

Study on the Utilization of Paper Mill Sludge as Partial Cement Replacement in Concrete

A.M. Md Nazar¹, N.F. Abas^{2,a}, M.A. Othuman Mydin³

^{1,2,3}School of Housing, Building and Planning, Universiti Sains Malaysia, 11800 Penang, Malaysia

Abstract. A major problem arising from the widespread use of forestry biomass and processed timber waste as fuel is related to the production of significant quantities of ash as a by-product from the incineration of such biomasses. A major portion (approximately 70%) of the wood waste ash produced is land-filled as a common method of disposal. If the current trend continues with waste products, such as paper mill sludge landfills, a large amount of space would be required by 2020. A revenue study was conducted as a result of investigations into the use of paper mill sludge as recycled materials and additives in concrete mixes for use in construction projects. The study had to provide the assurance that the concrete produced had the correct mechanical strength. Concrete mixes containing paper mill sludge were prepared, and their basic strength characteristics such as the compressive strength, flexural strength, ultra pulse velocity and dynamic modulus elasticity were tested. Four concrete mixes, i.e. a control mix, and a 10%, 20%, and 30% mix of paper mill sludge as cement replacement for concrete were prepared with a DoE mix design by calculating the weight of cement, sand and aggregate. The performance of each concrete specimen was compared with the strength of the control mix. As a result, when the percentage of paper mill sludge in the concrete increased, the strength decreased. Overall, a high correlation was observed between density and strength of the concrete containing paper mill sludge.

1 Introduction

This research is aimed at studying the effects of the addition of paper mill sludge on the original properties of concrete mixes by considering the performance of concrete containing different percentages of paper mill sludge and by developing a concrete mix that produces the highest compressive strength and flexural strength. Very few investigations have been conducted on the use of pulp and paper mill sludge in concrete. In early laboratory tests, some concrete mixtures containing fibrous residuals have been shown to possess higher compressive and splitting –tensile strengths than the control concrete mix without the residuals [8].

The use of paper mill sludge in structural concrete could be economical and profitable for landfills, incinerators and other options for reducing paper mill sludge waste. Paper mill sludge from recycled disposals could be a valuable material in construction as shown by the results that have been reported on the use of waste paper in structural concrete.

^a Corresponding author: nfaisal@usm.my

2 Materials and composition

The concrete mix used in this study was made from cement, coarse aggregate, fine aggregate, paper mill sludge and water.

2.1 Cement

Type I Portland cement, which meets the requirements of BS 12: 1996, was used in this research. To comply with MS 522, the cement will be described under the following headings as ordinary Portland cement.

2.2 Fine Aggregate

River sand and crushed granite with a maximum size of 5 mm and 20 mm, respectively were used in this research. The sand and gravel met the requirements of ASTM C 33.

2.3 Coarse Aggregate

The maximum nominal size of aggregate was as specified in the method. The fractions from 20mm to 4.75mm were used as the coarse aggregate. Coarse aggregate from crushed basalt rock, conforming to IS: 383, was used. The Flakiness and Elongation Indices were maintained well below 15%.

2.4 Paper Mill

Paper sludge was obtained from a local paper making factory. The sludge was disintegrated in a mortar mixer for 30 minutes and sieved through 2.36 mm openings. It had a moisture content of about 35%. However, heavy metal contents present in the paper sludge, which included copper (Cu), lead (Pb) and iron (Fe), were evaluated as 141 ppm, 241 ppm and 4088 ppm, respectively. A high range water reducing admixture (HRWRA) in a brown-yellowish powdery form was also used, and this met the requirements of ASTM C 494-99.

2.5 Water

The water has to comply with the requirements of MS 28. It has to be clean and free from material deleterious to concrete in a plastic and hardened state, and has to be from a source. Since it helps to strengthen the cement gel, the quantity and quality of water required has to be carefully considered. The water-cement ratio used was 0.40 for M25 concrete and 0.30 for M40 concrete.

3 Experimental Procedures

The research was carried out by mixing concrete in accordance with ASTM C 192 by using a revolving-drum tilting mixer. First, coarse aggregate, some of the mixing water, and paper mill sludge were added into the mixer. The mixer was then started and, after it had turned a few revolutions, it was stopped. Next, the sand was added, and the mixer was started and stopped again after it had turned a few more revolutions. Finally, the cement and the rest of the mixing water were added and mixed for three minutes. After all the ingredients were in the mixer, the new, fresh concrete was produced and was mixed for a further 2 minutes. After that, water was added during the mixing process to alter the concrete mixture to achieve the desired slump. The fresh concrete mixtures were determined, and the specimen tests were conducted for the evaluation of the strength of the concrete. The specimens were poured into moulds for 24 hours after casting and stored for air curing. The next day, the moulds were opened and the concrete specimens were cured in water to make them workable.

For each percentage specimen of added paper mill sludge, three cube specimens were tested for compression and two prism specimens were subjected to a flexural test, ultra pulse velocity test and dynamic modulus test. A total of 78 specimens were prepared for experimentation in this study. Each percentage had one reserved cube as a back-up. All the specimens were tested for curing periods of 1, 7, and 28 days.

4 Mixture Proportion, Results and Discussions

4.1 Mixture Proportion

Four concrete mixes containing Portland cement, paper mill sludge, gravel with 20 mm maximum size and river sand of 5 mm size together with water were studied and compared with a control mix. Various proportions of the paper mill sludge waste were investigated by batching each mix with 0 %, 10 %, 20 %, and 30 % of paper mill sludge waste by weight as shown in Table 1. The mixed proportions for all the mixes were based on the DoE mix design. The water to mixture of concrete containing paper mill sludge waste was based on preliminary testing to obtain a workable mix with enough water because of the high water absorption of the wastepaper.

Table 1. The mix proportion for all mixtures

Material	0 %	10 %	20 %	30 %
Cement (kg/m^3)	14.77	13.29	11.81	10.33
Paper mill sludge (kg/m^3)	0	1.48	2.96	4.44
Fine aggregate (kg/m^3)	37.83	37.83	37.83	37.83
Coarse aggregate (kg/m^3)	48.05	48.05	48.05	48.05
Water (kg/m^3)	9.66	9.66	9.66	9.66

4.2 Compressive strength

The test results showed that as the amount of paper mill sludge waste in the mix increased, the compressive strength of the mix decreased. As shown in Figures 1, 2 and 3, the compressive strength was generally lower for the 10%, 20% and 30 % added paper mill sludge waste compared to the 0% control mix. At Day 1, the compressive strength for the various mixes with the paper mill waste decreased from 2.51 to 1.41 N/mm² (Figure 1). At Day 7, the compressive strength decreased from 6.76 N/mm² to 4.39 N/mm² (Figure 2). At Day 28, the results showed a further decrease from 8.70 N/mm² to 3.36 N/mm² (Figure 3). This reduction in the compressive strength was mainly due to the high water-cement ratio of the mix.

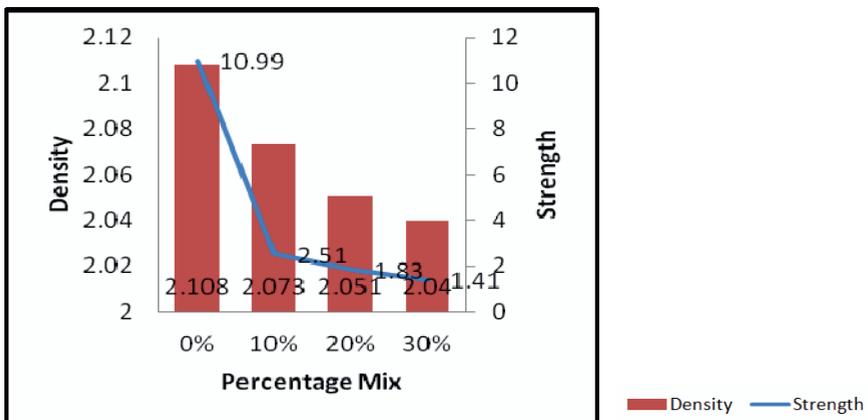


Figure 1. Compressive strength compared to density at Day 1

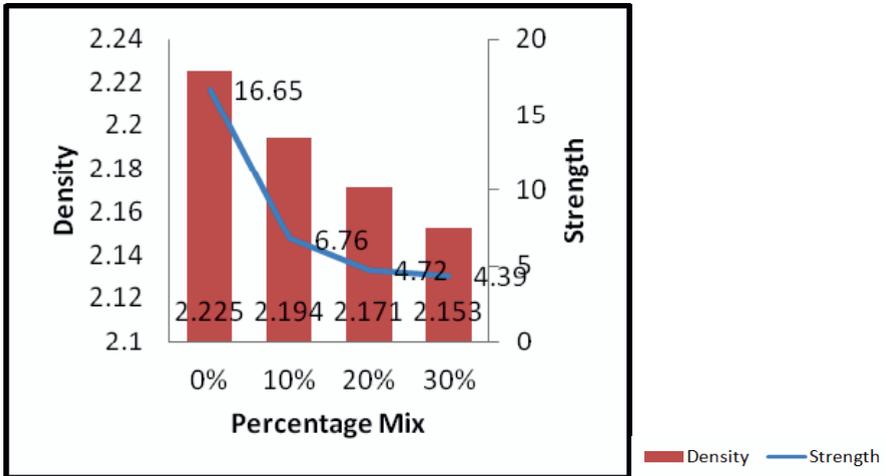


Figure 2. Compressive strength compared to density at Day 7

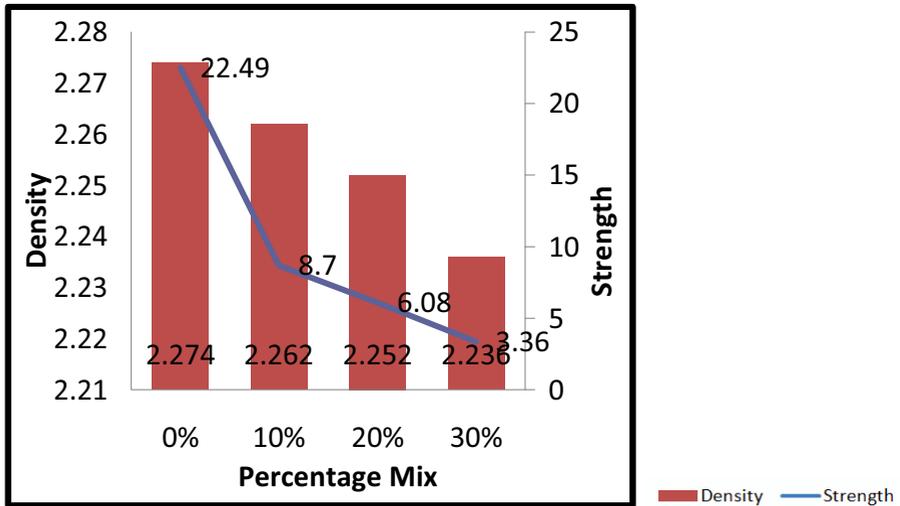


Figure 3. Compressive strength compared to density at Day 28

4.3 Flexural Strength

The flexural strength test was carried out in accordance with British Standard 1881: Part118:1983 “Method of determination of flexural strength”. This research compared the results of using 10%, 20%, and 30% of paper mill sludge waste respectively within 28 days. The results are presented in Figures 4, 5, and 6. The flexural strength was strongly affected by the water-cement ratio. The mix design of 10% paper mill sludge waste reached 2.98 N/mm² at 28 days. The average increment of flexural strength for 10%, 20% and 30% paper mill sludge waste within 28 days was about 11.75% compared to Day 1. This may be attributed to the lower water-cement ratio in the 10% and 20% mix compared to the 30% mix.

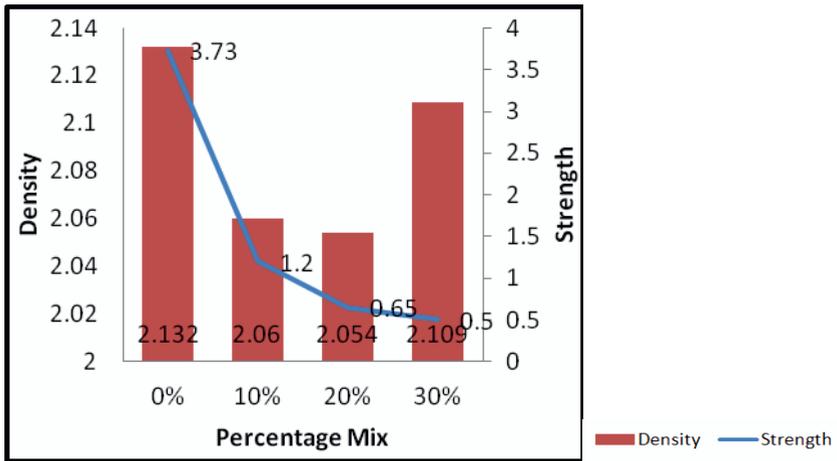


Figure 4. Flexural strength compared to density at Day 1

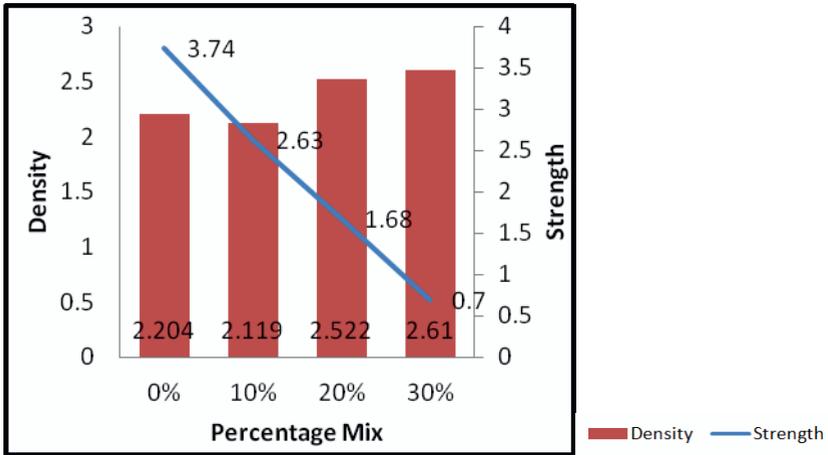


Figure 5. Flexural strength compared to density at Day 7

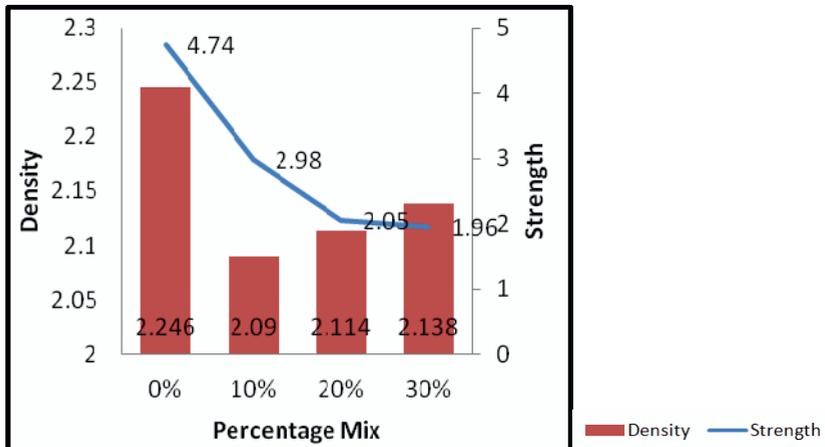


Figure 6. Flexural strength compared to density at Day 28

4.4 Ultra Pulse Velocity

From the experimental results, a table was used to determine the level of velocity along the length of the specimens.

Table 2. Ultrasonic Pulse Velocity Data 1 day

Mixture	Length (mm)	Pulse velocity (km/sec)		Probable Concrete Quality
		1	2	
Control Mix	100	3635	3687	Good
	500	3412	3496	Medium
10 %	100	2332	2430	Doubtful
	500	1399	1346	Doubtful
20 %	100	2212	2427	Doubtful
	500	1000	1093	Doubtful
30 %	100	1811	1845	Doubtful
	500	1072	943	Doubtful

Table 3. Ultrasonic Pulse Velocity Data 7 day

Mixture	Length (mm)	Pulse velocity (km/sec)		Probable Concrete Quality
		1	2	
Control Mix	100	4132	4291	Good
	500	3990	3886	Good
10 %	100	3340	3355	Medium
	500	3355	3460	Medium
20 %	100	1411	1448	Doubtful
	500	2732	2931	Doubtful
30 %	100	3067	3086	Medium
	500	1847	1916	Doubtful

Table 4. Ultrasonic Pulse Velocity Data 28 day

Mixture	Length (mm)	Pulse velocity (km/sec)		Probable Concrete Quality
		1	2	
Control Mix	100	4366	4132	Good
	500	4038	4068	Good
10 %	100	3472	3717	Good
	500	3270	3272	Medium
20 %	100	3158	3610	Medium
	500	2836	2886	Doubtful
30 %	100	3584	3334	Medium
	500	2978	3073	Medium

4.5 Dynamic Modulus

The results for this test followed the equation for the stress and strain relation curve. The correlation between the dynamic modulus of elasticity followed the American ASTM C215 standard (ASTM, 2002). The results in Table 5, Table 6 and Table 7 show the dynamic modulus for 1, 7, and 28 days.

Table 5. Dynamic modulus Test data 1 day

Mixture	Prism	Length (mm)	Width (mm)	Height (g)	Weight (g)	Frequency (Hz)	E_0 (N/mm)
Control mix	F1	499	100	100	10700	18.7	746.84
	F2	500	100	100	10600	19.4	797.88
10%	F1	498	100	100	10560	5.6	65.98
	F2	500	100	100	10005	5.4	58.35
20%	F1	500	100	100	10478	5.2	56.67
	F2	499	100	100	10050	5.3	56.36
30%	F1	500	100	100	10285	2.5	12.86
	F2	500	100	100	10813	2.9	18.18

Table 6. Dynamic modulus Test data 7 days

Mixture	Prism	Length (mm)	Width (mm)	Height (g)	Weight (g)	Frequency (Hz)	E_0 (N/mm)
Control mix	F1	499	100	100	11036	24.1	1279.4
	F2	500	100	100	10986	23.5	1213.4
10%	F1	498	100	100	10810	13	363.92
	F2	499	100	100	10321	12	296.65
20%	F1	500	100	100	10869	10.7	237.02
	F2	500	100	100	10351	11.6	278.57
30%	F1	500	100	100	10698	12	308.10
	F2	498	100	100	11350	12.6	358.94

Table 7: Dynamic modulus Test data 28 day

Mixture	Prism	Length (mm)	Width (mm)	Height (g)	Weight (g)	Frequency (Hz)	E_0 (N/mm)
Control mix	F1	499	100	100	11049	27	1607.72
	F2	500	100	100	11394	26.5	1600.29
10%	F1	498	100	100	10535	15	472.18
	F2	499	100	100	10110	16	516.60
20%	F1	500	100	100	10291	12.4	316.49
	F2	500	100	100	10849	12.9	361.08
30%	F1	500	100	100	10395	13	351.36
	F2	498	100	100	10941	12.5	340.54

5 Conclusions

Various tests were carried out on different specimens and the data collected were discussed in order to achieve the objective of this research. Marginally, the paper mill sludge did not increase the strength of the concrete mixtures. From the test results and the analysis of the experiments that were carried out, the following are the main conclusions and recommendations of this study:

1. Paper mill sludge waste is suitable for use in small amounts of concrete mixes as a replacement for cement, but it not appropriate for large quantities.

2. The best percentage of mix volume for paper mill sludge is 10 %, because it has a tendency to absorb water and its strength is long-lasting.
3. A good relationship was observed between the density and strength of concrete mixes containing paper mill sludge.

References

1. Castro J. et al. Effect of sample conditioning on the water absorption of concrete, *Cement & Concrete Composites* (33) (2011) 805–813.
2. F.D. Lydon, A.H. Mahawish, Tests of the permeability of concrete to nitrogen gas, *Construction and Building Materials*, Volume 5(1) (1991) 8-17.
3. M.Abdullai, Characteristic of wood ASH/OPC, Concrete Civil Engineering Department, Federal University of Technology ,P.M.B 65,Minna,Niger State,Nigeria ,(2009)
4. Picandet V. et al., Effect of axial compressive damage on gas permeability of ordinary and high-performance concrete. *Cement and Concrete Research* 31 (2001) 1525–1532.
5. Rajamma, R., Ball, R. J., Tarelho, L. A., Allen, G. C., Labrincha, J. A., & Ferreira, V. M. , Characterisation and use of biomass fly ash in cement-based materials, *Journal of hazardous materials*, 172(2), (2009) 1049-1060.
6. Sata, V., Tangpagasit, J., Jaturapitakkul, C., & Chindaprasirt, P., Effect of W/B ratios on pozzolanic reaction of biomass ashes in Portland cement matrix. *Cement and Concrete Composites*, 34(1), (2012) 94-100.
7. Scrivener, K. L., & Kirkpatrick, R. J. , Innovation in use and research on cementitious material. *Cement and Concrete Research*, 38(2), (2008) 128-136.
8. Tarun R. Naik, F.ASCE Concrete with paper industry fibrous residuel: mixture proportioning, *ACI Material Journal*,102 (4) (2005)
9. Uokino, E.Y.A. et al. Utilization of Wastepaper to Manufacture Low Density Boards. *Bioresource Technology*, Volume 73 (1) (2000) 77-79