

Effects of Ferromagnetic & Carbon-fibre Z-pins on the magnetic properties of composites

Mudan Chen

CDT 18

Supervisors:

Prof. Stephen R. Hallett

Dr. Bing Zhang

Dr. Giuliano Allegri

Dr. Sven Friedemann

4/13/2021

bristol.ac.uk/composites



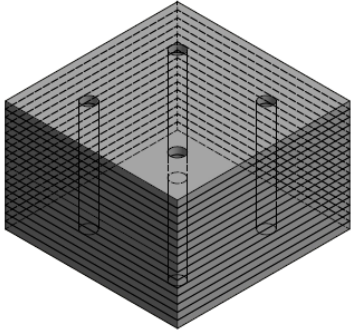
1. Introduction

2. Measurement method

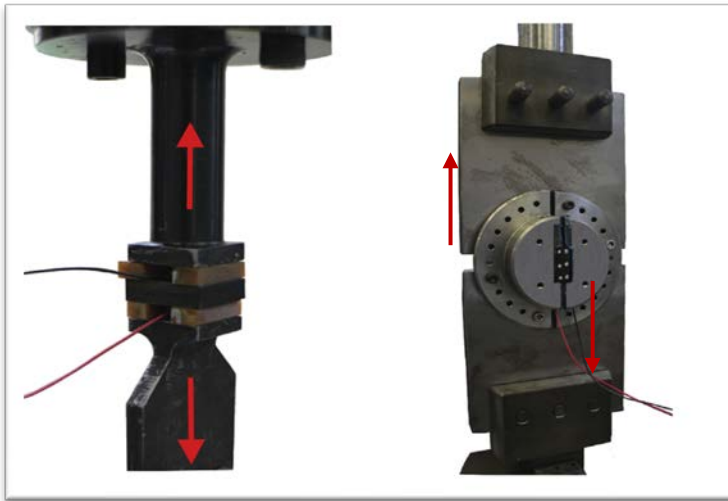
3. Experimental results

4. Discussion

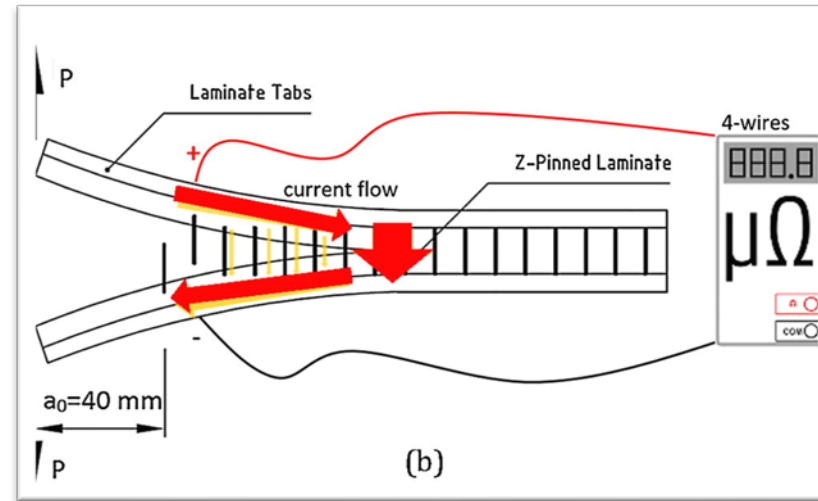
1. Introduction



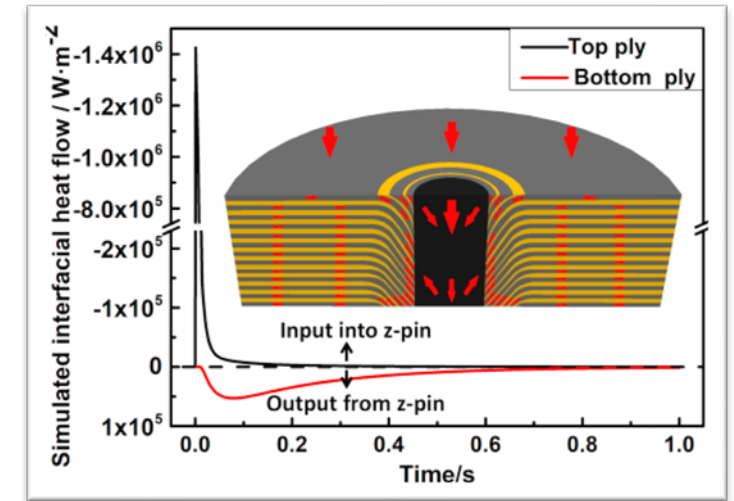
Multifunctional applications of Z-pinning



Mode I/II delamination bridging monitoring [1]



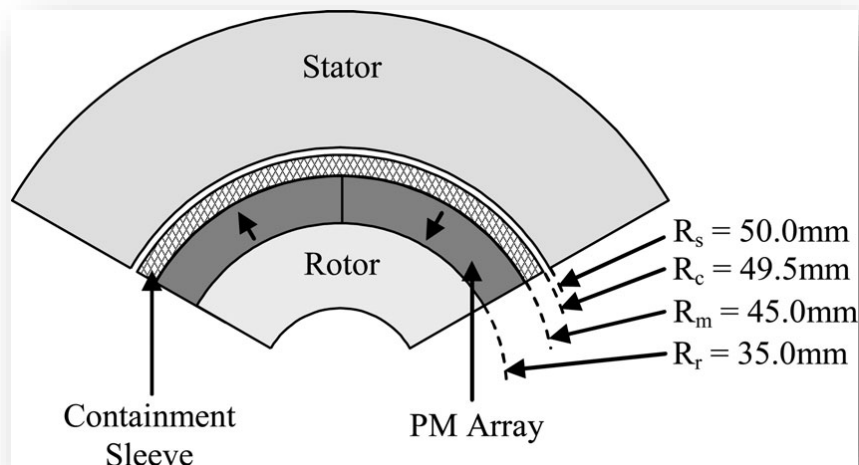
Mode I delamination crack sensing [2]



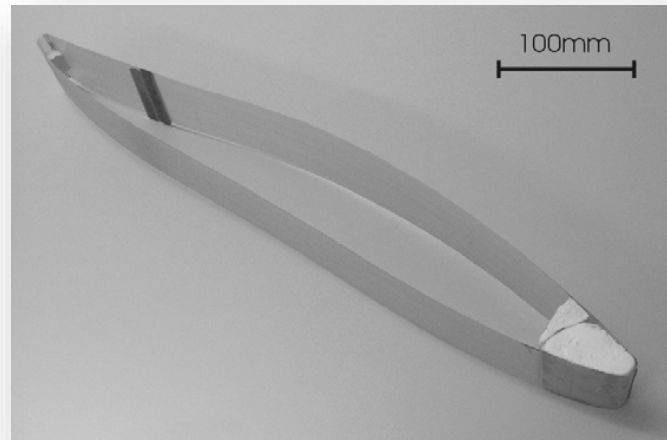
Heat flow transfer with Z-pin [3]

1. Introduction

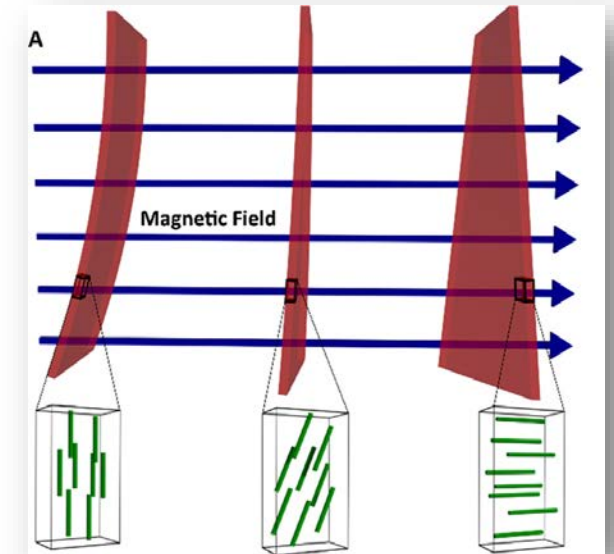
- Fibre reinforced polymer composites are magnetic inert.
- Incorporating magnetic fillers has been used to produce magnetic composites.
- Applications include actuation, electromagnetic interference suppression and sensing [1].



The containment sleeve of surface mounted permanent magnet machine [2]



Magnetic actuation of the trailing edge [3]



Static magnetic field actuation of PDMS films filled with short nickel-coated carbon fibers [1]

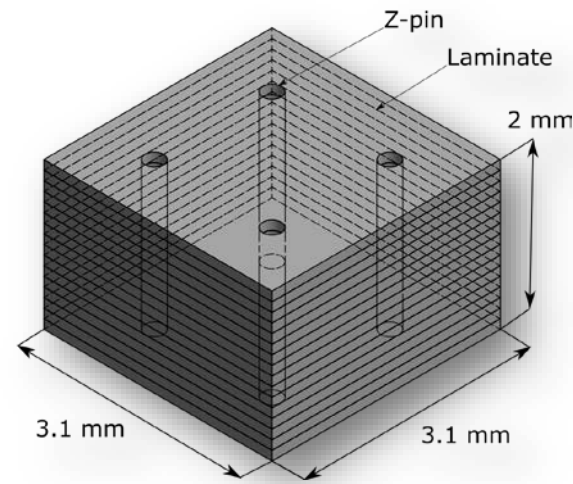
[1] Charles et al., Progress in Material Science, 2021

[2] Yon et al., IEEE TRANSACTIONS ON ENERGY CONVERSION, 2012

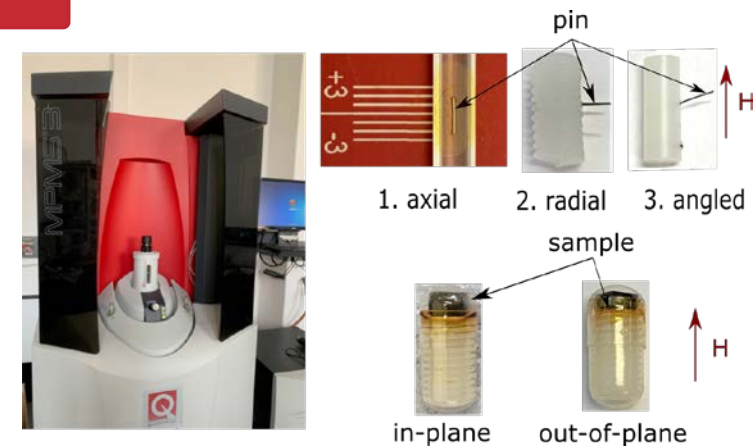
[3] Etches et al., Smart materials and structures, 2006

2. Measurement method

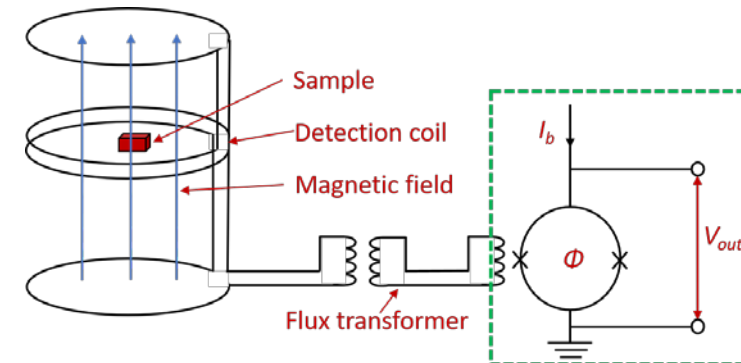
- IM7/8552 prepreg
- QI: $[0^\circ/+45^\circ/90^\circ/-45^\circ]_{2s}$
- Two pin materials: T300/BMI composite & ferromagnetic Ni/Fe permalloy
- Three different volume fractions: nominal 0.5%, 2% and 4%



2% Z-pinned sample configuration



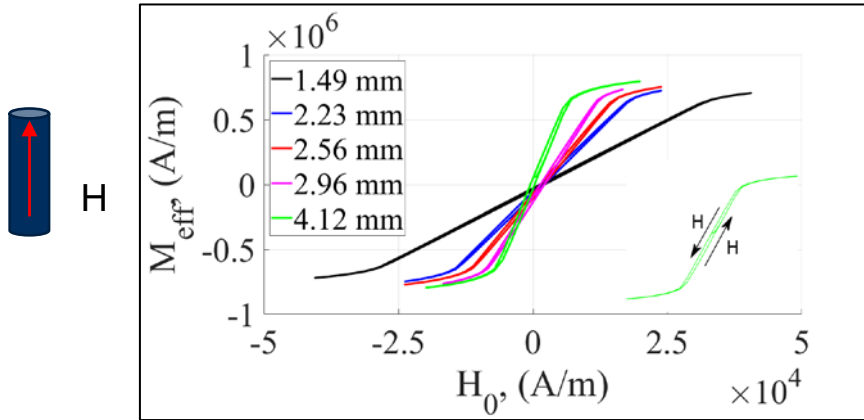
SQUID MPMS3 and sample installation



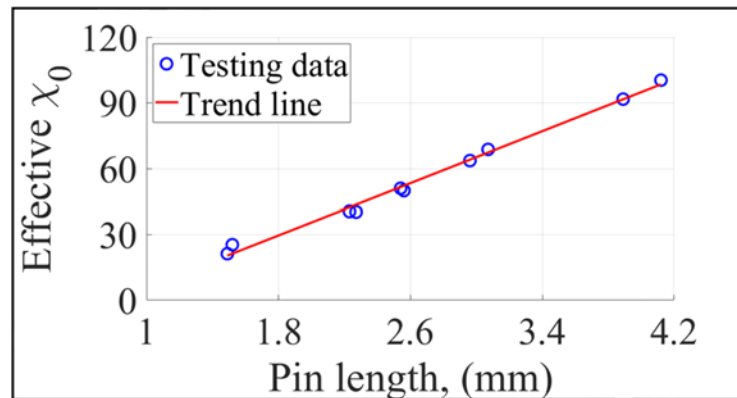
Schematic of the SQUID detecting system diagram

3. Experimental results – single pin (Ni/Fe)

Axial direction

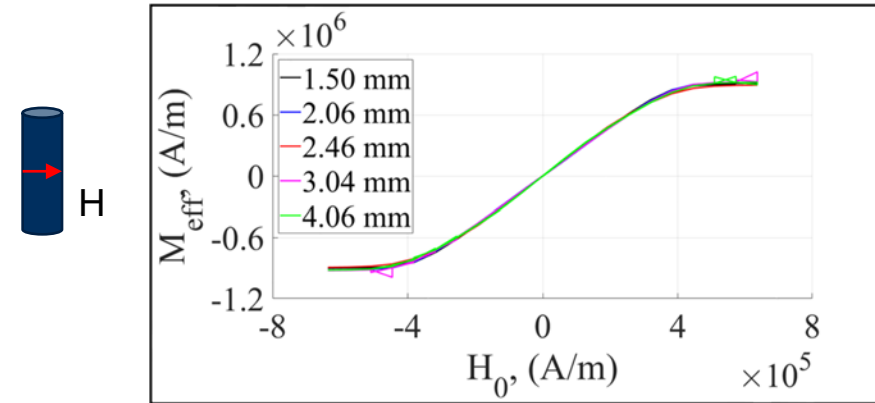


Ni/Fe wire M-H curves

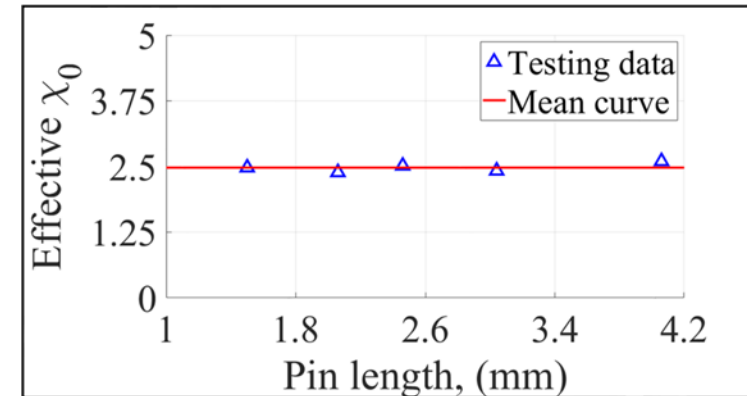


Linear-part effective susceptibility against pin length

Radial direction



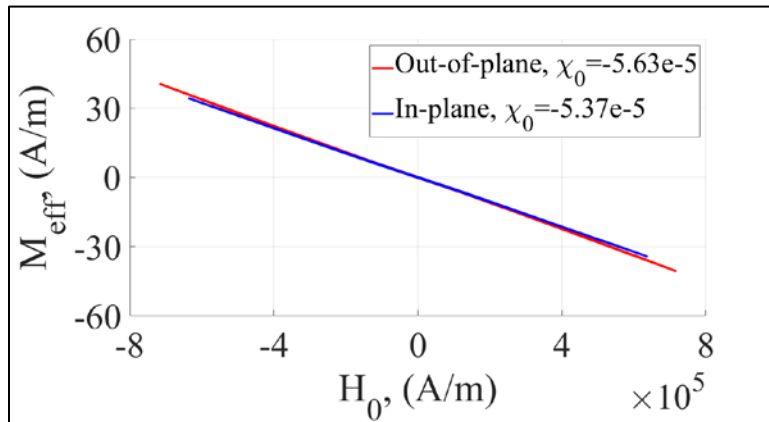
Ni/Fe wire M-H curves



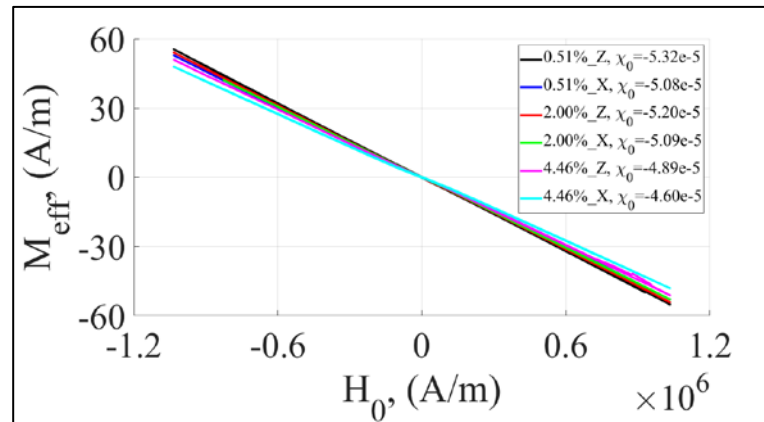
Linear-part effective susceptibility against pin length

3. Experimental results – laminate

Unpinned sample

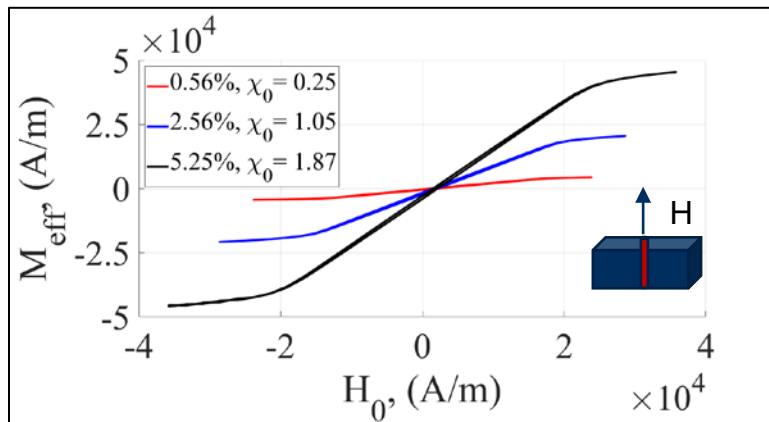


Carbon Z-pinned sample

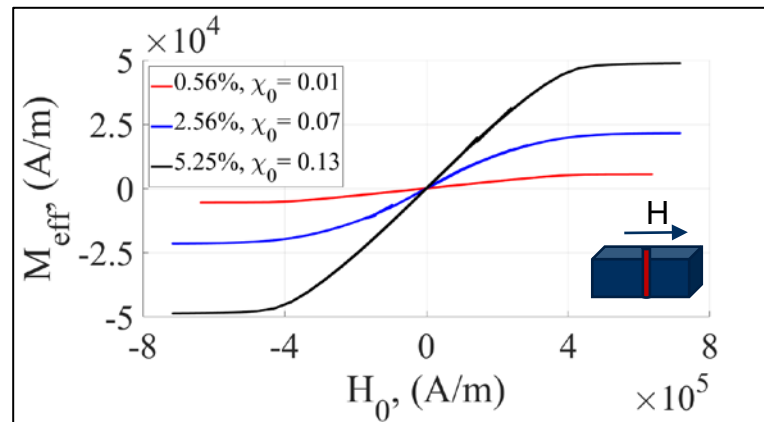


- Both unpinned and carbon pinned samples are weakly diamagnetic;
- The carbon-fibre pins have no large influence on the global magnetic susceptibility of the laminate.

Ni/Fe Z-pinned sample



Out-of-plane



In-plane

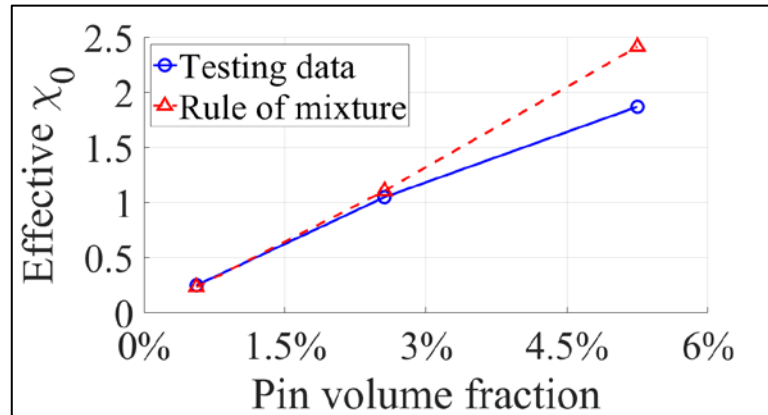
- The laminate with Ni/Fe Z-pins become strongly paramagnetic.
- The linear-part susceptibilities has been increased up to 1.87 and 0.13 for the out-of-plane and in-plane directions, respectively.

3. Experimental results – laminate

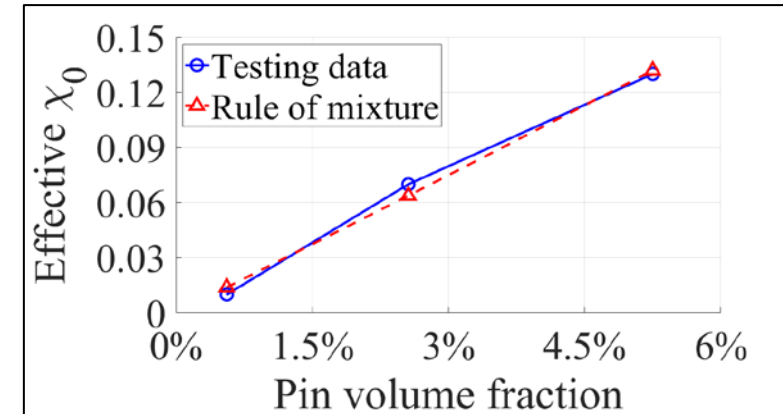
Rule of mixture

$$\chi_{v_sample} = (1 - V_{f_pin}) * \chi_{v_lam} + V_{f_pin} * \chi_{v_pin}$$

Out-of-plane

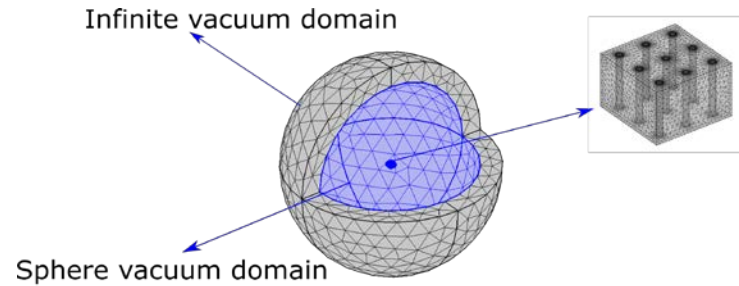


In-plane



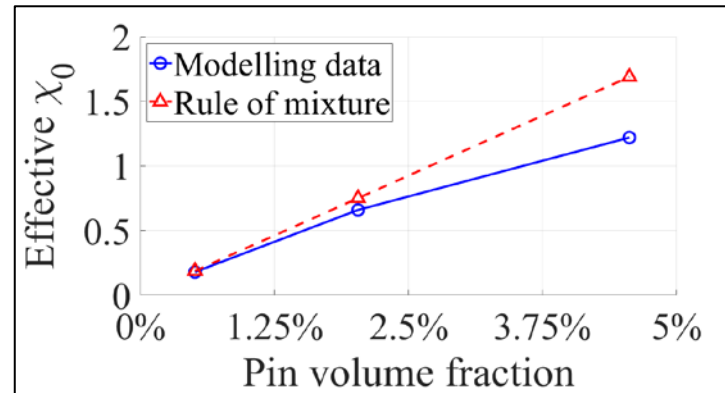
Linear-part effective magnetic susceptibility against the Ni/Fe pin volume fraction

- In the previous research on electrical properties of Z-pinned composites [1, 2], a linear relationship was found between the pin volume fraction and the through-thickness conductivity of Z-pinned composites. Contrary to that, **a non-linear trend** was seen here for the out-of-plane direction.
- The in-plane orientation follows a linear growth and fits well with the rule of mixture.

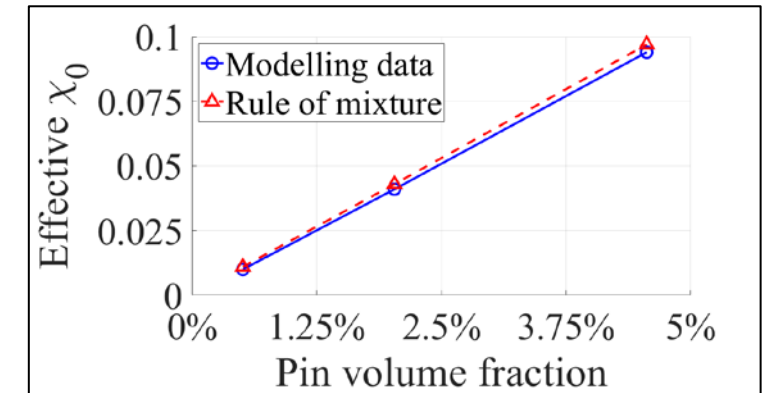


FEA model configuration and meshes

Out-of-plane

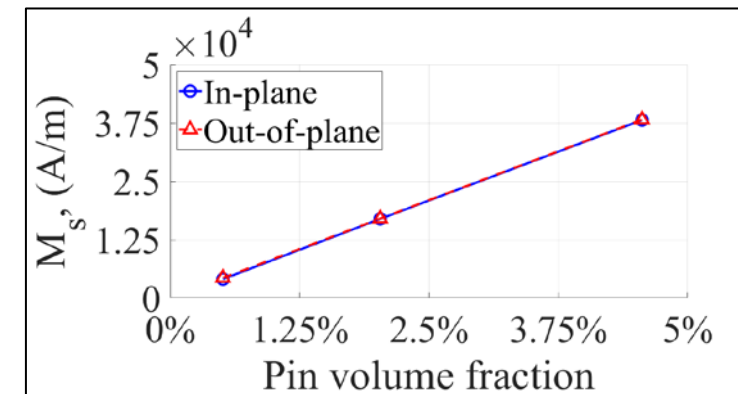


In-plane



Linear-part effective magnetic susceptibility against pin volume fraction

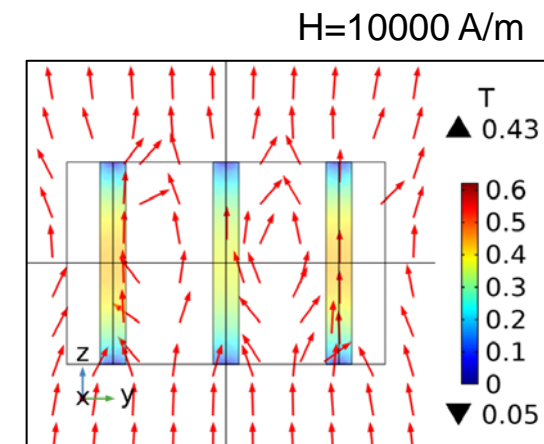
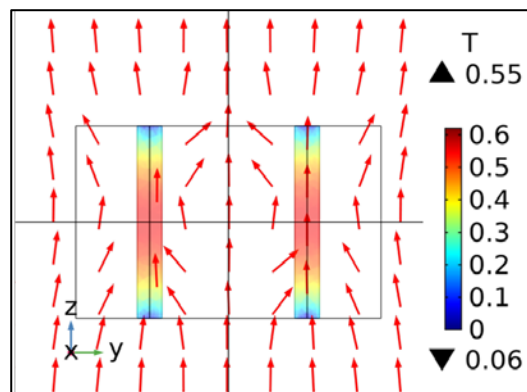
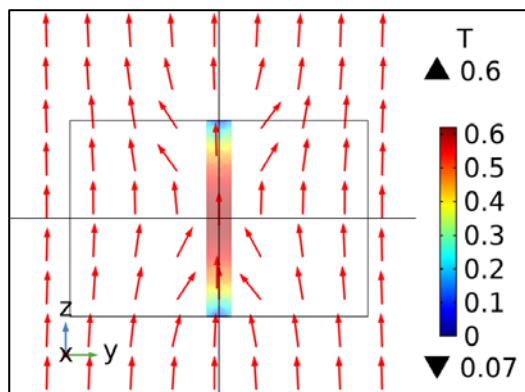
- Three ideal samples were modelled, without pin misalignment and protruding;
- Same trend were found with the experiments, with the non-linear relationship for the out-of-plane direction, while linear for the in-plane;
- The saturation magnetisation is proportional to volume fraction, and consistent with the experiments.



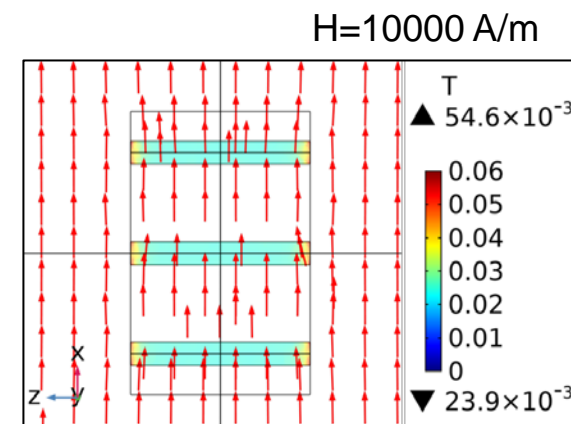
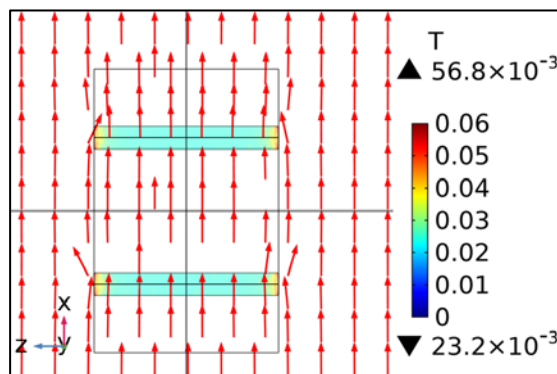
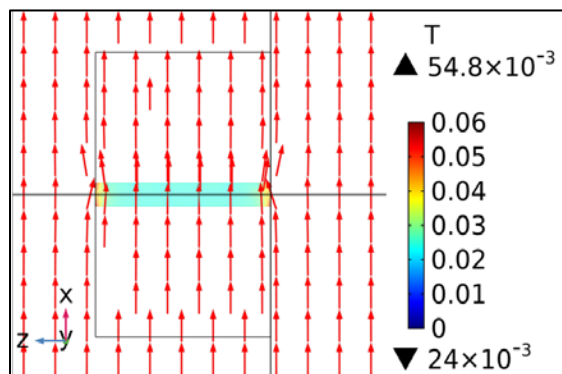
Saturation magnetisation against pin volume fraction

4. Discussion

Pin interaction on the flux was observed for the out-of-plane direction.



No interaction was shown for the in-plane orientation.



Conclusions

1. Carbon-fibre Z-pins do not have large influence on the global magnetic properties of composites.
2. Soft ferromagnetic Ni/Fe Z-pins lead to a much larger magnetic susceptibility in the axial direction than in the radial one.
3. Ni/Fe pins enhance the laminate out-of-plane and in-plane low-field linear-region effective susceptibilities up to 1.87 and 0.13 at 5.25% volume fraction, respectively.
4. The low-field linear-region effective susceptibility of Ni/Fe pinned laminate increases with pin volume fraction nonlinearly due to pin interactions for the out-of-plane direction, but linearly for the in-plane orientation.
5. The global saturation magnetisation is only dependent on pin volume fraction and independent from field direction.

Thank you!

CDT 18

Publication:

[1] Mudan Chen, Bing Zhang, Sven Friedemann, Giuliano Allegri, and Stephen R. Hallett. "Effects of Ferromagnetic & Carbon-Fibre Z-Pins on the Magnetic Properties of Composites." *Composites Science and Technology* (2021): 108749.

mudan.chen@bristol.ac.uk
bristol.ac.uk/composites