The Fire-Resistance of No-Fines Concrete Walls

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NON-LOADBEARING WALLS OF HEAVYWEIGHT AGGREGATE

No-fines concrete, an open textured material made from coarser aggregate, cement and water, is used for loadbearing and non-loadbearing walls of buildings, mainly of the domestic dwelling type. Since it can be poured from a considerable height without segregating and exerts a relatively low hydraulic pressure on formwork, it has been found very suitable for monolithic walls, but it is also used for making precast blocks. Owing to its open texture no-fines concrete requires rendering and provides an excellent key for the plaster.

Although no-fines concrete was used as early as the nineteen-twenties, its possibilities were not fully investigated until the shortages of the post-war period stimulated interest in forms of construction which economised in building materials. Results of research work on its physical properties and constructional application have been published in recent years, but data on its behaviour at high temperatures appear to be lacking.

The tests described were carried out to measure the fire-resistance, as defined by British Standard 176:1932, of non-loadbearing walls of no-fines concrete. Both monolithic and block constructions were tested, each made from two different aggregates, representative of low and high silica content rocks. The walls were 6in thick and rendered on both faces. Fire-resistances varying from 3½ to 6 hours were obtained, comparing favourably with the performance of alternative forms of non-loadbearing walls of the same thickness. The walls made from the aggregate of low silica content gave the greater fire-resistance, as they did not suffer the severe structural failure which occurred in the high silica aggregate walls after prolonged heating.

The investigation was made following a request for information on the fire-resistance of no-fines concrete from the Commonwealth Experimental Building Station, Australia. A programme of tests was planned to include both loadbearing and non-loadbearing walls in various representative aggregates; this report gives the results of tests on non-loadbearing walls made from basalt and from quartzite aggregates.

Materials Used for Test Specimens

Concrete

Cement. The cement used throughout was Rapid-hardening Portland Cement manufactured to British Standard 12:1947. The term “Rapid-hardening” is synonymous with “High early strength” which is used in other countries.

Aggregate. Two rock types were chosen as representative of the extremes of the ranges of silica content encountered in the commonly used natural aggregates, quartzite, which has a high silica content and a relatively large thermal expansion, and basalt, which is a low silica rock with a relatively small thermal expansion. The size and shape of the aggregate particles are important for making good no-fines concrete. A typical specification (1) states:

“The aggregate shall all pass a sieve having openings 3in square and shall not be more than 5 per cent by weight shall pass a sieve having openings 3in square. Pieces shall be clean, hard, strong, durable, preferably rounded or near-cubical and free from any coating of dust, clay or organic material. Aggregates containing soft, flaky, elongated or laminated pieces totalling more than 10 per cent by weight, or shale in excess of 1½ per cent by weight, shall not be used.”

In the specification quoted, terms such as “thin, flaked” are not defined quantitatively. If the definitions terms are taken to those given in British Standard 8: Sampling and testing of mineral aggregates, sand and pebbles above specification is so severe that it is extremely unlikely aggregates would be obtainable in Great Britain to comply with this relates particularly to basalt, which owing to its structure, yields a rather flaky aggregate when crushed.

After many enquiries, quarries were found which were supply aggregates approaching the requirements of the spec. The quartzite had an excellent shape, and the basalt, although considered suitable for the purpose. Two separate deli each rock were obtained which, although from the same and to the same nominal specification, varied slightly as in the analyses in Table I. Photographs of typical samples of aggregates are shown in Fig. 1.

Water. Clean tap water was used for gauging the concrete mix; it is also used for making precast blocks. Owing to its open texture no-fines concrete requires rendering and provides an excellent key for the plaster.

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The figures in parentheses refer to the bibliography which follows the article.

Fig. 1. Typical samples of aggregates shown on a 3in grid. The specimens are: (a) crushed quartzite gravel; (b) crushed basalt, batch No. 1; (c) crushed basalt, batch No. 2.
mixture, adopting the following procedure. The bulk of the aggregate was first saturated with water and as each batch was placed in the mixer a sample was taken for determination of the moisture content. After adding the cement by sprinkling on to the aggregate, the weight of water required to give the particles the appearance of being evenly coated with cement paste was noted. Mixing was continued for at least two minutes for all batches. The concrete was sampled at frequent intervals for making 6in cubes, 6in dia × 12in cylinders (having the tops capped with neat cement mortar) and 4in × 4in × 16in beams. These were tested in the standard manner after maturing under the same conditions as the corresponding walls; results are given in Table I. The walls were constructed in the 10ft square opening of the newly reinforced refractory concrete frame shown in Fig. 2, which gave a high degree of restraint at the edges.

Monolithic walls were cast in the frame using shuttering in 3ft lifts. The 1ft space at the top, which was necessary for placing the concrete, was subsequently filled with a precise slab of the same composition and thickness as the main body of the wall. Construction proceeded continuously; placing of the concrete was assisted by a light steel rod without compaction. Shuttering was struck three days after casting and the walls allowed to dry naturally in the Test Building.

The blocks, which had the shape and dimensions shown in Fig. 3, were cast in multiple moulds and were covered with wet sacks until demoulding after three days. In laying the blocks a 1:1:6 cement:lime:sand mortar was used in the horizontal joints only and the mortar bed was interrupted by the recess in the block. No mortar was placed in the vertical joints formed by the gaps between the blocks. This method of construction is designed to prevent moisture penetration by capillary action. One half-block was included in each course to break the vertical joints.

A thin rendering of 1:1:6 cement:lime:sand was applied to each face of both monolithic and block walls by a skilled tradesman. The rendering was in two coats, the first being a blinding coat. Fig. 4 shows the rendering in progress on a block wall.

Test Conditions and Requirements

Fire-resistance is defined in British Standard 476, which specifies the methods of test applicable to the various types of structural element. The test is of the full-scale type and for “separating” elements of structure, such as walls, which are required to resist the spread of a fire beyond the compartment of origin, the specimen element, when subjected to standard fire conditions. Tests were made in accordance with the British Standard current at the time, No. 476: 1952, which also specified for non-loadbearing walls an impact test and, for heatings of 2 hr or more duration water jet tests. Reference to other publications (2) (3) can

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**TABLE**

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Water-cement ratio by weight</th>
<th>Cubes</th>
<th>Age (days)</th>
<th>Batch</th>
<th>Analyses of Aggregates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Percentage Fleakiness</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Index per cent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bulk Density lb/ft³</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Voids ratio per cent</td>
</tr>
<tr>
<td>1. Monolithic construction in crushed quartzite gravel</td>
<td>Mean value = .462 Standard deviation = .0763</td>
<td>113.4 957 7</td>
<td>2</td>
<td>Total weight of dry sample = 3,920 g Passing 1/ in = .988 in = .171 in = .100</td>
<td>19.5 Compacted 98.1 Loose 91.1</td>
</tr>
<tr>
<td></td>
<td>Max. value = .595</td>
<td>113.1 1389 28</td>
<td></td>
<td>Total weight of dry sample = 13,500 g Passing 1/ in = .982 in = .42 in = .13</td>
<td>13 Compacted 94.4 Loose 87</td>
</tr>
<tr>
<td>2. Block construction in crushed quartzite gravel</td>
<td>Mean value = .377 Standard deviation = .0396</td>
<td>112.3 1022.3 7</td>
<td>1</td>
<td>Total weight of dry sample = 9,292 g Passing 1/ in = .54 in = .38</td>
<td>28.5 Compacted 94.4 Loose 87</td>
</tr>
<tr>
<td></td>
<td>Max. value = .432 Min. value = .300</td>
<td>111.3 1534.7 28</td>
<td></td>
<td>Total weight of dry sample = 12,816 g Passing 1/ in = .14 in = .19</td>
<td>29 Compacted 94.7 Loose 89</td>
</tr>
<tr>
<td>3. Monolithic construction in crushed basalt</td>
<td>Mean value = .475 Standard deviation = .0424</td>
<td>115.8 933 7</td>
<td>2</td>
<td>Total weight of dry sample = 9,292 g Passing 1/ in = .54 in = .38</td>
<td>28.5 Compacted 94.4 Loose 87</td>
</tr>
<tr>
<td></td>
<td>Max. value = .595 Min. value = .418</td>
<td>115.4 1391 28</td>
<td></td>
<td>Total weight of dry sample = 12,816 g Passing 1/ in = .14 in = .19</td>
<td>29 Compacted 94.7 Loose 89</td>
</tr>
<tr>
<td>4. Block construction in crushed basalt</td>
<td>Mean value = .434 Standard deviation = .0397</td>
<td>114.0 880 7</td>
<td>1</td>
<td>Total weight of dry sample = 9,292 g Passing 1/ in = .54 in = .38</td>
<td>28.5 Compacted 94.4 Loose 87</td>
</tr>
<tr>
<td></td>
<td>Max. value = .55 Min. value = .372</td>
<td>113.7 975 28</td>
<td></td>
<td>Total weight of dry sample = 12,816 g Passing 1/ in = .14 in = .19</td>
<td>29 Compacted 94.7 Loose 89</td>
</tr>
</tbody>
</table>

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Fig. 2. Furnace testing equipment, showing details of end restraint (a 1/2 section elevation (lower left), and a part sectional side elevation of the furnace cassettes with the non-loadbearing wall in position ready for test.

If British Standard 476:1953 had been followed for the tests described here, the fire-resistance of only one wall would be changed and that only by a few minutes; specimen No. 4 would be deemed to have failed after 3 hr 14 min instead of 3 hr 2 min, due to higher permitted maximum temperature on the unexposed face.

Test Procedure

The walls were allowed to dry out naturally in the laboratory; they were judged to be in a condition suitable for test when the relative humidity measured on the face of the specimen by form of hygrometer (4) was 80 per cent or less. When 1 test the restraint frame containing the specimen wall was to face the gas-fired furnace panel shown in Fig. 1, which is in detail elsewhere (2). Furnace temperatures were by means of nine No. 18 s.w.g. chromel-alumel thermocouples arranged symmetrically in three rows of three, and they were continuously throughout the test. Temperatures of the exposed face were measured in five standard positions (at the center and the center of each quarter section) by means of

Fig. 5. Temperature curves.
s.w.g. copper-constantan thermocouples soldered to thin copper discs which were cemented to the wall. These temperatures were read at intervals during the test. For obtaining information of temperature distribution through the specimens certain walls were provided during manufacture with thermocouples having the hot junctions accurately located at selected points in the thickness. Deflection of the walls was measured on the unexposed face by means of a scale and a fixed wire stretched between supports on either side of the restraint frame.

A test was considered as starting from the time the lighted furnace panel was in position to enclose completely the exposed face of the specimen. Observations of the behaviour of the specimens were made throughout. Heating was stopped as soon as a wall failed under any of the three requirements of British Standard 476. The furnace panel was then withdrawn and the water jet applied.

**Results of Tests**

A typical curve of mean furnace temperature is shown in Fig. 5 in comparison with the Standard time-temperature curve of British Standard 476. Curves of mean unexposed face temperature for the individual specimens have been plotted in the same figure. A summary of the results appears in Table II.

**SPECIMEN No. 1**

Age at rendering—14 days. Age at test—85 days.

Fig. 7 shows the appearance of the wall before and after test. The maximum recorded deflection was \( \frac{1}{4} \) in towards the furnace. Observations during test. The first crack in the rendering was observed after 1 hr on the exposed face (1 in Fig. 6). On the unexposed face the first crack (4 in Fig. 6) was noticed at 2 hr. Further cracking occurred until 3 hr 5 min when cracks 6 and 7 appeared. At 3 hr 44 min the rendering bulged in the region cracks 4, 2 and 6 and break-up of the concrete in the lower \( \frac{1}{4} \) of the wall commenced with considerable noise. The render and concrete to a depth of 2 to 3 in fell away from the area X the exposed face 6 min later. At 4 hr 8 min rendering fell from the unexposed face on an area corresponding to X and at 4 hr 14 min a crack formed in the wall through which flame could pass. Heating was then terminated. The impact test was reapplied with little apparent effect followed by the 4 min water test, which removed all the rendering and some of the concrete from the exposed face.

**SPECIMEN No. 2**

Block wall in crushed quartzite aggregate. Age at rendering (new blocks)—57 days. Age at test (newest blocks)—87 days.

Observations during test. Cracks appeared early on the exposed face and the finish coat rendering fell from small areas (1 in Fig. 6). By 1 hr the finish coat rendering had fallen from a large area in the vicinity of patches 1 and from vertical edges. The undercoat rendering had bulged and split at X. During the next 30 min crack 3 appeared on the unexposed face and opened to about 4 in. On the exposed face a general break-up of the rendering began along the horizontal line through X. At 1 hr 50 min pieces block fell from area X and during the next hour the damage to blocks extended in depth and area. The rendering fell from area of the unexposed face (7 in Fig. 6) at 2 hr 59 min, followed 16 min later by further falls of rendering with some concrete passage for flame through the wall was then formed by a verti construction joint (Fig. 8b) and the test finished. Fig. 8c shows the unexposed face during the test at 3 hr and the exposed face after the test. The maximum recorded deflection was away from the furnace.
Fig. 8. Specimen No. 2. (Left) Unexposed face after 3 hr. heating. (Centre) Unexposed face after end of heating. (Right) Exposed face of heating.

SPECIMEN No. 3
Monolithic wall in crushed basalt aggregate. Age at test—112 days. Observations during test. During the first 30 min cracks developed on the exposed face with some bulging in region of position 2 in Fig. 9 (above left), and a fall of the finish coat 3 min later. Except for a small fall of finish coat from area 1 on the exposed face no noticeable deterioration was observed in the condition of the wall when heating finished at 6 hr 3 min. The impact test was re-applied with little effect. Application of the water jet for 6 min removed all the rendering and some of the concrete from the exposed face. Fig. 10 shows the appearance of both faces at the end of heating and after the water test. The maximum deflection recorded was $\frac{3}{4}$ in away from the furnace.

SPECIMEN No. 4
Block wall in crushed basalt aggregate. Age at rendering (newest blocks)—41 days. Age at test (newest blocks)—79 days. Observations during test. During the first hour of test the only damage observed was crack 1 (Fig. 9 below left) on the exposed face with a slight bulging of the rendering. No further deterioration was visible when failure occurred by local temperature rise on the unexposed face after 5 hr 2 min. Heating was terminated at 5 hr 20 min, after which the impact test was re-applied. After the 5$\frac{1}{2}$ min water test removed all the rendering from the exposed face but caused little damage to the blocks. Fig. 11's appearance of the two faces of the wall after the water test parative temperatures measured at different points in approximately at the centre of a block and in adjacent vertical joints, are shown in Fig. 12. The maximum recorded was $\frac{3}{4}$ in towards the furnace.

Discussion of Results

Effect of Type of Aggregate
The type of failure obtained in the fire tests was determined by the aggregate used. The quartzite aggregate walls showed structural break-up of the concrete, while the basalt aggregate maintained their integrity until the limiting temperature was reached on the unexposed face. This difference in behaviour is explainable by the different thermal expansion of the aggregates, in that the stresses induced in the quartzite walls were greater than in the basalt walls. The coefficient of expansion of silica bearing rocks increases almost linearly with increasing silica content. Quartzite with its high silica content has a low coefficient of expansion, which results in the generation of tensile stresses during heating.

### TABLE II

**Summary of Results of Fire-Resistance Tests of No-Fines Concrete Walls**

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Aggregate</th>
<th>Type of Construction</th>
<th>Average temperature of unexposed face—°C</th>
<th>Fire-Resistance</th>
<th>Mode of Failure</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1-hr</td>
<td>2-hr</td>
<td>3-hr</td>
<td>4-hr</td>
</tr>
<tr>
<td>1</td>
<td>Crushed Quartzite</td>
<td>Monolithic</td>
<td>78</td>
<td>80</td>
<td>83</td>
<td>103</td>
</tr>
<tr>
<td>2</td>
<td>Crushed Quartzite</td>
<td>Block</td>
<td>70</td>
<td>73</td>
<td>77</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>Crushed Basalt</td>
<td>Monolithic</td>
<td>23</td>
<td>73</td>
<td>85</td>
<td>87</td>
</tr>
<tr>
<td>4</td>
<td>Crushed Basalt</td>
<td>Block</td>
<td>50</td>
<td>73</td>
<td>80</td>
<td>91</td>
</tr>
</tbody>
</table>

6
Effect of Type of Construction

The block walls in both types of aggregate were inferior performance to the monolithic walls. In the walls of quartz aggregate where the critical factor was the structural failure of concrete, the damage was observed earlier and extended over a greater area in the block walls than in the monolithic walls. It may be attributed to a number of causes, such as differences in concrete strength, moisture content of the specimens and in workmanship of the renderings. The consequences of one feature construction in the block wall were apparent; any fall of render from corresponding areas on both faces of the wall would reveal a fissure through which flame could pass. In the monolithic wall, however, a fissure would not develop in the concrete until considerable damage had been sustained. This weak point in block construction could be easily overcome by modifying the design so that the vertical joints were mortared in the same way as the horizontal joints.

In the basalt walls, the critical factor was heat transmission. Temperature measurements were made by means of thermocouples at the points in the blocks and joints shown in Fig. 12. Higher temperatures were observed at any given time in the joints that the concrete, indicating that heat transfer through a monolithic wall would be lower than through a block wall.

Effect of Moisture Content

Since no means were available to condition the specimen to a predetermined moisture content, there was necessarily a variation in the amount of water in the walls at the time of test. In general, the walls when tested were in equilibrium with the atmosphere of the test building. It would appear that the b...
wall of quartzite had a higher moisture content than the monolithic wall of the same aggregate, but for the basalt walls the reverse obtained. This would explain the differences in the unexposed face temperatures, but no quantitative data on the amount of water evaporated can be given.

**Effect of Renderings**

For cement : lime : sand renderings, $\frac{1}{3}$ in can be regarded as the minimum thickness which should be applied to obtain the performance of these tests. There is evidence that an increase in the thickness of the renderings will make little difference to the fire-resistance.

No tests were made on walls finished with gypsum plaster instead of cement : lime : sand, but the results of tests on other types of construction where a comparison has been made show that gypsum is not likely to be inferior in performance.

**Deflection of Walls**

The method used for measuring the lateral deflection of the walls, gave the total movement of the rendering on the unexposed face and not the true displacement of the wall, if any relative movement occurred between wall and rendering. From comparisons between the actual displacement measurements and the observed behaviour of the rendering, it is estimated that at no time did the lateral deflection at the centre of any of the four walls exceed $\frac{1}{2}$ in.

**Conclusions**

Restrained walls $6$ in thick of no-fines concrete made from natural aggregates representative of the high and low silica content rocks and rendered on both faces have been shown to possess a fire-resistance which is sufficient for most classes of buildings, and compares favourably with the ratings obtained by other types of construction. For example, clay brick walls $\frac{3}{4}$ in thick, plastered $\frac{1}{3}$ in on each face, are rated as constructions of 2-hr fire-resistance.

The walls of low silica aggregate were superior to the corresponding constructions of high silica aggregate. A lower fire-resistance was obtained for the block wall of either aggregate than for the corresponding monolithic wall.

It is reasonable to assume that the fire-resistance of a concrete wall of similar construction to those tested, but different aggregates, would not be less than that of the qu specimens.

**Acknowledgements**

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**BIBLIOGRAPHY**


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Fig. 11. Specimen No. 4. (Upper left) Exposed face after water test, with (lower left) close-up of face. (Right) Unexposed face immediately after water test.

Fig. 12. Specimen No. 4. (Above) Posi thermocouples in blocks. (Below) Con temperatures within block wall.