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Experimental Study on Fractional Replacement of Cement with Waste Paper Pulp in Concrete

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ABSTRACT

This study is about waste paper pulp from paper industries to be employed as a fractional substitution of cement in concrete at varying percentages to access its properties and performance. To evaluate the fresh property of concrete, slump cone test was conducted. The concrete compressive strength test (CST) was evaluated by testing 36 cubes of side 150mm. Twelve concrete cylinder specimens of ‘diameter 150mm and height 300mm’ were cast to evaluate the split tensile strength (STS) and twelve specimens of size ‘150mm x 150mm x 700mm’ were cast to find out the modulus of rupture (MOR) of concrete. The slump value showed an indirect correlation with the increment in the percentage of waste paper pulp. The 28th day strength tests revealed that the compressive strength was increased by 15.5% for a 10% substitution of cement. The compressive strength was nearly the same for 5% substitution and there was a fall in compressive strength by 16.67% for 15% substitution. The tensile strength was increased by a maximum of 7.5% for 5% substitution of cement and it decreased progressively after 10% substitution. Flexural strength was increased by about 10.89% for 5% substitution, 2.5% for 10% substitution and a decrease in flexural strength of about 13.9% for 15% substitution was observed. Thus, it was concluded that fractional substitution of cement by waste paper pulp can be achieved by 5% for optimum results. The 5% substitution of cement may yield an economic and environment-friendly concrete construction.

Keywords: Concrete; Slump Cone Test; Waste Paper Pulp; Compressive Strength; Tensile Strength; Flexural Strength.

1. INTRODUCTION

Presently concrete is utilized more than any other manmade substance in the world. The increasing population has created a huge demand for housing and infrastructure and this adds a big sum in both private and public sector budgets. Cement being a principle element in concrete, its manufacturing procedure is costly and ecologically unpleasant. “The manufacture of 1 ton of portland cement involves 1.5 tons of resources as raw materials” [1]. Conferring to the literature [2-3] the “production process of portland cement is highly energy-intensive, consuming 4–7 MJ of fossil fuel energy per kg, and releases approximately 1 ton of carbon dioxide for the manufacture of each ton”.

Keeping in view the economic and environmental perspective, efforts are made in finding an alternative to the cement as binding material. The complete substitution of cement in concrete has not been achieved yet. However, successful attempts in partial replacement of cement by definite proportions have been made resulting in economical and eco-friendly construction. Different researchers have reviewed the possible substitution of cement in concrete and suggested materials like “ceramic waste, paper pulp, blast furnace slag, silica fume, hypo sludge, fly ash, paper sludge, waste glass powder and waste paper sludge ash” [4-5]. Conferring to the literature [6] “more than 450 million tons of paper is produced worldwide per annum and it is expected that the demand for paper will reach 500 million tons per year by the end of 2020”. The “demand of paper to be imported to Ethiopia by the year 2015/16 was 157,956.7 tons of paper and paper board” [7]. The demand for paper is increasing from year to year because of education expansion policies and overall economic development of the countries.

In this study, waste paper pulp is used as the fractional substitution for cement in concrete. Waste paper pulp is obtained from the leftover materials generated in the paper industries and being a waste material, it is cheaper than other materials. To find the fresh property of the concrete slump cone test was done [8]. To evaluate the hardened property of the concrete strength tests were done [9,14] and the outcomes were recorded and compared with conventional concrete mix. Figure 1 shows the waste paper pulp.

Figure 1. Waste paper pulp

2. MATERIALS

The 53 grade ordinary Portland cement (OPC) approved by IS 12269:1987 [10], 20 mm downgraded coarse aggregate (CA), river sand as fine aggregate (FA) of zone II as specified by IS 383:1970 [11], potable water and industrial waste paper pulp was used in the study. The fineness of cement was 3% and consistency 32%. The initial setting time (IST) of cement was found to be 33 minutes and the final setting time of cement (FST) was 9 hours and 50 min [12]. The consistency by 5%, 10% and 15% cement substitution with waste paper pulp by weight was found out to be 40%, 42% and 44% respectively. The IST by 5%, 10% and 15% substitution by weight was found out to be 29 minutes, 25 minutes and 22 minutes and FST was found out to be 9 hours 30 min, 9 hours 26 min and 9 hours 23 min respectively [12]. Table 1 displays basic material properties with the recommended range as per Bureau of Indian Standard (BIS) [13].

Table 1. Properties of cement, fine aggregate and coarse aggregate

Description	Attained value	BIS recommended range
Cement - Specific gravity	3.14	3.1- 3.15
FA - Fineness modulus	2.94	2.9-3.2
FA - Specific gravity	2.53	2.4-2.6
CA - Fineness modulus	7.3	6.5 – 7.5
CA - Specific gravity	2.79	>2.6
Water absorption:	CA	0.57%

Surface moisture:	FA	1.00 %
	CA	0%
	FA	2.32%

The sieve analysis results of CA and FA have been displayed in Table 2 and Table 3 respectively.

Table 2. Grading of coarse aggregate

Sample = 5 kg					
Sieve Size		**Retained weight (kg)**	**Collective weight retained (kg)**	**Collective % retained**	**Collective % passing**
(mm)	**(micron)**				
80		0	0	0	100
40		0	0	0	100
20		1.519	1.519	30.38	69.620
10		3.444	4.963	99.26	0.740
4.75		0.037	5	100	0
2.36		0	5	100	0
1.18		0	5	100	0
	600	0	5	100	0
	300	0	5	100	0
	150	0	5	100	0
Total sum		5		729.64	
Fineness modulus = (729.64/100) = 7.3					

Table 3. Grading of fine aggregate

Sample = 1000 g					
Sieve Size		**Retained weight (g)**	**Collective weight retained (g)**	**Collective % retained**	**Collective % passing**
(mm)	**(micron)**				
4.75		11	11	1.1	98.9
2.36		63	74	7.4	92.6
1.18		141	215	21.5	78.5
	600	245	460	46	54
	300	214	674	67.4	32.6
	150	326	1000	100	0
Total sum		1000		243.40	
Fineness modulus = (243.40/100) = 2.44; "Grading zone II, IS 383:1970" [11]					

Keeping in view the above material properties, the mix proportion of ingredients for M25 grade concrete was designed as per IS 10262:2009 [13] and designated as M1, M2, M3 and M4 with proportioning of constituents as displayed in Table 4. The M25 conventional mix ratio calculated was 1:1.47:2.52 with a water-cement ratio as 0.45.

The mould, mixing and curing of samples conform to the requirements as specified in IS 516:1959 [9]. The average 28th day compressive strength for M25 grade of control concrete specimens was recorded as 34.85 MPa. The calculated target mean strength was 31.6 MPa. Therefore, the obtained mix design ratio was well within the standard.

Table 4. Mix proportion for 1m^3 concrete

Concrete mix	Cement (kg/m^3)	Paper pulp (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Water (l/m^3)
M1-Control	445	0	658	1125	200
M2	422.75	22.25	658	1125	200
M3	400.5	44.5	658	1125	200
M4	378.25	66.75	658	1125	200

3. EXPERIMENTAL PROGRAM

To assess the fresh property of concrete, slump cone test was conducted referring to IS 1199:1959 [8]. The change in level between the height of mould and peak point in the subsided concrete was measured and reported as a slump as shown in Figure 2. The concrete CST was evaluated by testing cubes as shown in Figure 3 of side 150mm at 7th, 14th and 28th day of curing time following IS 516:1959 [9] guidelines. The concrete samples of ‘diameter 150mm and height 300mm’ were cast to evaluate 28th day STS as shown in Figure 4 following IS 5816:1999 [14]. The specimen of size ‘150mm x 150mm x 700mm’ were cast and tested to find out the MOR of concrete as shown in Figure 5 following IS 516:1959 [9] guidelines. The CST and STS were performed using the compression testing machine of the capacity of 100 ton capable of loading rate of 14-21 kg/cm^2/minute. The MOR of samples was performed by using flexural apparatus with a 2-point loading system capable of loading rate of 400 kg/min.

Figure 2. Slump cone test setup

Figure 3. Compressive strength test setup

Figure 4. Split tensile strength test setup

Figure 5. Flexural strength test setup

4. RESULTS AND DISCUSSIONS

4.1 Slump and cone test

The concrete mix with selected proportions of waste paper pulp was added and slump value was determined. A total of 12 slump cone tests were conducted 3 in each category. The average slump cone test results are given in Table 5 and Figure 6 represents the respective bar chart.

Table 5. Slump cone results

Mix design	Replacement of cement (%)	Slump value	Variation (%)
M1	0%	75	-
M2	5%	72	-4%
M3	10%	68	-9.33%
M4	15%	62	-17.33%

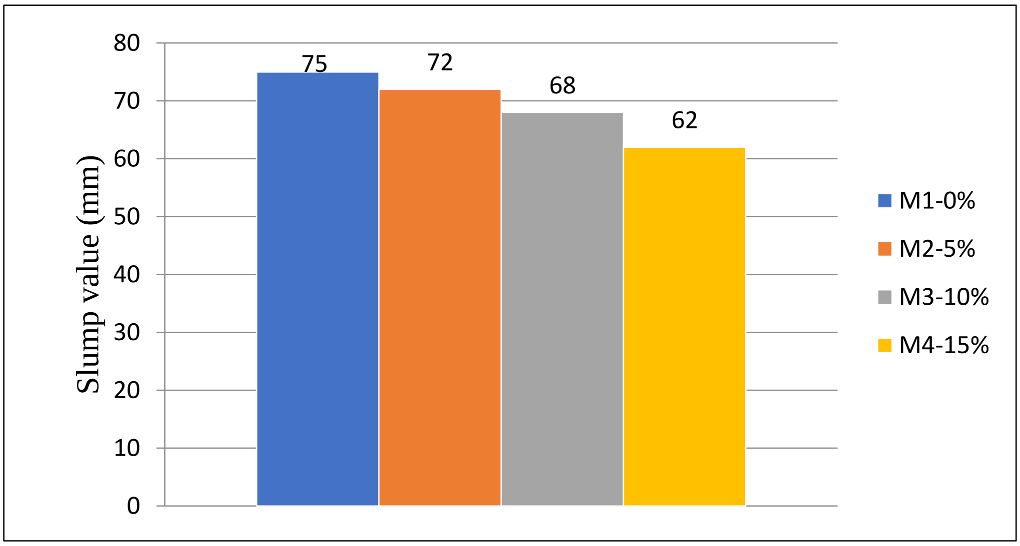

Figure 6. Slump value for trail mixes

From the bar chart, it was observed that slump value is gradually decreasing when the cement in the mix was partially replaced by waste paper pulp resulting in difficulty in mixing and handling of concrete.

4.2 Compressive strength test results

Totally 36 cubes of side 150mm were cast and tested for compressive strength (CS) of concrete. The average CST readings are given in Table 6 and displayed in Figure 7.

Table 6. Compressive Strength Results

Percentage of cement substitution by waste paper pulp	**Compressive strength (MPa)**		
	7^{th} day	14^{th} day	28^{th} day
0%	19.08	25.85	29.15
5%	20.60	27.43	29.27
10%	21.99	29.47	33.67
15%	18.83	25.43	24.29

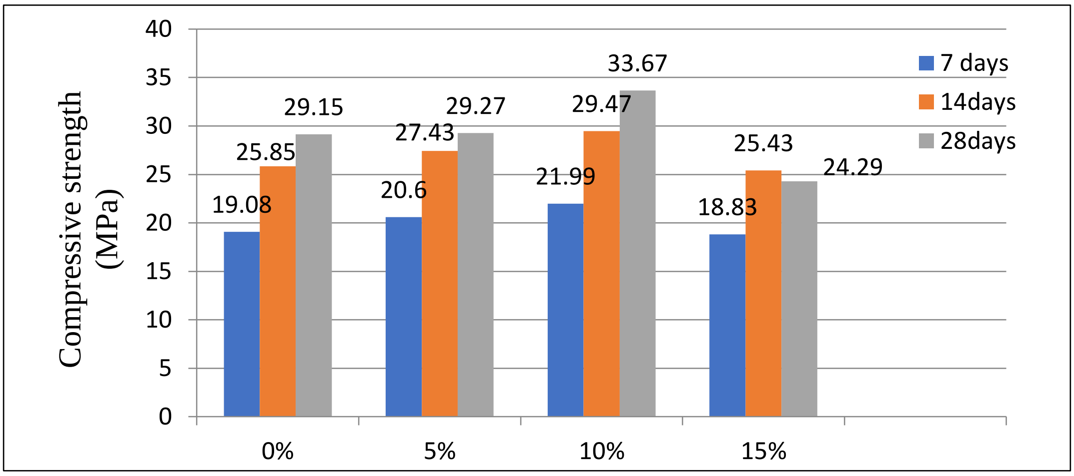

Figure 7. Compressive strength results

On the 28^{th} day, compressive strength was increased by about 15.5% by 10% substitution of cement with waste paper pulp. The strength was almost the same for 5% substitution and there was a fall in compressive strength of about 16.67% by 15% substitution than conventional concrete samples.

4.3 Tensile test results

Totally 12 cylindrical samples of dimensions ‘150mm diameter and 300mm height’ were cast to evaluate the tensile strength. The tensile strength of concrete was recorded on the 28^{th} day. The average STS test readings are presented in Table 7 and displayed in Figure 8.

Tensile strength was increased by about 7.5% by 5% substitution and increased by 3.6% by 10% substitution of cement with waste paper pulp and it gradually decreased after 10% substitution than conventional concrete samples.

Table 7. Split Tensile Strength Readings

Waste paper pulp (%)	28th day Split tensile strength (MPa)
0	3.07
5	3.30
10	3.18
15	2.76

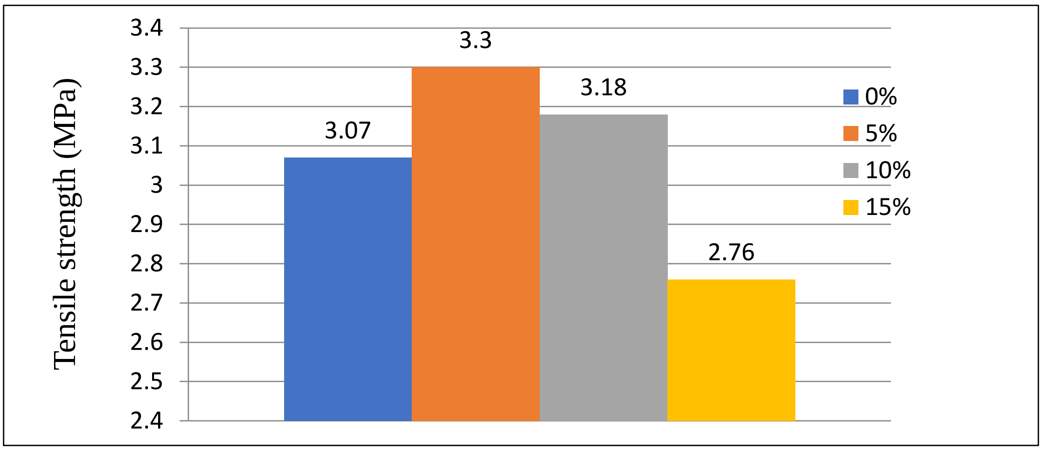

Figure 8. Split tensile strength results

4.4 Flexural strength test results

The average MOR test readings are given in Table 8 and depicted in Figure 9.

Table 4. Flexural Strength Readings

Waste paper pulp (%)	28th day Flexural strength (MPa)
0	13.50
5	14.97
10	13.84
15	11.63

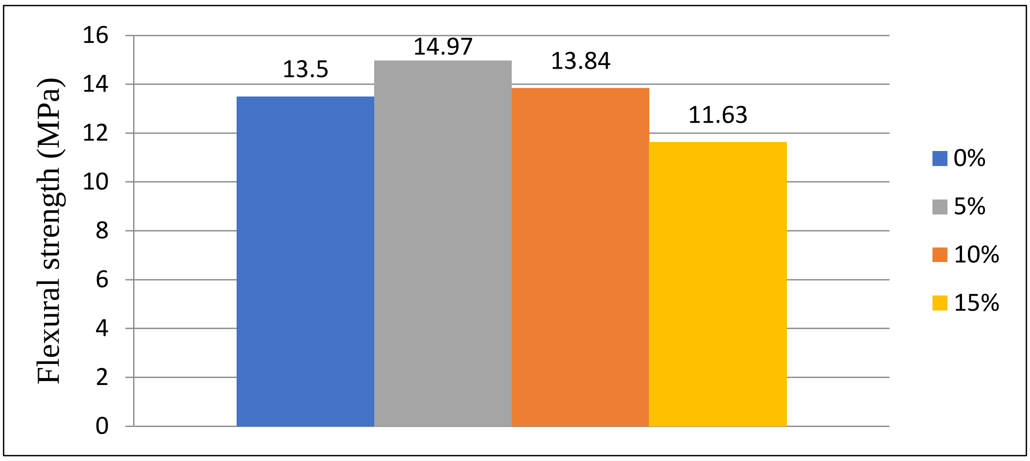

Figure 9. Flexural strength results

Totally 12 samples of dimensions ‘150mm x 150mm x 700mm’ were used for determining flexural strength or MOR of concrete. MOR of concrete was recorded on the 28th day.

Flexural strength was increased by about 10.89% by 5% substitution, 2.5% by 10% substitution and a decrease of about 13.9% by 15% substitution of cement by waste paper pulp than conventional concrete samples.

5. CONCLUSION

The experimental study of fractional substitution of cement with industrial waste paper pulp for economic and environment-friendly construction was carried out. The percentage substitution of cement in M25 grade concrete was done by 5%, 10%, 15%. The different strength tests were carried and compared with conventional concrete samples. The following deductions were drawn:

- The slump value was gradually decreasing when the cement was partially replaced with waste paper pulp. The 5% replacement of cement in M25 grade concrete yielded 4% less slump value than conventional concrete. However, 10% and 15% replacement of cement resulted in less workable concrete mixes.
- The compressive strength was increased by 15.5% by 10% replacement of cement. The strength was almost the same for 5% substitution and there was a fall in compressive strength of about 16.67% for 15% replacement of cement with waste paper pulp than conventional concrete samples.
- The tensile strength was increased by about 7.5% by 5% substitution and increased by 3.6% by 10% substitution of cement with waste paper pulp and it decreased gradually after 10% substitution than conventional concrete samples.
- The flexural strength was increased by about 10.89% for 5% replacement. There was a raise in flexural strength of about 2.5% for 10% replacement and a decrease in flexural strength of about 13.9% for 15% replacement of cement with waste paper pulp than conventional concrete samples.
- On the interpretation of results, partial replacement of cement can be achieved by 5% with waste paper pulp for satisfactory results.
- The use of waste paper pulp eliminates the need for disposal from paper mills. The cost of construction may reduce for large projects with 5% replacement of cement with waste paper pulp. Thus, the waste paper pulp can be recommended as a minor substitution of cement and it can be implemented in concrete construction.

CONFLICT OF INTERESTS

The authors would like to confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

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