Outline

• Aims and Objectives
• Materials used
• Characterisation/testing of Steel Fibre
• Demonstration elements
AIMS

• Demonstrate the use of steel fibre from waste tyres as reinforcement

• Optimise the amount of Recycled fibre in concrete

• Provide knowledge/data that will be used for the development of design models and feedback for further FE analysis
Objectives

• Develop suitable mix designs

• Develop characterisation tests for the fibres

• Match fibre characteristics with specific applications

• Test demonstration concrete products
Concrete Mix Development and Optimisation

Aggregates Used

Fluvial dragged gravel 20mm and 10 mm
Materials Used

Concrete Mix Development and Optimisation

Ordinary Portland Cement

Superpozzolan
Materials Used

Concrete Mix Development and Optimisation

Wind-blown Sand

Superplasticizer
Fibres from AMAT process

- Fibres from AMAT process contain carbon black on surface
- Clean from rubber
- Tensile properties not affected
- The fibre not so easy to cut
Chopped AMAT Fibre 50 mm

12 wires Ø 0.23mm twisted to a core strand of Ø 0.85 mm surrounded with another 15 twisted wires. On the surface there is a twisted single wire.

Overall external diameter is 1.55 mm
Effective diameter 1.16 mm
Tensile strength 1250 MPa
Fibre from the second shredding process

(provided by Charles Lawrence Recycling)

• Fibres contain small amounts rubber and fluff
• Long bid wires need to be removed
• Fibres are magnetised
• Fibres tend to ball-up
Fibre from the second shredding process
(provided by Charles Lawrence Recycling)

• Sieving can remove the large wires and fluff
• The dimensions of fibre passing each sieve varies

Concrete Mix Development and Optimisation

Passing the sieve of 1.1 mm
Diameter around 0.23 mm
Tensile strength: 1100 MPa

Sieve shredded steel fibres passing the sieves 6.35, 3.18, 2.4, 1.11 mm
Commerically available 50mm drawn wire fibre, COM50WIRE, (provided by BRC)

- The fibre is industrially produced from wire with flattened ends
- Fibre is rigid
Fibres from Pyrolysis process (to be tested)

- Fibres from (Coalite) pyrolysis process still contain some carbon black on surface
- Clean from rubber
- Tensile properties not seriously affected
- The fibre easier to cut
Concrete Mix Development and Optimisation

Specimen Used

- Prisms 100x100x500
- Cubes 100x100x100
Curing Regime

Specimens were wrapped with wet burlap and polyethylene sheets for 24 hours.

After removing the concrete from the moulds, the specimens were placed in a water tank at temperature of 20° c
Tests

Slump equipment according to the ASTM C 143 (1998)

Compressive strength according to BS 116 (1983)

Concrete Mix Development and Optimisation
Optimisation of Fibre Content

- The mix optimisation was undertaken by trying to incorporate as much fibre as was possible without fibre balling and to maintain a slump value over 50 mm
- Six different mixing methods were tried with the available shredded fibres
- The maximum amount of shredded fibre achieved was 3% by weight
- Three different mixing methods were tried with the AMAT fibres
- The maximum amount of AMAT fibre achieved was 6% by weight
### Compressive Strength Example

<table>
<thead>
<tr>
<th>Mix code</th>
<th>Fibre type</th>
<th>Fibre content (% by weight)</th>
<th>Fibre content (% vol)</th>
<th>7 days</th>
<th>28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPFA 40/30</td>
<td>Plain</td>
<td>0.0</td>
<td>0.0</td>
<td>26.6</td>
<td>43.6</td>
</tr>
<tr>
<td></td>
<td>Shredded</td>
<td>1.0</td>
<td>0.3</td>
<td>30.6</td>
<td>48.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.5</td>
<td>0.5</td>
<td>27.7</td>
<td>44.9</td>
</tr>
<tr>
<td>Shredded (sieved)</td>
<td></td>
<td>1.5</td>
<td>0.5</td>
<td>27.4</td>
<td>-</td>
</tr>
<tr>
<td>AMAT</td>
<td></td>
<td>1.5</td>
<td>0.5</td>
<td>27.4</td>
<td>-</td>
</tr>
<tr>
<td>COM50WIRE</td>
<td></td>
<td>1.5</td>
<td>0.5</td>
<td>26.1</td>
<td>-</td>
</tr>
</tbody>
</table>
Characterisation Tests

- **Pull-out tests**
  1. Single fibre pull-out tests
  2. Double-sided pull-out tests

- **Flexural toughness tests**
  1. Unnotched beam according to ASTM c108 (1995) and JSCE-SF4)
Pull-out Tests

Why?
- Useful to understand fibre bond characteristics
- Determination of the critical fibre length

Problems:
- Not always easy to perform on fibres (high accuracy required for very small displacement and load)
- No standard method
- A suitable test must be developed for each fibre
Single-sided Pull-out Tests

Specimen preparation

Standard steel mould

20 mm thick plate

9 small equi-distant holes at mid-height

Adhesive tape was used to debond fibre near the surface

The middle compartment is left empty
Single-sided Pull-out Tests

Phase 1: using spring calibrated to measure load

The phase comprised 48 tests on shredded, 21 tests on AMAT fibres and 9 tests on COM50WIRE fibres
Single-sided Pull-out Tests

Phase 1: using spring calibrated to measure load – Test results

- AMAT fibre has better energy absorption and bond stiffness
- COM50WIRE is relying on a frictional mechanism
Single-sided Pull-out Tests

Phase 1: using spring calibrated to measure load – Test results

Problems:

- The energy stored in the spring is released suddenly when the fibre starts pulling out
- There is scatter in the results

Pull-out response for 6 specimens, 10 mm embedded length
Single-sided Pull-out Tests

Phase 2: using load cell

This phase comprised 26 tests on shredded fibres and 33 tests on AMAT fibres
Characterisation Tests

Single-sided Pull-out Tests

Phase 2: using load cell – Test results

Zone 0: Initial straightening of the fibre
Zone A: Shear stress along the fibre do not exceed the bond strength
Zone B: Pull-out zone
Zone C: high frictional zone
Zone D: low frictional zone

Load vs displacement for AMAT fibre with embedment length, $L_{emb} = 10mm$
Single-sided Pull-out Tests

Phase 2: using load cell – Test results – influence of concrete strength and type of fibre used in concrete

- Shredded fibres develop lower bond strengths than AMAT fibres due to higher $L_{emb}/D_{eff}$ ratio
- Shredded fibres in a mix improve the bond characteristics better than AMAT fibres
Single-sided Pull-out Tests
Phase 2: using load cell – Test results

Comments on the results:

• AMAT fibre fractured at around 800 MPa. This may be a result of lateral pressure in the grip

• The tensile stress of the fractured shredded fibres varies considerably. This indicates that fibres that fractured did not reach their real strength, most likely due to damage inflicted during the shredding process possibly due to notches inflicted by the knives

• There is slip in the grip mechanism and therefore the stress-slip results are not accurate

• The fibre extension between the FRC prism and the grip needs to be eliminated
Double-sided Pull-out Tests

The test comprised 81 test specimens. Mix OPC50 without fibres was used in this investigation.

<table>
<thead>
<tr>
<th>Fibre codes</th>
<th>fibre codes</th>
<th>fibre codes</th>
<th>Number of pulled fibres</th>
<th>fibre embedded length</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMAT, A1*</td>
<td>I1-10</td>
<td>S1-10</td>
<td>1</td>
<td>10 mm 20 mm 30 mm</td>
</tr>
<tr>
<td>A3</td>
<td>I3-10</td>
<td>S3-10</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>A5</td>
<td>I5-10</td>
<td>S5-10</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

A1*: AMAT fibres with a cone at the end
Double-sided Pull-out Tests

Specimen Preparation

Perspex plate with 5 holes centrally located
The COM50WIRE fibre end was welded to a deformed metal anchor

To prevent surface cracking, 10mm plastic tubes filled with silicon were used

Steel anchor was threaded through the AMAT fibre

The nominal size of the each half is 100x100x80 mm

Casting was done in two stages
Double-sided Pull-out Tests

Specimen Preparation

Specially made steel clamps were fixed at the end of each specimen

Deformation was measured over a gauge length of 50mm using two transducers
Double-sided Pull-out Tests

Test set-up

1: 5 kN strain gauged spring beam
2: Chuck attached the clamp with a pin
3: Fixed metal clamp pinned on the chuck
4: Perspex plate with the fibre through its central holes placed in middle of specimen
5: 230 volt Single Phase Motor fitted with 3-step pulley drives the cross-head at a speed of 1.5 mm/min
6: Pulled part of the specimen
7: Cross-head attached to motor
8: Manual handles
## Double-sided Pull-out Tests

### Test Results for AMAT and COM50WIRE fibres

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>COM50WIRE</td>
<td>10</td>
<td>1.00</td>
<td>10.00</td>
<td>4.47</td>
<td>231</td>
<td>7.36</td>
<td>295</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>1.00</td>
<td>20.00</td>
<td>10.60</td>
<td>370</td>
<td>5.89</td>
<td>471</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMAT</td>
<td>10</td>
<td>1.55</td>
<td>1.18</td>
<td>6.45</td>
<td>8.47</td>
<td>3.25</td>
<td>359</td>
<td>7.37</td>
<td>328</td>
</tr>
<tr>
<td>1-fibre</td>
<td>20</td>
<td>1.55</td>
<td>1.18</td>
<td>12.90</td>
<td>16.95</td>
<td>0.88</td>
<td>443</td>
<td>4.55</td>
<td>405</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>1.55</td>
<td>1.18</td>
<td>19.35</td>
<td>25.42</td>
<td>1.44</td>
<td>653</td>
<td>4.47</td>
<td>633</td>
</tr>
<tr>
<td>AMAT</td>
<td>10</td>
<td>1.55</td>
<td>1.18</td>
<td>6.45</td>
<td>8.47</td>
<td>0.75</td>
<td>800</td>
<td>5.48</td>
<td>244</td>
</tr>
<tr>
<td>3-Fibres</td>
<td>20</td>
<td>1.55</td>
<td>1.18</td>
<td>12.90</td>
<td>16.95</td>
<td>1.58</td>
<td>1640</td>
<td>5.61</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>1.55</td>
<td>1.18</td>
<td>19.35</td>
<td>25.42</td>
<td>0.19</td>
<td>2015</td>
<td>4.60</td>
<td>643</td>
</tr>
<tr>
<td>AMAT</td>
<td>10</td>
<td>1.55</td>
<td>1.18</td>
<td>6.45</td>
<td>8.47</td>
<td>0.58</td>
<td>875</td>
<td>17.96</td>
<td>800</td>
</tr>
<tr>
<td>1-fibre with cone</td>
<td>20</td>
<td>1.55</td>
<td>1.18</td>
<td>12.90</td>
<td>16.95</td>
<td>1.53</td>
<td>1290</td>
<td>13.25</td>
<td>1180</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>1.55</td>
<td>1.18</td>
<td>19.35</td>
<td>25.42</td>
<td>0.83</td>
<td>1375</td>
<td>9.41</td>
<td>1257</td>
</tr>
</tbody>
</table>
Double-sided Pull-out Tests

Test Results for AMAT and COM50WIRE fibres (10 mm long fibre)

AMAT fibre indicates better bond at the initial stages due to its shape.
The end anchoring of the COM50WIRE fibre delays the start of pulling out.
Double-sided Pull-out Tests

Test Results for single and multi AMAT fibres

The initial behaviour of the load-slip curve in the multi fibre test is accurate than for single fibre test
Double-sided Pull-out Tests

Test Results for multi AMAT fibres and fibre with end cone

Welding a cone with a nominal diameter of 2.5mm at the fibre end increases the peak load. In fact the fibre appears to be fully bonded until the welding breaks.
Double-sided Pull-out Tests

Test results for AMAT and COM50WIRE fibres

Double-sided pull-out test

Aspect ratio l/d

Tensile stress [MPa]

1-com50wire  average of 3-AMAT  1-AMAT  1-AMAT with cone
Double-sided Pull-out Tests

Test results for shredded fibres

Double-sided pull-out for 3-shredded fibres

- The tested 0.23mm diameter shredded fibres are very fragile
- Only fibres with 10mm embedded length pulled out during loading
- All fibres with 20mm and 30mm embedded length fractured during loading
Pull-out test conclusions

- The tensile strength of the tested fibres is influenced by the test method used
- The multi-fibre test is more accurate than the single fibre pull-out test
- Shredded fibres of length $l$, $20 < l < 40$ are necessary for full bonding
- It is recommended to use AMAT fibres in the range of 50-60 mm length
- If possible, the AMAT fibre should be provided with a cone at the end
- AMAT fibre has stiffer initial bond-slip characteristics than the COM50WIRE fibre
Characterisation Tests

- **Pull-out tests**
  1. Single fibre pull-out tests
  2. Double-sided pull-out tests

- **Flexural toughness tests**
  1. Unnotched beam according to ASTM c108 (1995) and JSCE-SF4
Characterisation Tests

Flexural Toughness Tests

Phase 1: investigated the first crack values and toughness indices of FRC according to ASTM C1018 (1995) and toughness factor according to JSCE-SF4 with different matrix strength, fibre volume content and type using unnotched beams.

Phase 2: to be undertaken after the completion of this project will study the effect of localising the fracture location and the load-CMOD characteristics (using notched beams) on the toughness according to JSCE-SF4 (1994) with respect to the RILEM draft recommendation TC-89-TDF (2002).
Characterisation Tests

Flexural Toughness Tests

Testing Procedure

- Using four-point bending test
- Prisms size: 100x100x500 mm
- Age: 7 and 28 days
- One transducer was positioned along the central line of the top surface at each support and one at the mid-span
- Load controlled testing machine (100 kN)
- Loading rate 0.5 kN/min
Flexural Toughness Tests

Effect of fibre volume

Fibre volume increases the peak load and the residual strength after cracking. This applies to all types of fibres used.
Flexural Toughness Tests

Effect of fibre type

- Curves after peak load are stable for the AMAT and COM50WIRE fibres.
- AMAT fibres demonstrate a higher peak load and better ductility.
- When fibres start slipping higher resistance is achieved through the mobilisation of more fibres.
Flexural Toughness Tests

Effect of concrete strength

High strength concrete results in a much higher peak-load, but not necessarily ductility
Flexural Toughness Tests

Effect of fibre length

Specimens with 50mm long AMAT fibre are the only to exhibit a stable post peak load-deflection response.
Flexural Toughness Tests

Limitation of toughness measurements

- The main difficulty is measuring deflection accurately and to exclude extraneous deformations due to support and load-point deformations.

- Another problem is that it is practically impossible to determine the first crack load objectively. This is avoided in several standards through the offsetting of the initial slope of the load-deflection curve by a prescribed deflection limit.

- A third problem is the inability to control the post-peak response in a stable manner where the loading machine (if not stiff enough) undergoes sudden unloading and releases large amounts of energy.
Characterisation Tests

**Flexural Toughness Tests**

**Calculation of the toughness indices I5, I10 and I20 (ASTM)**

- Energy-based dimensionless indices, which are ratios of the area under the load deflection curve up to a prescribed multiple of the first-crack deflection and the area up to first-crack (ASTM C 1018-97; 1998).

- The triangle CDE should not be considered in the calculation

- $I_5 = \frac{\text{area under ACDFG}}{\text{area under ABH}}$
Characterisation Tests

**Flexural Toughness Tests**

**Toughness factor (JSCE-SF4):**

\[ \sigma = \frac{Tb \cdot l}{\delta_{tb} \cdot bh^2}; \quad \delta_{tb} = \frac{l}{150} \]

Based on the energy absorption capacity, which is determined as the load-deflection area up to prescribed deflection limits (JCI-SF, 1984; UNE 83-510, 1989; NBN B 15-238, 1992).

- The angle CDE should not be considered in the calculation

- **Tb = area under ACDFG**

- Does not account for all effects that accrue at small displacements due to instability and matrix brittleness
Flexural Toughness Tests

Toughness indices and toughness factor

**Index I5 is relatively insensitive to the fibre type**

**More sensitive to variations in fibre type than ASTM**
Characterisation Tests

Flexural Toughness Tests

Accurate deflection measurement – using a yoke

Aluminium bar

LVDT on each side

Pins

Angle pieces
Flexural Toughness Tests

Deflection measurements through the yoke

- Much better results at the early stages, since the local crushing effects are eliminated
- The yoke will be used in all future work
Main conclusions

1. Shredded and AMAT recycled steel tyre fibres can be used to produce fibre-reinforced concrete elements with good characteristics.

2. Incremental increase in fibre content is accompanied by reduced concrete slump and superplasticizers are needed to maintain workability.

3. Maximum amount of shredded steel tyre fibres achieved was 3% by weight.

4. The amount of AMAT fibres does not affect workability as much as shredded steel fibres since fibre bundles remaining mostly intact.

5. Maximum amount of AMAT steel tyre fibres achieved was 6% by weight.

6. AMAT fibres have good bond characteristics.

7. The failure of the majority of steel fibre reinforced concrete specimens in flexure failed due to pull-out rather than yield.
Slab Dimension

Common applications are in the road carriageway, hard shoulder and parking areas

Decathlon system drainage cover slab
## Slab test programme

<table>
<thead>
<tr>
<th>Mix code</th>
<th>Test type</th>
<th>Concrete type</th>
<th>Reinforcement type</th>
<th>Fibre content (% by weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rcon</td>
<td>Two Slabs</td>
<td>OPC 40</td>
<td>conventional</td>
<td>-</td>
</tr>
<tr>
<td>AMATcon</td>
<td>Two slabs, prisms and cubes</td>
<td>SP 40/30</td>
<td>AMAT Fibre</td>
<td>6%</td>
</tr>
<tr>
<td>Scon</td>
<td>Slab, prisms and cubes</td>
<td>SP 40/30</td>
<td>Shredded fibre</td>
<td>2%</td>
</tr>
<tr>
<td>SIScon</td>
<td>Slab, prisms and cubes</td>
<td>Slurry</td>
<td>Shredded Fibre</td>
<td>17.5%</td>
</tr>
</tbody>
</table>
The slab is normally reinforced in the bottom with nine ordinary steel bars 12 mm in diameter to satisfy the EN 124 (1994) loading condition C250.

Ready mixed concrete was cast in the steel mould by Hodkin and Jones Ltd.
From Waste Fibres to Concrete Reinforcement

DTI: Partners in Innovation Contract: CI 39/3/684, cc2227

SEMINAR 26 February 2003

Testing of Concrete Elements - Houssam Tlemat

Demonstration Slabs

Slab Description-AMATcon

AMAT fibre– 50mm length – diameter in the range of 0.8-1.5 mm
Demonstration Slabs

Slab Description-SIScon Slab

Un-sieved shredded fibre from the third shredding process was simply placed in up to the top of the mould.

Specimens were cast by pouring the slurry from the top.

The specimens were vibrated during casting to ensure a good penetration of the slurry.
Demonstration Slabs

Slab Description - Scon Slabs

Only the fibre from the third shredding process, that passed through the 8.0 mm sieve and that remained in the 6.3mm sieve was used – Average diameter around 0.23mm
Compressive test results

<table>
<thead>
<tr>
<th>Mixes</th>
<th>Cube strength</th>
<th>Slump test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>(day of slab test)</td>
<td>(28 days)</td>
</tr>
<tr>
<td>OPC40 (Plain concrete for Rcon slabs)</td>
<td>47.0(40d)</td>
<td>45.0</td>
</tr>
<tr>
<td>SP 40/30 (plain concrete for AMATcon slabs)</td>
<td>-</td>
<td>59.0</td>
</tr>
<tr>
<td>AMATcon (6% AMAT fibres)</td>
<td>46.8 (19d)</td>
<td>54.4</td>
</tr>
<tr>
<td>SP 40/30 (plain concrete for Scon slab)</td>
<td>-</td>
<td>43.6</td>
</tr>
<tr>
<td>Scon (2% shredded fibres)</td>
<td>35.9 (19d)</td>
<td>45.3</td>
</tr>
<tr>
<td>SIScon (17.5% shredded fibres)</td>
<td>52.8 (17d)</td>
<td>54.2</td>
</tr>
</tbody>
</table>

The compressive test of the SIScon cube indicated an extremely high ductility due to the high fibre content and very good bond between shredded fibre and cement paste.
Testing of Concrete Elements - Houssam Tlemat

**Demonstration Slabs**

- Simply supported on two opposite steel beams. To avoid stress concentrations within the support, a 5mm thick dental plaster was placed on a plywood base.

- Single point loading acting on a Ø 250mm steel plate in a 500 kN displacement controlled Screw jack machine was used.

- Slab deflections and crack opening were measured using LVDTs; One was fixed underneath in the centre of the slab, two in the support edge, two in the corner and two on the side.

- To stabilise the slab, each slab was subjected to five load cycles up to 2/3 of the design load at a rate of up to 5 kN/s.
Results and Discussion

Behaviour of SIS slab

The description begins with SIScon slab which was tested last, since more instrumental was used and that helps to describe a peculiarity in initial slab behaviour.

To study the influence of the slab stiffness and the support elasticity on the slab deformation, two more LVDTs (7&8) were fixed on the support edge.
Results and Discussion

Behaviour of SIScon slab – Initial deflection

The support is deforming as if on an elastic foundation.

The central stiffer part of the slab is not as deformable, hence the centre of the slab, initially deforms less than its central support.
Results and Discussion

Behaviour of SIScon slab – load versus slab deflection

-Slurry Infiltrated Shredded Fibre Reinforced Concrete Slab (SIScon)

- The transition from the uncracked behaviour is very gentle. This indicates a favourable crack development and good anchoring of the fibres

- The load at first crack is highest of all slabs investigated
Results and Discussion

Behaviour of SIScon slab – failure

- The slab cracked in to parts along the edge of the ribs
- The slab collapsed at peak load of 297 kN
Results and Discussion

Behaviour of Rcon slab – location of the strain-gauges

To measure the strain of the reinforcement bars, six strain-gauges were fitted in the bottom of the bars
Results and Discussion

Behaviour of Rcon slab – absolute load-displacement and slab failure -

Region 1: Elastic behaviour
Region II: Elastic plastic behaviour. The cracks propagated from the applied load to the boundary of the slab
Region III: The radial cracks increased in length until a yield pattern was formed. Final failure due to punching shear
Results and Discussion

Behaviour of AMATcon slab – relative load-displacement and slab failure -

- The slab cracked in two parts along the edge of the ribs
- The location of the crack confirms that many of the fibres did not penetrate in the narrow gaps of the diagonal slots.
- The fibre were well anchored since there was a lot of residual strength at post peak load
- Slab did not make the C250 class
- It passes the B125 class
Results and Discussion

Behaviour of Scon slab – relative load-displacement and slab failure -

Shredded Fibre Reinforced Concrete Slab (Scon)

- The slab was tested successfully for the class B125 loading condition
- The crack propagation is similar to Rcon
- The fibres did not penetrate completely in the slot region
- The relatively low capacity is more a function of the small amount of fibre.
Results and Discussion

Flexural strength and equivalent flexural ratio

\[ f_c = \frac{Pl}{b_{eff}h^2} \]

Where,

- \( f_c \) : flexural strength [N/mm²]
- \( P \) : Maximum load obtained in from test
- \( l \) : span [mm] = 256 mm
- \( b_{eff} \) : width of failed cross-section [mm].
  Only the stressed ribs under the load plate are considered (figure 2.16b) = 282-2 (holes) = 280 mm
- \( h \) : height of failed cross-section [mm] = 163 mm (Figure 2.16a)
Results and Discussion

Flexural strength and equivalent flexural ratio

- The equivalent flexural strength \((f_{e,3})\), is the strength which, for an elastic-perfect plastic behaviour, has the same energy-absorbing capacity as under the stress-deflection curve during the test up to a assumed deflection of 0.85% of the peak load in accordance to Eurocode 2 (ENV; 1992-1-1) as seen in Figure 2.17. The flexural toughness (area \(Dbz\)) is determinate according to RILEM TC 162-TDF (2002) and DVD (1994).

- The equivalent flexural ratio, \(R_{e3}\), is defined as the ratio between the equivalent flexural load, \(f_{e,3}\), and the concrete load, \(F_{ct}\), at the bend-over-point (BOP) obtained from the Rcon slab.
Results and Discussion

Flexural strength and equivalent flexural ratio

<table>
<thead>
<tr>
<th>Slab Code</th>
<th>Fibre content [%]</th>
<th>Load at BOP [kN]</th>
<th>Peak load [kN]</th>
<th>Flexural strength [N/mm²]</th>
<th>Eq. flexural load [kN]</th>
<th>Re,3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rcon</td>
<td>-</td>
<td>93.5</td>
<td>253.1</td>
<td>871</td>
<td>228</td>
<td>2.40</td>
</tr>
<tr>
<td>AMATcon</td>
<td>6</td>
<td>103</td>
<td>170</td>
<td>585</td>
<td>180</td>
<td>1.93</td>
</tr>
<tr>
<td>Scon</td>
<td>2</td>
<td>107</td>
<td>141</td>
<td>485</td>
<td>133</td>
<td>1.45</td>
</tr>
<tr>
<td>SIScon</td>
<td>17.5</td>
<td>196.8</td>
<td>297.8</td>
<td>1025</td>
<td>284</td>
<td>3.04</td>
</tr>
</tbody>
</table>
Conclusions

Rcon marginally passed the test for class C250 (BS EN 124, 1994. It had the lowest bend-over-point (BOP) of all slabs. Even small amounts of fibre reinforcement could improve the performance of this slab and avoid the punching mode of failure.

Scon behaved well considering the small amount of fibre included (2% by weight). The penetration of the fibre in the slotted region of the slab was not perfect. The Scon slab passed the test for class B125 loading condition.

AMATcon had a high ratio of fibre (6% by weight) and performed reasonably well, with high energy absorption. This indicates that the fibres were very well anchored. However, the penetration of the fibres in the slotted region of the slab was poor and, hence, the slab did not achieve as high load as expected. Hence, the slab can be considered to have passed only the B125 loading condition.

SIScon had a very high amount of shredded fibre (17.5% by weight). The fibre was placed in the mould without any processing and had a high amount of rubber. The cement slurry pretreated the bundled fibres well and hence, a good result was obtained. The slab exhibited extremely high strength and ductility, even higher than Rcon and passed the test for C250 comfortably.

Fibres extracted from waste tyres can be used to produce successful precast-concrete structural elements.