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CONCRETE BLOCK MASONRY USING LIGHTWEIGHT UNITS MADE WITH SAWDUST REPLACEMENT OF AGGREGATE

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ABSTRACT
A light-weight, oversized concrete block manufactured using saw dust as aggregate and marketed under the trade name of ENVIROBLOCK™ , was tested to find material and structural properties under several loading conditions. These included out-of-plane bending, in-plane shear, eccentric axial load and pure compression. Both ungrouted and fully grouted specimens were made with the fully grouted samples being either reinforced or unreinforced. The ability to use standard design practices represented in masonry design codes was confirmed with the exception of tensile bond for ungrouted construction.

KEYWORDS: compression, concrete block, environmental, grout, saw dust, shear, tension, testing, waste.

INTRODUCTION
The light weight block units used in this test program had a portion of the aggregate replaced with saw-dust. Previous research into the viability and properties of concrete blocks made with this type of mix was done in 1992[1]. Due to the use of the saw dust, the density of the block is reduced. This allows a larger block to be layed by one person. Each unit is 290 mm high by 590 mm long. Therefore, each unit produces 125% more wall area than a standard 190 mm high by 390 mm long unit. The layout of the unit can be seen in Fig. 1. By using standard 10 mm mortar joints, the blocks fit into modular dimensions. Each block is also a splitter unit due to the close spacing of the two centre webs.

Another advantage of this particular unit is that when placed in running bond, the cells and webs line up. This allows the designer to have the webs mortared and use this increased bearing area in strength calculations. For grouted assembly, the grout columns are vertical and continuous with no lateral variations. This greatly increases the efficiency of the grout column. When using partially grouted construction, the webs on either side of the grout column can be mortared to isolate the cells intended to be filled with grout and eliminate the possibility that grout will flow into adjacent cells.

Figure 1: Photograph of ENVIROBLOCK concrete blocks.

TEST PROGRAM AND TEST RESULTS

All ENVIRO BLOCK™ units were the same for a particular size. Pallettes of 140 mm and 190 mm units were selected from the same run of block manufactured to provide a compressive strength near 8 MPa. This strength level was chosen as an effective compromise between low density and high strength. All unit tests were carried out in accordance with CSA A165 C140 [2].

Dimensions. Five randomly selected units from each size of unit were measured to document dimensions. All measurements were to the nearest millimetre and variations from the average were never more than one millimetre. All dimensions are for the mid-height of the block found by averaging the larger top dimensions and the smaller bottom dimensions. The average dimensions for the 190 mm unit were 36 mm face shells, 30 mm internal webs and 32 mm end webs. The corresponding dimensions for the 140 mm unit were 30 mm face shells, 30 mm internal webs and 32 mm end webs. This resulted in net areas of 64190 mm² and 50120 mm² for the 190 mm and 140 mm units, respectively.

Density. The same five blocks used for size measurements were also weighed to find the density of the concrete. The average mass of the 190 mm unit was 22.5 kg, resulting in a density of 1,209 kg/m³. The average mass of the 140 mm unit was 16.5 kg, which results in a density of 1,111 kg/m³.

Strength. Compressive strength was found from testing five 190 mm units hard capped with hydrostone and tested between two 102 mm thick steel plates. The average failure stress was 8.66 MPa with a standard deviation of 0.47 MPa. By CSA S304.1 [3], the design strength at the 95 percent confidence level is 8.66 - 1.64 (0.47) = 7.89 MPa. This is very close to the intended strength of 8.0 MPa and, the test data can be used conservatively to verify design methods based on providing an 8 MPa block.

Moisture Content. Five units used were weighed in their natural moisture condition. They were then placed in room-temperature water for 48 hours to produce a saturated condition and weighed again. Finally, the units were oven dried and weighed again to find the mass when the moisture content was zero. The average moisture content in the natural state was 1.1% and the saturated moisture content was 22.3%. Therefore the average water absorption was 22.4(0.223)/(0.064190 x 0.290) = 268 kg/m³. This is less than the 320 kg/m³ allowed for a lightweight block made with normal aggregate [2].

Thermal Expansion. The coefficient of thermal expansion was determined by measuring the changes in length over a 200 mm gauge length as blocks were cooled from 20°C to -15°C. The average change in strain of 0.000474 corresponding to the 35°C temperature change results in a coefficient of thermal expansion of 12.8×10^{-6}/°C, which is slightly higher than that for normal weight concrete.

Shrinkage. Two sets of five blocks were gauged with four sets of gauge points using a gauge length of 200 mm. Using a demountable mechanical strain indicator (DEMEC), initial readings were taken at the natural moisture content. The units were then placed in room-temperature water for 48 hours to produce a saturated condition and readings were taken again. The units were then oven-dried to get the 0% moisture condition and readings were taken again. The expansion observed from the natural state to the saturated state amounted to a strain increase of 0.002190 and 0.002040, respectively, for the 140 mm and 190 mm units. The shrinkage induced from the natural state to the dry state was 0.00075 and 0.00097, respectively for the 140 mm and 190 mm blocks. In actual construction, shrinkage of the block will be some fraction of these values depending on the ambient humidity conditions of use and the natural moisture content during construction.

TEST OF BLOCK ASSEMBLAGES

Construction. All of the masonry test assemblages were constructed in full running bond by an experienced mason. Full mortar bedding, including the webs, was used for the construction of the grouted and ungrouted prisms. However, except for the purpose of confining grout, the webs of the wall assemblies were left unmortared and only face shell bedding was used. Test specimens were cured in air for 28 days.

Type S mortar was produced using the proportions of portland cement:lime:sand by volume of 1:0.5:4.5. However, the mortar was actually batched by weight to insure uniformity of mortar properties. The weight proportions of portland cement: lime: sand: water were 5.2 kg: 1.1 kg:22.7 kg:5.7 kg. A batch of this size was small enough to ensure it was used in less than one hour. The mortar flow was approximately 125%. Three 51 mm cubes were produced in accordance with CSA A179 [4] for each batch. The average strength of these samples was 12.5 MPa.

Coarse grout with a slump of 250 mm was proportioned of 1:3:2 by volume using portland cement:sand: 10 mm pea gravel. However, to ensure consistency, these values were converted to proportions by mass of portland cement:sand:course aggregate.water of 40 kg: 150 kg:90kg:32 kg. To produce samples of the grout with characteristics similar to the grout within the test assemblies, grout was poured into the empty cells of units and allowed to cure under the same conditions as the assemblies. When it was time for them to be tested, a grout prism of approximately 75 mm by 75 mm by 150 mm dimensions was cut from the cell using a dry diamond blade. The actual measured dimensions were used in the calculations of strength. These block-moulded prisms had an average compressive strength of 22.4 MPa.

Prism Compression Tests. Five ungrouted and five fully grouted prisms were made with each of the 140 mm and 190 mm units. The samples were built three blocks high by one unit wide in running bond using two half blocks for the middle course. Prisms tested in accordance with CSA S304.1 [3], were hard capped with hydrostone and loaded through 102 mm thick solid steel plates top and bottom. Four sets of strain readings were taken over a 300 mm gauge length over the bed joint at the mid-height of each prism

The compressive strengths of the ungrouted prism were based on the average net area of the unit. For the fully grouted prisms the gross areas of 82,600 mm² and 112,100 mm², respectively, for the 140 mm and 190 mm units were used. This ignores the fact that the 10 mm slot between the middle webs did not fill with grout. Modulus of Elasticity values were calculated using the strain increment corresponding to a change in stress from 5% and 33% of the prism strength. The average compressive strengths can be found in Table 1.

Table 1: Average Results for Pure Compressive Tests of Prisms

Block Size (mm)	Average Grout Strength (MPa)	Average Mortar Strength (MPa)	Average Prism Strength (MPa)	Average E_m (MPa)
140	-	12.1	6.02	2190
	22.9	12.2	12.80	8710
190	-	13.1	5.32	1600
	26.3	13.1	14.40	8510

The failure mechanism for the ungrouted prisms was quite consistent. Although vertical cracking occurred through the faceshells, final failure only occurred when vertical cracks developed in the webs and the face shells spalled-off. This usually occurred near one or both ends of a prism. A fairly similar pattern of failure occurred in the grouted prisms as well, however, the cracks were larger and spalling occurred over a larger region at ultimate load.

Compression Tests of Walls Under Eccentric Axial Compression. Using the 190 mm ENVIROBLOCK™, six walls were built 10 courses high by 2 blocks long. Three were fully grouted and reinforced with a No. 15 bar in the third cell from each end. The walls were tested for loadbearing capacity using equal eccentricities top and bottom to produce symmetric single curvature. Pin end conditions were used both top and bottom to produce well defined end conditions. This was necessary to permit reliable analysis of the test results. Figure 2 shows the wall set-up and the large deflections which can result under eccentric axial loading. The test results are summarized in Table 2, where two eccentricities were incorporated into each group of tests. In all cases, failure was preceded by opening of cracks in the bed joint near the mid-height of the wall which was followed by some localized crushing on the compression face of the wall or, in the case of the ungrouted samples, instability of the wall as cracking and deflection accelerated rapidly. An additional observation was that straight vertical cracks developed

a) Front elevation

b) Side Elevation Showing Deflection Near Failure

Figure 2: Photographs of Eccentric Axial Load Tests of ENVIROBLOCK Walls

through head joints and blocks in alternate courses as the level of axial load increased. Eventually this crack propagated until the wall split in half. Even under large eccentricities for walls with a slenderness ratio of 16, the loadbearing capacity is quite high. Grouting and reinforcing the wall prevented instability and sudden brittle failure.

Table 2: Compressive Strengths of 190mm Thick Walls Under Eccentric Axial Load

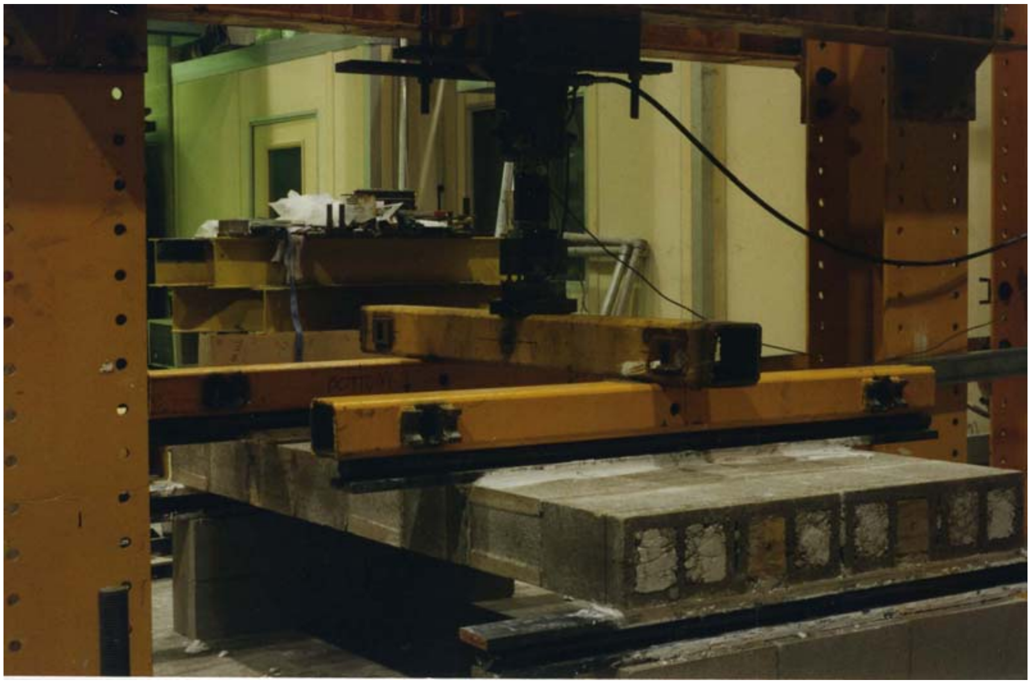
Wall No.	Eccentricity (mm)	Grout Strength (MPa)	Mortar Strength (MPa)	Failure Load (kN)
26	31.7	-	12.2	370.2
27	31.7	-	12.0	405.7
28	63.3	-	12.1	150.3
29	63.3	21.9	12.8	243.2
30	63.3	21.3	13.3	255.0
31	31.7	23.9	12.9	452.0

Bending Tests of Walls. Originally, it was intended to test walls to determine flexural capacity for both vertical bending (normal to bed joints) and horizontal bending (parallel to bed joints). However, very low bond strength resulted in the accidental destruction of some of the ungrouted samples when they were moved, regardless of the care taken to avoid applying external force leading to tensile failure.

Walls intended for bending normal to the bed joint were originally built in running bond with dimensions of 8 blocks high by 2 blocks long. For the reinforced and fully grouted walls, No. 15 bars were located in the centre of the third cell from each end of the wall and held in place during grouting by wooden jigs. The collapse of ungrouted walls led to the decision to grout an additional four walls to test for flexural strength of grouted walls normal to the bed joint. Walls intended for tests with bending parallel to the bed joints were originally built 4 units high by 4 units long. However, because of the difficulty with moving ungrouted walls, they were cut in half and the end cells (away from the failure region) were grouted to help hold the walls together.

Load was applied at the quarter points of the 2.34 m and 1.02 m flexural test spans for the full walls and half walls, respectively, in accordance with ASTM E72 [5]. Because the walls were tested in the horizontal position, self- weight of the wall and the weight of the loading apparatus were included in calculations of the maximum bending moment.

The reinforced and fully grouted walls for testing flexural resistance normal to the bed joint were tested as full walls. The yield of the reinforcing steel used in these walls was 446.7 MPa with all results within 1 MPa. The ductility of these walls was very high. There was an average deflection of 44 mm at failure. The average moment resistance of these walls was 18.2 kN-m. Figure 3(a) shows the test set-up and Figure 3(b) illustrates the large deflections associated with ductile behavior. Figure 4(a) shows the large rotation and opening of cracks for reinforced masonry.



a) Two Point Loading at Quarter Points of Span

b) Deflection of Reinforced and Fully Grouted Wall

Figure 3: Set-up for Flexural Tests of Walls

Fully grouted but unreinforced walls tested in bending perpendicular to the bed joint were tested as half walls. The moment resistance of the walls, which amounts to the cracking moment of the wall was 2.23 kN-m. This is much lower than the ultimate moment resistance of the reinforced specimens. This is because the unreinforced walls undergo a tensile failure, while the reinforced specimens undergo a compression failure. This tensile failure also results in a brittle failure of the specimen and collapse at ultimate load.

Specimens tested with bending parallel to the bed joint were tested as half walls with the failure area ungrouted. The toothed failure pattern can be seen in Figure 4(b). This failure was not a brittle failure and the wall did not collapse until deflections became very large. The average failure moment for these tests was 1.68 kN-m.

Diagonal Tension Tests. Grouted and ungrouted square wall panels consisting of 4 courses of blocks running 2 blocks long were built to conduct diagonal tension tests. These tests provide evidence of resistance to shear forces. Unfortunately, as was the case for the flexural walls, the low bond of mortar to the blocks resulted in premature failure of the ungrouted specimens either as they were moved into position or as the test apparatus was mounted on the specimens. This test is outlined in ASTM E519 [6].

The diagonal tensile resistance is calculated using the formula $f_t = 0.707$ P/A were P is the failure load and A is the effective mortared cross-sectional area along the bed joints. The average failure stress for the fully grouted walls was 0.937 MPa. The two failure patterns that occurred can be seen in Figure 5.

CONCLUSION

This paper contains a summary of the data resulting from an extensive research program [7]. It has been shown that masonry construction using ENVIROBLOCK™ units has very high bending and shear capacity when the walls are fully grouted. Reinforced assemblages behave and have capacities that are comparable to standard masonry construction. Unfortunately, because of the very low bond between the mortar and the block, load resistance is very low when this type of strength is required. Therefore, structures should not be designed to rely on the tensile strength of the ungrouted masonry. Ungrouted masonry is quite capable of carrying significant axial compression but at least partial grouting should be employed to ensure overall stability.

With the exception of not relying on tensile bond strength for ungrouted concrete block masonry, evaluation of the test results shows that standard design procedures [3] can be used for ungrouted, grouted and grouted and reinforced construction. Design may also be done in accordance with simple empirical methods.

An additional important factor is that block should be protected on site from wetting due to snow and rain. Normal shrinkage of block from a natural moisture content is manageable through proper placement of movement joints. Although the requirement to keep masonry units dry is not unique to ENVIROBLOCK™ construction, this requirement is often not enforced. Thus it is important to emphasize the need in order to avoid excessive post-construction volumetric changes.

a) Large Rotation and Opening of Cracks for Reinforced Walls

b) Toothed Failure for Bending Parallel to Bed Joints of Ungrouted Walls

Figure 4: Failure Conditions for Flexural Tests of Walls

a) Head Joint Failure Pattern

b) Diagonal Crack Pattern

Figure 5: Conditions at Failure for Diagonal Shear Tests

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