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Concrete Containing Pulp and Paper Mill Residuals

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Abstract

Fibrous residuals generated from pulp and paper mills were included in concrete. With proper dosage of HRWRA, slump and compressive strength of the concrete containing the residuals was managed as desired. In general, dosage of HRWRA was proportional to the amount of wood fibers in concrete. Residuals did not affect strength development of concrete. In general, at somewhat lower compressive strength, concrete containing the residuals showed equivalent length change (drying shrinkage) compared with the reference concrete made without the residuals.

INTRODUCTION

Pulp and paper mill wastewater treatment plant residuals (also called sludge) are the solid residue removed from mill wastewater before the water is discharged into the environment or reused in the mill. Residuals are removed via a two-step process of treating the wastewater (Smook 1992, Unwin 2000, NCASI 1992, Scott 1995, NCASI 1993). Primary residual is the solids removed from the primary clarifier. Primary clarification is usually carried out by sedimentation, but in some cases by dissolved air flotation. In the sedimentation process, chemical additives are used to make non-settleable solids settleable through flocculation. Primary residual consists mainly of cellulose fibers and papermaking fillers (kaolinitic clay, calcium carbonate, and/or titanium dioxide). In some cases, ash generated at mill and inert solids rejected during chemical recovery processes become part of the primary residual. The water clarified by the primary treatment is passed on to the secondary treatment. Secondary treatment is usually a biological process in which micro-organisms convert soluble organic matter to carbon dioxide and water while consuming oxygen. Secondary residual is mainly microbial biomass (also called biosolids) grown during this process and removed through clarification. Many times primary and secondary residuals are combined to facilitate handling. In most cases, the residual solids are dewatered before disposal or beneficial use.

Because of the cellulose fibers present in the residuals, use of the residuals as microfiber reinforcement in concrete could become an economical and beneficial alternative to landfills or other use options.

OBJECTIVES

The objectives of this research were to establish technical, economical, and performance benefits of using pulp and paper mill residuals in ready-mixed concrete and to establish optimum mixture proportions and production technology for concrete containing residuals.

MATERIALS

Cement, Fine and Coarse Aggregates, and Chemical Admixtures

Type I portland cement meeting the requirements of ASTM C 150 was used in this research. Fine aggregate (sand) used in this research had 1800 kg/m^3 bulk density, 2.73 specific gravity, 1.3 % absorption, and 2.88 fineness modulus. Crushed stones with a 19-mm maximum size were used as coarse aggregate in this research. The coarse aggregate had 1570 kg/m^3 bulk density, 2.67 specific gravity, and 0.4 % absorption. The sand and the coarse aggregate met the requirements of ASTM C 33.

High-range water-reducing admixture (HRWRA) used in this research was a carboxylated polyether liquid admixture meeting the requirements of ASTM C 494.

Residuals

A total of seven sources of pulp and paper mill residuals were used representing a wide variation in the type of wood fibers and processes. Types, physical properties, loss on ignition (LOI), and wood fiber content of the residuals are presented in Table 1. Mineralogical composition of the residuals is presented in Table 2. Scanning electron micrographs (SEM) of oven-dry samples of residuals are presented in Fig. 1. Magnification is 100 times.

Deflocculation (or "Repulping") of Residuals

Due to dewatering, as-received residuals contained fibrous clumps that consist of wood fibers, clay (if any), and other particulates (if any). These clumps may be considered as weaker spots in concrete compared with well-dispersed individual fibers and particles. Also, in order for the fibers to function as fibers, they must be separated into individual fibers.

Therefore, all seven sources of residuals were deflocculated, or "repulped", into separated wood fibers and particulates (if any) before their addition to the concrete mixture. The "pulper" used for this purpose in the laboratory consisted of a 19-liter (5-gal.) plastic bucket and a high-speed mixer with a spinning rotor positioned above the bottom of the bucket. Mechanical repulping was performed by immersing the residuals in room-temperature water in the bucket and subjecting the mixture to a high-speed rotation by the rotor blades for not less than 20 minutes. Residuals C1, C2, WG, and BR deflocculated readily upon mechanical repulping. However, it took higher mixing speed and longer mixing time to deflocculate Residuals I, S, and WV. The reason for this was attributed to higher-degree dewatering of I, S, and WV residuals.

SPECIMEN PREPARATION

Mixing was done in accordance with ASTM C 192 using a revolving drum, tilting mixer. Properties of freshly mixed concrete were determined (Table 3), and test specimens were cast for the evaluation of mechanical and long-term properties.

Compressive strength was determined by testing three 100 $\times$ 200 mm cylinders per each age, per each concrete mixture. Length change specimens used were 75 × 75 × 285 mm prisms which were stored in lime-saturated water until the age of 28 days and subsequently stored in a drying room maintained at a temperature of 23 ± 2 °C and a relative humidity of 50 ± 4 %.

MAJOR FINDINGS FROM PRELIMINARY INVESTIGATION

Series of preliminary concrete mixtures were made to establish mixture proportions for concrete containing paper mill residuals. Major findings from the preliminary investigation were as follows:

1. Residuals do not affect compressive strength development of concrete.
2. With proper combination of residuals and HRWRA, slump and compressive strength of concrete can be adjusted.
3. Practically, by achieving equivalent density, equivalent-strength residuals concrete can be produced.

TEST MIXTURES—MIXTURE PROPORTIONS, RESULTS, AND DISCUSSIONS

Mixture Proportions

Based on the mixture proportions established during the preliminary investigation, concrete mixtures were produced in the laboratory in two groups: (1) Reference 1 (without residuals), C1, WG, C2, and WV; and (2) Reference 2 (without residuals), BR, I, and S. As-received residuals content by mass of concrete was 0.65 % for C1, C2, WG, WV, I, and S; and 0.35 % for BR. Mixture proportions and fresh concrete properties are presented in Table 3.

Depending on the source of residuals, amount of wood fibers in concrete varied between 2.4 to 4.9 kg/m^3 (4.0 to 8.3 lb/yd^3) (when converted to fiber mass on dry basis). In general, to keep the slump within the range of 75 to 150 mm (3 to 6 in.), higher dosage of HRWRA was required for concrete with higher wood fiber content. Air-entraining admixture was not used. Density values of fresh concrete mixtures were almost uniform. In general, air contents of reference and residuals concrete mixtures were similar (1.8 vs. 1.9 % on average).

Compressive Strength

Test results for compressive strength of concrete are presented in Figs. 2 and 3. Overall, the 28-day compressive strength was 43.2 MPa (6270 psi) on average. In these particular groups of mixtures, residuals concrete showed average of about 15% lower 28-day compressive strength than the Reference Concrete. Reference and residuals concrete mixtures showed similar patterns of strength development.

Length Change

Test results for length change (i.e., drying shrinkage) of concrete are shown in Figs. 4 and 5. C1, C2, WG, and WV concrete mixtures showed somewhat higher drying shrinkage than their reference mixture (Ref. 1). BR, I, and S concrete mixtures showed a little lower drying shrinkage than their reference mixture (Ref. 2). Overall, drying shrinkage of residuals concrete was similar to that of the Reference Concrete.

CONCLUSIONS

Based on the data presented, the following conclusions can be drawn:

1. Without the use of HRWRA, fibrous residuals from pulp and paper mills either reduce slump or increase water demand of concrete.
2. With proper dosage of HRWRA, slump and compressive strength of the concrete containing the residuals can be managed as desired. In general, dosage of HRWRA was proportional to the amount of wood fibers in concrete. Residuals do not affect strength development of concrete.
3. In general, at somewhat lower compressive strength, concrete containing the residuals showed equivalent length change (drying shrinkage) compared with the reference concrete made without the residuals.

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REFERENCES

Smook, G.A. (1992), *Handbook for Pulp and Paper Technologists*, 2nd Ed., Angus Wilde Publications, Bellingham, WA.

Unwin, J. (2000), "Why Bury It When You Can Use It?: NCASI's Support of the Industry's Efforts To Find Beneficial Uses For Solid Wastes," *Proc. of the 2000 NCASI National Meeting*, National Council for Air and Stream Improvement (NCASI), Research Triangle Park, NC, 57-74.

NCASI (1992), *Solid Waste Management and Disposal Practices in the U.S. Paper Industry*, Technical Bulletin No. 641, New York, NY.

Scott, G., and Smith, A. (1995), "Sludge Characteristics and Disposal Alternatives for Recycled Fiber Plants," *1995 Recycling Symposium*, Technical Association of the Pulp and Paper Industry (TAPPI), Atlanta, GA, 239-249.

NCASI (1993), *Alternative Management of Pulp and Paper Industry Solid Wastes*, Technical Bulletin No. 655, New York, NY.

Table 1. Types, Physical Properties, LOI, and Wood Fiber Content of Residuals

Designation	Type	Fiber Origin(s)	Moisture Content (%)	Specific Gravity	As-Recd Bulk Density (kg/m^3)	Avg. Fiber Length (mm)	Loss On Ignition (%)	Wood Fiber (%)
C1	Primary	Virgin	185	1.77	1080	1.22	54.9	43
C2	Primary	Virgin	220	1.69	1000	1.20	73.1	64
I	Primary	Recycled	95	2.04	830	0.85	49.7	40
S	Primary	Recycled (80 %)	84	2.00	660	1.11	57.9	49

		+ Virgin (20 %)						
WG	Primary	Virgin	116	2.17	750	1.51	43.6	35
WV	Primary	Virgin	142	1.62	570	1.68	82.3	77
BR	Fiber Reclaim	Virgin	230	1.56	450	1.34	99.6	94
Avg.	…	…	153	1.83	760	1.27	65.9	57

Table 2. Mineralogical Composition of Residuals by Powder Diffraction Analysis (% by mass)

Mineral	Residuals					
	C1	C2	I	S	WG	WV
Calcite ($CaCO_3$)		15	51	36	63	21
Kaolinite* ($Al_2Si_2O_5(OH)_4$)	52	14	16	7		2
Magnesite ($MgCO_3$)				7		
Quartz (SiO_2)		5		1	2	3
Talc ($Mg_3Si_4O_{10}(OH)_2$)		< 1		3		

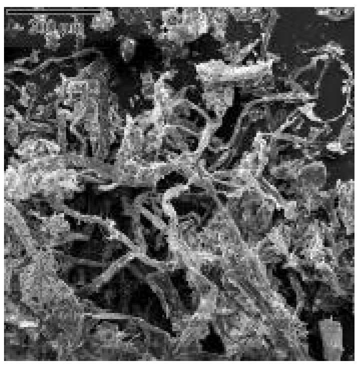
* Kaolin-type clay

Table 3. Mixture Proportions and Fresh Properties of Concrete

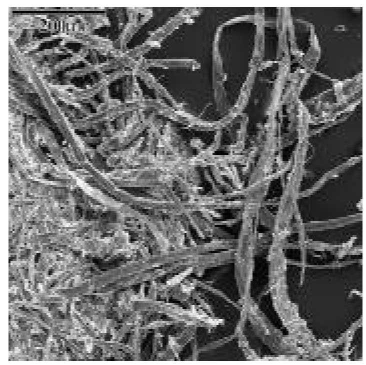
Mixture Name	Ref. 1	C1	C2	WG	WV	Ref. 2	BR	I	S
Residuals, as-recd (% of conc. by mass)	0	0.65	0.65	0.65	0.65	0	0.35	0.65	0.65
Wood Fibers (kg/m^3)*	0	2.4	3.1	2.5	4.9	0	2.4	3.3	4.2
Residuals, as-recd (kg/m^3)	0	15.6	15.7	15.6	15.7	0	8.5	16.0	15.7
HRWRA (L/m^3)	0.81	1.79	2.97	2.25	3.36	0.82	1.47	3.50	5.51
Cement (kg/m^3)	368	360	363	359	361	367	365	368	363
Sand, SSD (kg/m^3)	856	837	848	836	841	852	847	855	841
Coarse Agg., 19-mm max., SSD (kg/m^3)	1050	1030	1030	1020	1030	1050	1040	1050	1030
Water (kg/m^3)	156	149	156	162	158	158	151	156	159

w/cm	0.43	0.41	0.43	0.45	0.44	0.43	0.41	0.42	0.44
Slump (mm)	115	90	150	180	125	75	125	90	75
Air Content (%)	1.6	2.8	1.6	1.8	1.7	1.9	2.3	1.3	1.8
Density (kg/m^3)	2430	2390	2420	2400	2410	2420	2410	2440	2410

* From residuals. As-received (moist) residuals were used, but the mass of the fibers is reported on dry basis.



C1



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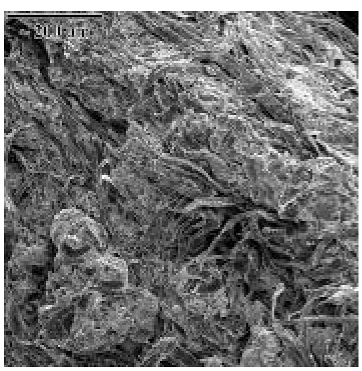

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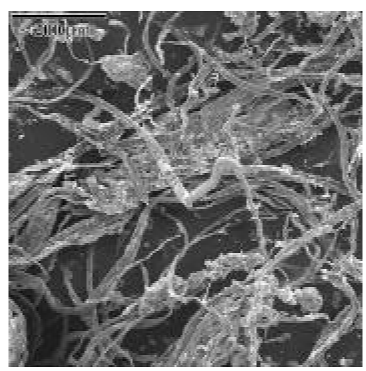
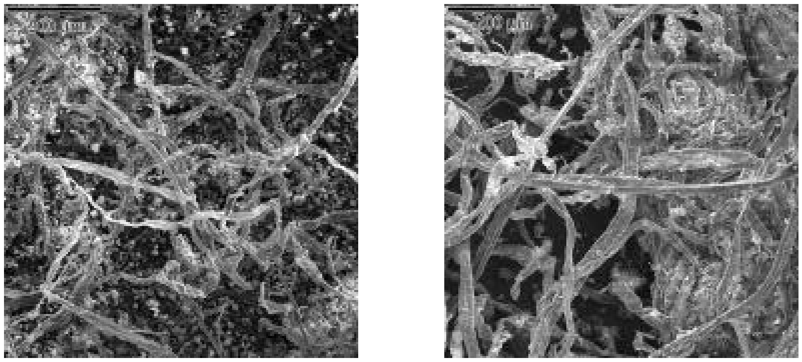


S



WG **WV**

Fig. 1. Scanning Electron Micrographs of Residuals (100 ´)

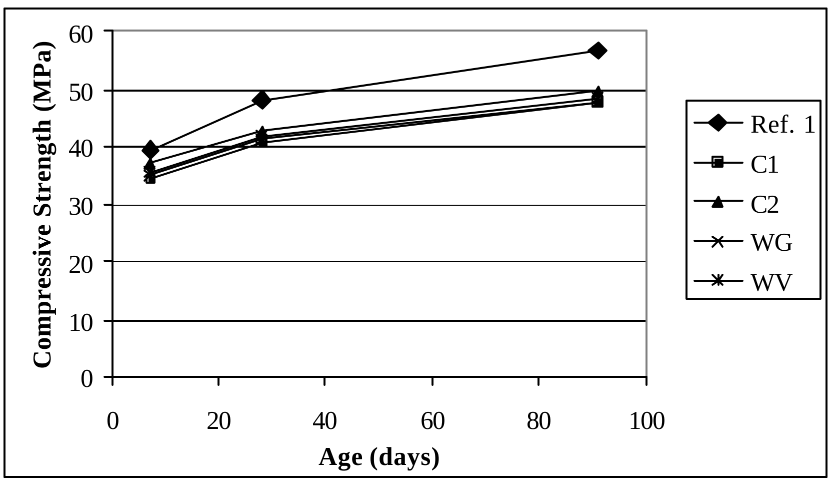


Fig. 2. Compressive Strength of Concrete (C1, C2, WG, WV)

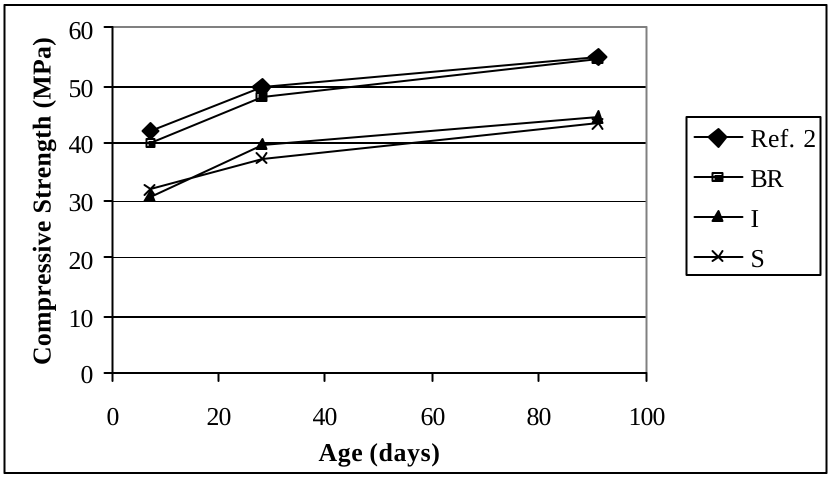


Fig. 3. Compressive Strength of Concrete (BR, I, S)

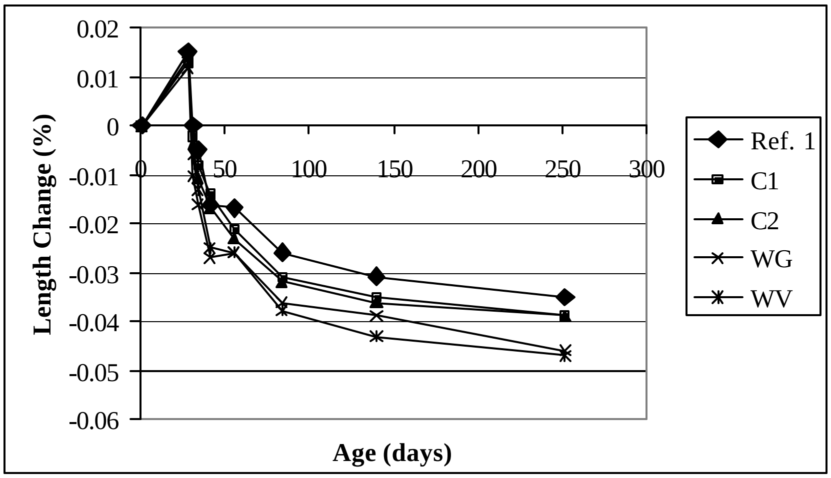


Fig. 4. Length Change of Concrete Due to Curing in Water and Drying in Air (C1, C2, WG, WV)

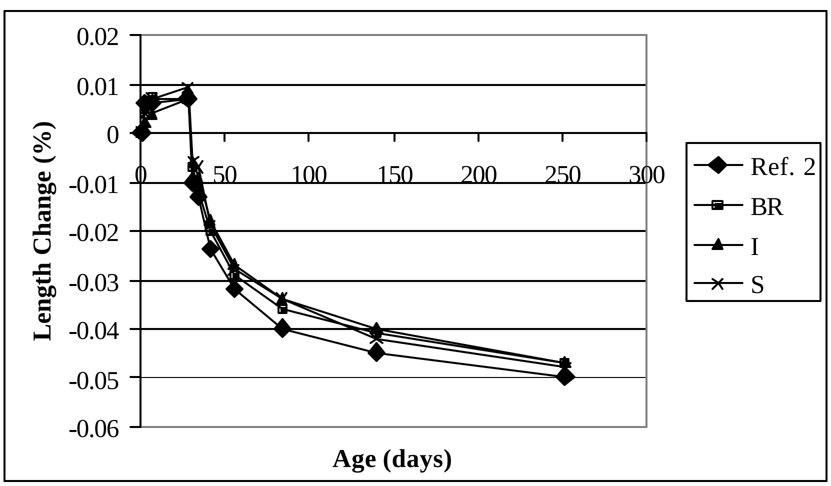


Fig. 5. Length Change of Concrete Due to Curing in Water and Drying in Air (BR, I, S)