1. INTRODUCTION
A structure is designed for a specific period and its design life varies depending on the nature of that structure. Deterioration in concrete structures is a major challenge faced worldwide by the infrastructure and bridge industries[4]. The deterioration of structures is mainly due to environmental effects, gradual loss of strength with ageing, repeated high intensity loading, variation in temperature, freeze-thaw cycles, contact with chemicals or saline water and exposure to ultra violet radiation. The most popular technique for strengthening of reinforced concrete beams is the use of externally bonded composite materials such as glass fiber reinforced polymers (GFRP) is a common retrofitting technique that is generally employed. In this paper a new alternative glass and cement-based composite material known as glass textile-reinforced mortar (GTRM), was used for retrofitting. It was mainly found that: (a) GTRM was generally inferior to GFRP in enhancing the flexural capacity of RC beams with an effectiveness ratio between the two systems varying from 0.40 to 1.22, depending on the parameters examined, (b) Doubling the number of GTRM layers (from one to two), the GTRM versus GFRP effectiveness ratio was increased and (c) Providing end-anchorage increased the performance of GTRM-retrofitted beams, but had only limited effect on GFRP retrofitted beams.

2. EXPERIMENTAL PROGRAMME

2.1 Test specimens and investigated parameters
Beam specimen used for the test consist of two 10mm diameter bars at bottom and two 8mm stirrup holders. The beam size was fixed as 120mm x 180mm x 1250mm and the transverse reinforcement used consist of 6mm diameter vertical stirrups (See Figure 1).

The parameters varied included the strengthening material namely Glass textile reinforced mortar (GTRM) and Glass fiber reinforced polymer (GFRP), Number of layers of strengthening material (1 and 2), End-anchorage system of the external reinforcement (See figures 3 to 6). The specimens were tested in a two point load testing machine of 3000 kN capacity (See Figure 11). A dial gauge of least count 0.01mm was used for obtaining deflections. Deflections at mid span
was noted at each load steps until failure. The ultimate load, load at first crack, load deformation behaviour and failure modes were observed.

![Loading diagram](image1)

2.2 Preparation of specimens

The retrofitting material (GTRM or GFRP) was externally bonded to the bottom of the beams over a length of 1140 mm (see Figure 3 to Figure 6). The strengthening procedure for both strengthening systems had the characteristics of a typical wet lay-up application and comprised the following steps:

Prior to strengthening, the concrete surface was prepared as follows: The surface was roughened using a grinding machine and the resulted concrete surface was cleaned from dust with compressed air (See Figure 7a and Figure 7b).

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Wrapping scheme</th>
<th>Beam code (GTRM)</th>
<th>Beam code (GFRP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GTRM - EA - 1</td>
<td>GTRM-EA-1</td>
<td>GFRP-EA-1</td>
</tr>
<tr>
<td>2</td>
<td>GTRM - EA - 2</td>
<td>GTRM-EA-2</td>
<td>GFRP-EA-2</td>
</tr>
<tr>
<td>3</td>
<td>GTRM - 1</td>
<td>GTRM-1</td>
<td>GFRP-1</td>
</tr>
<tr>
<td>4</td>
<td>GTRM - 2</td>
<td>GTRM-2</td>
<td>GFRP-2</td>
</tr>
</tbody>
</table>
The procedure for application of GTRM materials included: (a) Dampening the concrete surface with water (b) Application of a layer of mortar with approximately 4 mm thickness (See Figure 8a) (c) Application of the textile into the mortar and gently pressing with hand to ensure good impregnation with cement mortar (See Figure 8b).

The procedure for GFRP-retrofitted specimens included: Application of the textile over a thin layer of resin and then impregnated with resin using a plastic roll (See Figure 9a and Figure 9b).

The above procedure for both strengthening systems was repeated in case of more than one textile layers were applied. For GTRM-retrofitted beams, the final layer of textile was covered with a final layer of mortar with approximately 4 mm thickness and levelled (See Figure 10a and Figure 10b).
2.3 Testing of specimens
All beams were subjected to two point loading as shown in Figure 11. The clear span was 1140 mm, and the selected configuration resulted in a 380 mm-long constant moment zone and a 380 mm-long shear span. The load was applied using a 3000 kN capacity machine. The load was applied monotonically. A dial gauge was fixed at the mid-span of the beam to measure the mid-span deflection.

![Figure 11. Testing of specimen](image)

2.4 Observations
The main observations of all tested beams are presented in Table 2 which includes: (1) Cracking load (2) Ultimate load (3) Displacement at cracking load (4) Displacement at ultimate load (5) Observed failure mode.

Table 2: Observations

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Beam Code</th>
<th>Cracking load-kN</th>
<th>Ultimate load-kN</th>
<th>Displacement at cracking load (mm)</th>
<th>Displacement at ultimate load (mm)</th>
<th>The observed failure mode</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>CON</td>
<td>64</td>
<td>79</td>
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<td>3.2</td>
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<td>2</td>
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<td>98</td>
<td>2</td>
<td>3.3</td>
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<tr>
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<td>GTRM_2</td>
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<td>114</td>
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<td>3.28</td>
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<td>98</td>
<td>2</td>
<td>3.2</td>
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</tr>
<tr>
<td>5</td>
<td>GTRM_EA-2</td>
<td>80</td>
<td>115</td>
<td>2.5</td>
<td>3.2</td>
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</tr>
<tr>
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<td>GFRP-1</td>
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<tr>
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</tr>
<tr>
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<td>GFRP-EA-1</td>
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<td>90</td>
<td>1.8</td>
<td>5.9</td>
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<tr>
<td>9</td>
<td>GFRP-EA-2</td>
<td>85</td>
<td>108</td>
<td>1.8</td>
<td>7.3</td>
<td>Flexural</td>
</tr>
</tbody>
</table>

3. RESULTS AND INTERPRETATION
3.1 Load deformation curve for TRM retrofitted beams.
The load-deflection curves of GTRM retrofitted beams are presented in figure 12. The difference between the curves of the retrofitted beams and the control one is attributed to the contribution of strengthening materials to the flexural performance of the beams. The effect of strengthening was more pronounced for beams retrofitted with two layers of GTRPM. The beams retrofitted with one layer of GTRPM also showed an improved performance when compared with control specimen. It is to be noted that the beams retrofitted with end anchorage and partial U wrapping schemes showed almost the same load displacement variation.
The load-deflection curves of GFRP retrofitted beams are presented in figure 8. The difference between the curves of the retrofitted beams and the control one is attributed to the contribution of strengthening materials to the flexural performance of the beams. The effect of strengthening was more pronounced for beams retrofitted with two layers of GFRP. The beams retrofitted with one layer of GFRP also showed an improved performance when compared with control specimen. Beams retrofitted using partial U wrapping scheme performed better than those retrofitted using bottom with end anchorage scheme.

The values of maximum loads and the observed failure modes of all tested beams are presented in Table 2 supported by Figures 12 and 13. The reference beam (CON) failed in flexure after the formation of large flexural cracks at the constant moment region. The failure was due to yielding of the tensile reinforcement followed by concrete crushing at the compression zone. This type of failure mode is typical for under-reinforced beams. The yield and ultimate load was 64 kN and 79 kN, respectively, at corresponding mid-span deflection of 1.8 mm and 3.2 mm, respectively.

All GFRP strengthened beams also failed in flexure at loads substantially higher than the control beam (Table 2). The ultimate load recorded for specimens GFRP-1, GFRP-2, GFRP-EA-1 and GFRP-EA-2, was 145 kN, 176 kN, 90 kN and 108 kN, respectively. Thus, the contribution of various GFRP strengthening systems in increasing the flexural capacity was 83.5%, 122%, 13.9% and 36.7% respectively. The beams strengthened with both one and two layers of GFRP failed due to fibre rupture at the constant moment region of the beam.

Similar to the FRP-retrofitted beams, all specimens strengthened with TRM failed in flexure after displaying flexural strength considerably higher compared to the control specimen. The maximum load recorded for specimens GTRM-1, GTRM-2, GTRM-EA-1, GTRM-EA-2 were 98 kN, 114 kN, 98 kN and 115 kN respectively, which yielded 24%
40.5\%, 24\% and 40.56\% increase in the flexural capacity respectively. The beams strengthened with both one and two layers of GTRM failed due to crack in mortar along with fibre rupture at the constant moment region of the beam.

3.4 Flexural strength
The contribution of various GFRP strengthening systems in increasing the flexural capacity were 83.5\%, 122\%, 13.9\% and 36.7\% respectively and corresponding value for GTRM retrofitted beams were 24\%, 40.5\%, 24\% and 45.56\% (See figure 14).

![Figure 14. Percentage increase in flexural strength](image)

4. CONCLUSION
This study was an experimental investigation on the performance of GTRM and GFRP composite in flexural strengthening of RC beams. The parameters examined were (a) Strengthening material (GTRM and GFRP) Number of GFRP/GTRM layers and (c) End anchorage system. The obtained results revealed the following conclusions:

The effectiveness of GTRM system in increasing the loading carrying capacity of retrofitted beams were less than that of GFRP but was higher than that of the control specimen.

GFRP effectiveness was sensitive to the number of layers. It was found that the effectiveness factor increased for partial U wrapping scheme from 0.83 to 1.22 when the number of GFRP layers increased from 1 to 2.

Providing end-anchorage with U-jackets to GTRM-retrofitted beams showed same enhancement in the flexural capacity compared to partial U wrap. However, the corresponding enhancement in GFRP-retrofitted beam was limited and was attributed to the presence of slippage of the fibres at the constant moment zone.

5. REFERENCES