THE EFFECT OF FIBROUS CONCRETE BATCHES AT THE AGE OF 730-DAYS THROUGH ANALYTICAL AND EXPERIMENTAL TESTS

Indradi Widjatmiko, Ari Wibowo, Devi Nuralinah, D. Mulyaningrum

Brawijaya University
Faculty of Engineering, Department of Civil Engineering
E-mail: indradi@ub.a.c.id

ABSTRACT

This research is a continuous study to investigate the effect of fibrous concrete batches at the age of 730-days and hence makes a comparison with experimental results conducted by Bryceson (2003). Modelling the finite element is carried out in linear static solver and non-linear static solver to verify the experimental results of column specimens recorded by Bryceson (2003). Polypropylene fibres were used in this study with the high strength concrete of recorded compressive strength of 72 MPa (Bryceson, 2003). Two fibre contents (0.1 %, and 0.3 %) with different fibre location were proposed by Bryceson (2003) for the column specimens. For each batch of fibre content, three columns were cast by Bryceson (2003). One consisted of fibrous concrete for the entire section, while the second column consisted of fibrous concrete at the cover and the region through the steel reinforcement only and the third column consisted of fibrous concrete at the cover only. A control references column was cast with non-fibrous concrete at the entire cross-section for comparison purpose (Bryceson, 2003). Therefore, in this study, similar modelling of columns was done in finite element analysis to conduct the analytical results. All column models were tested in finite element analyses in both linear static solver and non-linear static solver under concentric axial compression. Linear static solver used the ultimate load which was recorded by Bryceson (2003) to determine the displacement, while the non-linear static solver used ultimate load with increment (0%, 20%, 40%, 60%, 80%, and 100%). The analytical results are then graphed and compared with the experimental results which were conducted by Bryceson (2003). This study found that the analytical results obtained from non-linear static solver provides a better comparison for the experimental results conducted by Bryceson (2003) as compared to analytical results obtained from linear static solver. This study found that the column of 0.1% fibre content at the cover produced the least displacement of 11.19 mm in non-linear static solver compared to others. In conclusion, 0.1 % fibre content exhibited a better performance in terms of lower displacement.

Key Words: fibrous concrete, linear static solver, non-linear static solver

INTRODUCTION

The idea of using discrete, ductile fibres to reinforce brittle materials such as concrete columns is not an innovative technique; many studies having been conducted over the past twenty years. Fibre addition into concrete offers convenient and practical means of achieving improvements in many of the engineering properties of the material, such as fracture toughness, fatigue resistance, impact resistance, flexural strength and shear strength. Even though many studies show that there is a significant relationship between adding fibre and improving durability, further research needs to be conducted in order to form a conclusion stating whether any kind of fibres, namely steel, carbon or Polypropylene fibre will result in better durability throughout some tests. This paper focuses on the investigation of Polypropylene fibre as the reinforced concrete with the treatment of compressive strength test, indirect tensile test and flexural strength test on the day of 7, 28 and 730 days (2 years), and also perform analytical analysis to verify the differences between the analytical results and experimental results on the columns.
specimens. The aim of the project is to find out analytically the result of adding fibres to the cover of reinforced concrete.

Ganesan and Murhty (1990) performed an experiment on the strength and behaviour of short confined steel fibres and non-steel fibres reinforced concrete columns. This study shows that there was an improvement in the strength and ductility of the fibrous reinforced concrete. It is also important to notice that adding steel fibres in the concrete mixing can also improve tensile behaviour, durability, integrity and dimensional stability.

Hsu and Hsu (1994) performed a study on stress-strain behaviour of steel-fibre high-strength concrete under compression. The idea was to conduct tests using a modified test method to give the complete stress-strain behaviour of steel-fibre concrete with or without tie confinements. The results of these tests indicated that there was good agreement for the stress-strain relationships between the present experimental results and the analytical equation, either in confined or unconfined fibre concrete. Furthermore, the results show that adding steel fibre did not perform any major increase in strength; however, it caused an increase in strain corresponding to the peak stress.

EXPERIMENT

Samples Capping (High Strength Plaster)

High strength plaster was used to ensure a smooth and even surface of the nine 100 mm x 200 mm cylinders that were tested during compression tests (Figure 1).

Strain gauges were used to obtain data relating to deformation of the various concrete batches during loading. The related strain-stress data are used for the finite element analysis for the columns. Since the applied load would be concentric, it was decided that strain gauges should be placed at half the height of the column: one horizontally and one vertically at the opposite side. Two gauges were used in each of the concrete samples. In order to attach the gauges to the concrete samples, the surfaces were ground smooth for a distance of 100 mm on both sides and then sanded by hand and cleaned with acetone. The gauges were attached with super glue, wrapped in electrical tape, and then covered with a sealant to protect the gauges from water and impact.

Figure 1. Sample Casting with High Strength Plaster

Experimental Test

Experimental tests were carried out in order to determine the properties of fibrous high strength concrete with an age of 730 days (2 years) after the cast used in this study. The experimental results are compared with 7 days and 28 days which were conducted by Bryceson (2003). The fibres selected for this study were polypropylene, Econo-net fibres, supplied by MRT Australia. Compressive, indirect tensile and flexural strength tests were undertaken on concrete samples of varying fibre contents.

After 7 days it was found that the high-strength concrete had gained a compressive strength of 58.7 MPa (except the 1.4% of concrete batch).
The overall compressive strength for all batches in 28-day testing was shown higher compared with 7-day testing. For 730 days compressive strength testing, it was found that significant gains were noted for the fibre concrete batches of 0% and 0.1% with respective 93 MPa and 105 MPa. The compressive strengths for the 0.5%, 1.0% and 1.4% mix began to decline and did not produce the respective strength that was expected. 0.1% fibre concrete batches were found to gain the highest value for the overall compressive strength tests.

The testing of the larger cylinders showed an increase in indirect tensile strength with an increase in fibre content. The overall indirect tensile strength for all batches at 730 days testing showed higher strength was gained compared to 30 days testing. 1.0% fibre concrete batches were recorded to gain the highest tensile strength of 7.28 MPa compared to other batches.

The flexural strength test showed increases in flexural strength with an increase in fibre content (except 1.4% batches). The flexural strength for all batches at 730 days testing showed higher strength gained compared with 98 days testing (except 1.4% batches).

The main finding of the preliminary testing was found with the introduction of fibre into the mix; the explosive characteristic of the high strength concrete was highly reduced. Bryceson (2003) stated that increasing fibre content reduces workability, and had proposed several methods in order to overcome the problems for the main experimental work. The summary of the 730 days experimental testing results is presented in Figure 2. Figure 3 show the summary of experimental results conducted by Bryceson.

![Figure 2. Comparisons of Compressive, Tensile and Flexural (730 days)](image)

![Figure 3. Comparison of Compressive, Tensile and Flexural (Bryceson, 2003)](image)

**COLUMN DETAILS AND PROPERTIES**

Each of the columns had 6N12 deformed bars as longitudinal and an R10 helix as lateral reinforcement. The helix was constructed at a pitch of 50 mm and the 6N12 bars were equally spaced around and tied to the inside of the helix. The longitudinal bars were cut to ensure at least 25 mm cover at the top and base of the column was available.

According to Bryceson (2003), three types of fibre content (0%, 0.1%, and 0.3%) were proposed to determine the optimum fibre quantity in the study. First, a column with 0% fibres (Column 1) was constructed to provide a reference point to which results could be compared. For each batch of fibres (0.1% and 0.3%) three columns were proposed. One containing a uniform fibrous cross-section (Column 2 and Column 5), one
containing fibres in the cover extending into the core (Column 3 and Column 6) and one containing fibres located only in the cover (Column 4 and Column 7). The fibre content and location for each column are shown in Table 1 and details and diagrams of the columns are presented in the following sections.

Table 1. Columns Number by Fibre Content and Location (Bryceson, 2003)

<table>
<thead>
<tr>
<th>Column Number</th>
<th>Fibre Content</th>
<th>Fibre Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column 1</td>
<td>0%</td>
<td>N/A</td>
</tr>
<tr>
<td>Column 2</td>
<td>0.1%</td>
<td>Entire Cross-Section</td>
</tr>
<tr>
<td>Column 3</td>
<td>0.1%</td>
<td>Cover + Extending into Core (outer 45 mm)</td>
</tr>
<tr>
<td>Column 4</td>
<td>0.1%</td>
<td>Cover only (outer 22.5 mm)</td>
</tr>
<tr>
<td>Column 5</td>
<td>0.3%</td>
<td>Entire Cross-Section</td>
</tr>
<tr>
<td>Column 6</td>
<td>0.3%</td>
<td>Cover + Extending into Core (outer 45 mm)</td>
</tr>
<tr>
<td>Column 7</td>
<td>0.3%</td>
<td>Cover only (outer 22.5 mm)</td>
</tr>
</tbody>
</table>

Comparison between Analytical and Experimental result

Non-linear static solver uses increments of load in order to analyse the FHSC models. The properties and stress-strain tables obtained from the experimental of the cylinder model are introduced to conduct the non-linear static solver in order to produce a similar model with the experimental column. However, the results obtained from the analytical and experimental do not have the same degree of accuracy. The comparison of the experimental results and analytical results are presented in Table 2 and Figure 4 to Figure 6 show the load and deflection curve for all the columns.

Table 2. Comparison between analytical and experimental results using Non-Linear Solver of FEA

<table>
<thead>
<tr>
<th>Column model no</th>
<th>Fibre Content (in % volume)</th>
<th>Fibre Location</th>
<th>Compressive Strength (Mpa)</th>
<th>Axial Displacement (mm)</th>
<th>Experimental</th>
<th>Finite Element Analysis</th>
<th>Different of Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>N/A</td>
<td>53.93</td>
<td>14.8</td>
<td>19.84</td>
<td>34.05</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.1</td>
<td>Entire Cross-Section</td>
<td>56.02</td>
<td>11.2</td>
<td>12.6263</td>
<td>12.73</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.1</td>
<td>Cover + Extending into Core (outer 45 mm)</td>
<td>55.44</td>
<td>13.6</td>
<td>12.2441</td>
<td>9.97</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.1</td>
<td>Cover only (outer 22.5 mm)</td>
<td>50.57</td>
<td>19.5</td>
<td>11.1879</td>
<td>42.63</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.3</td>
<td>Entire Cross-Section</td>
<td>58.63</td>
<td>78</td>
<td>20.7896</td>
<td>73.35</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.3</td>
<td>Cover + Extending into Core (outer 45 mm)</td>
<td>60.87</td>
<td>39</td>
<td>19.9676</td>
<td>48.80</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.3</td>
<td>Cover only (outer 22.5 mm)</td>
<td>57.11</td>
<td>28.5</td>
<td>17.3214</td>
<td>39.22</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 shows that the degrees of accuracy are better compared to the results obtained from the linear static solver. However, these values indicated that there are problems related either to the Experimental test or Finite Element Analysis method.

From Figure 4 to Figure 6 shows that there is a significant difference between the analytical results and experimental results where the experimental results form a curve line, while the FEA results form a linear line. The reason is that the stress-strain table was recorded from different samples which are from the small cylinder (100 mm x 200 mm) instead of from the columns. The compressive strength in the small cylinders is shown to gain higher strength compared to columns. For instance, the biggest compressive strength in cylinder test is 104.91 MPa, while the biggest compressive strength in column is only 60.87 MPa (column 6).
Therefore when the computer system plots the increments load of column (which is from 0 MPa to 60.87 MPa) based on the stress-strain tables, a single line without changed slope is graphed due to the compressive strength in column being much less compared to the small cylinders. It is strongly recommended that the stress-strain table should be obtained from the same samples in order to increase the degree of accuracy.

Another significant difference between experimental and analytical results is in the terms of displacement obtained from experimental test (refer to Table 2). For instance, Columns 5 to 7 have a similar fibre content of 0.3%, but the results obtained in the experimental test show that the displacement in Column 5 is 79 mm, which is twice that of Column 6 and triple that of Column 7. Therefore such huge errors in experimental results would produce greater differences in making the comparisons between experimental and analytical results. There are few factors that could be accredited to this phenomenon, which have already been discussed in the linear comparison above. It could be due to inaccurate measurements from the strain gauges or during the concrete cast. Introduction of fibre content into the mix would highly reduce the workability in casting the concrete, resulting in rough surfaces and voids.

CONCLUSIONS
This study of fibre reinforced concrete columns involved testing the concrete samples at the day 730 (2 years) in terms of compressive strength test, indirect tensile test, and flexural strength test, and made comparisons with the experimental results which were conducted by Bryceson (2003). Analysis of the columns is performed using Strand 7 software and compared with the experimental results from Bryceson (2003). The conclusions of this study are briefly explained as following.

- Introduction of fibre content into the concrete mix highly reduces the explosive behaviour of the High Strength Concrete.
• 0.1 % fibrous concrete recorded the highest compressive strength at the age 7, 28, and 730 days and 1.4 % fibrous concrete recorded the lowest compressive strength compared to other concrete batches for all of the testing periods.
• 1.0 % fibrous concrete recorded the highest indirect tensile strength of all the testing periods of 30 and 730 days.
• During the flexural strength test at the age of 98-days, 0.1 % fibrous concrete recorded the highest flexural strength of 4.8 MPa (Bryceson, 2003). However, at the age of 730-days, 0 % fibrous concrete recorded the highest flexural strength of 8.73 MPa.
• In linear static solver, the compressive strength has a significant effect on the displacement.
• In non-linear static solver, the smallest displacement gained is found on the 0.1 % fibrous concrete batch for the comparison with different fibre content batches. For the comparison within the same fibrous concrete batch, the smallest displacement is found on the sample with the fibre location at the cover only (outer 22.5 mm).
• Unsatisfactory results are obtained from the comparison between the linear static solver and experimental results due to the assumption that both concrete and steel bars have linear behaviours.
• Better results are obtained from the comparison of non-linear static solver and experimental results.

REFERENCES


