Intumescent coatings

The art of baking, cooking, burning, and melting paint

Cristian Maluk

Structures in Fire Forum
29th September 2022 (IStructE HQ)S

Semper

The University Of Queensland
AUSTRALIA

One problem...several solutions


Concrete encasement


Flexible blankets


Board systems


Spray-on systems (cementitious)


Intumescent coatings

Intumescent coatings used in the built environment

In reference to thin intumescent coatings…

These offer a competitive advantage over other fire engineering solutions are mainly the following:

- Little constrain to architectural vision
- Ease of application (compared to other solutions)
- On-site or off-site application

The Gherkin (London)

Thin intumescent coatings used in the built environment

Amazon’s Fulfilment Centre (Dunfermline, Scotland)

How intumescent coatings came to be?

- The basic principle is that of a paint that when heated will swell (i.e., increase in volume and therefore decrease in density) resulting in a thermal 'buffer' media between the source(s) of heat and the substrate painted.

- There are four main ingredients in a water-based intumescent coating:
  - Acid donor
  - Carbon source
  - Blowing agent
  - Binding polymer
  - Flame retardants (opt.)
  - Fibres (opt.)

- Choice of ingredients and ratios is key in the overall performance during application, normal service conditions, and during a fire.

How intumescent coatings came to be?

United States Patent Office

3,654,190

Patented Apr. 4, 1972

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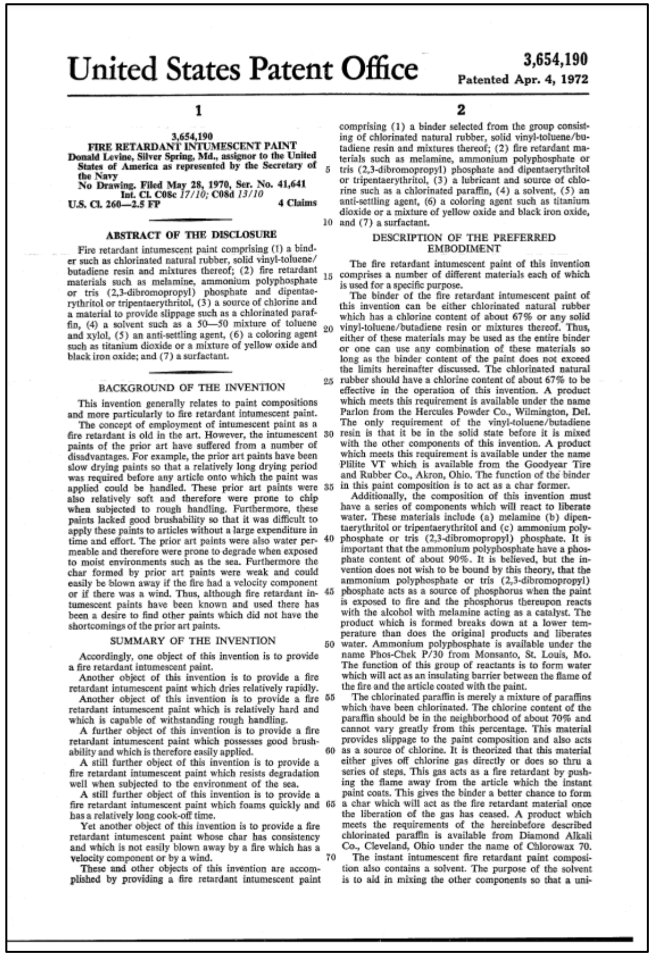
FIRE RETARDANT INTUMESCENT PAINT

Donald Levine, Silver Spring, Md., assignor to the United States of America as represented by the Secretary of the Navy

No Drawing. Filed May 28, 1970, Ser. No. 41,641

Int. Cl. C08c *17/10;* C08d *13/10*

U.S. Cl. 260—2.5 FP 4 Claims



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ABSTRACT OF THE DISCLOSURE

Fire retardant intumescent paint comprising (1) a binder such as chlorinated natural rubber, solid vinyl-toluene/butadiene resin and mixtures thereof; (2) fire retardant materials such as melamine, ammonium polyphosphate or tris (2,3-dibromopropyl) phosphate and dipentaerythritol or tripentaerythritol, (3) a source of chlorine and a material to provide slippage such as a chlorinated paraffin, (4) a solvent such as a 50—50 mixture of toluene and xylol, (5) an anti-settling agent, (6) a coloring agent such as titanium dioxide or a mixture of yellow oxide and black iron oxide; and (7) a surfactant.

BACKGROUND OF THE INVENTION

This invention generally relates to paint compositions and more particularly to fire retardant intumescent paint.

The concept of employment of intumescent paint as a fire retardant is old in the art. However, the intumescent paints of the prior art have suffered from a number of disadvantages. For example, the prior art paints have been slow drying paints so that a relatively long drying period was required before any article onto which the paint was applied could be handled. These prior art paints were also relatively soft and therefore were prone to chip when subjected to rough handling. Furthermore, these paints lacked good brushability so that it was difficult to apply these paints to articles without a large expenditure in time and effort. The prior art paints were also water permeable and therefore were prone to degrade when exposed to moist environments such as the sea. Furthermore the char formed by prior art paints were weak and could easily be blown away if the fire had a velocity component or if there was a wind. Thus, although fire retardant intumescent paints have been known and used there has been a desire to find other paints which did not have the shortcomings of the prior art paints.

SUMMARY OF THE INVENTION

Accordingly, one object of this invention is to provide a fire retardant intumescent paint.

Another object of this invention is to provide a fire retardant intumescent paint which dries relatively rapidly.

Another object of this invention is to provide a fire retardant intumescent paint which is relatively hard and which is capable of withstanding rough handling.

A further object of this invention is to provide a fire retardant intumescent paint which possesses good brushability and which is therefore easily applied.

A still further object of this invention is to provide a fire retardant intumescent paint which resists degradation well when subjected to the environment of the sea.

A still further object of this invention is to provide a fire retardant intumescent paint which foams quickly and has a relatively long cook-off time.

Yet another object of this invention is to provide a fire retardant intumescent paint whose char has consistency and which is not easily blown away by a fire which has a velocity component or by a wind.

These and other objects of this invention are accomplished by providing a fire retardant intumescent paint

2

comprising (1) a binder selected from the group consisting of chlorinated natural rubber, solid vinyl-toluene/butadiene resin and mixtures thereof; (2) fire retardant materials such as melamine, ammonium polyphosphate or tris (2,3-dibromopropyl) phosphate and dipentaerythritol or tripentaerythritol, (3) a lubricant and source of chlorine such as a chlorinated paraffin, (4) a solvent, (5) an anti-settling agent, (6) a coloring agent such as titanium dioxide or a mixture of yellow oxide and black iron oxide, and (7) a surfactant.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The fire retardant intumescent paint of this invention comprises a number of different materials each of which is used for a specific purpose.

The binder of the fire retardant intumescent paint of this invention can be either chlorinated natural rubber which has a chlorine content of about 67% or any solid vinyl-toluene/butadiene resin or mixtures thereof. Thus, either of these materials may be used as the entire binder or one can use any combination of these materials so long as the binder content of the paint does not exceed the limits hereinafter discussed. The chlorinated natural rubber should have a chlorine content of about 67% to be effective in the operation of this invention. A product which meets this requirement is available under the name Parlon from the Hercules Powder Co., Wilmington, Del. The only requirement of the vinyl-toluene/butadiene resin is that it be in the solid state before it is mixed with the other components of this invention. A product which meets this requirement is available under the name Plilite VT which is available from the Goodyear Tire and Rubber Co., Akron, Ohio. The function of the binder in this paint composition is to act as a char former.

Additionally, the composition of this invention must have a series of components which will react to liberate water. These materials include (a) melamine (b) dipentaerythritol or tripentaerythritol and (c) ammonium polyphosphate or tris (2,3-dibromopropyl) phosphate. It is important that the ammonium polyphosphate have a phosphate content of about 90%. It is believed, but the invention does not wish to be bound by this theory, that the ammonium polyphosphate or tris (2,3-dibromopropyl) phosphate acts as a source of phosphorus when the paint is exposed to fire and the phosphorus thereupon reacts with the alcohol with melamine acting as a catalyst. The product which is formed breaks down at a lower temperature than does the original products and liberates water. Ammonium polyphosphate is available under the name Phos-Chek P/30 from Monsanto, St. Louis, Mo. The function of this group of reactants is to form water which will act as an insulating barrier between the flame of the fire and the article coated with the paint.

The chlorinated paraffin is merely a mixture of paraffins which have been chlorinated. The chlorine content of the paraffin should be in the neighborhood of about 70% and cannot vary greatly from this percentage. This material provides slippage to the paint composition and also acts as a source of chlorine. It is theorized that this material either gives off chlorine gas directly or does so thru a series of steps. This gas acts as a fire retardant by pushing the flame away from the article which the instant paint coats. This gives the binder a better chance to form a char which will act as the fire retardant material once the liberation of the gas has ceased. A product which meets the requirements of the hereinbefore described chlorinated paraffin is available from Diamond Alkali Co., Cleveland, Ohio under the name of Chlorowax 70.

The instant intumescent fire retardant paint composition also contains a solvent. The purpose of the solvent is to aid in mixing the other components so that a uni-

How intumescent coatings came to be?

- Although the initial development of a formulation is done in the "chemistry lab" – refinement takes place using a fire resistance furnace testing.
- Testing of intumescent paints using the fire resistance furnaces happens in two ways (as far as I know):
  - Steel plates (with adiabatic conditions at the back of the tested plates) or
  - Range of steel cross-sections (section factor – A/V) heated from all sides
- The above is done for a range of Dry Film Thickness (DFTs) and (at the most) a handful of temperature-time standard curves.
- **Are we all ok with this approach?**

Acknowledgements (ppl who actually did the work)

Dr Andrea Lucherini
FRISSBE (Slovenia)

Rosy Hartl
ARUP (Melbourne)

Nemer Abusamha
INRAE (France)

Diana Bejarano
PhD Candidate (UQ)

Jupiter Segall-Brown
ARUP (Sydney)

Ivan Lam
AECOM (Brisbane)

Stavros Spyridakis
PhD Candidate (UQ)

Research team with a mission

Learn from "failure"

Not to only focus on the several instances for which intumescent coatings might work 'very well', but investigate the fire scenarios and design conditions for which we things might not work out as expected.

Willis Tower (formerly Sears Tower)

Fire Literacy in Structural Engineering

"When structures do fail in fire it is usually for reasons that would not (or could not) have been expected on the basis of the structural fire engineering design or analysis"

- Paraphrasing from multiple authors, colleagues, myself

Brisbane Skytower – a.k.a. Christmas bon-bon

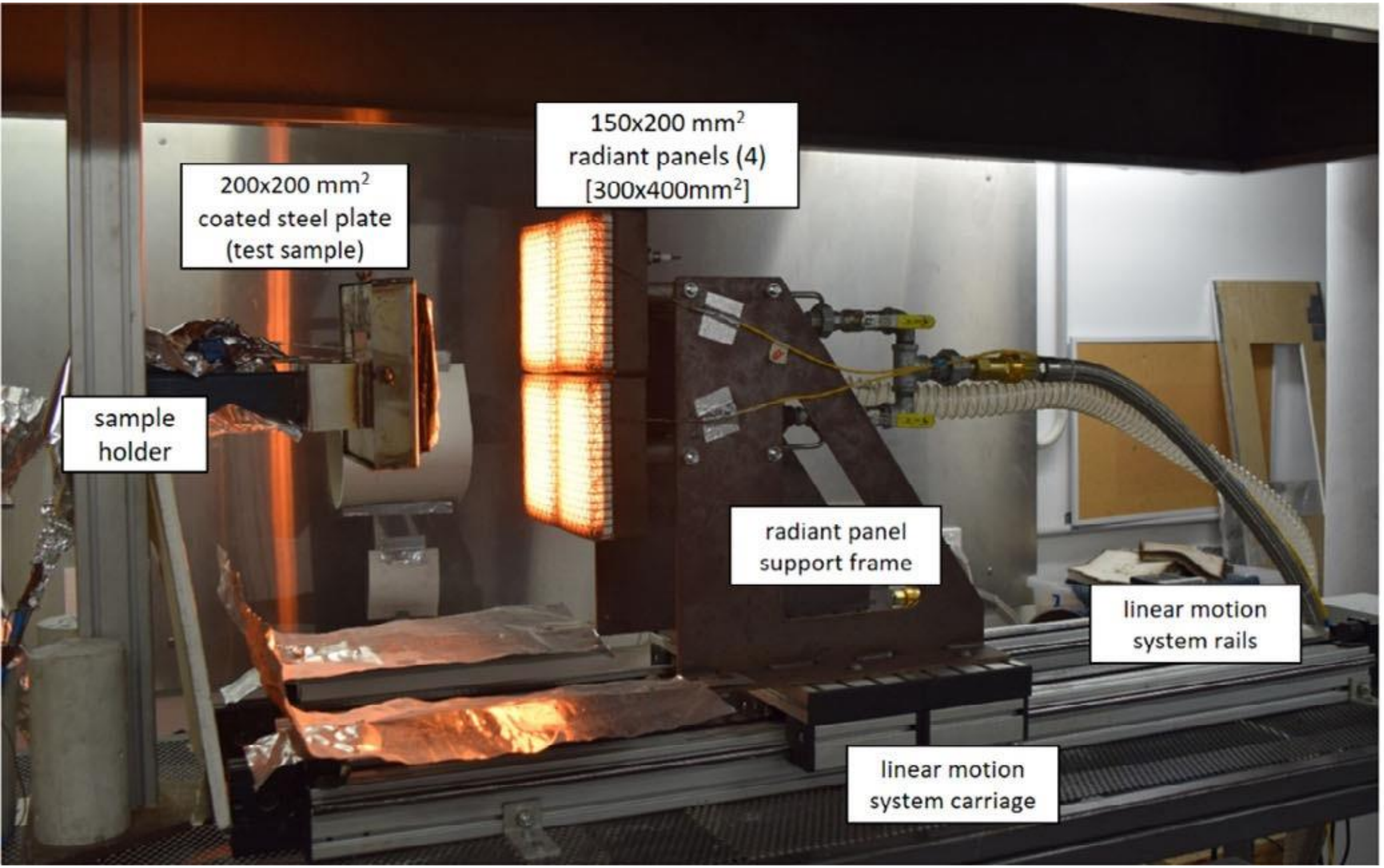
Fire Literacy in Structural Engineering

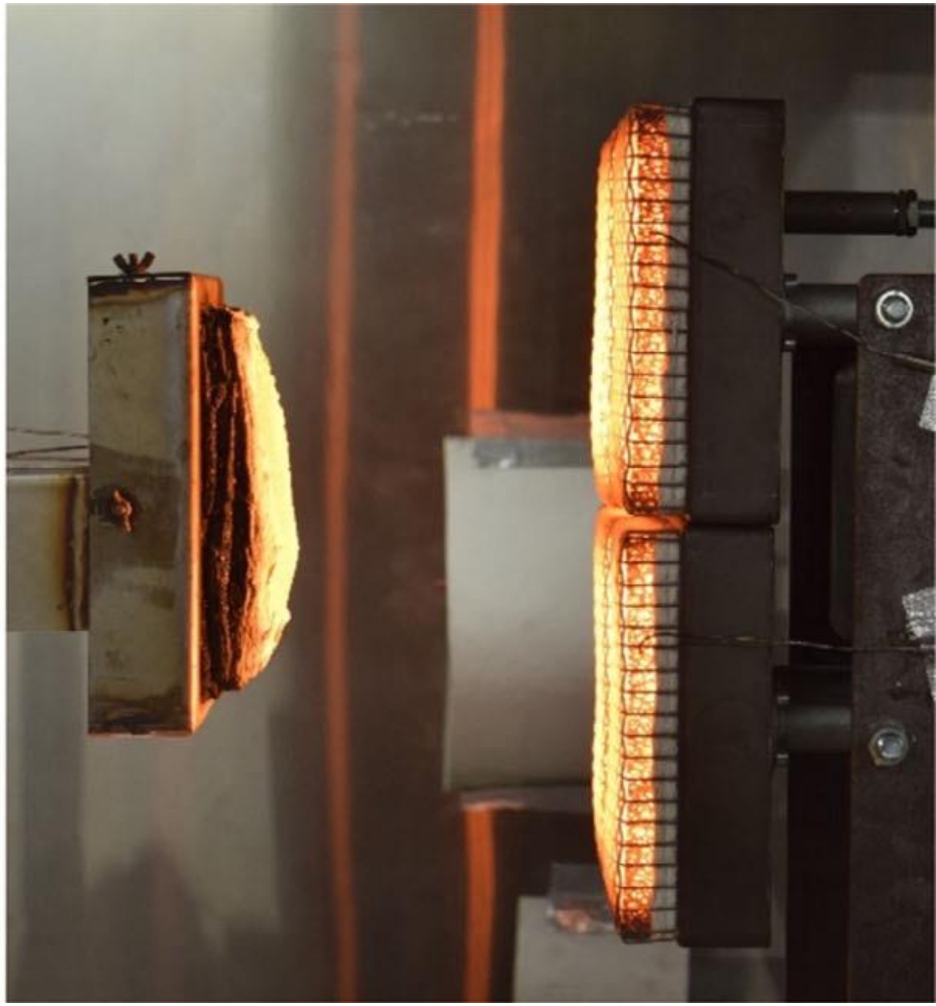
Structural Model / Fire Model		Materials & Partial Elements	Single Elements	Sub-Frame Assemblies	Transiently Simulated Restrained Assemblies	Real Structures
Elevated Temperature Exposures (transient or steady-state)	Steady-state / Transient-state	38 Generate design/model input data	5	5		9a - 9b
Standard Fires	ISO 834	Generate design input data	**23 - 24 - 26 27 - 41** Standard fire resistance tests	1 - 3 - 10 18 - 21 - 22 28 - 29 - 39	36 - 39 - 40	2 - 14
Equivalent Fire Severity to a Standard Fire	ISO 834	Validation of fire severity concept	41 Fire resistance ratings (using alternative severety metrics)	34 - 39 - 43	39 - 40	4 - 12
Parametrically Defined Model Fires	Fire = f( )	Generate design input data	25	19 - 39	39	9c - 9d - 9e 15
Localised Fires		Generate design input data				13
Zone Model Defined		Research		35		
Field Model Defined		Research				
Real Fires	Real fire	22 Research	30 - 31	6 - 7 - 8 - 11 17 - 20 - 32 33 - 37 - 42		**9f - 16 - 42** REAL behaviour in a REAL fire

Bisby, L., Gales, J. & Maluk, C. Fire Sci Rev (2013) 2: 1.
https://doi.org/10.1186/2193-0414-2-1

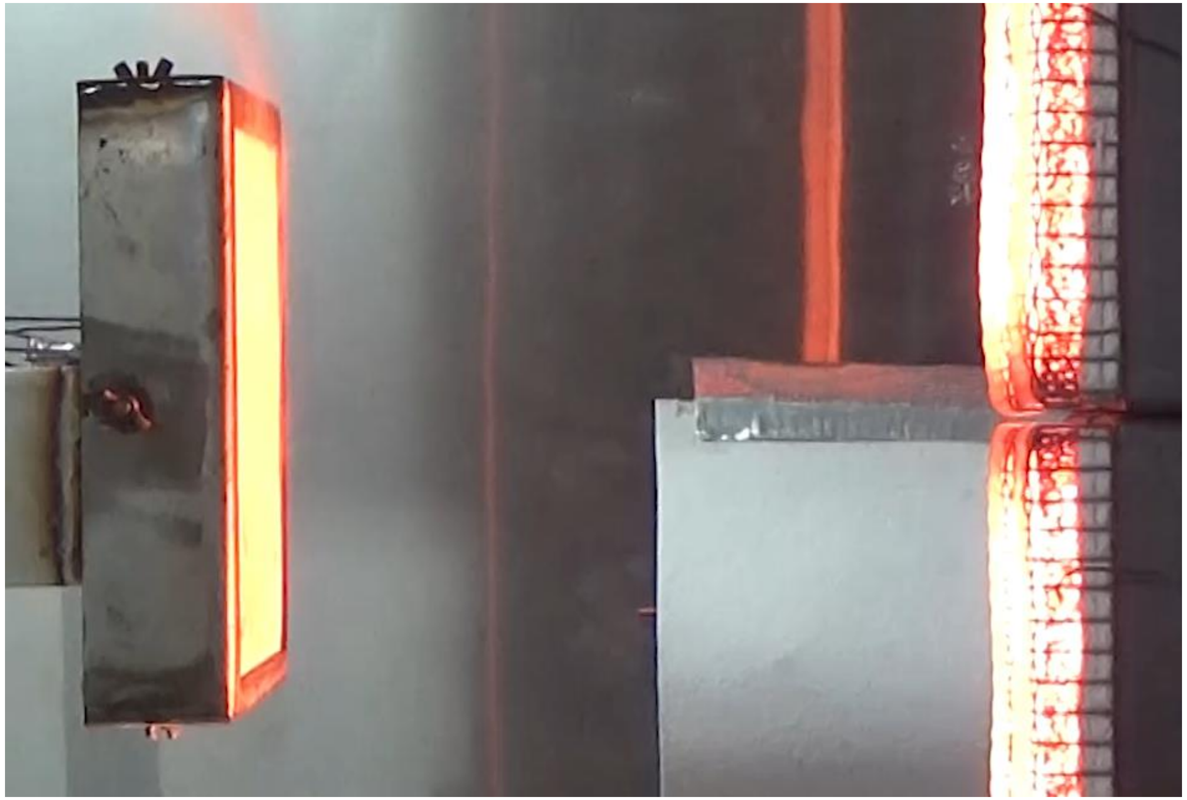
Key research outcomes

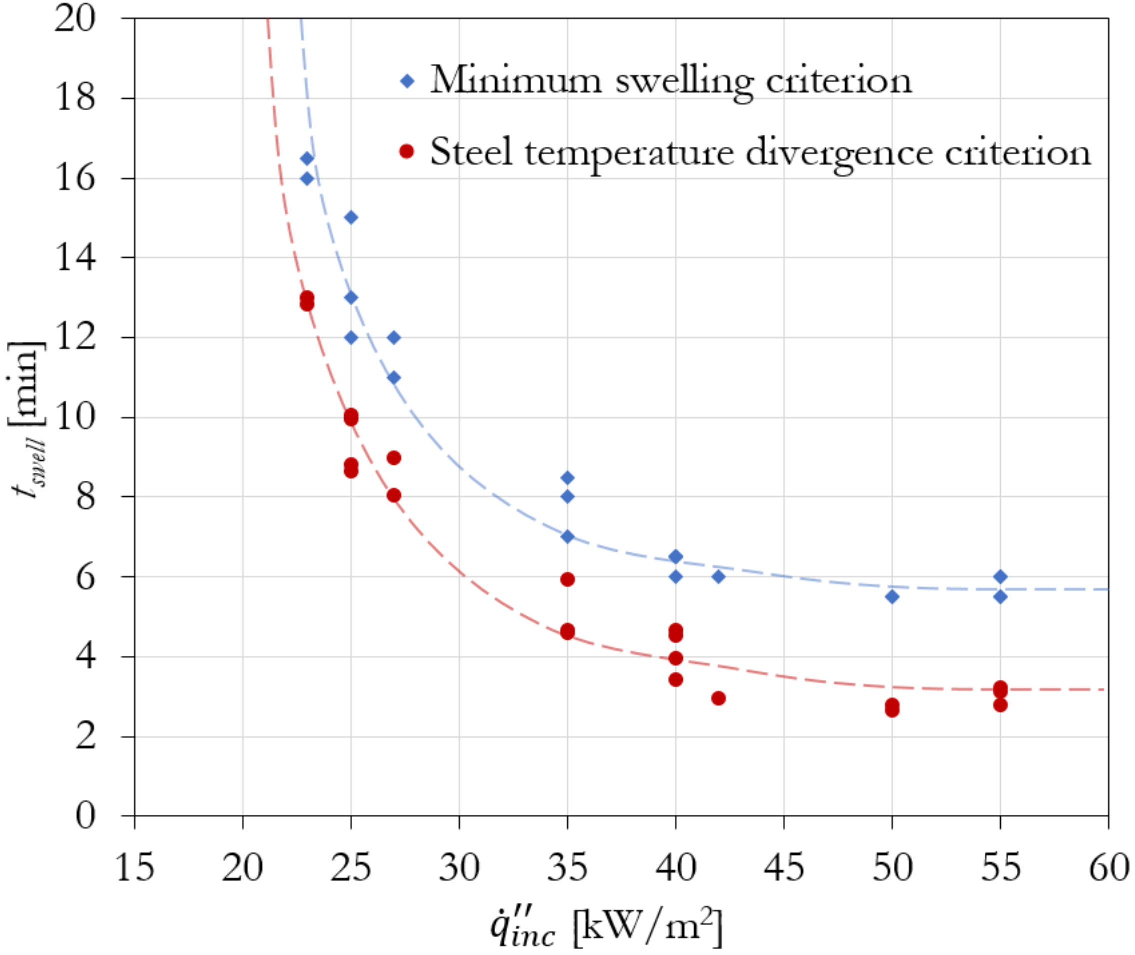
Heat Transfer Rate Inducing System (H-TRIS)





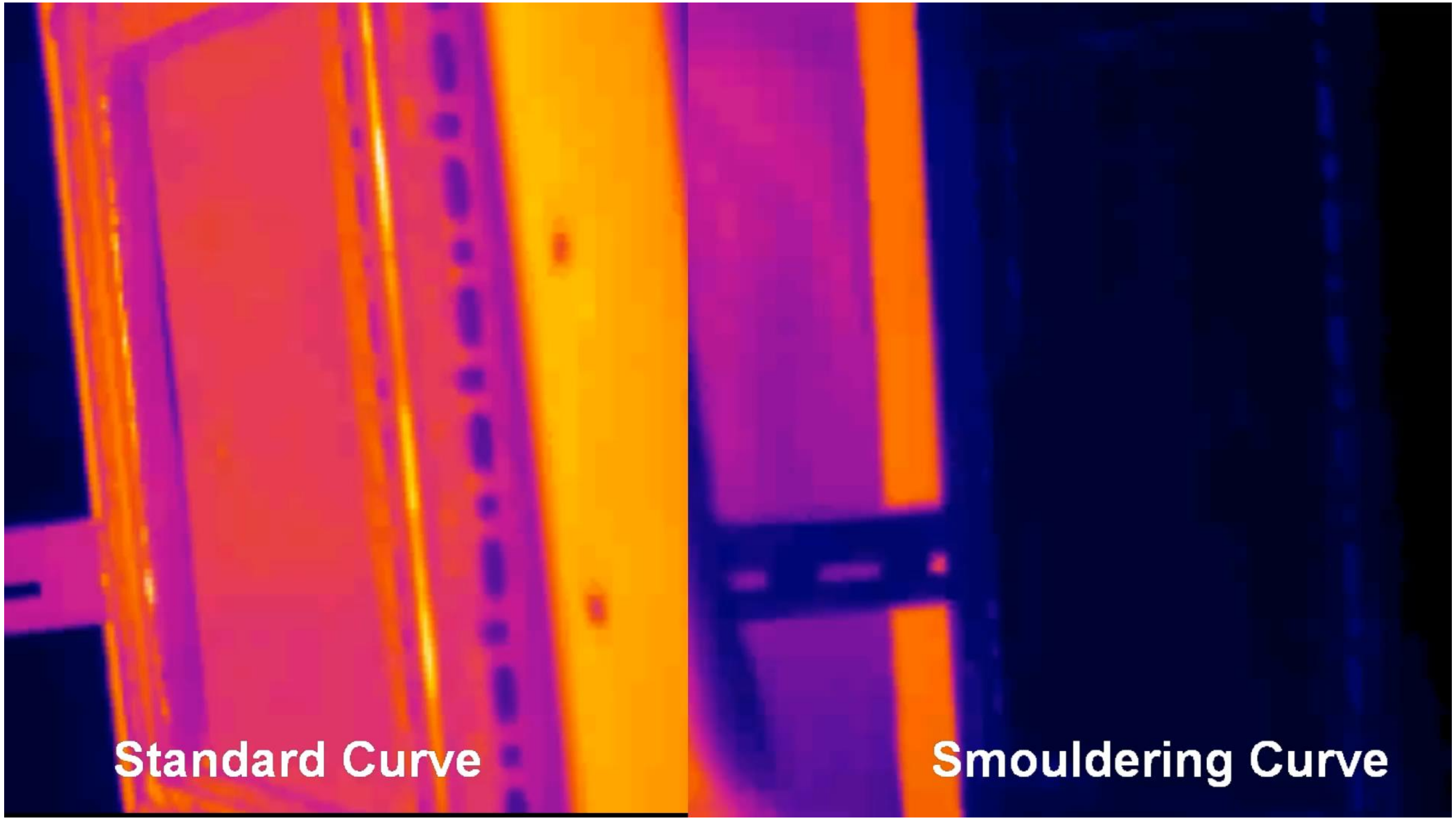
Critical heat flux for onset of swelling





Dr Andrea Lucherini - Fundamentals of thin intumescent coatings for the design of fire-safe structures
https://doi.org/10.14264/uql.2020.1021

Sensitivity of swelling and heating to the fire scenario



Elliot A, Temple A, Maluk C, Bisby L - Novel Testing to Study the Performance of Intumescent Coatings under Non-Standard Heating Regimes

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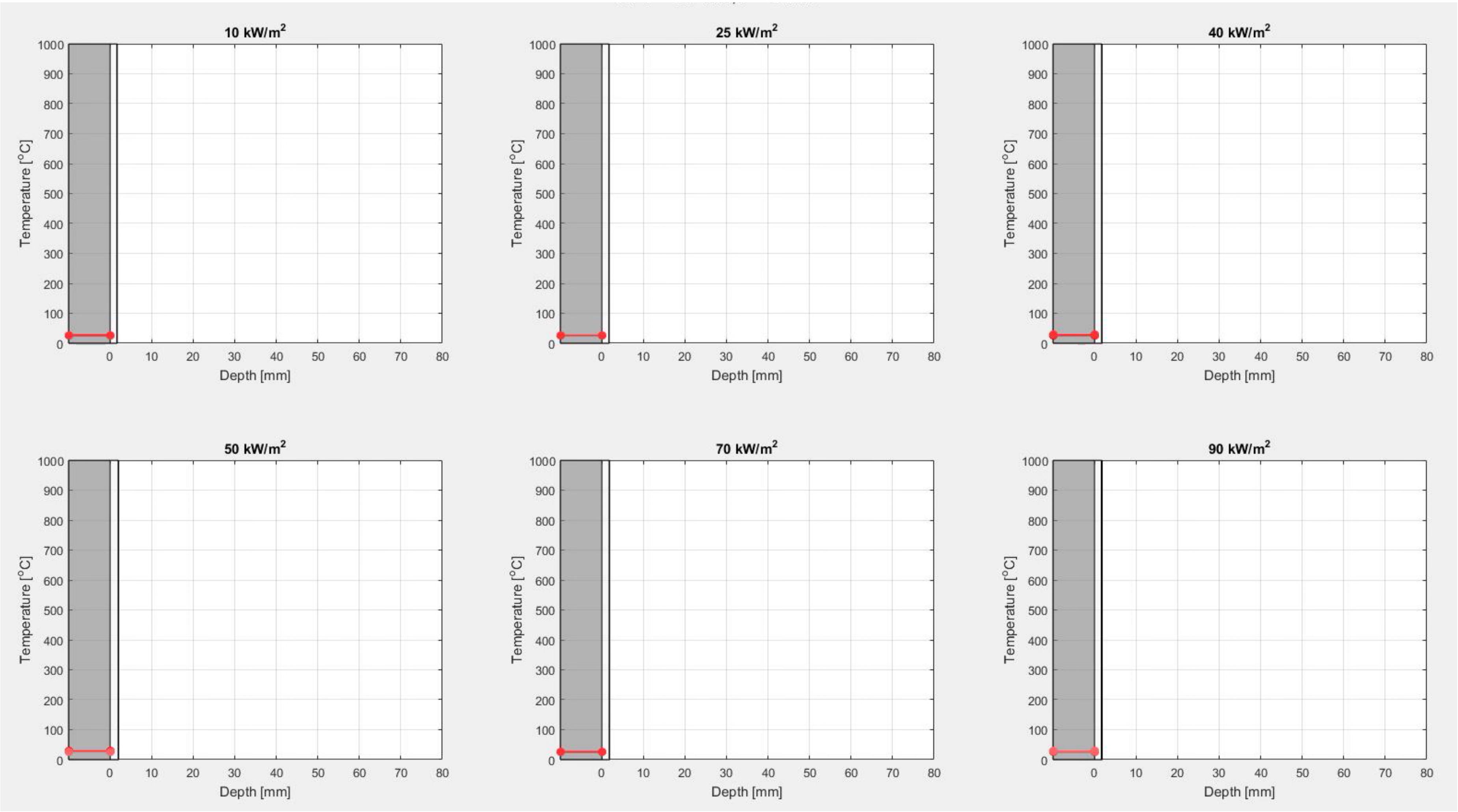

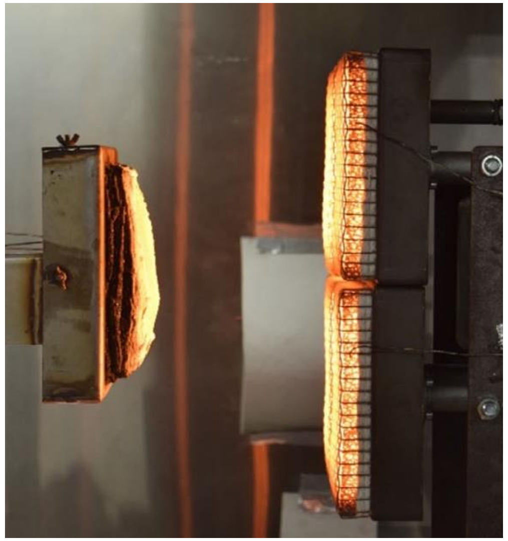

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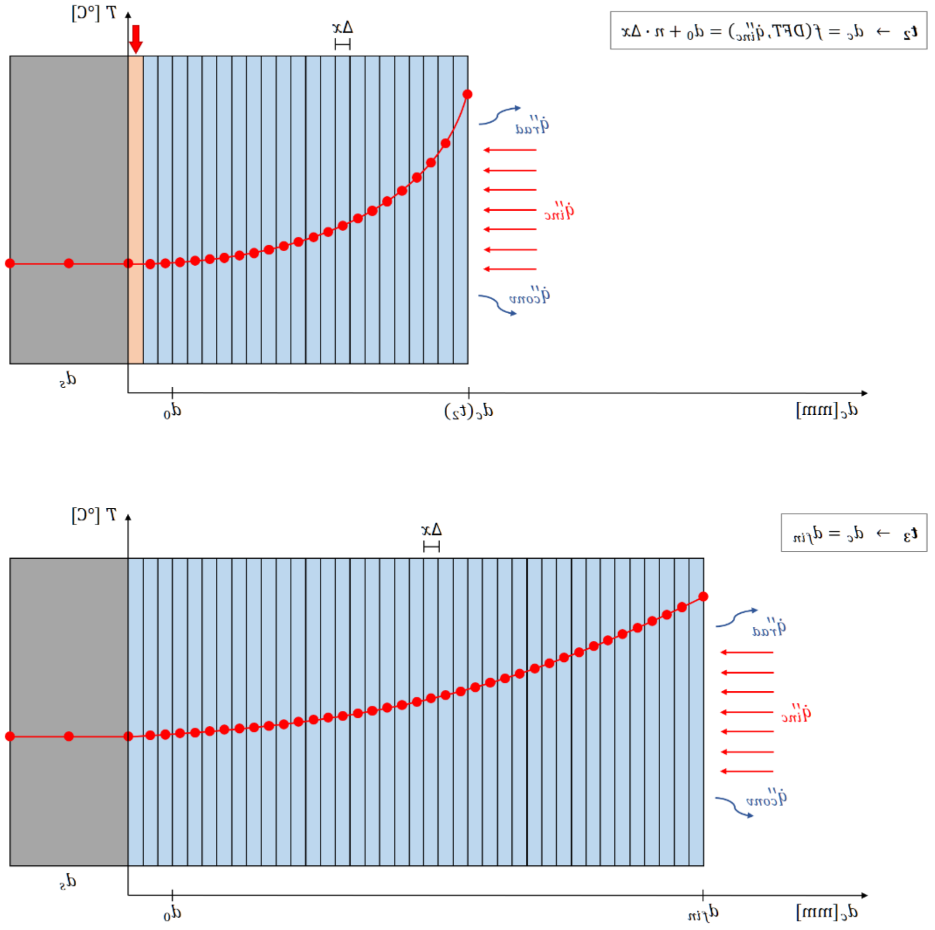
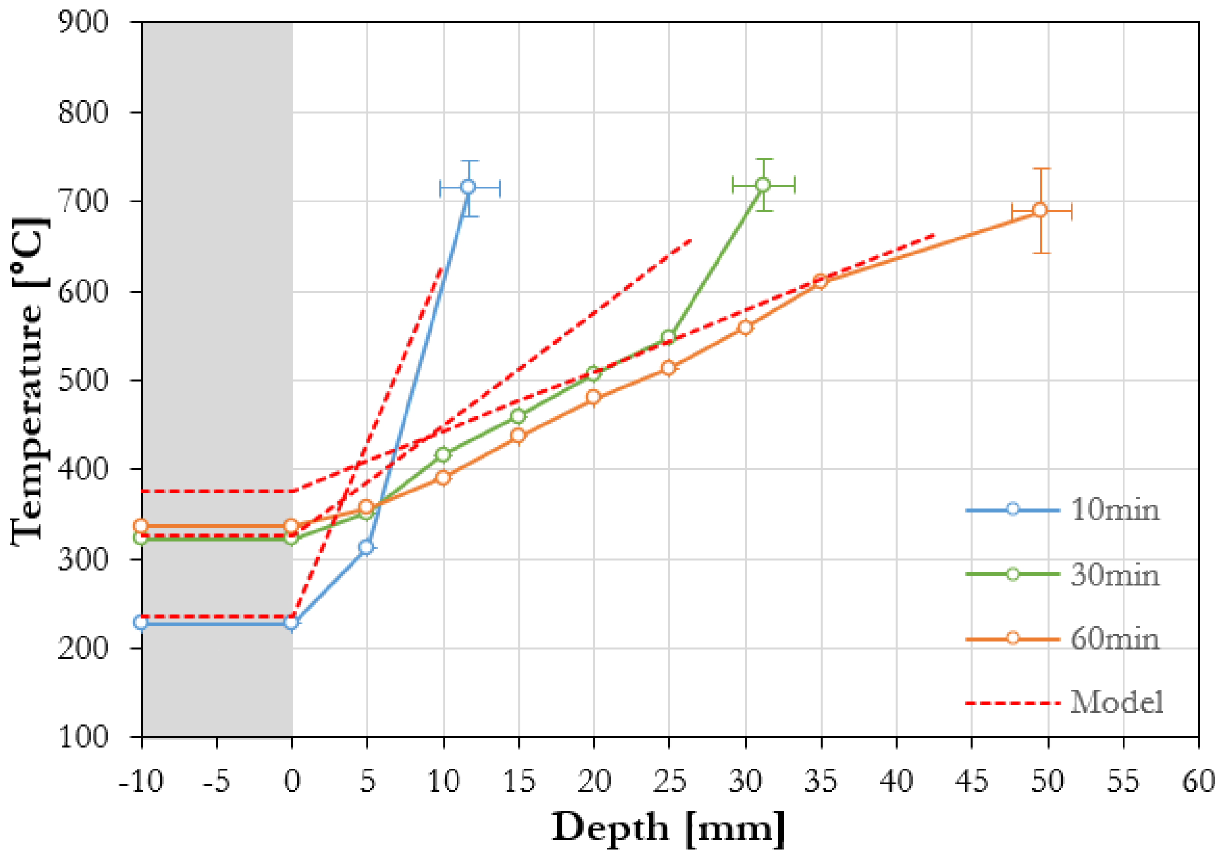
Explicit modelling of swelling and heating conditions





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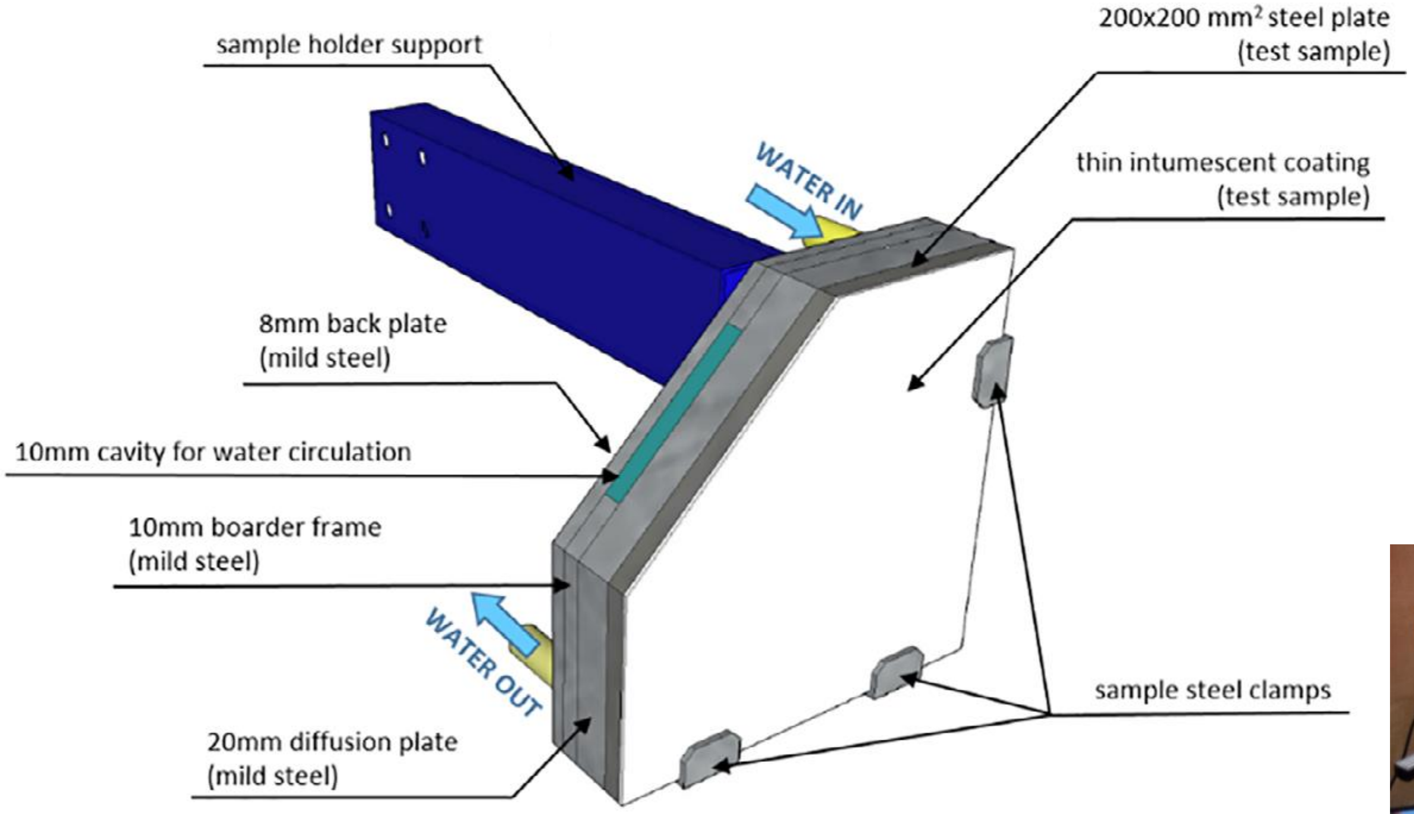
Effects of substrate thermal conditions on the swelling behaviour



Lucherini A, Torero JL, Maluk C - Effects of substrate thermal conditions on the swelling of thin intumescent coatings
https://doi.org/10.1002/fam.2840

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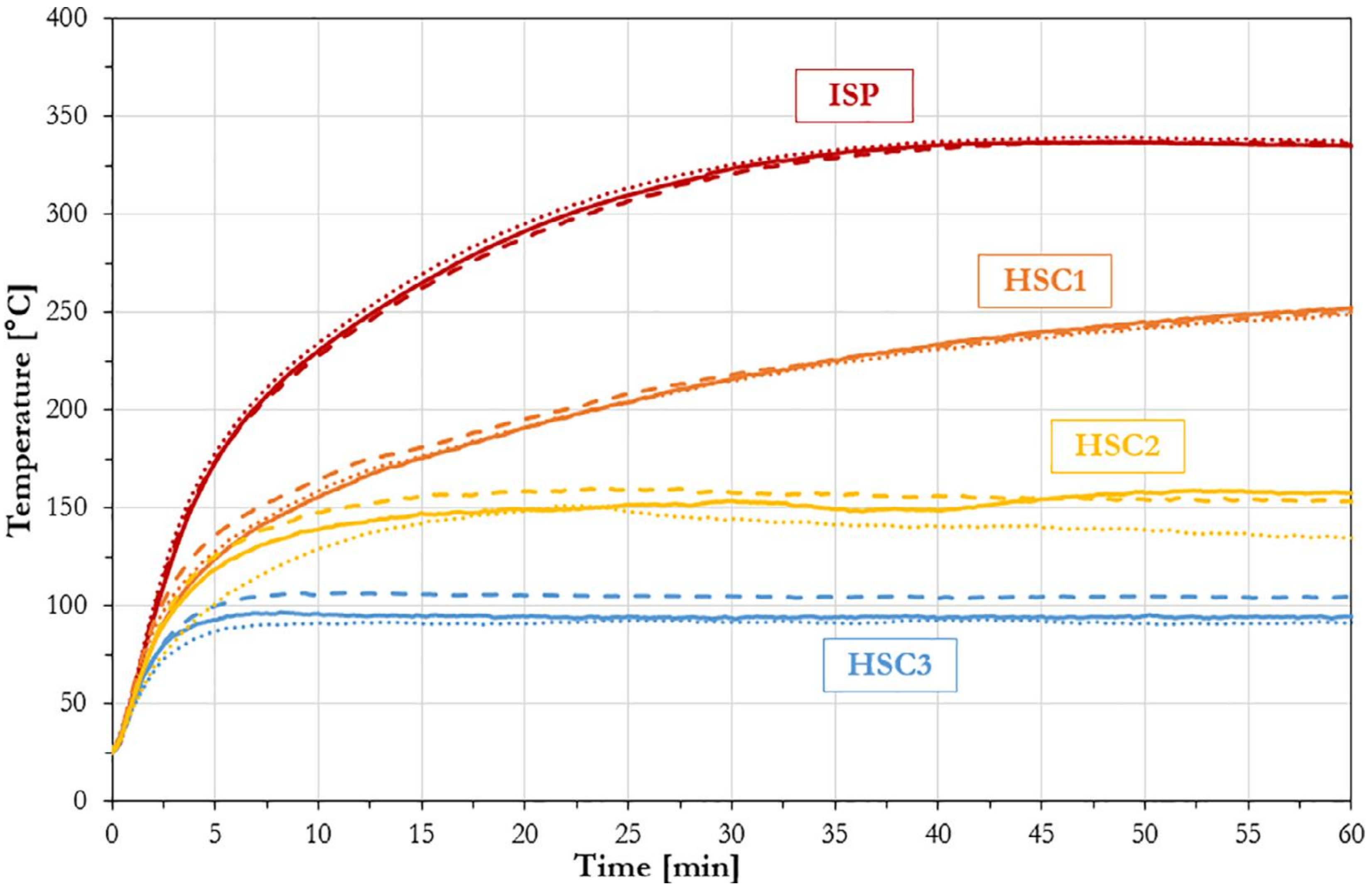

Lucherini A, Torero JL, Maluk C - Effects of substrate thermal conditions on the swelling of thin intumescent coatings

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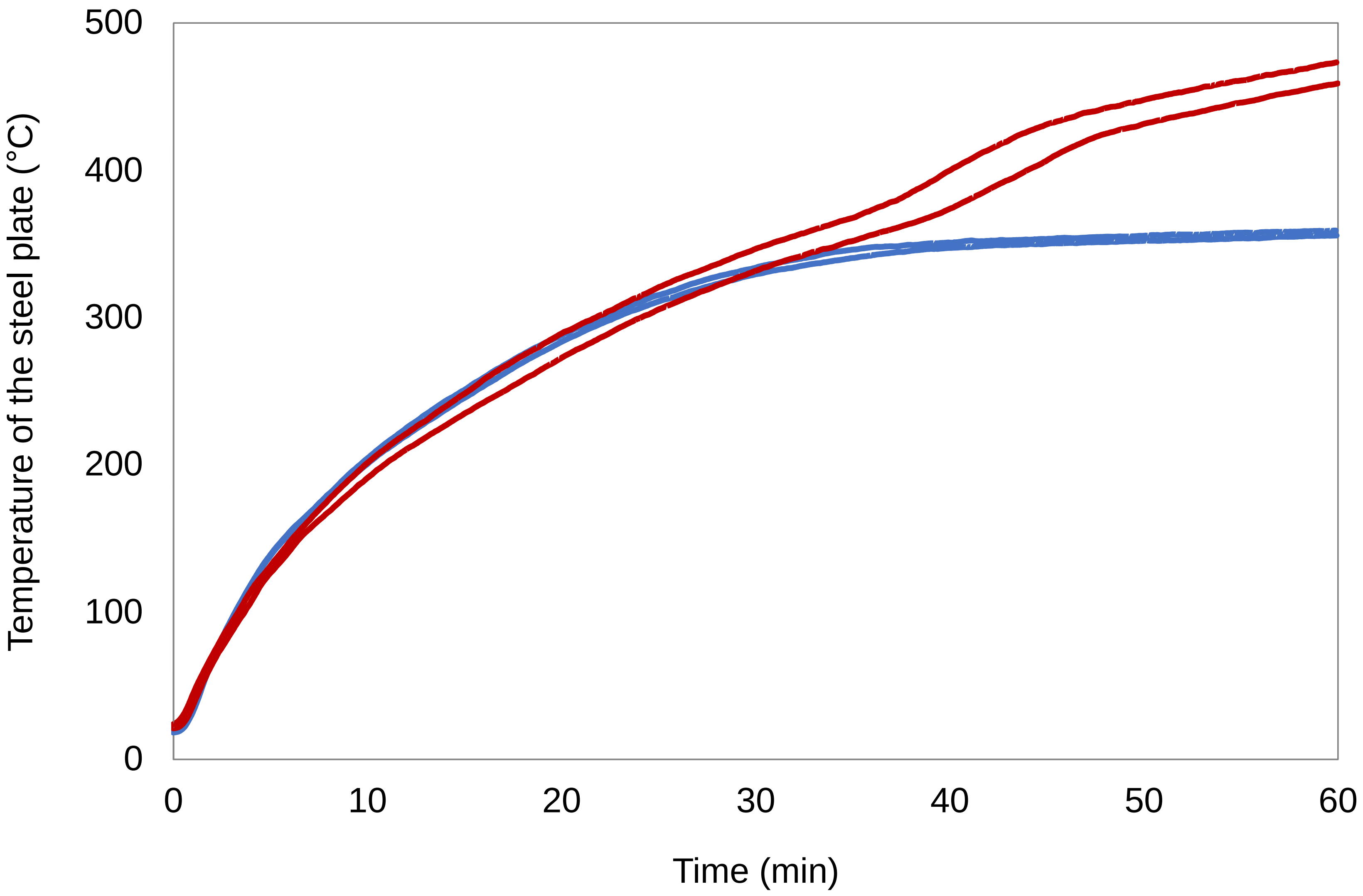
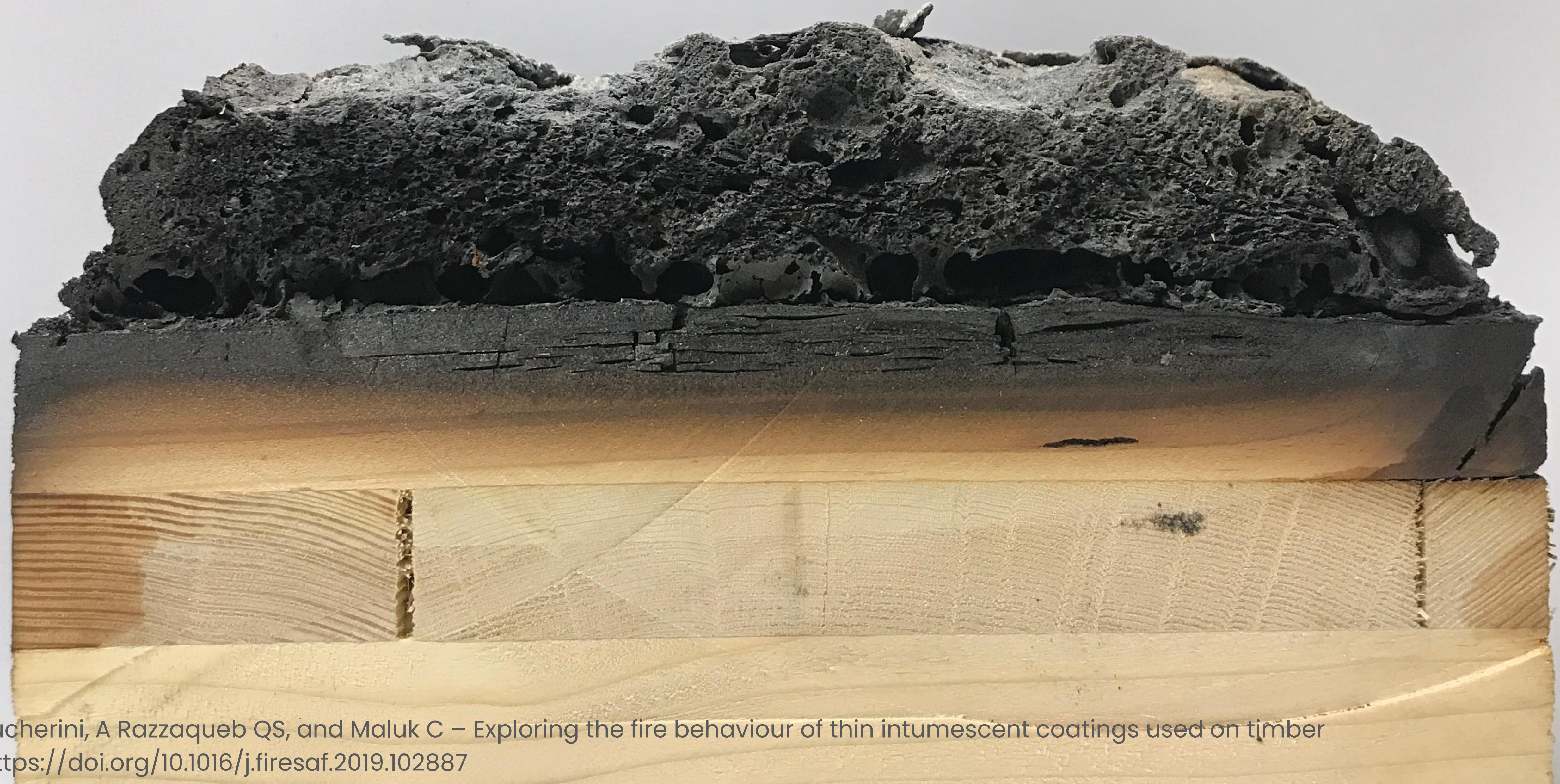
Effects of hindered free swelling



Bejarano D - Fire Behaviour of Intumescent Coatings upon Hindered Swelling (MEng Thesis, UQ)

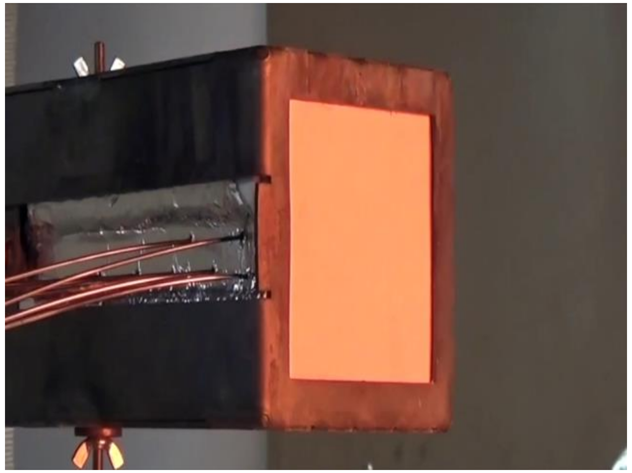
Timber protected using thin intumescent coatings



Lucherini, A Razzaqueb QS, and Maluk C – Exploring the fire behaviour of thin intumescent coatings used on timber
https://doi.org/10.1016/j.firesaf.2019.102887

Timber protected using thin intumescent coatings

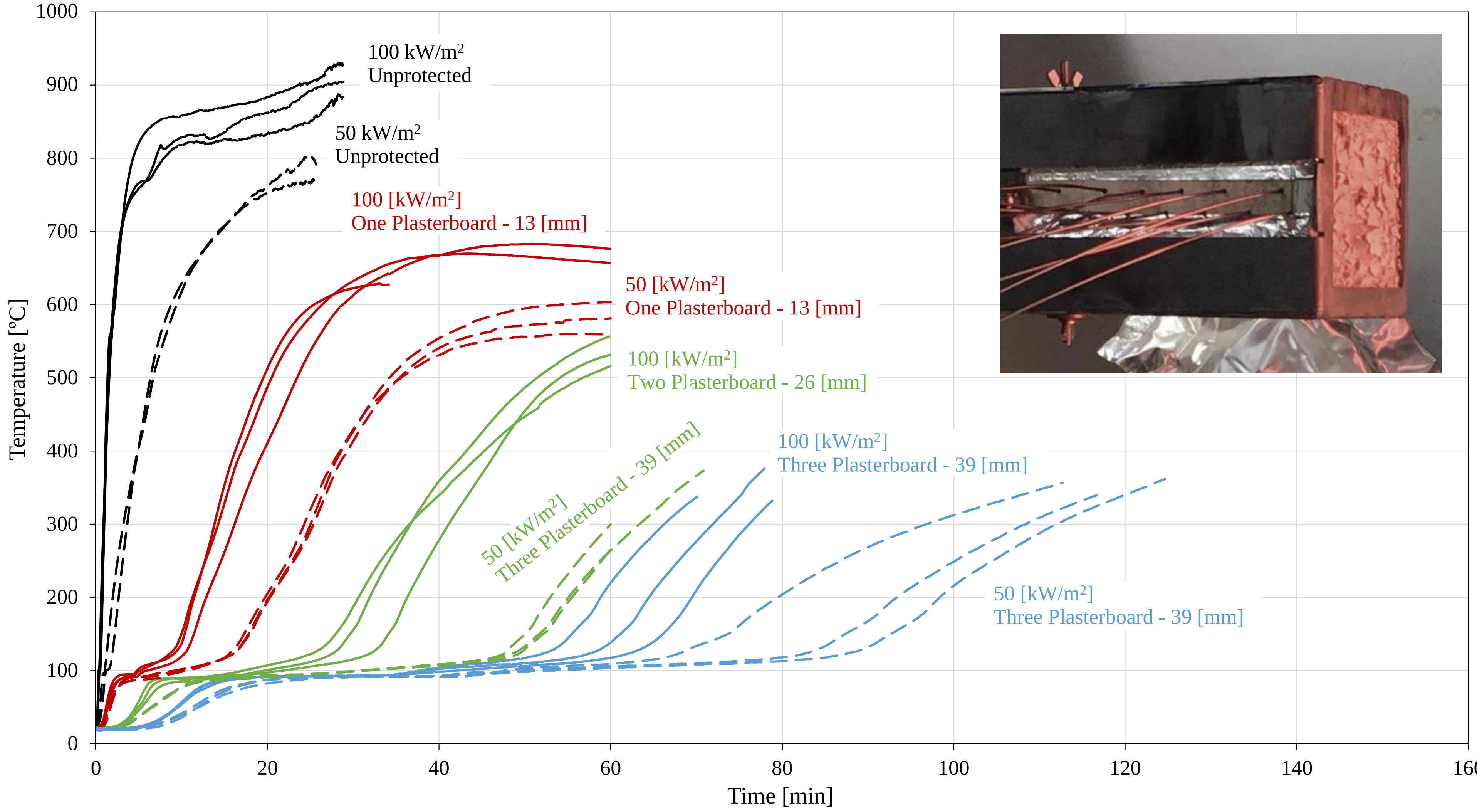
Fire-Rated Plasterboard



Intumescent Coating

Hartl R - Comparative fire study between plasterboard and intumescent coatings used in mass timber structures (MEng Thesis, UQ)

Timber protected using thin intumescent coatings



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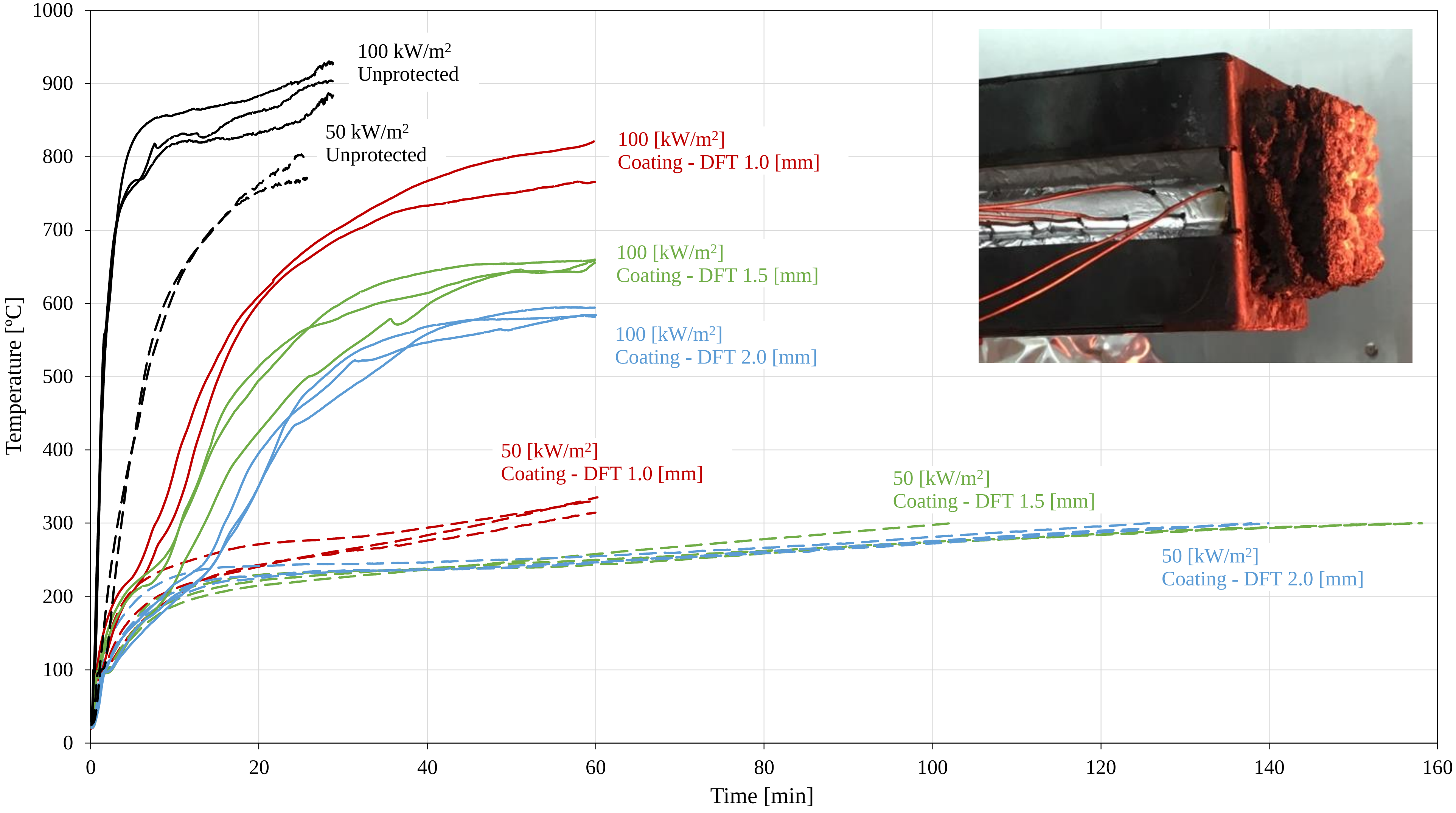

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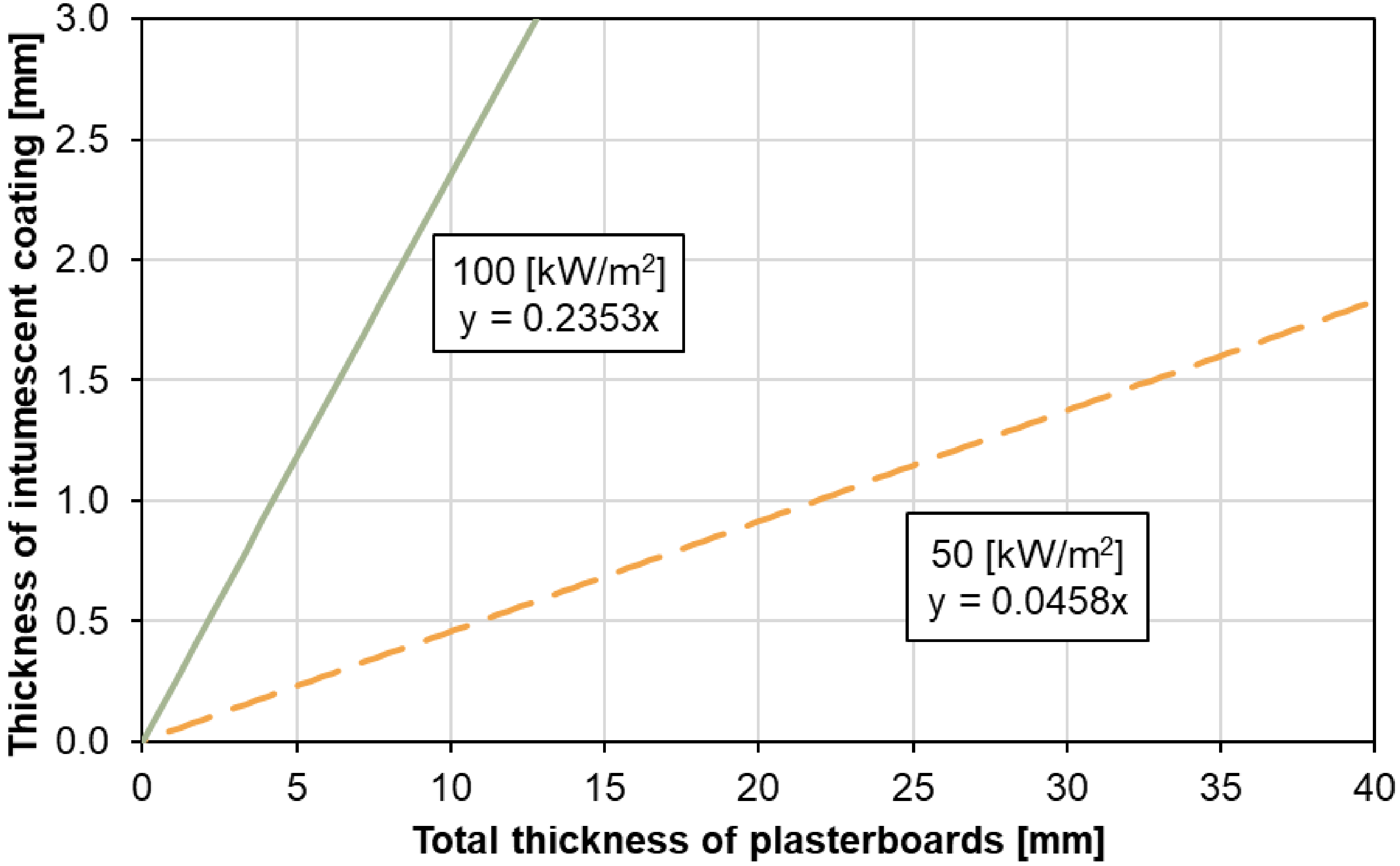


Derived formulations for approximating the amount of intumescent required to deliver the same protection as given thickness of plasterboard.

Hartl R - Comparative fire study between plasterboard and intumescent coatings used in mass timber structures (MEng Thesis, UQ)

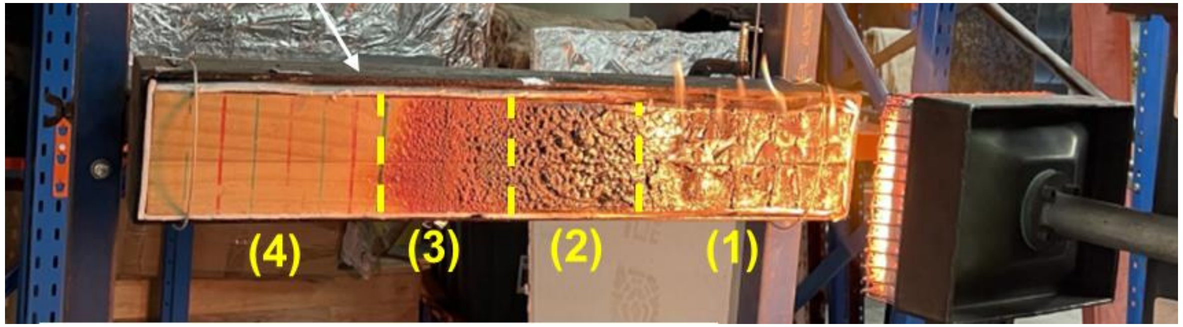
Timber protected using thin intumescent coatings

Ongoing studies (Stavros Spyridakis)

- Study 1 – Onset of swelling
- Study 2 – In-depth charring
- Study 3 – Heat Release Rate
- Study 4 – Surface flame
- *Study 5 – Influence of weathering
- *Study 6 – Demonstrative medium-scale compartment with a relatively large opening

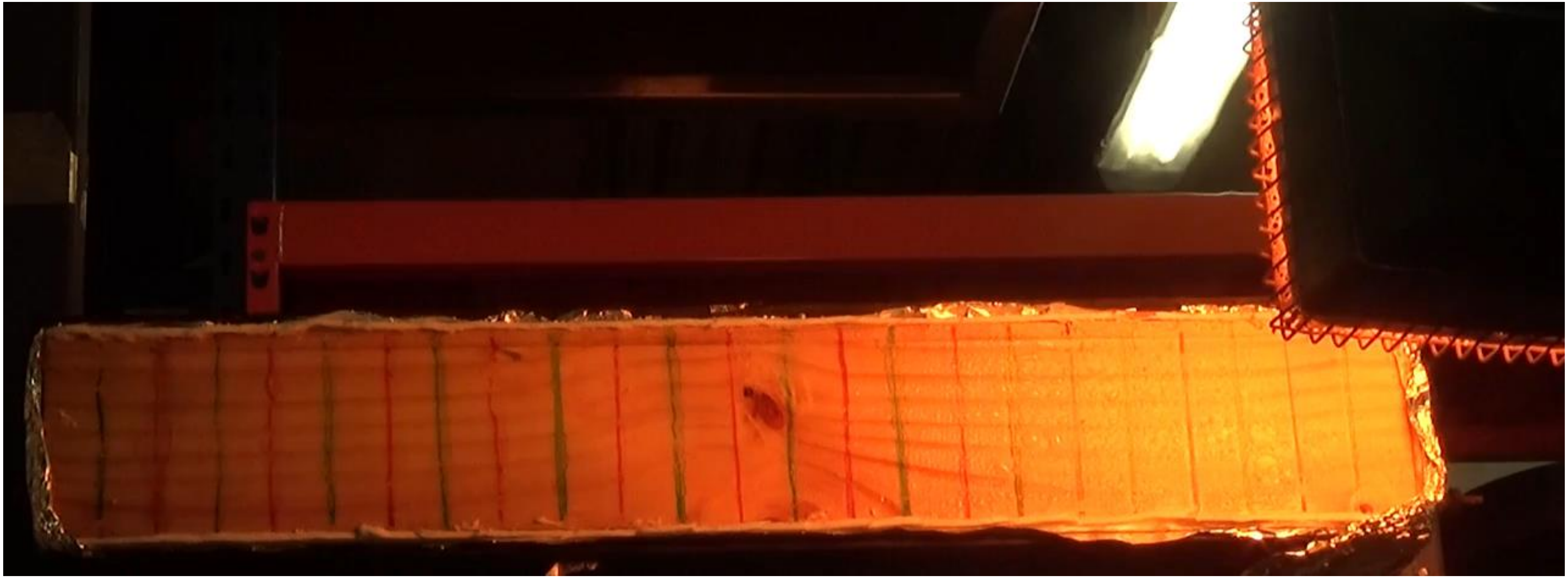
The above is being performed for three paint types at different DFTs.

Transparent thin intumescent coating



Fire spread test

Timber protected using thin intumescent coatings



Fire spread test

Concluding remarks

What we "think we know" and we "definitely do not know"

We know that…

- (as expected) Higher DFT results in higher total swelling, therefore better insulation of the substrate
- We can explicitly model the internal temperature of swelling intumescent
- The physical swelling governs the performance of thin intumescent coatings
- Thermal conditions of the substrate can influence the swelling behaviour
- Hindered free swelling can influence the temperature of the protected substrate
- Thin intumescent can work in delaying the onset of timber charring

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We don’t know …

- A quantifiable (yet practical) prediction for the thresholds in which swelling of intumescent will not be effective
  - Fire scenario
  - Type of coating
  - DFT
  - Substrate type (and thermal conditions)
  - Hindered free swelling
- How timber protected using thin intumescent coatings (even in small amounts) can change ignition, surface flame spread and overall burning behaviour of timber (*Stavros Spyridakis – ongoing*)

What can 'we' do today?

Is not all bad news…

- We can design using intumescent coatings as long as we demonstrate that during the expected "real fire(s) in the real building" the local heating conditions at the surface of the paint will not be 'very' different to those for which the paint is know to work (standard temperature-time curve).
- In my experience, some of the paints that we have tested have a 'normal' swelling during slow growing fires or very-very rapid growing fires.
- Having said that, there is no mainstream fire test environment which aims to understand and provide guidance on the required type of coating or DFTs appropriate for non-standard temperature-time curves.

Credits of the work go to UQ Fire
The University of Queensland

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Engineered fire safety

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