

Beneficial Reuse of Corrugated Board in Slurry Applications

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ABSTRACT: Use of virgin and post-consumer corrugated board as a replacement for bentonite in slurry mixes was investigated. The effectiveness of the slurry mixes was assessed using typical tests including Marsh funnel viscosity, density, and filtrate loss. Filter cake permeability was also determined. Corrugated board was fiberized for the test program. Test results indicated that corrugated board could be used to replace 9 to 27% (0.5 to 1.5% corrugate content) of bentonite in slurry mixes with a total solids content of 5.5%. Slurry applications provide a new and viable beneficial reuse alternative for paper/paperboard products, which constitute the largest weight and volume fraction of municipal solid waste generated and disposed of in the U.S.

INTRODUCTION

Bentonite slurries are used in construction of vertical cutoff walls for geotechnical and geoenvironmental applications. The construction of cutoff walls typically is a step-by-step process, where a trench is excavated, filled first with slurry, and then backfill. The slurry covers the inside walls of the trench forming a low permeability filter cake layer. The slurry also provides hydrostatic pressure to keep the trench open prior to placement of the backfill. Typical slurries consist of 4 to 7% bentonite and 93 to 96% water by weight (Boyes 1975). Paper and paperboard constitute the highest fraction by both weight and volume of municipal solid waste generated (32.7% by weight) and disposed of (22.3% by weight) in the U.S. The amount of paper and paperboard generated and disposed of was 83 million and 37.8 million tons in 2007, respectively (USEPA 2009). The use of recovered paper in manufacturing containerboard has remained stable at approximately 16 million tons since 1997 (Paper Industry Association Council 2008). An economical limit for incorporating

waste papers into containerboard has been reached. Some corrugated board is not suitable for conventional recycling due to presence of contamination. Pizza boxes are a common example, which comprise nearly 1% of the total annual production of 313 million m² of corrugated board (Flaherty 2009). Residue on pizza boxes is problematic for recycling as grease prevents absorption of moisture, proper pulping of paper fiber, and quality of binding of fibers in recycled paper (RecycleBank 2009). Innovative recycling options (beyond the packaging industry) need to be investigated to promote beneficial reuse of paper products. This study has been conducted to evaluate reuse of paper and paperboard in civil engineering applications. Results from the portion of the study with use of corrugated board in slurry applications are presented herein.

EXPERIMENTAL TEST PROGRAM

Tests were conducted to assess the feasibility of using corrugated board in slurry mixtures. Bentonite was replaced by corrugated board at varying ratios. Properties of bentonite-board-water mixes were compared to baseline bentonite-water mixes to evaluate the influence and practical limits of corrugated board addition.

Materials

A commercially available standard powder bentonite was used in the test program. Baroid AQUAGEL is a finely ground, premium-grade Wyoming sodium bentonite that meets the American Petroleum Institute (API) Specification 13A, section 4 requirement. The bentonite had a liquid limit = 539, plastic limit = 82, and specific gravity = 2.65. Corrugated board was selected as the paper/paperboard product due to the significant quantities available for reuse. Tests were conducted on non-waxed products. Two types of corrugated board were used in the test program: conventional box material (c-flute corrugated board) and pizza boxes. Identical products for virgin (V) and post-consumer (PC) corrugated board were tested to determine potential effects of use on the properties of corrugated board in slurry applications. The c-flute corrugated board was subjected to standardized laboratory conditioning as prescribed by ISTA (2009) to provide post-consumer status. The post consumer pizza boxes were collected from a garbage bin and contained representative amounts of food product (i.e., grease and food remains) residue. The corrugated board samples were fiberized by mixing with water in a Waring cb 15 stainless steel 4-L capacity blender that contained a specially fabricated blade adhering to the specifications outlined by White and Kendrick (2009).

Corrugated Board Tests

Tests (summarized in Table 1) were conducted on virgin and post-consumer corrugated board to determine material properties. The corrugated board properties are presented in Table 2. The edge crush and water absorption tests on corrugated board provided indication of the fiberization potential and shredding of the corrugated board for the proposed slurry application.

Table 1. Corrugated Board Tests

Test Name	Standard Designation	Description of Test
Grammage of paper and paperboard (weight per unit area)	TAPPI T 410 om-02	Weight per 92.90 m ² of all three containerboard components of a single wall corrugated fiberboard is determined after conditioning for 24 hours at 21±1°C temperature and 52±0.5% RH.
Bursting strength of corrugated and solid fiberboard	TAPPI T810 om-06	Square corrugated fiberboard samples with dimension 31.50±0.03 mm are tested by distending an expandable diaphragm under a pressure of 690 kPa to 4825 kPa.
Edgewise compressive strength of corrugated fiberboard	TAPPI T839 om-02	A test specimen with length 50.8±0.8 mm and height 25.4±0.4 mm is compressed vertically (load parallel to flutes) to failure at the rate of 111±22 N/s.
Water absorptiveness of corrugated fiberboard (Cobb test)	TAPPI T 441 om-04	A sample with a diameter of 11.28±0.02 cm is exposed to 100 mL of water (23±1°C) and a head of 1±0.1 cm for 120 seconds.

Table 2. Corrugated Board Properties

Material	Weight/Unit Area (g/m ²)	Burst Strength (kPa)	Edge Crush (N)	Cobb Test (g/m ²)
V c-flute box	579	1350	162	78.3
PC c-flute box	588	1140	146	89.0
V pizza box	447	900	155	94.3
PC pizza box	493	1025	165	99.0

Slurry Tests

Slurry mixes were prepared using bentonite and water and also using bentonite, fiberized corrugated board, and water. Visual comparison was made for the solids suspension / sedimentation behavior of the bentonite and fiberized corrugated board by allowing mixtures to settle in hydrometer jars and by centrifugation. Example photographs of the slurries are presented in Fig. 1. The centrifuge was run at 1500 rpm for 1 minute to assess segregation and sedimentation in the mixtures. At high fiber ratios, the homogeneity of the slurries was decreased as flocculation and segregation of the fibers occurred (presence of clear water within the grab samples and at the top of the centrifuge samples). Bentonite dispersed in water and remained in suspension for extended periods of time, whereas the paper fibers alone flocculated in the presence of water and became segregated from the bentonite with time. In addition, high corrugate content mixtures exhibited gas production within 5-6 days of mixing, which remained entrapped within the fiber matrix. Overall, fiber-only and low-bentonite content mixes (<2.5% bentonite) were deemed inappropriate to provide effective slurry behavior. Solids remained in suspension for slurry mixtures that contained both fibers and sufficient amounts of bentonite. The specific mixtures tested for slurry behavior were based on these observations.

All mix ratios are provided on weight basis (Table 3). Tap water was used for all slurry mixes. The water was conditioned to a pH of 8.5 ± 0.12 using small amounts of soda ash before solids were added to the slurry mixtures. Pure bentonite slurries were mixed in a blender on low speed for 2 minutes prior to testing. For slurries containing corrugated board, water and corrugated board were mixed on low speed

for a 2-minute period to allow corrugate to be pulped into fibers, then mixed again after the addition of bentonite for an additional 2 minutes. The post-consumer corrugated board was more difficult to pulp than the virgin corrugated board. The original pulping period of 2 minutes was increased to 5 minutes for post-consumer corrugated board samples in subsequent tests to investigate the effect of increased pulping duration on the engineering properties of the slurry mixtures.

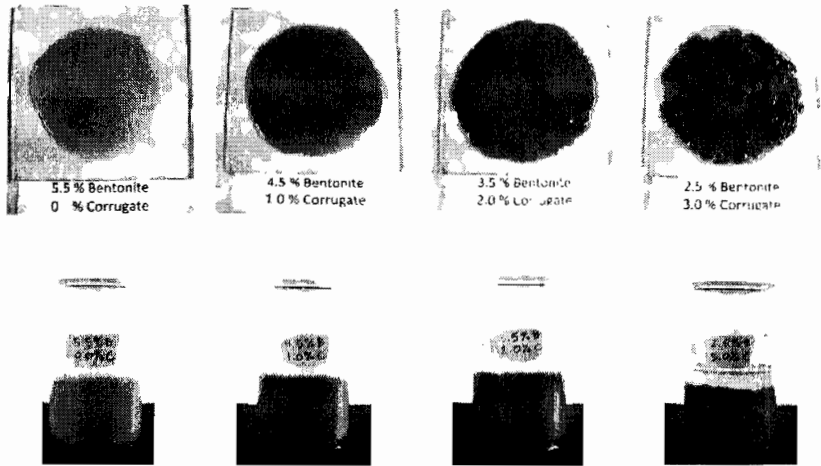


Figure 1. Comparison of Slurry Mixtures (grab and centrifuge samples)

Table 3. Slurry Mix Ratios

Mix Number	Corrugate Type	Bentonite (%)	Corrugated Board (%)	Water (%)
B5.0	None	5.0	0	95
B5.5	None	5.5	0	94.5
B6.0	None	6.0	0	94
V0.5	Virgin	5.0	0.5	94.5
V1.0	Virgin	4.5	1.0	94.5
V1.5	Virgin	4.0	1.5	94.5
V2.0	Virgin	3.5	2.0	94.5
V2.5	Virgin	3.0	2.5	94.5
V3.0	Virgin	2.5	3.0	94.5
PC0.5	Post-consumer	5.0	0.5	94.5
PC1.0	Post-consumer	4.5	1.0	94.5
PC1.5	Post-consumer	4.0	1.5	94.5
PC2.0	Post-consumer	3.5	2.0	94.5
PC2.5	Post-consumer	3.0	2.5	94.5
PC3.0	Post-consumer	2.5	3.0	94.5

Typical slurry tests (D'Appolonia 1980, USEPA 1984) were used in the experimental program: Marsh funnel viscosity (ASTM D 6910); mud balance (ASTM

D 4380); filter press (API Recommended Practice 13B); and filter cake permeability (conducted in conjunction with / immediately following API Recommended Practice 13B). Standardized test methods were generally followed. In order to prevent segregation of paper fibers from the slurries, the mixtures containing fibers were not poured through the attached funnel screen in Marsh funnel testing. The thickness of the filter cake was measured by averaging values determined at three locations on the cake using a pair of digital calipers. Thickness of the filter cake was measured after permeability tests had been conducted to minimize damage and disturbance to the filter cake. Separate tests were conducted to verify that filter cake thickness did not change during the permeability stage of the experiments. The permeability tests were conducted using a pressure differential of 140 kPa. The hydraulic gradient varied depending on the thickness of the filter cake and was on the order of 5,000.

RESULTS AND DISCUSSION

The results of the slurry tests are provided in Table 4. The Marsh funnel viscosity of the bentonite-water slurry mix was equal to 40.5 s for the 5.5% solids content and this mixture was established as the baseline mixture for the tests. The total solids content of the mixes containing both bentonite and corrugated board was set to 5.5%. The viscosity of the mixture with 5% bentonite was in general similar to the baseline mix, whereas the 6% bentonite mix had higher viscosity and density and lower filter cake thickness than the baseline mix. For mixes containing bentonite, corrugated board, and water, viscosity, filter loss, filter cake thickness, and filter permeability generally increased with increasing corrugate content. Mud balance density generally decreased with increasing corrugate content.

Acceptable slurry mix properties were established as: Marsh funnel viscosity of approximately 40 s (up to 50 s was deemed acceptable for this test program); density of 1010-1040 kg/m³; and filtrate loss of less than 30 ml based on specifications provided in USEPA (1984) and Ryan and Day (2003). The variations of Marsh funnel viscosity, density, filtrate loss, and permeability as a function of corrugate content are presented in Fig. 2. Shaded regions in the plots in Fig. 2 represent areas that are outside acceptable limits for Marsh funnel viscosity, mud balance density, and filtrate loss. In general, mixtures up to approximately 1.5% corrugate content (baseline, V mixes up to 1.5%, PC mixes up to 1.0%, and PC(+) mixes up to 2% corrugate content, Table 4) maintain acceptable engineering properties. The corrugated board can be used to replace 9 to 27% (0.5 to 1.5% corrugate content in a 5.5% mixture) of the bentonite used in the slurry mixes. In addition, the PC2.0-P(+) slurry (2% corrugate) and other 2% corrugate slurry mixtures were close to the acceptable range and may be used based on specific site and construction conditions. Significant amount of this natural resource (i.e., bentonite) can be saved using the corrugated board, in consideration to large-scale construction projects.

The differences between virgin and post-consumer board were not significant with regard to performance in slurry mixes. The changes in engineering properties of the slurries with added corrugate content were attributed to the fibrous structure of the corrugate. Specifically, a fibrous matrix developed with sufficient addition of corrugate, which promoted more viscous, less cohesive behavior. This resulted in an

increase in Marsh funnel viscosity (up to 2.5 corrugate content beyond which Marsh funnel readings could not be obtained due to excessive bridging of the fibers in the testing device); a decrease in mud balance density (due to replacement of bentonite with the lighter fibers); and increase in filtrate loss and permeability (attributed to presence of sufficient fiber content to provide preferential pathways for flow).

Table 4. Slurry Test Results

Corrugate Type	Mix	MFV (s)	MB (kg/m ³)	FL (mL)	CT (mm)	k/t (s ⁻¹)	k (cm/s)
None	B5.0	38.3	1030	19	2.4	4.68×10^{-8}	1.12×10^{-8}
	B5.5	40.5	1030	16	2.7	4.89×10^{-8}	1.33×10^{-8}
	B6.0	49.2	1035	14	1.8	3.24×10^{-8}	5.93×10^{-8}
C-flute box	V0.5-C	42.4	1025	19	3.8	4.20×10^{-8}	1.58×10^{-8}
	V1.0-C	41.8	1010	17	3.1	4.74×10^{-8}	1.46×10^{-8}
	V1.5-C	47.1	1010	22.8	3.2	4.30×10^{-8}	1.36×10^{-8}
	V2.0-C	57.0	1010	26.3	4.8	5.14×10^{-8}	2.48×10^{-8}
	V2.5-C	NM	1015	32.8	8.3	4.71×10^{-8}	3.91×10^{-8}
	V3.0-C	NM	1010	39.8	10.8	6.92×10^{-8}	7.48×10^{-8}
	PC0.5-C	47.3	1025	20.6	3.2	3.80×10^{-8}	1.22×10^{-8}
	PC1.0-C	49.7	1020	20.1	3.5	4.38×10^{-8}	1.53×10^{-8}
	PC1.5-C	52.7	1010	21.6	3.6	3.72×10^{-8}	1.36×10^{-8}
	PC2.0-C	58.0	1010	26.2	4.2	5.02×10^{-8}	2.09×10^{-8}
	PC2.5-C	NM	1015	32.1	9.1	6.53×10^{-8}	5.92×10^{-8}
	PC3.0-C	NM	1015	36	11.0	8.00×10^{-8}	8.83×10^{-8}
	PC0.5-C(+)	46.5	1025	19	4.0	3.75×10^{-8}	1.49×10^{-8}
	PC1.0-C(+)	49.0	1015	20.7	3.0	4.08×10^{-8}	1.23×10^{-8}
	PC1.5-C(+)	49.4	1010	19.6	3.7	3.41×10^{-8}	1.26×10^{-8}
	PC2.0-C(+)	56.8	1010	25	5.5	4.25×10^{-8}	2.33×10^{-8}
	PC2.5-C(+)	79.1	1010	27.8	5.1	3.42×10^{-8}	1.74×10^{-8}
	PC3.0-C(+)	NM	1005	32.9	11.4	4.90×10^{-8}	5.58×10^{-8}
Pizza box	V0.5-P	44.44	1025	18.8	3.2	4.27×10^{-8}	1.35×10^{-8}
	V1.0-P	47.7	1020	20.1	4.0	4.07×10^{-8}	1.62×10^{-8}
	V1.5-P	49.0	1015	22.6	4.1	4.38×10^{-8}	1.80×10^{-8}
	V2.0-P	56.4	1010	24.6	5.7	4.80×10^{-8}	2.73×10^{-8}
	V2.5-P	NM	1010	31	8.0	6.19×10^{-8}	4.89×10^{-8}
	V3.0-P	NM	1010	33.6	10.5	7.48×10^{-8}	7.83×10^{-8}
	PC0.5-P	46.4	1025	20.1	3.1	4.13×10^{-8}	1.27×10^{-8}
	PC1.0-P	47.1	1020	21.1	3.4	4.02×10^{-8}	1.35×10^{-8}
	PC1.5-P	52.0	1010	23.2	4.4	4.61×10^{-8}	2.03×10^{-8}
	PC2.0-P	55.2	1010	24.6	6.2	3.22×10^{-8}	1.98×10^{-8}
	PC2.5-P	70.2	1015	28.7	8.2	4.37×10^{-8}	3.58×10^{-8}
	PC3.0-P	NM	1015	34.3	6.2	4.83×10^{-8}	3.00×10^{-8}
	PC0.5-P(+)	39.4	1025	16.8	2.2	3.44×10^{-8}	7.60×10^{-9}
	PC1.0-P(+)	38.5	1020	17.5	1.5	3.55×10^{-8}	5.23×10^{-9}
	PC1.5-P(+)	40.6	1010	18.8	2.7	3.65×10^{-8}	9.91×10^{-9}
	PC2.0-P(+)	48.1	1000	24	4.0	4.82×10^{-8}	1.93×10^{-8}
	PC2.5-P(+)	65.1	1015	30.2	8.0	6.96×10^{-8}	5.54×10^{-8}
	PC3.0-P(+)	NM	1015	31	10.7	7.66×10^{-8}	8.17×10^{-8}

MFV – Marsh funnel viscosity, MB – Mud balance density, FL – Filtrate loss, CT – Thickness of filter cake (t), k/t – Quotient of permeability of filter cake and thickness of filter cake, k – permeability of filter cake, “-C” – C-flute corrugated box, “-P” – Pizza box, “(+)” – sample subjected to additional blending time, NM – Not measurable due to flocculation and bridging in the Marsh funnel device.

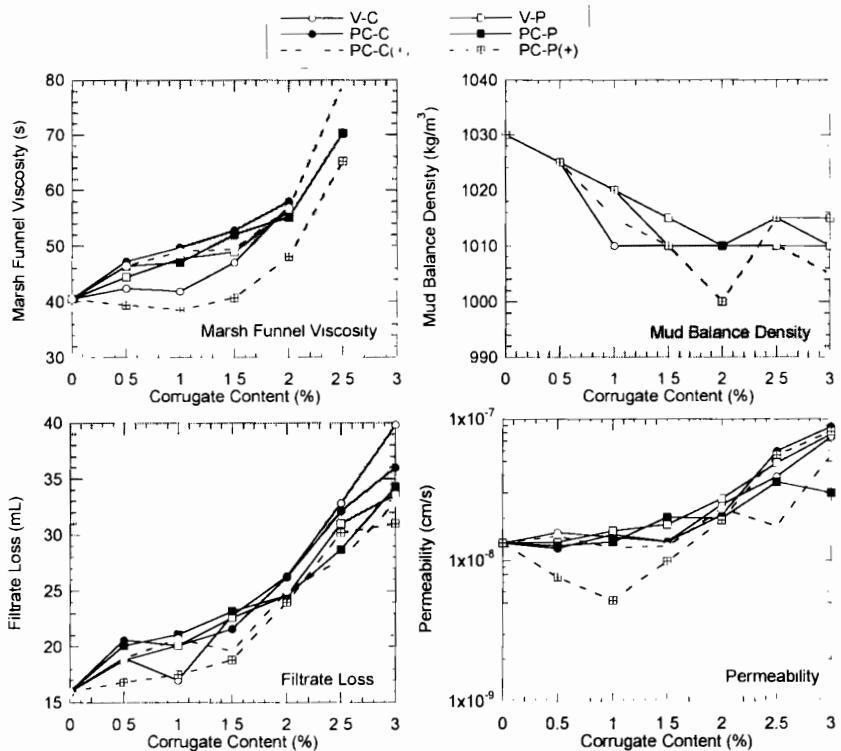


Fig. 2. Engineering Properties of Slurries

The additional blending time for the post-consumer samples had a more pronounced effect on engineering properties of the slurries containing pizza box fibers than the c-flute box fibers. The greater differences were attributed to the breakdown of greasy film on the pizza box allowing access to water and softening during the extended blending. In comparison, the c-flute fibers had already sufficiently broken down after 2 min. of blending and additional blending did not change the behavior significantly.

CONCLUSIONS

Tests were conducted to assess the feasibility of using corrugated board in slurry applications. Bentonite used in typical slurry mixtures was replaced by fiberized corrugated board at varying ratios. Properties of bentonite-corrugated board-water mixes were compared to baseline bentonite-water slurry mixes to evaluate the influence and practical limits of corrugated board addition to the mixes. The results indicated that the corrugated board could be used to replace 9 to 27% (corresponding to 0.5 to 1.5% corrugate content in a 5.5% mixture) of the bentonite used in the slurry

mixes based on Marsh funnel viscosity, density, and filtrate loss tests. Corrugated board may be used to replace up to 36% of bentonite (2.0% corrugate in a 5.5% mixture) for specific site and construction conditions requiring high MFV. In addition, permeability of the mixes with corrugated board was similar to baseline bentonite-water mix permeability. The differences in engineering properties of the slurries containing corrugate content were attributed to the presence of a fibrous matrix that influenced viscosity and flow characteristics. Overall, slurry applications provide a new and viable beneficial reuse alternative for paper / paperboard products, which constitute the largest weight and volume fraction of municipal solid waste generated and disposed of in the U.S. as well as other countries.

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