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PRELIMINARY RESULTS ON THE INNOVATIVE USE OF PAPER-MILL WASTE SLUDGE AND FIBRE FROM WASTE TYRES AS PERFORMANCE ENHANCER OF GREEN CONCRETE

F. Smith, C. Trois, S. Moodley

(School of Engineering, Civil Engineering Discipline, South African Research Chair in Waste and Climate Change (SARChI) group, University of KwaZulu-Natal, Durban, South Africa)

INSPIRING GREATNESS

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Structure of the presentation

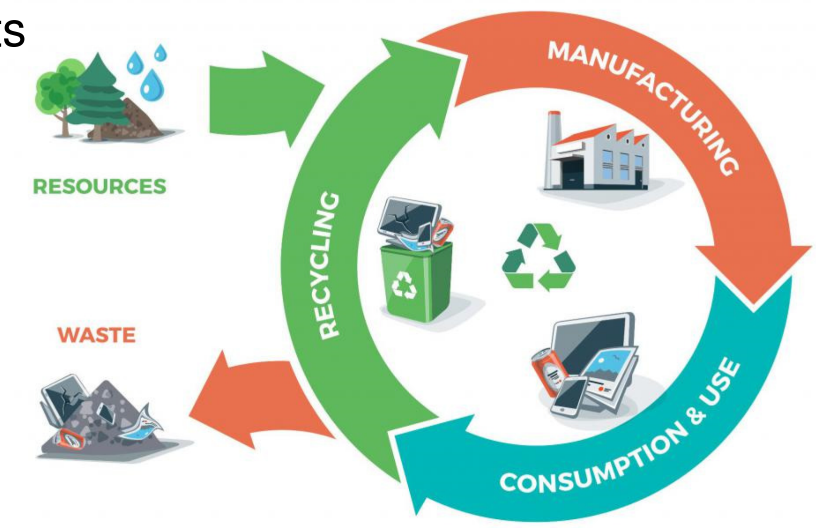
- Introduction
- Literature Review
- Methodology
- Performance Testing
- Results and discussion
- Conclusions
- Research and future development

Introduction

Use of recycled waste materials as substitutes/additives for construction products

Potential to utilise large volumes of waste through a circular economy approach

Relevance in developing countries' context



Two largely available waste materials in South Africa were considered for incorporation into a concrete mix (integrated waste management approach addressing context-specific barriers):

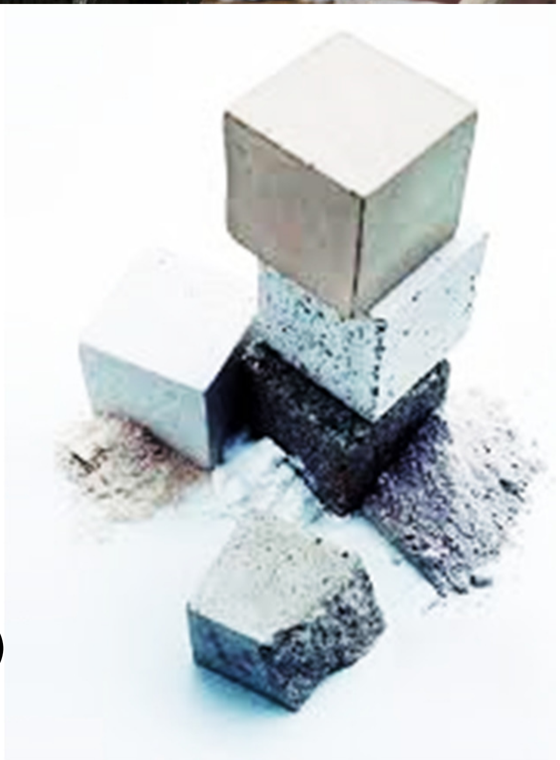
- Fibre from recycled vehicle tyres (typically Polyamide (Nylon), Rayon or Polyester)
- Recycled Paper Mill Sludge (RPMS) (largely natural cellulose fibres)

Literature Review

CONCRETE

- most widely used material in construction
- high degree of adaptability (possible addition or substitution of individual constituents to form composite materials)

GREEN CONCRETE: concrete materials incorporating alternative or recycled waste materials aimed at reducing the environmental impact of construction



Green concrete can be seen as part of a more holistic and integrated waste management approach (including collection and recovery facilities), oriented to offer new opportunities to municipalities and the private sector (circular economy, business opportunities and job creation)

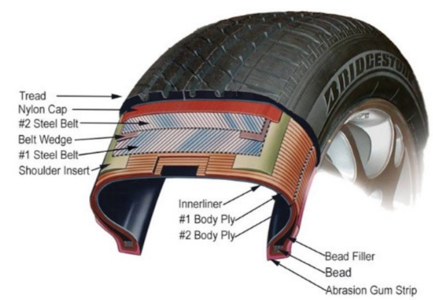
Literature Review

Focus on two types of waste materials largely available in the South African context and characterised by barriers to waste recycling purpose

FIBRE FROM RECYCLED VEHICLE TYRES

- About 100 million scrap tyres are stockpiled in South Africa (SAPA, 2012), and around 11 million waste tyres are added each year.

- Environmental and health risks, clogging up landfills
- When burnt for their small scrap metal content, waste tyres produce air pollution and respiratory infections from the emitted black smoke and toxic fumes.
- During the recycling of waste tyres, the fibre fraction is separated (de-beading operated by a local waste reclamation facility), but has not found a useful application and continues to be sent to landfill

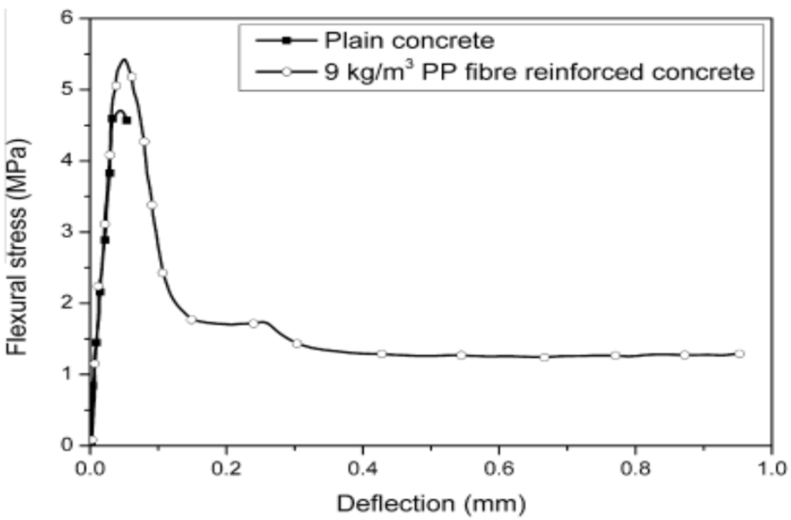


Literature Review

Polymeric fibres in concrete

- The use of polyester (PET), polypropylene (PP) and high density polyethylene (HDPE) fibres showed some reduction in 'slump' or 'workability'
- An increased tensile strength of the concrete was reported
- Improved crack resistance, impact strength and fatigue resistance were also reported.
- The fibres act as crack inhibitors, providing a 'sewing effect' increasing the toughness by reducing the propagation of micro-cracks

(Bon-Min Koo et. al., 2014; Al-Hadithi, 2015; Shi Yin et al., 2015; Pešic et al., 2016)



(Source: Shi Yin et al., 2015)

Literature Review

RECYCLED PAPER MILL SLUDGE (RPMS)

- Paper mill sludge is part of the solid residuals separated from mill wastewater (Naik et al., 2004).
- For every tonne of paper made, approximately 300kg of waste paper mill sludge is produced (30%) (Balwaik & Raut, 2015)
- Paper mill sludge is generally composed of the original recycled paper fibres, and inorganic compounds like $CaCO_3$ (calcium carbonate), talc and kaolinite (Abdullah et al., 2015)
- Paper mill sludge is often incinerated for heat recovery and also for an important volume reduction. Paper mill sludge ash, if replaced by 5 to 10% of Portland cement, shows a positive effect on the mechanical performance of the concrete (Corinaldesi, Fava et al. 2010)

- In research carried out by Singh, L. R., et al. (2015). ‘Concrete mixes containing 5% and 10% paper sludge waste (not ash from incineration), have shown an increase of 3.0% and 1.4% in compressive strength respectively when compared to control mix Balwaik

- Raut A. and S. P. (2015), further concluded that when substituting cement with 5% paper sludge waste, compressive, splitting tensile and flexural strength increased up to 10% but further addition of waste paper sludge reduced the strengths gradually

- **This indicates that paper mill sludge can be used in concrete, with positive results, without first incinerating the sludge: Providing an alternative to incineration**

Methodology

- Quantitative approach: experimental testing of green concrete materials using various percentages of volumetric cement substitution against a control sample (0% substitution)

- **Tyre fibre:** Literature investigated polymer fibre volumetric substitution of fine aggregate of under 2%. However, due to the large availability of stockpiled tyres in South Africa, the research attempts to evaluate higher volumetric substitution (5%)

- **Recycled Paper Mill Sludge:** substitution of cement with 5%, 10% and 15% recycled paper mill sludge.
  (relating to 2%, 4% and 6% of fine aggregate by weight)

- Assessed properties: workability, compressive, tensile, flexural strength (7, 14, 28 days; water:cement ratio remaining constant

- Carbon and economic analysis to assess the proposed green concrete solution

Waste Tyre Fibre in Concrete - Preparation

- The waste fibre (typically Polyamide (Nylon), Rayon or Polyester) sourced from tyre recycling was very 'matted', of varying fibre length and contaminated with rubber particles.

- This material is currently sent to landfill

- The fibre was cleaned by hand to remove the bulk of the loose contamination

- To assist in breaking down the matted clumps of tyre fibre and to promote the maximum dispersion and distribution of fibres the weighed fibre was mixed well with the fine aggregate (sand)

Tyre fibre as received

Waste Tyre Fibre – Concrete Mix Design

- **Quantity of fibre**: Previous research on **clean** fibres as additives in concrete were carried out on volumetric sand substitution of under 2%. Fibre, this is an expensive raw material but as we are considering the use of waste fibre, a high level of **13% volumetric sand substitution** was used for this investigation (5% by weight)

- **Mix ratio**: Based upon the control concrete mix, the cement, water, large aggregate (stone) and fine aggregate (sand) were unchanged. The only variable was the 5% by weight substitution of fine aggregate

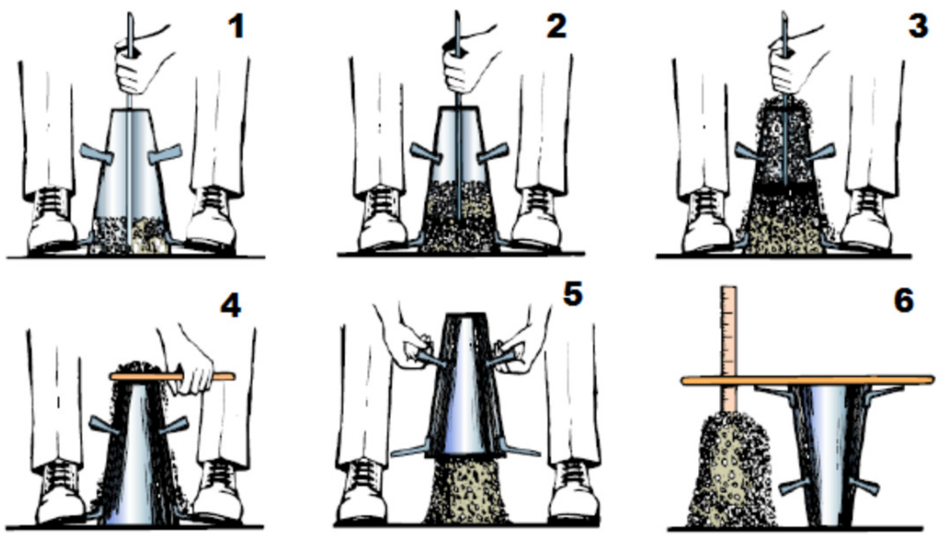
- **Workability or 'Slump' test**

  Design specification 75mm - 150mm

  Control sample = 120mm

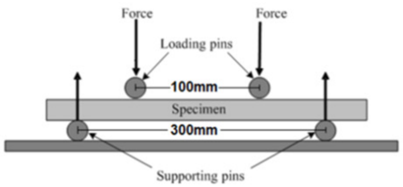
  Fibre sample = 10mm

Note: kerbs and bedding for pipework specification = 10 - 40mm

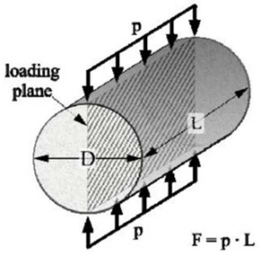


Waste Tyre Fibre - Performance Testing

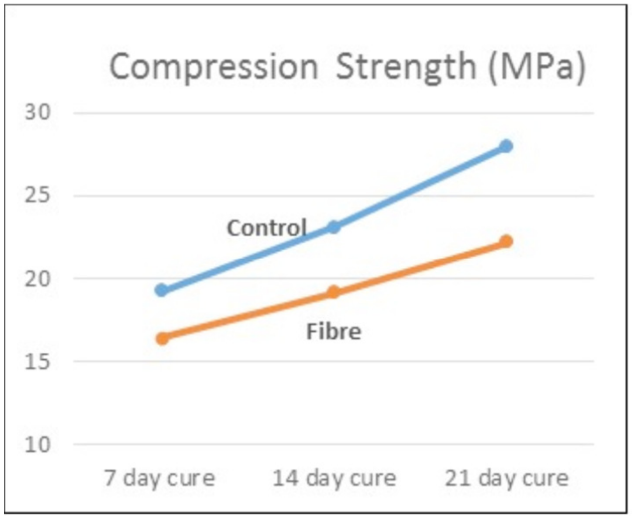
Compressive Strength

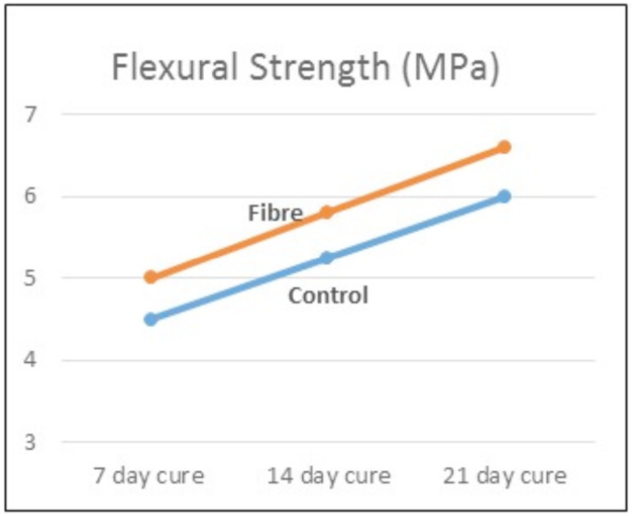


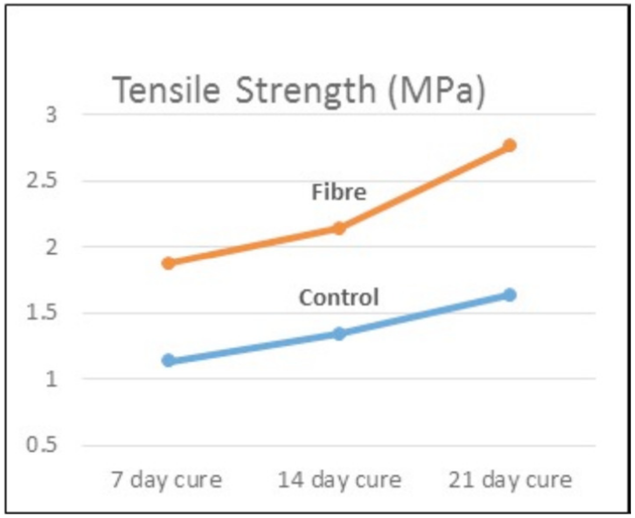
Flexural Strength



Tensile Strength







-17% average

+10% average

+65% average

Waste Tyre Fibre - Discussion

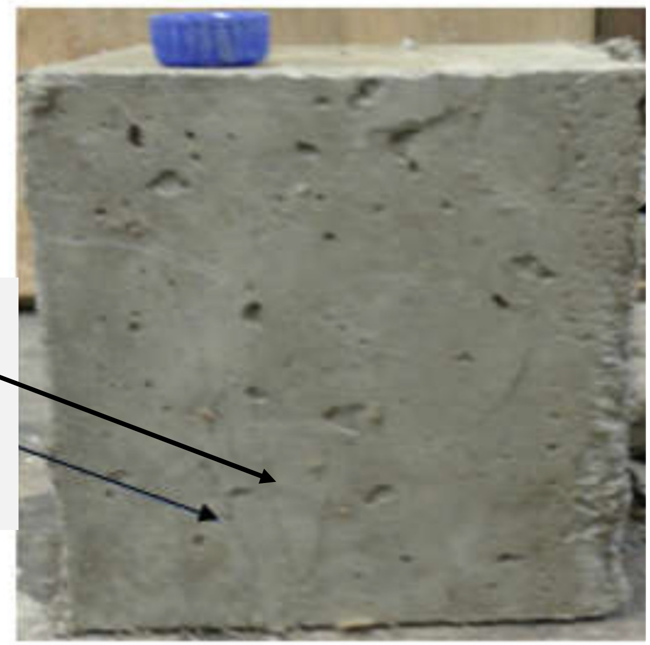
- Although the tyre fibre sample had lower compression strength it remains serviceable with hairline cracks unlike the control sample which had large cracks exposing the large aggregate

Control compression test

Large cracks

Tyre fibre compression test

Hairline cracks from the base



Recycled Paper Mill Sludge in Concrete – Mix design

- **Preparation:** Sludge was crumbled by hand before being used in the mix.
- **Quantity of paper sludge**: 5%, 10% and 15% (by weight) of the quantity of cement in the mix design was replaced by (a) raw wet paper sludge and (b) dried paper sludge (relating to 2%, 4% and 6% of fine aggregate)

Dried paper mill sludge

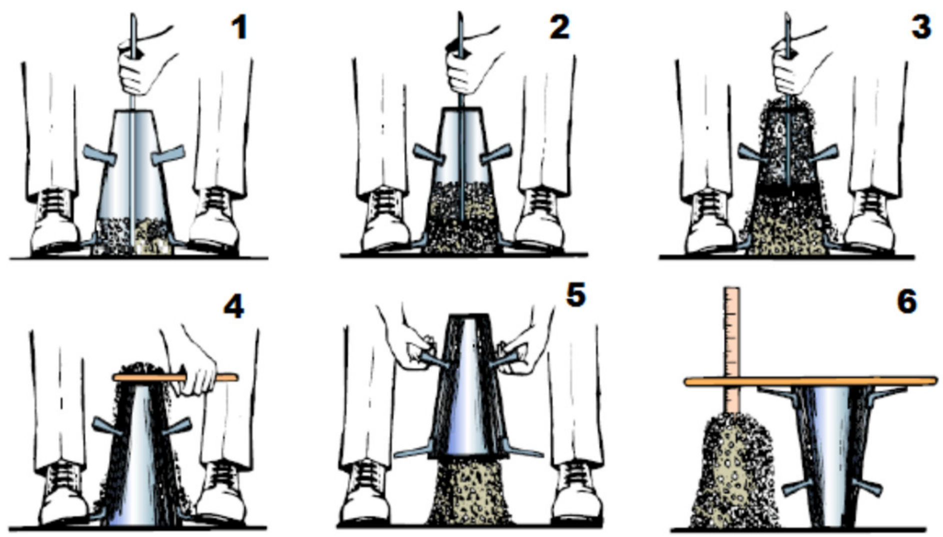
- **Mix ratio**: Based upon the control concrete mix, the cement, water, large aggregate (stone) and fine aggregate (sand) were unchanged. The only variable was the substitution of cement by paper sludge

- **Workability or 'Slump test'**

Design specification 75mm - 150mm

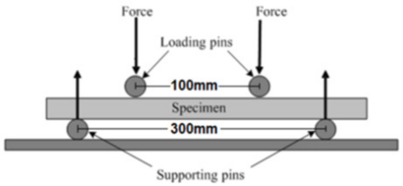
Control sample = 80mm

Wet Sludge:	5% = 85mm	Dried Sludge:	5% = 65mm
	10% = 90mm		10% = 50mm
	15% = 110mm		15% = 30mm

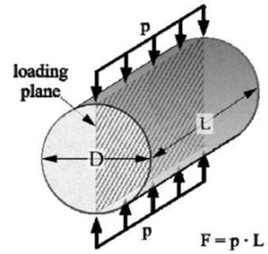


Paper sludge – Performance Testing

Compressive Strength

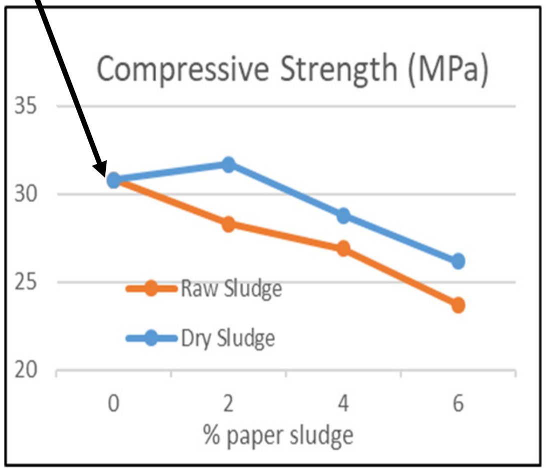


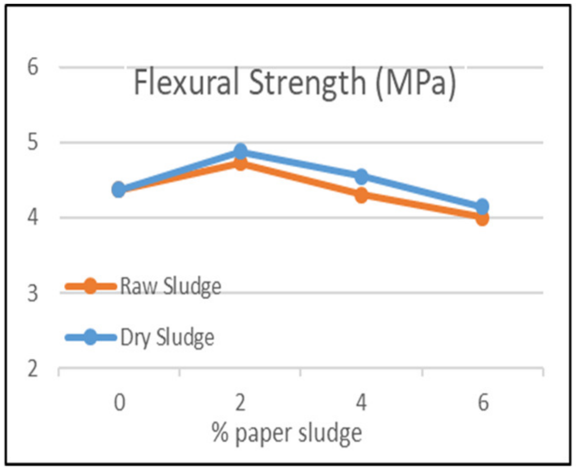
Flexural Strength

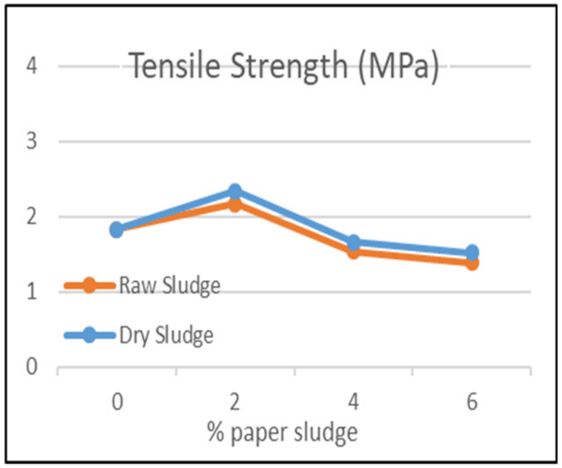


Tensile Strength

Control Sample







Compressive, Tensile and Flexural strength after 28 days ageing

Paper sludge – Discussion

- The samples with the dried paper-mill sludge performed better in terms of compression, tensile and flexural strength, than the raw paper-mill sludge. This may be attributed to the increase in water content of the mix.

- All measured strengths increased with 5% cement replacement with dry paper sludge (by weight), tensile strength being the most significant

  - Compression strength + 3%
  - Flexural Strength + 11%
  - Tensile Strength + 28%

- All performance levels reduced with 10% cement replacement and further again with 15% cement replacement

Conclusions

Tyre fibre

❖ Replacing 5% fine aggregate in a concrete mix with rubber contaminated tyre fibre waste destined for landfill, created ‘tough Concrete’

Astounding increase in tensile strength (+69%)
Significant increase in flexural strength (+10%)
Reduction in compression strength (-17%)
[Note: the compression sample remained ‘serviceable’ with only hairline cracks]

Paper sludge

❖ Paper sludge destined for incineration or landfill, used as a partial replacement of cement created ‘tough Concrete’

Large increase in tensile strength (+28%)
Significant increase in flexural strength (+11%)
Insignificant change in compression strength (+3%)

On-going Research and Development at UKZN

- Limited testing of **Tyre fibre and paper mill sludge** has provided very promising results in terms of tough and durable concrete, opening a pathway for extended research in several areas such as:

  + Analytical study: (SEM, failure analysis, fibre dispersion and distribution, fibre length and aspect ratio etc.)
  + Fibre type aspect ratio and quality analysis
  + Mixing (compounding) optimisation
  + Mix design (formulation) optimisation
  + Casting (moulding) optimisation
  + Durability (crack resistance)
  + Crack tip opening displacement (CTOD)
  + Evaluation of potential applications
  + Commercialisation requirements