Durability Performance Of Polymer Concrete In Strongwall Construction

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Summary: The concept of a polymer concrete based innovative construction system has been developed by Strongwall. This system enables speedy and economical construction of internal and external load bearing as well as non-load bearing walls. Research is focussed on identifying various materials that could be used for manufacturing the Strongwall system. Two polymer concrete formulations have been developed using industrial wastes.

Before the system is manufactured commercially, it is essential that its material and engineering characteristics are assessed and documented to aid design. This is even more compelling when the new material is manufactured using industrial wastes. Accelerated weathering tests were conducted using highly concentrated sodium chloride, sodium sulphate, sulphuric acid and sodium hydroxides. Circular disc specimens were prepared from cast cylinders and splitting tensile strength was evaluated after accelerated weathering to assess the degradation of strength.

The results indicate that the tested polymer concrete formulations have significant resistance to environmental degradation. It is noted that high concentration of sulphuric acid and sodium hydroxide can be harmful.

Keywords: Polymer Concrete, Durability, Strong Wall, Splitting Test, Environmental Degradation

1 INTRODUCTION

Conventional brick masonry walls are a popular and economical way to enclose modern buildings. However, over the past decade an increasing number of masonry veneer problems have come to plague building designers and owners around the world. To overcome some of the problems associated with traditional construction, new concepts of construction methods and materials have been explored. The innovative construction system developed by Strongwall combines the advantages of both the construction method and a new lightweight material to enable speedy and economical construction.

The new system could be used for both internal and external load bearing as well as non-load bearing walls. Besides its adaptability and economy, the construction system has been designed for durable residential houses in regional and remote outback areas where construction resources are in scarcity, for use in cyclone regions where strength and durability are essential, for external cladding in multi-storey residential & commercial buildings etc.

Polymer concrete has been selected on the basis that its relative strength is higher than conventional concrete, and it has the ability to cure at a faster rate. Further, if appropriate materials are chosen then a high strength to weight ratio could be achieved. In recent times, construction materials with ecological characteristics have generated great interest. From this point of view, polymer concrete is very attractive as it can be manufactured using recycled and/or industrial waste materials.

Three types of concrete polymer composites are popular throughout the world primarily due to their high strengths and durability. The materials are:

- Polymer impregnated concrete (PIC) which consists of a precast Portland cement concrete impregnated with a monomer system that is subsequently polymerised in-situ.
- Polymer cement concrete (PCC) with polymeric admixtures to green concrete in the form of latexes or plasticisers.
- Polymer concrete (PC) which consists of an aggregate mixed with a monomer or resin that is subsequently polymerised in place.

All these have strength and durability properties that are considerably better than that of Portland cement concrete. Also, the behaviour of concrete polymer composites is substantially different to that of normal cement concrete since the former uses a viscoelastic resin binder while the later uses an organic cement binder.
The characteristics of polymer composites depend upon various factors such as the type and amount of binder, the amount, size and type of aggregates and fillers etc. The ability to fill the voids between solid particles by fine fillers and to disperse in the mixture is considered to be vital to achieve high strength and stiffness.

At present, the Division of Building, Construction & Engineering of CSIRO is engaged in a sponsored research project. The primary aims of the research are to identify and develop a suitable material (or an array of materials) for the construction of the system and assess its (their) characteristics. While developing the materials reported in this paper, a large number of exploratory tests were conducted using various types of industrial wastes. However, due to lack of space, only characteristic properties of two types of polymer concrete are reported in this paper. Also, the durability performances under simulated aggressive forces of nature are included.

2 EXPERIMENTAL STRATEGY

As mentioned above only two types of materials are reported in this paper. Both materials are designed to achieve 40 MPa compressive strength. The mechanical properties of the two materials are shown in Table 1. The ingredients used are not disclosed here due to the commercial nature of the product.

Four test cylinders (76 mm diameter x 150 mm high) were cast from each mix type. They were initially cured at 35°C for 45 minutes and then at 25°C for 5 days. Results obtained from the initial tests indicated that the specimens gained full strength within 3 to 7 days. The disc specimens were primarily grouped into two categories, namely control specimens and specimens to be subjected to accelerated weathering. The accelerated weathering was simulated by subjecting the specimens into wetting and drying cycles in an aggressive environment. The specimens subjected to the accelerated weathering conditions were also divided into two groups. The specimens in one of the groups were only subjected to fan drying under the laboratory conditions, whereas the specimens in other group were oven dried after every five cycles for weight measurements. The control specimens and the specimens which were not subjected to oven drying were finally tested for strength tests.

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Type A</th>
<th>Type B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength (MPa)</td>
<td>40MPa</td>
<td>40MPa</td>
</tr>
<tr>
<td>Flexural Tensile Strength (MPa)</td>
<td>10.5MPa</td>
<td>10.7MPa</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>1440kg/m³</td>
<td>1530kg/m³</td>
</tr>
</tbody>
</table>

3 EXPERIMENTAL PROCEDURE

Approximately 10 mm thick circular specimens were cut and placed back together in their original positions within the cylinder. Each test specimen (circular disc) was numbered sequentially in the cylinder for future reference. Altogether 32 circular discs were prepared for the investigation.

For the durability tests, some of the specimens (circular discs) were subjected to accelerated weathering while others were left as control specimens.

3.1 Durability Assessment

In order to understand the durability characteristics, an appropriate test as well as a performance indicator is needed. The type and nature of the test will depend upon its intended use and a wide range of variables must be considered in developing the test. Further, the accelerated laboratory experiments should be corroborated using long term monitoring of the in-situ durability performance of the material.

As a consequence of the brittle nature of polymer concrete, flexural tensile strength has been widely used as a performance indicator. In this study splitting tensile strength of the material under diametral loading was selected as the performance indicator due to the following reasons.

- Simplicity of the test set up
- Several test specimens (1 cm thick discs) can be prepared from the same cylindrical specimen
- Effect of the variability of the material in different test specimens can be minimised since several test specimens can be prepared from the test cylinder.
- Because specimens are relatively small, it is easy to perform the drying and wetting cycling tests.
- Cylindrical specimens are large enough to be representative of the material as a whole
- Effect of the aggressive agent can be assumed uniform through the thickness of the test specimen because of its thinness.
- To the authors knowledge, this is the first time the splitting test method has been used for the assessment of strength degradation of specimens subjected to exposure. Therefore, this study would also allow assessing the suitability of the test technique to such applications.
Continuous assessment of deterioration is a difficult task, as the deterioration is progressive and small in its early stages. Visual inspection, change in volume/dimensions and change in weight are some of the commonly used parameters to assess the degree of deterioration.

The weight loss or gain of the specimens was monitored in this study. Because of its non-destructive nature, weight loss/gain can be used as an indicator to identify the time at which the destructive splitting tests should be carried out.

3.2 Weathering Test & Agents

Most durability tests involve a prolonged period of soaking the specimens in a weathering agent, and then assessing the degree of deterioration. On using a reasonably strong weathering agent, the rate of deterioration will be slow, and therefore, the test itself must be of reasonably long duration. Also, it does not simulate what is happening in a real life situation, where both wetting and drying processes cause the degradation of the material.

An alternative approach to the above, is a shorter duration cyclic test where the specimen is immersed in the weathering solution for a specified time and then dried in a controlled environment. This process is repeated for a set number of cycles, or until measurable deterioration occurs. In this case, the rate of deterioration will be influenced by the concentration of the solution and severity of the cycling procedure. This approach reasonably simulates the real life performance.

For the current study, the cycling process as described above was selected and the following agents were used.

- Sulphuric Acid – 25%
- Sodium Hydroxide – 10 molar
- Sodium Chloride – 14%
- Sodium Sulphate – 14%

The Australian/New Zealand Standard AS/NZS 4456:1997 recommends the use of a mixture of 14% of Sodium Chloride and 6.2% of Sodium for the degradation assessment of masonry units due to salt attack. The same strength mixture was used for the current specimens to test for salt resistance ability. Under normal conditions, 25% of Sulphuric Acid and 10 molar Sodium Hydroxide are highly unlikely to occur. However, to understand the worst case performance, these mixtures were used.

As the test progresses, the concentration of the sulphate/chloride ions and the pH value of the solution vary due to reactions with the sample. Unless these parameters are kept constant, they can influence the results and increase the length of the test.

It should be noted that whatever type of accelerated test method is used, a correlation must be obtained between laboratory and field performance so that the test method could be fine tuned for realistic conditions for future tests. Unfortunately, when materials are newly developed, there are no past records for comparison.

3.3 Test Procedure

Eight, approximately 10 mm thick, circular test specimens were prepared from each cylinder. A typical example is schematically shown in Fig. 1. The specimens 1 to 6 were meant for the splitting test and 7 & 8 for the weight loss assessment. The specimens used for the weight assessment were initially oven dried (at 105 °C) and their datum weights were recorded. Then all the test specimens, other than the control specimens were subjected to 24-hour wet and dry cycling.

<table>
<thead>
<tr>
<th>Spec. No.</th>
<th>Test Cylinder</th>
<th>Weight (gms)</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specimen to be Weathered</td>
<td>98.32</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>and subjected to</td>
<td>99.37</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Splitting Test</td>
<td>99.88</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>99.58</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Specimen to be Weathered</td>
<td>102.91</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>and subjected to</td>
<td>102.79</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Weight Measurement</td>
<td>101.15</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Control Specimen</td>
<td>100.88</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. A Typical Layout of Specimens prepared from a Cylinder
The control specimens were left in the laboratory while others were subjected to 24-hour wet and dry cycling at the age of 7 days. For each cycle, they were immersed in the solution for about 2 hours and then fan dried for 22 hours in the temperature controlled (23 °C) laboratory. Two replicates were tested for each test condition.

The specimens 7 & 8 were oven dried at every fifth cycle (except at the start when oven drying took place after 2 cycles) for weight assessment. At the end of every fifth cycle, fan drying commenced followed by oven drying for 2 hours. Then the specimens were cooled for about 5 minutes and weighed prior to the commencement of the next cycling period. The specimens intended for splitting tests were not oven dried.

After every 10 cycles the old solutions were replaced with fresh solutions. The wetting and drying cycles were terminated after 37 cycles, when some of the specimens indicated signs of deterioration by loosing weights.

4 RESULTS AND DISCUSSION

The weight loss/gain of specimens are shown in Fig. 2 and 3 (positive values indicate weight gain). Each result shown is the average of two replicates. The variability of the results produced by similar specimens was found to be insignificant, and therefore the results were averaged.

The following comments could be made on the above results:

• Behaviour of both material types is quite similar and is understandable as the materials are quite similar.
• Specimens do not show any significant deterioration with a severe exposure to sodium chloride and sodium sulphate solutions.
• The specimens subjected to severe sodium hydroxide exposure, initially gained weight, and subsequently, started to loose weight. The initial weight gain may be due to reaction products being deposited in the pores. As the specimen begins to deteriorate, a decrease in weight would have occurred due to spalling and similar effects. The signs of reaction taking place were observed by a noticeable change in colour. Initially, the specimens were grey in colour and after the first cycle, turned into a slightly yellowish colour.
• A significant deterioration of specimens, which were subjected to severe sulphuric acid attack, was noticed after the 27th cycle. Although there was no significant loss of weight initially, a considerable colour change has been observed, especially after oven drying at 105 °C for 2 hours. The grey colour of the specimens was changed into a dark black colour. However, subsequent investigation has shown that the change in colour has occurred only on the surface. Fig. 4 shows the affected specimens under the influence of sulphuric acid together with two control specimens.
The splitting test results are graphically shown in Figs. 5 and 6. The specimen numbers from 1 to 6 are consecutive specimens, and have been prepared from the same test cylinder. This enables comparison of the control specimens and the weathered specimens. The tensile splitting strength at the centre of the circular disc specimens was calculated using the equation shown below. The diameter and the thickness of the specimens were measured at three different locations and the average value was taken for calculations.

Splitting tensile strength (MPa) = \( \frac{2P}{pDt} \)

where,
\( P \) – Failure Load (N)
\( D \) – Diameter of the Specimen (mm)
\( t \) – Thickness of the specimen (mm)
Figure 7. Splitting Tensile Load of Material Type 2 Specimens subjected to Accelerated Weathering

Figs. 5 and 6 show that the splitting tensile strengths of control specimens can be significantly different within the same test cylinder. This is probably due to non-uniformity of the mix and local crushing that took place at the loaded points in some of the specimens prior to tensile splitting failure. The average of the two adjacent specimens is compared with the weathered specimen in order to look at the effect of the weathering.

Table 2 summarises the loss/gain in tensile strength of the weathered specimens compared with the control specimens.

<table>
<thead>
<tr>
<th>Weathering Agent</th>
<th>Material Type</th>
<th>Spec. 2</th>
<th>Spec. 5</th>
<th>Spec. 2</th>
<th>Spec. 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphuric Acid</td>
<td>A</td>
<td>-29.2%</td>
<td>-15.7%</td>
<td>-34.3%</td>
<td>-39.7%</td>
</tr>
<tr>
<td>Sodium Hydroxide</td>
<td>A</td>
<td>-26.6%</td>
<td>-12.3%</td>
<td>-30.8%</td>
<td>-25.7%</td>
</tr>
<tr>
<td>Sodium Sulphate</td>
<td>A</td>
<td>12.8%</td>
<td>11.4%</td>
<td>-4.2%</td>
<td>-3.1%</td>
</tr>
<tr>
<td>Sodium Chloride</td>
<td>A</td>
<td>2.4%</td>
<td>-0.8%</td>
<td>5.2%</td>
<td>-0.7%</td>
</tr>
</tbody>
</table>

Both materials show a similar trend in the results. Effect of both sodium sulphate and sodium chloride solutions is not adverse after continuous wetting and drying for 37 cycles. Any loss or gain in strength shown by the specimens subjected to salt attack is not more than the variability of strengths shown by control specimens. However, it should be noted that both sulphuric acid and the sodium hydroxide have significantly affected the strength of the specimens.

The accelerated agents used in this study, especially the sulphuric acid and the sodium hydroxide, are extreme cases, and unlikely to occur in general applications. However, results obtained reveal that sulphuric acid and sodium hydroxide can be harmful for the polymer concrete materials developed. Further investigations are needed to assess their resistance to mild concentrations of the agents.

5 CONCLUDING REMARKS

Two new polymer concrete based materials were developed using industrial wastes. These materials were used to form the basis of a novel construction system. Circular disc specimens of these materials were manufactured in the laboratory so that
accelerated weathering and strength tests could be conducted to assess their durability characteristics. Preliminary tests indicate that sulphuric acid and sodium hydroxide significantly affect the tensile strength of these materials and reduce their durability. However, other normally occurring agents such as sodium sulphate and sodium chloride, do not adversely affect these materials. Further investigations are being carried out and will be reported in the future.

6 ACKNOWLEDGMENTS
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7 REFERENCES