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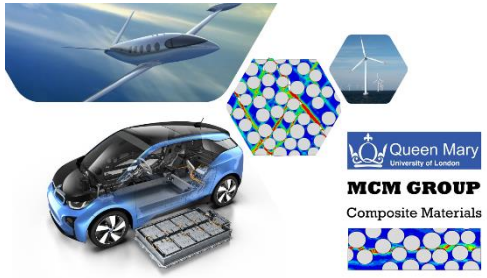

Mechanical Properties of Carbon Nanotube Composite Film Under High-Velocity Impact

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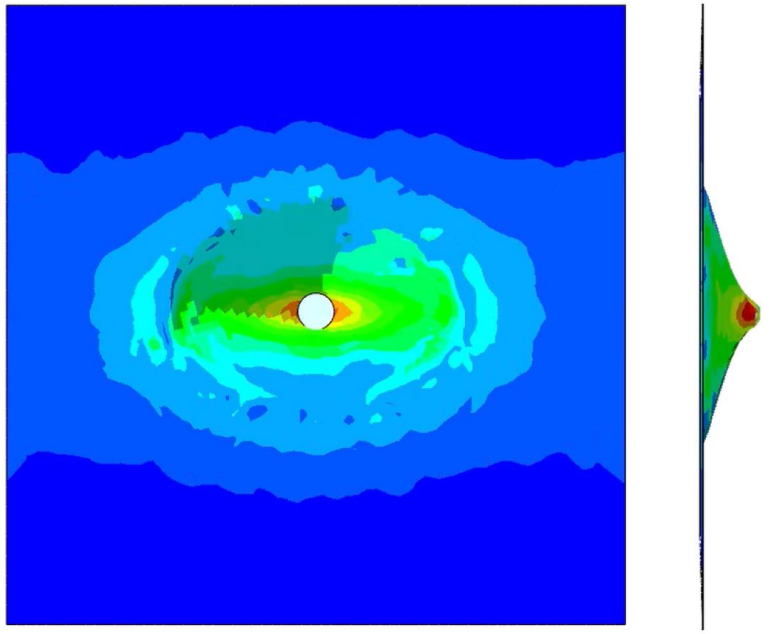


ICCM23, Belfast, 30th July-4th August 2023

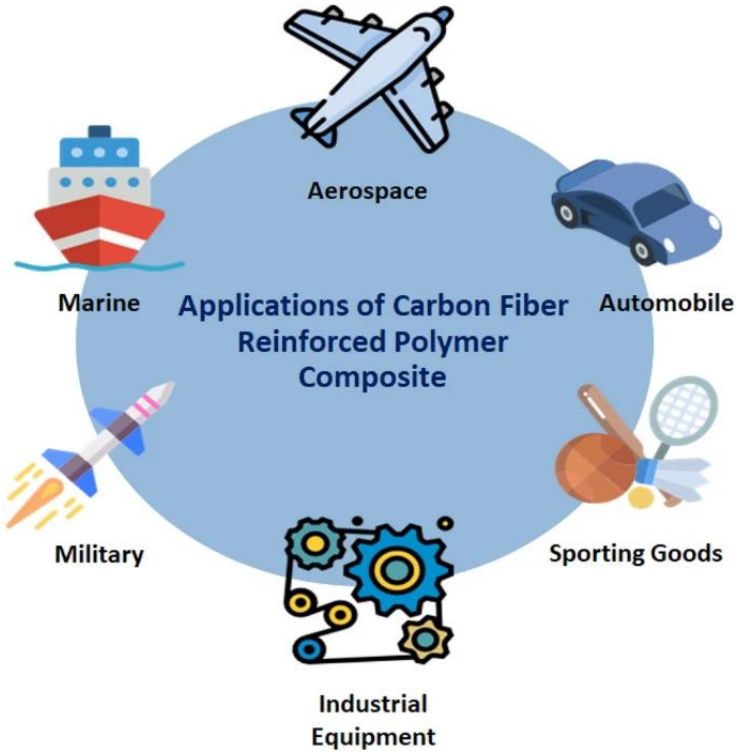
Presentation Outline

Motivation

Research Methods

Results & Discussion

Background: Carbon Fibre Composites



Advantages

- Lightweight
- Good Mechanical Properties
- Good Corrosion Resistance

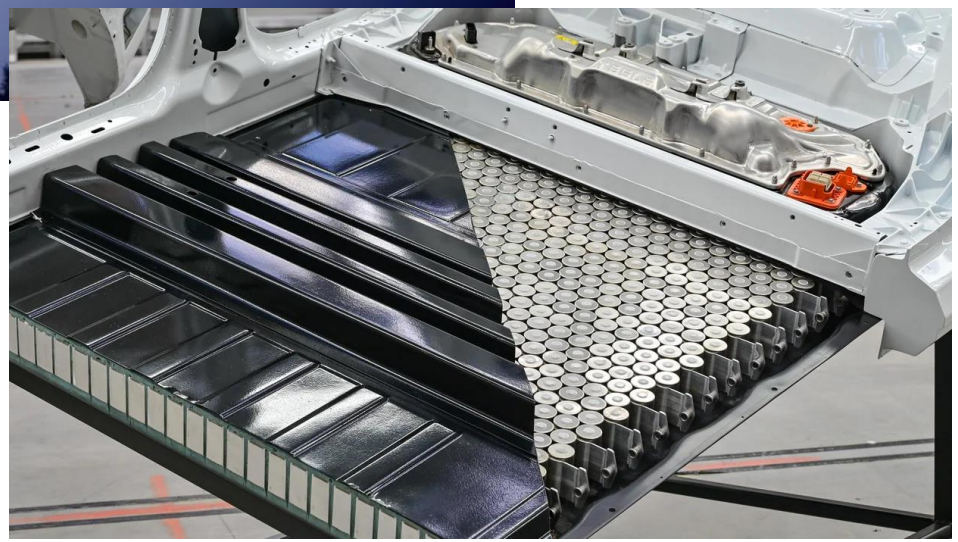
Disadvantages

- Low Electric Conductivity
- Low Thermal Conductivity

But what if we need a multi-functional material…

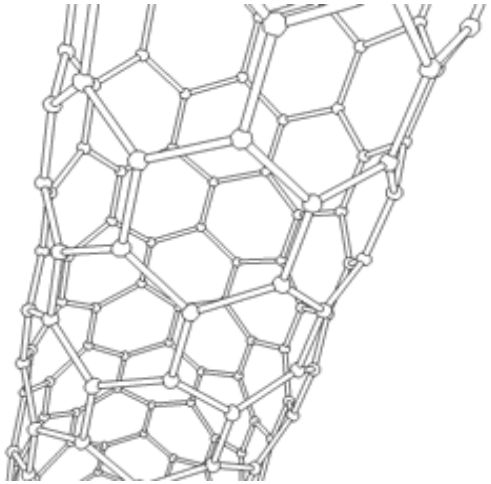
Protect the airplane from lightening?

Be a component of car battery?

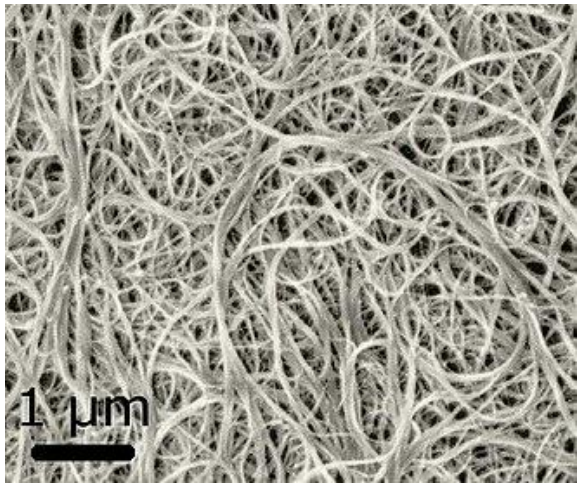


Carbon Nanotubes (CNT)

- High electric/thermal conductivity with low density.



(a)



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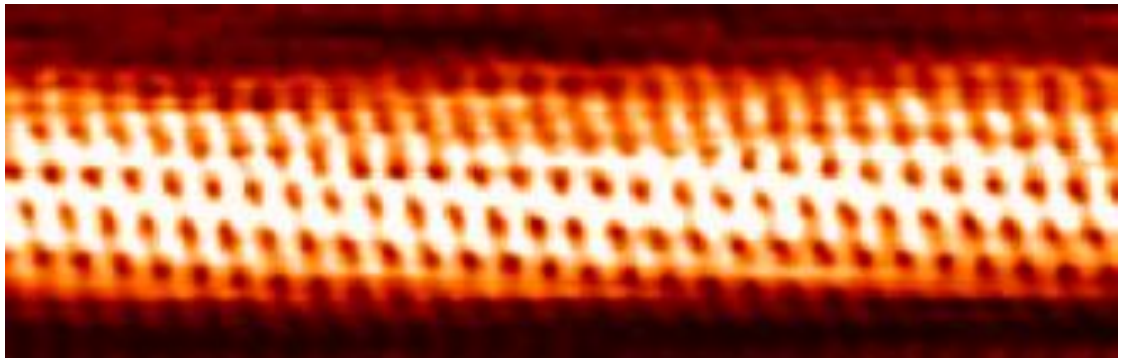

(c)

Figure 1. CNT Micro-structures: (a).Single-walled zigzag carbon nanotube. (b).SEM image of carbon nanotube bundles. (c).AFM image of a single-walled carbon nanotube.

(Carbon Nanotubes – Wikipedia, https://en.wikipedia.org/wiki/Carbon_nanotube)

Table 1. Comparison of CFRP/CNT/Metal in Different Properties.

	CFRP	CNT	Metal
Density	Low	Low	High
Mechanical Properties	High	Relatively High	High
Orientation	Anisotropic/Isotropic	Anisotropic	Isotropic
Electric Conductivity	No	High	High
Heat Conductivity	Low	High	High

Problem: Impact Resistance

- The majority of the advanced application areas involving Carbon Nanotubes (CNTs) are highly susceptible to impacts.
- The research on the impact resistance of CNTs is relatively limited and not well-explored.
- This research mainly focus on the impact resistance properties of CNT film.

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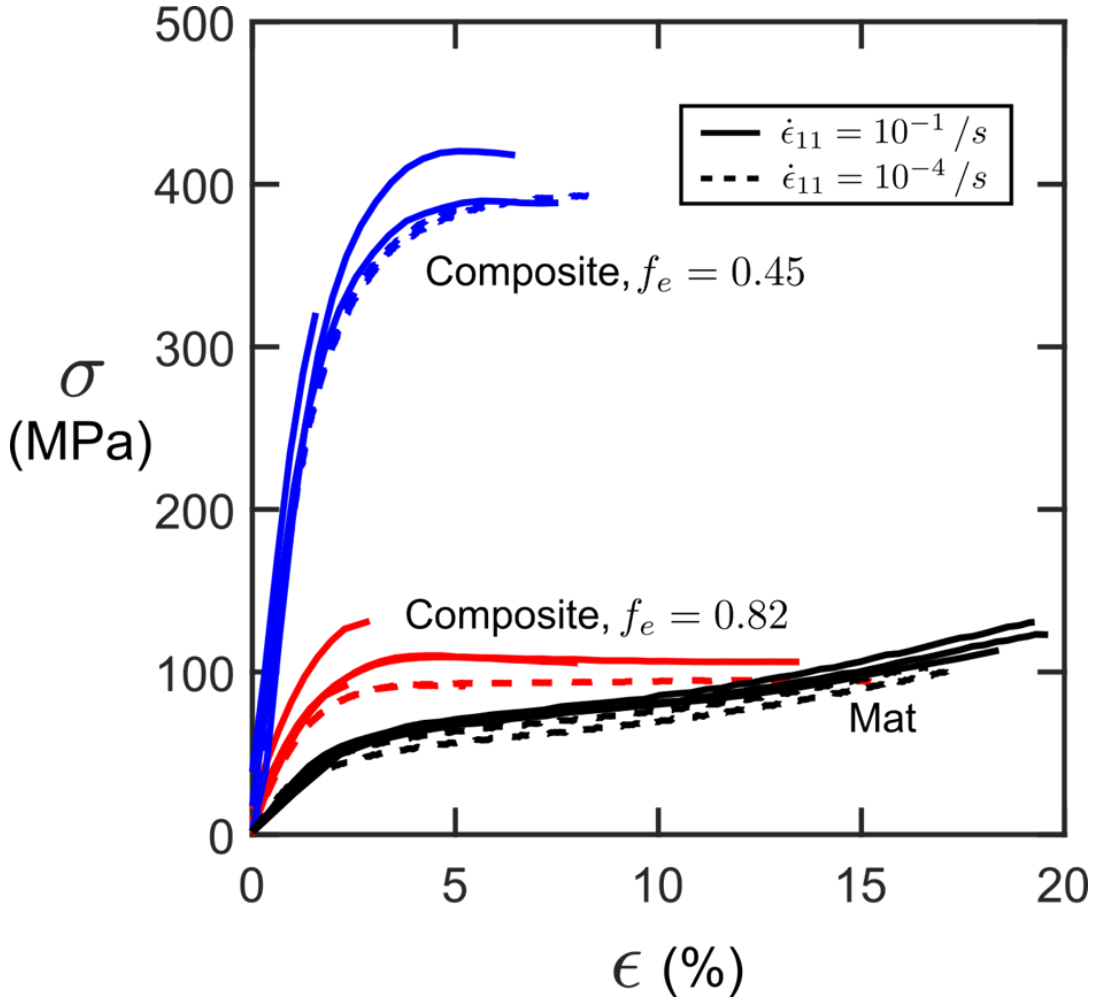
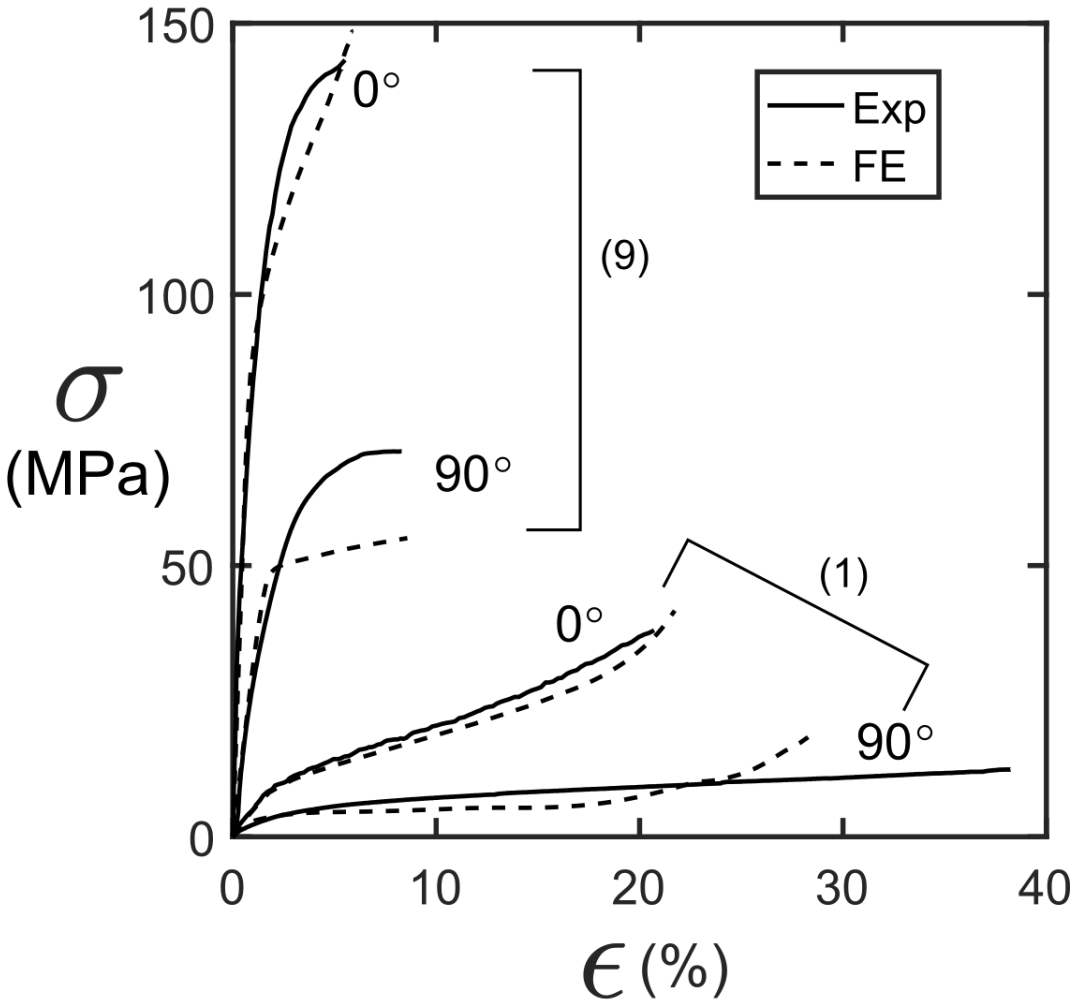
CNT Film Mechanical Properties

Tensile behaviour



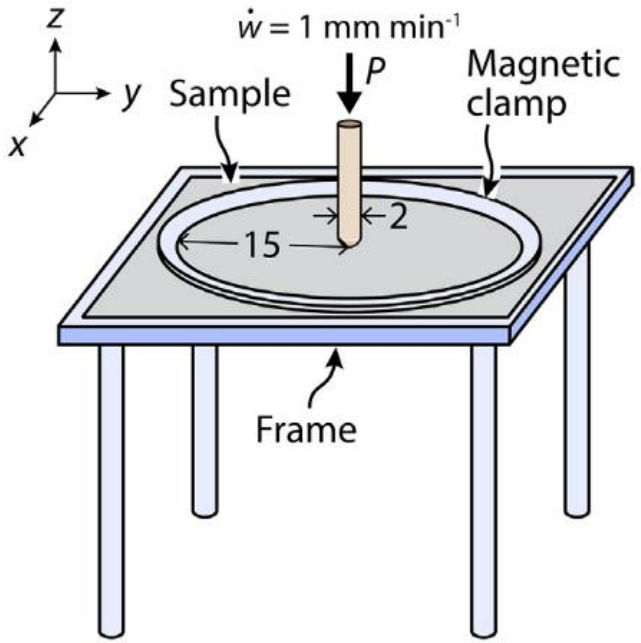
Anisotropic behaviour

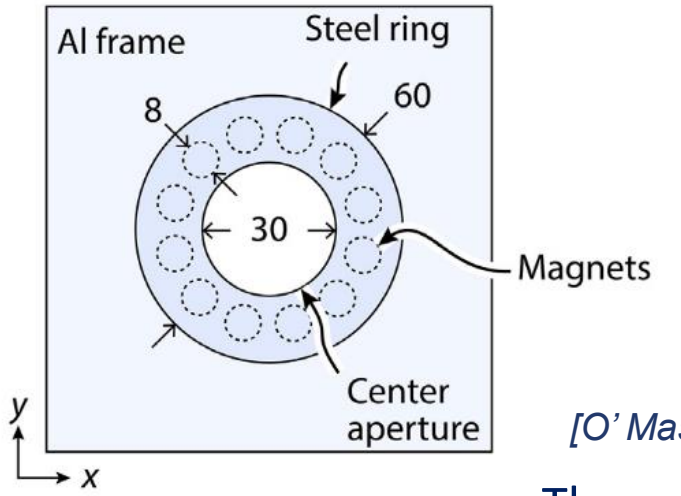


- The mechanical properties of CNT composite vary with different epoxy volume fraction.
- CNT film and CNT-epoxy composite both show a strong anisotropy.

Impact Test System

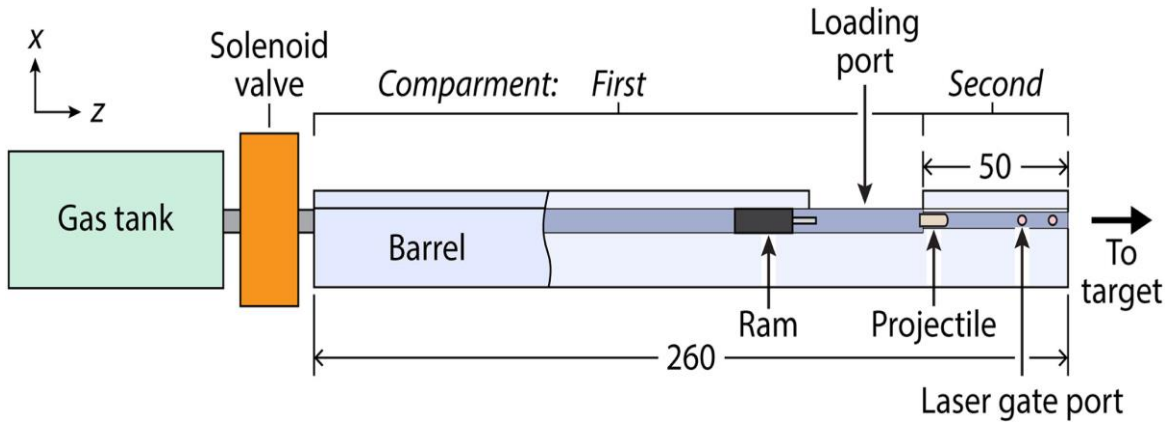
Low Velocity (1mm/min)

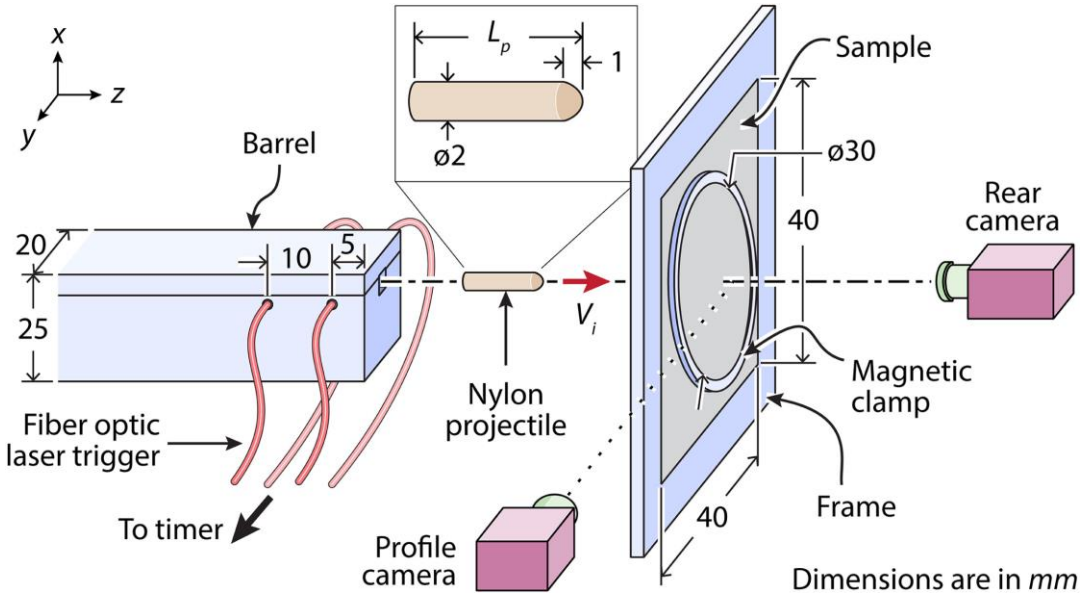




[O' Masta, 2016]

High Velocity (40 – 60 mm/s)

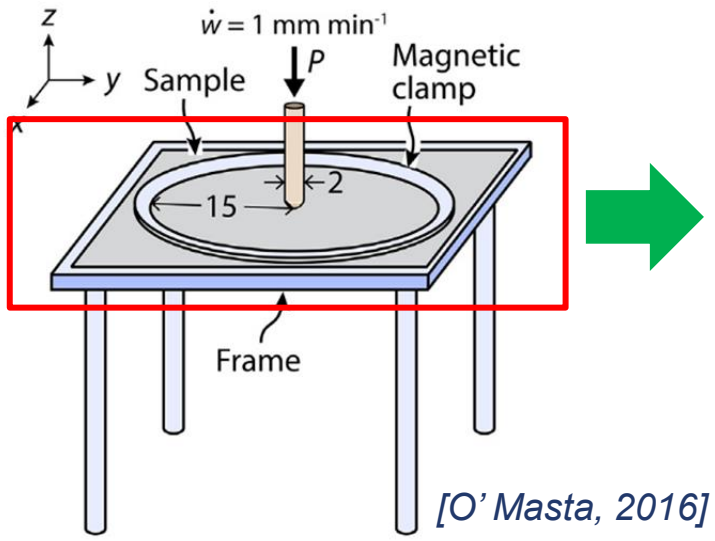




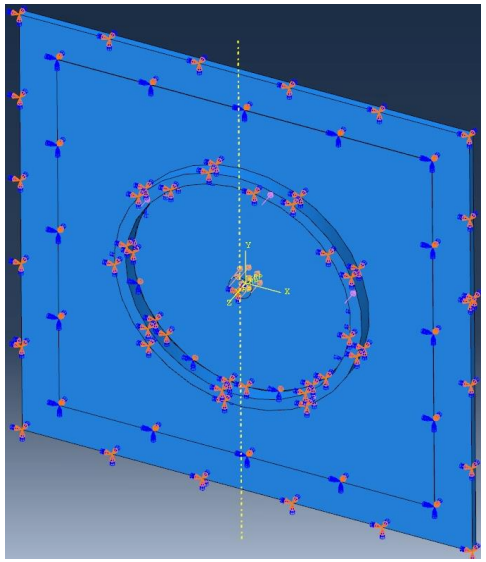
[O' Masta, 2016]

- There exists friction between sample and magnetic clamp.

Finite Element Modelling



[O' Masta, 2016]



- The impactor, frame and magnetic clamp are modelled as rigid body.
- Pressure applied in the ring to create the friction.
- Friction coefficient f = 0.2 applied in all surface contact.

Constitutive models

Model	Elastic	Plastic	Damage Property	Applied in
Iso-Non damage Model	Isotropic Elastic	Isotropic Plastic	Non	Indentation
Iso-Damage Model	Isotropic Elastic	Isotropic Plastic	Ductile Damage + Displacement Damage Evolution	Indentation /Impact
Aniso-Non damage Model	Anisotropic Elastic (Engineering Constants)	Isotropic Plastic + Potential	Non	Indentation
Aniso-Damage Model	Anisotropic Elastic (Engineering Constants)	Isotropic Plastic + Potential	Ductile Damage + Displacement Damage Evolution	Indentation /Impact

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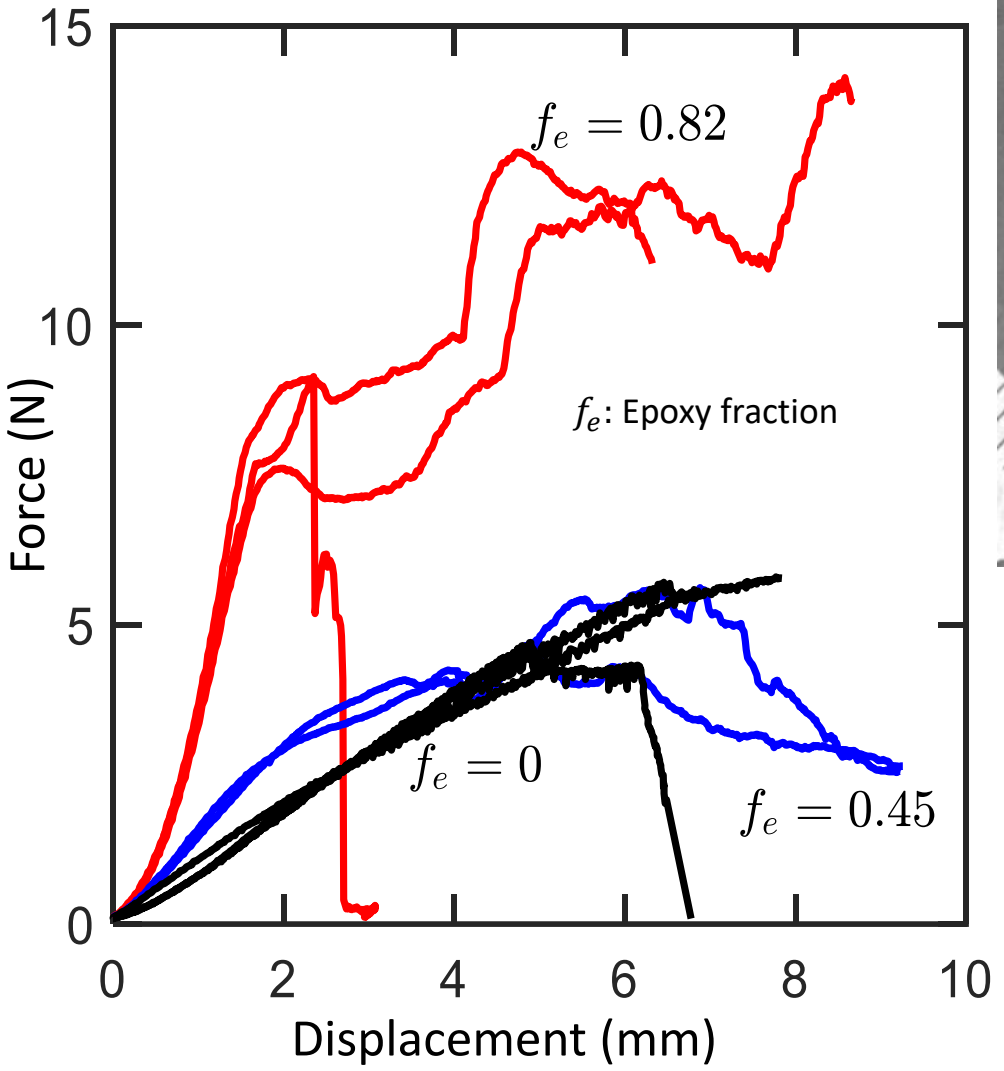
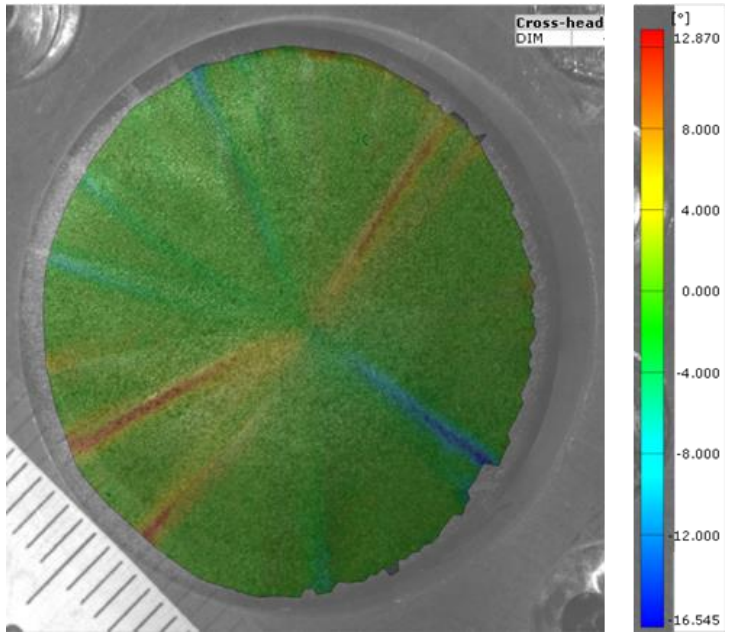
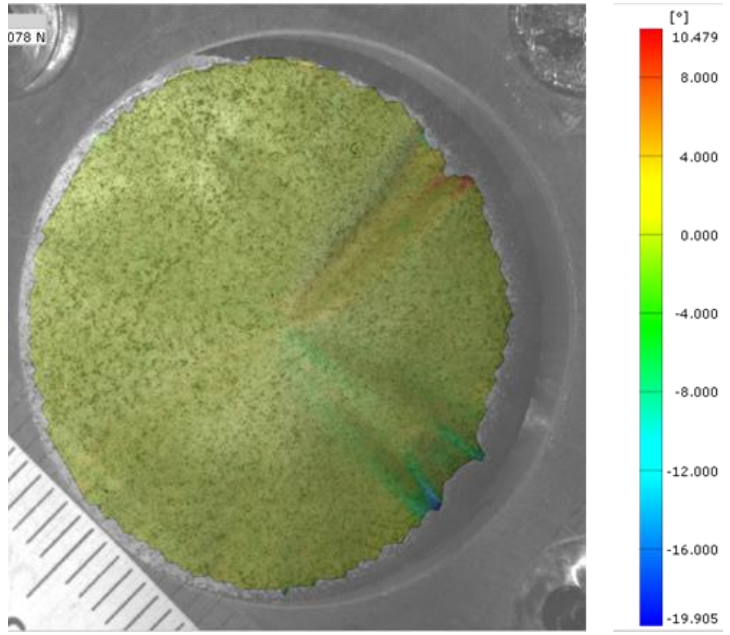
Quasi-static Indentation



$f_e = 0$ γ_{12}

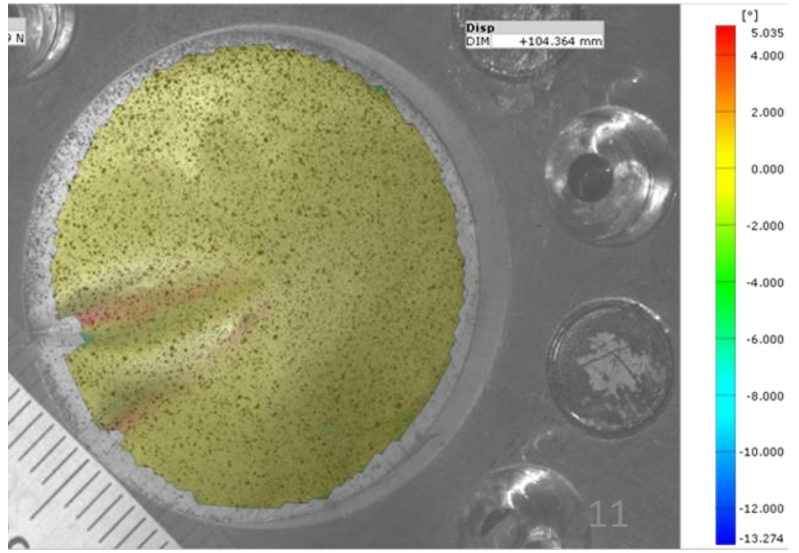


$f_e = 0.45$ γ_{12}

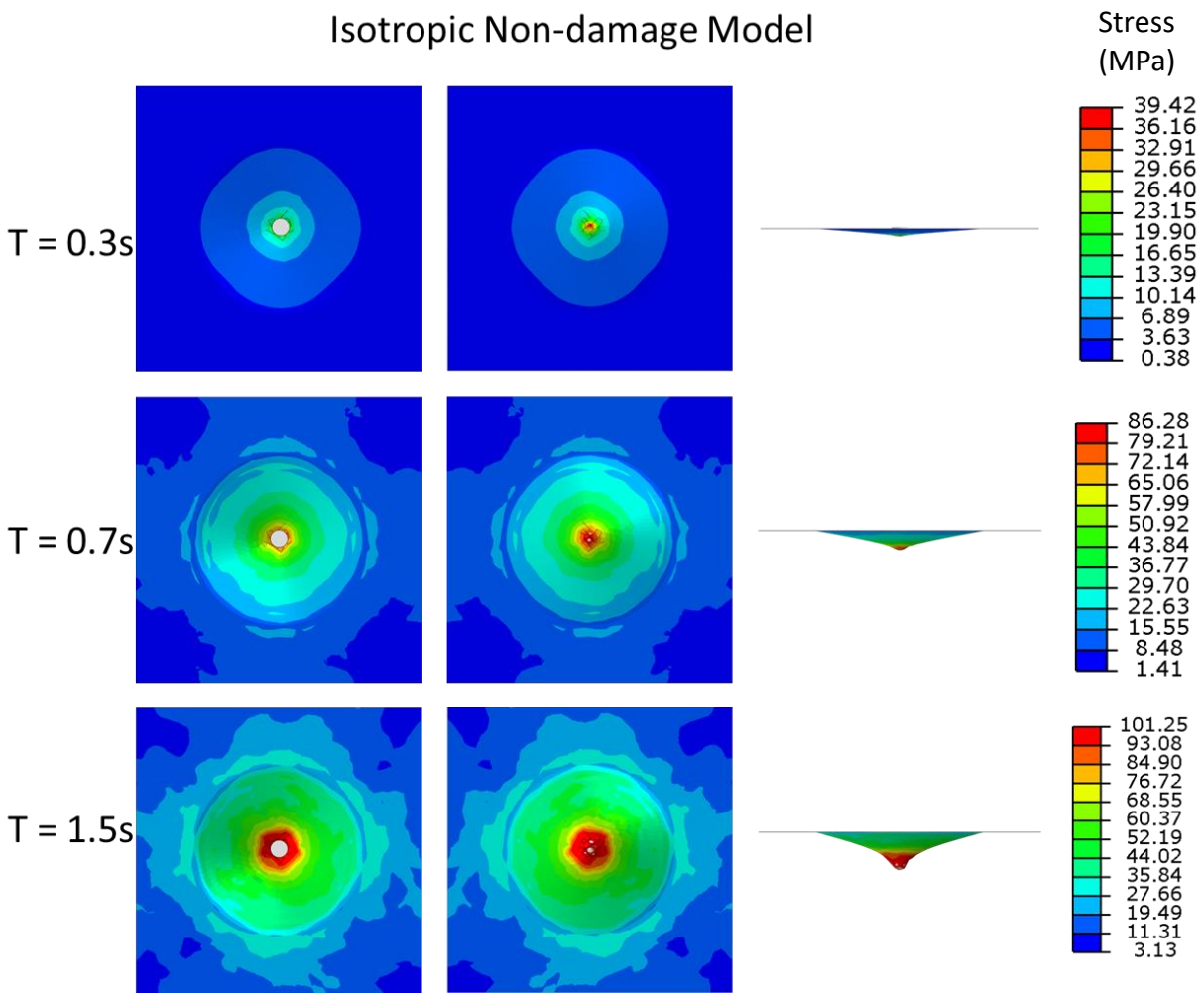


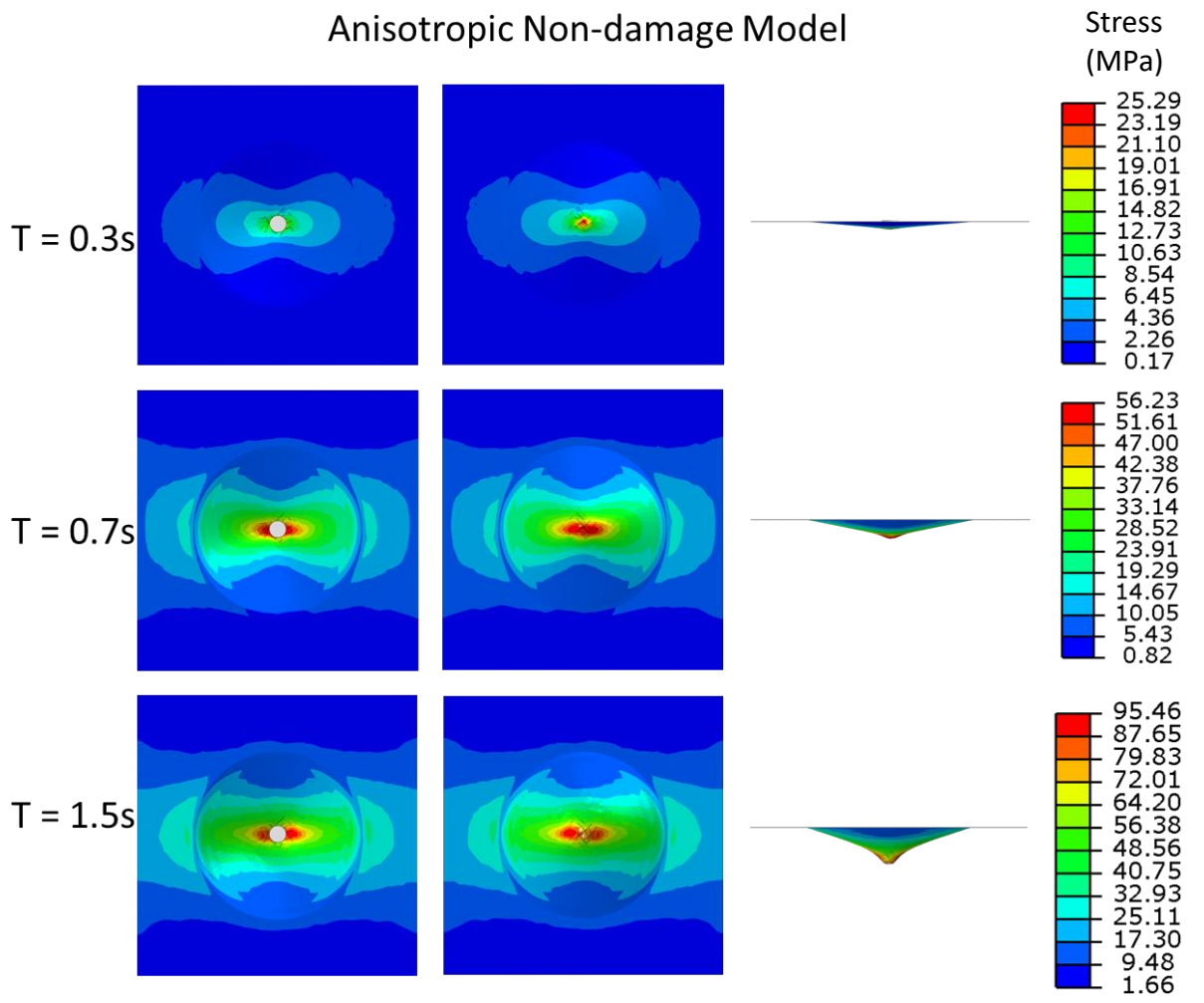
- Epoxy can improve the indentation resistance of CNT-epoxy composite.
- The improvement shows more significant with the increase of epoxy fraction.

$f_e = 0.82$ γ_{12}



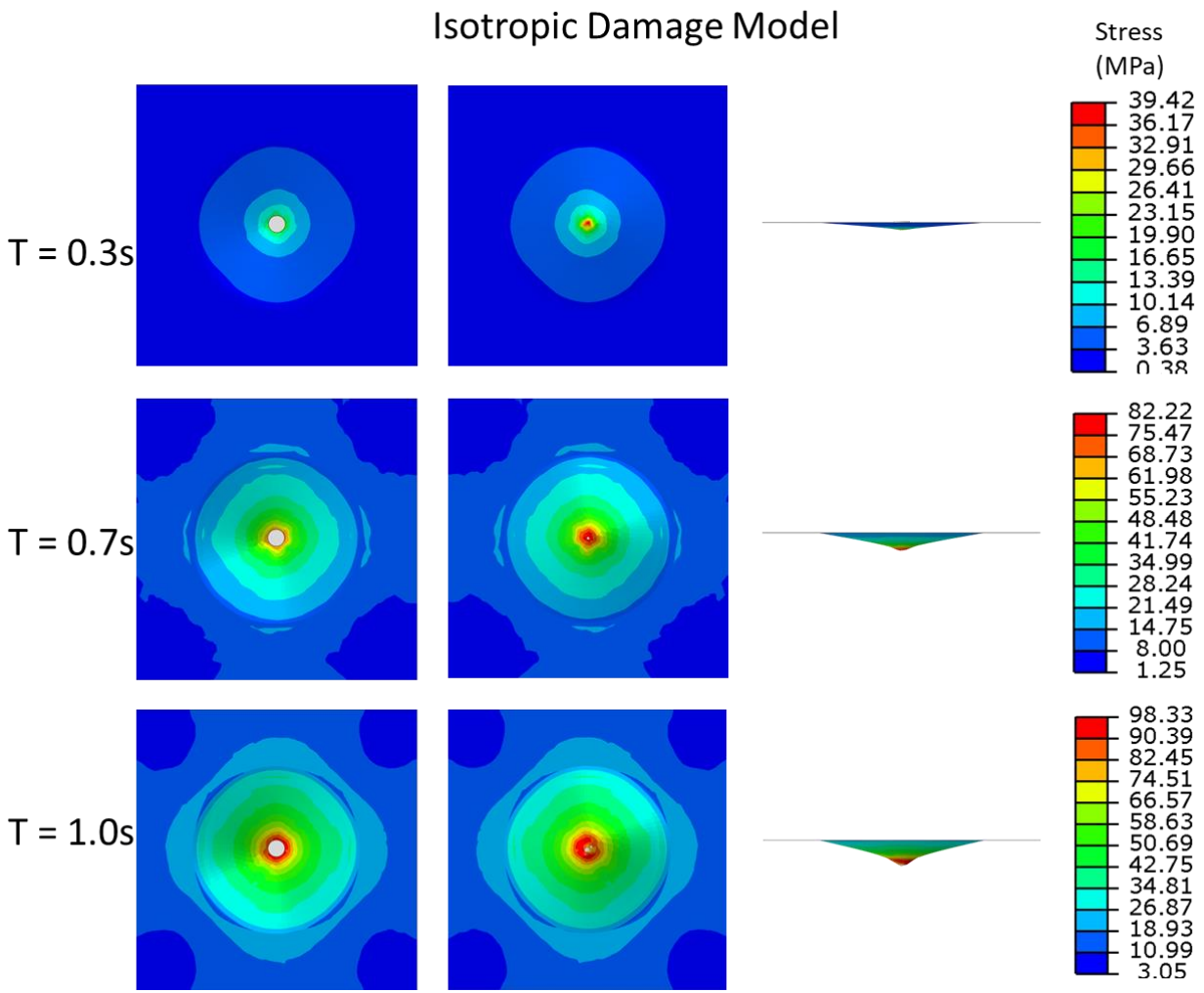
Indentation Simulation

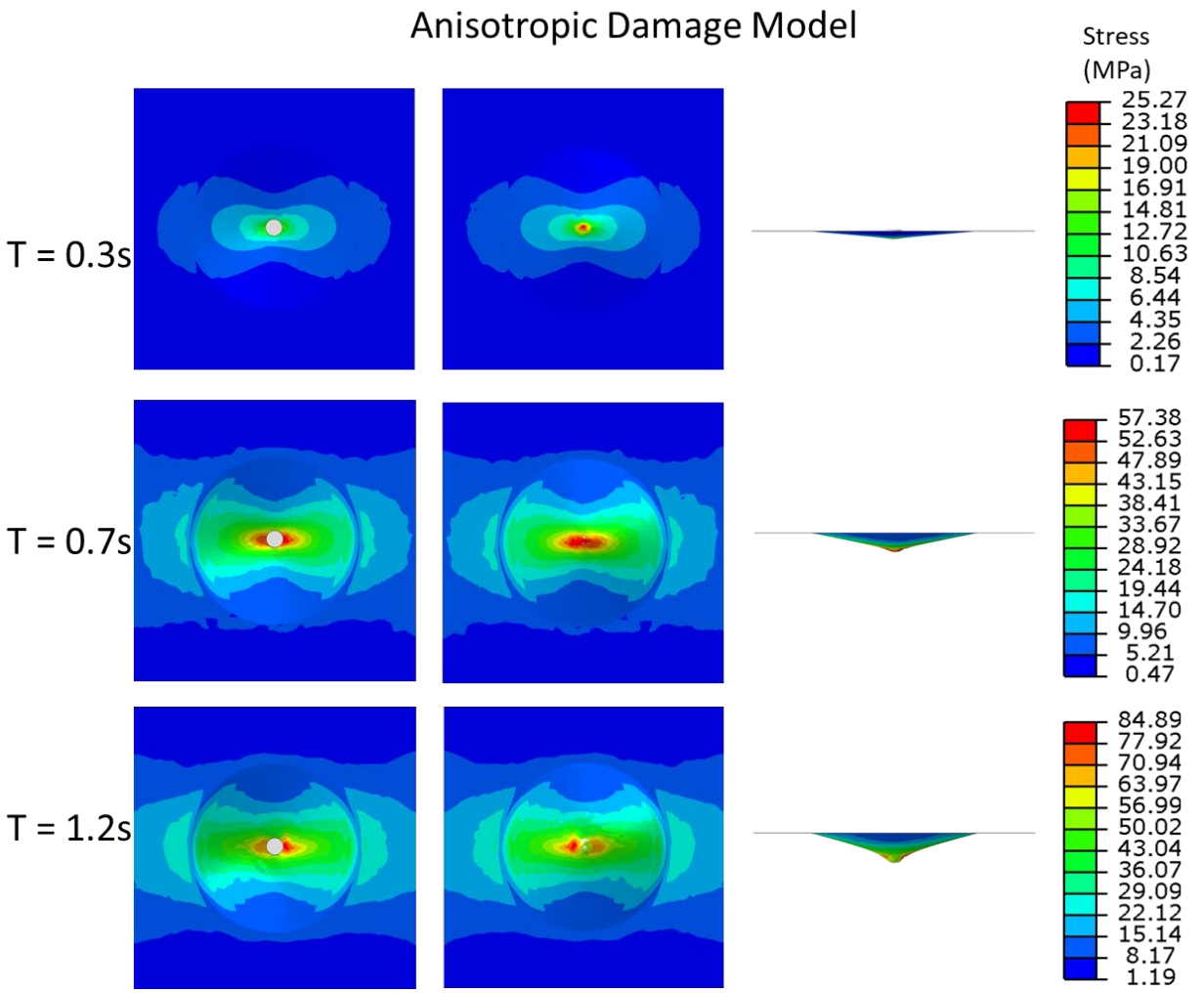




- Stress distribution: concentric circles.
- Stress distribution: Butterfly shape – parallel to the fibre direction.

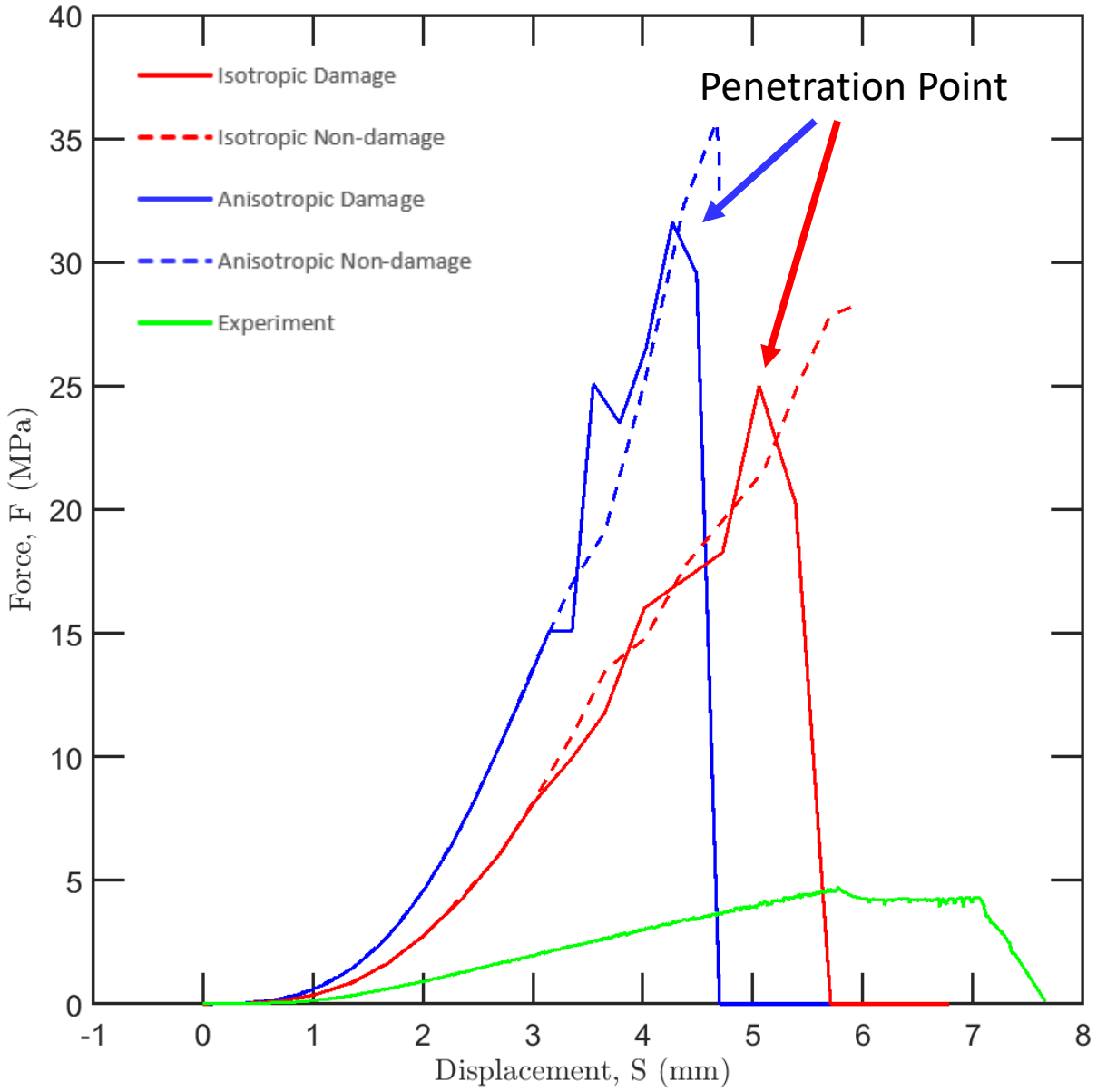
Indentation Simulation





- Penetration time: 1 s
- Penetration time: 1.2 s

Indentation Simulation



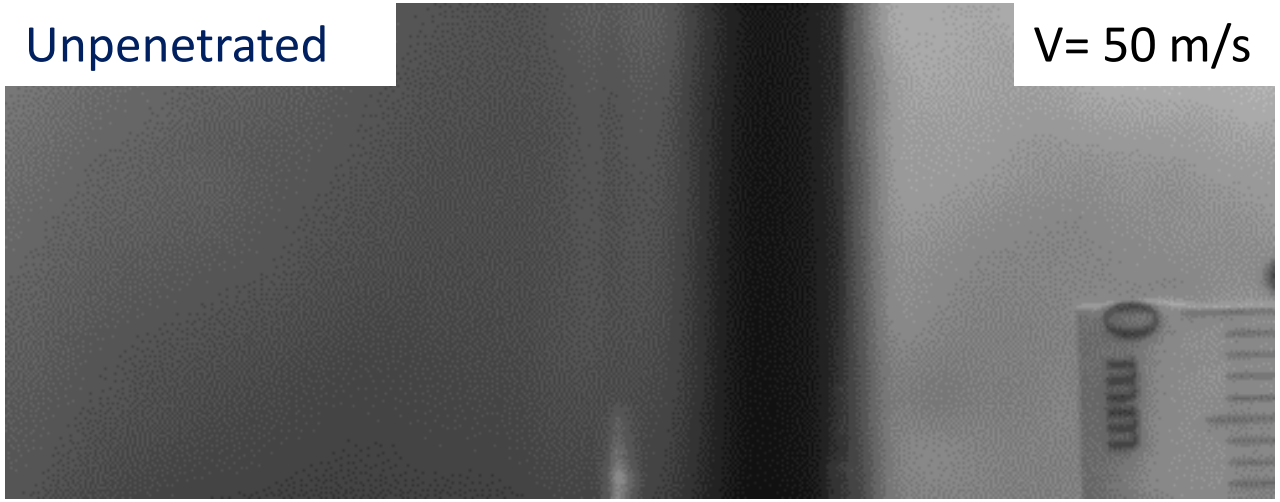
Remarks:

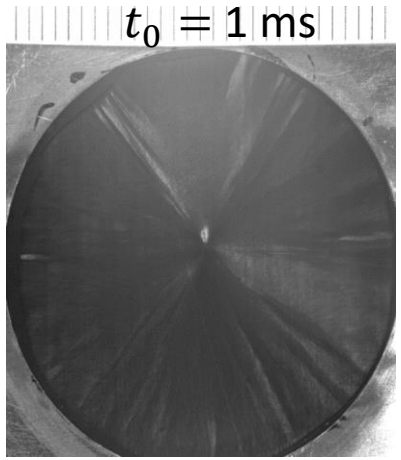
- The indentation resistance performance of CNT-epoxy composite **increases** with the increasing epoxy fraction.
- Compared with isotropic model, the anisotropic model shows stress concentration parallel to the CNT direction.
- The anisotropic model shows less indentation resistance than isotropic model.

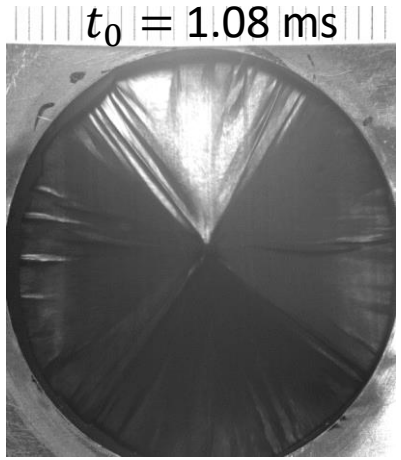
High Velocity Impact of CNT film

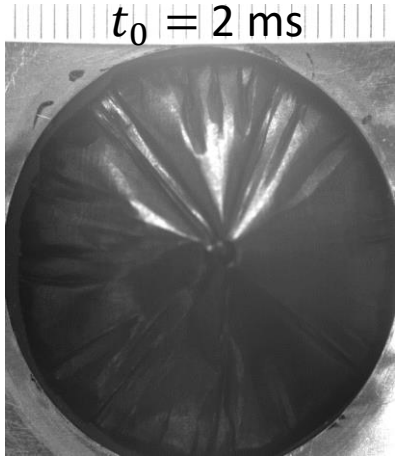
Unpenetrated

V= 50 m/s



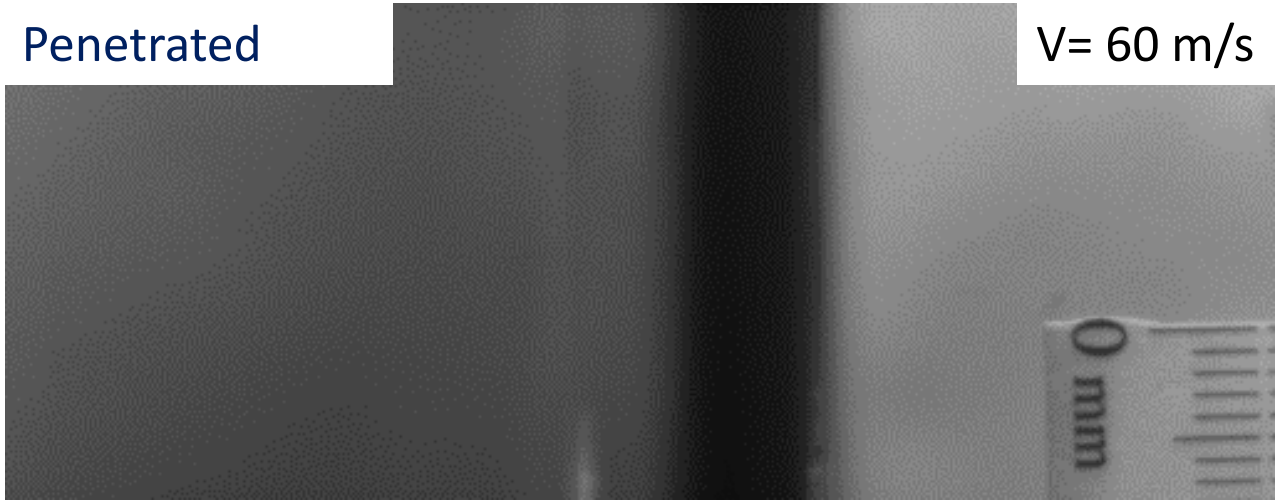


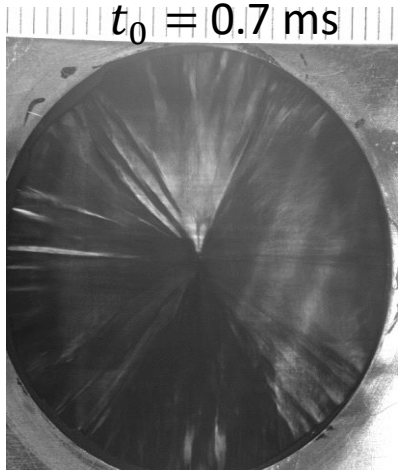


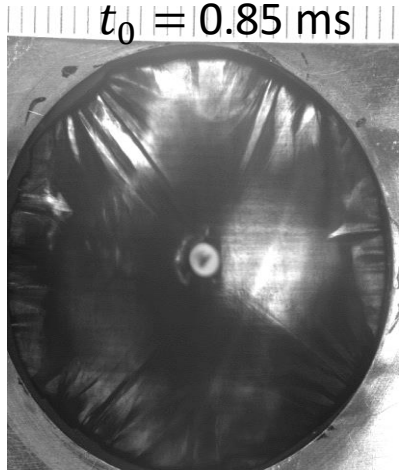


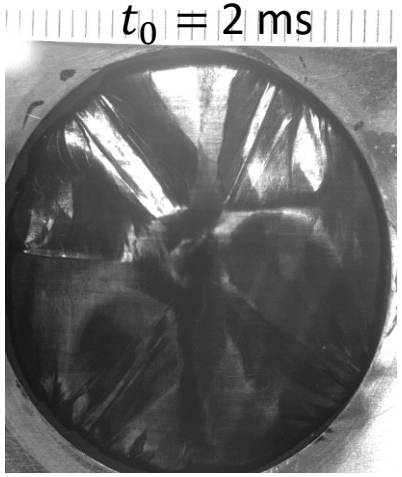
Penetrated

V= 60 m/s

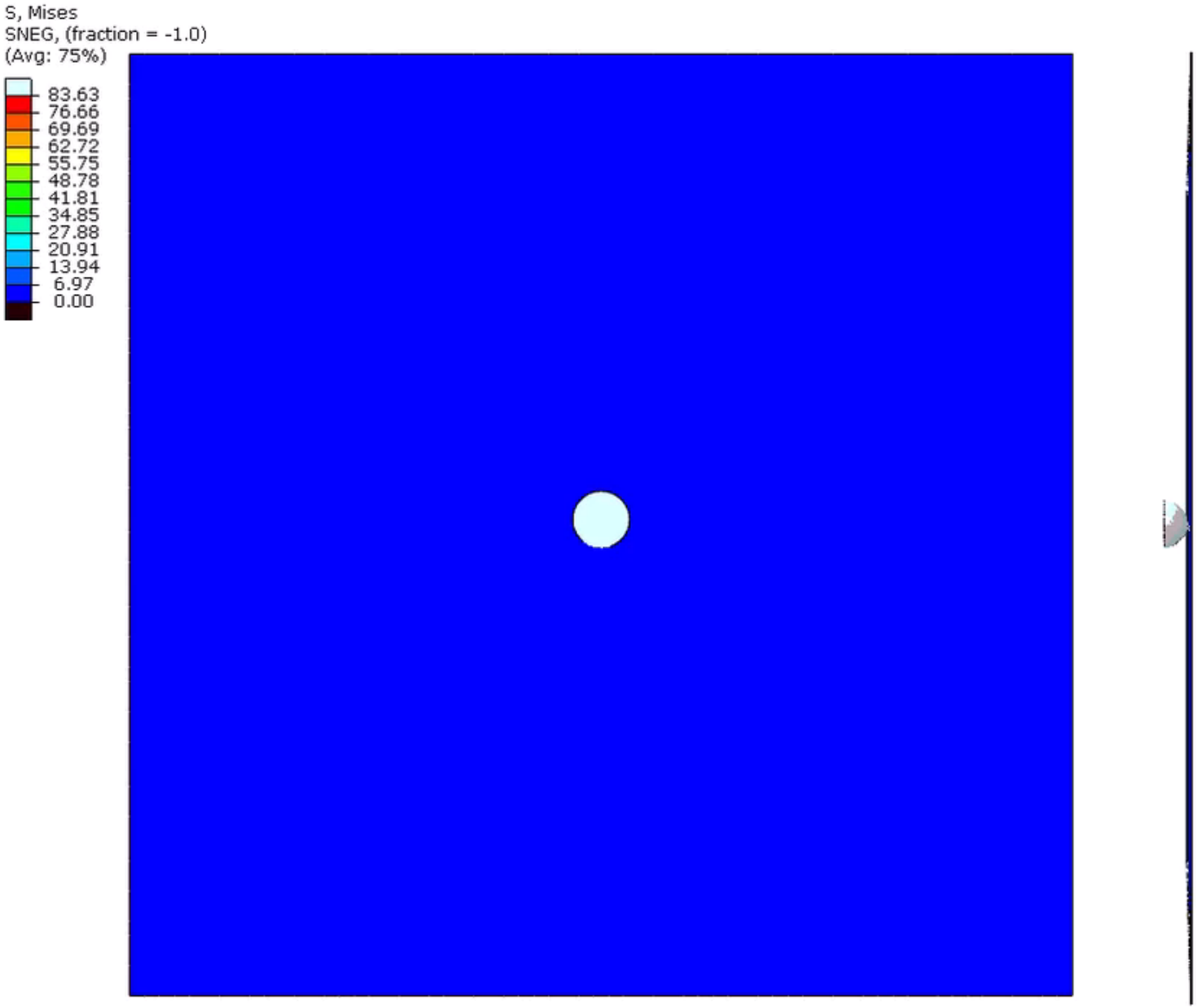






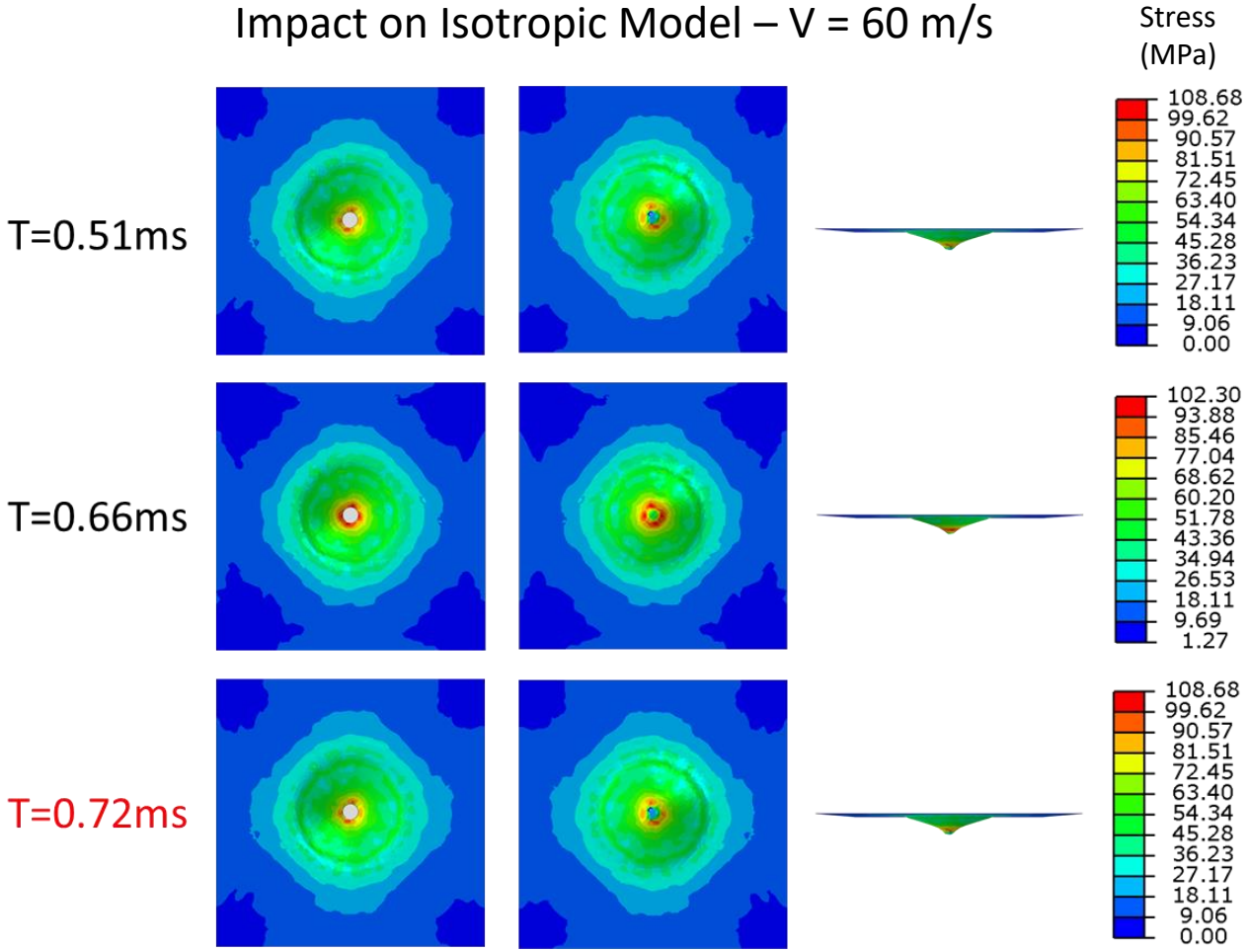


High Velocity Impact Simulation of CNT film



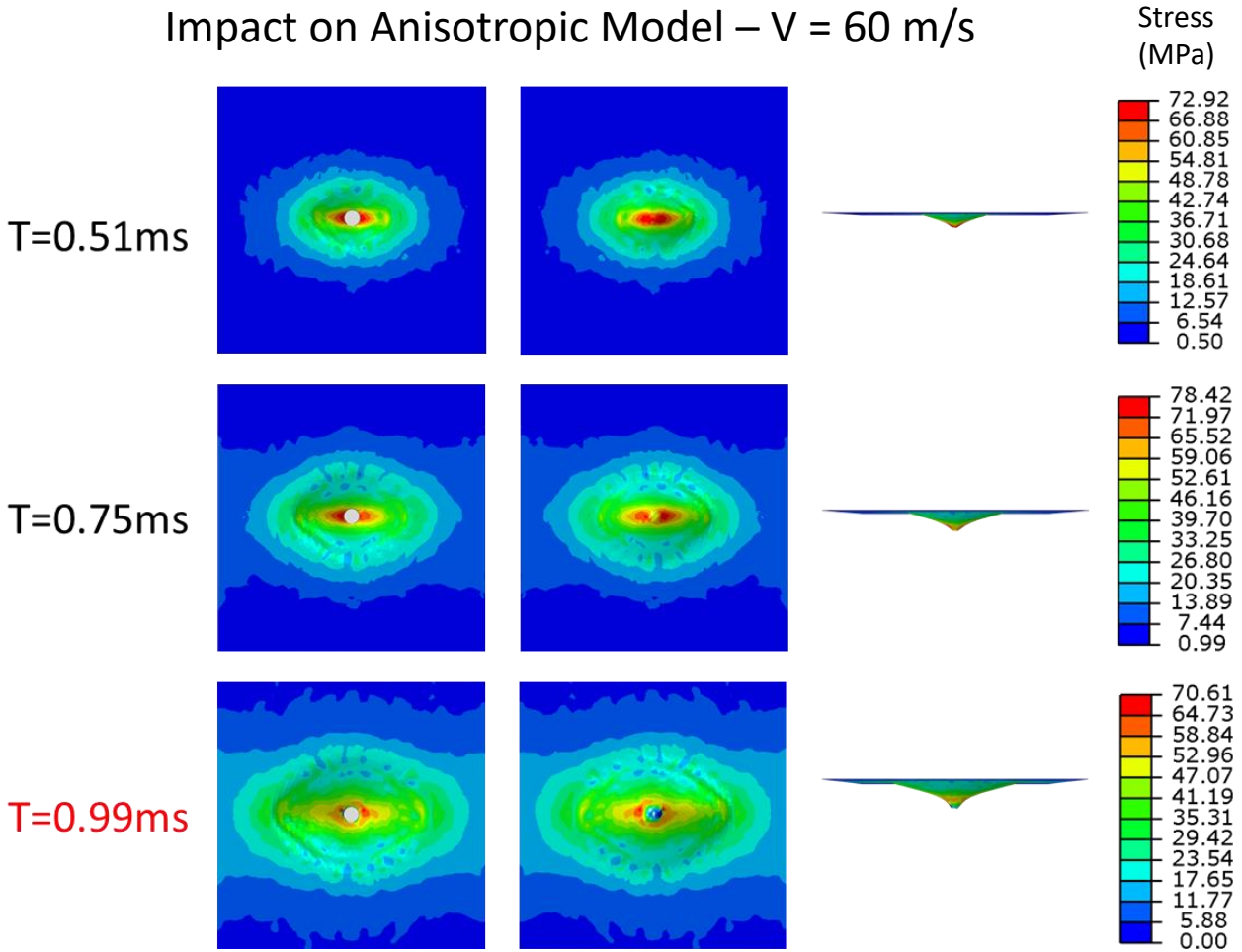
High-velocity Impact Simulation

Impact on Isotropic Model – V = 60 m/s



- Penetration time: 0.72 ms

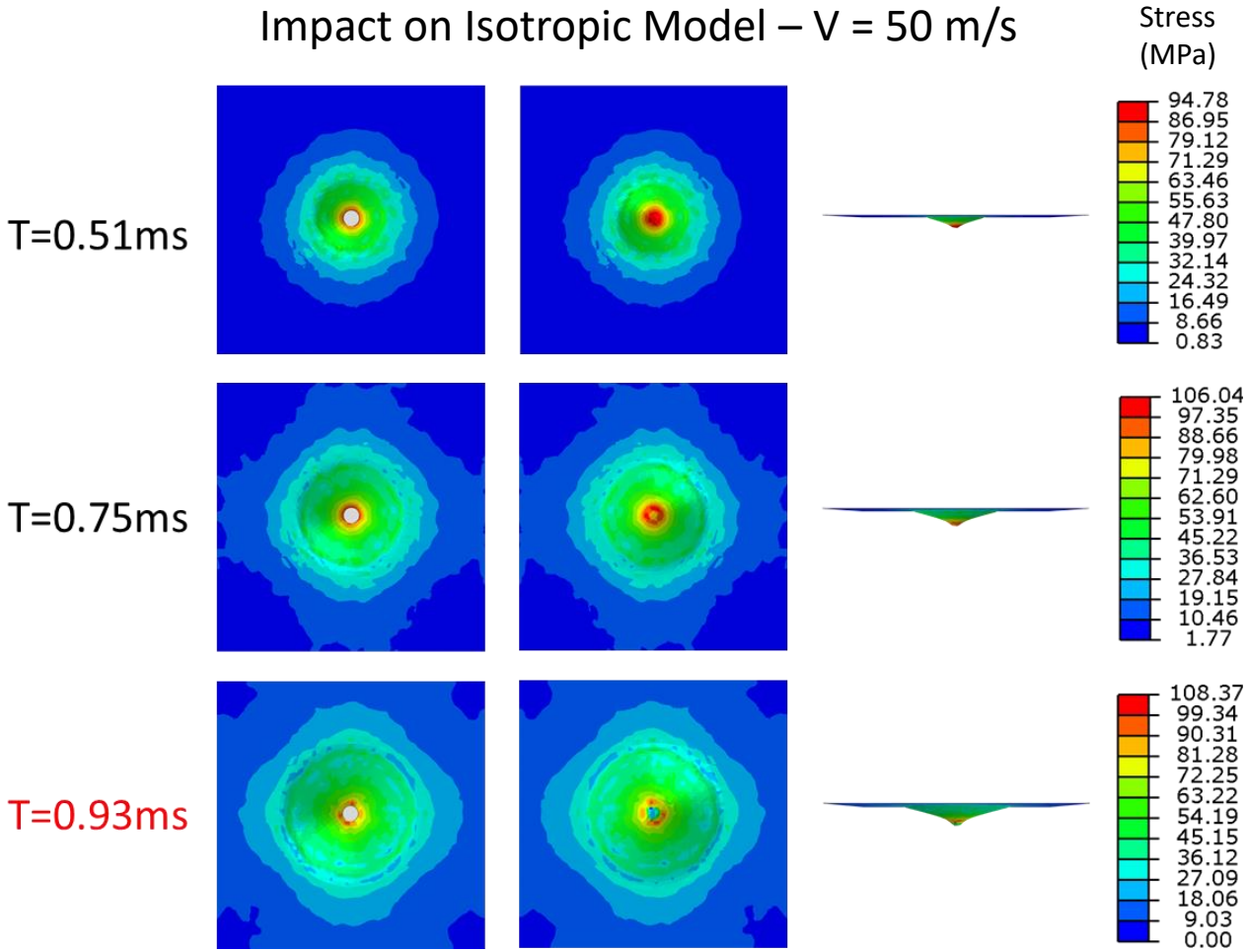
Impact on Anisotropic Model – V = 60 m/s



- Penetration time: 0.99 ms

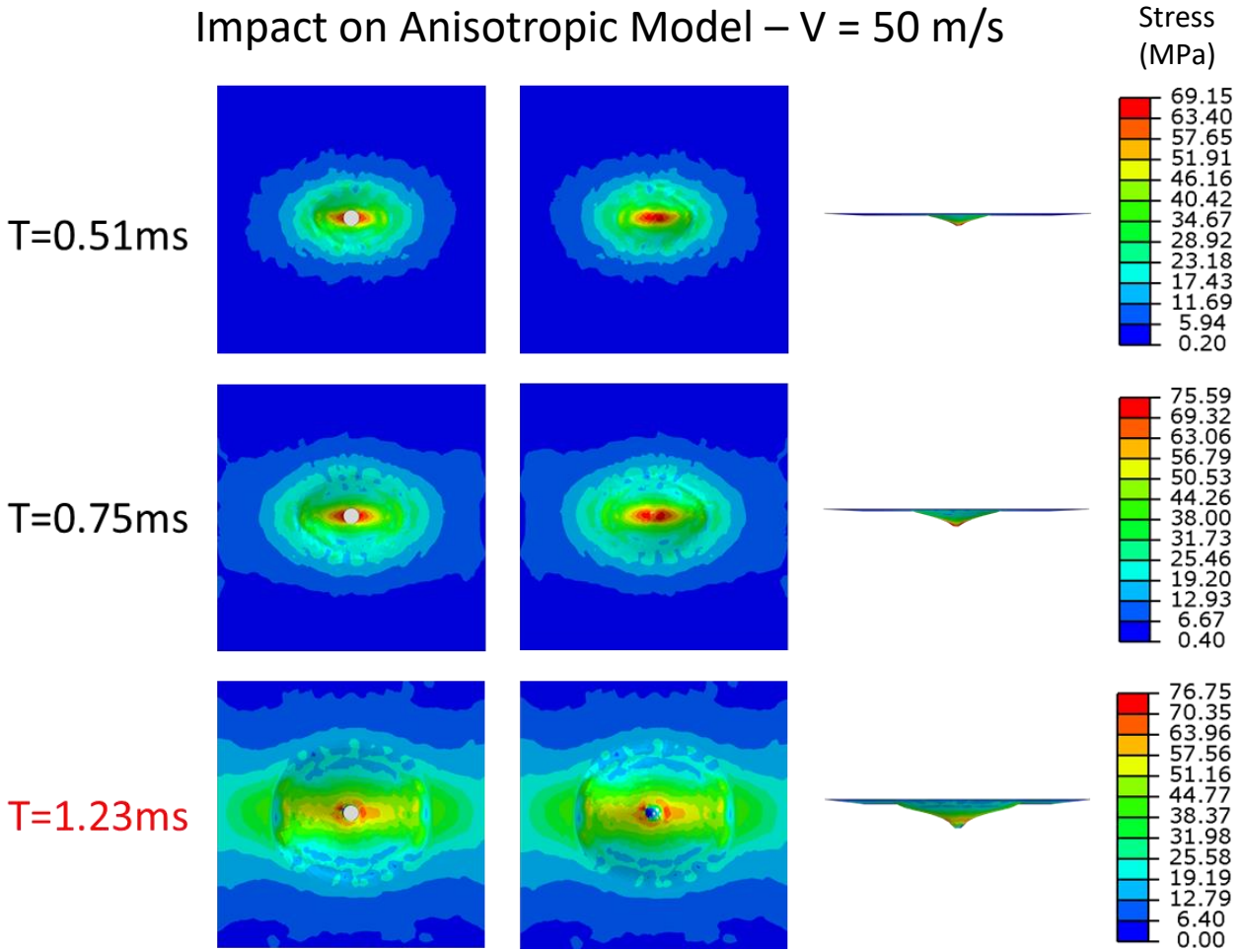
High-velocity Impact Simulation

Impact on Isotropic Model – V = 50 m/s



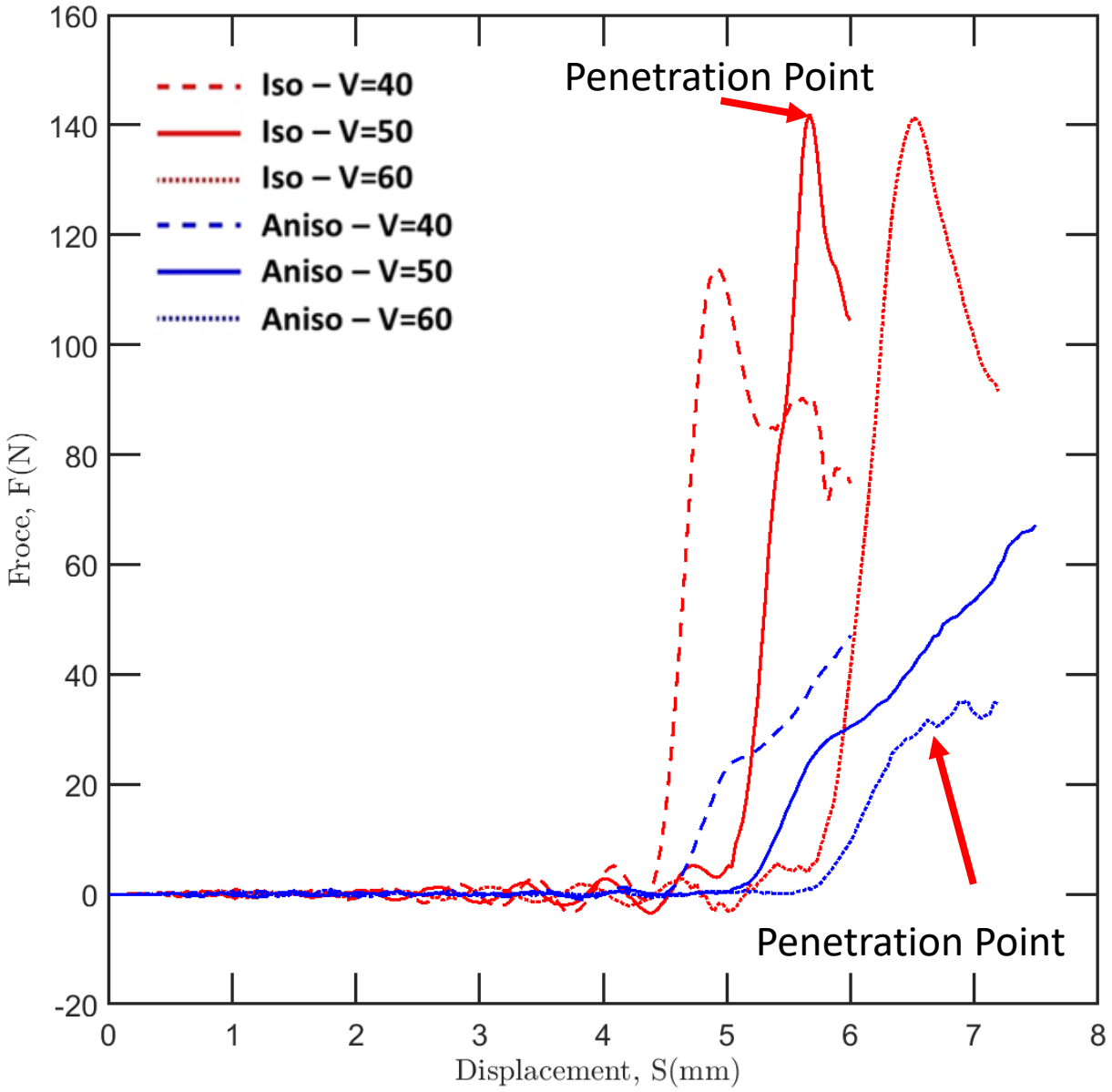
- Penetration time: 0.93 ms

Impact on Anisotropic Model – V = 50 m/s



- Penetration time: 1.23 ms

Impact Simulation



Remarks:

- Compared with isotropic model, the anisotropic model shows stress concentration parallel to the CNT direction – same with indentation.
- The maximum deformation before penetration and the reaction force both increase with the increase of impact velocity.
- The anisotropic model shows less impact force resistance than isotropic model, but more deformation before penetration.

Summary

- Epoxy can significantly improve the tensile mechanical property and impact resistance of CNT-epoxy composite, only when it large than CNT fraction ($f_e > 0.5$) .

- The stress distribution of anisotropic material in indentation/impact is similar, which the critical area (maximum stress) distribute wider along the fibre direction (main direction).

- The anisotropic model shows less force resistance but more deformation before penetration than isotropic model, both in indentation and impact conditions.

Future Work

- Improve the impact test monitor method to collect details and data of CNT performance in high velocity impact process.

- Improve the simulation model to get more accurate simulation of CNT film resistance performance on indentation/impact situation.

- Explore the potential specific applications of CNT film/composites in academic and industry field.

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Thank you for your attention!

Key references:

[1] O'Masta, M. R., Russell, B. P., & Deshpande, V. S. (2017). An exploration of the ballistic resistance of multilayer graphene polymer composites. Extreme Mechanics Letters, 11, 49–58.

[2] Yi, M., & Shen, Z. (2015). A review on mechanical exfoliation for the scalable production of graphene. Journal of Materials Chemistry A, 3(22), 11700–11715.

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