An Aerospace Solution to Leading Edge Erosion

15th January 2019 | Peter Greaves

CATAPULT Offshore Renewable Energy

Agenda

- Leading Edge Erosion
- Introduction to LEFT Project
- Methodology
    - Modelling
    - Experimental
- Results
- Conclusions

Leading Edge Erosion

- Leading edge erosion is caused by raindrops impacting the leading edge near to the tip of the blade, where the local velocity can be close to 100m/s (225mph)
- It is a big problem for the industry (their biggest on blades according to a survey carried out among OEMs and owner operators)
- It costs the industry in two ways:
    - the aerodynamic performance decreases as erosion gets worse
    - Repairs need to be carried out approximately every 5 years
- 108 turbines x 6 days at €100k per day for a jack up rig is €65m in vessel hire, before lost revenue and the cost of repairs has been accounted for!

reNEWS

RENEWABLE ENERGY NEWS ■ ISSUE 377

Orsted to repair hundreds of UK offshore blades

Orsted is facing a two-year
campaign to repair almost
500 Siemens Game
turbine blades at U
wind farms affecte
are understood to
edge erosion probl
The Danish deve
hoping to kick off w
this year at the 389MW West
of Duddon Sands project in
the Irish Sea, co-owned by
Sc
wh
at
an
up
rubber edges will be attached.
Lightning receptors and
so-called DinoTails are also
due to be exchanged on the

58.5-metre components. An
as-yet-unnamed contractor
at the wind farm, which
entered service in 2014,
by installing a fresh set of
The Danish giant is also
laying the groundwork for a
similar repair operation next
year on all 51 3.6-120s at the

184MW Walney 2 wind farm,
it is understood. A spokesman
e yet to
verhaul
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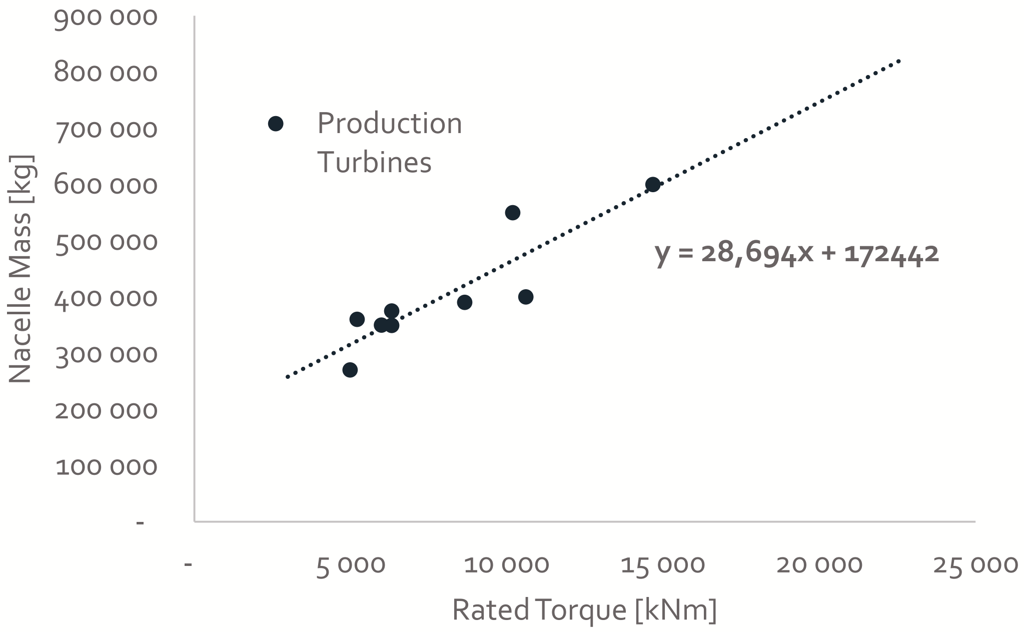
pecify
o the
nly
rosion".
Siemens Gamesa's 3.6-120
model began serial production
in 2010 and a total of 950
its are installed in
n waters.
st one 80-machine
m in German waters
ed by a similar issue
operator is in talks
with the manufacturer about
repairs, it is understood.
Siemens Gamesa declined
to comment.

is expected to take between three and 10 days to tackle each turbine, depending on

where all 108 turbines need attention.

Benefits of Higher Tip Speeds

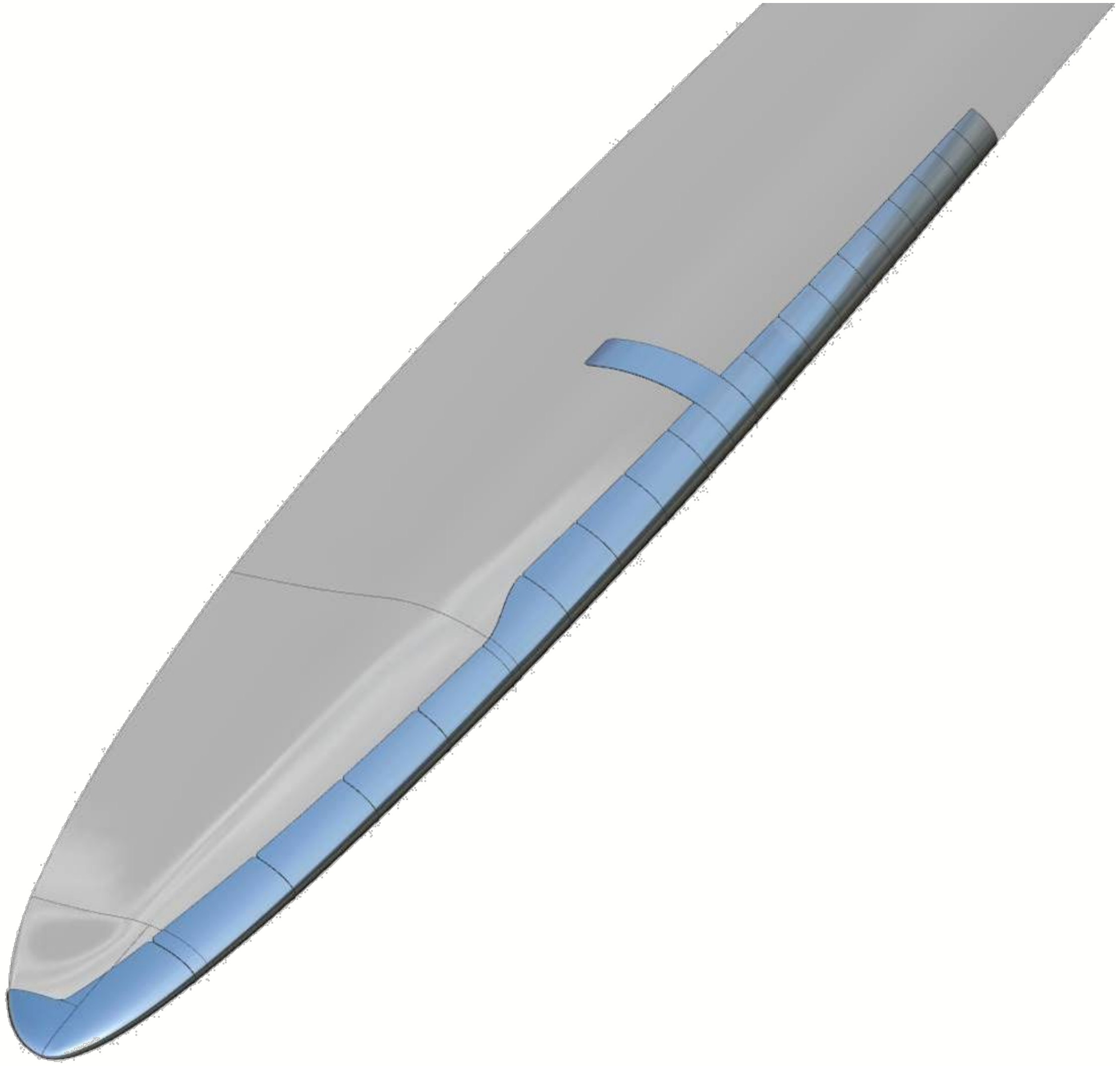
- If the speed limit of leading edge erosion is removed then tip speeds could increase to 120m/s or more
    - A 30% increase on current speeds!
- A nacelle mass trend derived from a survey of current nacelles has shown that the estimated nacelle mass for a 20MW turbine would be:
    - 1025t at 90 m/s
    - 815t at 120 m/s
    - This would lead to a substantial decrease in tower cost as well as nacelle cost
- Jamieson et al [1] demonstrated a turbine CAPEX reduction of 20% for a 5MW turbine when increasing the tip speed and moving to a downwind rotor
- Dykes et al [2] demonstrated a 5.5% reduction in LCOE by moving from 80 m/s to 100m/s flexible blade



[1] Jamieson P (2009) *Light Weight, High Tip Speed Rotors for Offshore*. EWEC 2009, Stockholm.
[2] Dykes K, Platt A, Guo Y, Ning A, King R, Parsons T, Petch D, Veers P and Resor B (2014) *Effect of Tip Speed Constraints on the Optimised Design of a Wind Turbine*, NREL TP-50000-61726

The LEFT (Leading Edge for Turbines) Project

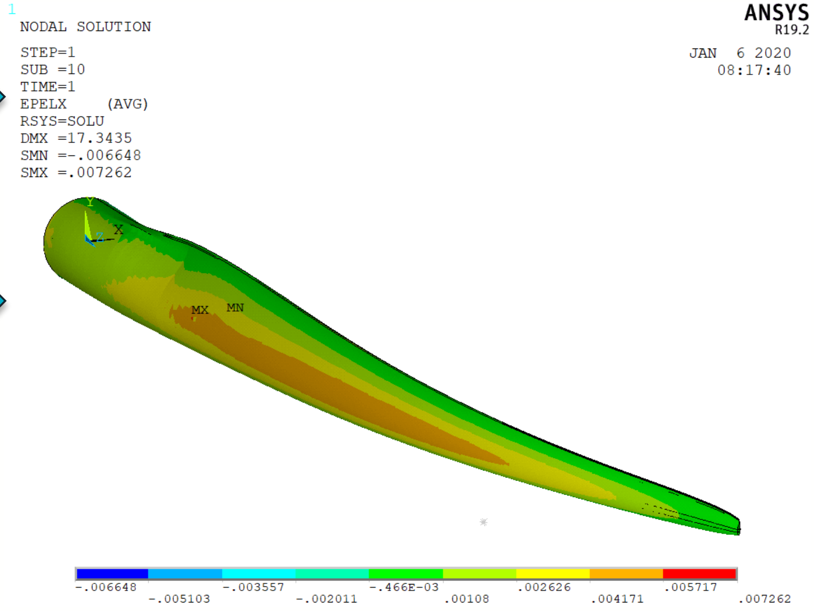
- The LEFT project is a collaboration between:
  - Radius Aerospace UK
  - Performance Engineered Solutions Ltd
  - The Offshore Renewable Energy Catapult
- It aims to transfer the use of electroformed Ni-Co leading edge protection from the aerospace industry to wind turbines
- The Ni-Co solution has demonstrated extremely good rain erosion performance:
  - It lasts for 85 hours in the ORE Catapult rain erosion rig at 173 m/s
  - Typical solutions last for around 15 hours at 120 m/s
- However, it will be challenging to integrate with wind turbine blades:
  - The alloy has high relative stiffness compared to the blade
  - Lightning protection
- The LEFT project aims to address these issues



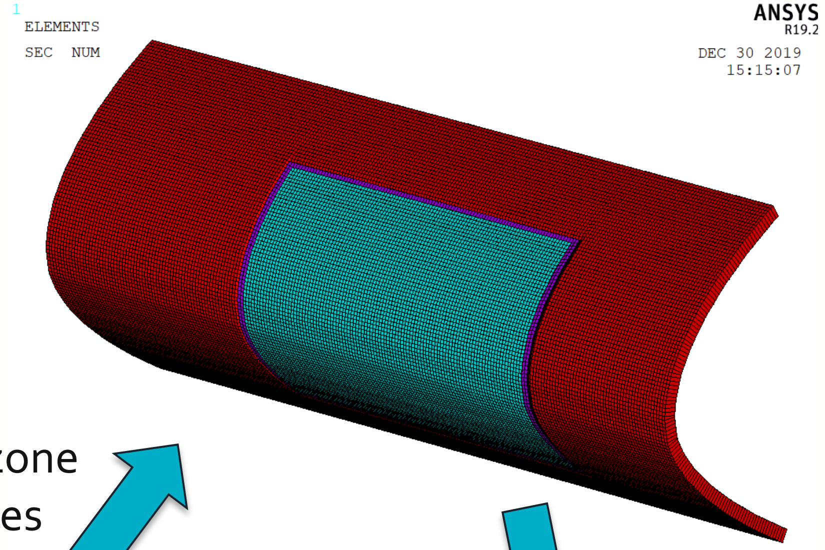
Adhesive Validation Methodology

DTU 10MW Blade

Extreme Loads

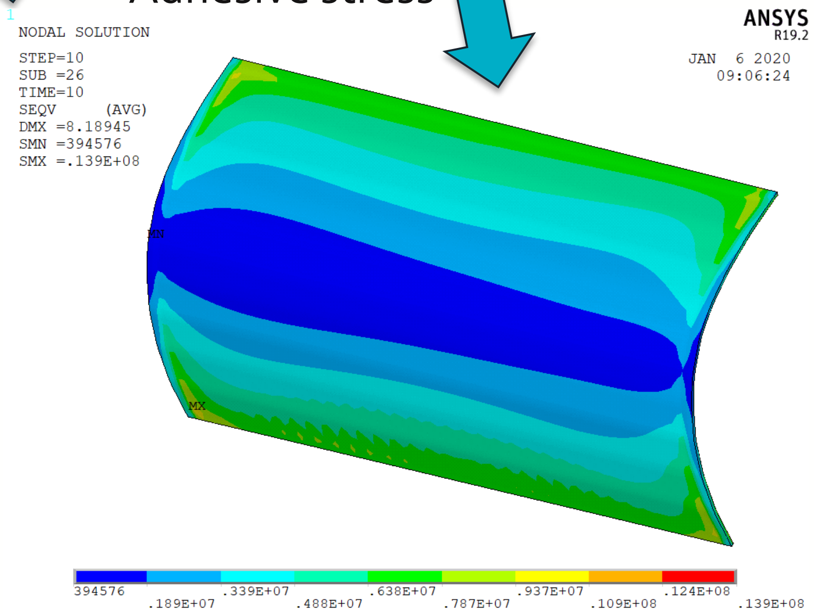


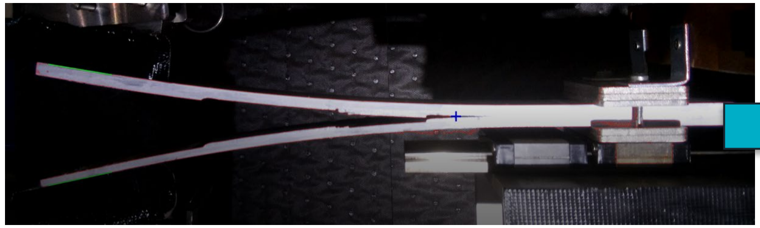
Nodal displacements

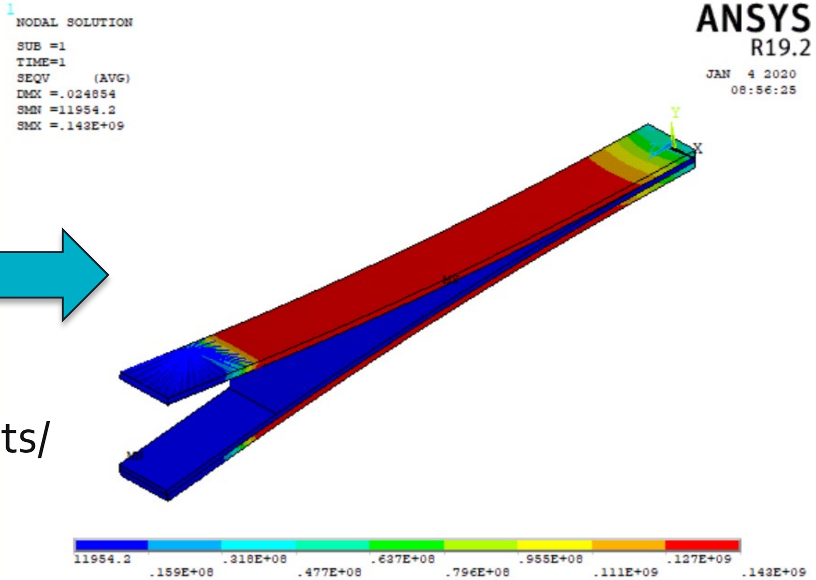


Cohesive zone properties

Adhesive stress

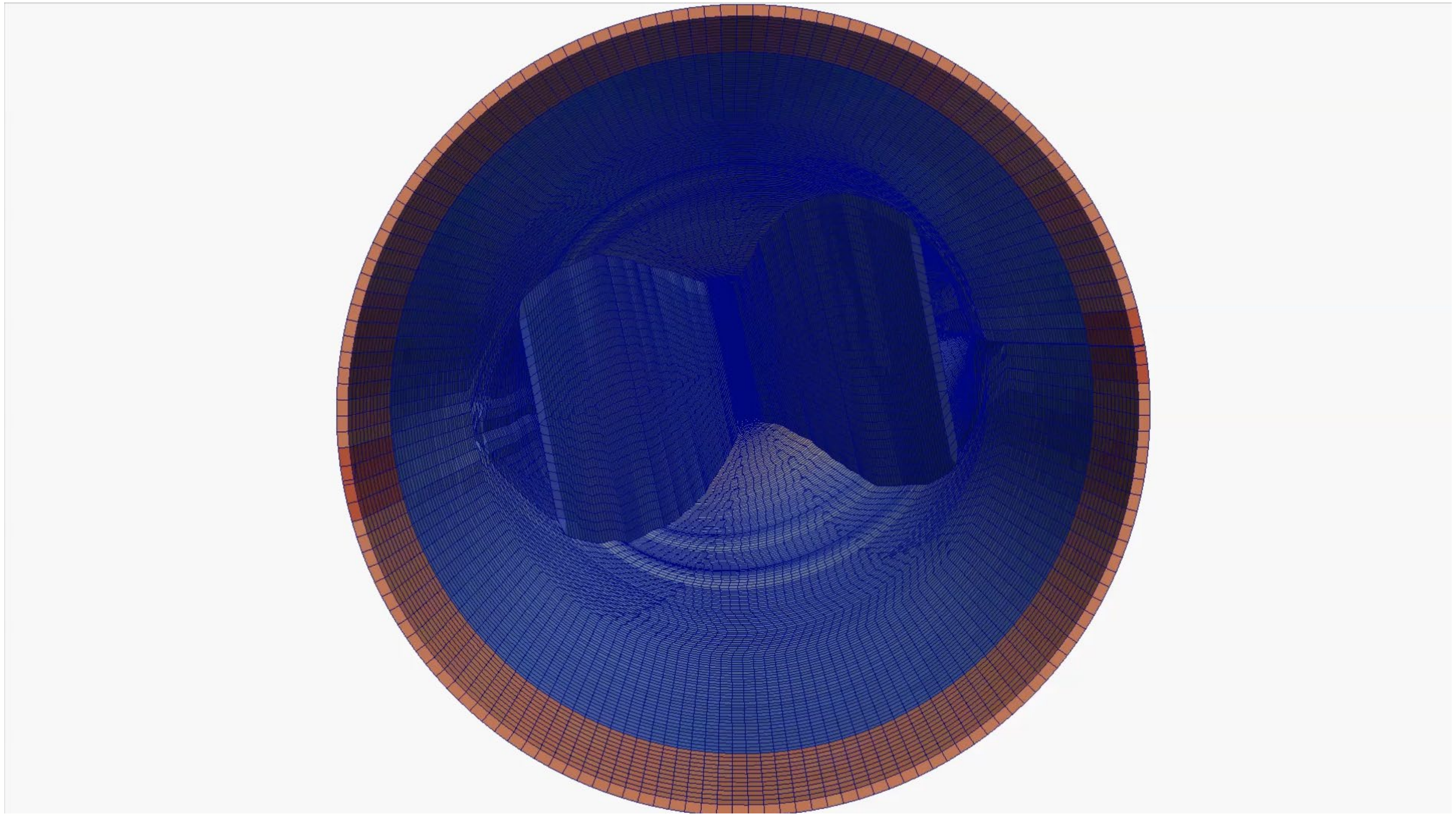


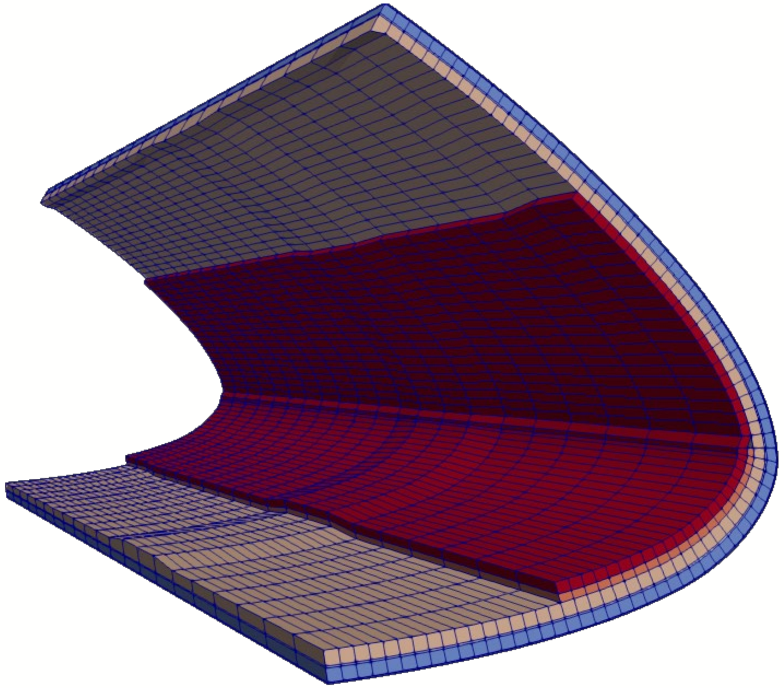




Displacements/ Moments

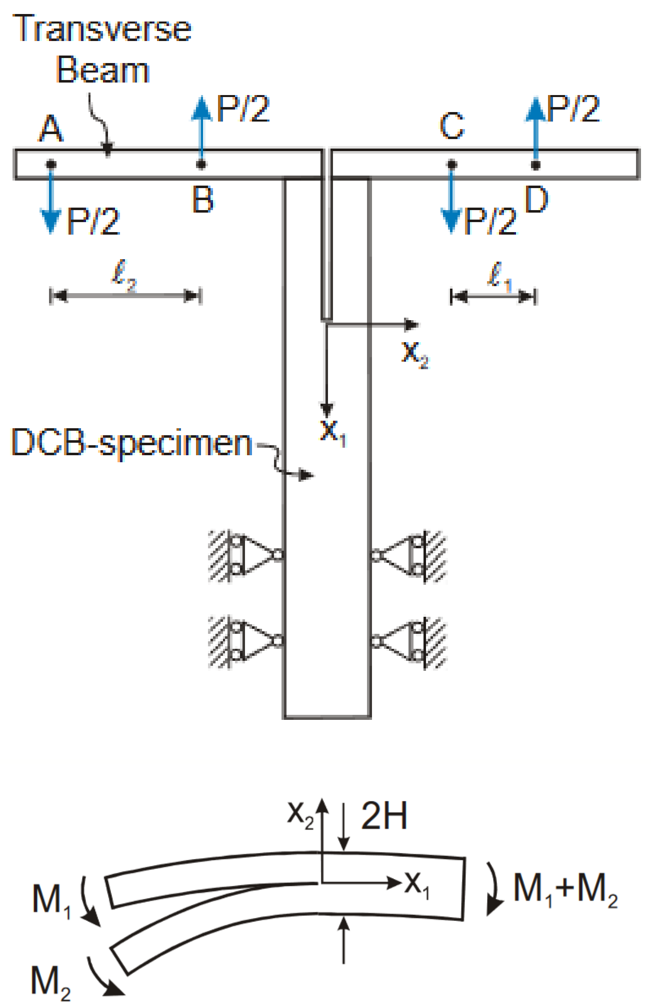
Global and Sub-Models





Fracture Mechanics Rig

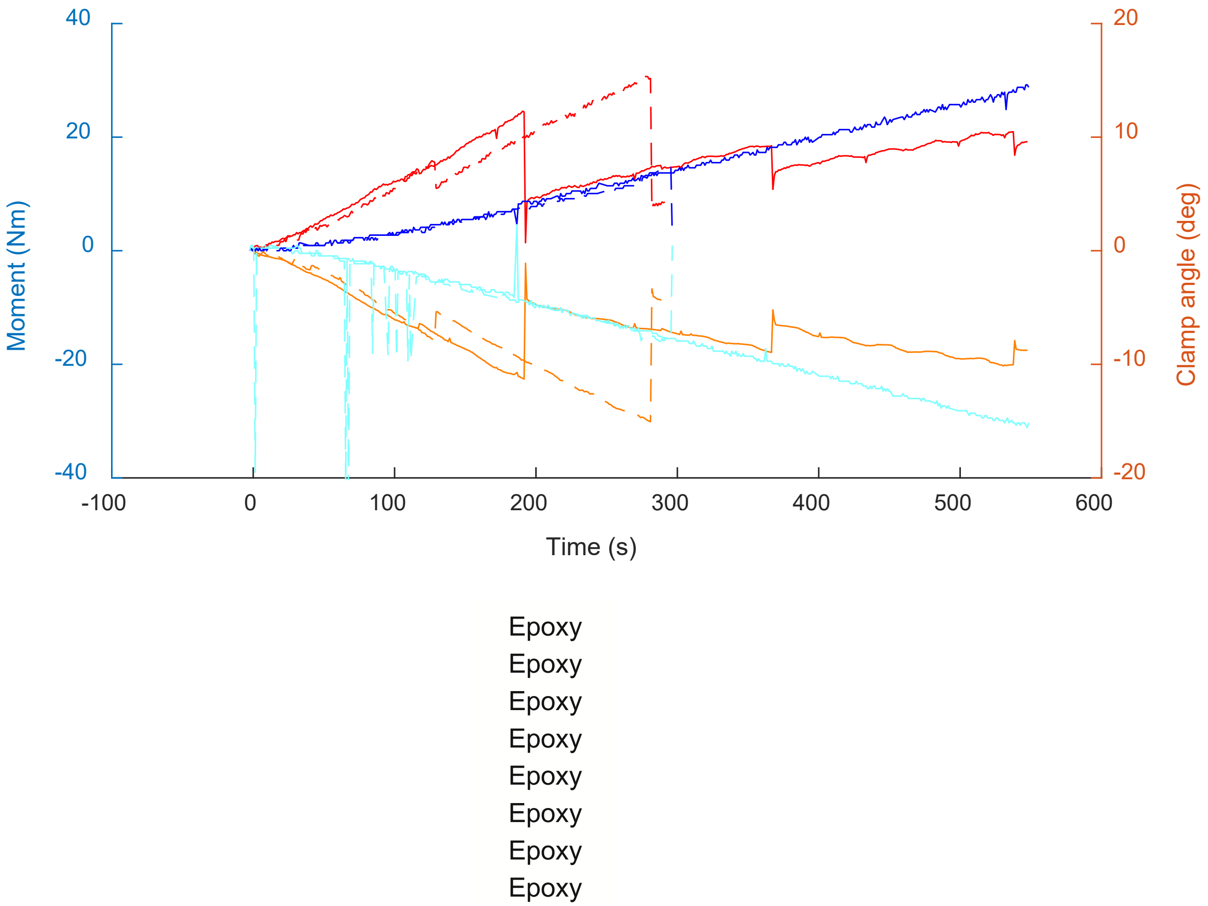
- The test rig was designed and built by PES with rig control using a Raspberry Pi developed by ORE Catapult
- The rig is based on a design by Sorenson et al [3] and applies pure bending moments to the ends of the specimen
    - Enables steady crack growth in mode 1 and mode 2
    - Calculated values are not dependent on the crack length
- The crack length and angle of the arms were determined using a custom image processing algorithm developed in OpenCV

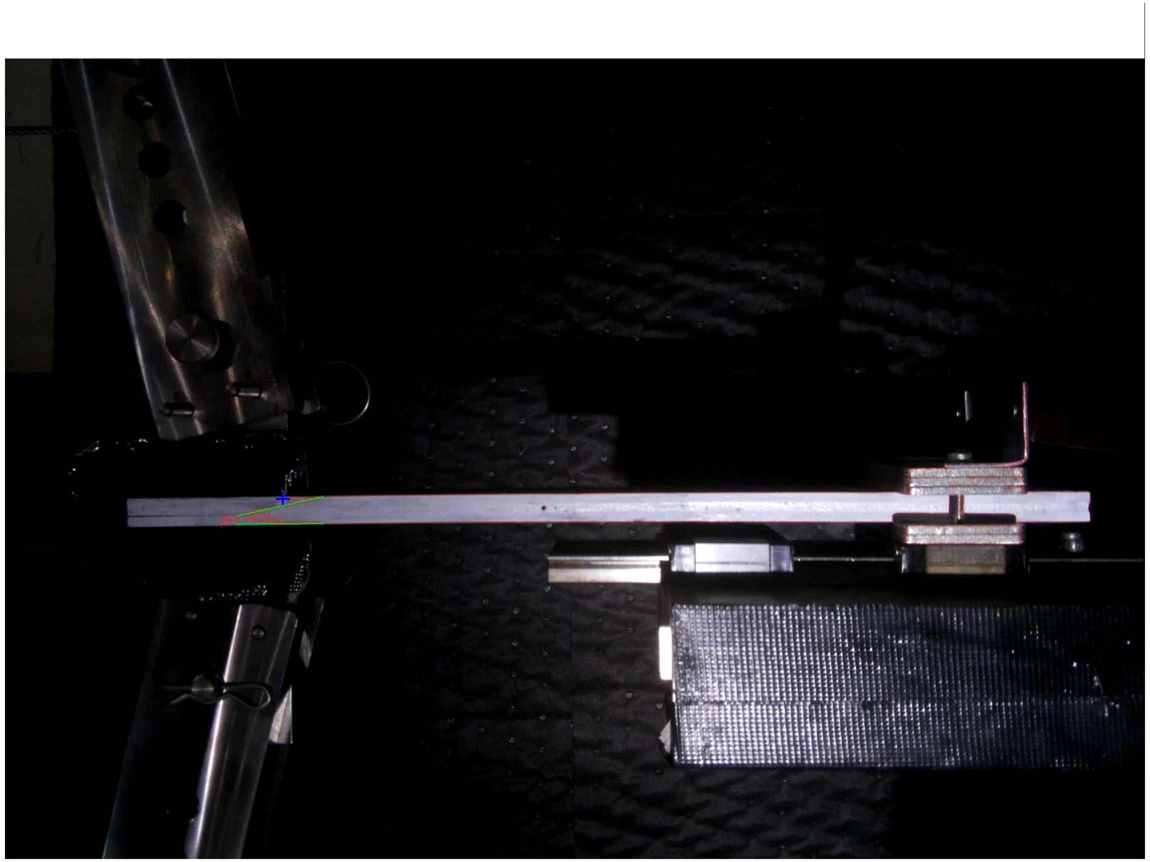


$$J_{ext} = (1-\upsilon^2)\frac{21(M_1^2 - M_2^2) - 6M_1M_2}{4B^2H^3E}$$

[3] Sorenson B (2004) *A General Mixed Mode Fracture Mechanics Test Specimen*, DTU Report

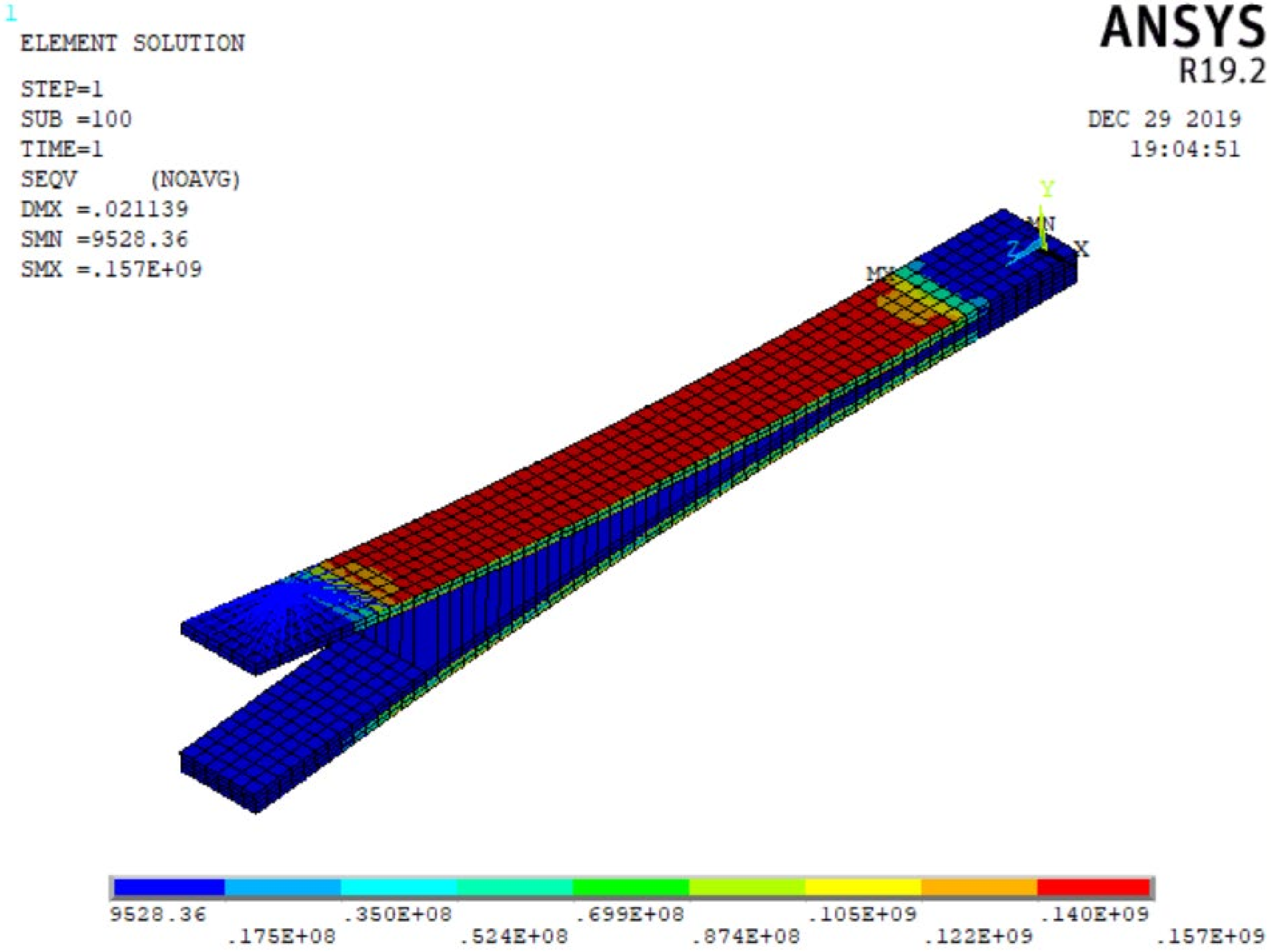
Fracture Mechanics Testing





Finite Element Modelling Approach

- The experimental tests have been modelled in ANSYS:
  - SOLID185 elements for adhesive and substrate
  - INTER205 elements with bi-linear cohesive zone model
  - BEAM188 Beam elements connect remote point at which beam angular displacements are applied to the substrate nodes
- The STP Adhesive proved very difficult to model in mode 2 because of its very low modulus



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1
ELEMENT SOLUTION

STEP=1
SUB =100
TIME=1
SEQV      (NOAVG)
DMX =.021139
SMN =9528.36
SMX =.157E+09
```

```
ANSYS
R19.2

DEC 29 2019
19:04:51
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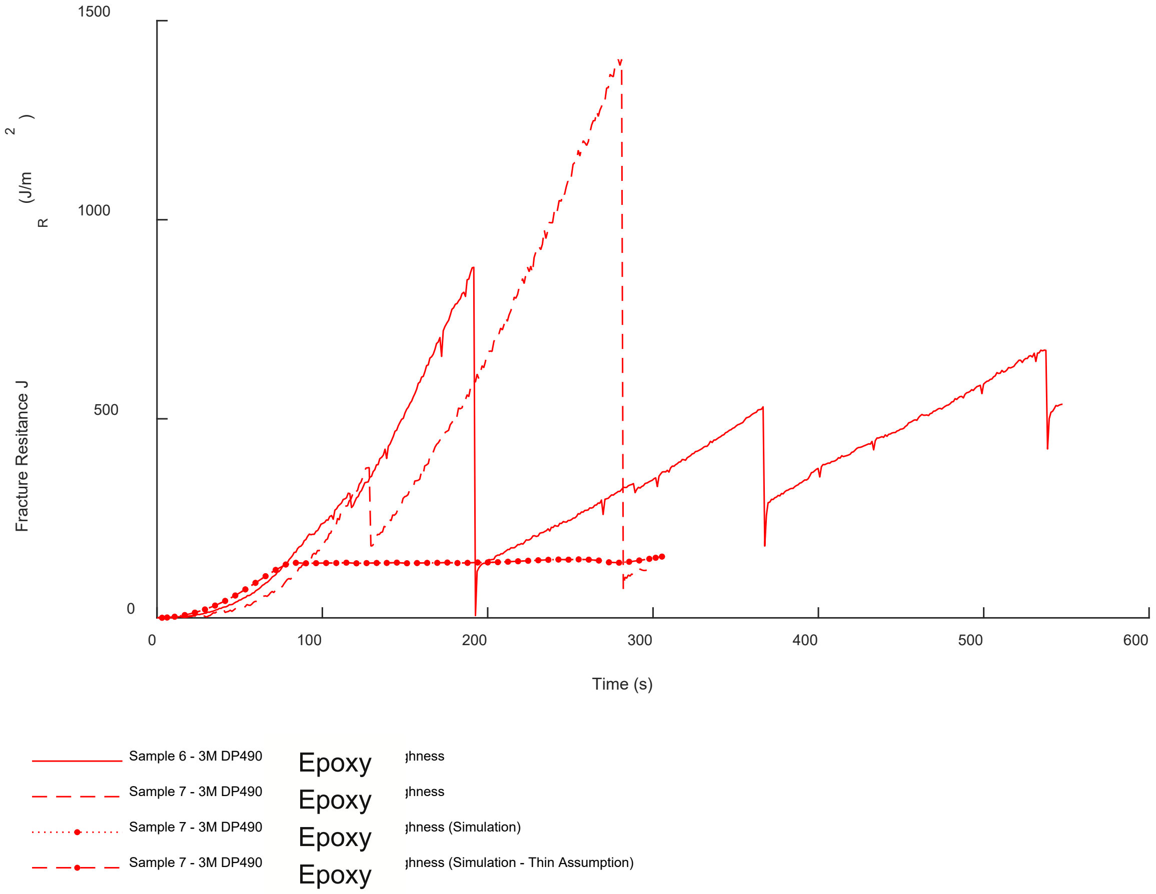
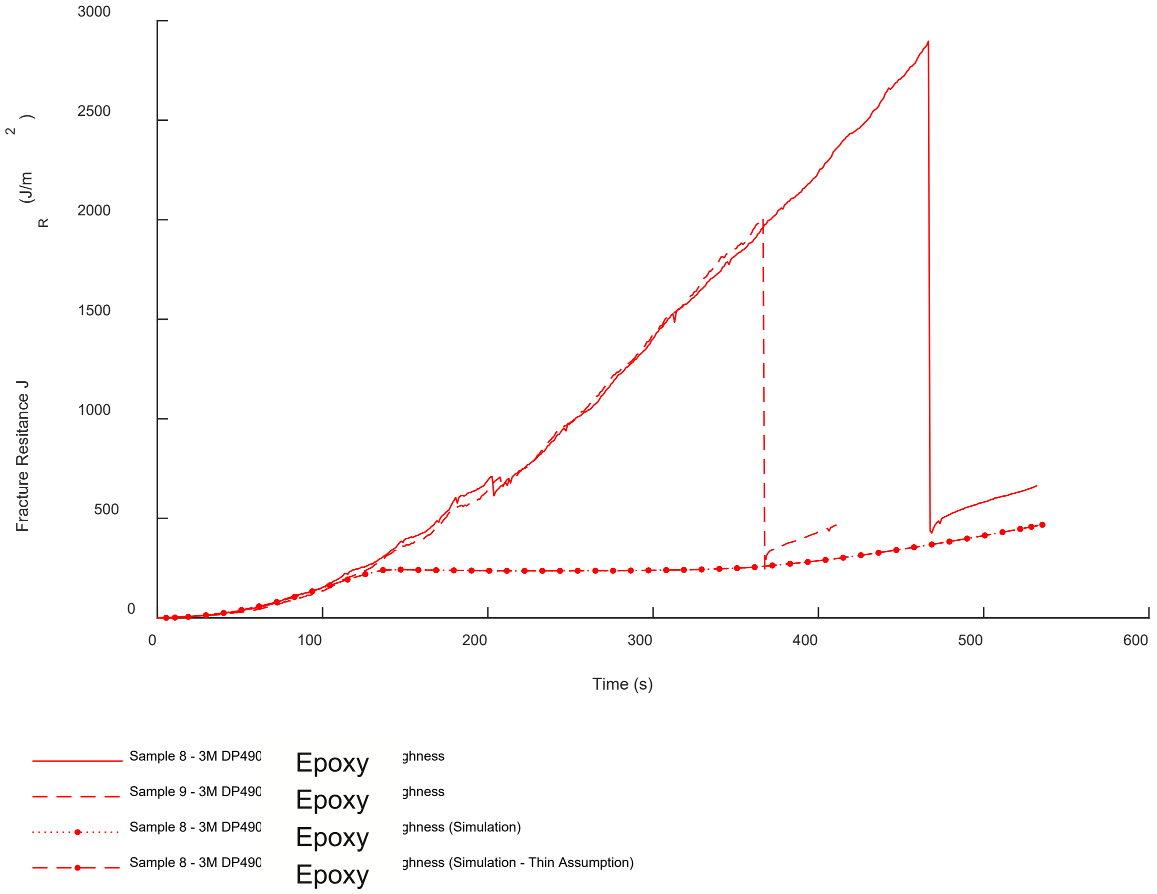
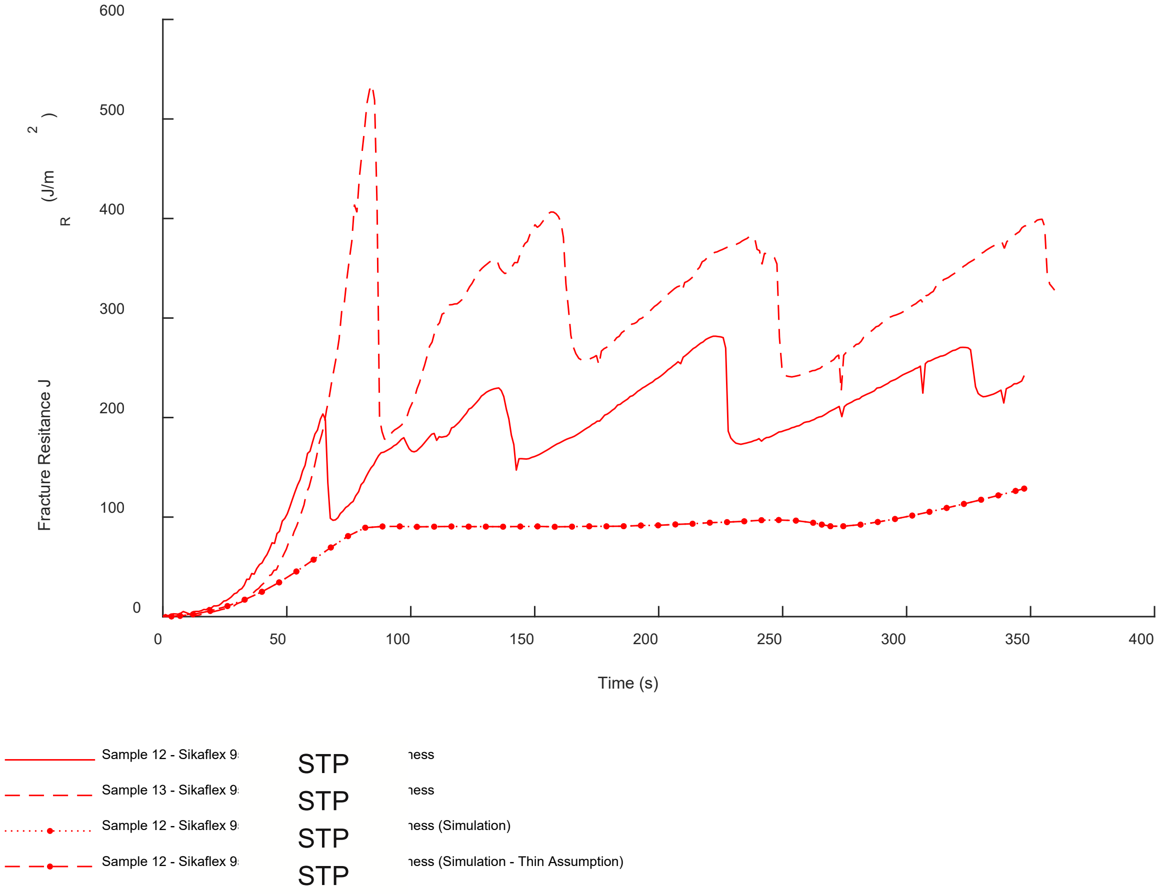
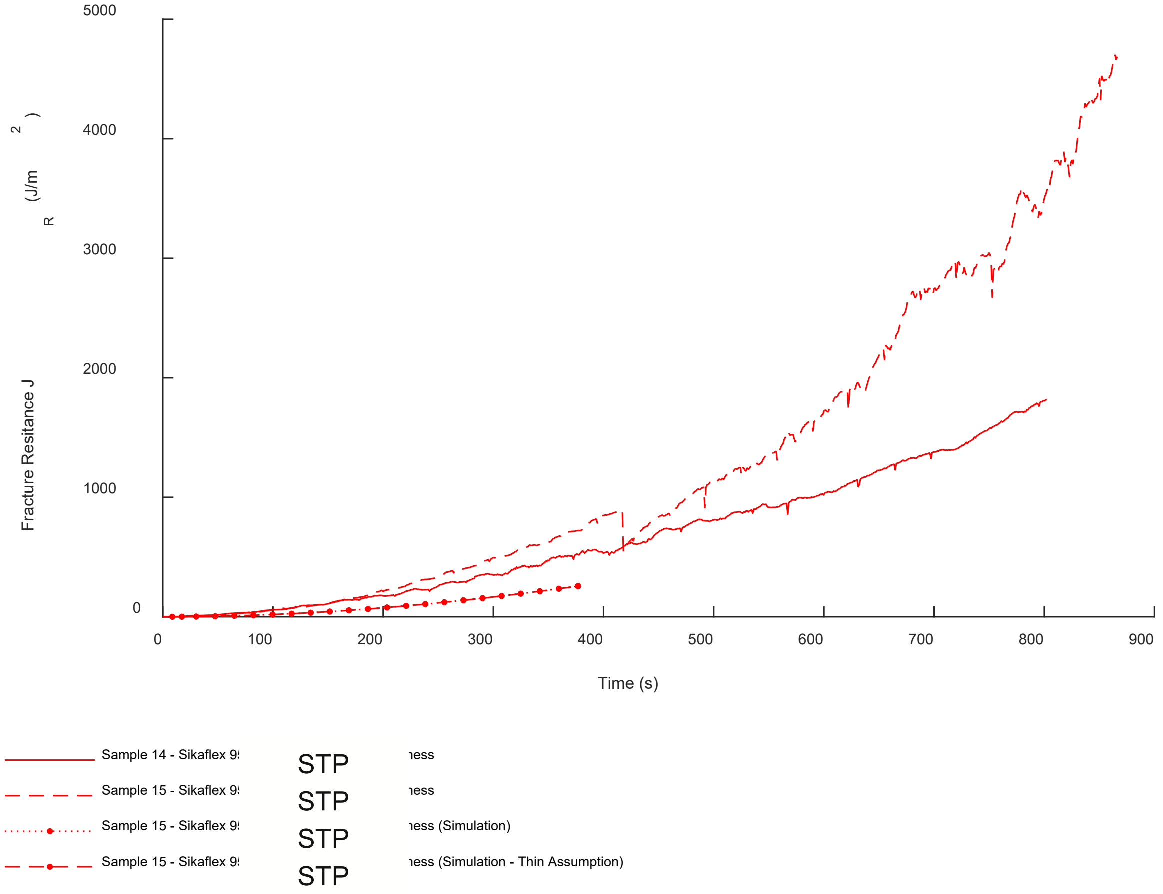
Epoxy Adhesive Results



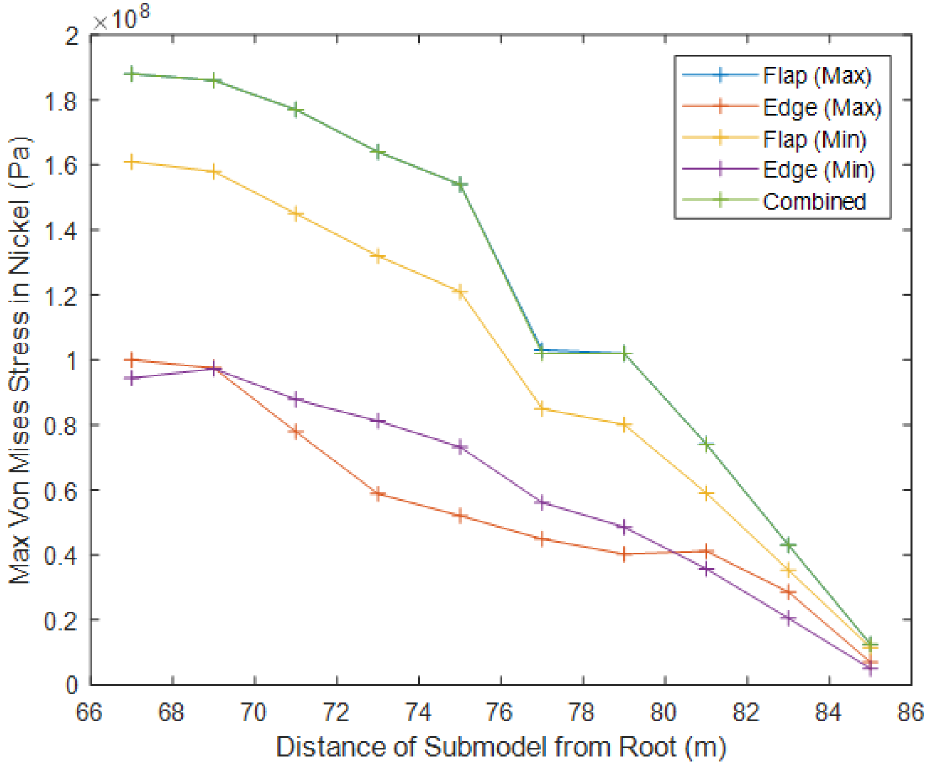


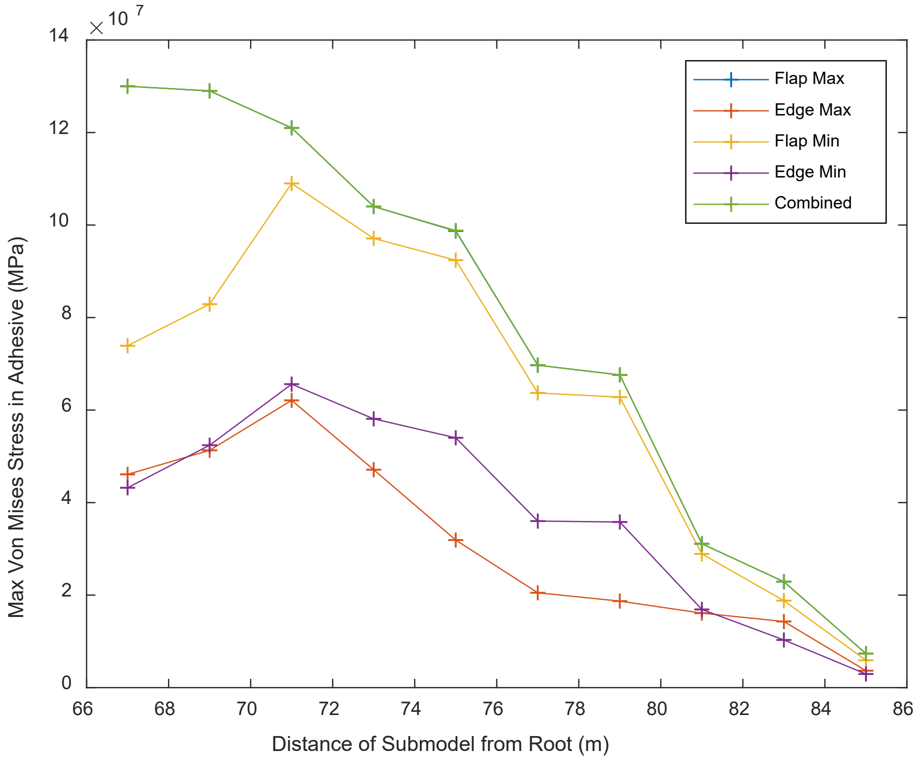
Silane Terminated Polymer Adhesive Results





Critical Load Case/ Position for Sub-Model





Sub-Model Results: Epoxy Adhesive

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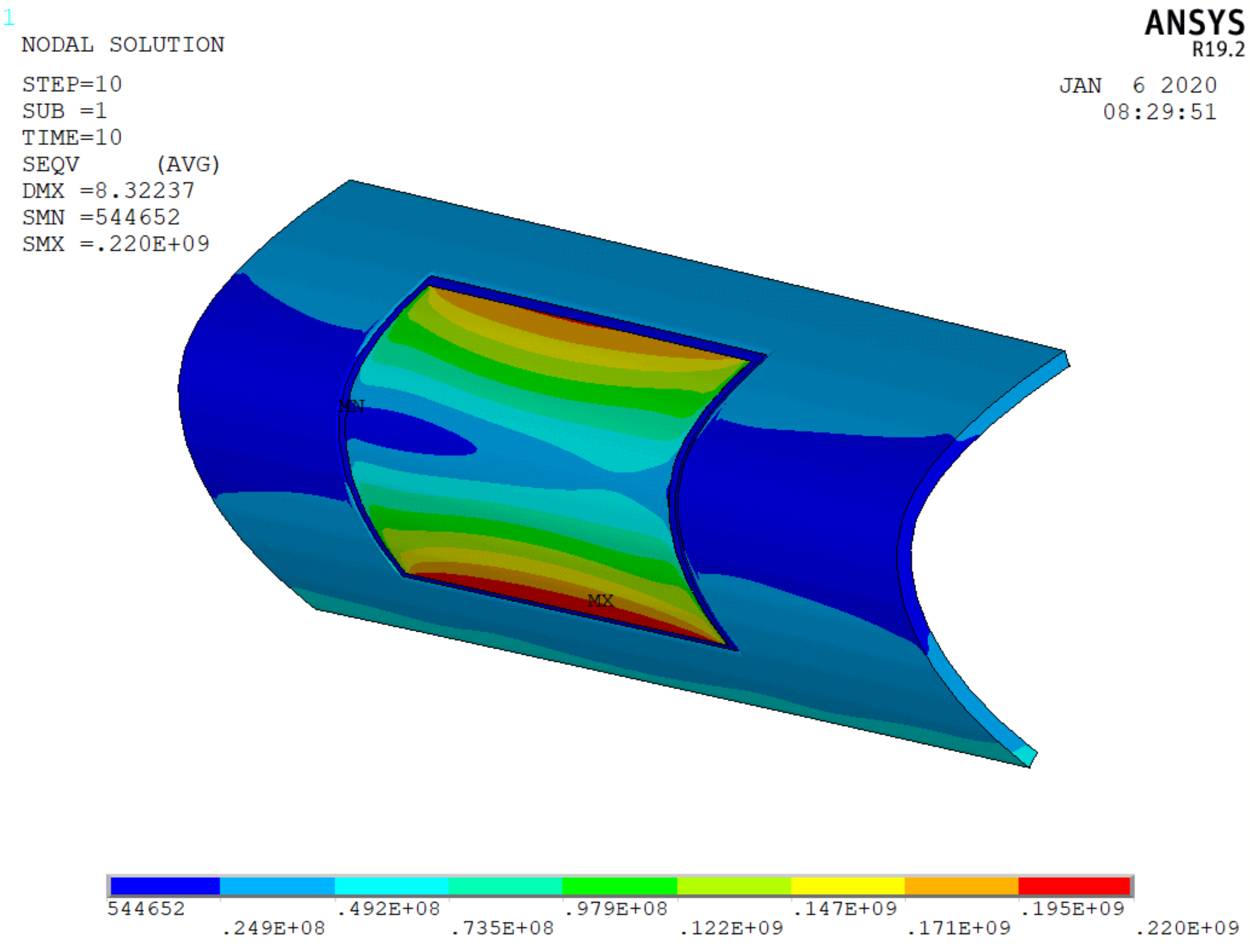
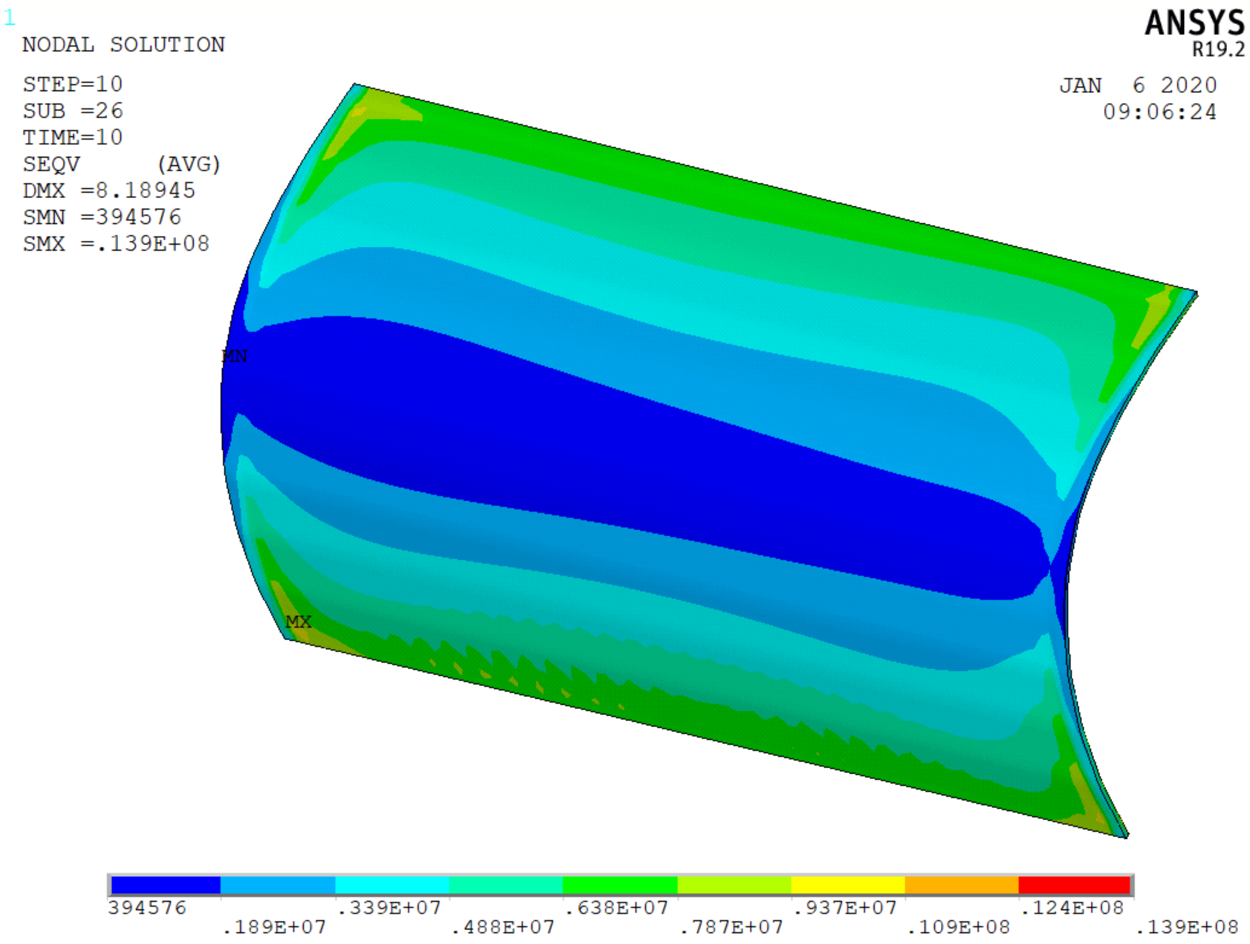
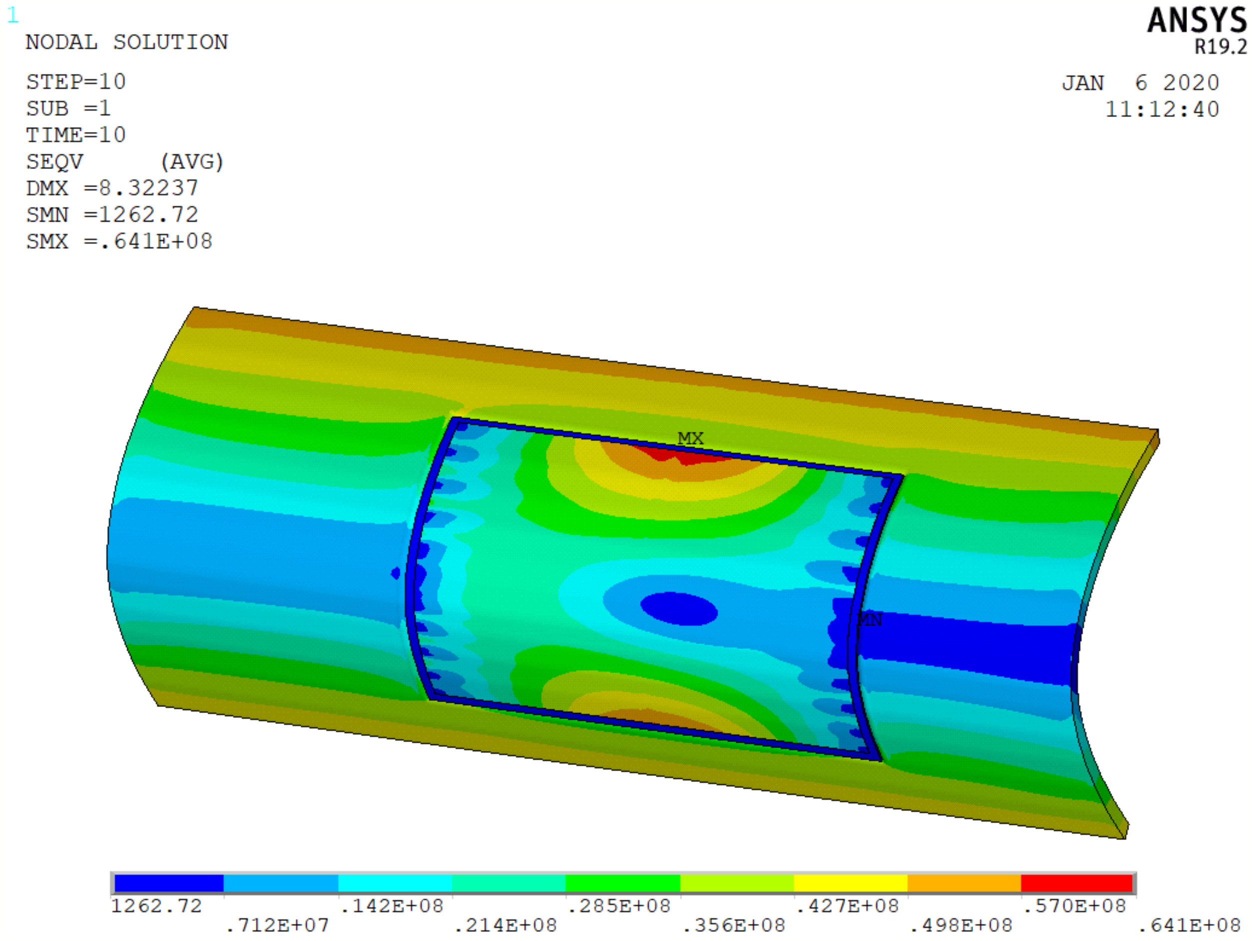




Sub-Model Results: STP Adhesive



```
1
NODAL SOLUTION

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DMX =8.32237
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SMX =.641E+08
```

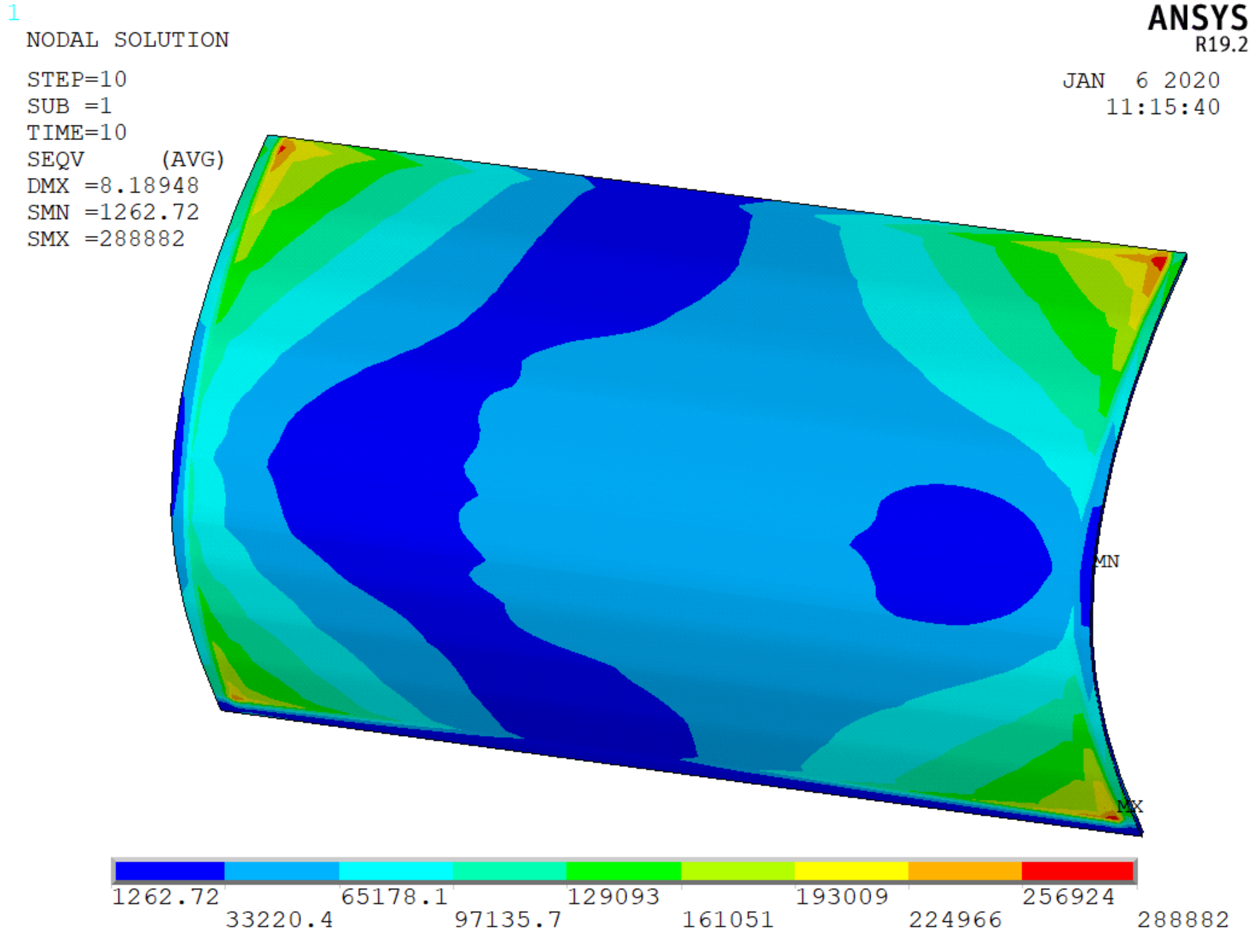

```
1
NODAL SOLUTION

STEP=10
SUB =1
TIME=10
SEQV       (AVG)
DMX =8.18948
SMN =1262.72
SMX =288882
```

Conclusions

- A blade meshing tool has been developed which can generate a global solid mesh of the blade and a detailed solid mesh of the tile system
- A model chain has been developed which can accurately predict the adhesive stresses in the Ni-Co tile system
- It can also be used with more detailed models developed from CAD as long as they occupy the same position in space as the global blade mesh
- The next steps are:
    - Produce a demonstrator of the leading edge system
    - Investigate how the interface between tiles affects the stress
    - Look at certification
    - Integrate the tile into the blade lightning system

Contact us

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