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Use of Post-Consumer Corrugated Fiberboard as Fine Aggregate Replacement in Controlled Low-Strength Materials

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ABSTRACT: This study was conducted to investigate the use of post-consumer corrugated board in controlled low-strength material (CLSM) applications. Corrugated fiberboard (termed corrugate), which constitutes a significant fraction of the municipal solid waste stream in the United States (approximately one third by weight), was used as a partial replacement for fine aggregate in CLSM at aggregate replacement ratios ranging from 0 % (i.e., control) to 6 %. The corrugate was fiberized (i.e., repulped) in a blender prior to being mixed with other constituents in the CLSM. The density, air content, and flow consistency of the fresh CLSM were determined, and bleeding was qualitatively assessed. Also, the unconfined compressive strength was determined for the resulting mixtures at different test ages. As the corrugate content increased, air content and water demand increased, density and compressive strength decreased, and some mixtures exhibited excessive bleeding. Corrugated fiberboard was determined to be effective as a fine aggregate replacement to produce mixtures with 28-day compressive strengths within the range for excavatable CLSM.

Introduction and Background

Controlled low-strength material (CLSM) is a self-leveling, self-compacting cementitious material used primarily in lieu of compacted sand/soil backfill. Alternative terms for CLSM include flowable fill, unshrinkable fill, controlled density fill, flowable mortar, and soil-cement slurry, among others [1]. ACI Committee Report 116 [2] defines CLSM as a cementitious material that is fluid at placement and which results in a long-term compressive strength of 8.3 MPa (1200 psi) or less. Applications for CLSM include structural fills beneath buildings, backfill behind retaining walls, pavement base, conduit bedding, void filling, and bridge reclamation [1].

Materials used in conventional CLSM mixtures are described in Table 1. Various alternative materials have been used to produce satisfactory CLSM, including high fines (greater than 20 %), silty sands, and local soils. Soils with high clay contents are avoided, as they can have deleterious effects on mixture properties, such as increased water demand, increased shrinkage, and mixture heterogeneity from incomplete mixing of the clay. [Table 1]

CLSM mixtures must have the ability to fill desired spaces and voids with a minimum need for manual labor during the placement effort. The properties of both fresh and hardened CLSM, including bleeding and density (fresh) and unconfined compressive strength (hardened), provide an indication of the field performance. The engineering properties of CLSM that have relevance to mixture proportioning and performance include flowability, bleeding, density, and unconfined compressive strength as described below.

Flowability refers to the ability of a CLSM to self-compact and readily fill voids. Good flowability as determined using a flow consistency test (ASTM D6103 [10]) allows for placement of the CLSM without the need for conventional compaction equipment or labor.

The bleeding of water from a fresh CLSM mixture indicates settlement of the freshly placed CLSM, and typically low bleeding is desirable. The volume of CLSM placed for a given application may need to be increased to account for this settlement and to obtain a desired final surface elevation.

The density of CLSM is affected by mixture materials and amounts. Low density CLSM mixtures are used when low overburden stresses are required (e.g., weak underlying soils or insulating fill for thermal or shock isolation), whereas high density mixtures may be acceptable for cases with relatively high strength requirements.

Unconfined compressive strength is the most commonly used requirement for CLSM mixtures. Several factors influence the requirements for compressive strength, including the application and the likelihood of future excavation. For a given project, a minimum strength, maximum strength, or both may be specified.

The requirements and specifications used for CLSM mixtures are relatively limited compared to those for conventional concrete mixtures. Typical specifications for CLSM include provisions for the proportioning of ingredients (e.g., limits on grain size distributions and mixture proportions), plastic properties (e.g., flowability, segregation), and in-service properties (e.g., compressive strength of the mixture) [1]. Riggs and Keck [11] conducted a survey of CLSM specifications used by six state transportation agencies. For the states surveyed, the only mechanical property specified was the unconfined compressive strength. Several of the states surveyed waived any gradation requirements for aggregates. Some applications for CLSM require unconfined compressive strengths of less than 2.1 MPa

(300 psi) to allow for future excavation [1]. Limited requirements given in specifications for CLSM mixtures allow for ease of incorporation of byproducts in CLSM mixtures [e.g., Ref 1].

Broad initiatives have been underway since the 1980s to divert materials from landfills by recovering materials for alternative use in CLSM (e.g., Ref 12). When materials are diverted from landfills to construction activities, the costs of both disposal and virgin material are avoided. Many engineering applications have been at the forefront of such reuse due to the high volumetric quantities involved in construction. For such operations, even small replacement ratios translate into significant diversion quantities. CLSM mixtures provide a viable application for incorporating post-consumer byproducts in construction because the performance requirements for CLSM could be less rigorous compared to those for the use of such materials in other cement-based materials such as concrete. Byproducts previously used in CLSM include shredded rubber tires, crushed glass, spent foundry sands, coal combustion products, pulp and paper mill residuals, incinerated sewage sludge ash, and similar materials [12-22].

Byproducts have been used to replace both cementitious materials (e.g., coal combustion byproducts) and aggregates (e.g., recycled glass, foundry cupola-slag, recycled concrete, and scrap tire rubber) in CLSM mixtures. A summary of byproduct materials incorporated in CLSM is presented in Table 2. Several of the byproducts included in mixtures have been materials with relatively high organic or carbon contents (e.g., high carbon content ash, pulp, and paper mill residuals).

The addition of byproduct materials may require the adjustment of mixture proportions due to changes in the specific gravity and other properties of the byproducts. Poor mixture proportioning of CLSM can lead to excessive bleeding [14,18,19] and fluidity issues [15].

This investigation was conducted to evaluate the innovative use of corrugated fiberboard (referred to as corrugate) as an aggregate replacement for CLSM mixtures. Paper and paperboard constitute the highest fraction by weight and volume of municipal solid waste generated (33 % by weight) and disposed in landfills (22 % by weight) in the United States [23]. In 2007, the total amount of paper and paperboard generated in the United States was 83 x 10^6 tons, and the amount disposed of was 37.8 x 10^6 tons [23]. Due to its high strength to weight ratio, corrugated packaging is poised to be the leading choice for transport packaging in the United States [24]. Approximately 80 % of the paper-based packaging used is corrugated fiberboard shipping containers [24]. Corrugated fiberboard, which is widely used in the manufacturing of corrugated boxes and shipping containers, is a paper-based material consisting of a fluted containerboard sheet and at least one flat linerboard sheet. The use of recovered paper in the manufacturing of containerboard has remained nearly stable (at approximately 16 x 10^6 tons) since 1997 [25]. Therefore, a practical limit for incorporating waste paper into containerboard has been reached according to the paper industry. The beneficial reuse of corrugated fiberboard in geotechnical engineering and construction applications is not common [26]. Innovative reuse applications (beyond the packaging industry) need to be investigated in order to promote the beneficial reuse of paper products. [Table 2]

Experimental Test Program

Materials, Mixture Proportions, and Mixing Procedures

The CLSM mixtures were prepared using cementitious materials (cement or cement and fly ash), fine aggregate, water, and fiberized (i.e., repulped) corrugate. Details of the materials used in the test program are provided in Tables 3 and 4. The baseline mixture design was based on a sample mixture design provided by the Ohio Department of Transportation [1]. The cementitious materials content was identical to those of the sample mixture design, and the fine aggregate content was adjusted to account for differences in the specific gravity of aggregates [American Concrete Institute (ACI) versus local source]. An assumed air content of 3 % was used for batch calculations [36]. Mixtures with variable cement to cementitious materials (c/cm) ratios were prepared for the test program. The mixtures had c/cm ratios of 0.29 (baseline), 0.65, and 1.0 (entirely portland cement with no fly ash). Fine aggregate was replaced with fiberized corrugate at specified replacement rates (ranging between 0.25 % and 6 % on a dry weight basis). A photograph of a sample of fiberized corrugate (i.e., pulp) is presented in Fig. 1, together with a microscopic image indicating the typical aspect ratios of individual fibers. The corrugated fiberboard was characterized according to Technical Association of the Pulp and Paper Industry (TAPPI) standards (Table 4). Results of the tests conducted on the corrugated fiberboard are provided in order to thoroughly document the materials used in the test program for potential future comparisons. [Table 3] [Table 4] [Figure 1]

A total of 21 CLSM mixtures was tested in the investigation (Table 5). Aggregate material quantities are reported for saturated surface dry conditions in the table. The mixtures were assigned designations for reference: the number preceding the letter C is the percentage of fine aggregate replaced by corrugate, and the number following the hyphen is the c/cm ratio expressed as a percentage. For example, in mixture 0.5C-65, 0.5 % of the fine aggregate was replaced with corrugate, and 65 % of the cementitious material was cement (the remaining 35 % is fly ash). The water quantities provided in Table 5 represent all water in the mixture beyond the saturated surface dry condition of the fine aggregate. The amount of water that was held by the fiberized corrugate versus the amount that was available for the hydration of cement was not quantified. The amount that is held by the fiberized corrugate is variable as a function of confining stress conditions as the fibers represent a compressible solids fraction of the mixtures. [Table 5]

The first round of testing was conducted using batches with an approximate volume of 0.057 m^3 (2.0 ft^3), termed full-scale batches. The majority of tests were conducted using batches of approximately 0.014 m^3 (0.5 ft^3), termed small-scale batches. The actual volumetric batch sizes varied due to the effects of decreased specific gravity of the corrugate as compared to the fine aggregate.

Adjustments to the water content were made based on aggregate absorption and moisture content. Water masses equal to those of the baseline mixtures were used as a starting point for mixtures containing corrugate. Water was added as needed to reach equivalent flowability as compared to the baseline. The amount of added water was recorded to calculate the actual batched proportions (reported in Table 5). A similar approach was used previously by Cheung et al. [19] to prepare CLSM mixtures with shredded rubber tires used as a fine aggregate replacement.

Prior to the preparation of the test batches, individual materials were weighed and sealed in buckets in order to prevent changes in their moisture content. After the corrugate was fiberized, the pulp was allowed to drain in order to remove some of the excess water. The mass of the corrugate and the total pulp mass were recorded to determine the effective water content of the pulp. Some but not all of this water was assumed to be available as free water in the CLSM mixture.

Materials were mixed in a Multiquip rotary drum mixer (MC64PE) for full-scale batches and in a mortar mixer for small-scale batches. Materials were added in a manner consistent with the order provided by the ACI [1]. First, approximately half of the aggregate and approximately 75 % of the mix water were added. After mixing for several revolutions the cementitious materials were added, followed by the remaining aggregate and the balance of the mixing water. For mixtures with corrugate, the water content of the pulp was close to, if not in excess of, the baseline water content. For these mixtures, the addition of the fiberized corrugate-water blend was adjusted so as to follow the procedure described by the ACI [1].

Testing Procedures

Fresh Batch Tests—The fresh batches were tested for flowability, bleeding, density, and air content. Flowability of the CLSM mixtures was determined according to ASTM D6103 [10]. This test was performed by filling a 75 diameter x 150 height cylindrical mold with CLSM and then lifting the cylinder vertically, allowing the material to flow out the bottom of the mold. The diametral spread of the mixture was measured across two perpendicular axes, and the average was recorded. For this test program, a flow consistency of 200 mm was established as the minimum threshold for acceptance [1]. An additional criterion used to assess flowability relates to the lack of excessive bleed water and segregation in a test material. In cases in which excessive bleed water was observed, no additional water was used, and the cylinders were cast for strength testing.

Bleeding was qualitatively assessed based on the procedure reported by Cheung [37]. Bleeding was considered excessive if substantial bleed water was observed immediately after placement. Severe bleeding refers to substantial bleed water in the 20 min following placement. Moderate or minor bleeding referred to less pronounced bleeding that was not likely to detrimentally affect the properties of the CLSM.

The density of each test batch was determined according to ASTM D6023 [38]. The mold used for density measurements had a volume of 7079 cm^3 (0.25 ft^3). The air content was determined using a pressure meter according to ASTM C231 [39]. This method was selected because the air content could not be calculated using the amount of materials included in a given mixture, due to the uncertainty in the amount of water absorbed by the corrugate.

Strength Tests—After the materials were mixed and fresh batch tests were conducted, 150 mm x 300 mm cylinders were prepared in accordance with ASTM D4832 [40]. Six specimens were prepared for each full-scale batch for replicate testing at 7, 14, and 28 days. For small-scale batches, two cylinders were prepared for testing at 28 days. Specimens were removed from the molds by cutting the molds. Unconfined compressive strength tests could not be conducted on some weak specimens that were damaged during removal from the molds.

Subsequent to removal from the molds, specimens were capped with Hydrostone plaster to provide a smooth bearing surface. Plaster was selected as the capping material to avoid damaging weak specimens, which can occur with sulfur capping compounds. Compression tests were conducted in accordance with ASTM C39 [41] using a loading rate of 100 kPa/s.

Results and Discussion

The results of the test program are summarized in Table 6. In general, the addition of corrugate resulted in lower densities for the CLSM mixtures. This was attributed to the combined effect of the lower specific gravity of the corrugate as compared to fine aggregate and the increased entrapped air in the mixtures. Plots of density and air content versus corrugate content are presented in Figs. 2 and 3, respectively. The addition of corrugate resulted in the use of higher water contents than in baseline mixtures to maintain acceptable flowability (Fig. **4).** The increased water demand was attributed to both the water absorption by the corrugate and the increased shear resistance of the interlocking network of fibers. The normalized yield (the quotient of the volumetric yield of mixtures with corrugate and the volumetric yield of baseline mixtures) versus corrugate content is presented in Fig. 5. The combined effect of the decreased specific gravity of the corrugate and air entrapment resulted in a bulking of the mixtures. Corrugate replacement ratios on the order of 4 % by weight produce a 30 % bulking (i.e., 30 % increase in total volume).

The unconfined compressive strength of CLSM mixtures was significantly affected by the presence of corrugate. At medium replacement rates (1 % by *r* weight), the resulting 28-day strengths were between 17 % and 31 % of the strengths of the baseline mixtures. A higher reduction in strength was observed for the all-cement mixtures (c/cm = 1) as compared to the mixtures that contained fly ash. The presence of organics in corrugate was assumed to detrimentally affect the strength gain of the cement [8]. The overall reduction in strength with the addition of corrugate also was attributed to the increased water/cement ratio of the mixtures containing corrugate. A design chart for selecting corrugate replacement quantities for CLSM mixtures is presented in Fig. 6. [Table 6] [Figure 2] [Figure 3]

The fibers of the corrugate in the mixture are of sufficiently consistent geometry to provide discrete reinforcement throughout the matrix; however, the strength of the individual fibers is virtually negligible in this regard. The detrimental effects on strength heavily outweigh any benefit from the reinforcement mechanism. The durability of CLSM that incorporates fiberized corrugate remains a potential concern that was not evaluated in the current study. Further testing is required in this regard. Testing by Naik et al. [42] on concrete slabs containing paper-mill fibrous residuals indicated that the presence of fibrous residuals enhanced the freeze-thaw durability of non-air-entrained concrete. [Figure 4] [Figure 5]

An economic analysis was conducted to further evaluate the feasibility of incorporating corrugate in CLSM. The cost of mixtures was determined using typical costs for individual materials. The costs per metric ton of the materials were: cement ($99/ton), fly ash ($83/ton), fine aggregate ($22/ton), water ($0.80/ton), and pulped corrugate ($200/ton). A plot of the resulting cost per mixture versus corrugate content is presented in Fig. 7. Due to the volumetric bulking, the addition of corrugate significantly reduced the calculated costs of the mixtures, even though the unit price of pulped corrugate is higher than the unit price of fine aggregate. [Figure 6] [Figure 7]

An analysis that combines strength characteristics with cost of the mixtures is presented in Figs. 8 and 9. Both plots present compressive strength versus cost. Figure 8 presents this relationship as a function of the c/cm ratio, and Fig. 9 presents the relationship as a function of the corrugate content. In terms of cost, the all-cement mixtures (c/cm = 1) provide the highest strength for a given cost (or the least cost for a given strength). The dashed lines in Fig. 9 represent the typical range of strengths for excavatable CLSM. Based on Fig. 9, the economic benefits of aggregate replacement with corrugate are evident for several mixtures with strengths associated with excavatable CLSM. Specifically, mixtures with costs less than $\$50/m^3$ are economically attractive, with material cost savings of approximately 7 to 13 % (for mixtures with c/cm = 0.65) for corrugate replacement ratios up to 1 % in comparison to baseline mixtures with no corrugate.[Figure 8] [Figure 9]

Conclusions

This investigation was conducted to determine the feasibility of using corrugated fiberboard in CLSM applications. Corrugate was used as a fine aggregate replacement in the preparation of CLSM mixtures. Based on the results of the experimental test program, the following conclusions were drawn:

- As the corrugate content increased, the air content and water demand increased, the density and compressive strength decreased, and some mixtures were observed to exhibit excessive bleeding.
- The differences in engineering properties between the baseline mixtures and mixtures with corrugate were attributed to corrugate characteristics including low specific gravity, high water absorption capacity, and high organics content, as well as the presence of a fibrous matrix that influenced entrapped air and flow characteristics.
- Corrugate may be used to replace up to 1 to 2 % of fine aggregate while maintaining appropriate engineering properties for excavatable CLSM. Selected mixtures with replacement ratios of up to 1 % were economically beneficial, with approximately 7 to 13 % material cost savings.

- Overall, CLSM applications provide a new and potentially viable beneficial reuse alternative for paper/paperboard products, which constitute a significant fraction of the municipal solid waste stream in the United States.

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Portland cement	Typically type I or II portland cement conforming to ASTM C150 [3] is used for CLSM. Other cements, such as blended cements conforming to ASTM C595 [4], can be used if verified with successful test results.
Fly ash	For use in CLSM, fly ash does not need to conform to either Class F or Class C designation as defined in ASTM C618 [5]. This allows for the use of substandard products such as ponded ash or basin ash that are generally stockpiled or discarded [1]. These products generally have a high carbon content, making them undesirable for use in conventional concrete mixtures. Fly ashes with carbon contents of up to 22 % have been successfully used in CLSM mixtures [1]. Due to its high calcium oxide content, Class C fly ash exhibits some self-cementation reaction, resulting in long-term strength gain. Such strength gain may render Class C fly ash unacceptable for use in CLSM, resulting in mixtures with compressive strengths greater than 2.1 MPa when re-excavation is likely to occur [6].
Aggregates	The aggregate types used in the production of CLSM vary widely. Mixtures may contain fine aggregate, coarse aggregate, a combination of both, or no aggregate at all. Aggregates used in CLSM generally conform to the requirements of ASTM C33 [7] because ready mix suppliers have these materials on hand. However, aggregates not meeting the requirements in ASTM C33, normally used in concrete production, may be used as an alternative [1].
Water	Generally, any potable water is suitable for use in concrete mixtures [8], although non-potable water can also be used. Additional requirements for water are provided in ASTM C1602 [9].

TABLE *1—Materials in conventional CLSM.*

Material Used	Replacement Rate	Reference(s)
Spent foundry sand	30 to 100 %	13–15
Recycled glass	10 to 30 %	16
Recycled concrete	100 %	17
Scrap tire rubber	15 to 50 %	18,19
Coal combustion products	5 to 31 %	1,12,20
Pulp and paper mill residuals	2 to 20 %	21
Incinerated sewage sludge ash	10 to 30 %	22

TABLE *2—Summary of byproduct materials in CLSM.*

Constituent	Description
Cement	Type II/V portland cement was used in all CLSM mixtures. Type II/V cement was selected for its sulfate resistance in line with common practice in California. The specific gravity of cement was assumed to be 3.15 [8].
Fly ash	A class F fly ash was used. The fly ash was classified according to chemical composition based on ASTM C618 [5]. Based on the mill report, the major oxide contents were silicon dioxide 61.7 %, aluminum oxide 24.6 %, and ferric oxide 4.36 %. The loss on ignition for the fly ash was 0.22 %. The specific gravity was determined to be 2.19 [27].
Fine aggregate	The specific gravity was determined to be 2.56 [28], and the absorption was determined to be 2.1 % [28]. The fine aggregate particle size distribution [29] generally adhered to ASTM C33 guidelines [7]; however, there was a slight excess in material finer than the number 50 sieve. Nevertheless, the fine aggregate that was obtained directly from a ready mix supplier was used in the test program as allowed by ACI [1].
Water	Tap water was used for the mixtures.
Corrugate	The corrugate had a single wall C flute construction and Container Type 201 (Regular Slotted Container) format, with no printing. The material was obtained in virgin condition and subjected to simulated handling as prescribed by the International Safe Transit Association [30] in order to provide a consistent post-consumer condition for the material. Then, the corrugate was fiberized by mixing it 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 [31]. The resulting fibers were on the order of 5 to 10 mm in length. All corrugate was fiberized less than 48 h prior to batch preparation to minimize any potential biological activity. Due to the freshness of the mixtures and the use of exclusively corrugated fiberboard as the source of fibers (as opposed to other paper products), the biological and physicochemical properties (e.g., biological status, presence of adhesives, and lack of bleaching agents and kaolin) of the resulting pulp were different from those in previously reported tests on paper mill residuals [21].

TABLE *3—Materials used in this investigation.*

Test	Standard Designation	Description of Test	Average Value
Grammage of paper and paperboard (weight per unit area)	TAPPI T 410 om-02 [32]	Weight per 92.90 m^2 of all three containerboard components of a single wall corrugated fiberboard is determined after conditioning for 24 h at 21 ± 1°C temperature and 52 ± 0.5 % relative humidity.	588 g/m^2
Bursting strength of corrugated and solid fiberboard	TAPPI T 810 om-06 [33]	Square corrugated fiberboard specimens with dimensions of 31.50 ± 0.03 mm are tested by distending an expandable diaphragm under a pressure of 690 kPa to 4825 kPa.	1140 kPa
Edgewise compressive strength of corrugated fiberboard	TAPPI T 839 om-02 [34]	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.	146 N
Water absorptiveness of corrugated fiberboard (Cobb test)	TAPPI T 441 om-04 [35]	A test specimen 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 s.	89.0 g/m^2

TABLE *4—Corrugated fiberboard properties.*

Mixture Designation	Batch Size	Cement, kg/m^3	Fly Ash, kg/m^3	Fine Aggregate, kg/m^3	Water, kg/m^3	Corrugate, kg/m^3	Water/Cementitious Materials, kg/kg	Corrugate Solids, m^3/m^3
0C-100	Small	206.4	0.0	1553.0	295.3	0.0	1.4	0.000
0.25C-100	Small	209.4	0.0	1554.7	223.2	3.9	1.1	0.003
0.5C-100	Small	176.2	0.0	1306.8	375.9	6.5	2.1	0.005
1.0C-100	Small	154.4	0.0	1140.8	431.8	11.4	2.8	0.009
2.0C-100	Small	132.6	0.0	969.3	528.2	19.6	4.0	0.015
4.0C-100	Small	98.6	0.0	717.1	567.6	28.8	5.8	0.023
6.0C-100	Small	67.2	0.0	485.2	719.7	29.7	10.7	0.022
0.0C-65	Small	135.2	74.0	1535.6	311.9	0.0	1.5	0.000
0.25C-65	Small	115.9	63.5	1328.7	193.6	3.3	1.1	0.003
0.5C-65	Small	124.0	67.9	1394.2	271.0	7.1	1.4	0.006
1.0C-65	Small	115.7	63.3	1287.7	302.0	13.2	1.7	0.011
2.0C-65	Small	82.9	45.4	922.2	550.3	19.4	4.3	0.014
4.0C-65	Small	67.0	36.7	730.7	701.5	30.3	6.8	0.021
6.0C-65	Small	50.9	27.3	546.6	812.0	34.5	10.4	0.023
0C-29	Full	58.3	145.1	1472.6	290.8	0.0	1.4	0.000
0.25C-29	Small	64.3	155.6	1628.2	152.0	4.1	0.7	0.003
0.5C-29	Small	61.0	147.6	1489.4	225.3	7.7	1.1	0.006
1.0C-29	Small	51.8	125.4	1252.3	348.4	13.1	2.0	0.010
2.0C-29	Full	44.7	111.2	1106.2	267.1	22.3	1.7	0.021
4.0C-29	Full	35.5	88.3	860.6	282.7	36.0	2.3	0.037
6.0C-29	Full	38.0	95.2	907.5	341.3	57.8	2.6	0.053

TABLE 5—*Summary of CLSM mixtures.*

Mix Designation	Flow, mm	Density, kg/m^3	Air Content, %	28-Day Compressive Strength, MPa
0C-100	255	2057	2.7	3.9
0.25C-100	205	1988	5.6	2.4
0.50C-100	210	1862	6.0	1.2
1.0C-100	210	1735	8.0	0.7
2.0C-100	205	1647	7.0	0.3
4.0C-100	180[a]	1410	6.0	0.1
6.0C-100	180[a]	1300	5.0	0.0
0C-65	265	2053	1.3	1.1
0.25C-65	235	1702	5.6	1.1
0.50C-65	230	1861	3.4	0.7
1.0C-65	210	1779	6.0	0.3
2.0C-65	220	1617	7.0	0.2
4.0C-65	210	1564	7.0	0.0
6.0C-65	205	1468	8.5	0.0
0C-29	330	1964	0.7	0.7
0.25C-29	255	2001	5.0	0.4
0.50C-29	260	1928	4.3	0.3
1.0C-29	235	1788	4.3	0.2
2.0C-29	220	1549	9.4	0.2
4.0C-29	N/A[a]	1301	21.0	0.1
6.0C-29	N/A[a]	1437	5.0	N/A

[a]Mixture did not meet flow requirements due to excessive bleeding.

TABLE *6—Test results.*

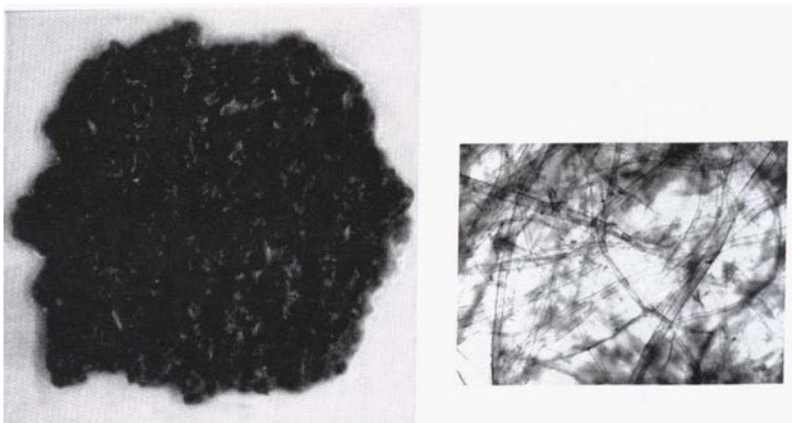

FIG. *1—Sample of fiberized (i.e., pulped) corrugated board and microscopic image of fibers.*

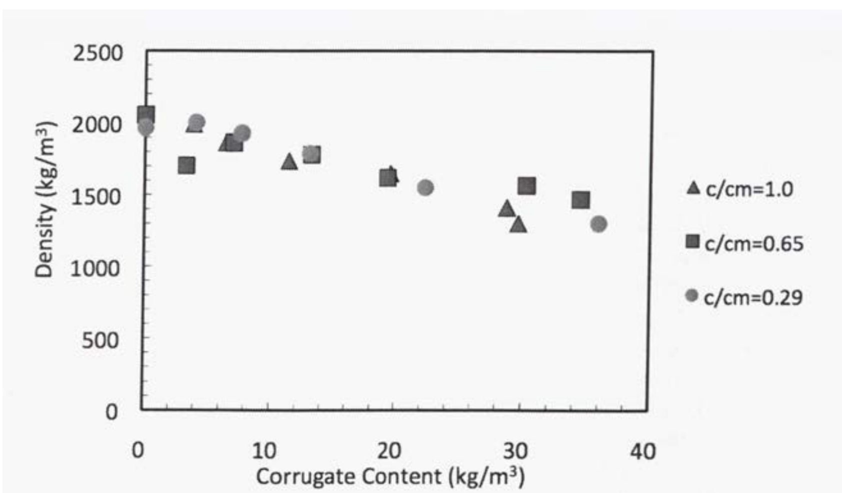

FIG. 2—*Density versus corrugate content.*

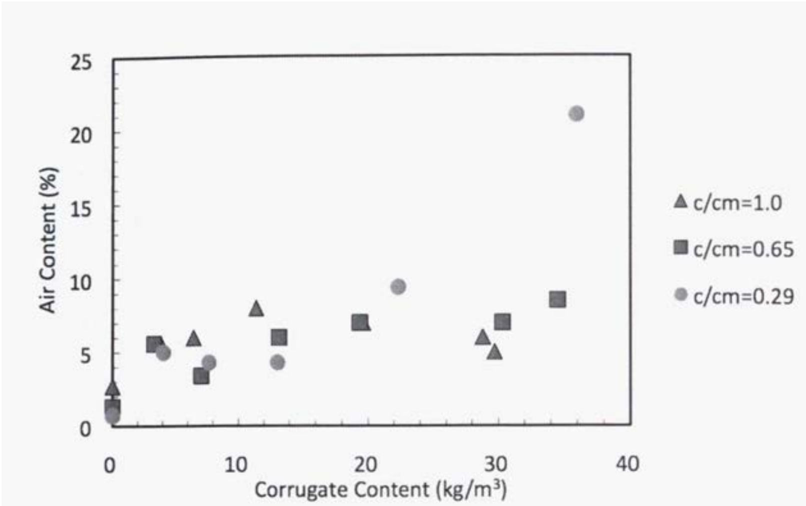

FIG. *3—Air content versus corrugate content.*

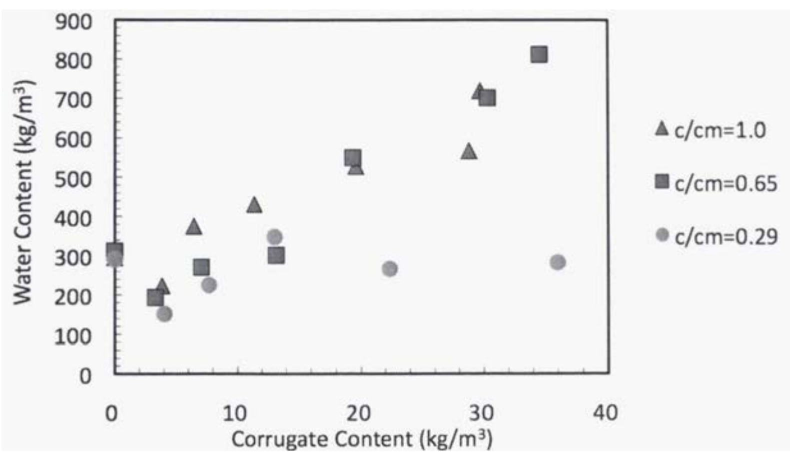

FIG. *4—Water demand versus corrugate content.*

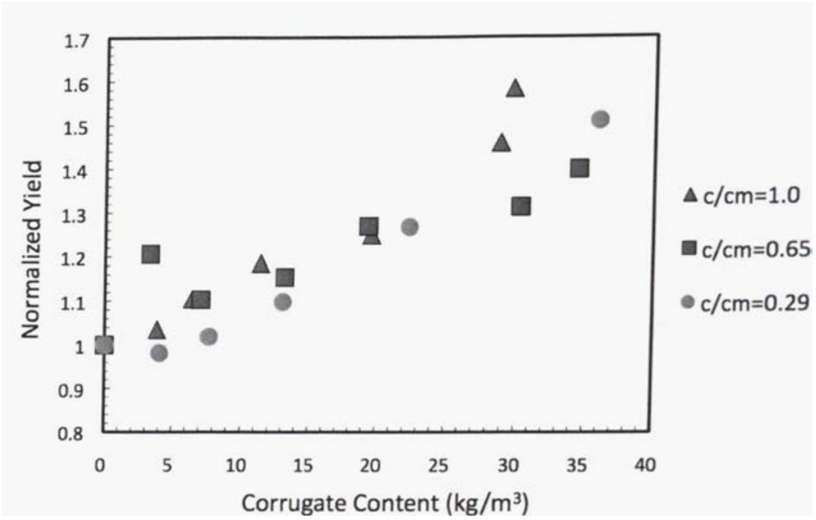

FIG. *5—Normalized yield versus corrugate content.*

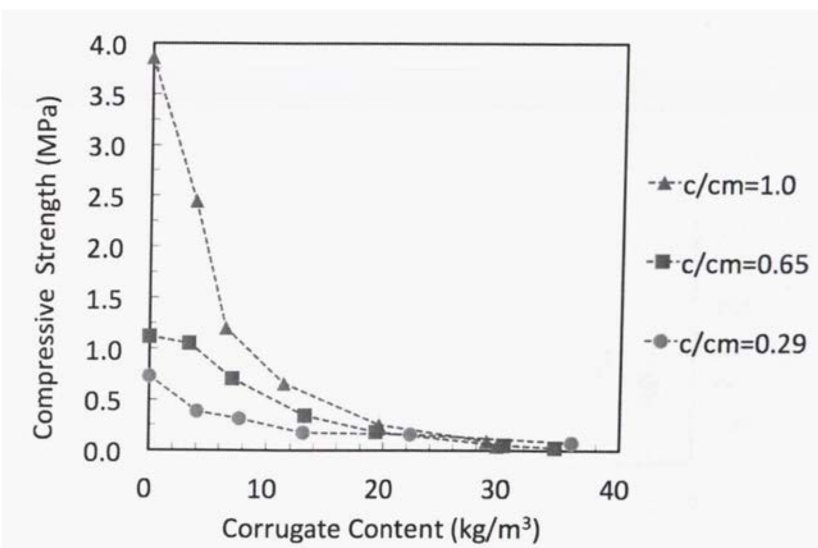

FIG. *6—Design chart for unconfined compressive strength versus corrugate content.*

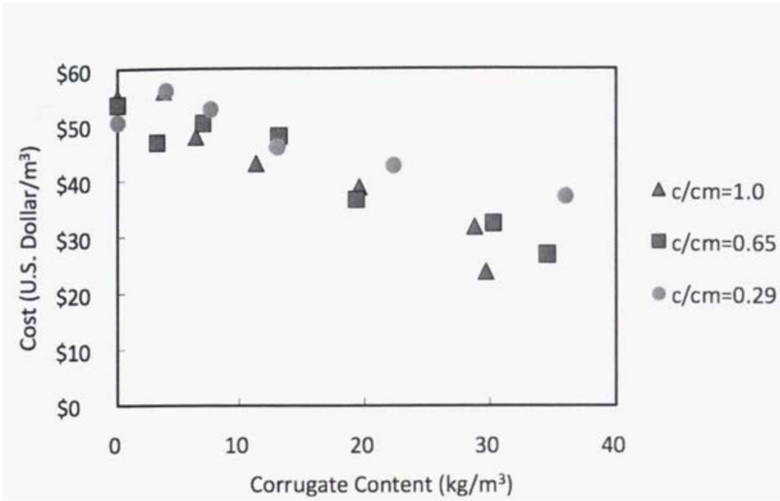

FIG. *7—Cost of mixtures versus corrugate content.*

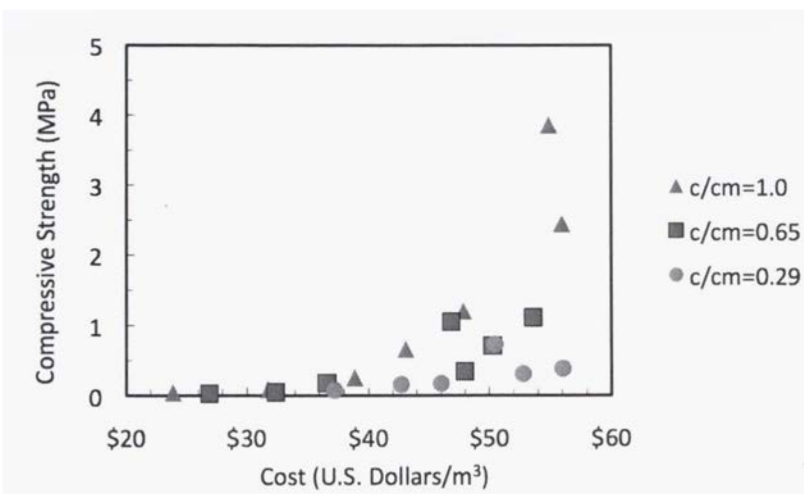

FIG. *8—Compressive strength versus cost for variable c/cm ratios.*

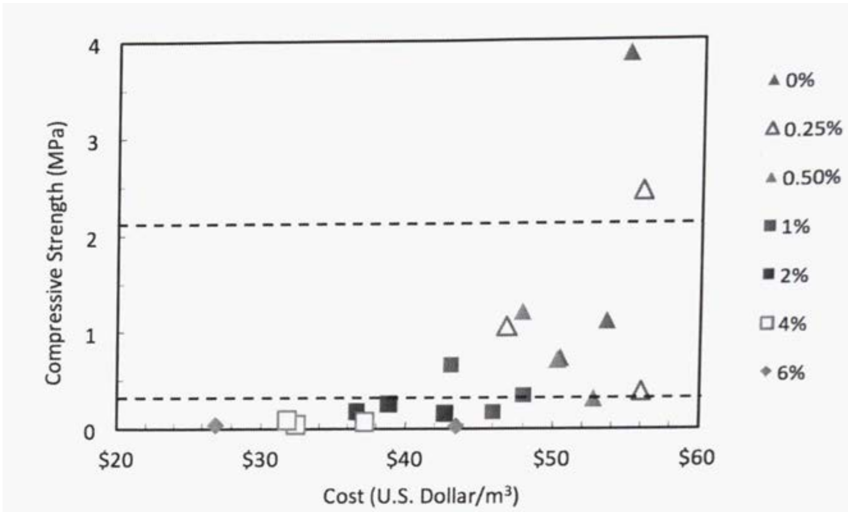

FIG. 9—*Compressive strength versus cost for variable corrugate replacement rates.*