Update on Intumscent Coating Research – New EPSRC Project

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Objectives

- To develop a method to predict intumescent coating protected steel temperature under different fire conditions, based on one set of material properties obtained from readily available test results;
- To develop methods of extracting material properties.

Methods of Prediction

- EN 13381-Part 4: thermal conductivity (k) from standard fire resistance tests, inverse calculation of k from measured steel T;
- Modified EN 13381-Part 4: k from above modified by ratio of expansion thicknesses;
- Including chemical reactions & calculation of thermal conductivity based on void radiation and expansion rate.

Properties related to EN 13381-4

- Thermal conductivity: inverse calculation from measured protected steel temperature;
- Modified thermal conductivity: above & modified by ratio of expansion thicknesses.

EN 13381-4 Related Equations

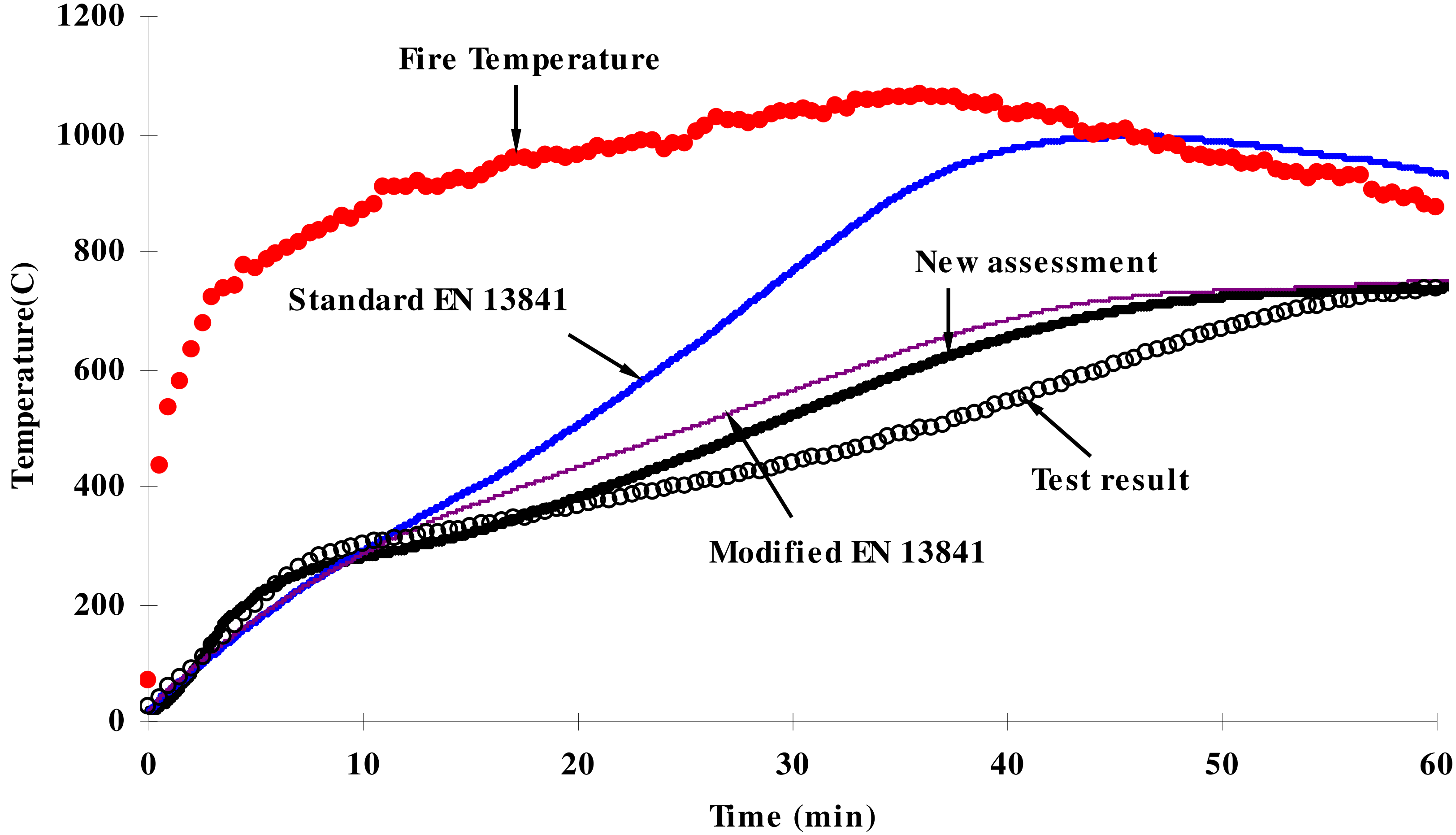
$$\lambda_p = \left[d_p \times \frac{V}{A_p} \times C_s \rho_s \times (1 + \phi / 3) \times \frac{1}{(T_{fi} - T_s)\Delta t} \right] \times \left[\Delta T_s + (e^{\phi/10} - 1)\Delta T_{fi} \right]$$

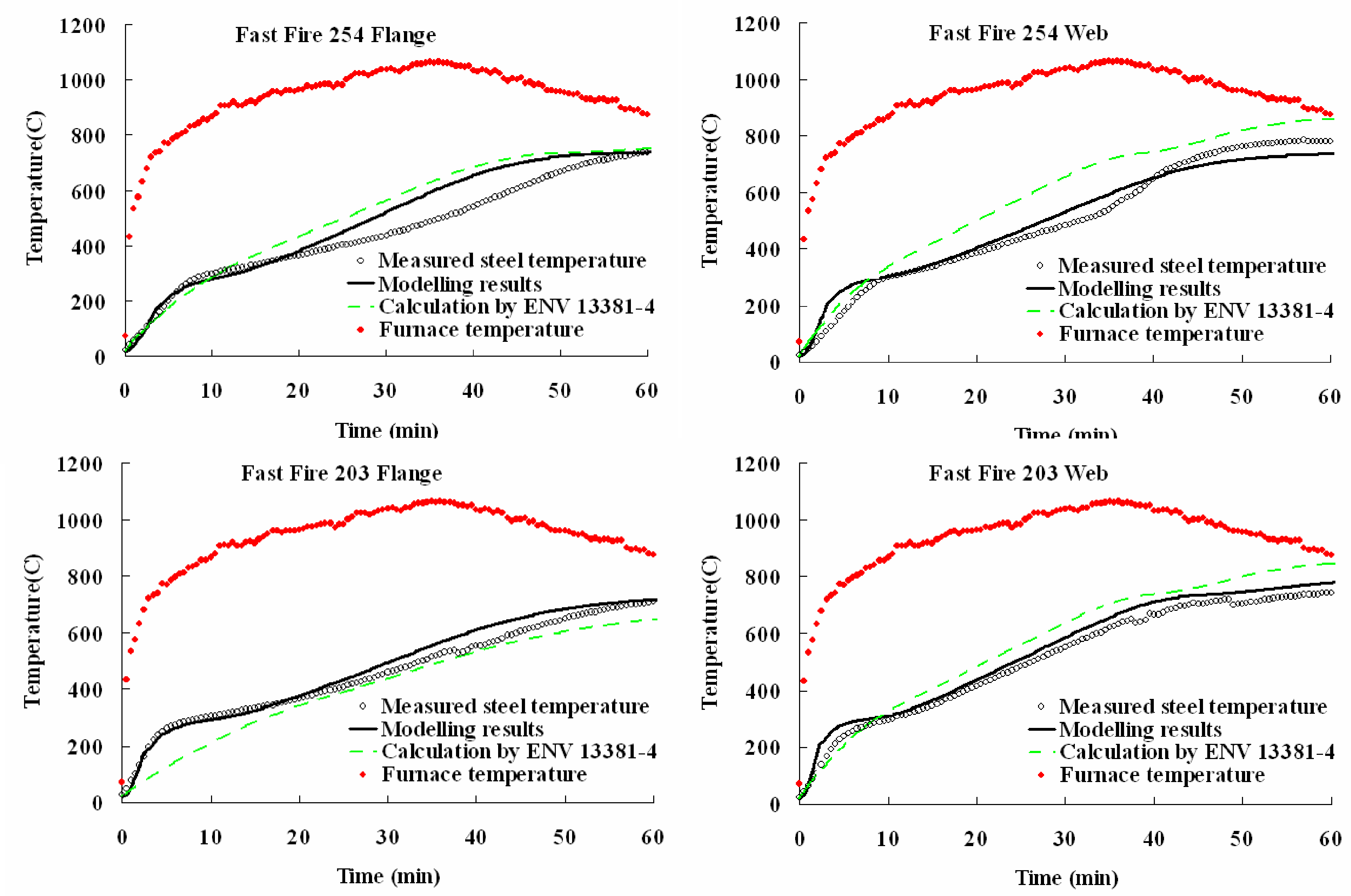
$$\lambda_{eff,para} = \frac{\lambda_{eff,iso}}{E_{\max,para} / E_{\max,iso}}$$

Important Properties & Methods of Extraction

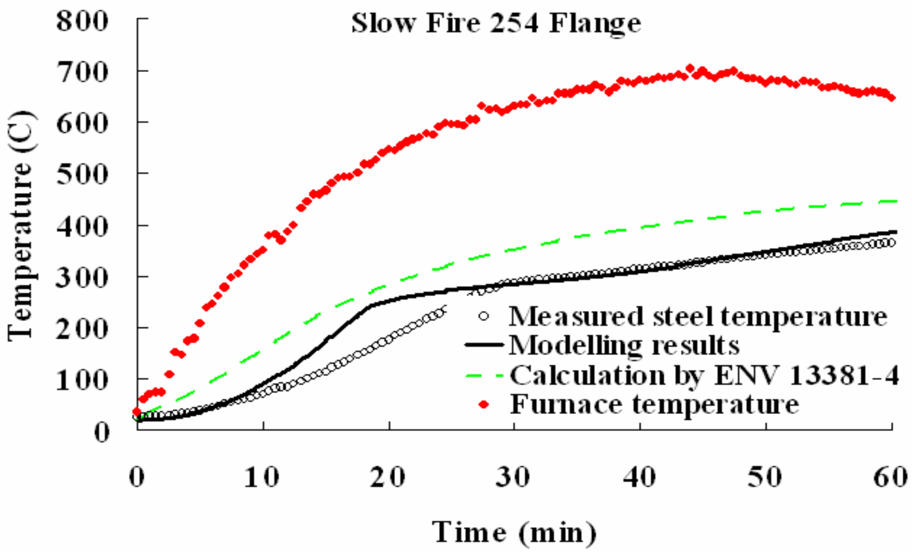
- Chemical reaction kinetics (pre-exponential factor/activation energy) for three main ingredients (acid/blowing agent/charring material): TGA tests;
- Final bubble size: microscopic measurement;
- Expansion factor: ideal gas law between lower and upper expansion temperatures?

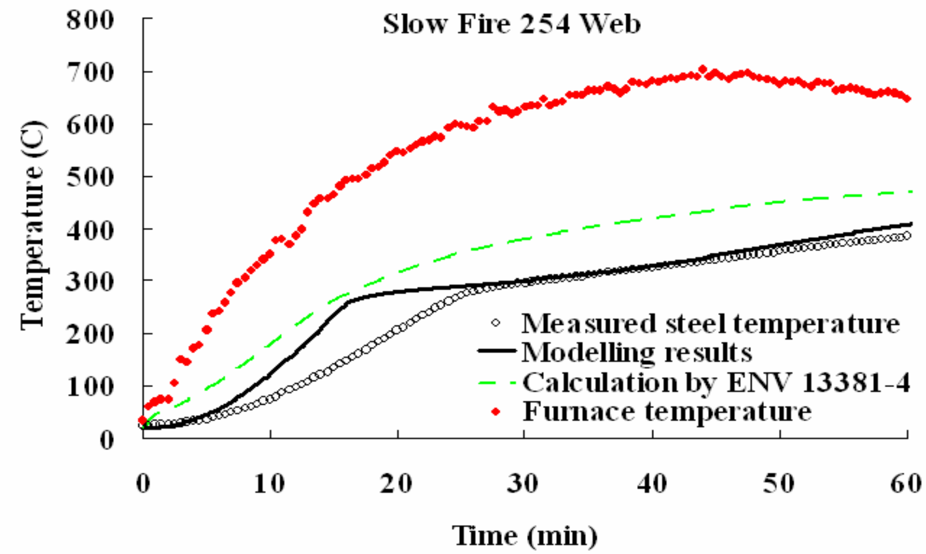
Most Important Factor: Expansion Factor

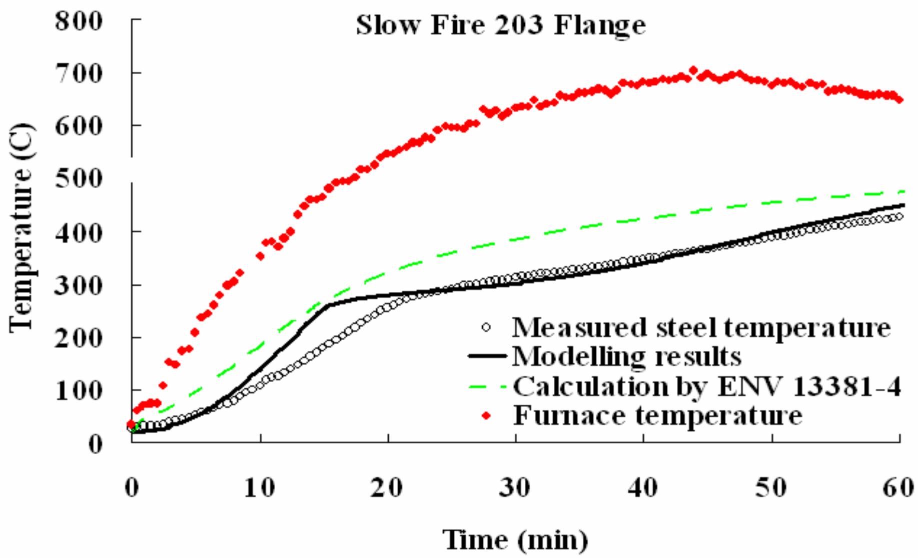


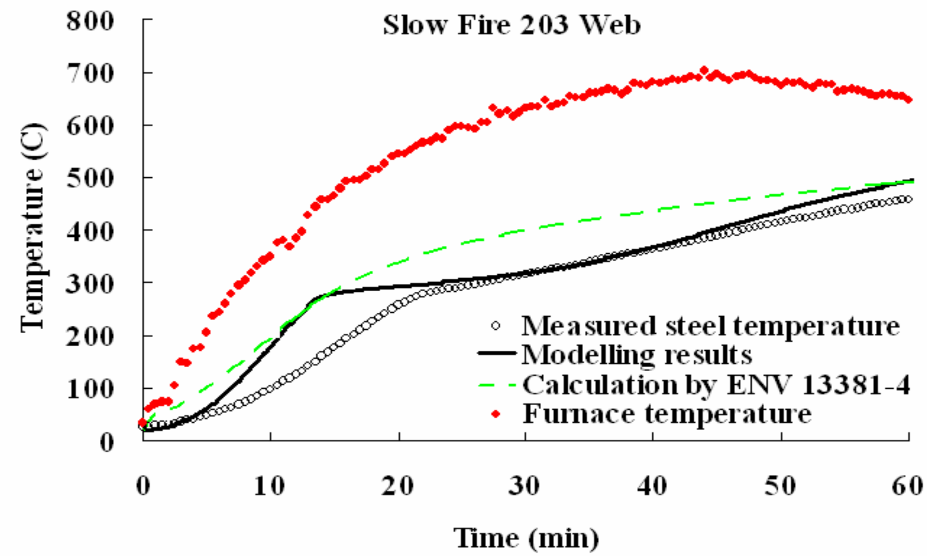


Fast Fire 254 Flange
Temperature(C)
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
Time (min)
Measured steel temperature
Modelling results
Calculation by ENV 13381-4
Furnace temperature
Fast Fire 254 Web
Temperature(C)
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
Measured steel temperature
Modelling results
Calculation by ENV 13381-4
Furnace temperature
Fast Fire 203 Flange
Temperature(C)
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
Time (min)
Measured steel temperature
Modelling results
Calculation by ENV 13381-4
Furnace temperature
Fast Fire 203 Web
Temperature(C)
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
Time (min)
Measured steel temperature
Modelling results
Calculation by ENV 13381-4
Furnace temperature


Slow Fire 254 Flange
Temperature (C)
0
100
200
300
400
500
600
700
800
0
10
20
30
40
50
60
Time (min)
Measured steel temperature
Modelling results
Calculation by ENV 13381-4
Furnace temperature


Slow Fire 254 Web
Temperature (C)
0
100
200
300
400
500
600
700
800
0
10
20
30
40
50
60
Time (min)
Measured steel temperature
Modelling results
Calculation by ENV 13381-4
Furnace temperature


Slow Fire 203 Flange
Temperature (C)
0
100
200
300
400
500
600
700
800
0
10
20
30
40
50
60
Time (min)
Measured steel temperature
Modelling results
Calculation by ENV 13381-4
Furnace temperature


Slow Fire 203 Web
Temperature (C)
0
100
200
300
400
500
600
700
800
0
10
20
30
40
50
60
Time (min)
Measured steel temperature
Modelling results
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Furnace temperature

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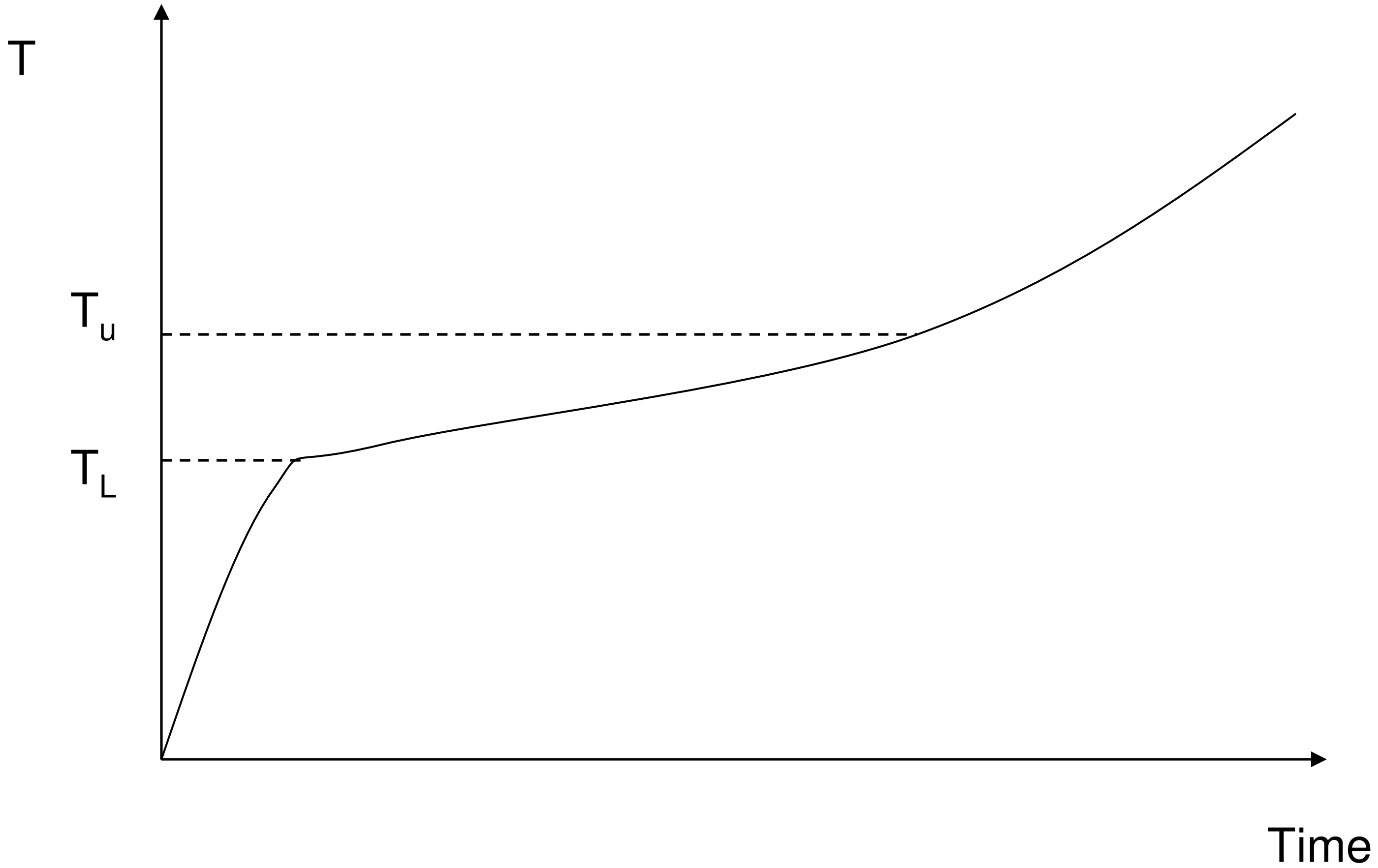
Prediction of Expansion Thickness

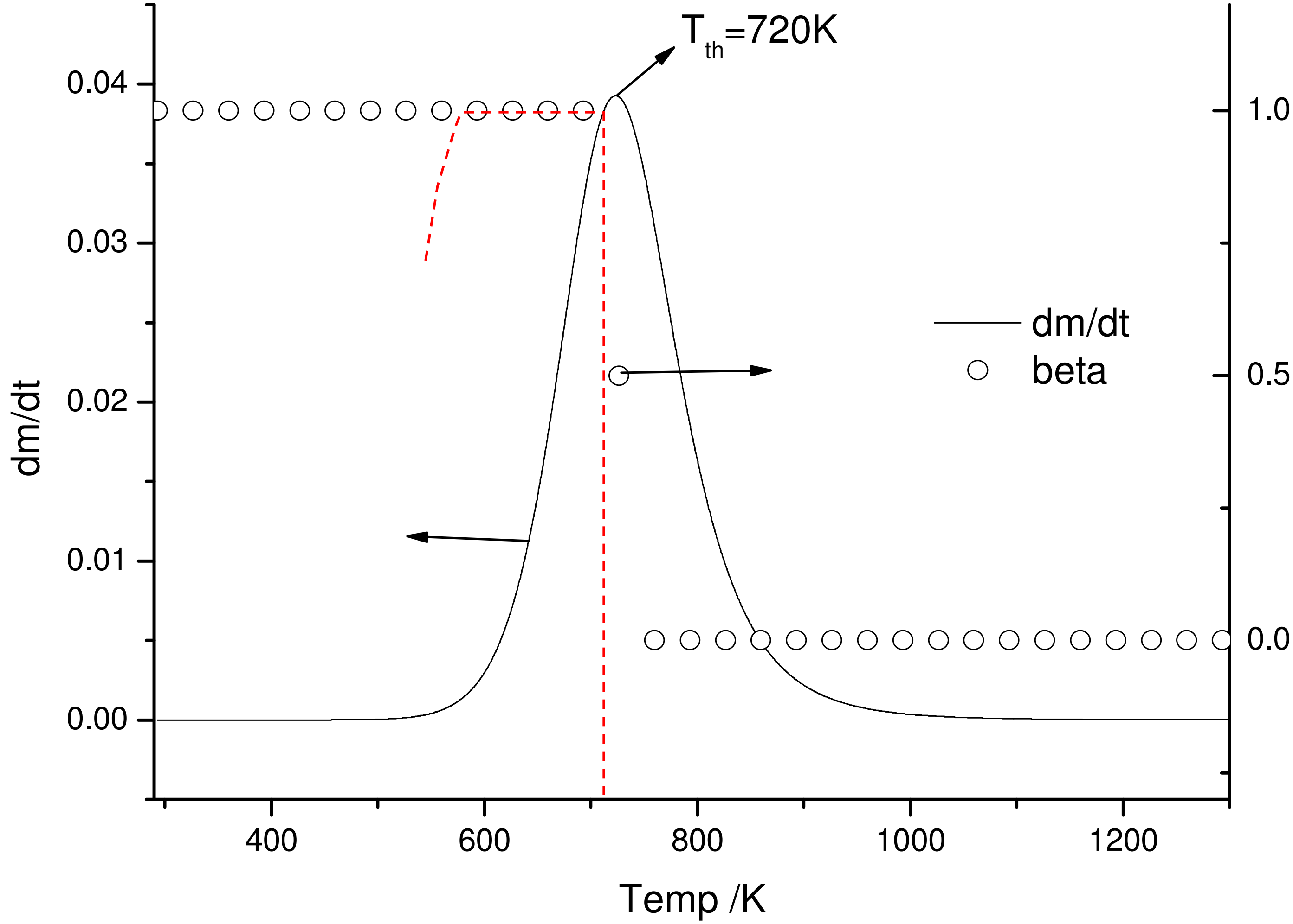


Expansion according to Ideal Gas Law

$$\rho_{gas} = \frac{WP}{RT} \qquad V = S.x = \frac{m}{\rho_{gas}} \qquad \int_{t_1}^{t_2} \dot{x}\,dt$$

$$\dot{x} = \frac{dx}{dt} = \frac{d\left(\frac{\beta m R T}{WPS}\right)}{dt} = \frac{R\beta}{WPS} \bullet \left(T\frac{dm}{dt} + m\frac{dT}{dt}\right)$$

Beta & dm/dt



T_th=720K
dm/dt
beta
0.04
0.03
0.02
0.01
0.00
1.0
0.5
0.0
400
600
800
1000
1200
Temp /K

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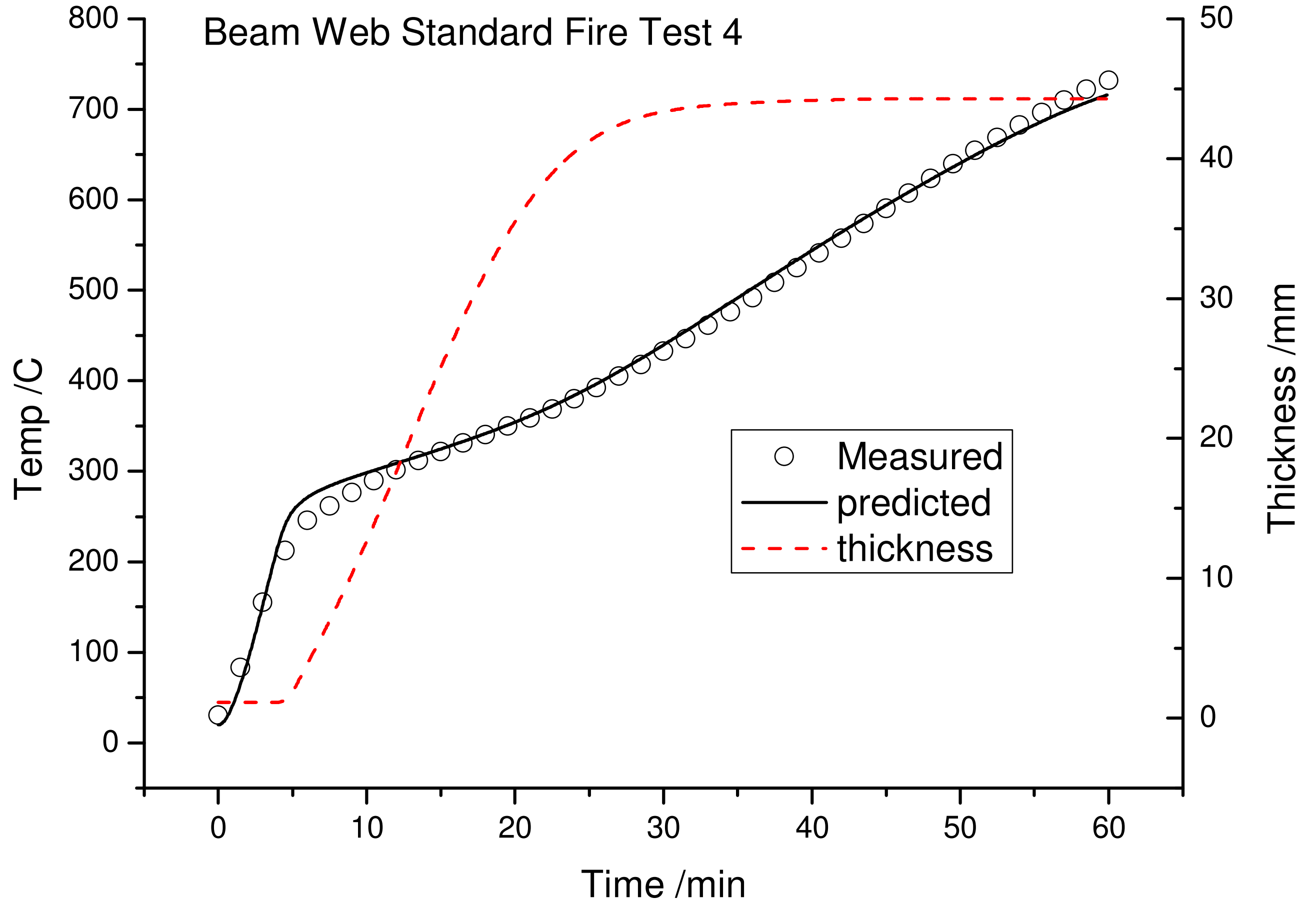
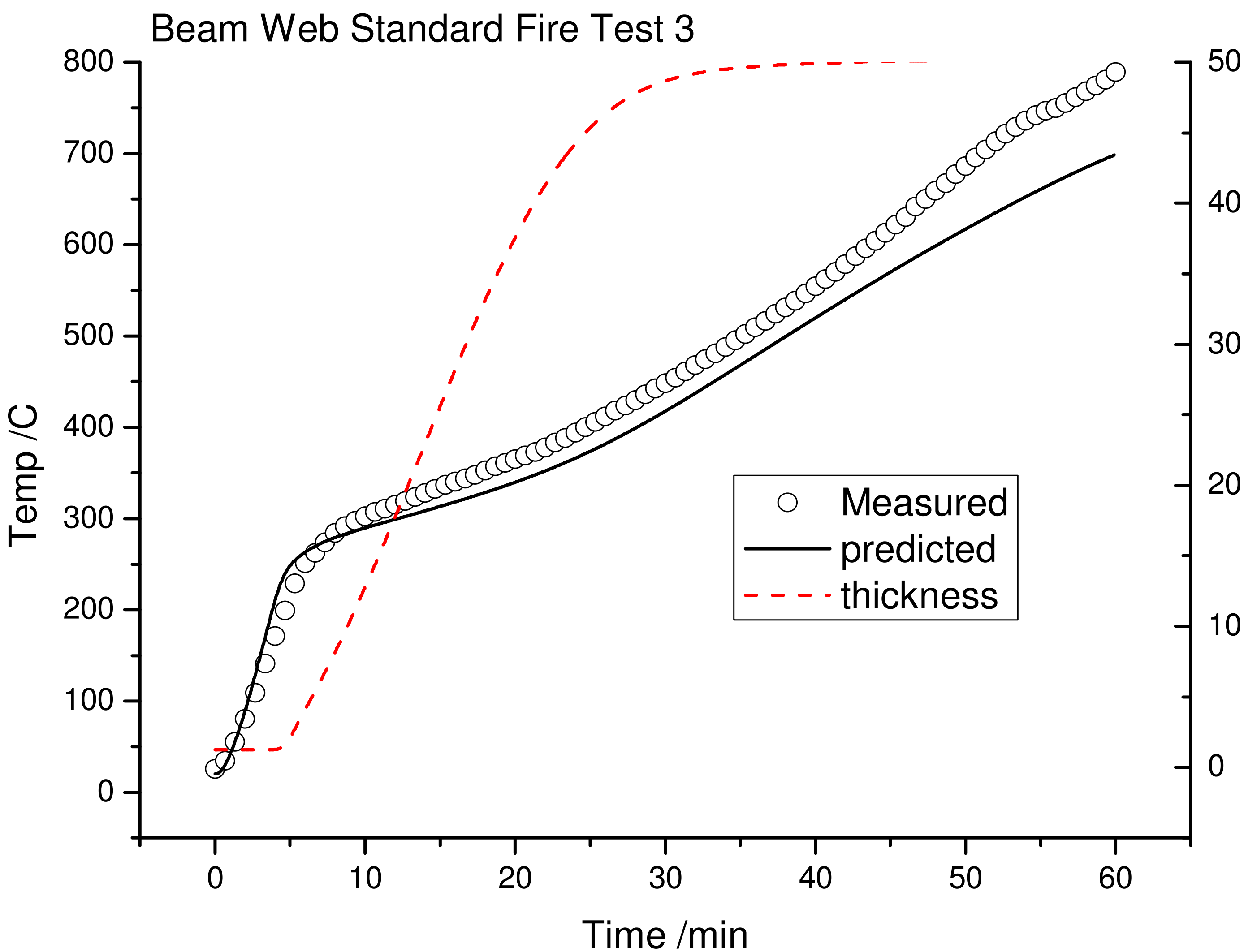
Some Preliminary Results: Expansion Thickness

Sample	Initial thickness (mm)	Expansion ratio Measured/Predicted	Error *%
BWST1	1.075	46.1/39.3	-15%
BWST2	1.116	48.2/39.7	-17%
BWST3	1.259	28.1/39.8	41%
BWST4	1.167	36.2/39.8	10%
CFST1	0.679	32.0/38.2	19%

Some Preliminary Results: Steel Temperature




Beam Web Standard Fire Test 3
800
700
600
500
400
300
200
100
0
50
40
30
20
10
0
Temp /C
0
10
20
30
40
50
60
Time /min
Measured
predicted
thickness

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Next Phase

- TGA tests to determine mass loss as function of rate of heating;
- Determination of upper expansion temperature: relate to viscosity/heat rate;
- Determination of beta factor;
- Cone calorimeter tests to record expansion process;
- Parametric fire tests to check predictions.

$$\dot{x} = \frac{dx}{dt} = \frac{d(\frac{\beta mRT}{WPS})}{dt} = \frac{R\beta}{WPS} \bullet (T\frac{dm}{dt} + m\frac{dT}{dt})$$