DIRECT SHEAR STRENGTH OF ANNEALED-WIRE FIBRE CONCRETE

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Summary: Annealed wire is easy to get and less expensive compared to the steel fibre that usually used in fibre reinforced concrete applications. AW-fibre used as replacement of steel fibre by cutting annealed wire into pieces by size of 30 mm. The use of annealed wire fibre (AW-fibre) in concrete mix is to strengthen the shear capacity of concrete. This research outcomes is based on a set of laboratory experimental works done to numbers of double L concrete specimens size of 30 cm x 20 cm x 7.5 cm loaded under direct shear force by a universal compression machine. The specimens were constructed from 25 MPa AW-fibre concrete, using 0%, 4%, 6%, 8%, 10%, and 12% percentage of fibre content to the weight of cement proportion. The result from this research shows that by addition of 8% of AW-fibre can produced a maximum improvement of the direct shear strength capacity of this type of AW-fibre concrete.

1 INTRODUCTION

Steel has good nature in tensile strength. If it is used as one of composition in concrete mix design, tensile strength of concrete will improve. Not only limited in tensile strength only, but also flexural strength and shear strength because this strength has correlation with tensile strength.

In Jayaprakash, 2009, experiment using Carbon Fibre Reinforced Polymer (CFRP) fabrics has been done. Concrete strength is 30 MPa. Concrete specimen is precracked and it is equipped with CFRP fabrics external reinforcement. Quantity of CFRP fabrics used in concrete specimens has variation of 0.14%, 0.28%, and 0.42% of concrete volume. The result indicated that with CFRP fabrics reinforcement, can increase shear strength from 7% up to 56%. But this CFRP fabrics is not easy to get, compared to annealed wire that usually used in construction work.

In this experiment, annealed wire is used as one of ingredients of concrete mix design because it is easy to get and the price relatively not expensive compared to another high tensile strength materials. Hopefully the result of this experiment can be adapted for applications in construction field.

Specifically, content of this paper is direct shear strength of annealed wire fibre concrete. Focus of this experiment is to investigate the effect of annealed wire fibre addition and optimum percentage of annealed wire fibre in normal concrete for its direct shear strength. Basically, direct shear strength is more difficult to determine by experiment compared to other mechanic strength because the difficulties in isolating direct shear strength from another strength. Experimental studies of direct strength indicated correlation from 20% up to 85% compared to compressive strength (Edward G. Nawy).
2 EXPERIMENT

Cement used for concrete specimens is PCC Portland Concrete Cement. Coarse aggregate with maximum diameter of 25 mm and retained in ASTM sieve no 4. Fine aggregate with maximum diameter of 4.75 mm and get through ASTM sieve no 4. Fly ash with type F specification. The fibre is made of annealed wire cut into pieces of 3 cm ± 0.1 cm with diameter of 0.80-1.00 mm and its percentage in concrete based on cementitious materials are 0%, 4%, 6%, 8%, 10%, dan 12%. Target strength of concrete is 25 MPa with mix design method of ACI 211.1-91. Water cement ratio is 0.5. Target slump is 15 cm ± 2 cm and practically it is maintained in that slump range. Concrete specimen is double-L shape concrete with dimension of 30 cm x 25 cm x 7.5 cm. Data that will be collected during the experiment are annealed wire percentage compared to cementitious materials, height of slump, condition when mixing (temperature, humidity, weather), specimens weight, maximum direct shear strength (strength before it is cracked) when the concrete age is 28 days.

Double-L Shape specimen
It has dimension of 30 cm x 20 cm x 7.5 cm. The crack is planned on the red marked area. Dimension of crack area is 9 cm x 7.5 cm. For ensure the crack position, steel reinforcement used in L-shape area. Reinforcement steel bar for L-area is using the diameter of 8 mm with fy 240 MPa. Detailed dimension of reinforcement steel is on green marked picture.
SPECIMEN TESTING METHOD

Method of curing is by drown the specimens in curing pond. Test of direct shear strength done when concrete age is 28 days and in dry concrete condition. Specimens taken out from curing pond 48 hours before testing and putted on dry place so it can dry by air. Specimens tested in Universal Testing Machine in Structure and Material Laboratory, Civil Engineering Department, Universitas Indonesia. Experiments done with five double test samples for each AW-fibre percentage. It is limited to five samples for each fibre percentage because there is not any mold exist for this kind of experiments. The mold for this experiments built from laminated wood with 10 mm thick to make sure the mold is stiff enough to hold the pressure of the fresh concrete.

3 ANNEALED WIRE FIBRE

Fibre is made from manufactured rolled annealed wire. It is cut into pieces by bar cutter and with support of steel mold so the AW-fibre has consistent length of $3 \pm 0.1$ cm. Diameter of the wire is between 0.8-1.0 mm. This fibre specification refers to Balaguru, length of fibre is between 12 mm to 38 mm, diameter between 0.25 mm to 2.5 mm, and it has length per diameter ratio less than 100. If the ratio is over 100, there will be balling effect because the fibres are interlock each other when mixing the concrete.

4 MIX DESIGN

Mix design using ACI method. The specifications are

- $f'_c = 25$ MPa
- Maximum Size of Aggregate (MSA) = 25 mm
- Target slump = 150 mm
- Coarse aggregate specific gravity (SSD) = 2.907 gr/cm$^3$
- Fine aggregate specific gravity (SSD) = 2.585 gr/cm³
- Fine aggregate finess modulus = 2.40
- Cement specific gravity = 3.15 gr/cm³

In mixing process, annealed wire fibre spread into concrete when it is in fresh concrete shape inside the mixer. The fibre is in the mixer for 2 to 3 minutes so it can scattered in the concrete.

### Table 1: Mix Design

<table>
<thead>
<tr>
<th>Materials</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>202</td>
<td>202</td>
<td>202</td>
<td>202</td>
<td>202</td>
<td>202</td>
<td>202</td>
</tr>
<tr>
<td>Cement</td>
<td>404</td>
<td>343.4</td>
<td>327.24</td>
<td>319.16</td>
<td>311.08</td>
<td>303</td>
<td>294.92</td>
</tr>
<tr>
<td>Coarse agg</td>
<td>1100.5</td>
<td>1100.5</td>
<td>1100.5</td>
<td>1100.5</td>
<td>1100.5</td>
<td>1100.5</td>
<td>1100.5</td>
</tr>
<tr>
<td>Fine agg</td>
<td>716.31</td>
<td>716.31</td>
<td>716.31</td>
<td>716.31</td>
<td>716.31</td>
<td>716.31</td>
<td>716.31</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>60.6</td>
<td>60.6</td>
<td>60.6</td>
<td>60.6</td>
<td>60.6</td>
<td>60.6</td>
<td>60.6</td>
</tr>
<tr>
<td>AW-Fibre</td>
<td>16.16</td>
<td>24.24</td>
<td>32.32</td>
<td>40.4</td>
<td>48.48</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Keterangan:
- A = Concrete fc’ 25 Mpa
- B = Concrete fc’ 25 Mpa with 15% fly ash
- C = Concrete specification B with AW-fibre 4%
- D = Concrete specification B with AW-fibre 6%
- E = Concrete specification B with AW-fibre 8%
- F = Concrete specification B with AW-fibre 10%
- G = Concrete specification B with AW-fibre 12%

### 5 RESULT

![Direct Shear Strength Double-L Specimens](image)

Optimum percentage, compared to cementitious materials, of annealed wire fibre in concrete is 8% with 75 kg/cm² direct shear strength.
6 ANALYSIS

Figure 6: Polynomial Graphic for Double-L Specimen

Detail optimum percentage of annealed wire fibre in concrete can be obtained with polynomial analysis. X coordinate on the graphic is annealed wire fibre percentage and Y coordinate is direct shear strength in kg/cm². Equation can be obtained by knowing the peak of curve with one time differential \( \frac{dy}{dx} \) on the equation.

\[
y = -5359.7x^2 + 745.41x + 42.086
\]

\[
0 = -10719.4x + 745.41
\]

\[
x = 0.06964 = 6.954\%
\]

means the optimum percentage of annealed wire fibre concrete is 6.954%.

In 4% to 6% annealed wire fibre percentage, the amount of fibre in concrete is still not enough to reach its peak performance. The effect of fibre in concrete is not good enough compared to the 8% percentage of annealed wire fibre. In the 10% and 12% annealed wire fibre percentage, the amount of fibre in concrete is too many. Each specimen has same behavior. The crack occurred in the target area which is not strengthen by steel reinforcement. From the crack of 10% and 12% AW-Fibre content specimens, researchers found that there are balling effect of AW-fibre. Some AW-fiber accumulate in several area of the crack. Balling effect correlated with strength reduction because interlocking area between aggregate and cement inside the concrete decreased. Optimum strength of direct shear strength reached in the percentage of 8% because it has low percentage of balling effect or accumulated AW-fibre in several area and the amount of AW-fibre is spread evenly in crack area. Thus, bond strength between aggregate, cement, and AW-fibre increased. It has behavior like shear connector.

<table>
<thead>
<tr>
<th>% fibre</th>
<th>Direct Shear Strength Double-L Specimens (kg/cm²)</th>
<th>% Improvement, compared to concrete without AW fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>43.64</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>56.74</td>
<td>30%</td>
</tr>
<tr>
<td>6</td>
<td>70.37</td>
<td>61%</td>
</tr>
<tr>
<td>8</td>
<td>75</td>
<td>72%</td>
</tr>
<tr>
<td>10</td>
<td>56.29</td>
<td>29%</td>
</tr>
<tr>
<td>12</td>
<td>55.67</td>
<td>28%</td>
</tr>
</tbody>
</table>
Figure 7: Fresh Fibre Concrete

Figure 8 Result of Direct Shear Strength Double-L Specimens

In other experiments done with same fiber characteristics has result of

Table 3: Compressive, Flexural, Tensile, and Direct Shear Strength of AW-Fibre

<table>
<thead>
<tr>
<th>% fibre</th>
<th>fc’ (Mpa)</th>
<th>% up</th>
<th>f_{flexural} (Mpa)</th>
<th>% up</th>
<th>f_{tensile} (Mpa)</th>
<th>% up</th>
<th>f_{direct-shear} (kg/cm2)</th>
<th>% up</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25.08</td>
<td></td>
<td>3.77</td>
<td></td>
<td>5.01</td>
<td></td>
<td>43.64</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>24.05</td>
<td>-4%</td>
<td>4.9</td>
<td>30%</td>
<td>4.9</td>
<td>-2%</td>
<td>56.74</td>
<td>30%</td>
</tr>
<tr>
<td>6</td>
<td>26.5</td>
<td>6%</td>
<td>5.5</td>
<td>46%</td>
<td>5.15</td>
<td>3%</td>
<td>70.37</td>
<td>61%</td>
</tr>
<tr>
<td>8</td>
<td>25.67</td>
<td>2%</td>
<td>4.84</td>
<td>28%</td>
<td>5.07</td>
<td>1%</td>
<td>75</td>
<td>72%</td>
</tr>
<tr>
<td>10</td>
<td>24.11</td>
<td>-4%</td>
<td>3.7</td>
<td>-2%</td>
<td>4.91</td>
<td>-2%</td>
<td>56.29</td>
<td>29%</td>
</tr>
<tr>
<td>12</td>
<td>22.75</td>
<td>-9%</td>
<td>3.55</td>
<td>-6%</td>
<td>4.77</td>
<td>-5%</td>
<td>55.67</td>
<td>28%</td>
</tr>
</tbody>
</table>

From the experiments, optimum AW-fibre percentage reached in the range of 6% to 8% of cementitious materials. The effect of AW-fibre can increase flexural strength and direct shear strength better than other mechanical properties of concrete, compared to compressive strength and tensile strength.
7 CONCLUSIONS

From the experiments of direct shear strength of annealed wire fibre concrete with 3 cm ± 0.1 cm length and 0.8-1.0 mm diameter, there are some conclusions:

- Addition of annealed wire fibre can increase direct shear strength of concrete.
- Optimum percentage of annealed wire fibre compared to cementitious materials in concrete from experiment is 8%.
- Direct shear strength of concrete increase 72% in 8% percentage of annealed wire fibre compared to no fibre concrete.
- Increasing fibre amount in concrete can affect water cement ratio and slump height getting lower.
- 10% and 12% percentage of annealed wire fibre has smaller strength because balling effect can make void inside the concrete.
- Mixing process need extra attention because it has huge effect on the homogeneity of fibre concrete.

8 NOTES FOR ADVANCED RESEARCHS

From experiment, there are few problems. Researchers noted some notes for advanced research:
- Special mold must be made from stronger material like steel so it is more easy to open the mold and it will be cost saving if researcher want use it for other experiment.
- A void or soft materials like styrofoam can be placed in some position in the mold so it is easier to open and avoid precracked concrete.
- The condition (i.e. weather, temperature, and humidity) when mixing process affect the result.
- Make annealed wire fibre concrete with SCC (Self Compacting Concrete) method so it can avoid porous concrete.
- Give extra attention on water cement ratio and slump height.
- Advance research should be done so it is more applicable in construction field and civil industry.
- Advance research about microstructure from annealed wire fibre concrete.

REFERENCES


