Modelling and testing of an electrofusion joint in thermoplastic composite pipes

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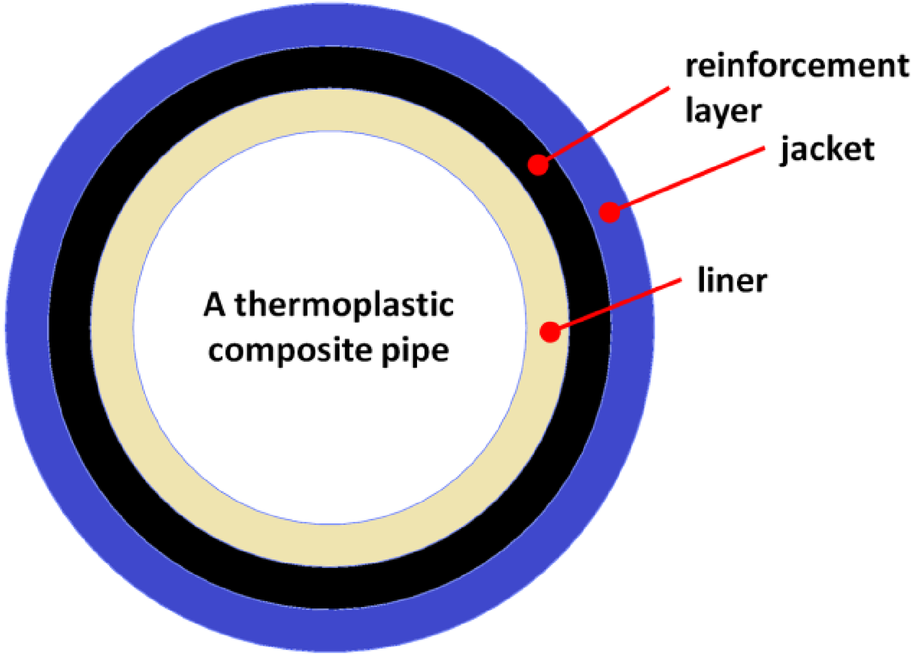
Connecting composite pipes

- Project background: oil pipelines are currently made from steel, which is prone to corrosion and the metallic connectors require maintenance.
- Aim: design a non-metallic connector utilising electrofusion (EF) welding technology for polyethylene (PE) composite pipes.
- This project utilises glass fibre (GF) reinforced, fully bonded PE pipes – thermoplastic composite pipes (TCP). Novel material, little data available!
- Currently steel connectors are used



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Electrofusion welding

- Common technology in everyday use since 1960s
- The mechanical and corrosion resistance significantly better than in mechanical joints
- Not yet widely applied to TCPs

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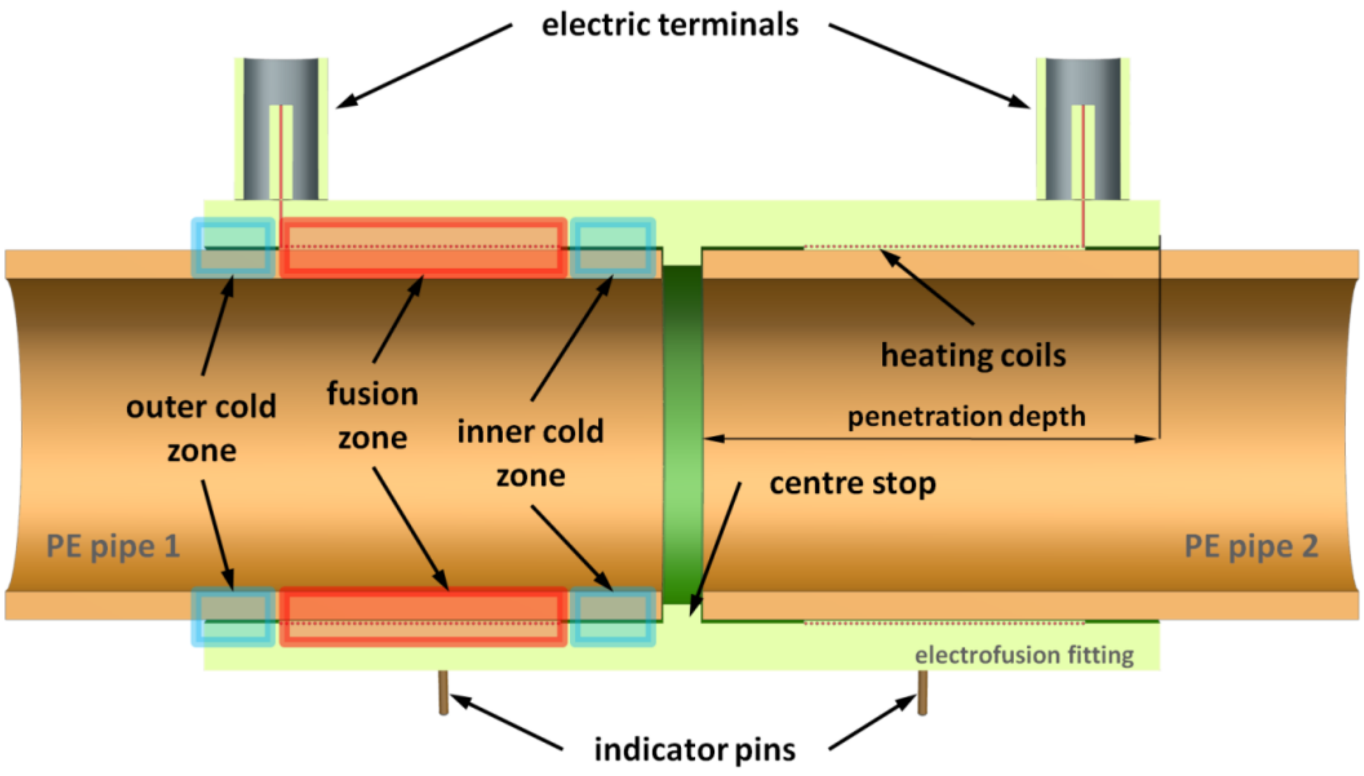
Electrofusion process

- First, pipes are cleaned, then slid into the socket
- Current is applied to the wiring, heating and melting the plastic, the joint is then left to cool down
- Industrial experience and FEA confirm that the inner and outer cold zones have the highest stress concentrations, this is where failure starts



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EF welding of TCP

- EF welding of TCPs would solve the corrosion problem and potentially make connections cheaper
- First an FEA model of a joint made from a standard coupler and TCP was developed to investigate its behaviour under internal pressure and axial load with properties from literature
- Recently, the focus of the project was to obtain the actual pipe properties in order to use in the model
- Two experiments were carried out to validate the FEA simulations

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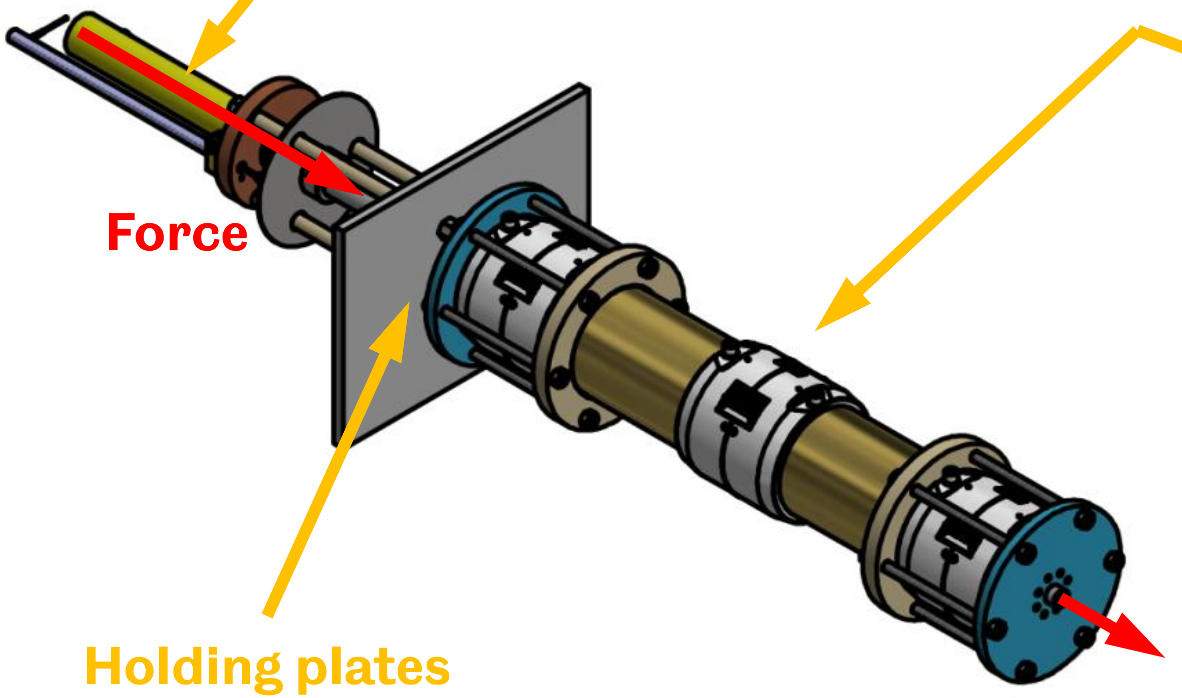
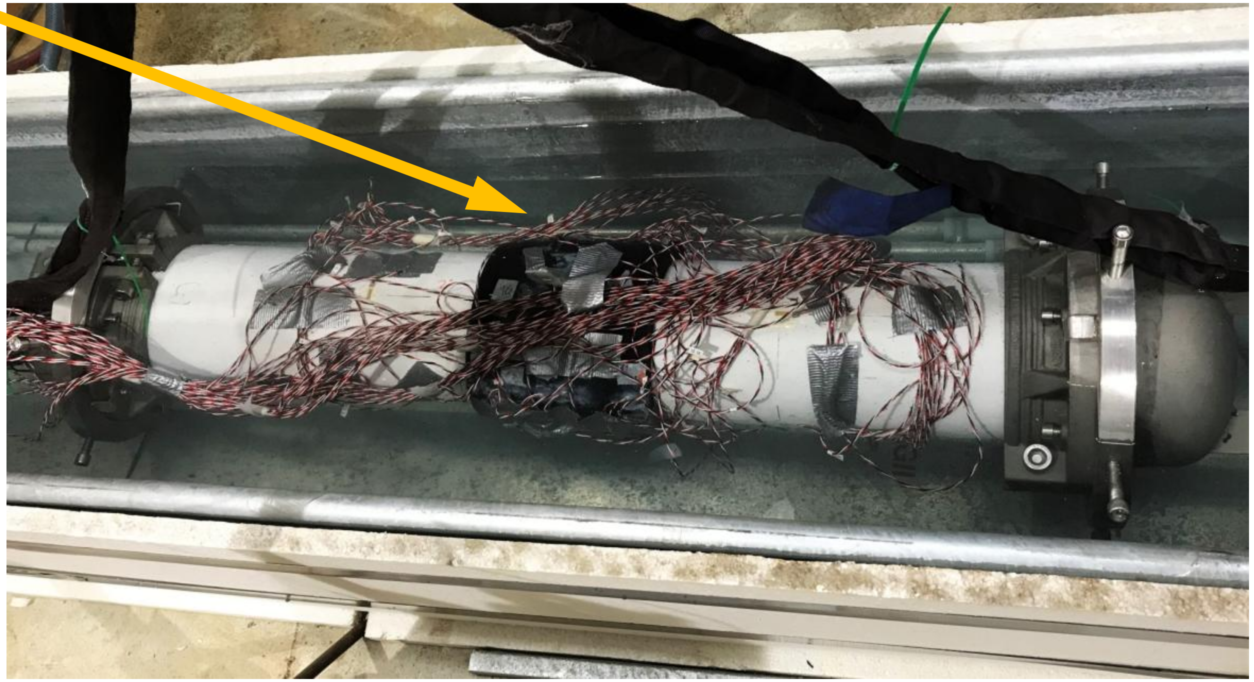
Full scale experiments

Axial tension test

Hydrostatic pressure test





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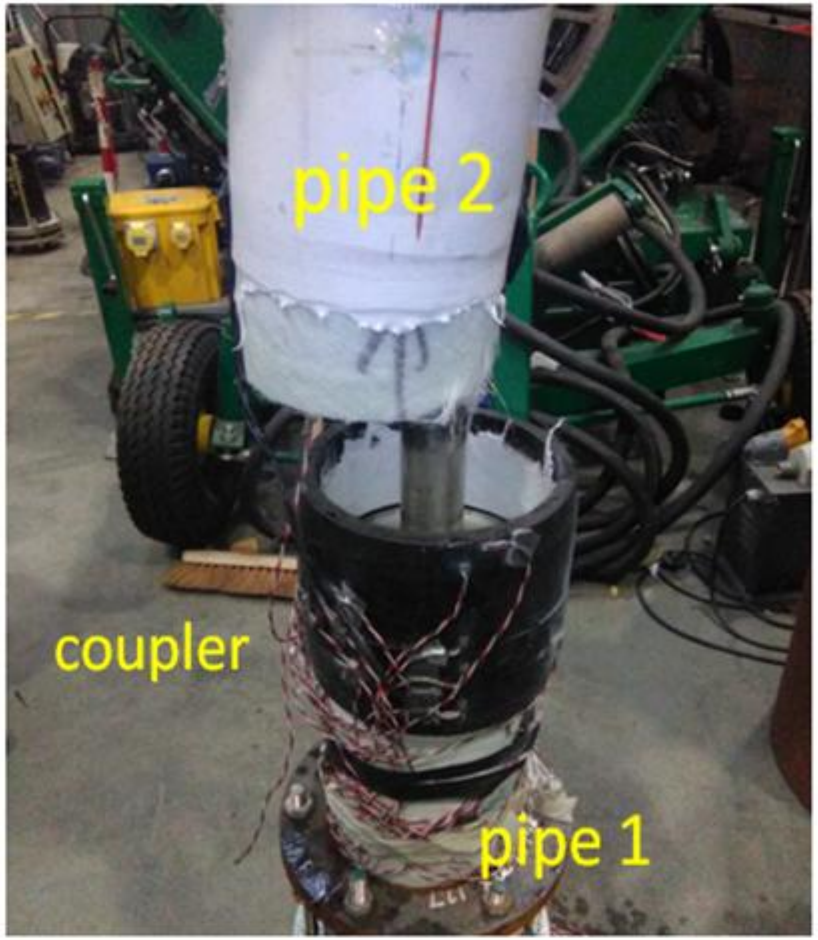
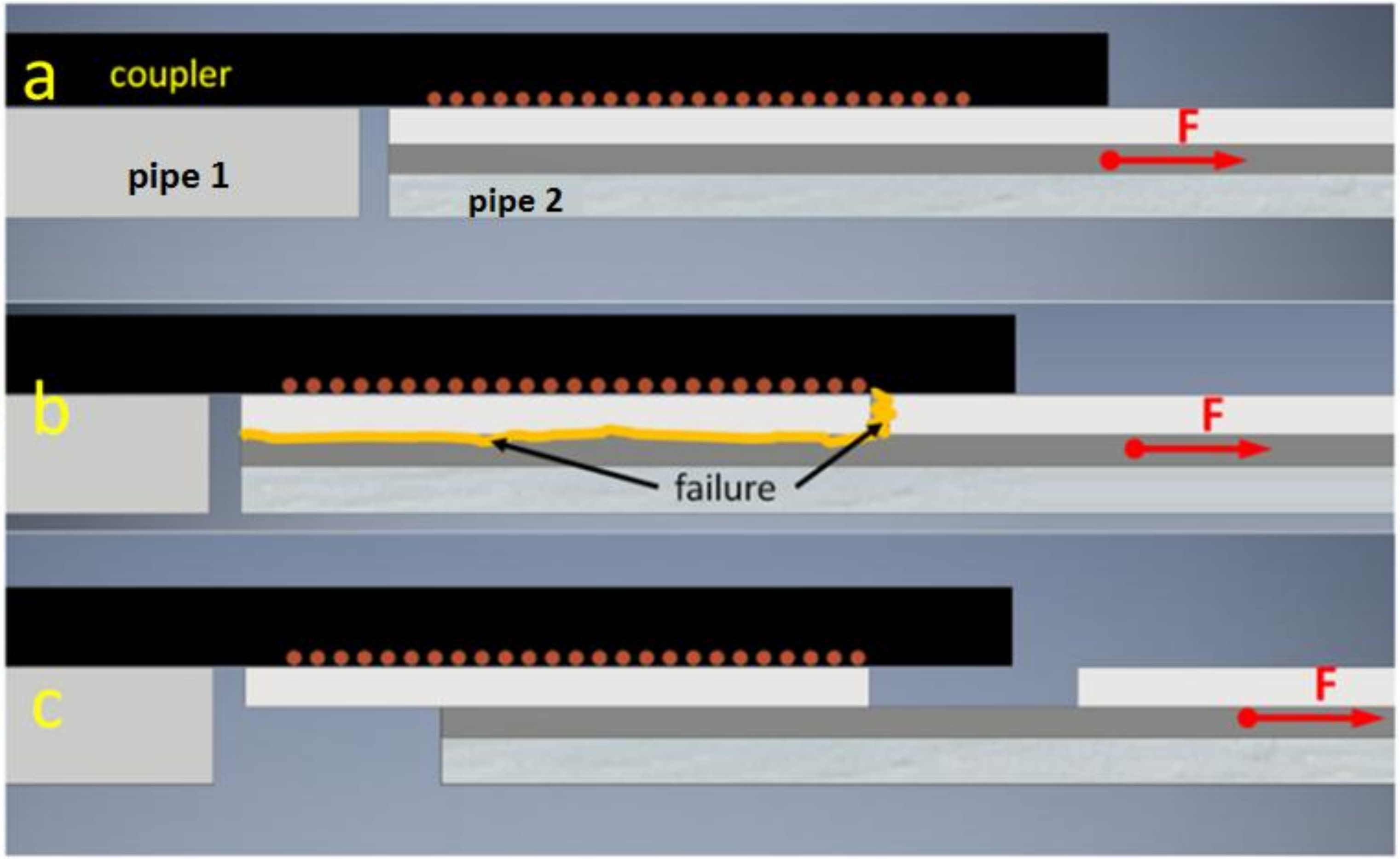
Axial tension test outcome





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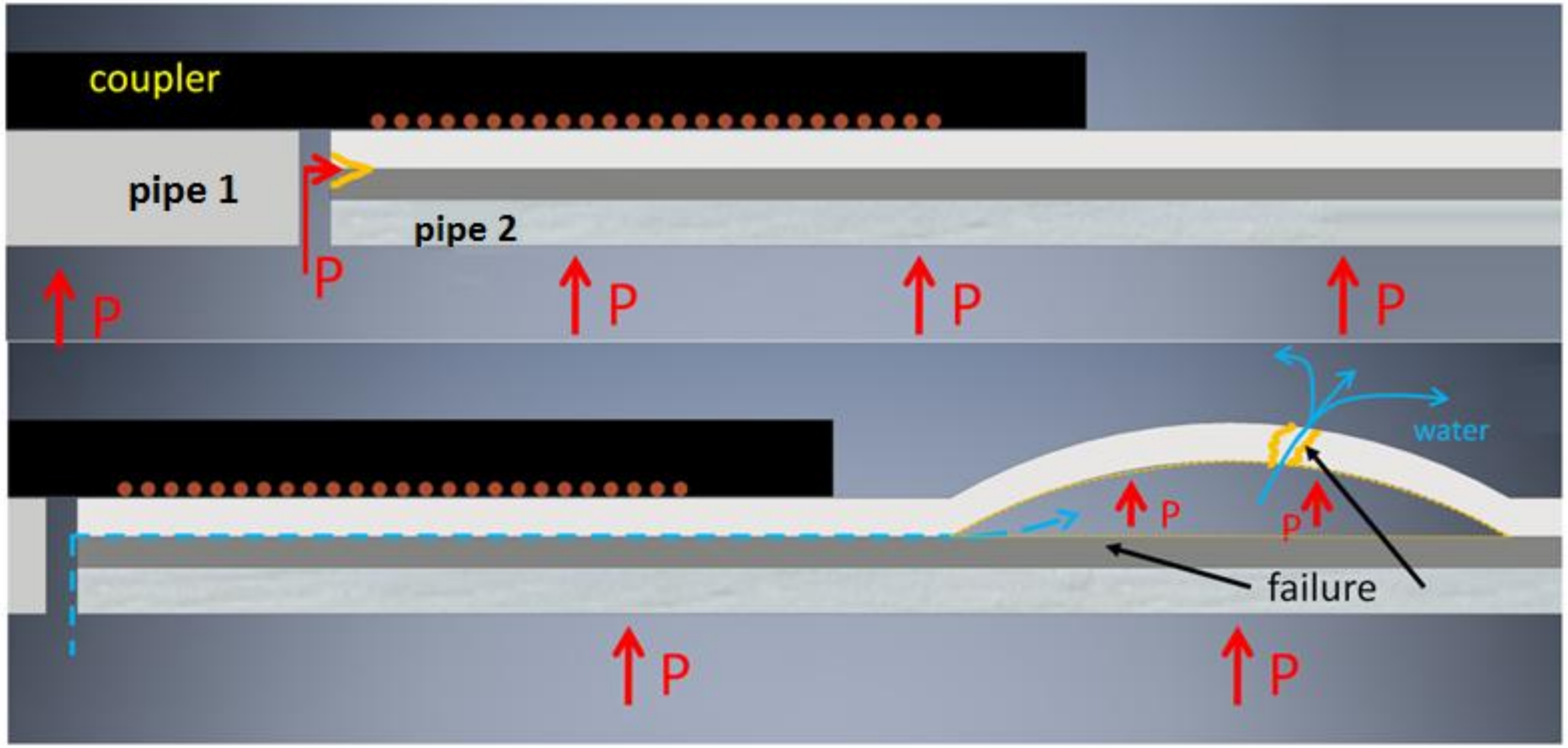
Hydrostatic pressure test outcome



Conclusion: the dedicated coupler must isolate the reinforcement from the fluid!

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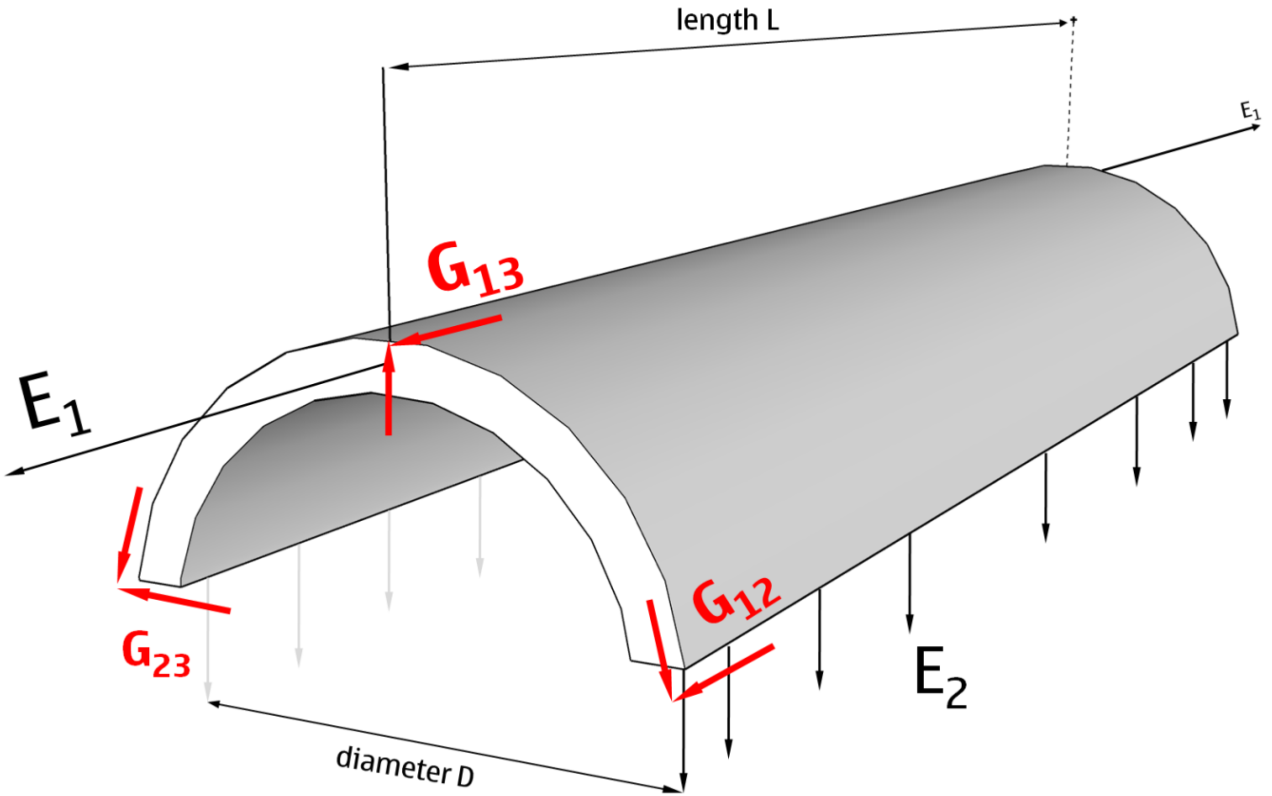
Designing a new coupler

- In order to design a new coupler FEA was used
- This requires knowing precise properties of the pipe and coupler
- The properties can be calculated using classical laminate theory and information given by manufacturer, but this should be validated, and not all data is available
- The pipe needs to be tested for every property, but is it possible?



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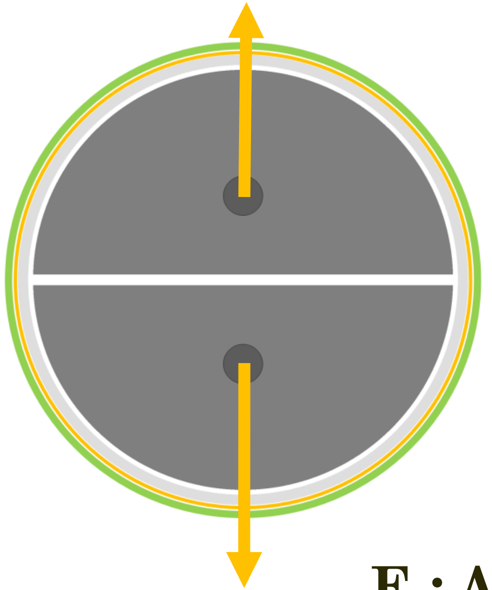
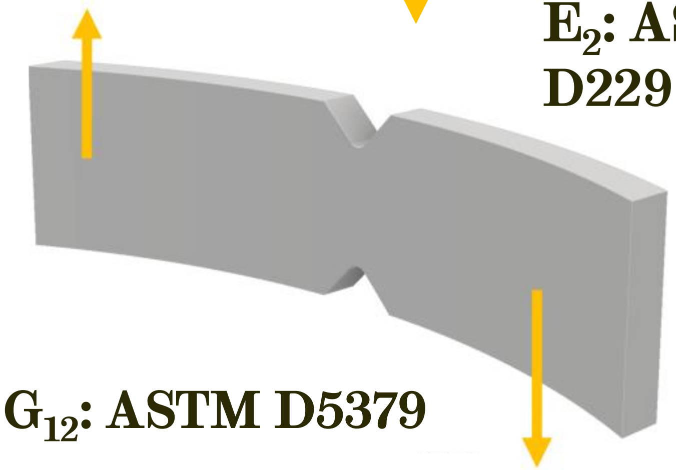
Specimen tests

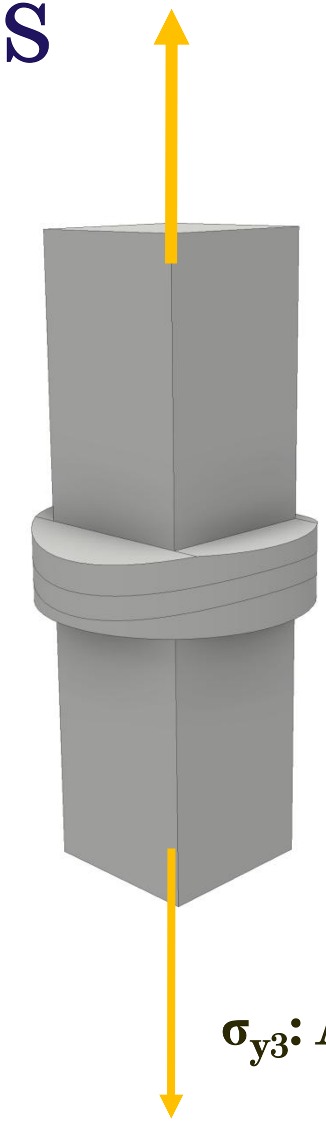
E_1: EN ISO527-2 and -4



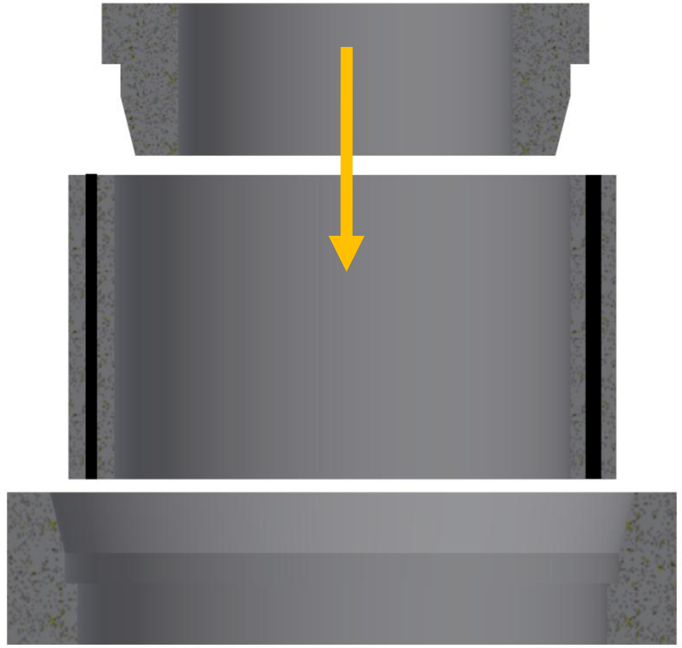
E_2: ASTM D2290



G_{12}: ASTM D5379



σ_{y3}: ASTM C297



τ_{y13}: EN ISO 12736 A:I

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Specimen tests

- Strain gauges (SGs) were initially the primary intended source of data
- Where possible, digital image correlation (DIC) was also used
- All tests were performed at 65°C because this is the maximum operating temperature of the TCP
- Initial experience with DIC and SGs in full scale tests suggested that the latter were the better option for obtaining data

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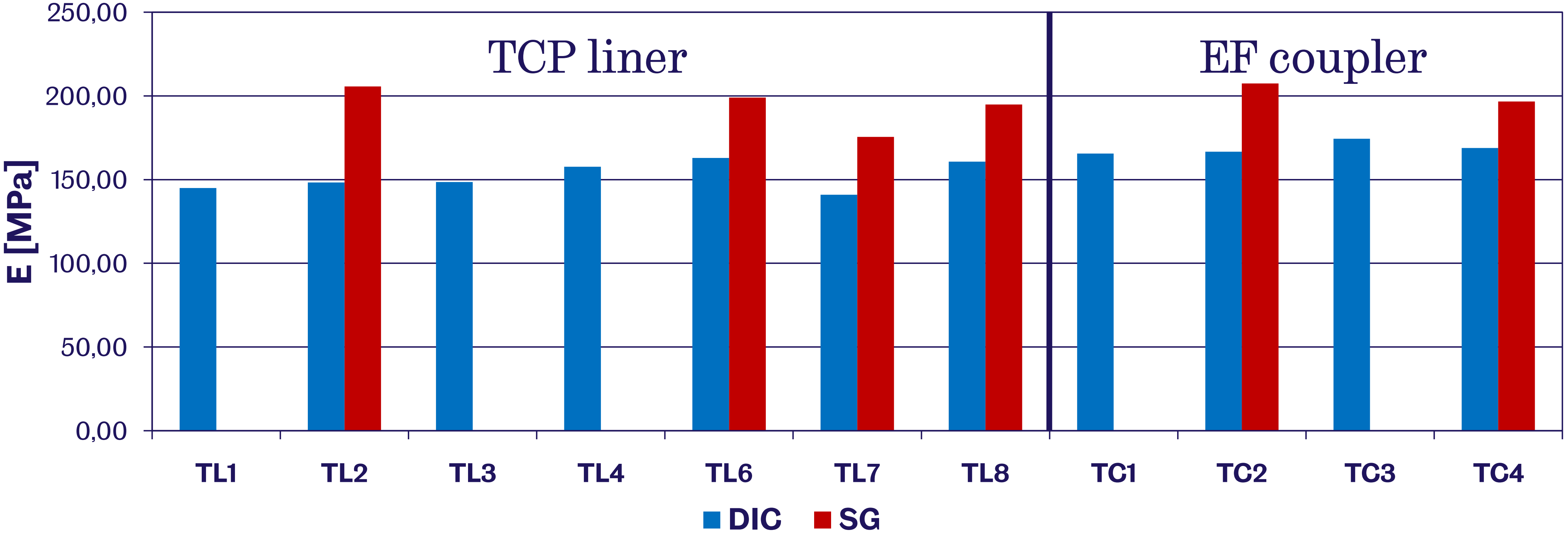
Tensile tests E_1 results (PE)

- All these bars are for PE100 EN ISO 527-2, so should be similar – not all SG produced results as they came off before 2,5% strain



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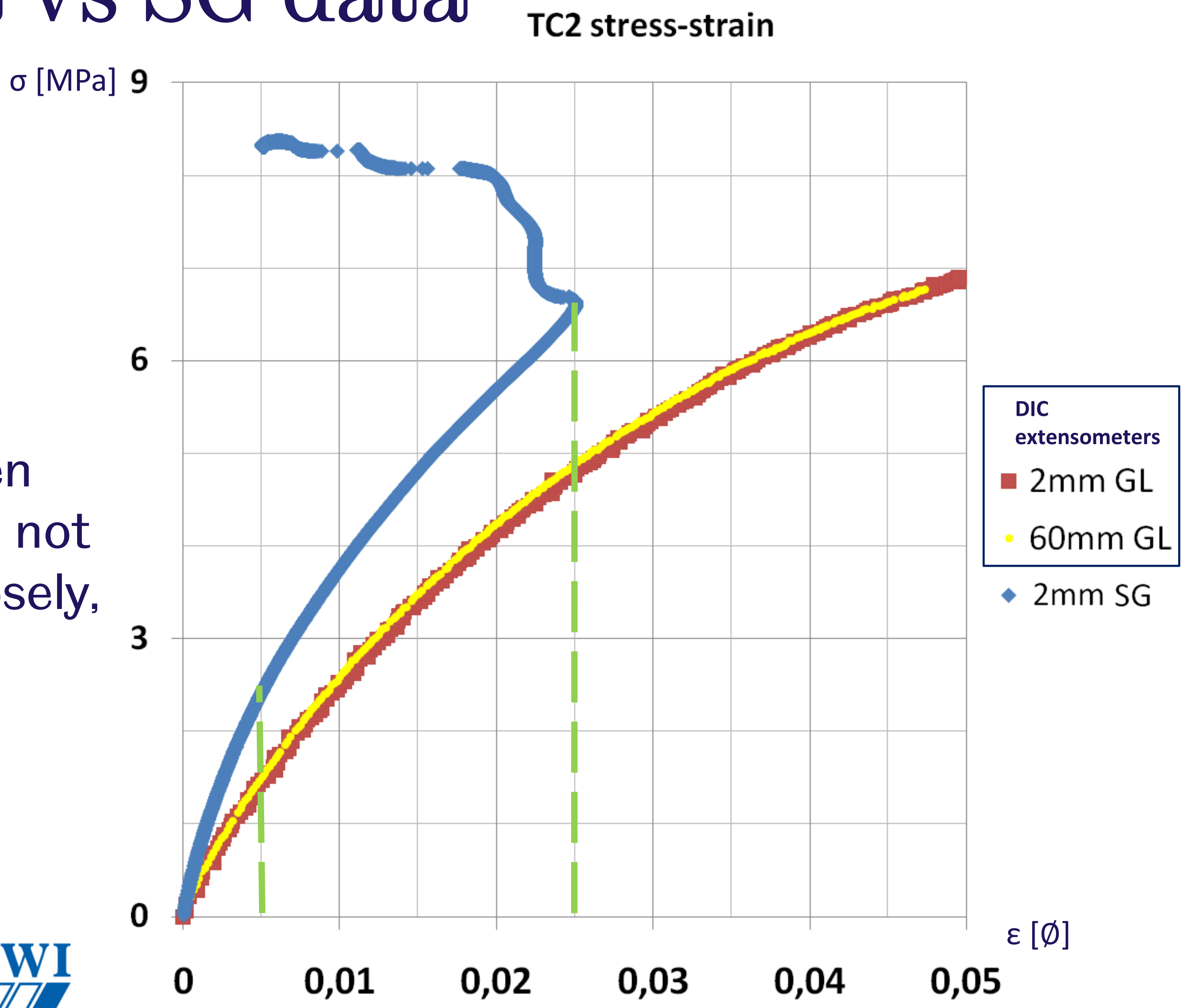
DIC data vs SG data

- DIC modulus results were consistently lower than SG
- Strains recorded by SGs were lower than DIC
- Reason: poor adhesion between SG and polymer, gauges would not follow the straining surface closely, no such problem with DIC



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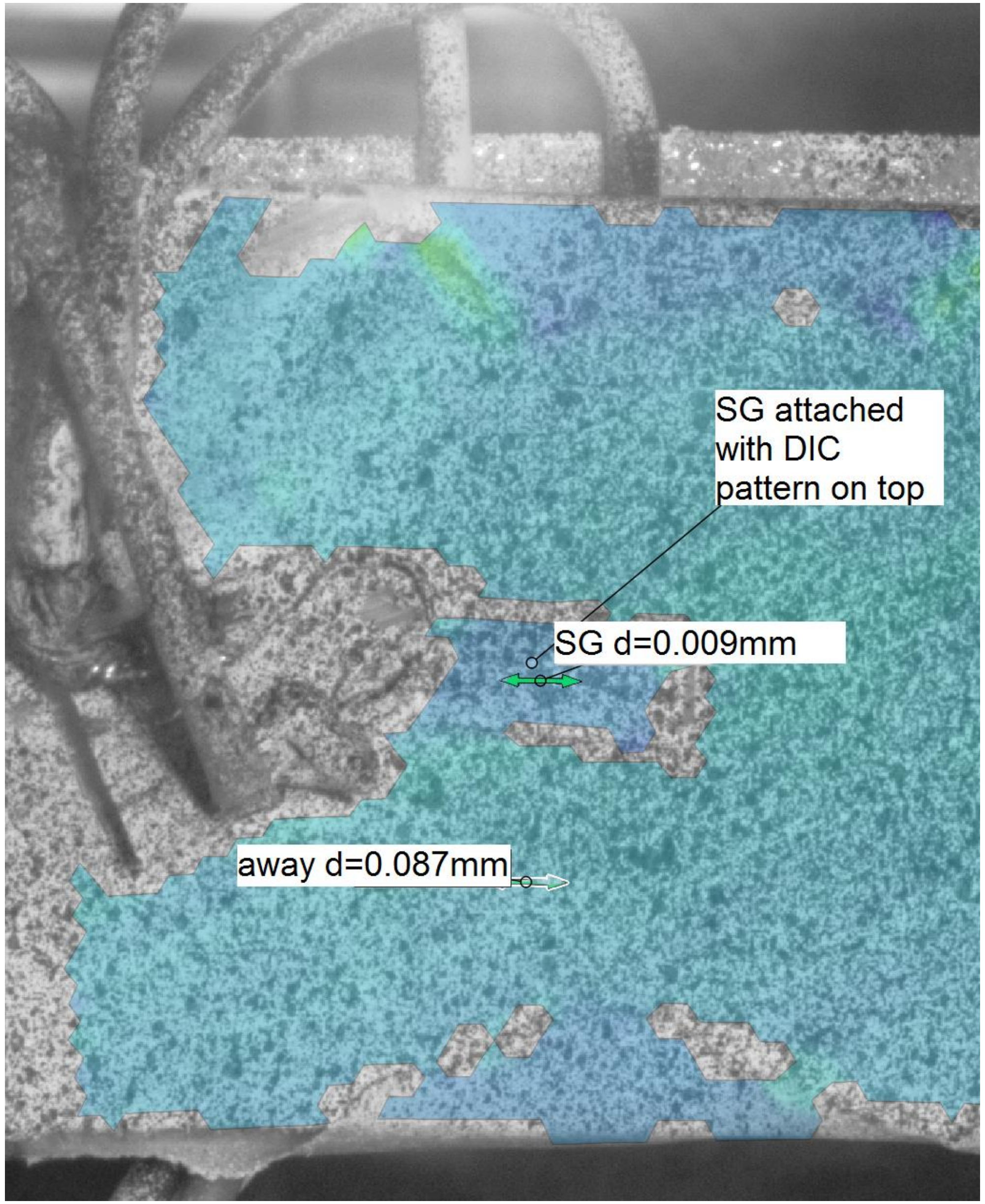
Strain gauges and PE – problems

- SGs did not adhere properly even though the recommended adhesive and bonding procedure was used and the surface was pre-treated with a primer
- Similar problems reported in literature
- Conclusion: DIC is the best option for strain measurement on PE



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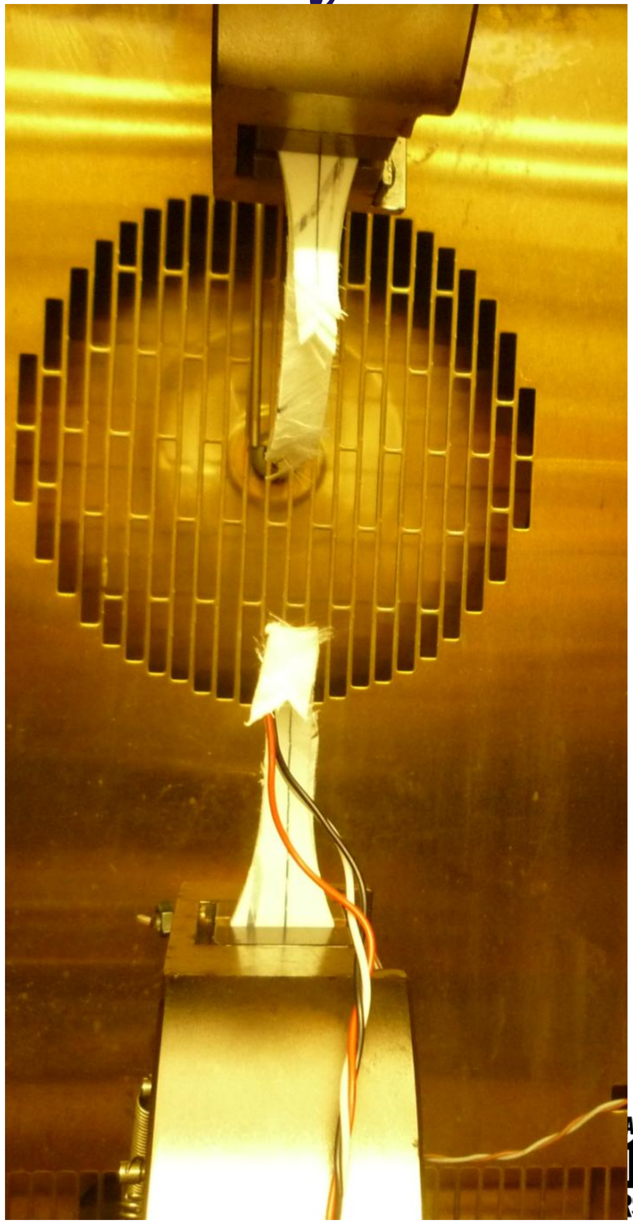
Testing the reinforcement layer

All specimens cut from the pipe reinforcement layer:

- σ_{3y}=0.27±0.09 MPa
- τ_{13y}=0.5±0.1 MPa
- E_1=252.55±61.38 MPa
- E_2=2579±538 MPa
- G_{12}=907±337 MPa

Some values have high scatter or are significantly different to theoretical values



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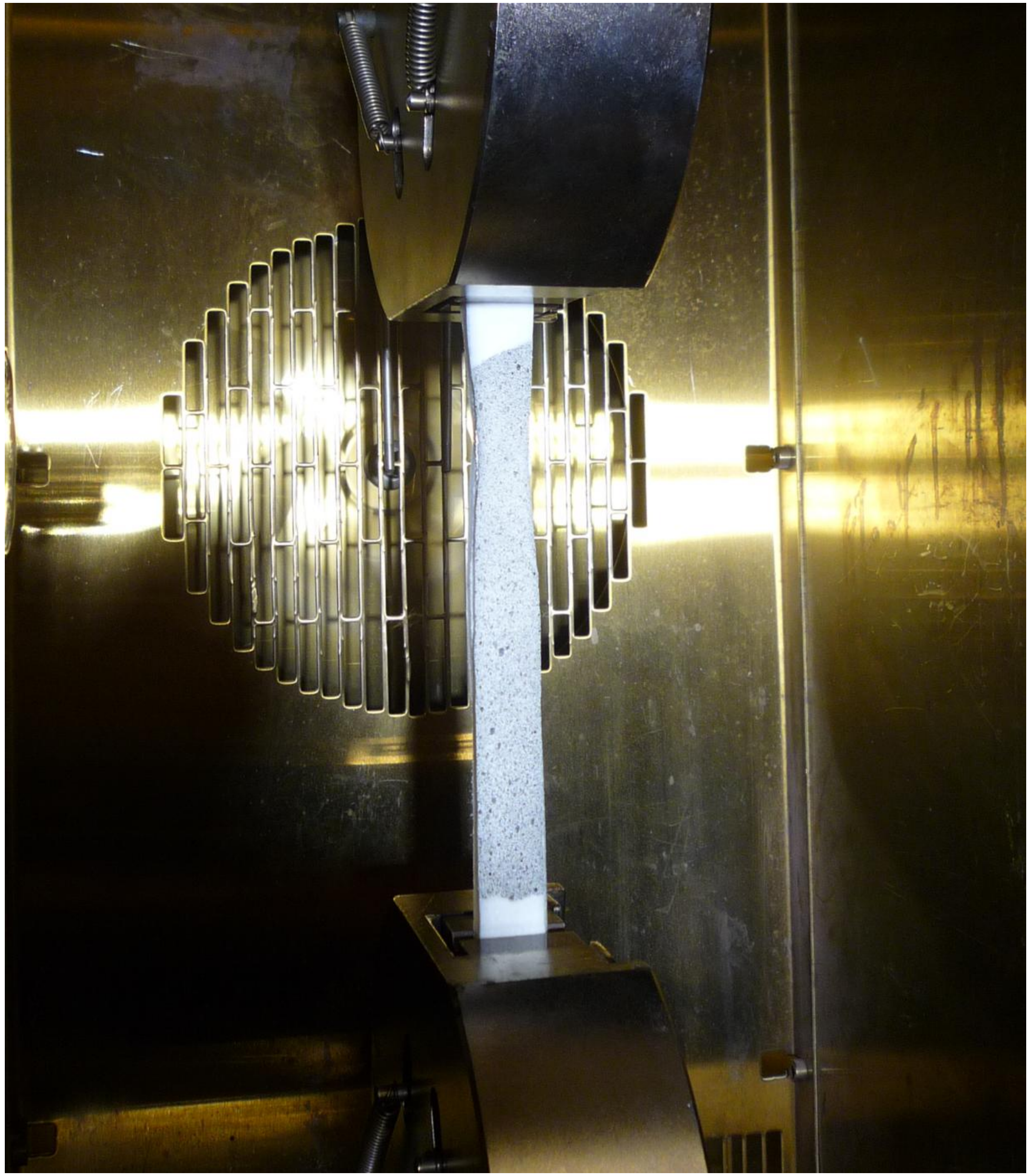
Reinforcement layer tests – conclusions

It was difficult to obtain properties of the TCP reinforcement layer by sectioning the pipe itself:

- Biggest problem – uneven thickness of respective layers, difficult to cut specimens precisely
- Layers not fully welded together
- Not all tests could be done with DIC
- Maybe a different approach should be tried?



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Making my own PE-GF composite

- As the results of some tests were inconclusive, a PE-GF composite sheet was made, using the tape that was used for winding the actual TCP
- The same layup as in the TCP reinforcement layer was recreated: (+55/+55/-55/-55/+55/+55/-55/-55/+55/-55)
- A 19 cm side rhomboidal plaque was cured in an autoclave at ~1.5 bar pressure, calculated knowing tape tension from the TCP manufacturer

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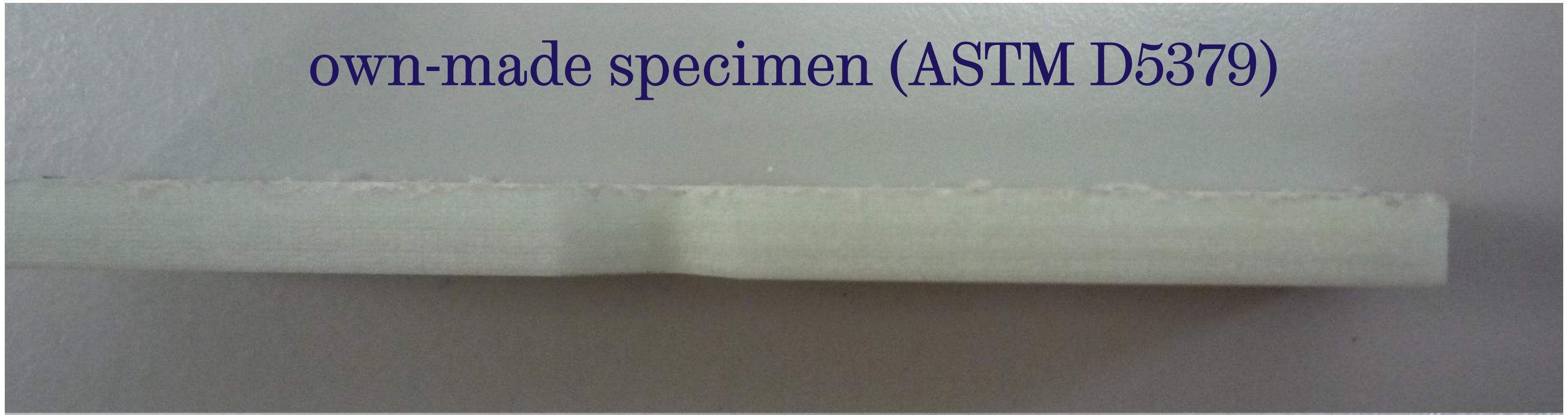
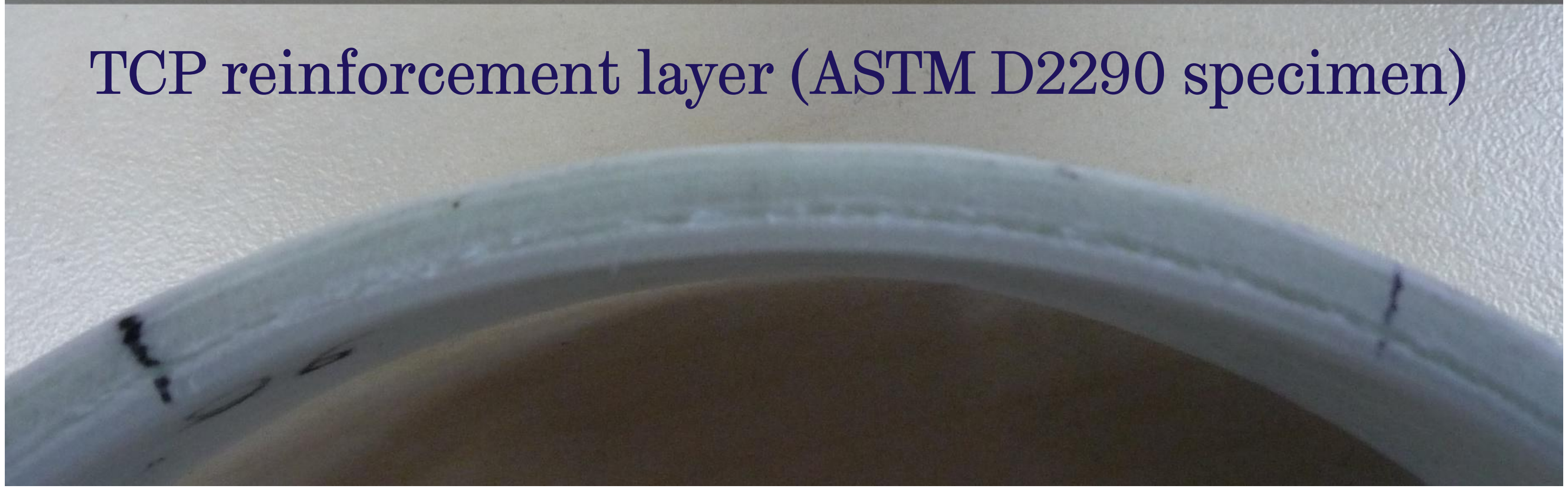
Flat composite specimens

- Specimens for EN ISO 527-4 and ASTM D5379 tests were cut from the composite sheet
- They were of very high quality, no delamination was observed
- Likely to be representative of a freshly cut TCP, however much stronger and stiffer than previously tested specimens cut from TCP samples, which developed cracks some time after being cut





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Own-made composite test results

- The specimens were stiffer and much stronger than those cut from TCP reinforcement
- Strength values could not be obtained as the failure mode was by the outer layers getting peeled off at the grip
- Results:
  - E1: 619 MPa (one measurement)
  - E2: 1822±132 MPa
  - G12: 1547±371 MPa (DIC), 1551 MPa (SG, one measurement)

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Tests – general discussion

- The autoclave-made specimens were not representative of the TCP that was EF welded, so their properties cannot be used for validating the FE model
- They should be representative of a freshly cut pipe, so will be used in the model to design new prototype EF coupler
- The model of whole joint tests can be validated for small strains using a mixture of properties found experimentally and calculated with classical laminate theory

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Conclusions

- It is difficult to obtain material data from specimens from the TCP reinforcement because it cracks due to residual stresses some time after cutting
- Cracking is not an issue in the field, with metallic connectors, because pipes have the layers compressed from outside and inside in the radial direction shortly after being cut, and the reinforcement layer is isolated from the liquid; these joints satisfy all quality requirements specified in the relevant product standard (**API 15S**)
- For any tests done on PE samples DIC is the best method for measuring strains
- Experience from the project suggests an ideal experiment for validating FEA models of prototype couplers would happen in a large environmental chamber at 65°C and DIC should be used to measure all the strains.

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Thank you for your attention

Any questions?

This work was made possible by the sponsorship and support of the Non-metallic Innovation Centre. The work was enabled through, and undertaken at, the National Structural Integrity Research Centre (NSIRC), a postgraduate engineering facility for industry-led research into structural integrity, established and managed by TWI through a network of both national and international universities.

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