INTRODUCTION TO FIRE PERFORMANCE ASSESSMENT OF FIBRE REINFORCED COMPOSITES

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YOUR HOST

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Professor, School of Engineering and Built Environment
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Griffith University

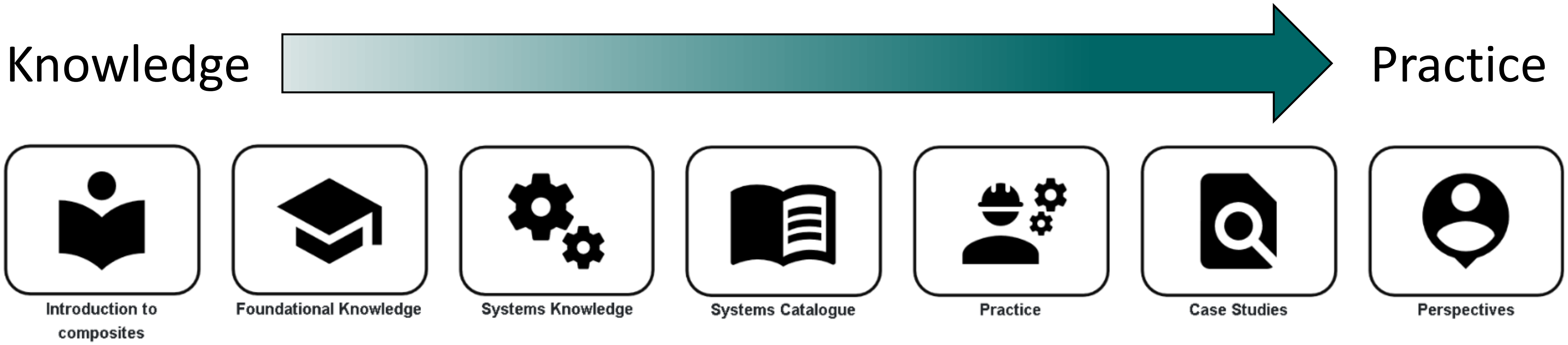
- PhD, MEng and Diplom-Ingenieur in Mechanical Engineering
- Over 30 years experience in academia and industry-facing R&D in lightweight material design, manufacturing, and experimental and numerical performance characterization
- Passion for translating R&D outcomes to aerospace, wind, maritime, oil & gas, and medical industry sectors

KNOWLEDGE IN PRACTICE CENTRE (KPC)

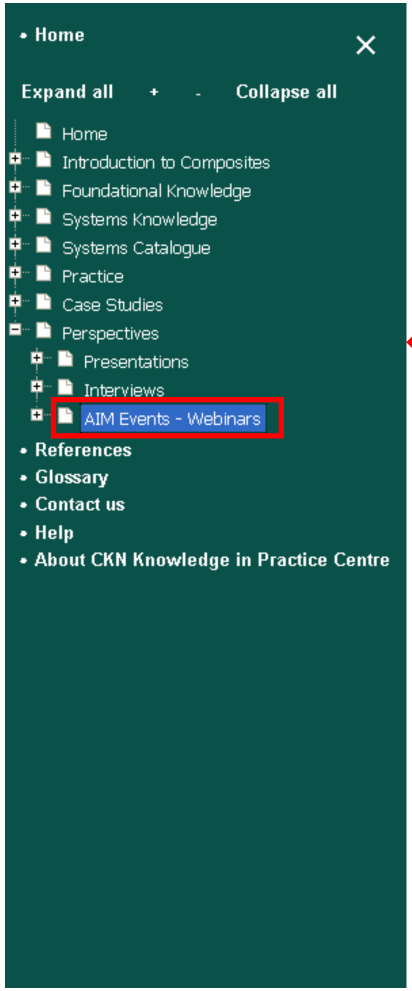
- A freely available online resource for composite materials engineering:

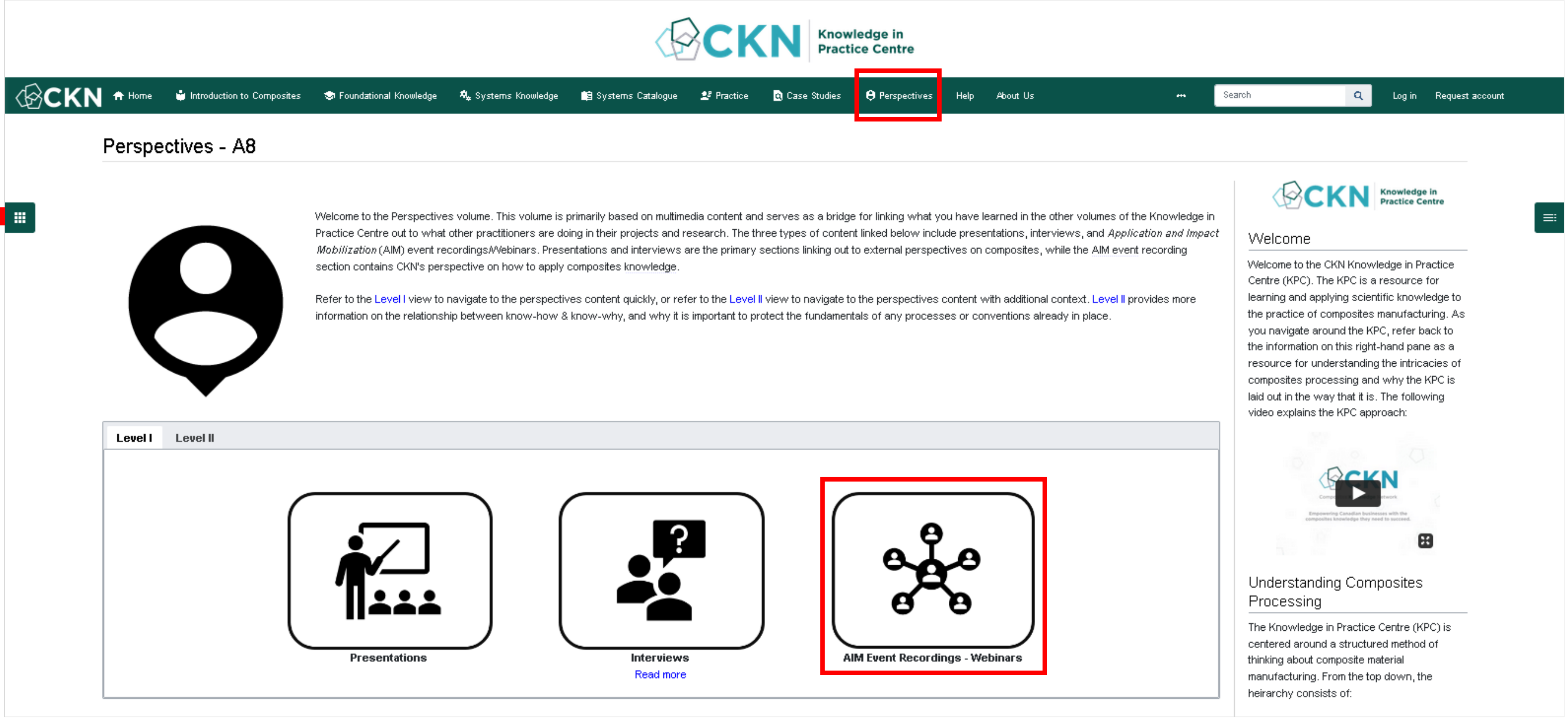
compositeskn.org/KPC

- Focus on practice, guided by foundational knowledge and a systems-based approach to thinking about composites manufacturing



PAST WEBINAR RECORDINGS AVAILABLE





Today's Webinar will be posted at:
https://compositeskn.org/KPC/A394

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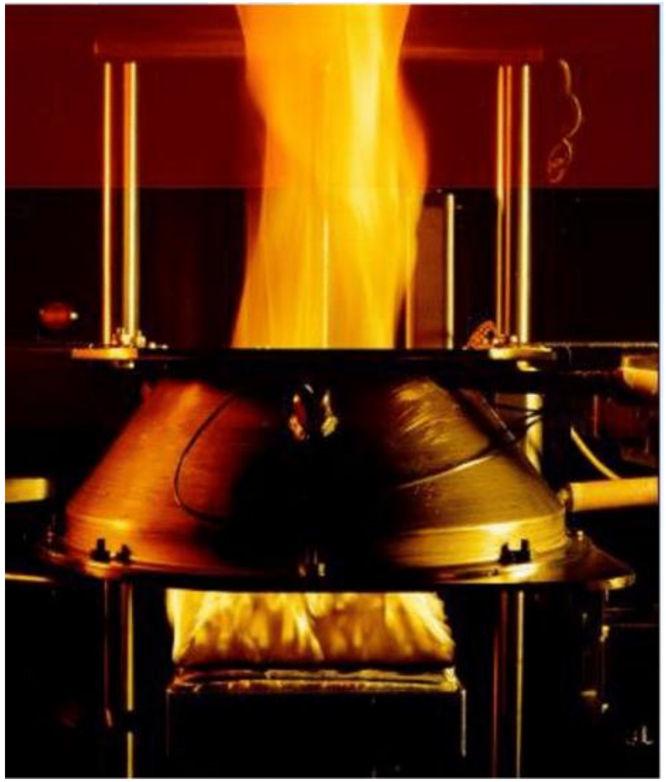
TODAY'S TOPIC:

Introduction to Fire Performance Assessment of Fibre Reinforced Composites

OUTLINE

- Why is Fire Performance Assessment Critical?
- Response of Composite Materials to Fire
- Fire Safety Testing and Standards
- Thermal Modelling of Composites during Fire
- Mechanical Modelling of Composites during Fire
- Designing for Fire Safety
- Conclusions



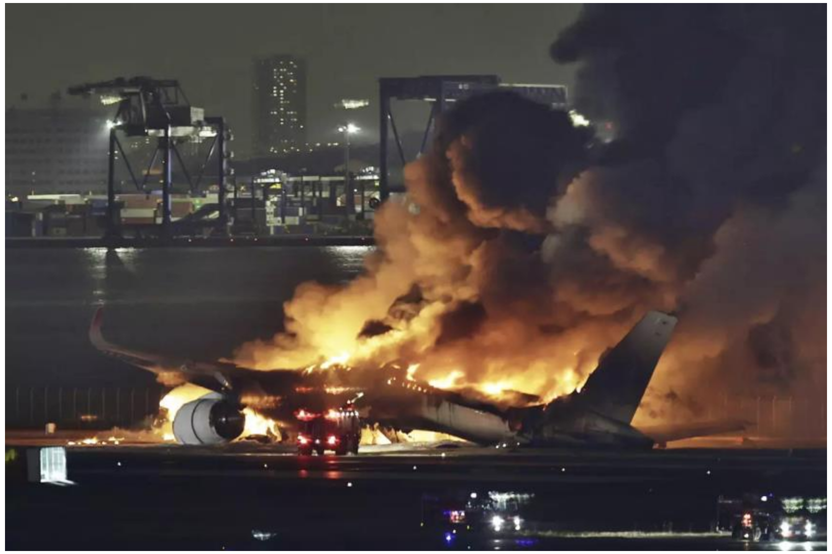
Cone calorimetry testing of composites

RATIONALE: MARITIME AND AVIATION FIRES

Norwegian minehunter KNM Orkla, 20th November 2002 (**GFRP**)

https://zbiam.pl/ostatni-rejs-bylej-norweskiej-fregaty/

Japan Airlines A350 Haneda Airport, January 5th 2024 (**CFRP**)



https://www.latimes.com/world-nation/story/2024-01-05/a-jets-carbon-composite-fiber-fuselage-burned-on-a-tokyo-runway-is-the-material-safe

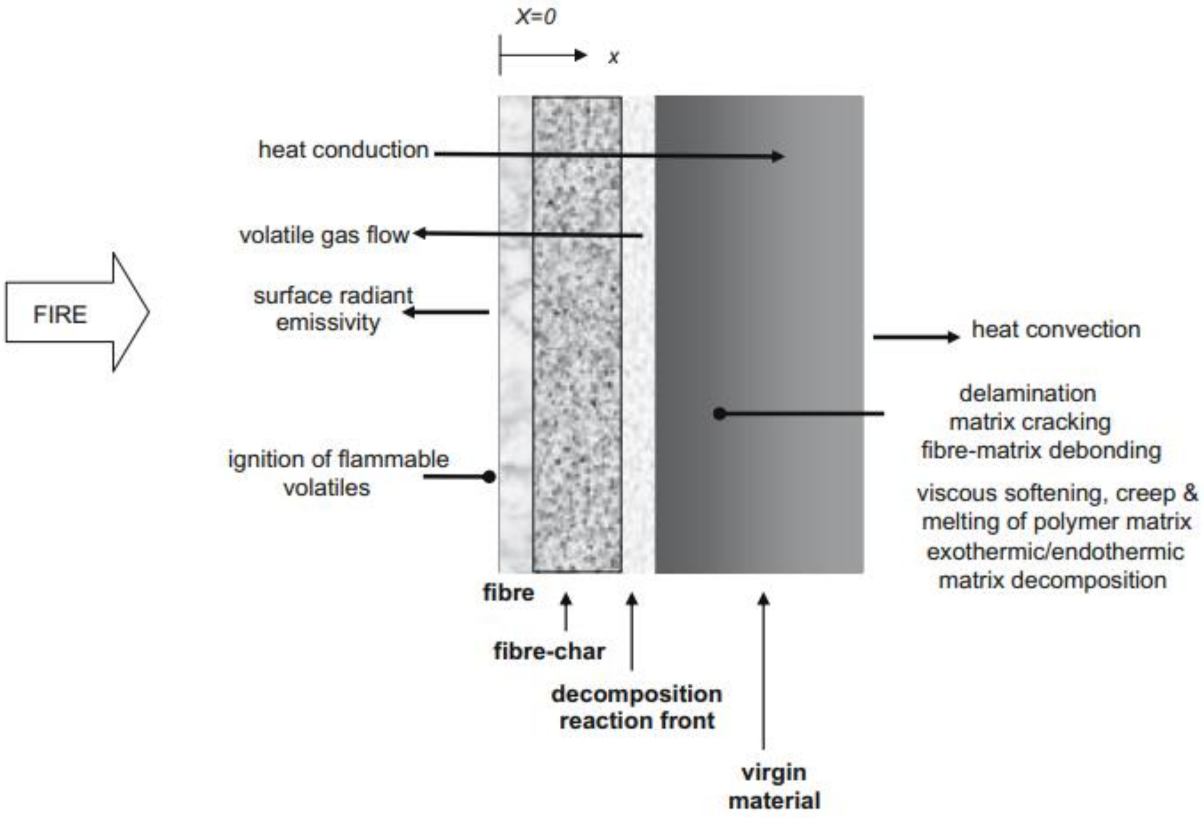
Major concerns about:

- Smoke toxicity from burning resins
- Fibrous dust and sharp splinters from exposed material
- Integrity of structure during fire event to ensure safety of passengers and fire fighting crew

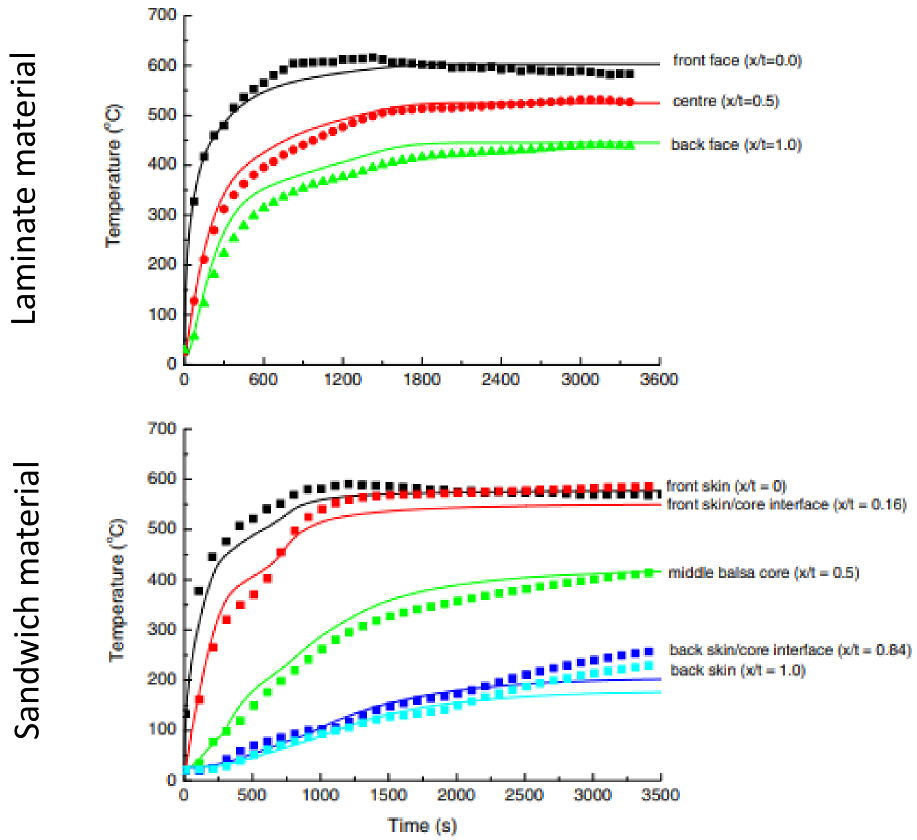
RESPONSE OF COMPOSITE MATERIALS TO FIRE

COMPOSITE FIRE EXPOSURE SCENARIO

Fire scenarios result in initially one-sided heat exposure:



Composite materials and cores act as insulators by default:



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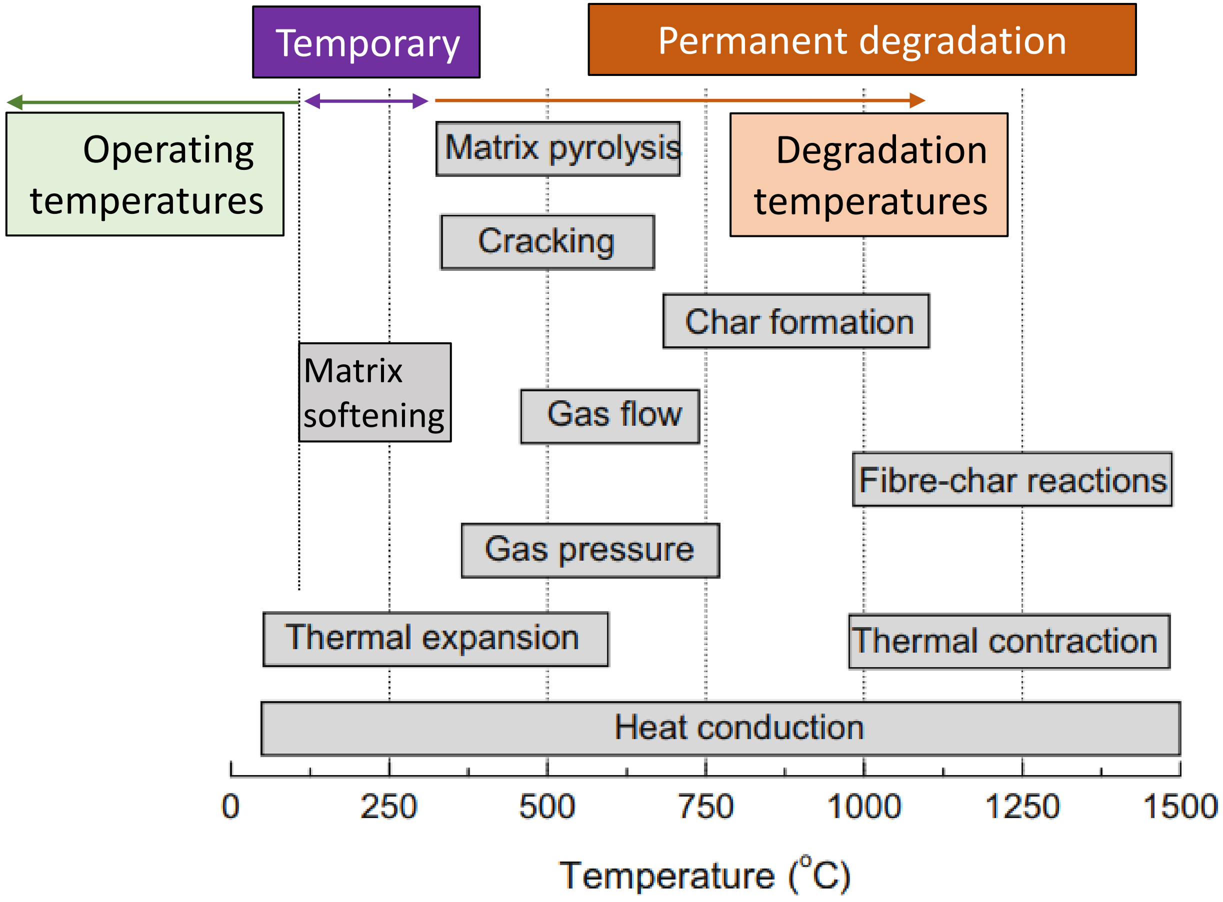
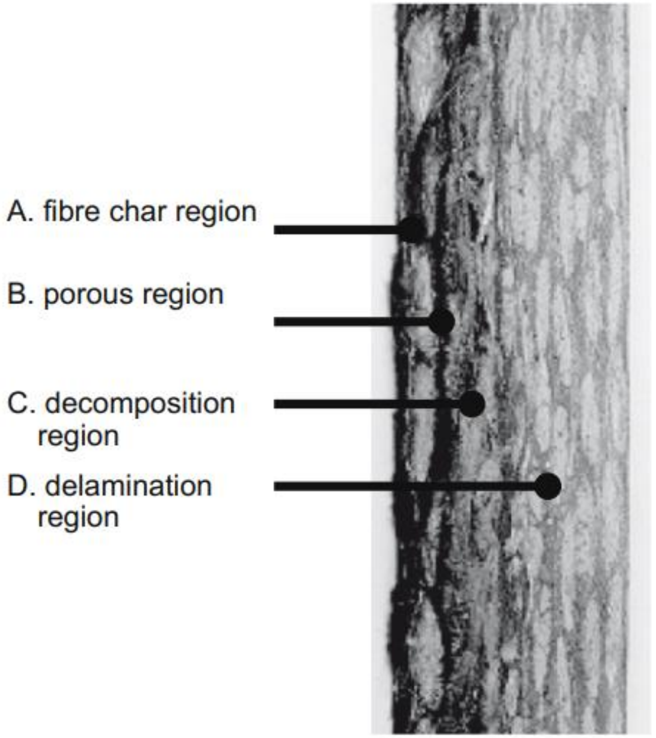
MECHANICAL/CHEMICAL RESPONSE TO FIRE

Material degradation occurs in various temperature-dependent stages:





FIRE SAFETY TESTING AND STANDARDS

FIRE SAFETY STANDARDS

Different standards apply for different industry sectors and often also depend on local governance rules:

Maritime
Safety of Life at Sea (SOLAS) / IMO 2010
Flammability and smoke, back face temperature
Walls and doors of high-risk areas (control room, bridge)

Rail
NFPA 130 (USA / Canada) / EN 45545 (Europe)
Flammability, smoke density and toxicity level limits, providing sufficient time for passengers to exit train

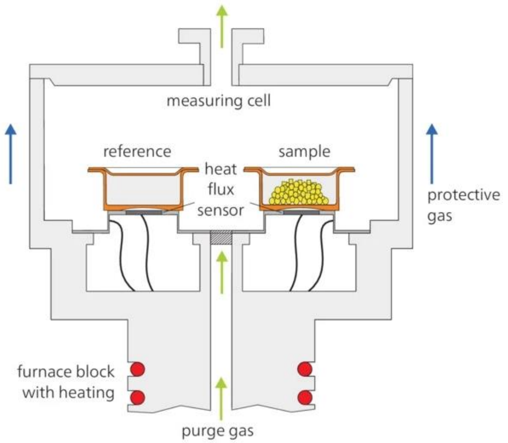
Aerospace
AWM 525 Appendix F / FAR 25.853
Flammability, smoke density , combustion toxicity, sufficient time to land and for passengers to escape

Building and Construction
CAN/ULS (Canada) – analogous to EU/US tests
Exterior wall flame spread, flammability, combustibility, enabling building occupant escape

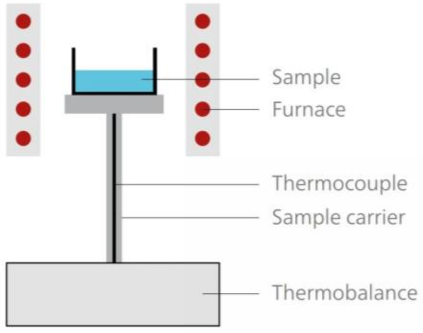
We need to understand the thermal and mechanical responses of composite materials to design structures adequately according to fire safety standards

DIFFERENTIAL SCANNING CALORIMETRY /THERMOGRAVIMETRIC ANALYSIS

DSC



TGA



Combine information from both for full material characterisation (Simultaneous Thermal Analysis)

https://analyzing-testing.netzsch.com/en/services/contract-testing/methods/differential-scanning-calorimetry-dsc

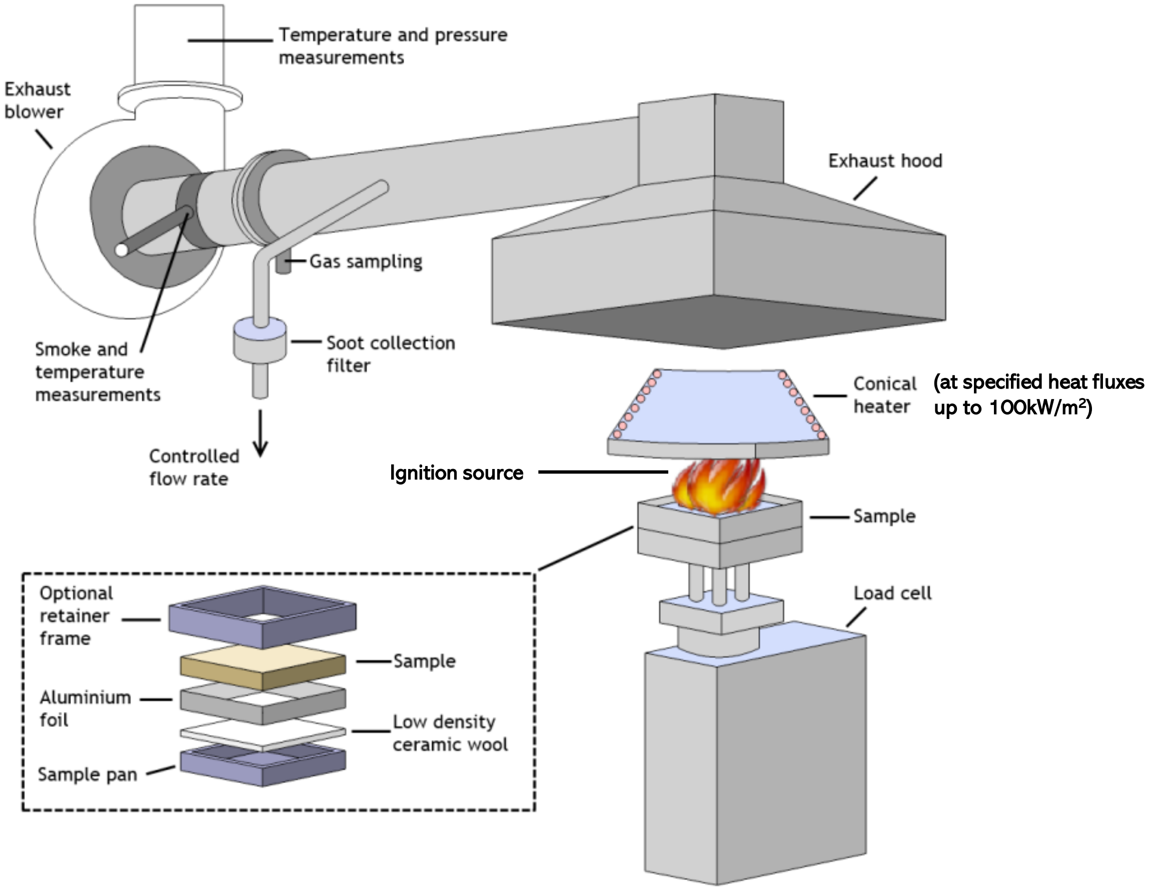
https://analyzing-testing.netzsch.com/en/products/thermogravimetric-analysis-tga-thermogravimetry-tg

Test outcomes:
- Glas transition temperature (DSC)
- Specific heat and cure state (DSC)
- Decomposition onset/char yield and Arrhenius kinetics (TGA)
- Inputs for heat transfer models (DSC/TGA)

Key test for the following sectors:
- Material characterisation
- Not mandatory for compliance with fire test standards, but excellent in de-risking composite performance evaluation

Important material tests on smallest scale

CONE CALORIMETER TEST (ISO 5660 / ASTM E1354 / NFPA 271)



https://efectis.com/app/uploads/2017/08/Leaflet_ConeCalori.pdf

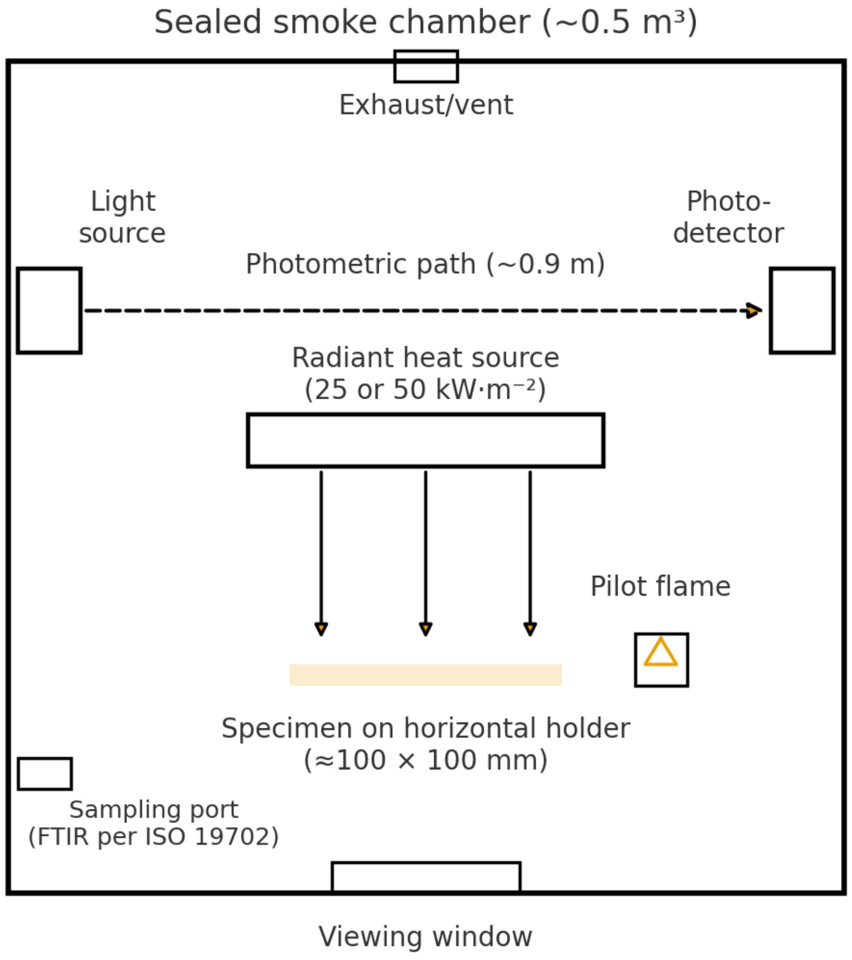
https://www.youtube.com/watch?v=hRKQttXvoco

Test outcomes:
- Ignition time
- Heat Release Rate (HRR)
- Mass loss rate
- Smoke production
- Toxic gas production

Key test for the following sectors:
- Maritime
- Building / construction
- Rail
- Aerospace (R&D purposes only, FAR25.853 used instead)

Most significant bench scale test in the field of fire testing.

SINGLE CHAMBER SMOKE DENSITY (ISO 5659 / ASTM E662)



Test outcomes:

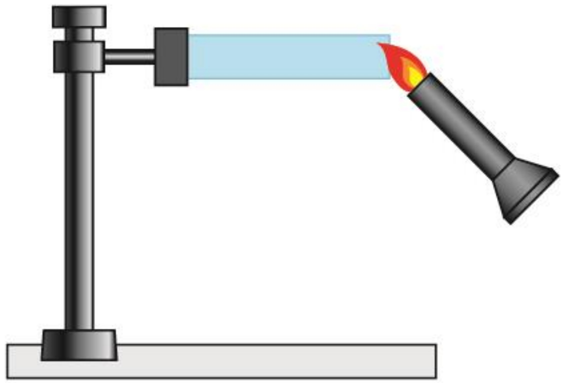
- Specific optical density (visibility) to determine smoke density and smoke growth index (VOF4) during the **first 4 minutes**
- Gas toxicity (as per sampling port) to calculate toxicity indices for asphyxiants (CO/CO_2), O_2 depletion, etc

Key test for the following sectors:

- Rail
- Maritime
- Aerospace

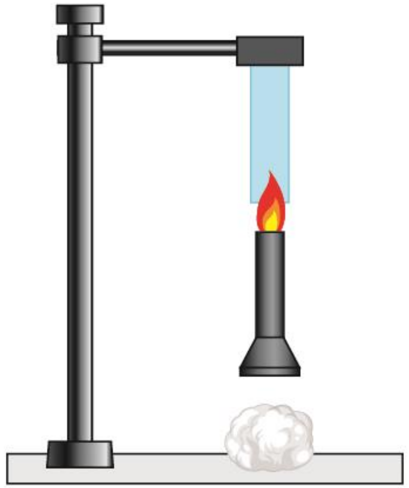
HORIZONTAL AND VERTICAL PLASTIC BURN TEST (FAR 25/UL94)

Horizontal burn



FAR 25 Pass / fail:
Flame exposure: 15s
Burn rate: < 60mm/min

Vertical burn



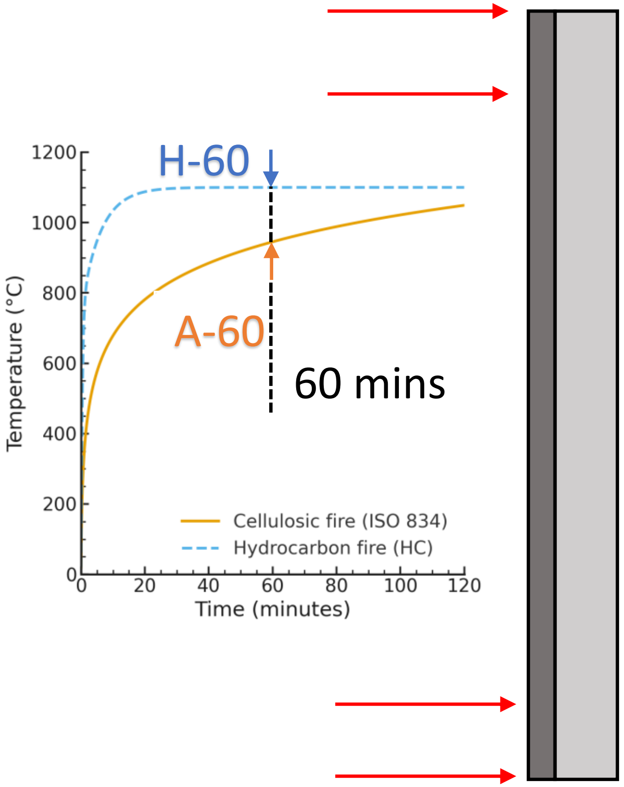
FAR 25 Pass / fail:
Flame exposure: 60s
Burn length: < 6 inch
Av after flame: < 15s
Drip flame: < 3s

Test outcomes:
- Burning time after flame removal of Bunsen burner
- Burn rate (horizontal)
- Burn length (vertical)
- Drip flame

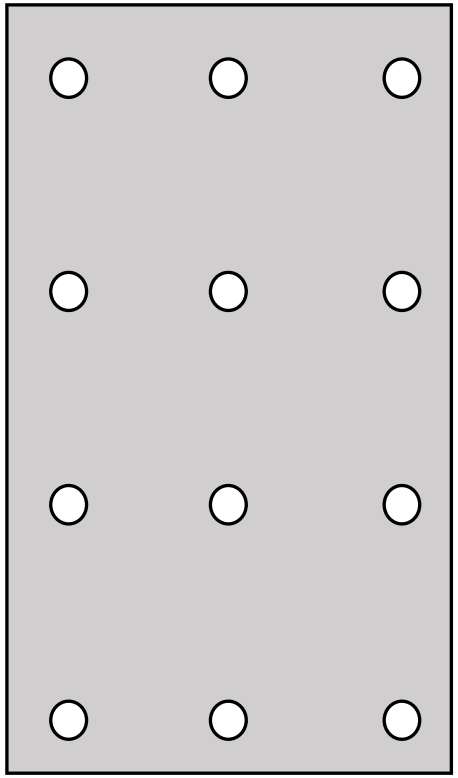
Key test method:
- Aerospace cabin interiors – all materials must pass the vertical burn test
- Related method **UL94** often quoted in material data sheets

SOLAS A-60 / H-60 Testing

Side view of panel



Back view of thermocouples



SOLAS A-60 Pass / fail:

T_{max} ≤ 180 °C T_{av} ≤ 140 °C

Test outcomes:

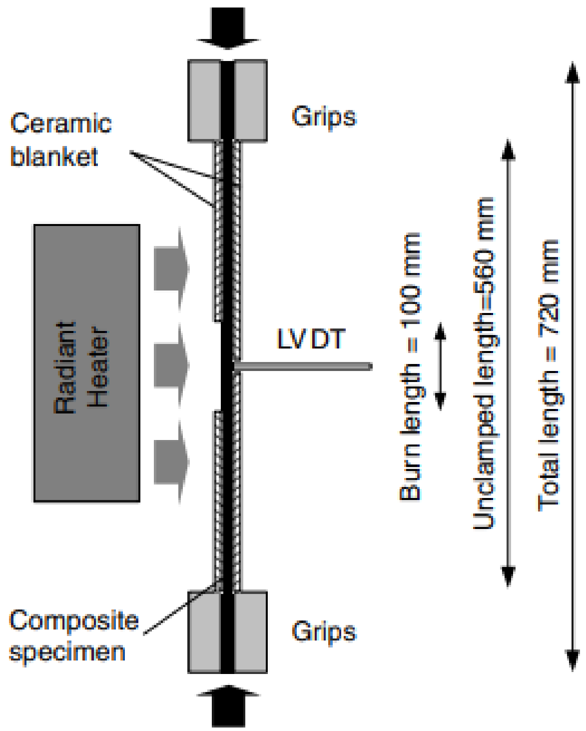
- Back face temperatures @60 mins (average and maximum)
- Structural integrity (no sustained smoke through the structure)
- Effectiveness of insulation (if applied)

Key test method:

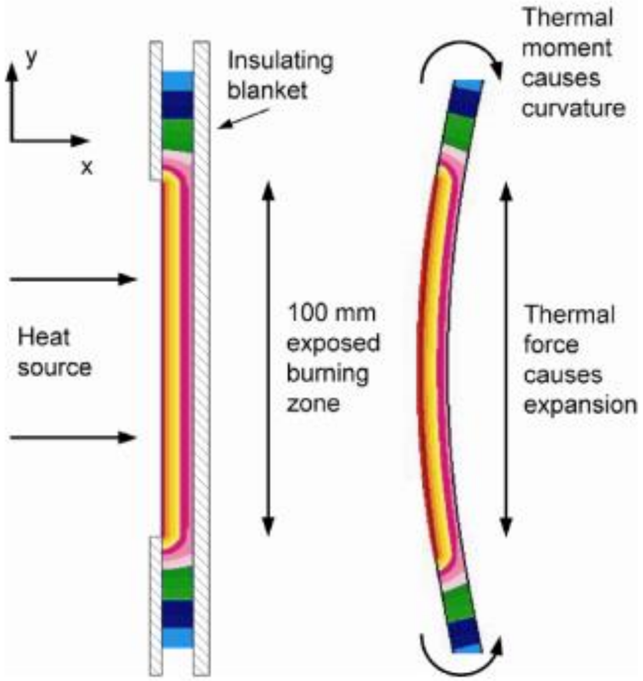
- Maritime and offshore structures (critical walls and doors)
- Building may be marketed as 'A-60' buildings, but not a substitute for building-code compliance.

FIRE UNDER LOAD TESTING

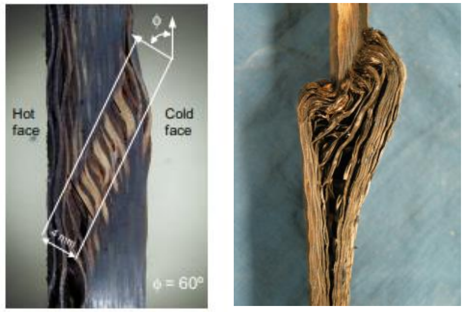
Test set-up



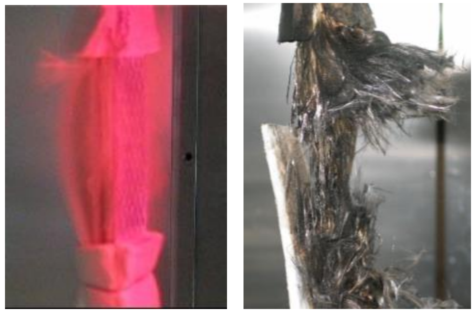
Temperature distribution



Compression failure



Tension failure



Test outcomes:

- Time-to-failure under applied load and various heat flux exposures

Key test method:

- Developed for structural assessment of maritime composite structures (RMIT Australia)

THERMAL MODELLING DURING FIRE

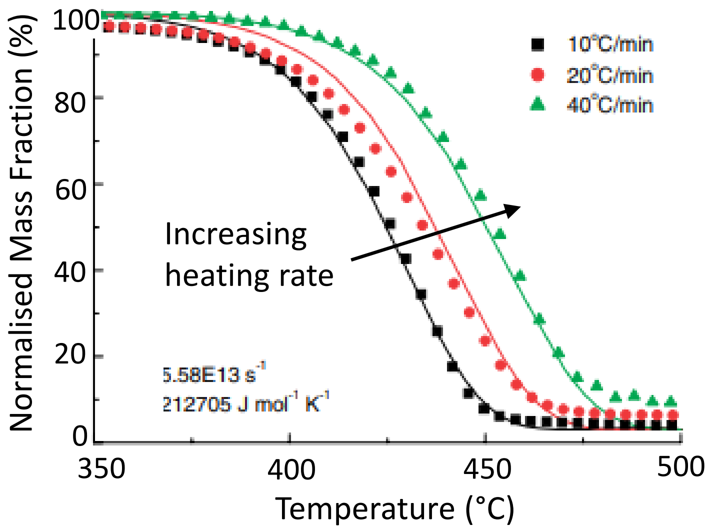
THERMAL MODELLING OF COMPOSITE MATERIALS IN FIRE

Three levers are in balance for any heating / fire scenario of combustible materials:

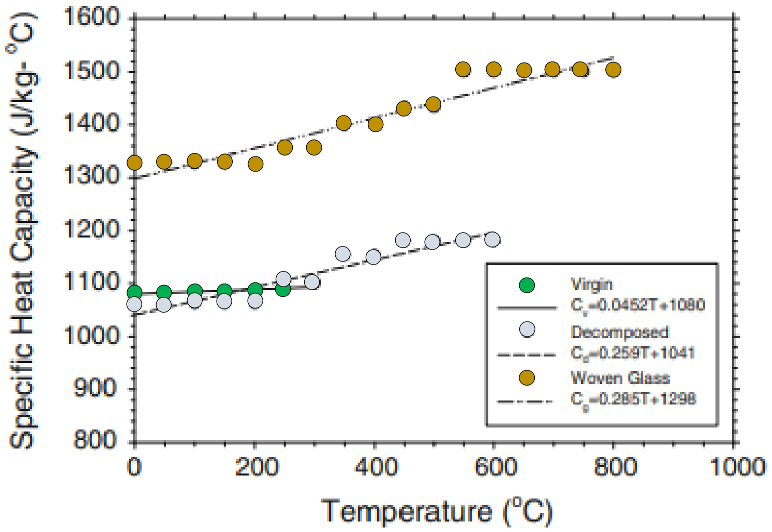
Heat Stored	=	Heat conducted through-thickness	+	Heat from decomposition
How much heat can the material store?		How fast can heat move?		How much have the resin (and the fibres) broken down?
Differential scanning calorimetry (DSC)		Laser flash analysis/ transient plane source / hot disk		Thermal gravimetric analysis (TGA)
Specific heat (temperature-dependent)		Thermal conductivity (anisotropic and temperature-dependent)		Heating rate-dependent decomposition (Arrhenius kinetics)

SPECIFIC HEAT, DEGRADATION KINETICS AND THERMAL CONDUCTIVITY

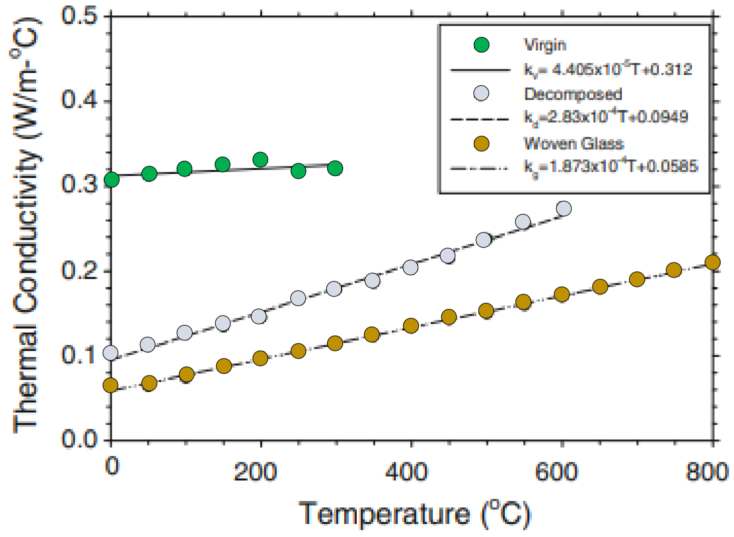
Degradation kinetics



Specific heat capacity



Through-thickness thermal conductivity



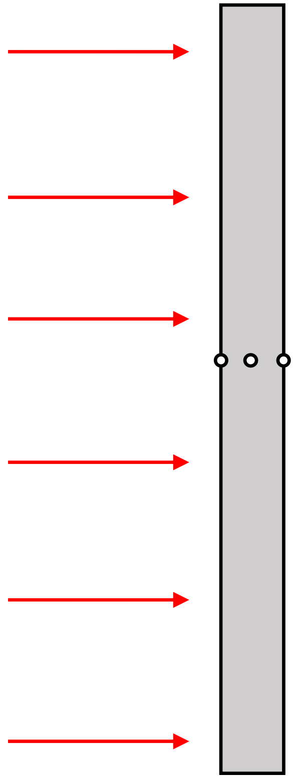
Rule-of-mixtures is assumed for transitioning material stages between virgin-to-decomposed material for specific heat capacity and thermal conductivity

S. Feih Z. Mathys, A.G. Gibson, A.P. Mouritz, Composites Science and Technology, 67, 551-564, 2007

BY Lattimer, J Oulette and J Trelles, Fire Technology, 47, 823-850, 2011

PREDICTED TEMPERATURE DISTRIBUTIONS AND MASS LOSS

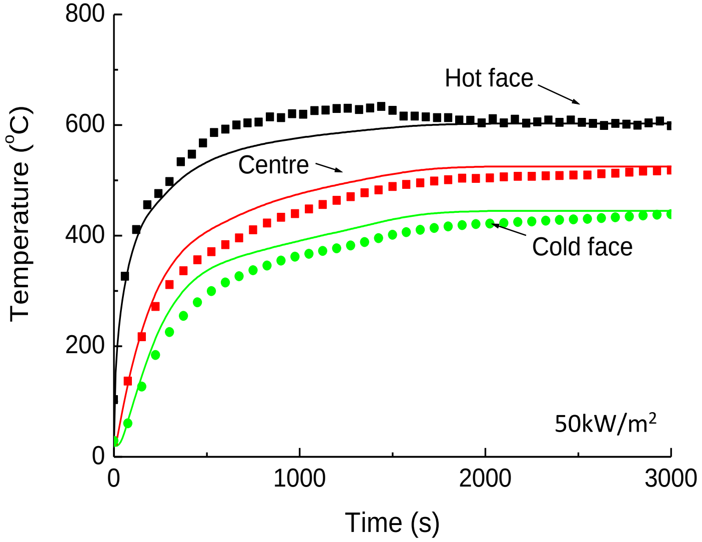
Side view of panel



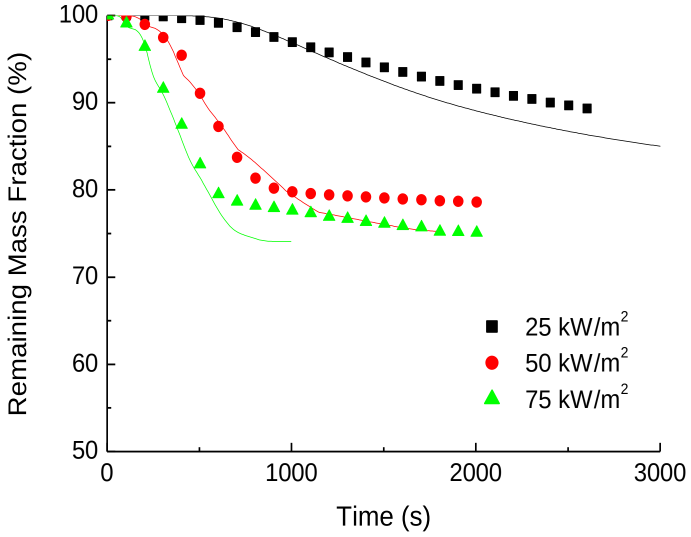
As function of time:

- Thermocouples attached and inserted into composite for temperature measurement
- Mass loss recording

Temperature distribution



Mass loss



Accurate prediction of temperature distributions and weight loss as function of heating rates and maximum temperatures

BY Lattimer, J Oulette and J Trelles, Fire Technology, 47, 823-850, 2011

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MECHANICAL MODELLING DURING FIRE

MECHANICAL MODELLING DURING FIRE

Mechanical modelling approach depends on loading conditions and underlying softening mechanisms:

Strength loss = Resin influence + Fibre influence

Strength loss

Composite failure if reduced strength < applied loads

Resin influence

- Resin type
- Loss of fibre load transfer / support ability

↓

Dominates compression loading

Fibre influence

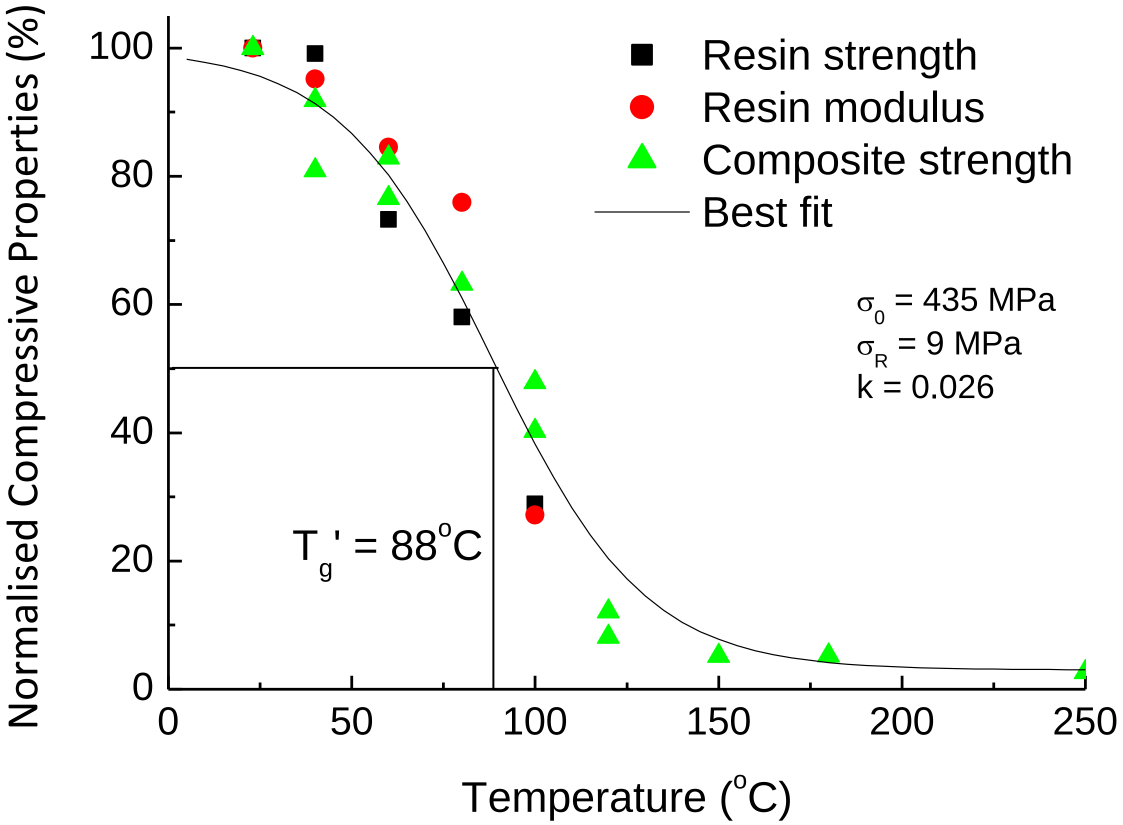
- Fibre type
- Fibre strength loss mechanism
- Resin-fibre interface degradation

↓

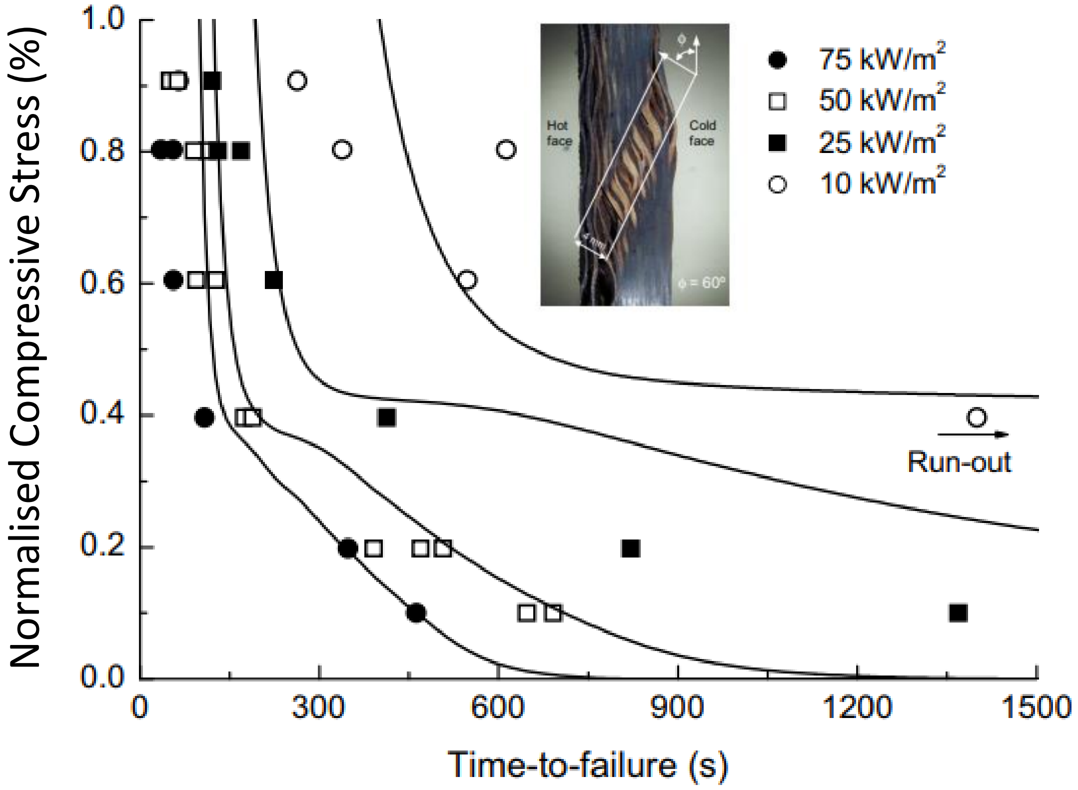
Dominates tension loading

DURING FIRE PERFORMANCE - COMPRESSION

Uniform temperature (resin-dominated)



Combined compression loading and fire

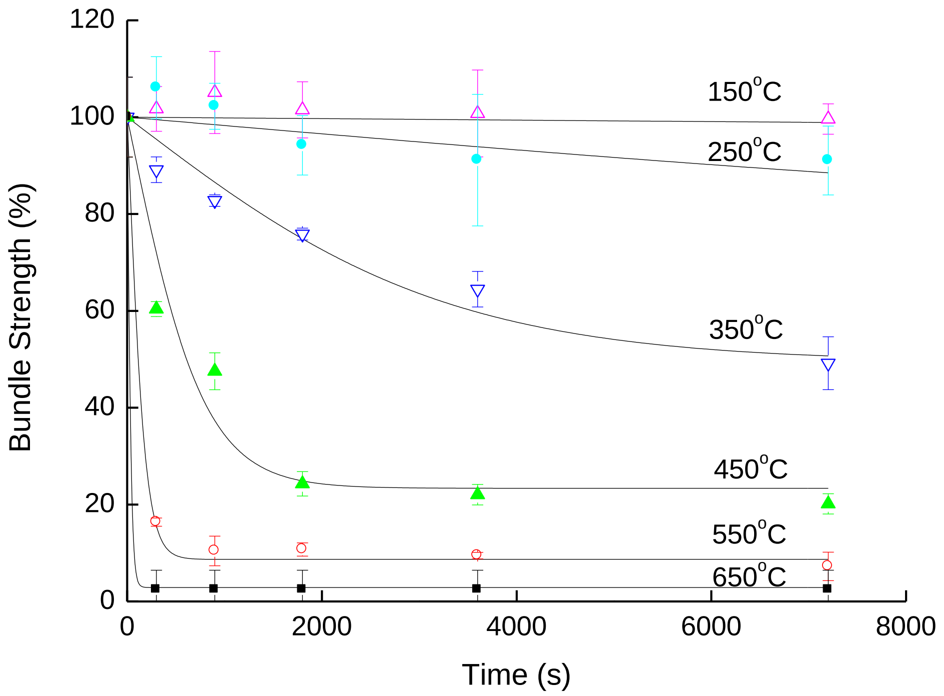


S. Feih Z. Mathys, A.G. Gibson, A.P. Mouritz, Composites: Part A, 38, 2354-2365, 2007

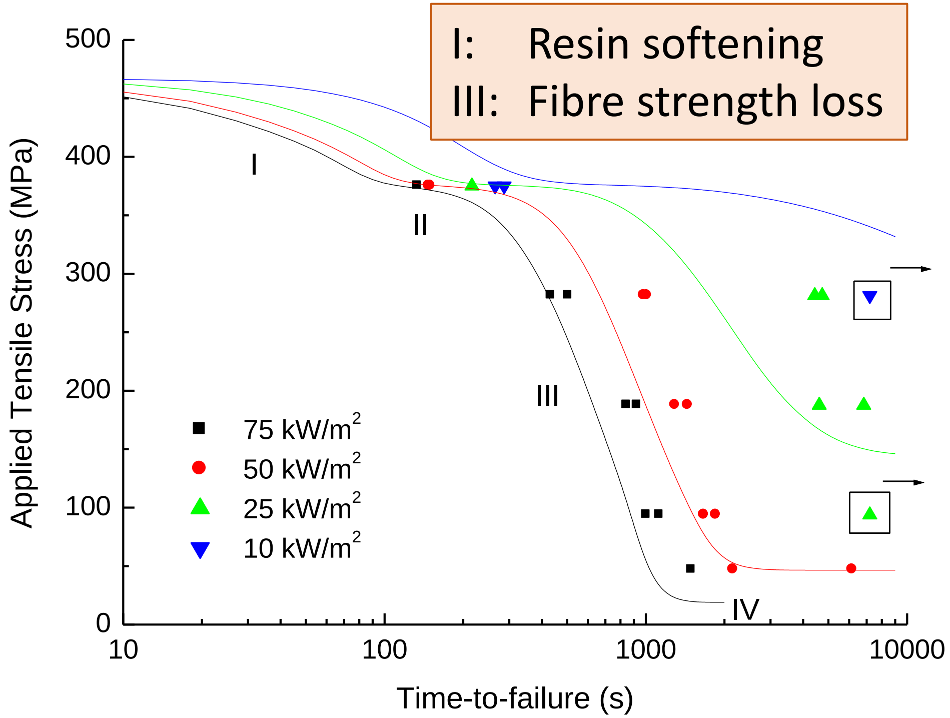
DURING FIRE PERFORMANCE - TENSION

Fibre reinforced composites survive longer during fire when loaded in tension:

Uniform temperature (fibre-dominated)



Combined tension loading and fire



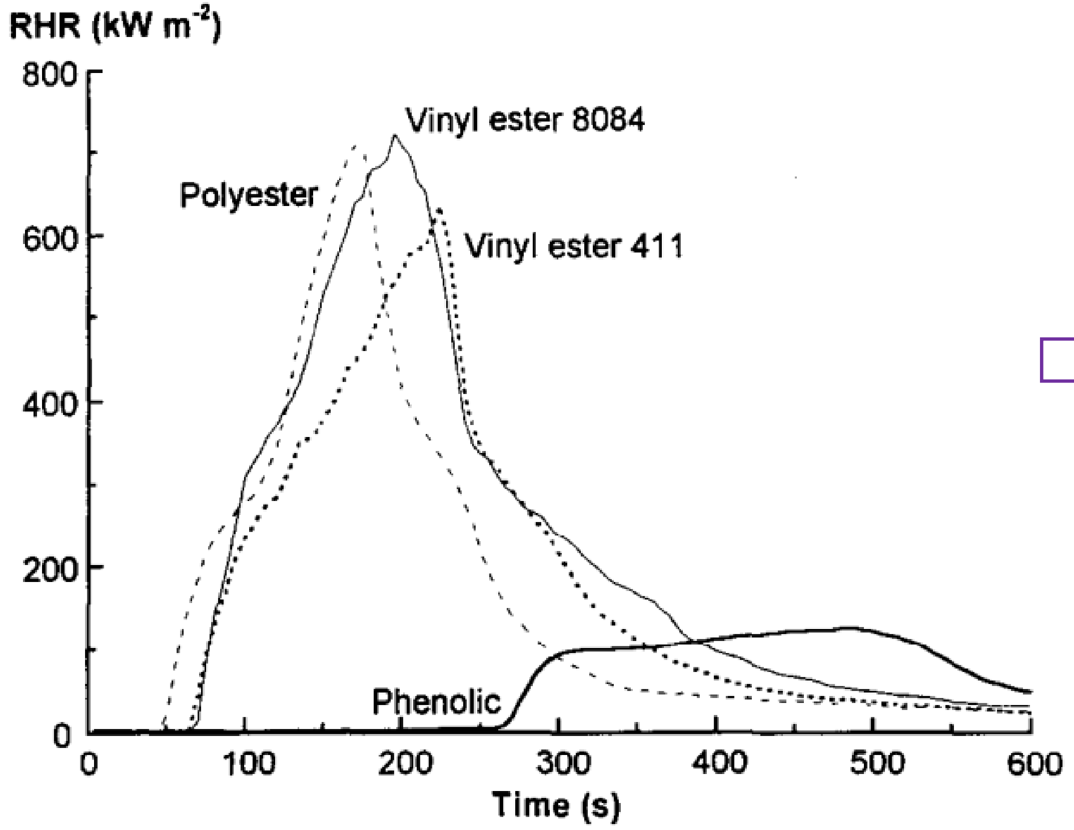
S. Feih A.P. Mouritz Z. Mathys and A.G. Gibson, Journal of Composite Materials, 41(19), 2387-2410, 2007

DESIGNING FOR FIRE SAFETY

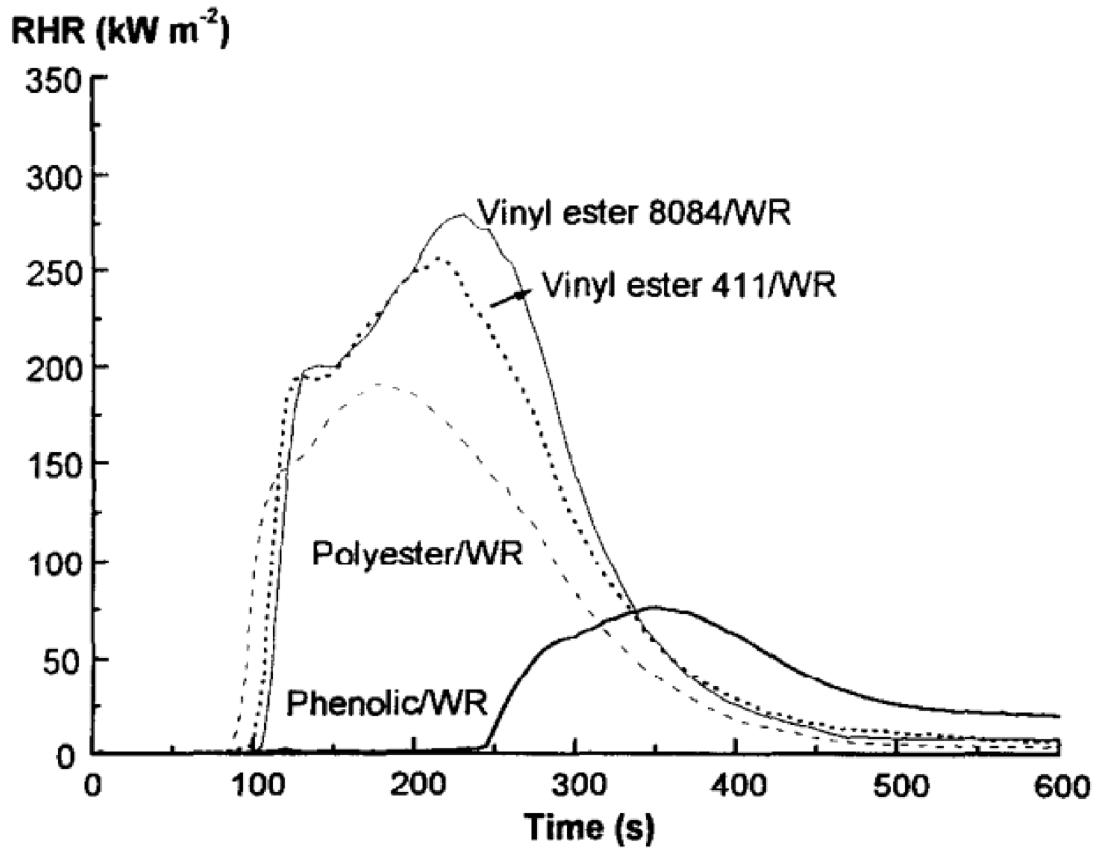
THE ROLE OF RESINS FOR COMPOSITES DURING FIRE

Composite heat release rate is dominated by the resin characteristics.

Rate of Heat Release (RHR) Pure Resin



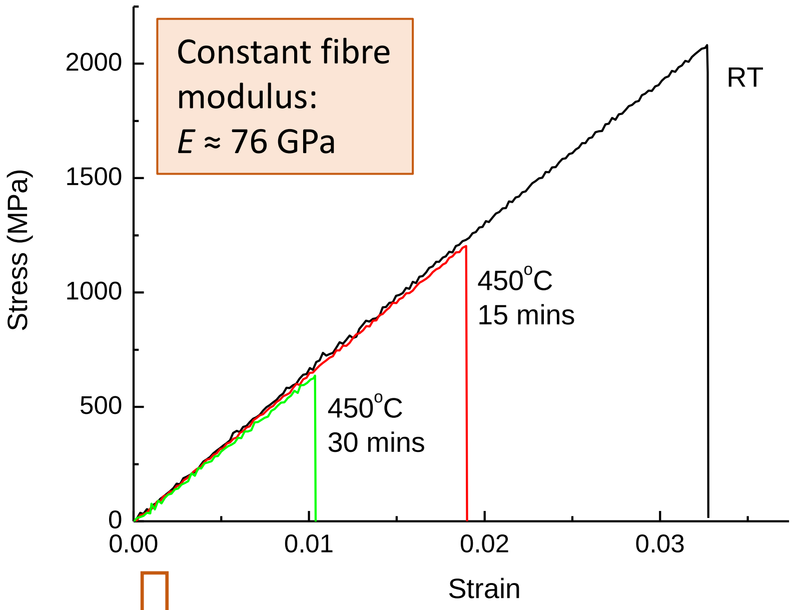
Rate of Heat Release Woven GF Composites



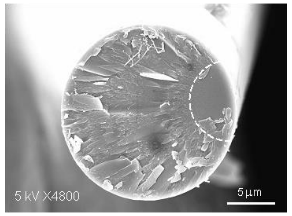
JR Brown and Z Mathys, Composites: Part A, 1997, 675-681

THE ROLE OF FIBRES FOR COMPOSITES DURING FIRE

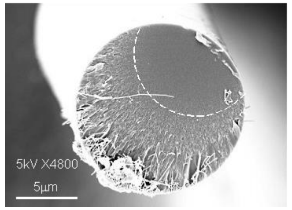
Fibre strength loss mechanisms are different and offer insights for recycling of composites.

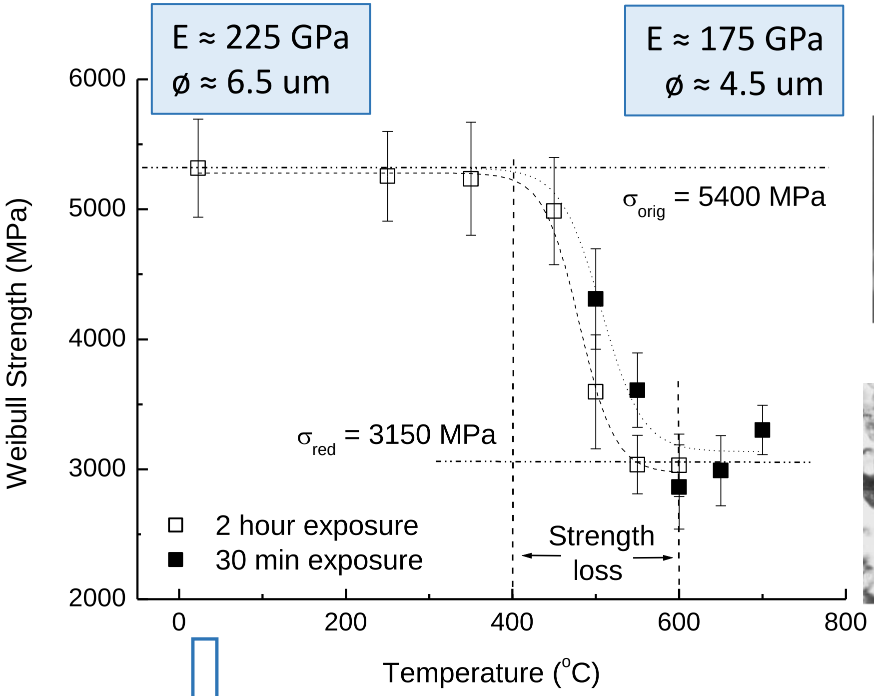


15mins 450˚C

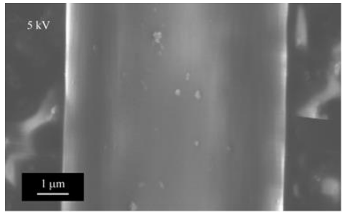


30mins 450˚C

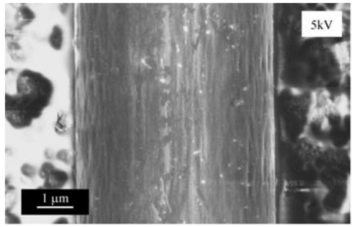




As-received



1 hour 600˚C



Flaw growth on glass fibre surface during heat exposure, diffusion-driven process

Diameter reduction accompanied by flaw growth, oxidation-driven process

S. Feih et al, Journal of Materials Science, 44, 392-400, 2009
S. Feih and AP Mouritz, Composites: Part A, 43(5), 765-772, 2012

INCREASING FLAME RETARDANCY FOR COMPOSITES (ON-GOING RESEARCH FIELD)

Inorganic Hydrates
Endothermic water release to cool and suppress smoke
Common in polyester/vinyl ester laminates and gelcoats
High loadings required, can reduce composite properties

Phosphorus-based Additives
Promotes char creation
Efficient at low to medium loadings
Go-to for epoxies / vinyl esters targeting strict FST

Nitrogen-based Additives
Gas release + intumescence synergy
Helps smoke reductions, moderate loadings

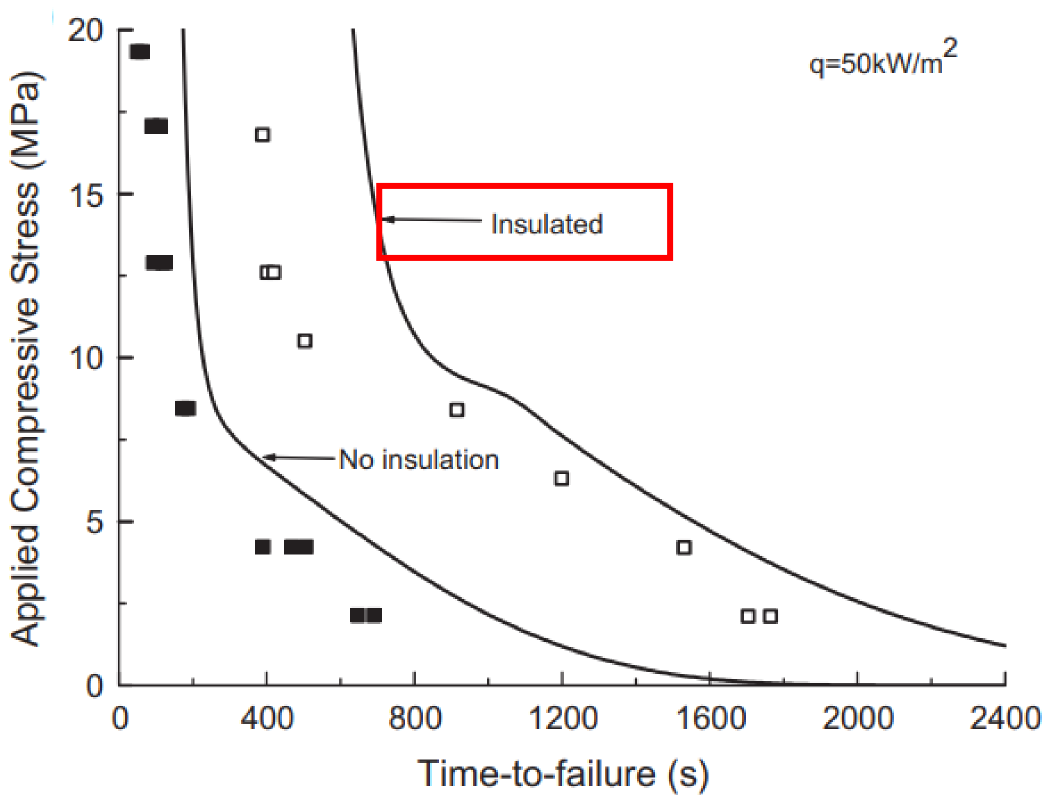
Halogenated Systems
Very effective at low loadings – but higher smoke/toxic
Being *phased out* in many specs due to health concerns

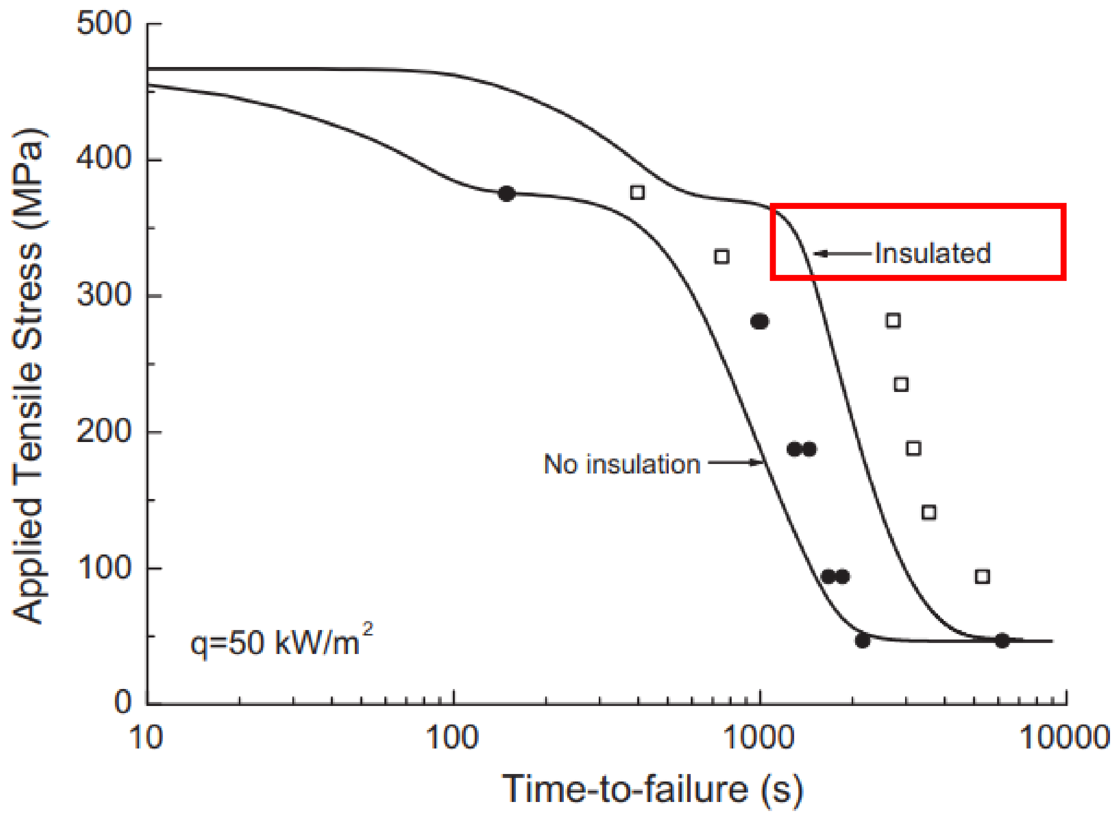
Mineral / ceramic & nano synergists
Reinforce char / barrier formation
Typically an add-on to other FR methods

Barriers and Coatings
Reduce TTI/HRR/smoke at the surface
Useful with non-phenolic resins

THE INFLUENCE OF INTUMESCENT COATINGS

Insulation protects the composite surface from heat and can significantly enhance structural survival times, as highlighted below for lightweight intumescent coatings:





Kandare et al., Composites: Part A 43 (2012) 793-802

PREFERRED SOLUTIONS BY INDUSTRY SECTOR

Maritime

Intumescent coatings, insulation for high performing composites in critical zones
Phenolics for interiors / partitions

Rail

Phenolic laminates and foams,
FR epoxies (P/N systems) for higher mechanical performance, thermoplastic systems

Aerospace

Interior: Phenolic skins/cores, P-modified epoxies and smoke-suppressant synergists
Structures: Epoxies (primary), BMI/cyanate esters for hot zones, high performance thermoplastics for clips/brackets

Building and Construction

Polyester / vinyl ester pultrusion with inorganic hydrates
Epoxy/CFRP with FR gelcoats/barriers
Low smoke solutions preferred

Phenolics where regulations are very strict, else P/N + barriers to make epoxy / vinyl ester work
Avoid halogens due to smoke/tox/regulatory pressure

CONCLUSIONS

- A wide range of industry sector specific standards exist for assessing fire safety for composite materials.
- Testing methods and modelling concepts to assess critical fire performance are established for realistic, yet simplified scenarios during initial fire spreading.
- Glass and carbon fibre reinforced composite materials based on epoxy and vinyl ester resins generally require insulation to pass stringent fire safety tests.
- Some resin systems, i.e., phenolic resins, possess significantly improved flammability resistance, but their mechanical properties are lower.
- Resin systems can be formulated to contain ignition-delaying & smoke-reducing additives, but these can result in adverse health effects, especially in the case of brominated flame retardants (BFRs) which are being phased out across all sectors.
- Fibre performance under fire has produced insightful data relevant to composite recycling.

ACKNOWLEDGEMENTS

Professor Arthur Geoff Gibson (1946 - 2021)

Professor Adrian Mouritz (1963 - 2023)

Australian Government
Department of Defence
Defence Science and
Technology Organisation

RMIT UNIVERSITY

Newcastle University

VirginiaTech

EMPA
Materials Science & Technology

Thank you for joining us!

Keep an eye out for upcoming AIM events:

Material-extrusion Additive Manufacturing of Thermoplastic-based Composites
Hosted by Dr. Daniel Therriault
October 29, 2025
https://compositeskn.org/KPC/A327

And don't forget to visit the KPC for more information:

https://compositeskn.org/KPC

Today's Webinar will be posted at:
https://compositeskn.org/KPC/A395

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