the environment pollution by paper and lime production wastes and perceptibly economize the price of civil construction [6]. The use of paper-mill residuals in concrete formulations was investigated as an alternative to landfill disposal [7].

The raw dry paper sludge mainly contains silica and calcium oxide, followed by alumina and magnesium oxide. Cement blended with 10% and 20% calcined paper sludge exhibits a smaller reduction in compressive strength than the control cement [8]. A study on the reuse of paper de-inking sludge, undertaken in Spain, shows its potential as raw material for yielding a product with pozzolanic activity [9].

The compressive strength, average residual strength and drying shrinkage of concrete containing residuals were also comparable to the reference concrete without residuals when the proper dosage of high-range water-reducing agent (HRWRA) was added [10-11]. Concrete containing an average of 15% residuals had a lower 28-days compressive strength than the reference concrete and showed either equivalent or somewhat lower chloride-ion penetration resistance than the reference concrete [12].

Although there are potential advantages of including paper-mill residuals in a concrete mixture, such as cost savings in both waste management and concrete production, to date still lot of work has to be done on the utilization of paper pulp in concrete production. This paper summarized the behavior of concrete with the waste paper pulp by replacement of cement in the range of 5%, 10%, 15% and 20% which may helps to reduce the disposal problem of sludge and enhance the properties of concrete.

II. MATERIALS AND MIXTURE PROPORTIONS

A. Portland Pozzolanic Cement, paper pulp, fine and coarse aggregates

The cement used in all mixtures was 53 grade Portland pozzolanic cement (PPC), which corresponds IS 1489 (Part 1)-1991 [13]. The coarse aggregates used were crushed stone passing through 20 mm and retaining on 12.5 mm IS sieve, with a specific gravity of 2.67. The crushed stone was used to ensure good mechanical performance so that any differences in the mechanical properties of mixtures containing residuals and reference mixtures could be easily detected. The fine aggregate (river sand) had a specific gravity of 2.61 [14]. The concrete mix was designed for M-20 (1:1.43:3.18) with w/c ratio of 0.5 and M-30 (1:1.22:2.85) with w/c ratio of 0.45 [15]. All the stipulated ranges about the concrete materials and strengths are given in IS 456-200 [16].

B. Characterization of waste paper pulp

The waste paper pulp used in this study was collected from Apex Paper Mill, Bazargaon, which is then dried in sun light and pulverized. Chemical analysis of the paper pulp has been done by using Energy Dispersive X-ray Fluorescence Spectrometer (XRF, Philips, PW 1840). Proximate and ultimate analysis of paper pulp has been carried out using gravimetric methods. X-Ray Diffraction pattern has been recorded on a model XRD-Philips X'Pert Pro with a scan rate of 2^o/min. XRD pattern have been recorded in the 2θ range of 5^o-100^o. Thermo-gravimetric-differential thermal analysis (TG-DTA) (Mettler, TA 4000) has been carried out to determine the thermal stability. Scanning electron micrograph photographs have been recorded using JEOL Model No JXA – 840 A, Japan.

Paper pulp mainly contains Si (60%) and Ca (14%) (Table 1) depicting the XRF scan data. Table 2 gives the proximate analysis, and Table 3 presents an ultimate analysis.

According to the TG curves (Fig. 1) of paper pulp samples have not been thermally pre-treated and the mass loss of 45% occurs between 29^0 and 300^0C. This curve reveals the appearance of three distinct mass loss regions. The first loss (7.5%), between 30 and 280^0C, is attributed to the removal of superficial water molecules or water from the solid pores. At the second mass loss, the material gets thermally degraded and gets sintered. Thus, the bricks made of paper pulp can withstand the maximum of 300^oC.

The diffraction patterns of virgin and binder mixed paper pulp is given in Fig. 2. The samples present amorphous patterns based on small reflection angles and 2θ peak between 25 to 30. The nature of materials has not changed even after different extents of addition of cement in paper pulp (5-20%wt).

SEM images (Fig. 3) for paper pulp clearly indicate the presence of irregular pores and fibrous nature. The paper pulp holds the moisture in these pores and the fibrous envelops providing obstacle for moisture to move towards the surface. Fibrous nature gives very high energy absorbing ability and hence the high compressive strength.

Table 1 - Elemental Analysis of Paper Pulp

	O %	Ca %	Si %	Al %	Mg %	S %	Ti %	K %	Fe %	Na %	Cu %	P %	Cl %
Paper Pulp	15.83	14.94	60.57	2.06	3.59	1.07	0.15	0.16	0.92	0.22	0.05	0.03	0.41

Table 2 - Proximate Analysis of Paper Pulp

Sr. No.	Wt. in grams	Moist %	Ash %	Volatile Materials %	Free Carbon %	GCV Kcal/kg
1.	420	5.8	40.6	44.7	8.9	2372

Table 3 - Ultimate Analysis of Paper Pulp

Sr. No.	Wt. in grams	C %	H %	N %	S %	O %
1.	420	22.7	2.5	0.3	0.4	23.6

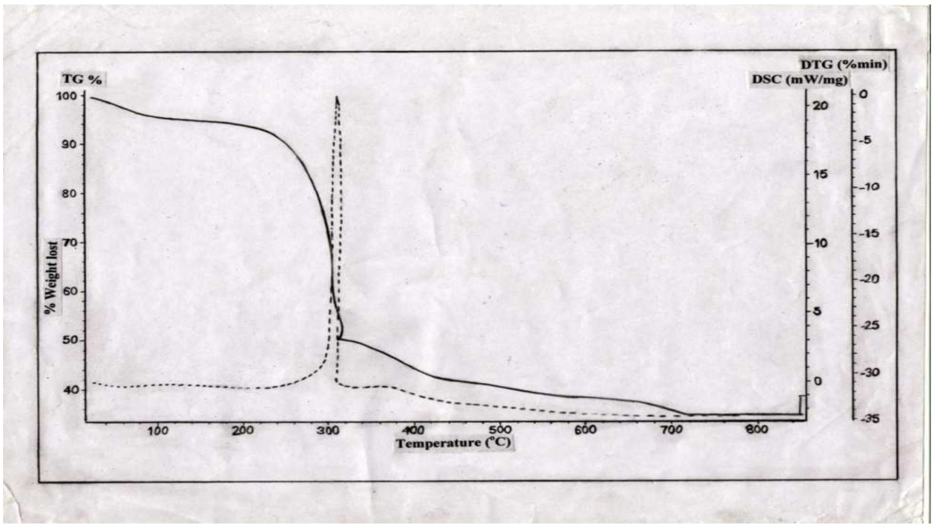

Fig. 1. TG-DTA of paper pulp

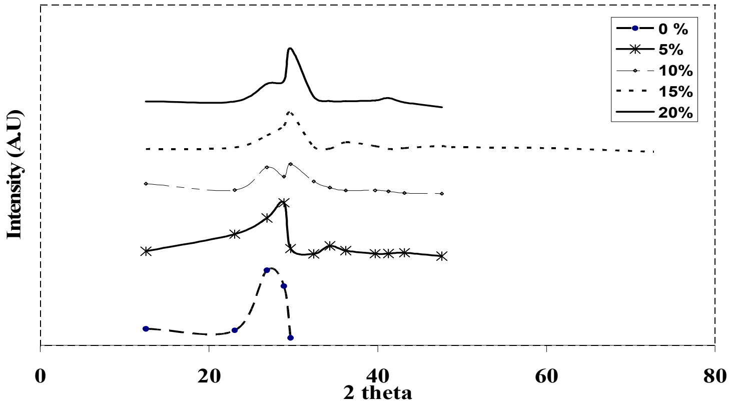

Fig. 2. XRD pattern of paper pulp-cement (0-20%wt)

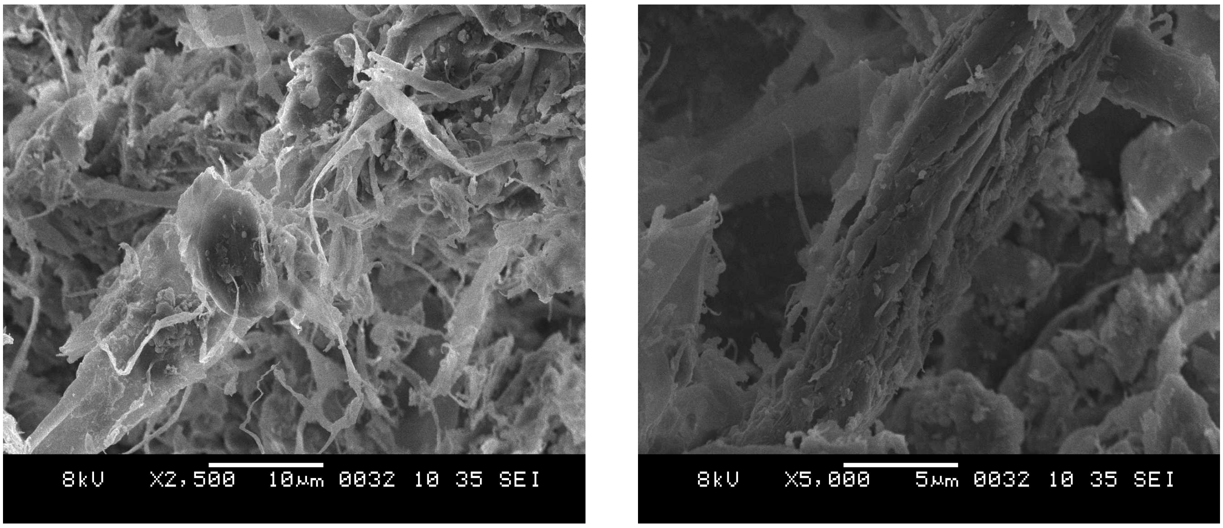

Fig. 3. SEM monograph of virgin paper pulp sample

C. Mixture proportions

The mixture proportions and fresh properties of the concrete mixtures produced in the laboratory are shown in Table 4. A total of 10 concrete mixtures were produced. The types of mixtures produced, which were the partial replacement of mass of Portland cement with waste paper pulp in concrete ranging from 5% to 20%. Portland pozzolanic cement, fine aggregate (sand), and coarse aggregate supplied by the college were used in this research. The cement and the aggregates met the requirements of IS 1489 (Part 1)-1991and IS 383-1970, respectively.

III. Experimental program and test procedures

A. Tests on fresh concrete

The consistency and workability of all the concrete mixtures was determined through slump tests. The slump tests were performed according to IS 1199-1959 [17]. The vertical distance between the original and displaced positions of the centre of the top surface of the concrete was measured and reported as the slump.

B. Tests on hardened concrete

The tests have been performed to determine the mechanical properties were compressive strength, splitting tensile-strength and flexural strength. The test results were reported as the average of three tested specimens in the respective testing. From each concrete mixture, 150 mm^3 cubes, 100 x 100 x 500 mm beams, and 150 x 300 mm cylinders has been casted for the determination of compressive strength, flexural strength test [18] and splitting tensile strength [19] respectively. Cube compressive strengths has been determined at 14 and 28 days in accordance with IS 516-1959. Flexural strength test was carried out using a simple beam with two-point loading method at 28 days of curing age, conforming to IS 516-1959. Splitting tensile-strength test was carried out according to IS 5816-1999.

IV. Results and Discussion

A. Fresh concrete

The slump test results are presented in Table 4. The slump decreased when a higher amount of paper pulp content was included. The as-received pulp exhibited a high water-absorption capability. Consequently, when a higher amount of paper pulp was included in the mixture, it required more water to achieve a given slump. The workability of concrete containing paper-mill residual was improved by the addition of excessive water instead of admixtures as we have to achieve economy.

Several factors could lead to adverse effects on the workability of paper pulp concrete. The amount of paper pulp replacement, paper pulp physical properties, and the carbon content of the paper pulp would be the main reasons for the reduction of concrete workability. The reduction in water demand becomes larger with an increase in the paper pulp content to about 20%.

B. Hardened concrete

The compressive strength, splitting tensile strength and flexural strength test results are given in Table 5. The compressive strength tests were carried out at 14, and 28 days. The compressive strength development of paper-mill residual concrete mixtures was very similar to the reference mixtures, showing a high early strength gain. The compressive, splitting tensile and flexural strength of concrete mixtures with paper pulp were less than reference mixtures. The results showed that the compressive, splitting tensile and flexural strength were reduced when higher paper pulp contents were included in the concrete mixtures.

Fig. 4 and 5 present the compressive strengths of all 10 mixtures at 14 and 28 days, respectively. The compressive strength of the mixtures decreased when the paper pulp content was increased. The paper pulp content in the concrete mixtures played a great role in the mechanical properties. However, the effects of paper pulp on the mechanical properties of the concrete did not vary much from the findings of previous researchers. Many previous studies have also shown that, at any percentage, the replacement of Portland cement with paper pulp in concrete on a one-for-one basis, either by volume or by weight, results in lower compressive and flexural strength up to about 3 months of curing, with the development of greater strengths at and beyond 6 months.

Results similar to the 28-days compressive strength tests were also found in the 28-days splitting tensile strength test and flexural strength tests presented in Fig. 6 and 7 respectively. The splitting tensile and flexural strength decreased when the paper pulp content was increased in the mixtures. Fig. 8 and 9 shows relation between compressive strength and splitting tensile strength of M-20 and M-30 mix respectively.

Table 4 - Mixture Proportion

Mix	Paper Pulp %	w/c ratio	Water (Kg/m^3)	Waste Paper Pulp (Kg/m^3)	Cement (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Slump (mm)	Vee-Bee (Sec)
M-20	0	0.5	191.6	0	383.2	548.17	1219.5	69	10
	5	0.5	191.6	19.2	364	548.17	1219.5	71	9
	10	0.5	191.6	38.32	344.88	548.17	1219.5	58	15
	15	0.5	191.6	57.48	325.72	548.17	1219.5	50	17
	20	0.5	191.6	76.64	306.56	548.17	1219.5	42	18
M-30	0	0.45	191.6	0	425.8	520	1212.16	50	11
	5	0.45	191.6	21.3	404.5	520	1212.16	52	10
	10	0.45	191.6	42.6	383.2	520	1212.16	45	15
	15	0.45	191.6	63.9	361.9	520	1212.16	35	17
	20	0.45	191.6	85.2	340.6	520	1212.16	30	19

Table 5 - Compressive strength, splitting tensile-strength and flexural strength test results

Mix	Waste Paper Pulp in %	Cube compressive strength (N/mm^2)		28-days strength (N/mm^2)	
		14 days	28 days	Splitting	Flexural
M-20	0	22.04	31.63	2.74	12.30
	5	25.62	33.93	2.90	14.17
	10	23.53	32.33	2.76	12.75
	15	18.85	25.43	2.33	10.75
	20	16.72	21.62	2.20	9.19
M-30	0	24.37	40.70	3.4	14.71
	5	26.85	42.37	3.70	15.78
	10	25.63	41.86	3.60	14.92
	15	22.77	38.41	3.20	12.51
	20	19.91	34.87	2.80	10.24

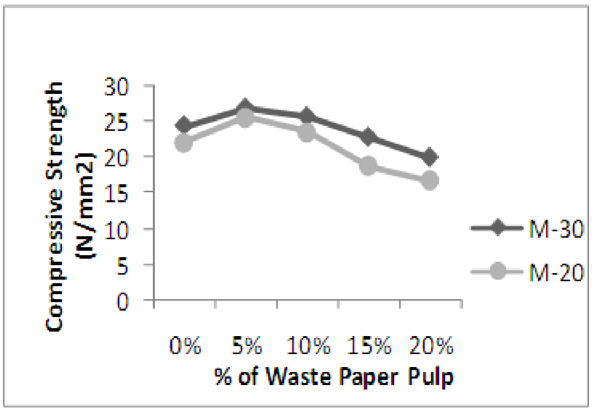

Fig. 4. Compressive Strength of Cubes at 14 Days

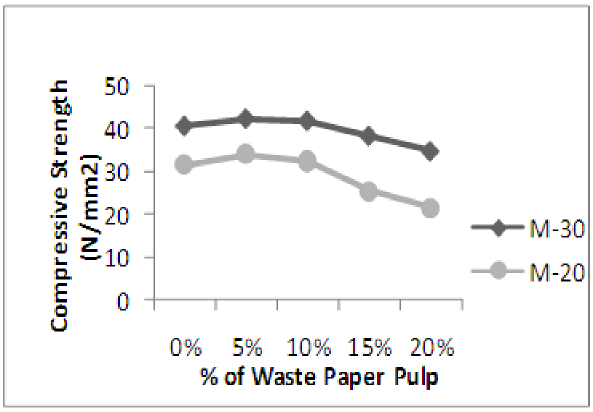

Fig. 5. Compressive Strength of Cubes at 28 Days

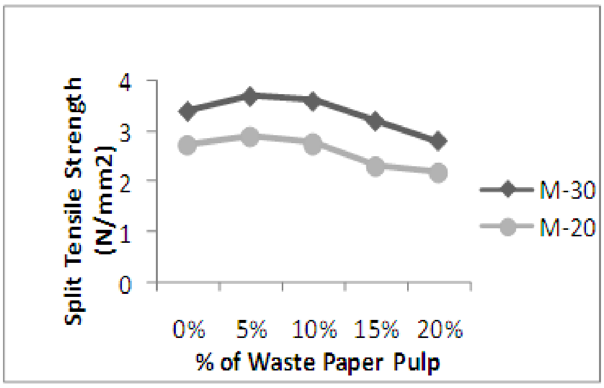

Fig. 6. Split Tensile Strength of Cylinders at 28 Days

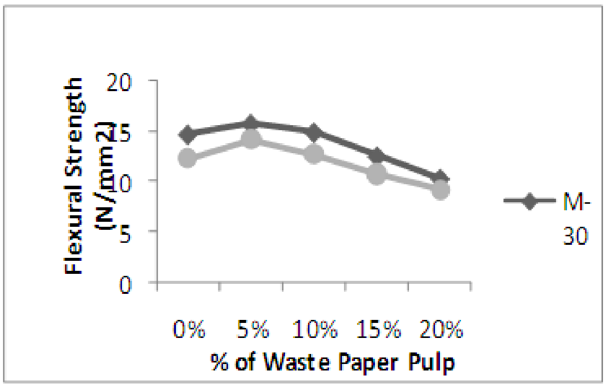

Fig. 7. Flexural Strength of Beams at 28 Day

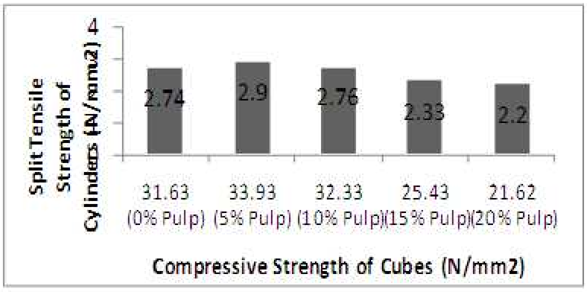

Fig. 8. Compressive Strength Vs Split Tensile Strength of M-20 Mix

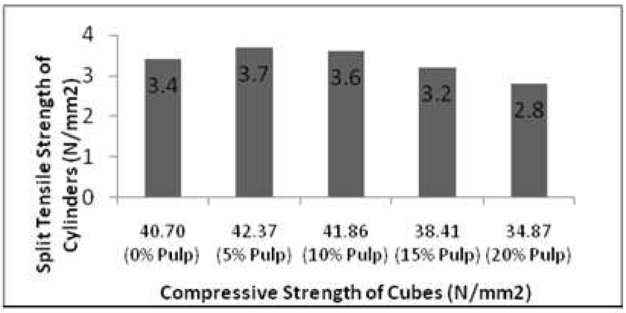

Fig. 9. Compressive Strength Vs Split Tensile Strength of M-30 Mix

V. Conclusions

Based on the results presented above, the following conclusions can be drawn:

1. The slump increased up to 5% replacement of cement, above 5% the slump decreased as the paper pulp content in the concrete mixtures was increased.
2. Generally, the compressive, splitting tensile and flexural strength increased up to 10% addition of waste paper pulp and further increased in waste paper pulp reduces the strengths gradually.
3. The most suitable mix proportion is the 5 to 10 % replacement of waste paper pulp to cement.
4. There was an increase in water absorption of the concrete mixes as the content of the paper pulp increased. This phenomenon is expected since more amount of paper pulp in term of quantity will involve in the hydration process. Therefore, additional amount of water was required for cement hydration which is the common solution to this kind of problem. However, higher water content decreases the strength of concrete.
5. Use of waste paper pulp in concrete can save the pulp and paper industry disposal costs and produce a 'greener' concrete for construction.

ACKNOWLEDGEMENTS

The authors are thankful to Dr. R. V. Ralegaonkar, Associate Professor, Department of Civil Engineering, VNIT, Nagpur-10, Maharashtra, India and Dr. Sachin A. Mandavgane, Associate Professor, Department of Chemical Engineering, VNIT, Nagpur-10, Maharashtra, India for their support, comments and valuable suggestions.

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