PULL-OUT BEHAVIOUR OF STEEL FIBRES RECYCLED FROM USED TYRES

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Introduction

Fibres from Recycled Waste Tyres

Single sided Pull-out Tests

Double sided Pull-out Tests

Conclusions
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Waste Tyres

- International Problem
- 400 k tonnes used tyres/year in UK
- > 160 k tonnes go to landfill
- > 60 k (100) tonnes of steel fibre

Waste shredded fibres
Pyrolysed Recycled Steel Fibre (PRSF)

- Clean from rubber
- Tensile properties not affected
- Fibres from PRSF process contain carbon black on surface
- Fibre not so easy to cut
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PRSF

Fibres used in experiments

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.

Chopped PRSF Fibre 50 mm
Fibre from the second shredding process (SRSF)
(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
ISF Fibre (provided by BRC)

- The fibre is industrially produced from wire with flattened ends
- Fibre is rigid

Length: 50 mm
Diameter 1.0 mm  Tensile strength: 1150 MPa
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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

- FRC specimen
- Embedded fibres
- Perspex plates
- Standard steel mould
- 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

This phase comprised 26 tests on shredded fibres and 33 tests on PRSF fibres.
Single-sided Pull-out Tests

Test results

Load vs displacement for PRSF, $L_{emb} = 10\text{mm}$

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
Pull-out Tests

Single-sided Pull-out Tests

Test results – influence of concrete strength and type of fibre

- Shredded fibres develop lower bond strengths due to higher $L_{emb}/D$ ratio
- Shredded fibres in a mix improve the bond characteristics
Single-sided Pull-out Tests

Test results

Comments on the results:

• PRSF fractured at around 800 MPa (lateral pressure in the grip)
• Shredded fibre strength varies considerably (damaged during process)
• Fibre (free) extension needs to be eliminated
• Slip in grip mechanism (stress-slip results are not accurate)
Double-sided Pull-out Tests

Specimen Preparation

- Perspex plate with ISF
- 10mm plastic tubes filled with silicon were used
- Nominal size 100x100x80 mm
- Casting done in two stages

Pull-out Tests
Double-sided Pull-out Tests

Specimen Preparation

Steel clamps are fixed at the end of each specimen. Deformation is measured over a gauge length of 50mm using two transducers.

Double-sided pull-out test
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

PRSF

and

ISF fibres

(10 mm length fibre)

PRSF fibre has better bond at the initial stages (shape)
Double-sided Pull-out Tests

Test Results for single and multi PRSF fibres

The initial pull-out response of 1-PRSF fibre

The initial load versus slip response for 3-PRSF fibre

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

Test Results for fibre with end cone

Pull-out responses for 1-PRS with end anchoring

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 PRSF and ISF fibres

![Graph showing pull-out behaviour](image)
Double-sided Pull-out Tests

Test results for shredded fibres

- The tested 0.23mm diameter shredded fibres are very fragile
- Only fibres with 10mm embedment length pulled out during loading
- All fibres with 20mm and 30mm embedded length fractured during loading
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 PRSF fibres in the range of 50-60 mm length
• If possible, the PRSF fibre should be provided with a cone at the end
• PRSF fibre has stiffer initial bond-slip characteristics than the ISF fibre