PFPNet Conference 2024

Three Sided PFP Scoping Study – Finite Element Results

Amsterdam

21st – 22nd October 2024

Introduction

The main objective of this study is defined as the provision of guidance on the severity of three sided PFP partially protected I-sections subjected to hydrocarbon fires impingement.

This project involves understanding of the structural consequence of leaving the top flange unprotected allowing for local heat conduction that can lead to prevent premature failure of the protected item.

The present study is to undertake a scoping study, thereby defining a project plan that can be used in support of generic guidance through the future design of three-sided PFP, in conjunction with categorisation of the nature of structural response, to ultimately assist a suitably qualified person in making a judgement on the influence of 3-sided PFP with respect to the fire resistance period of a protected structure or item.

A series of heat transfer and stress analyses were performed on different beam sizes to understand the parameters that affect the response of partially protected 3-sided PFP beams.

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01

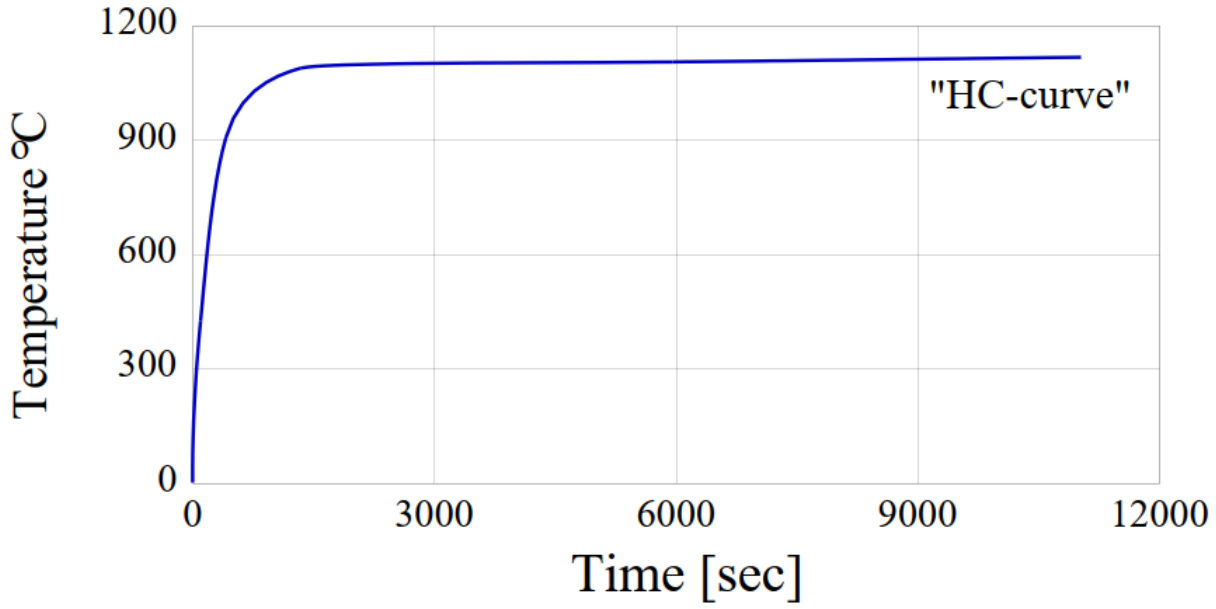
Fire Scenario

Hydrocarbon fire curve

The hydrocarbon fire curve was applied to the beams modelled:

1) The burning rates for certain materials e.g. petrol gas, chemicals, etc, are well in excess of the rate at which, for instance, timber would burn.

2) The temperature development of the Hydrocarbon (HC) fire curve is described by the following equation: T = 20 + 1080 * (1 - 0,325 * e - 0,167 * t - 0,675 * e-2,5 * t).



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02

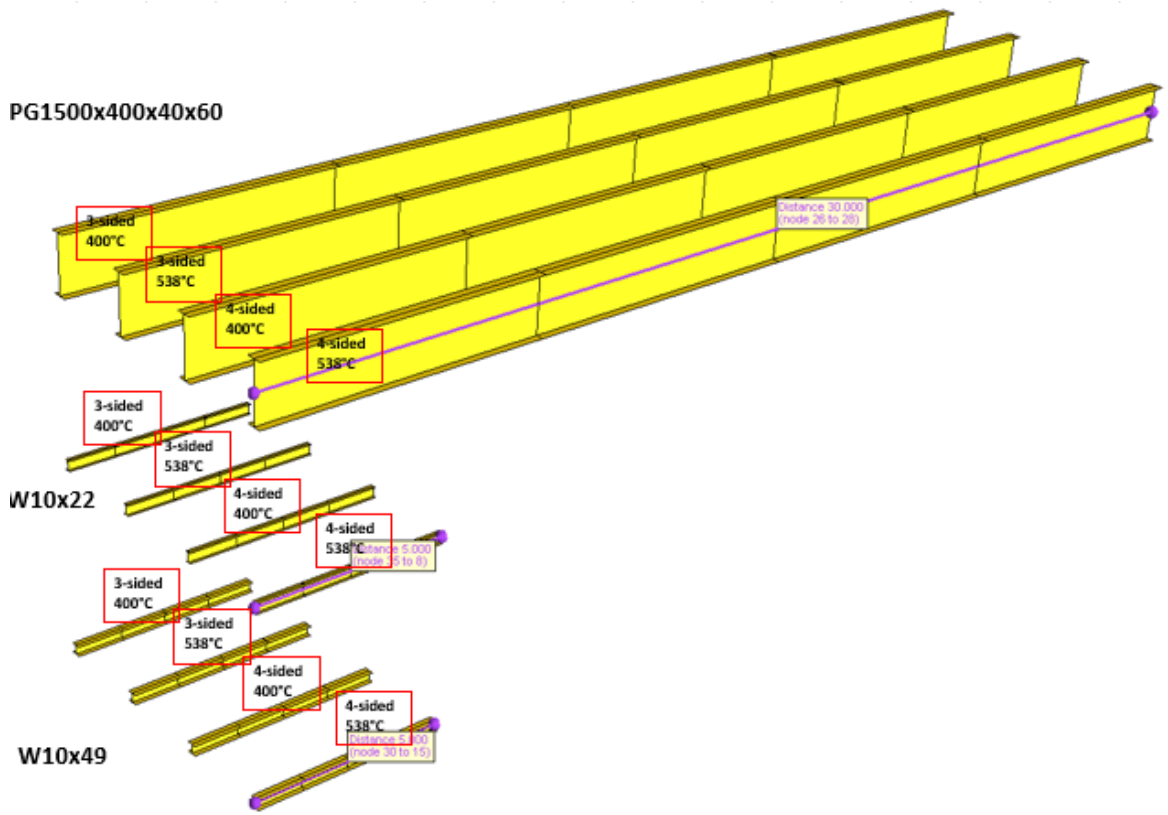
Heat Transfer and Structural Fire Results

Structures Assessed

- 24 beam configurations were assessed against the selected pool fires.
- Vertical loading was applied to the structural model prior the application of the fire loads.
- A series of heat transfer analyses was then performed on the fully protected or partially protected PFP beams. The heat transfer analyses calculated the heat up of the structure subjected to the fire event.
- Finally, the structural transient fire collapse analysis calculated the response of the structure subjected to gravity and fire loads.

Analyses Combinations

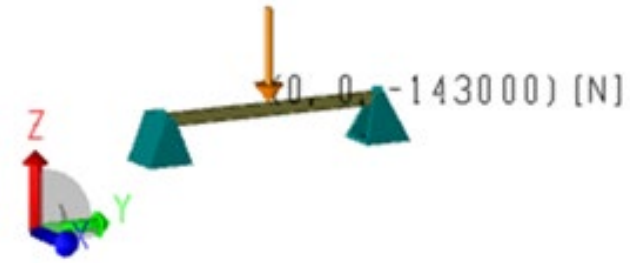
Number of Cases	Section Size	PFP Coverage	CCT [°C]	Fire Rating
17	PG1500x400x40x60	3-sided	400	HC 60
18				HC 120
19			538	HC 60
20				HC 120
21		4-sided	400	HC 60
22				HC 120
23			538	HC 60
24				HC 120
9	W10x22	3-sided	400	HC 60
10				HC 120
11			538	HC 60
12				HC 120
13		4-sided	400	HC 60
14				HC 120
15			538	HC 60
16				HC 120
1	W10x49	3-sided	400	HC 60
2				HC 120
3			538	HC 60
4				HC 120
5		4-sided	400	HC 60
6				HC 120
7			538	HC 60
8				HC 120



Beam Loading

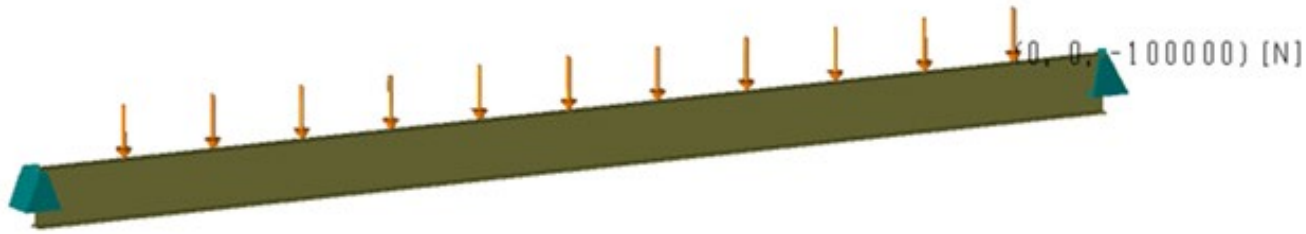
The applied load was calculated to provide approximately 50% plastic moment utilization according to the Eurocode 3 (EN 1993-1-1:2005). However, universal beam type of sections are dominated by lateral torsional buckling stability checks.

The figure below shows the loading and boundary conditions of the beams, the beams were modelled as pin in one support and a roller pin support with free axial displacement in the other support.



W10x49

W10x22

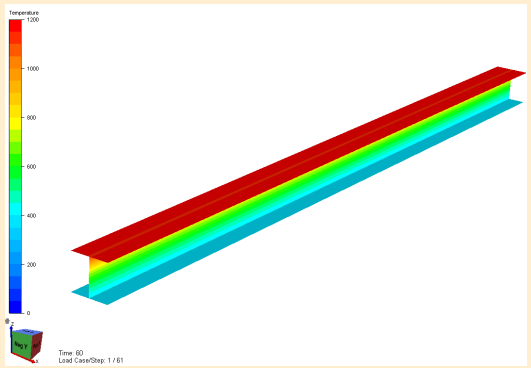
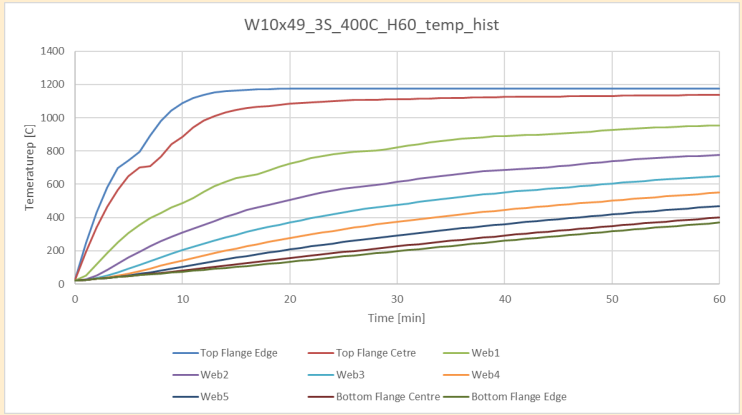
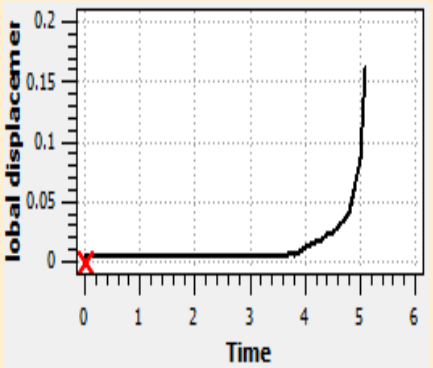
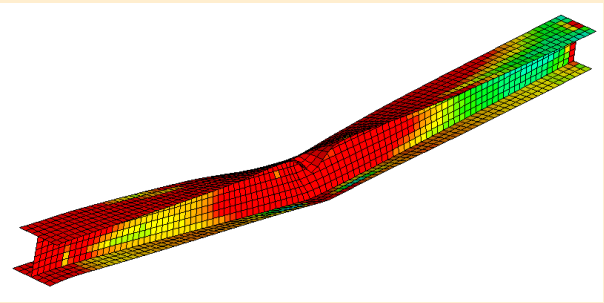


PG1500x400

H60 PFP Results

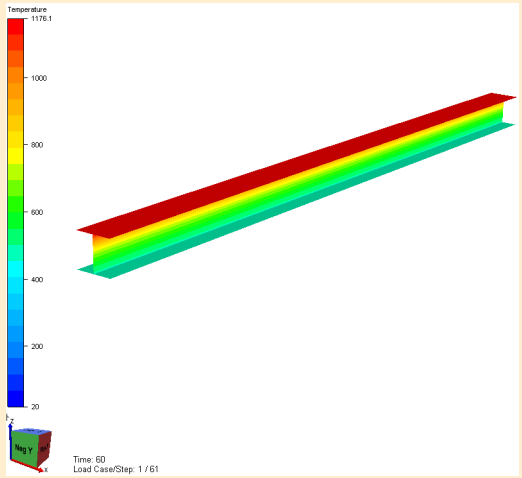
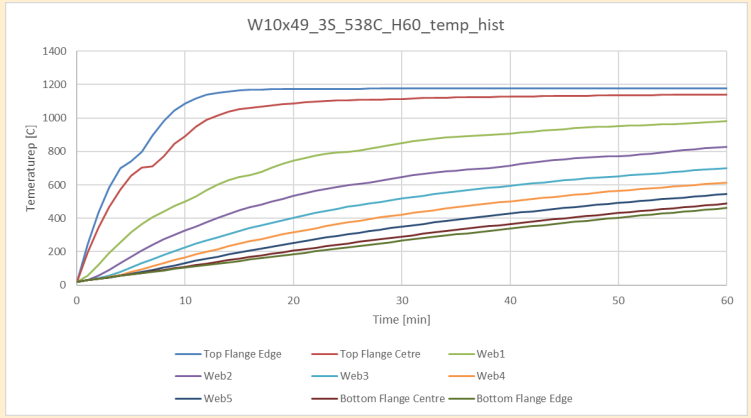
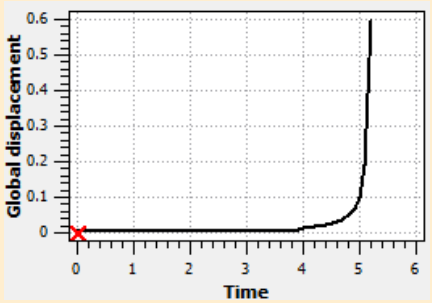
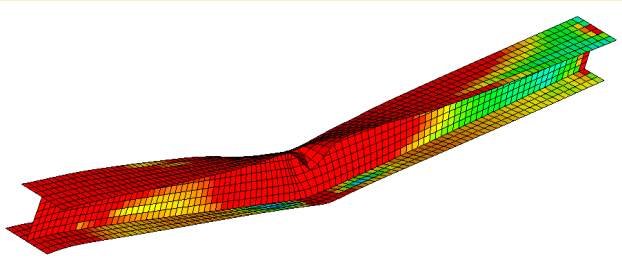
W10x49 3-Sided 400°C H60

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		5mins 	Bending 

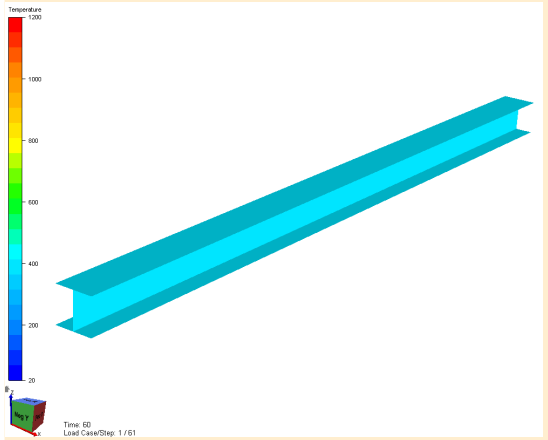
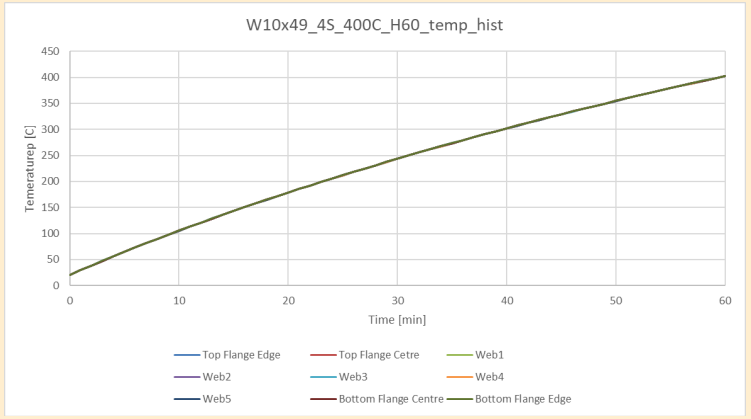
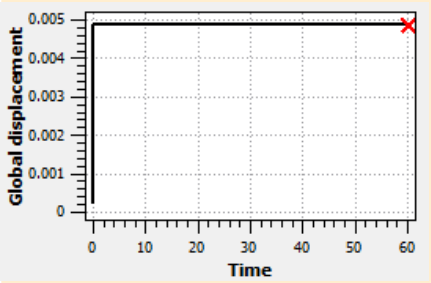
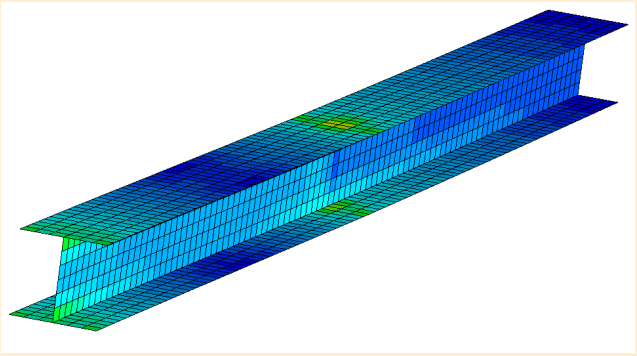
W10x49 3-Sided 538°C H60

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		5mins 	Bending 

W10x49 4-Sided 400°C H60

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		+60mins 	N/A 

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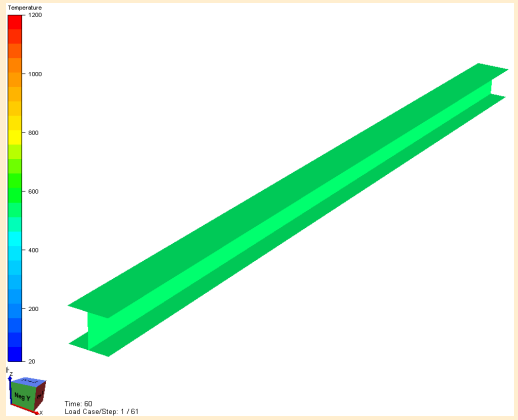
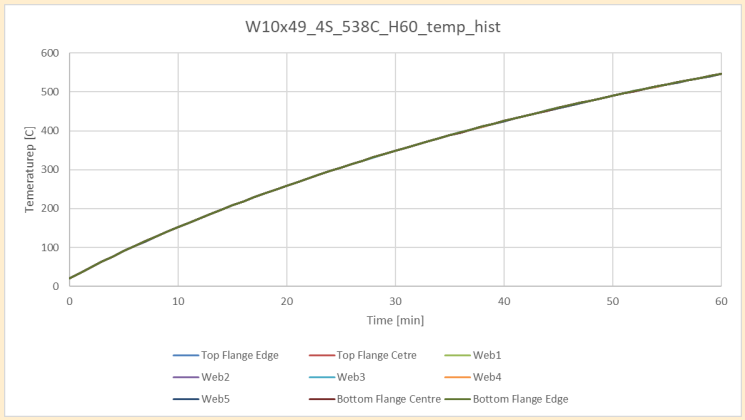
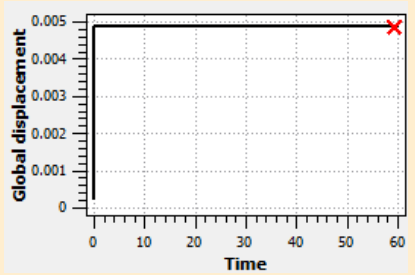
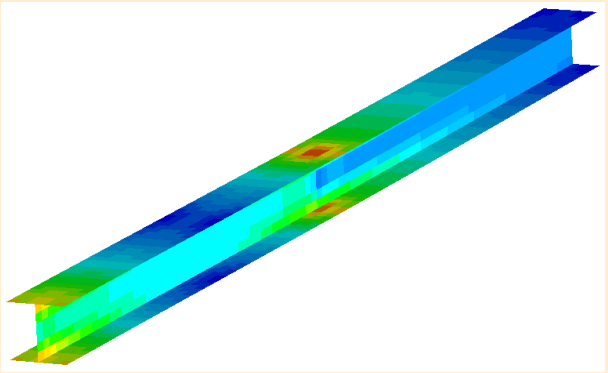
		+60mins 	N/A 

W10x22 3-Sided 400°C H60

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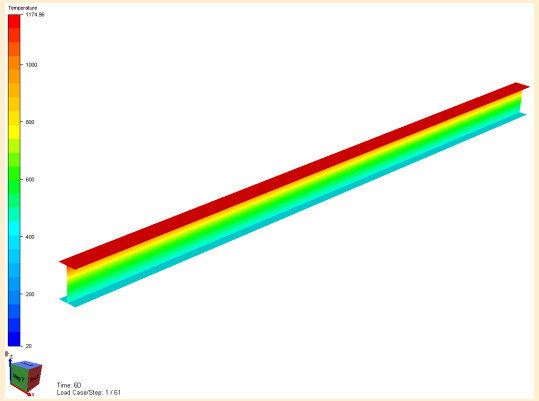
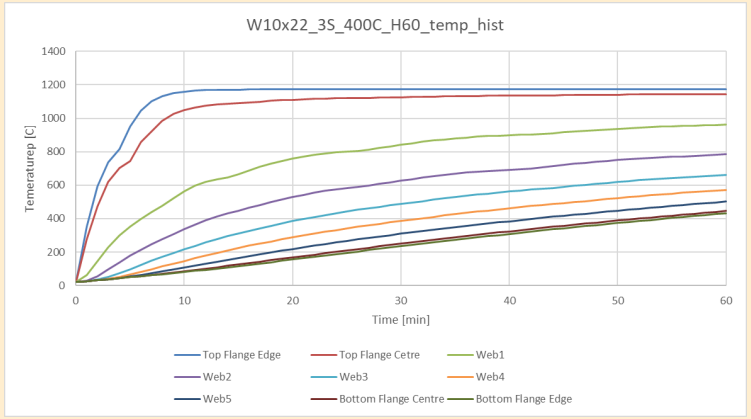
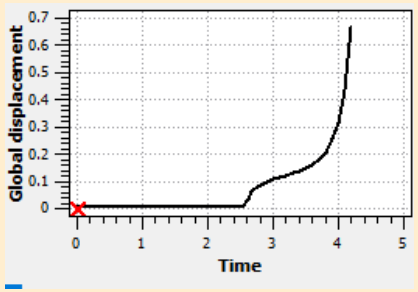
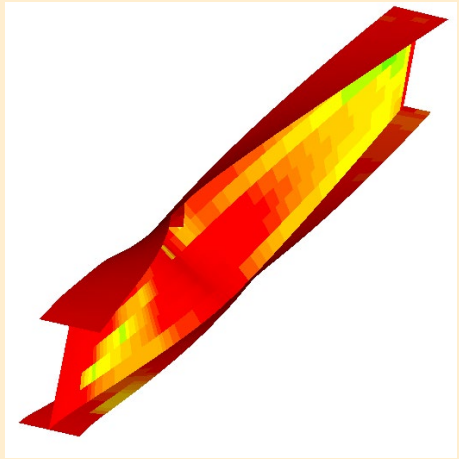
Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		4mins 	LTB 

W10x22 4-Sided 538°C H60

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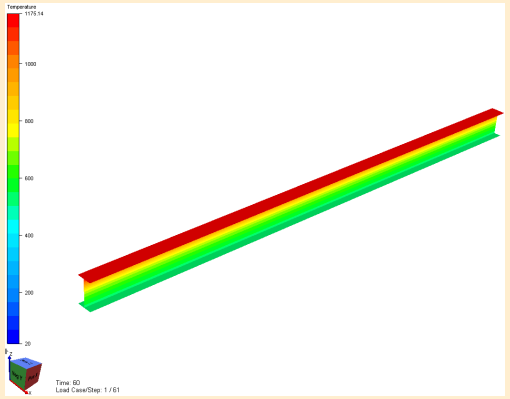
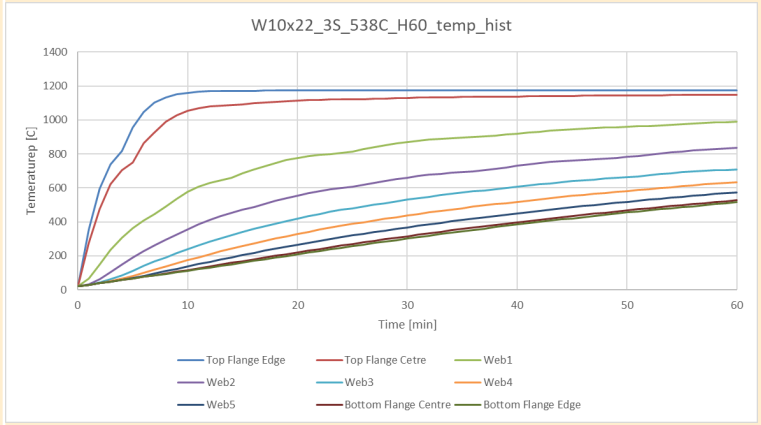
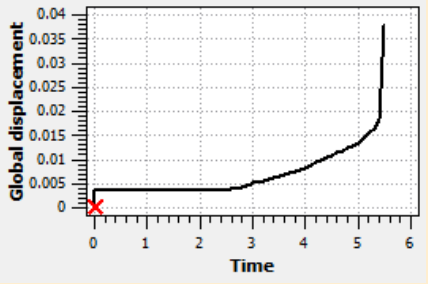
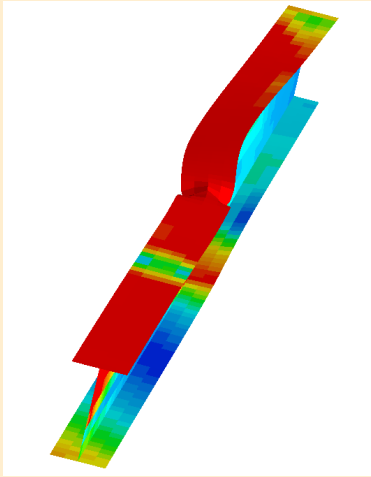
		5mins 	LTB 

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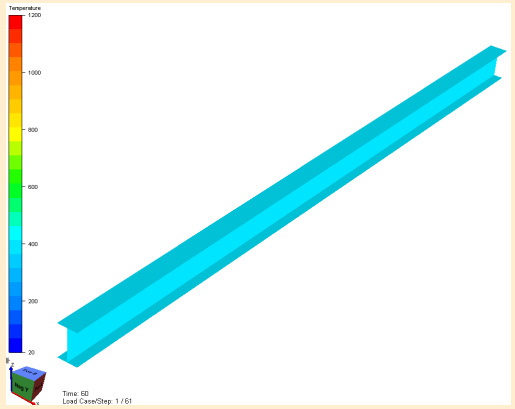
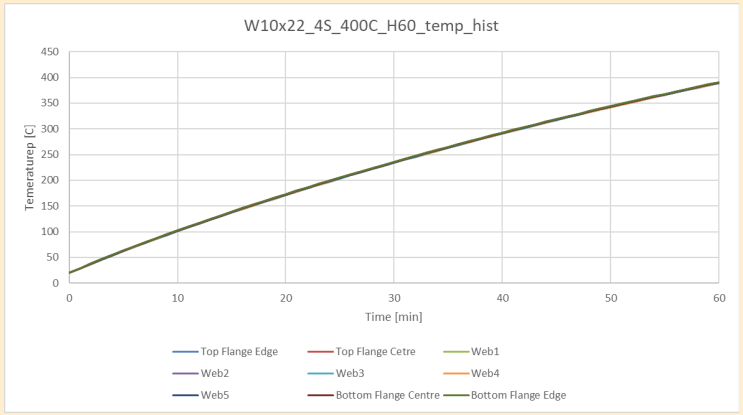
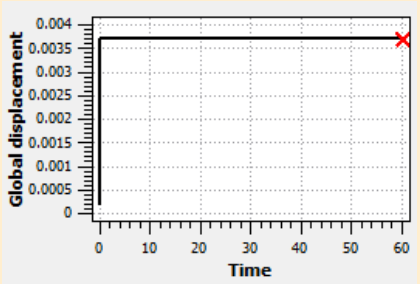
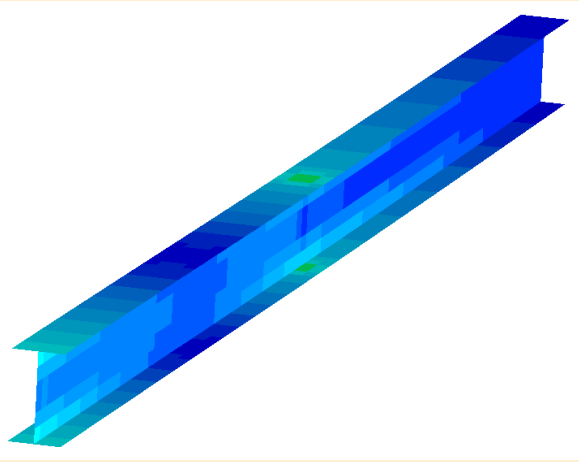
		+60mins 	N/A 

W10x22 4-Sided 538°C H60

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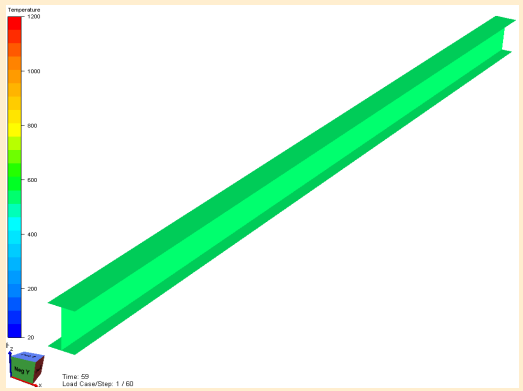
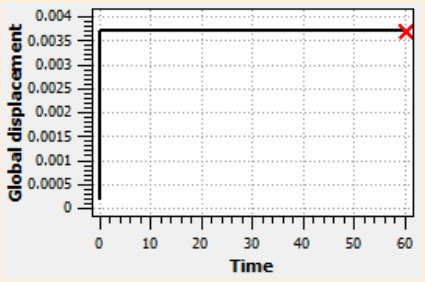
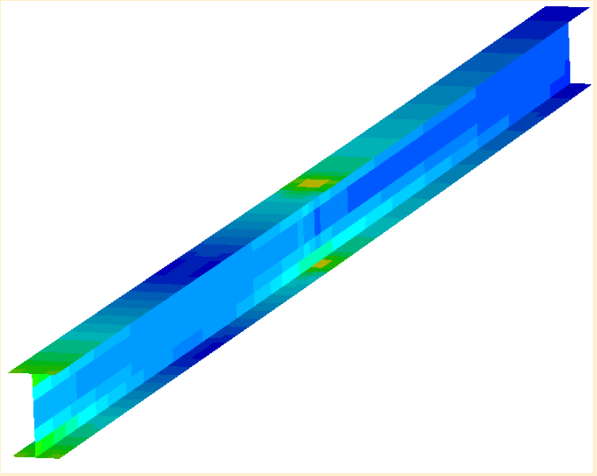
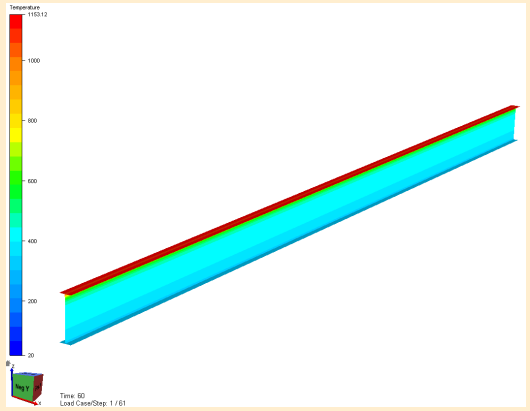
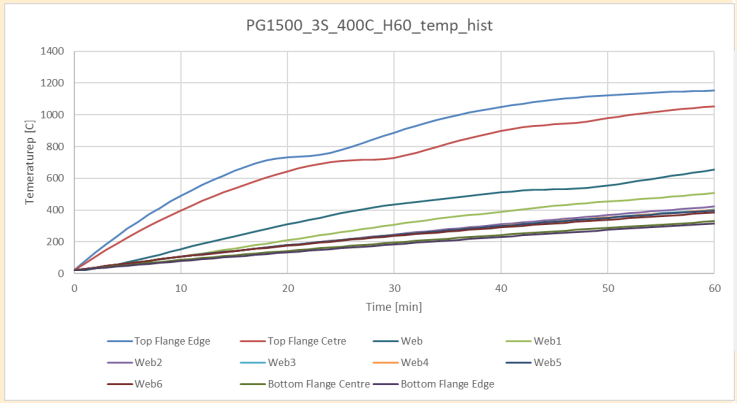
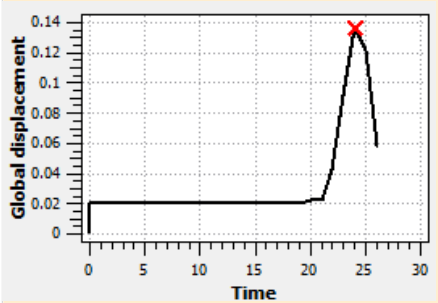
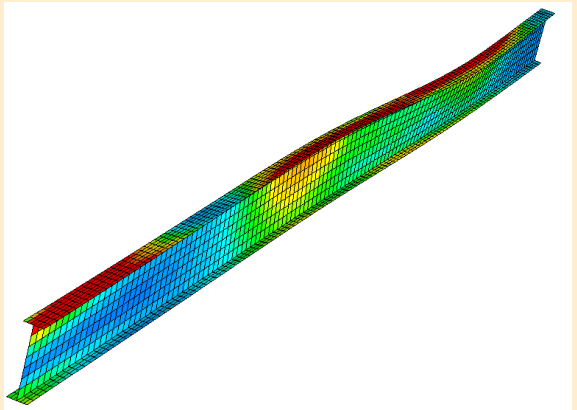
		+60mins 	N/A 

PG1500 3-Sided 400°C H60

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		22mins 	LTB 

PG1500 3-Sided 538°C H60

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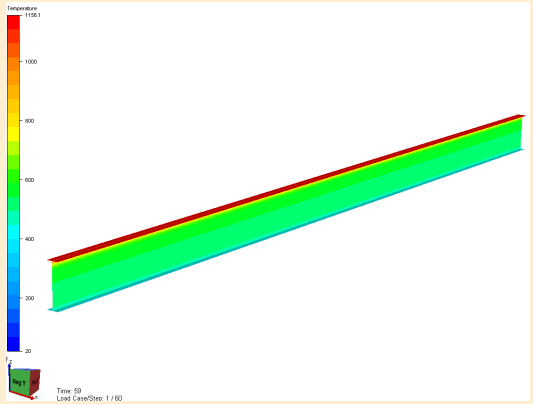
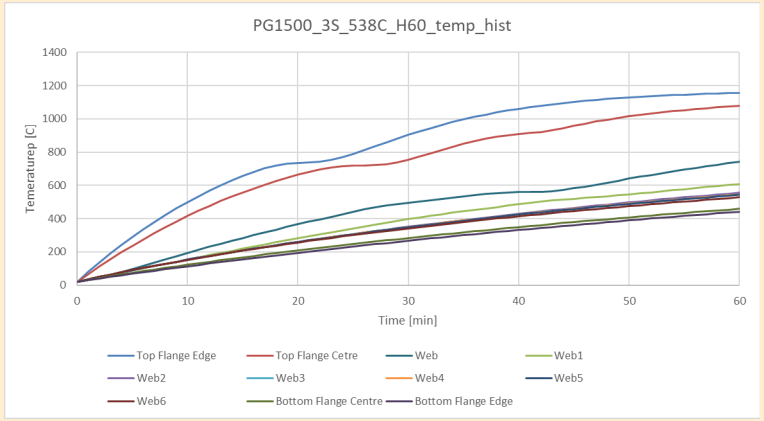
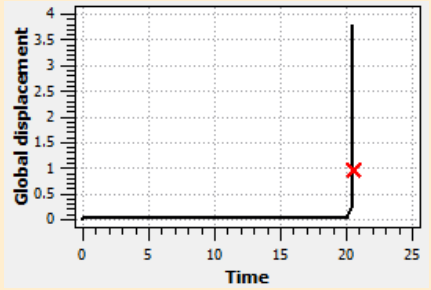
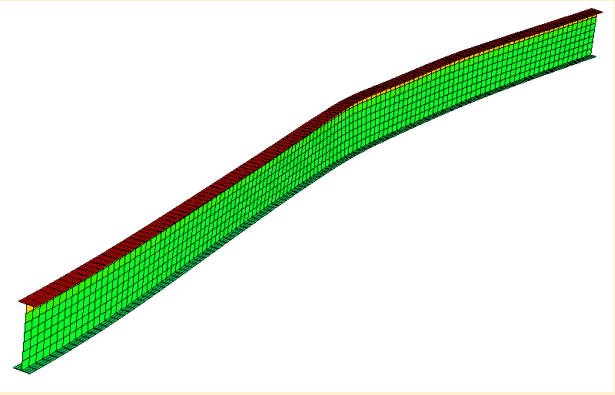
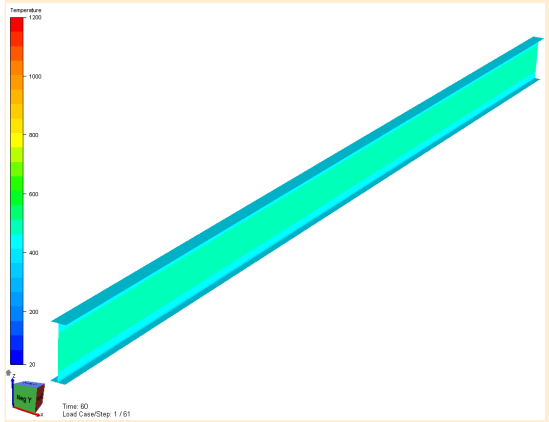
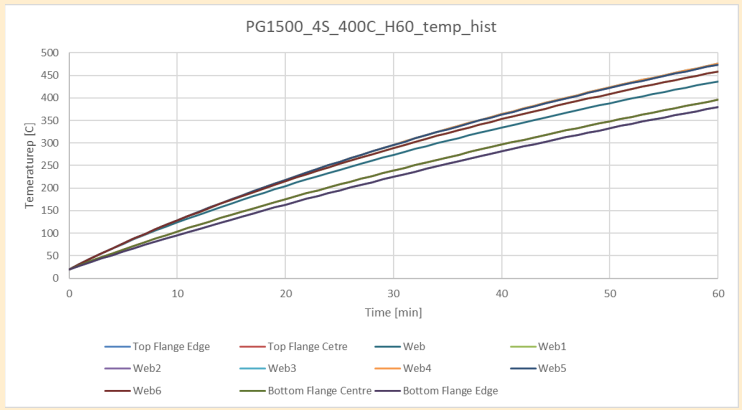
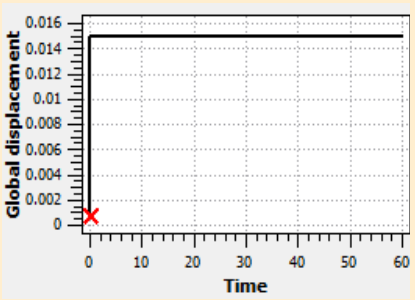
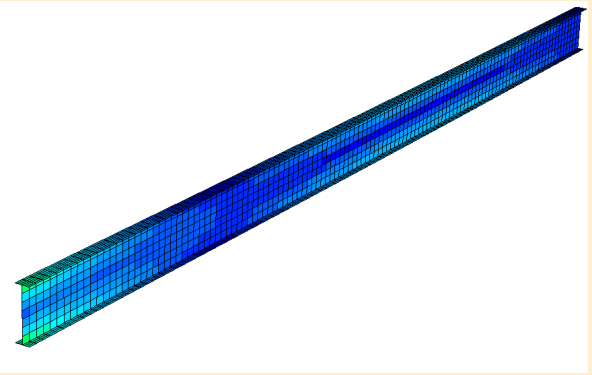
Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		20.5mins 	LTB 

PG1500 4-Sided 400°C H60

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		+60mins 	N/A 

PG1500 4-Sided 538°C H60

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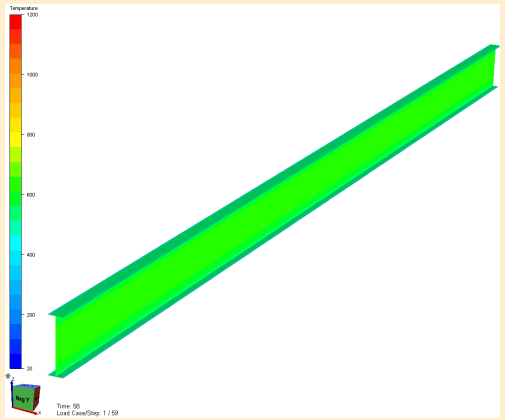
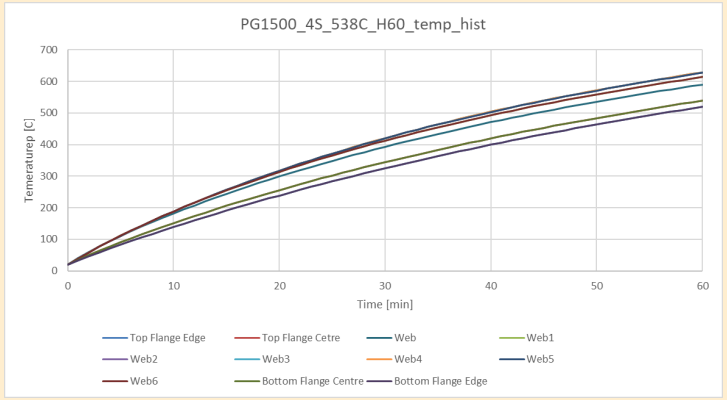
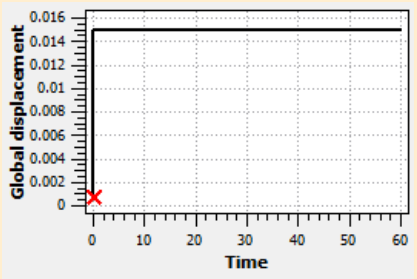
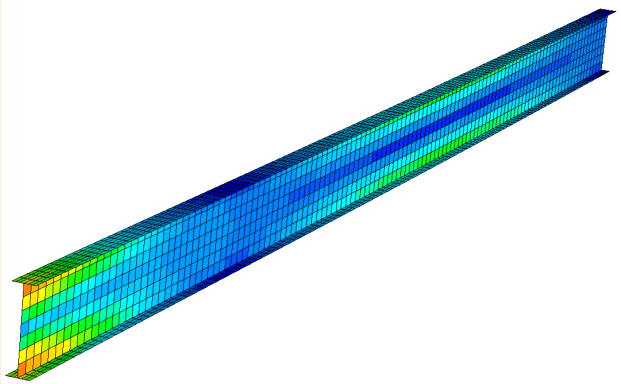
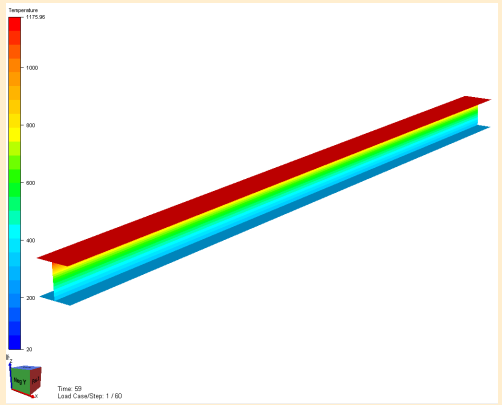
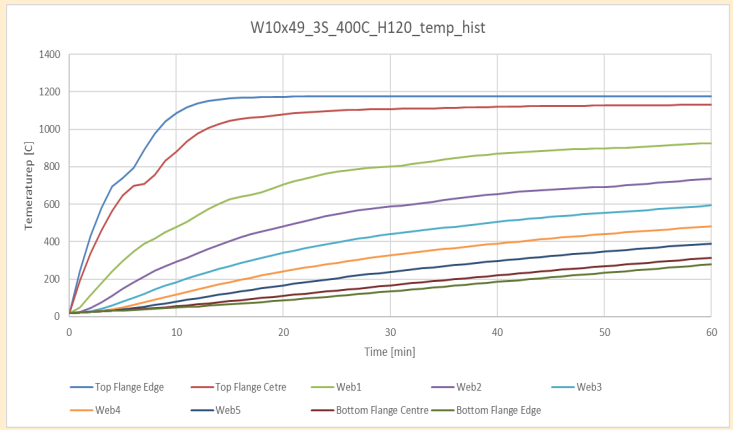
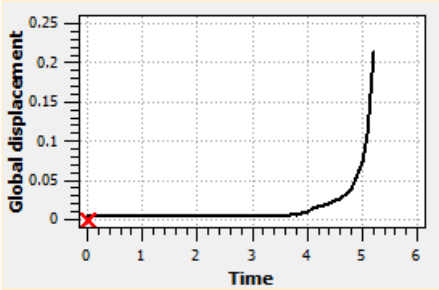
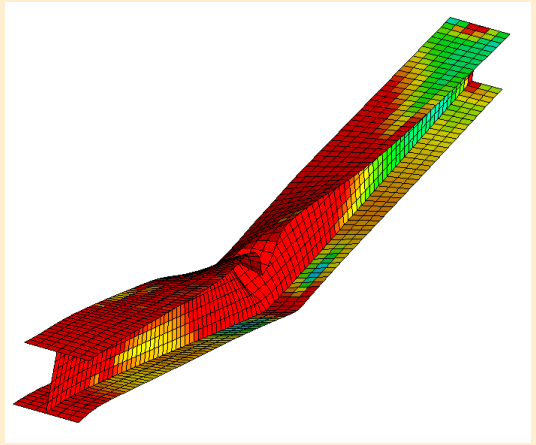
Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		+60mins 	N/A 

H120 PFP Results

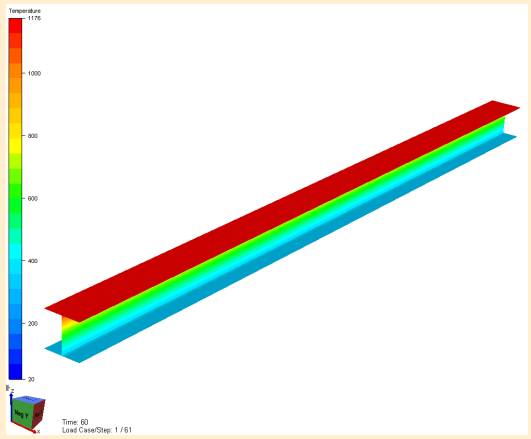
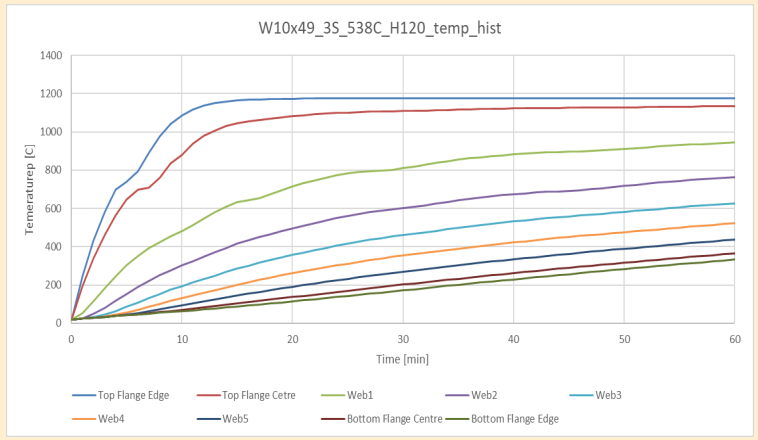
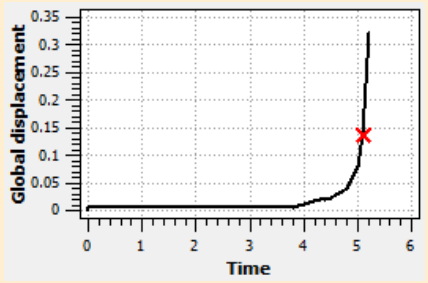
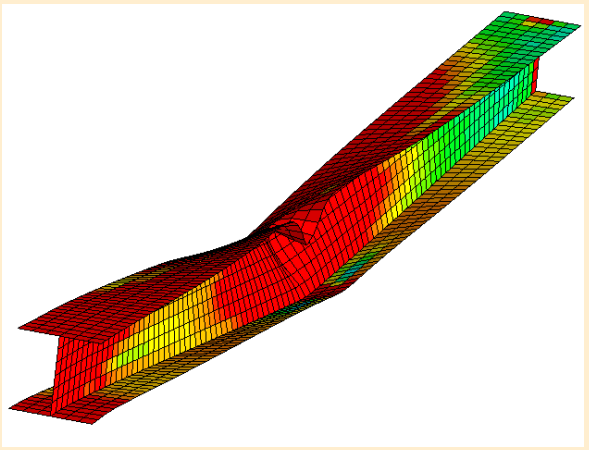
W10x49 3-Sided 400°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		5.1mins 	Bending 

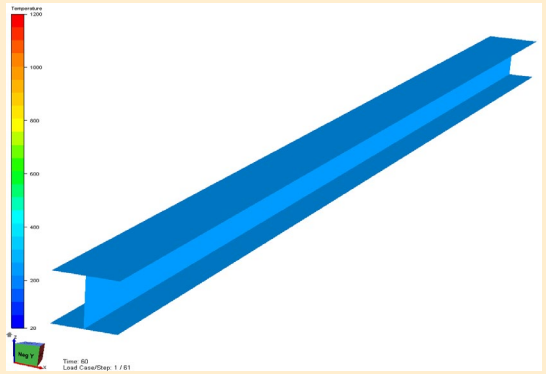
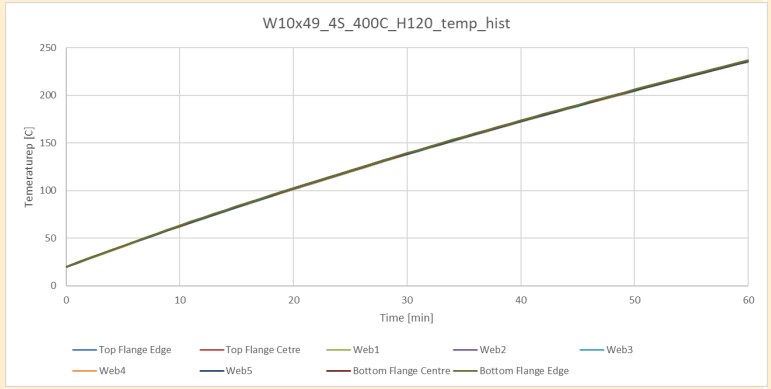
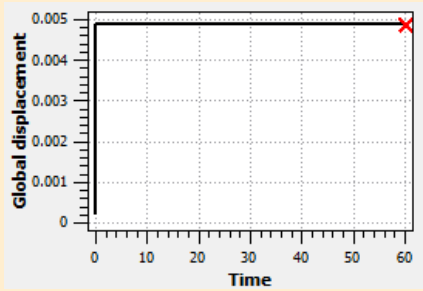
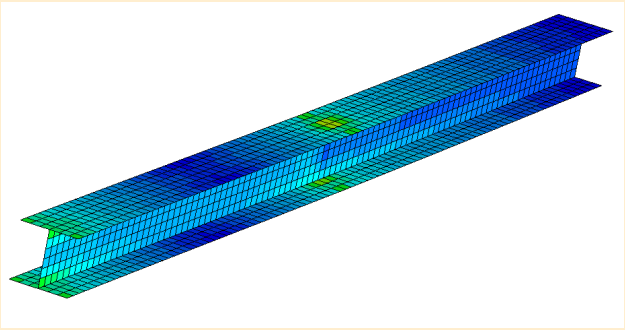
W10x49 3-Sided 538°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		5.1mins 	Bending 

W10x49 4-Sided 400°C H120

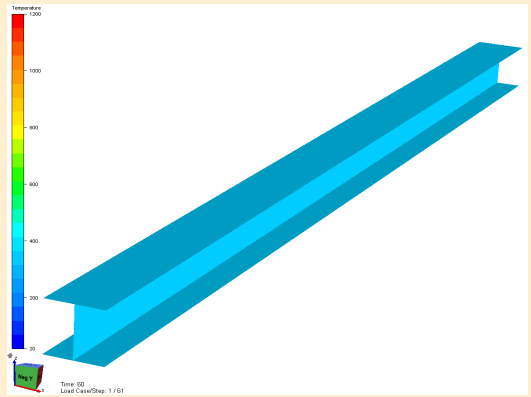
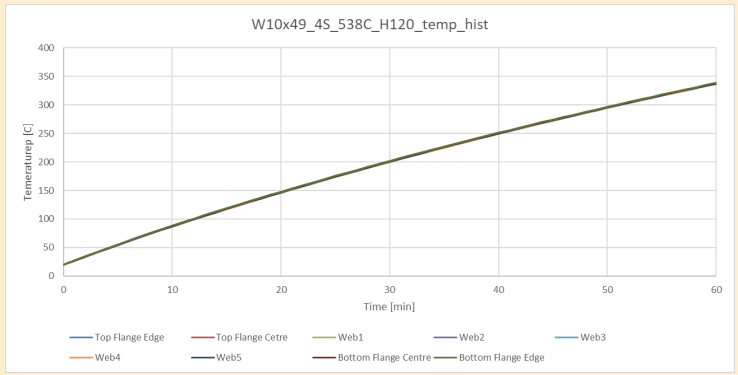
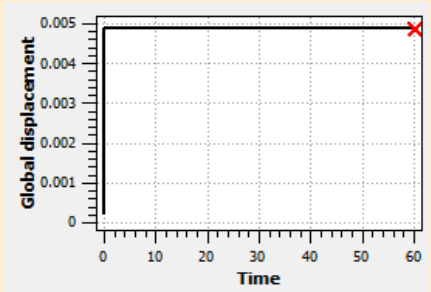
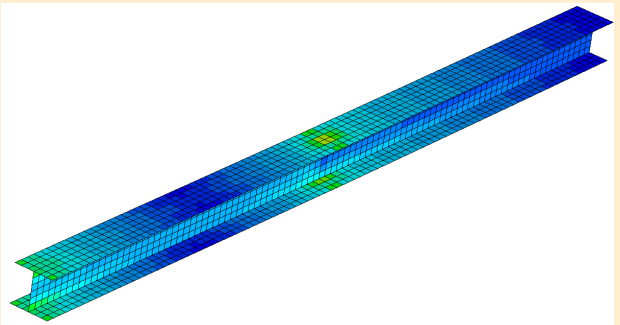
- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		+60mins 	N/A 

25 kent

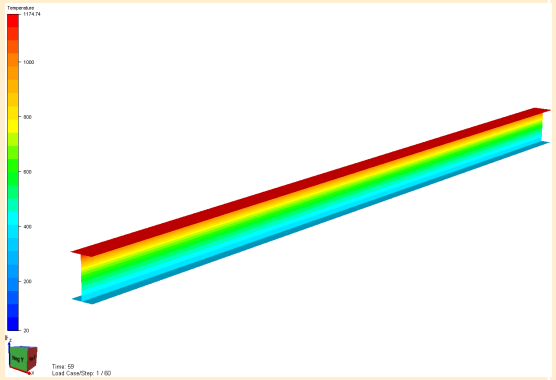
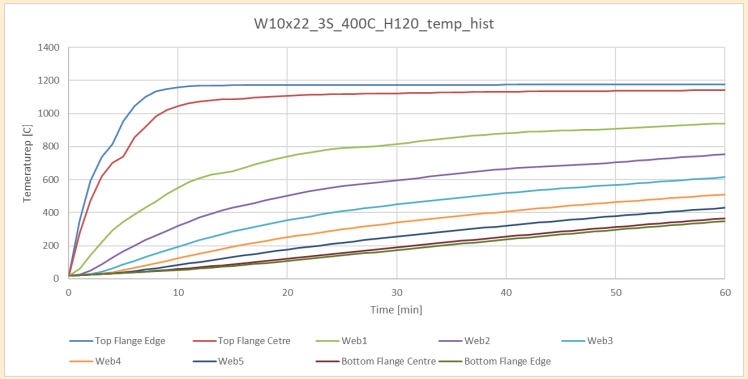
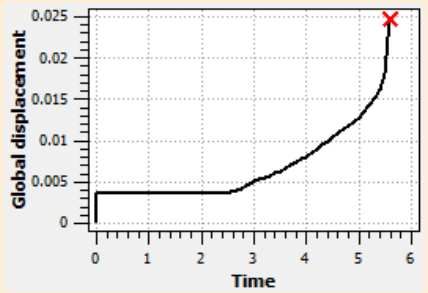
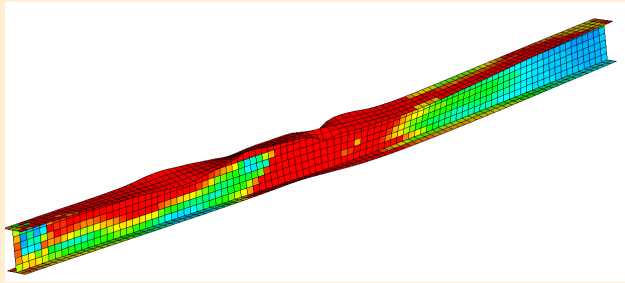
W10x49 4-Sided 538°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		+60mins 	N/A 

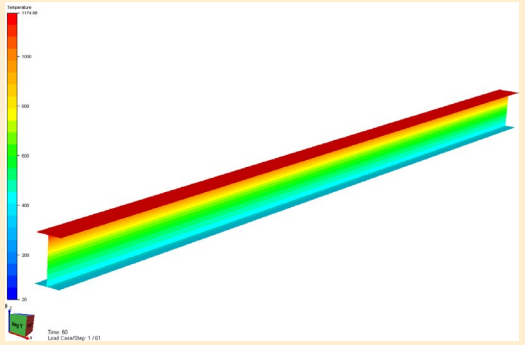
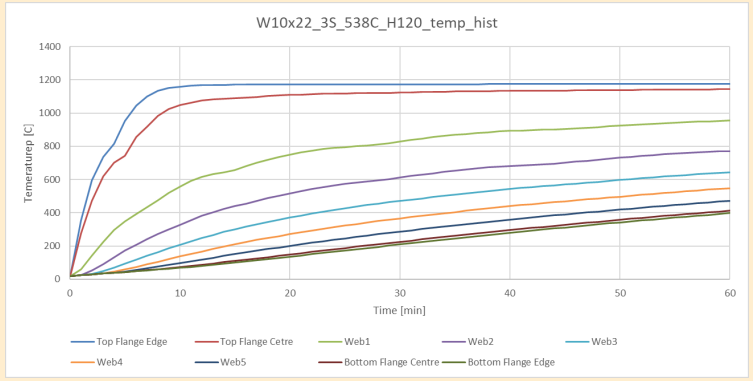
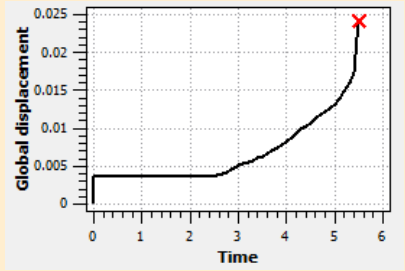
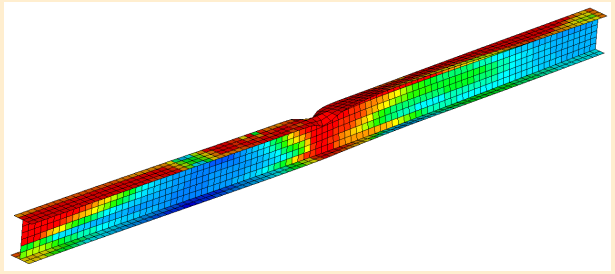
W10x22 3-Sided 400°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		5.6mins 	LTB 

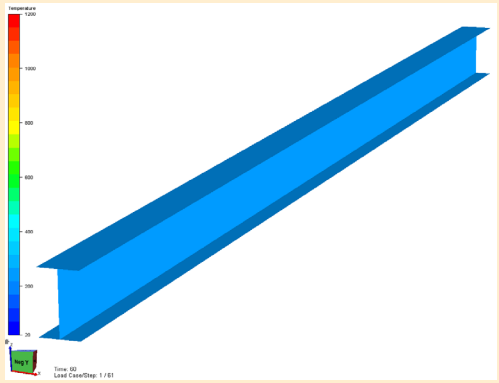
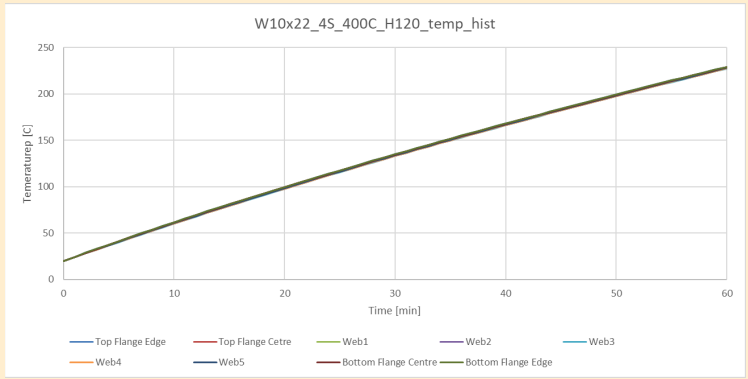
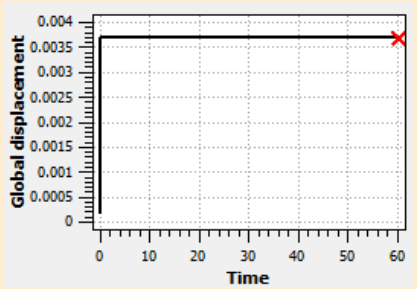
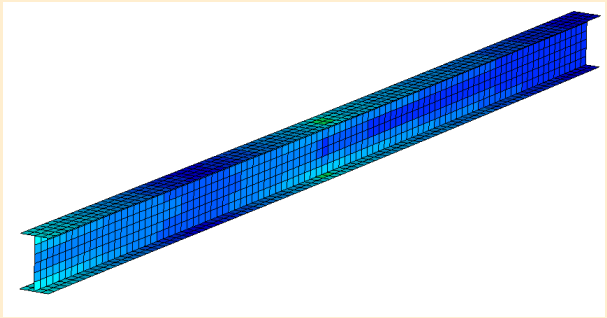
W10x22 3-Sided 538°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		5mins 	LTB 

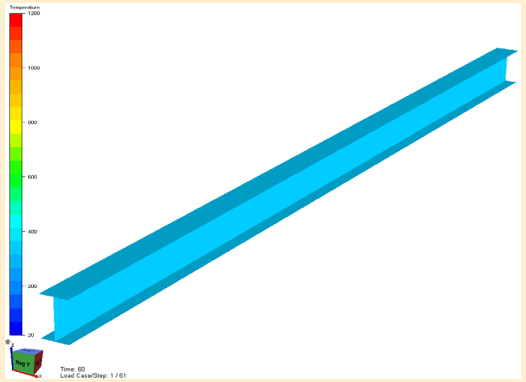
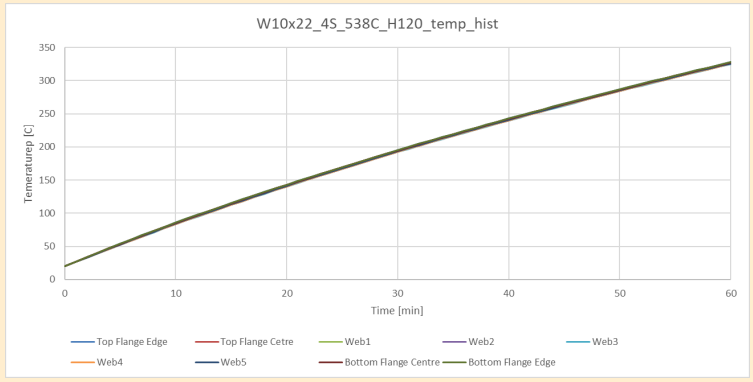
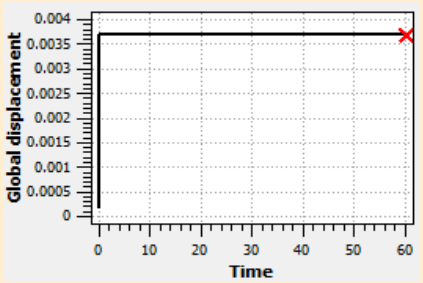
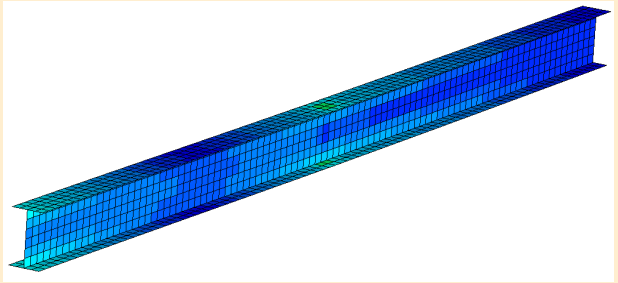
W10x22 4-Sided 400°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		+60mins 	N/A 

W10x22 4-Sided 538°C H120

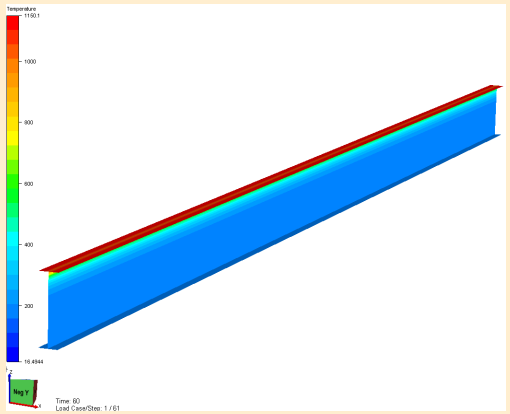
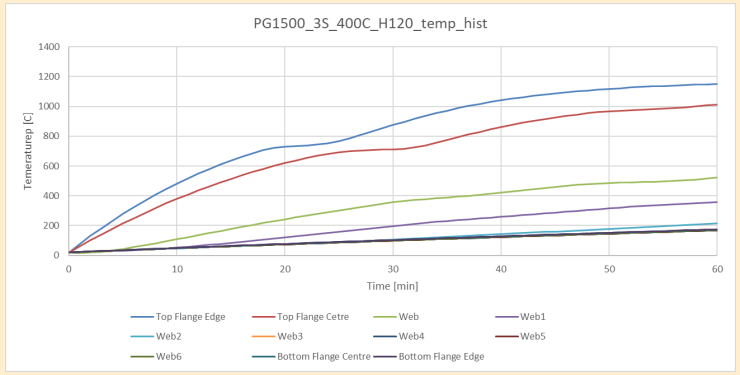
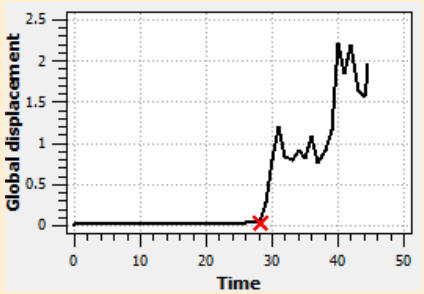
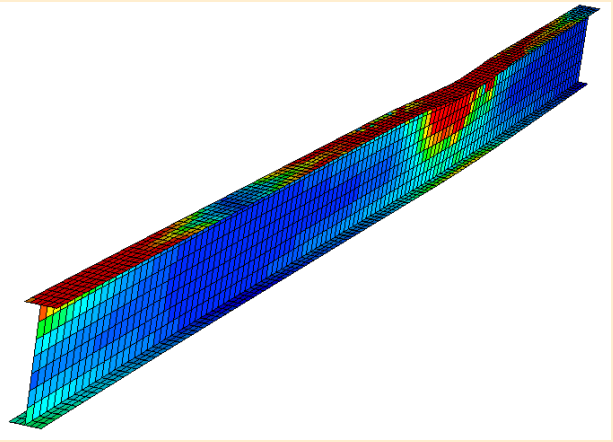
- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		+60mins	N/A
			

30 kent

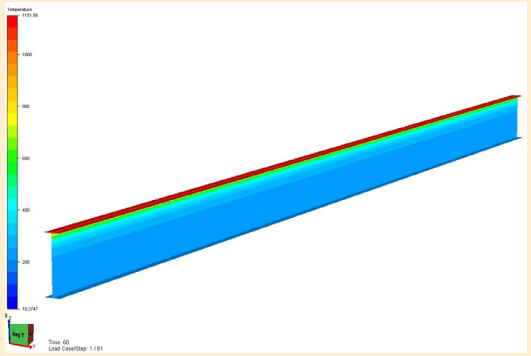
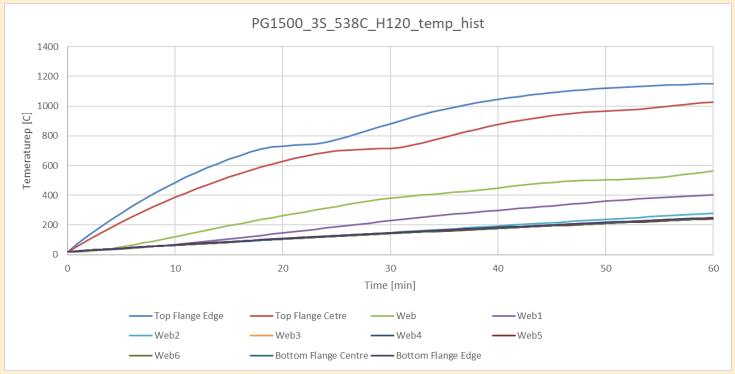
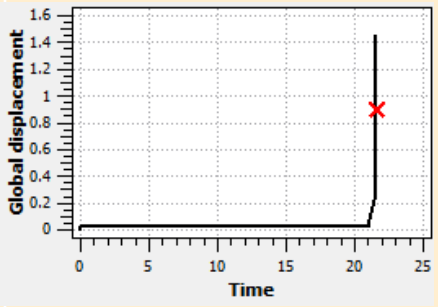
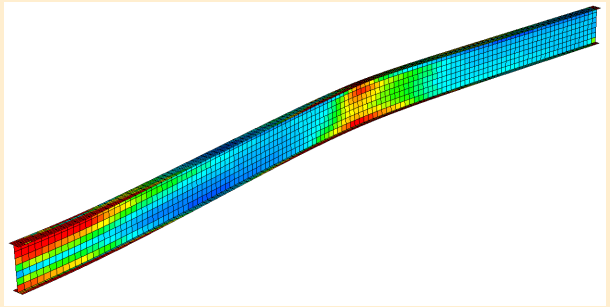
PG1500 3-Sided 400°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		27mins 	LTB 

PG1500 3-Sided 538°C H120

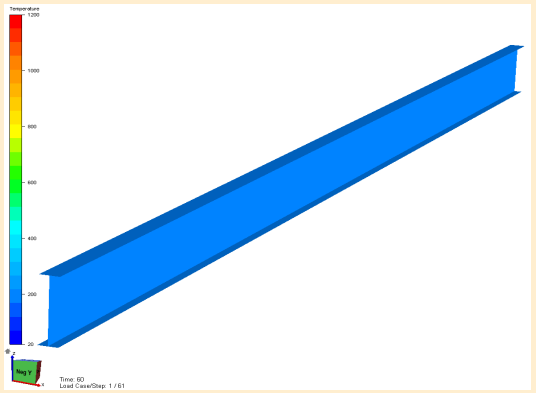
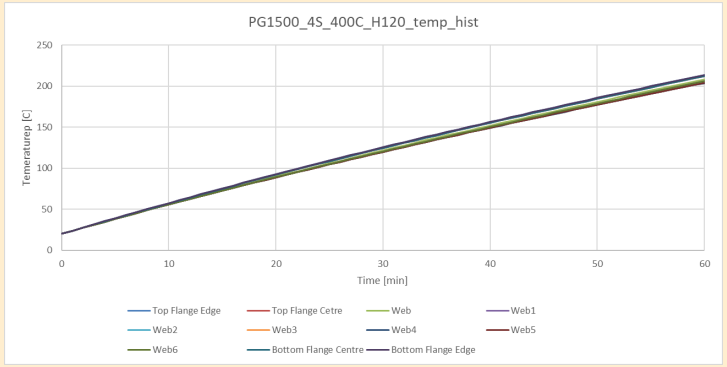
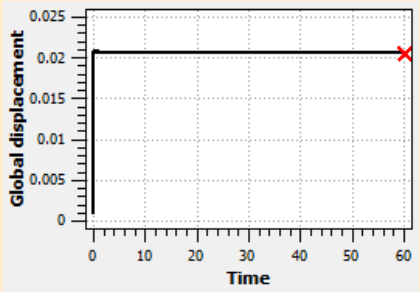
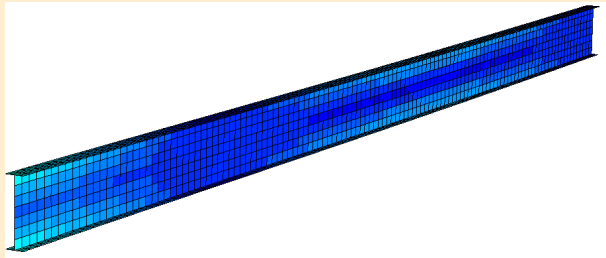
- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		+21.5mins 	LTB 

32 kent

PG1500 4-Sided 400°C H120

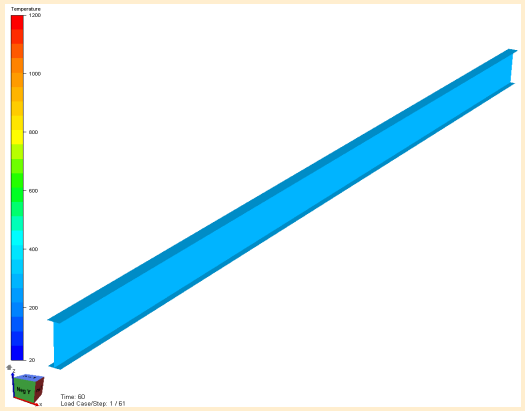
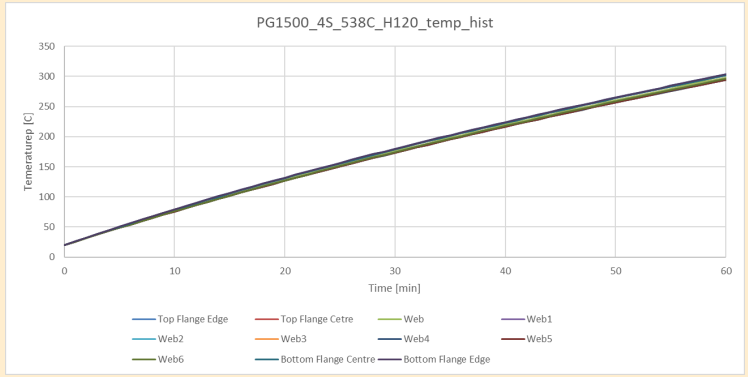
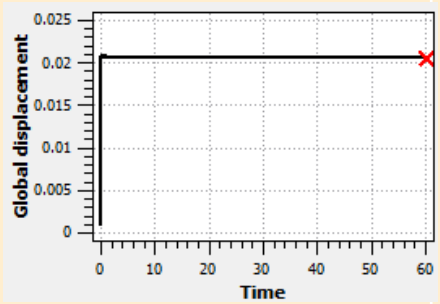
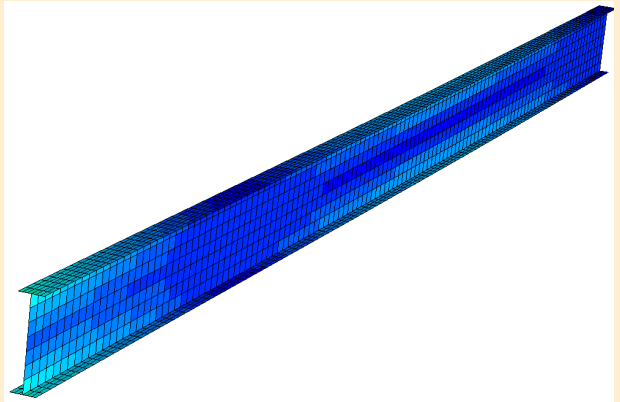
- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		+60mins 	N/A 

33 kent

PG1500 4-Sided 538°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		+60mins 	N/A 

34 kent

Results Summary

Results Summary

- The results are summarized in the table below:

Beam Size	PFP Coverage	CCT [°C]	Fire Rating	Failure Time	Failure Mechanism
PG1500x400x40x60	3-sided	400	HC 60	22	LTB
			HC 120	27	LTB
		538	HC 60	20.5	LTB
			HC 120	21.5	LTB
	4-sided	400	HC 60	60	-
			HC 120	60	-
		538	HC 60	60	-
			HC 120	60	-
W10x22	3-sided	400	HC 60	4	LTB
			HC 120	5.6	LTB
		538	HC 60	5	LTB
			HC 120	5	LTB
	4-sided	400	HC 60	60	-
			HC 120	60	-
		538	HC 60	60	-
			HC 120	60	-
W10x49	3-sided	400	HC 60	5	Bending
			HC 120	5.1	Bending
		538	HC 60	5	Bending
			HC 120	5.1	Bending
	4-sided	400	HC 60	60	-
			HC 120	60	-
		538	HC 60	60	-
			HC 120	60	-

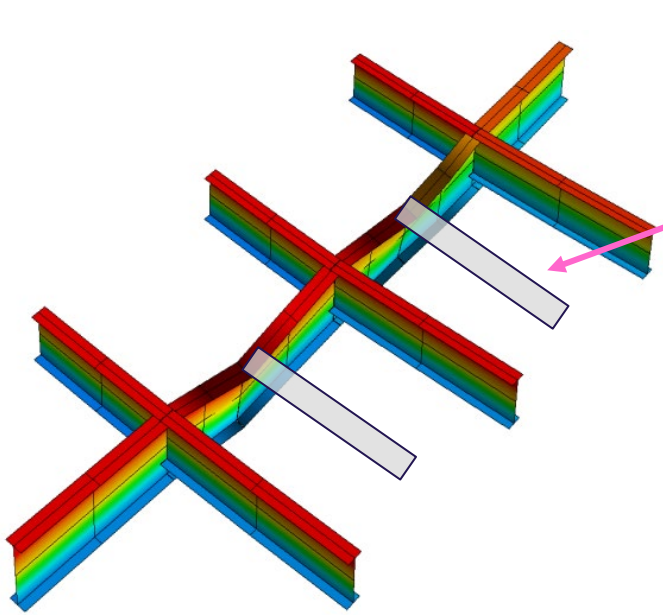
Sensitivity Analysis
Effect of Lateral Support

Sensitivity on Lateral Support

Protecting intermediate orthogonal beams reduces the unrestrained length of the beam, helping to improve the response against Lateral Torsional Buckling (LTB).

For this sensitivity assessment, the following restrain was provided:

- W10x49 and W10x22 were only laterally restrained at mid span,
- PG1500x400x40x60 was restrained at every 2.5 metres i.e., 11 internal lateral supports.



Results Summary

- The results are summarized in the table below:

Case number	Beam Size	PFP Coverage	CCT [°C]	Fire Rating	Unrestrained Failure Time	Failure Mechanism	*Restrained Failure Time	Failure Mechanism
1	W10x49	3-sided	400	HC 60	5	Bending	7.3	Bending
2				HC 120	5.1	Bending	7.4	Bending
3			538	HC 60	5	Bending	7.2	Bending
4				HC 120	5.1	Bending	7.4	Bending
5		4-sided	400	HC 60	60	-	60	-
6				HC 120	60	-	60	-
7			538	HC 60	60	-	60	-
8				HC 120	60	-	60	-
9	W10x22	3-sided	400	HC 60	4	LTB	4	LTB
10				HC 120	5.6	LTB	6	LTB
11			538	HC 60	5	LTB	6	LTB
12				HC 120	5	LTB	6	LTB
13		4-sided	400	HC 60	60	-	60	-
14				HC 120	60	-	60	-
15			538	HC 60	60	-	60	-
16				HC 120	60	-	60	-
17	PG1500x400x40x60	3-sided	400	HC 60	22	LTB	60	Slightly increased sagging displacement, but no failure
18				HC 120	27	LTB	60	Slightly increased sagging displacement, but no failure
19			538	HC 60	20.5	LTB	60	Slightly increased sagging displacement, but no failure
20				HC 120	21.5	LTB	60	Slightly increased sagging displacement, but no failure
21		4-sided	400	HC 60	60	-	60	-
22				HC 120	60	-	60	-
23			538	HC 60	60	-	60	-
24				HC 120	60	-	60	-

Conclusions

Conclusions

- The results show that adding more PFP thickness either by reducing the PFP critical core temperature (CCT) from 538°C to 400°C, or increasing the fire ratings (HC60 vs HC120), has a negligible effect in the failure times specially on shallow beams which are dominated by conduction from the unprotected to flange.

- For deeper beams, increasing the PFP thickness shows a modest improvement in the response, however the beam still fails prematurely compared to a 4-sided protected beam.

- As expected, all 4-sided PFP beams were able to withstand the 60 minutes of fire impingement without reaching failure.

- Implementing lateral supports had a negligible impact on the shallow beams, but proved effective for the deeper beam.

Any Questions?

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