



# PFPNet Conference 2024

Three Sided PFP Scoping Study –  
Finite Element Results

Amsterdam

21<sup>st</sup> – 22<sup>nd</sup> 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.



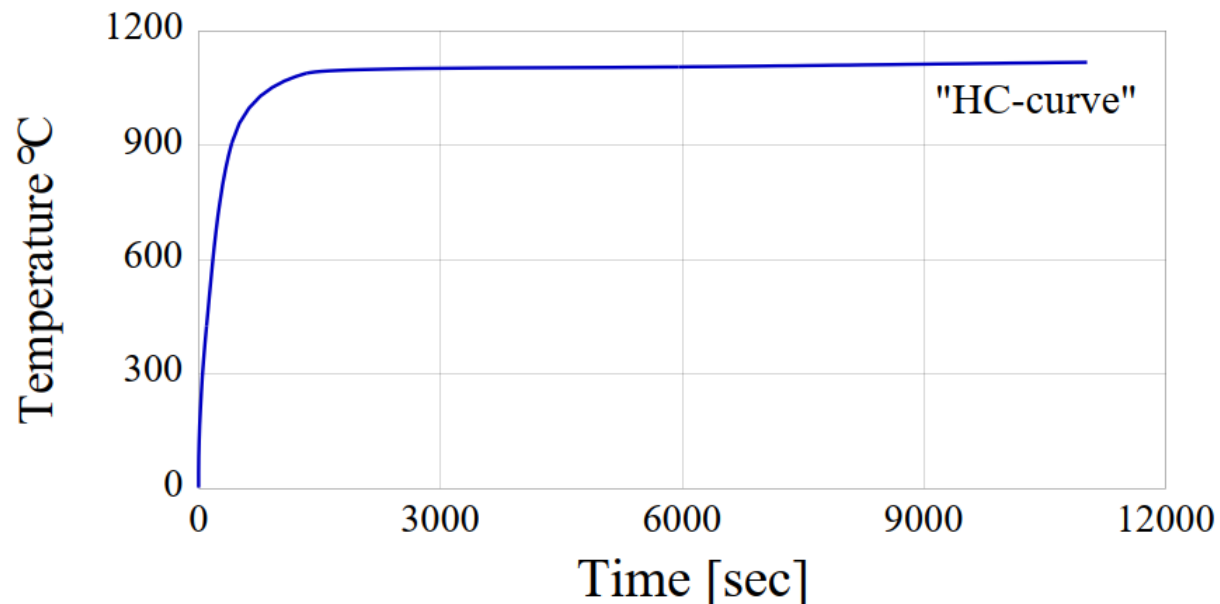
01

**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:  $T = 20 + 1080 * (1 - 0,325 * e^{-0,167 * t} - 0,675 * e^{-2,5 * t})$ .





02

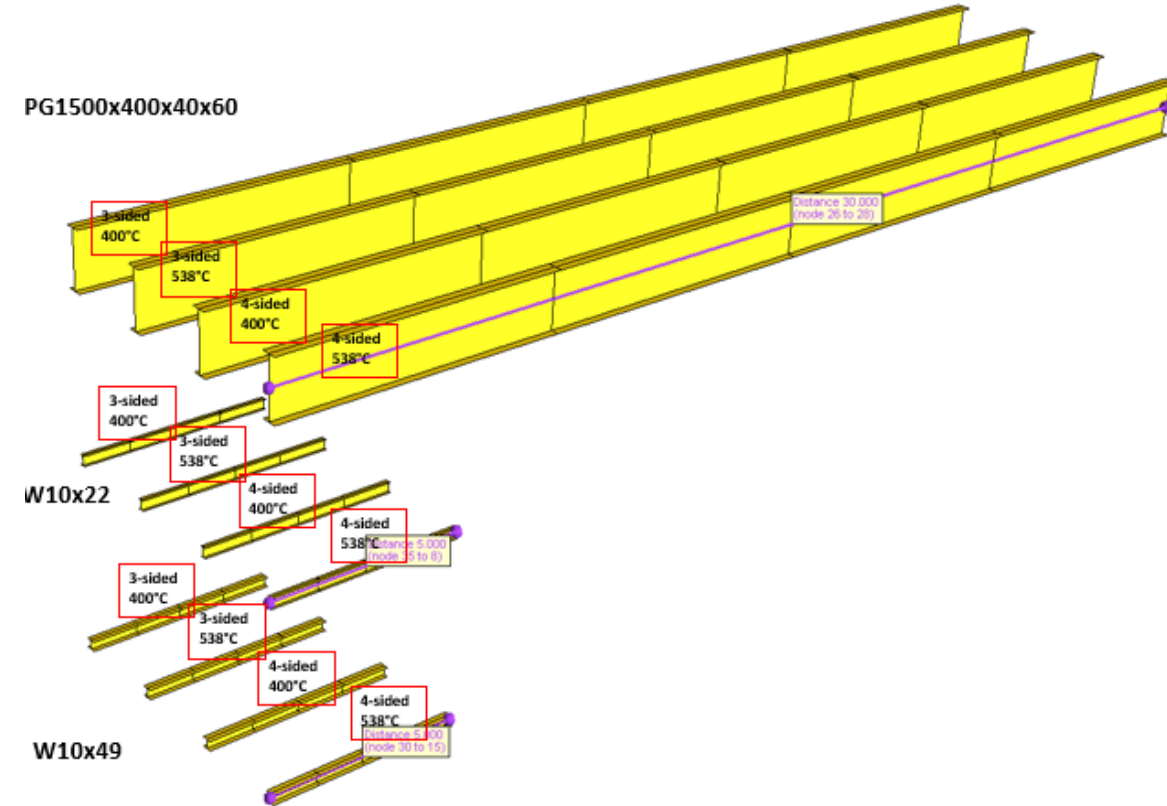
# Heat Transfer and Structural Fire Results

# 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

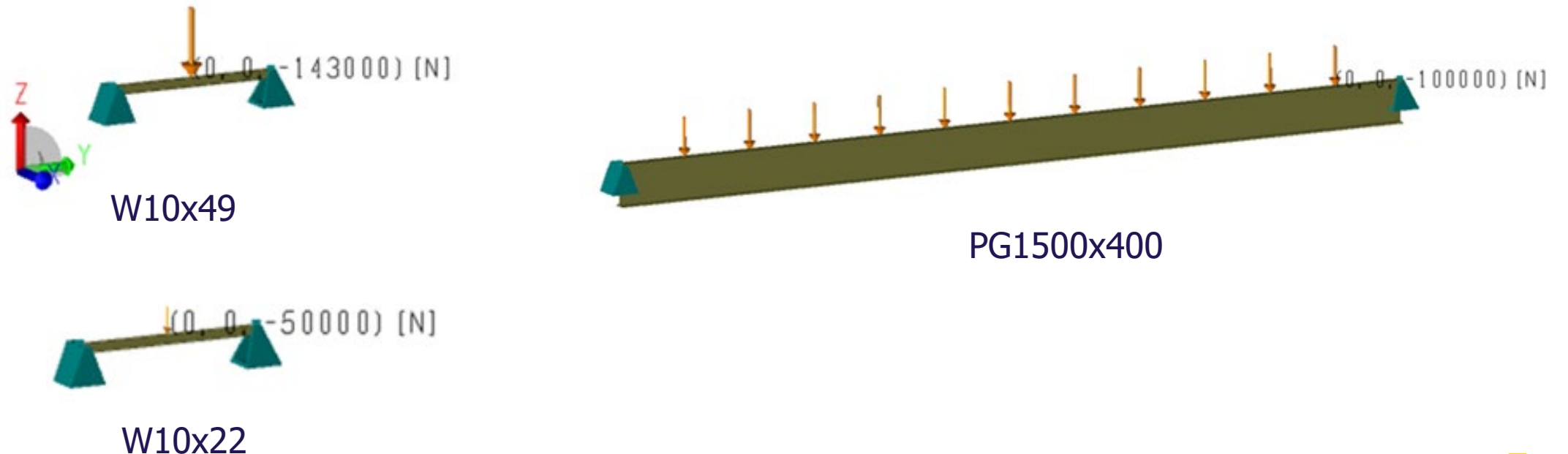
Number of Cases	Section Size	PPF Coverage	CCT [°C]	Fire Rating
17	PG1500x400x40x60	3-sided	400	HC 60
18				HC 120
19			538	HC 60
20				HC 120
21		4-sided	400	HC 60
22				HC 120
23			538	HC 60
24				HC 120
9	W10x22	3-sided	400	HC 60
10				HC 120
11			538	HC 60
12				HC 120
13		4-sided	400	HC 60
14				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.

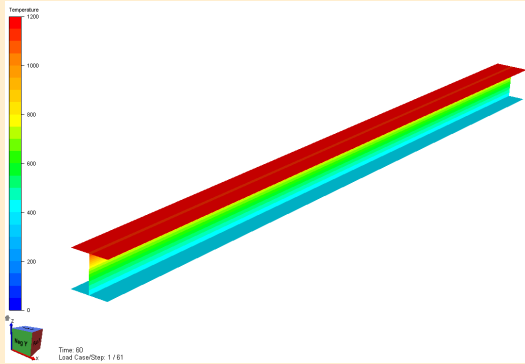
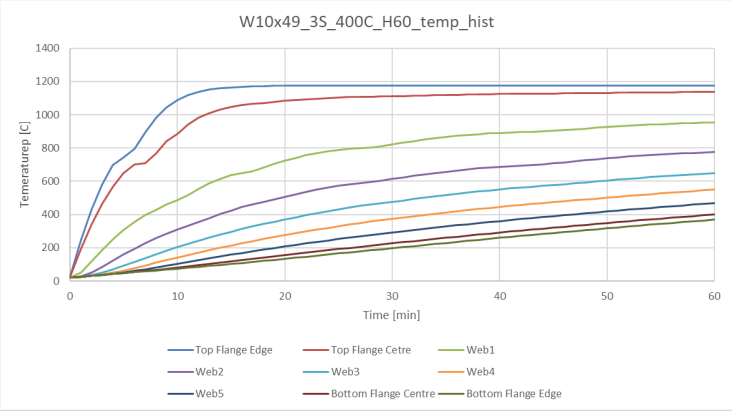
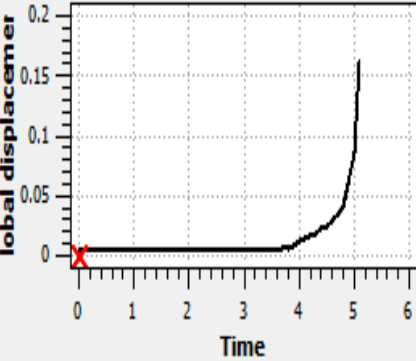
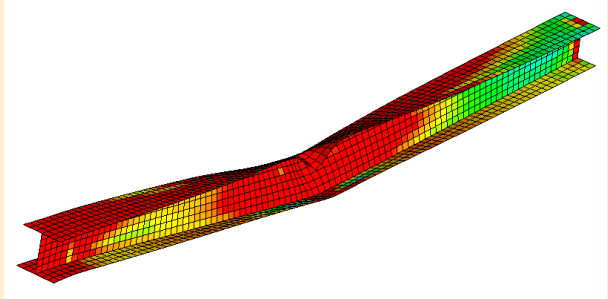




# H60 PFP Results

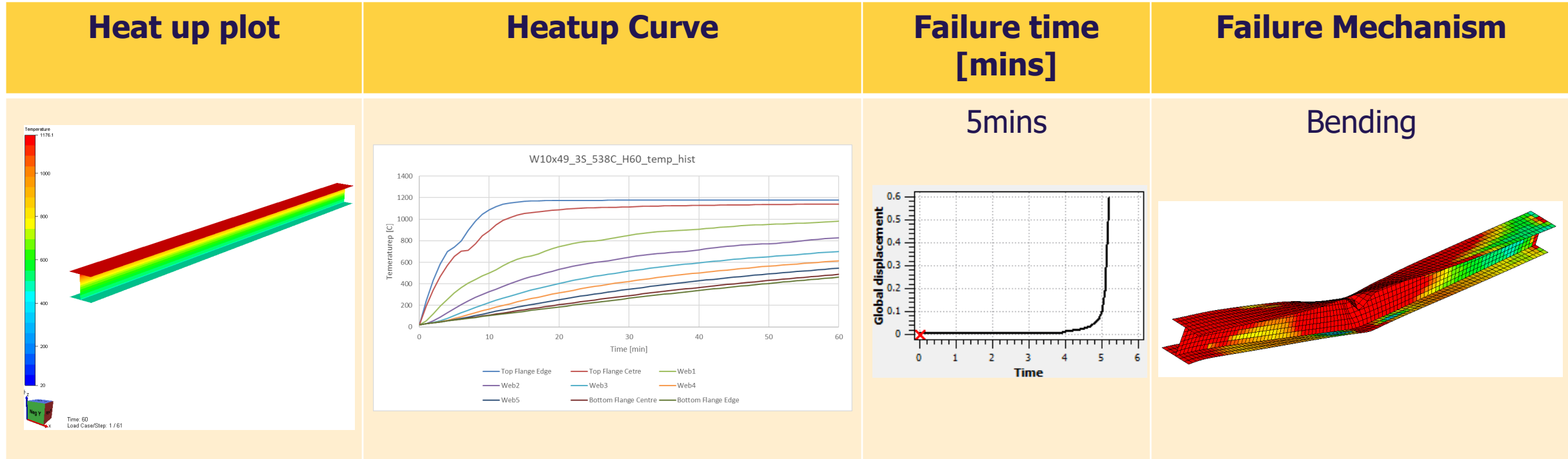
# W10x49 3-Sided 400°C H60

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
	<p>W10x49_3S_400C_H60_temp_hist</p> 	<p>5mins</p> 	<p>Bending</p> 

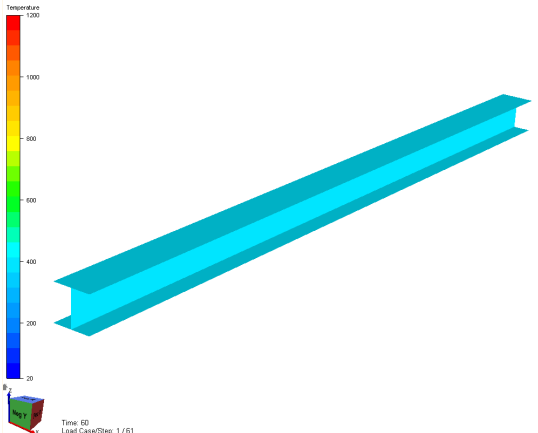
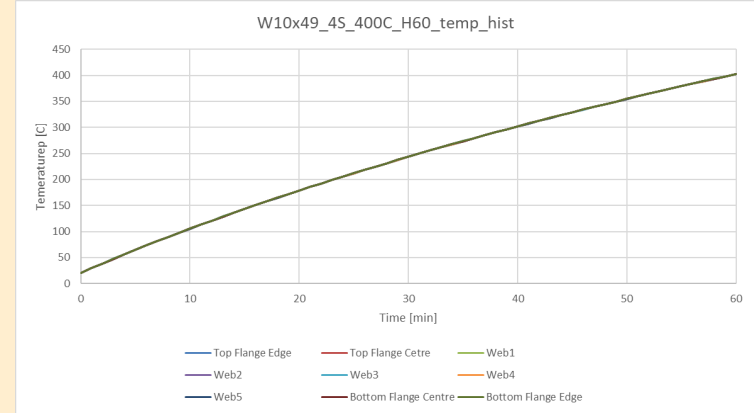
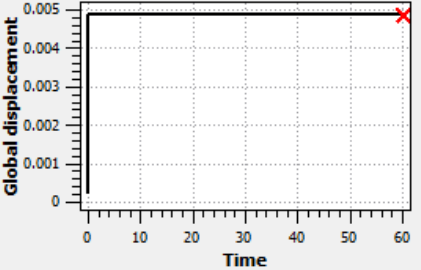
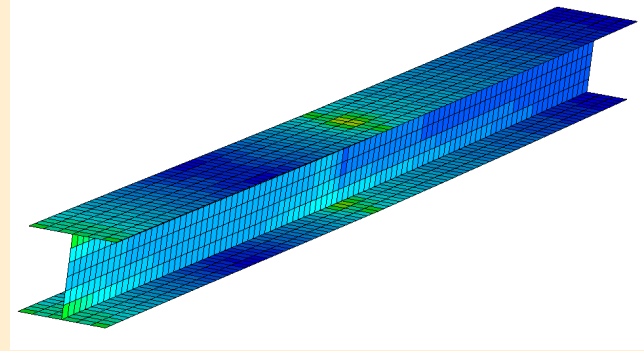
# W10x49 3-Sided 538°C H60

- The following results were obtained for this beam



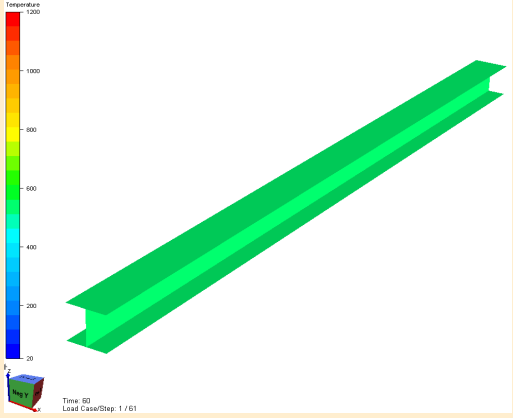
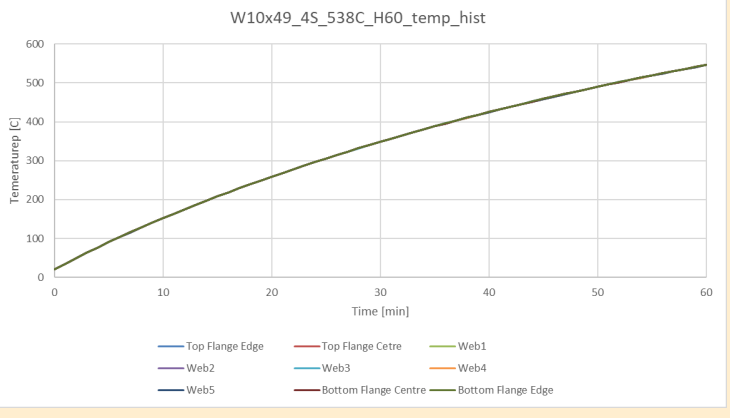
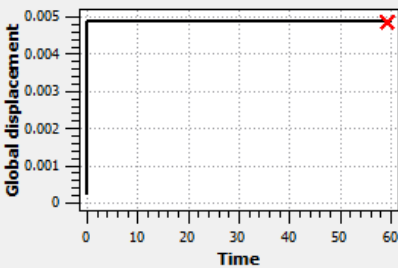
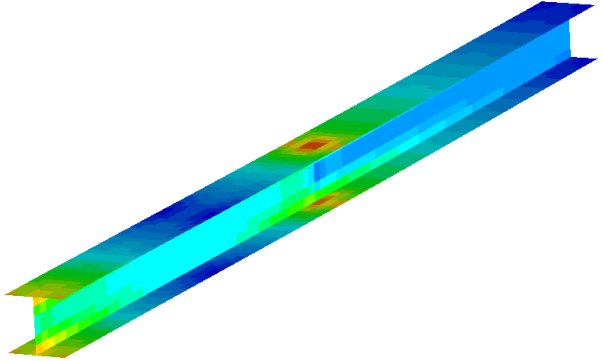
# W10x49 4-Sided 400°C H60

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
 <p>Temperature 1200 1000 800 600 400 200 20</p> <p>Time: 60 Local Case: Step: 1/61</p>	 <p>W10x49_4S_400C_H60_temp_hist</p> <p>Temperature [C]</p> <p>Time [min]</p> <p>Legend:</p> <ul style="list-style-type: none"><li>Top Flange Edge</li><li>Top Flange Centre</li><li>Web1</li><li>Web2</li><li>Web3</li><li>Web4</li><li>Web5</li><li>Bottom Flange Centre</li><li>Bottom Flange Edge</li></ul>	<p>+60mins</p>  <p>Global displacement</p> <p>Time</p>	<p>N/A</p> 

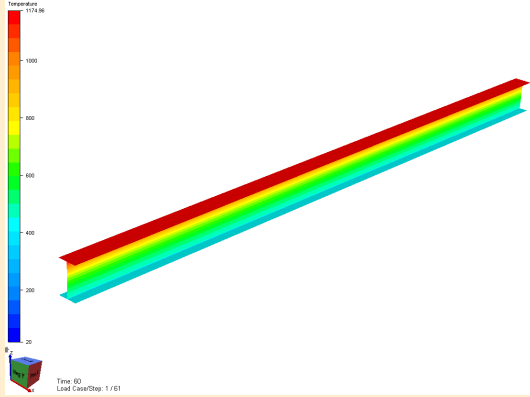
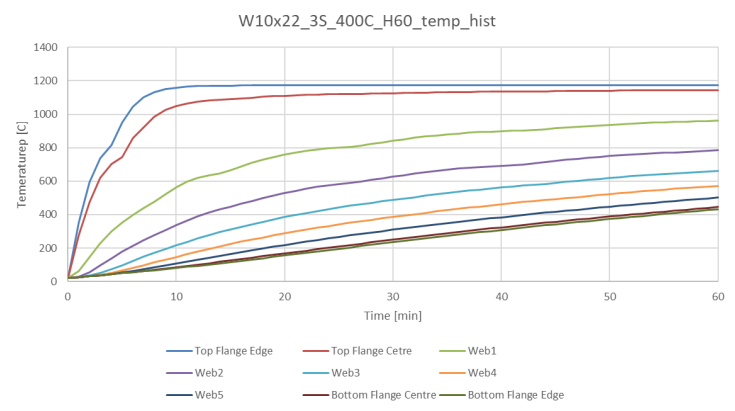
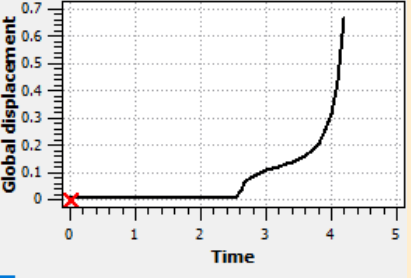
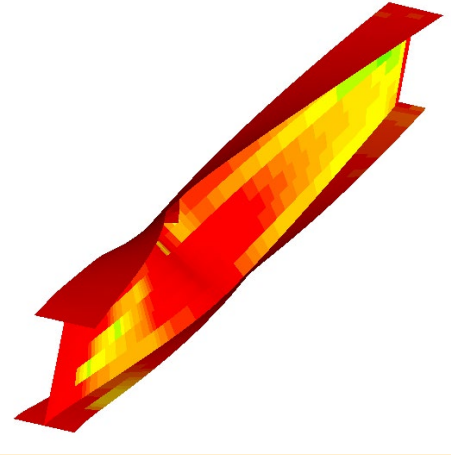
# W10x49 4-Sided 538°C H60

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism																
 <p>Temperature plot showing a 3D model of the beam. The color scale ranges from 20°C (blue) to 1000°C (red). The beam is shown at an angle, with the top flange and web visible. The temperature is highest at the top flange and lowest at the bottom flange.</p>	 <p>W10x49_4S_538C_H60_temp_hist</p> <table border="1"><thead><tr><th>Time [min]</th><th>Temperature [C]</th></tr></thead><tbody><tr><td>0</td><td>0</td></tr><tr><td>10</td><td>150</td></tr><tr><td>20</td><td>250</td></tr><tr><td>30</td><td>350</td></tr><tr><td>40</td><td>450</td></tr><tr><td>50</td><td>500</td></tr><tr><td>60</td><td>550</td></tr></tbody></table> <p>Legend:</p> <ul style="list-style-type: none"><li>Top Flange Edge</li><li>Web2</li><li>Web5</li><li>Top Flange Centre</li><li>Web3</li><li>Bottom Flange Centre</li><li>Web1</li><li>Web4</li><li>Bottom Flange Edge</li></ul>	Time [min]	Temperature [C]	0	0	10	150	20	250	30	350	40	450	50	500	60	550	<p>+60mins</p>  <p>Global displacement vs Time graph. The y-axis is Global displacement (0 to 0.005) and the x-axis is Time (0 to 60). The displacement is 0 until approximately 58 minutes, then jumps to 0.005.</p>	<p>N/A</p>  <p>Failure Mechanism plot showing a 3D model of the beam. The beam is shown at an angle, with the top flange and web visible. The failure mechanism is indicated by a red 'X' on the top flange.</p>
Time [min]	Temperature [C]																		
0	0																		
10	150																		
20	250																		
30	350																		
40	450																		
50	500																		
60	550																		


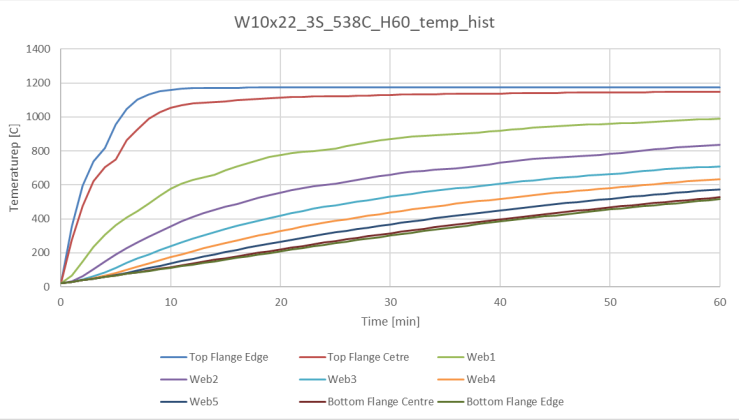
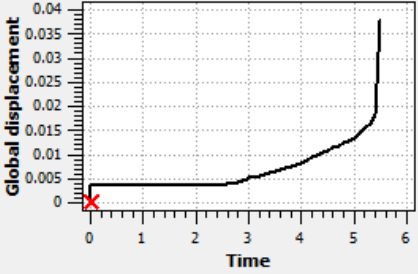
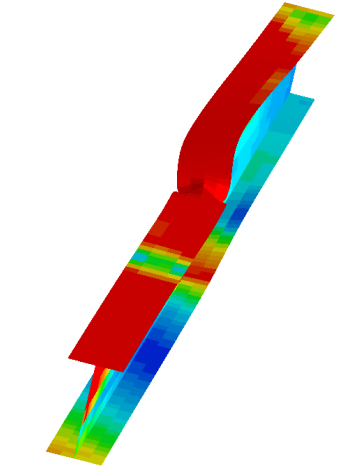
# W10x22 3-Sided 400°C H60

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		<p>4mins</p> 	<p>LTB</p> 

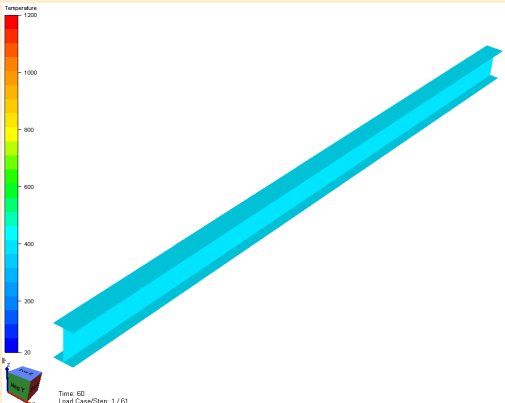
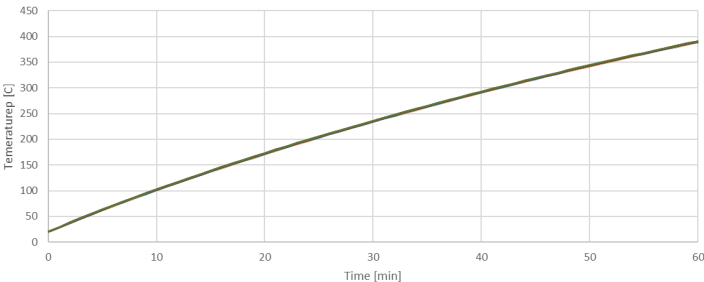
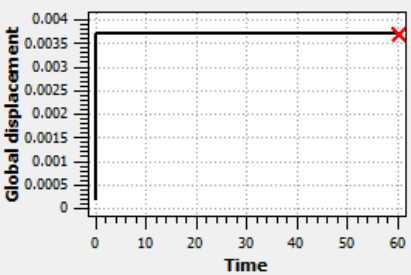
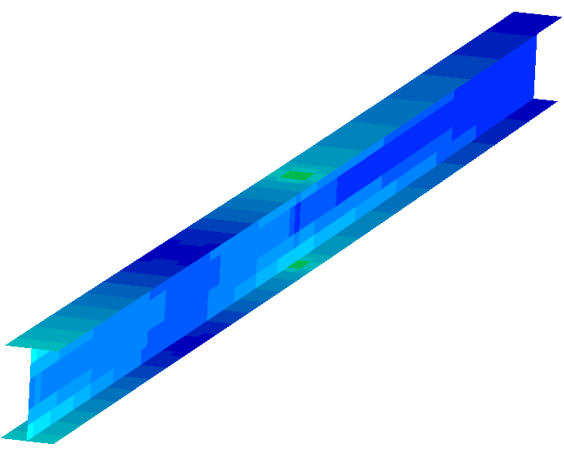
# W10x22 4-Sided 538°C H60

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		<p data-bbox="1574 539 1702 582">5mins</p> 	<p data-bbox="2142 539 2226 582">LTB</p> 

# W10x22 4-Sided 400°C H60

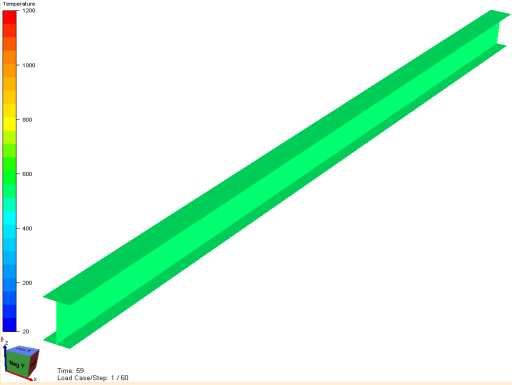
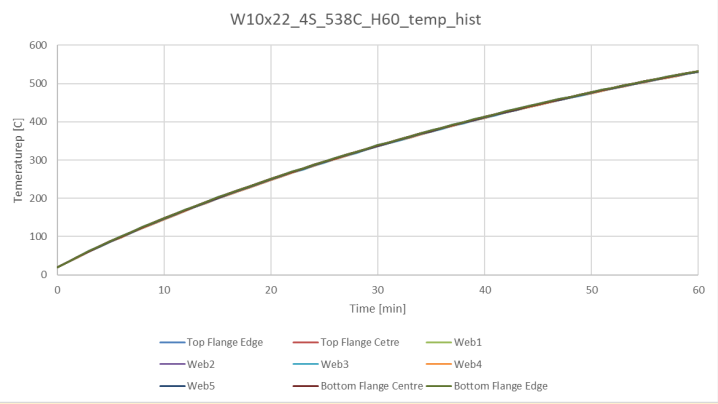
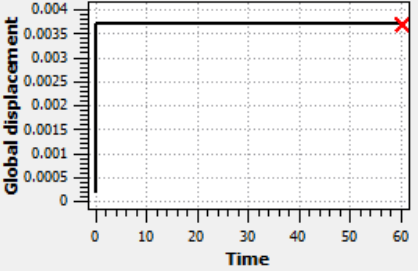
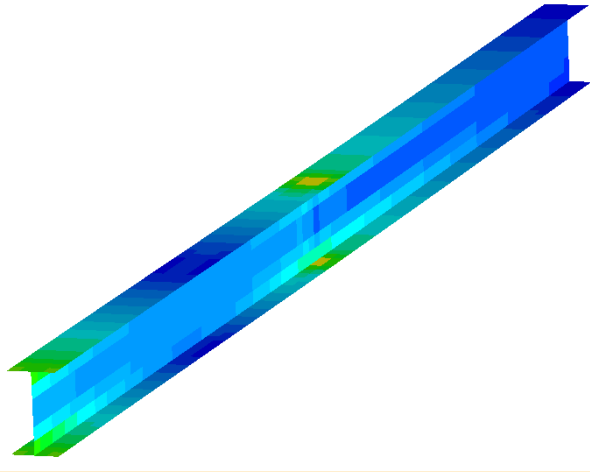
- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism																								
	<p data-bbox="891 621 1146 642">W10x22_4S_400C_H60_temp_hist</p>  <table border="1" data-bbox="675 942 1375 1013"><caption>Approximate data from Heatup Curve</caption><thead><tr><th>Time [min]</th><th>Temperature [C]</th></tr></thead><tbody><tr><td>0</td><td>0</td></tr><tr><td>10</td><td>67</td></tr><tr><td>20</td><td>133</td></tr><tr><td>30</td><td>200</td></tr><tr><td>40</td><td>267</td></tr><tr><td>50</td><td>333</td></tr><tr><td>60</td><td>400</td></tr></tbody></table> <p data-bbox="815 949 1223 1006">Legend: Top Flange Edge, Top Flange Centre, Web1, Web2, Web3, Web4, Web5, Bottom Flange Centre, Bottom Flange Edge</p>	Time [min]	Temperature [C]	0	0	10	67	20	133	30	200	40	267	50	333	60	400	<p data-bbox="1528 535 1732 578">+60mins</p>  <table border="1" data-bbox="1439 678 1847 949"><caption>Approximate data from Global displacement vs Time</caption><thead><tr><th>Time [min]</th><th>Global displacement</th></tr></thead><tbody><tr><td>0</td><td>0.0000</td></tr><tr><td>58</td><td>0.0000</td></tr><tr><td>60</td><td>0.0035</td></tr></tbody></table>	Time [min]	Global displacement	0	0.0000	58	0.0000	60	0.0035	<p data-bbox="2140 535 2242 578">N/A</p> 
Time [min]	Temperature [C]																										
0	0																										
10	67																										
20	133																										
30	200																										
40	267																										
50	333																										
60	400																										
Time [min]	Global displacement																										
0	0.0000																										
58	0.0000																										
60	0.0035																										



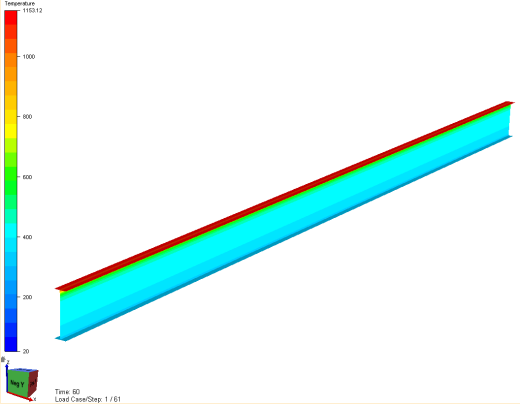
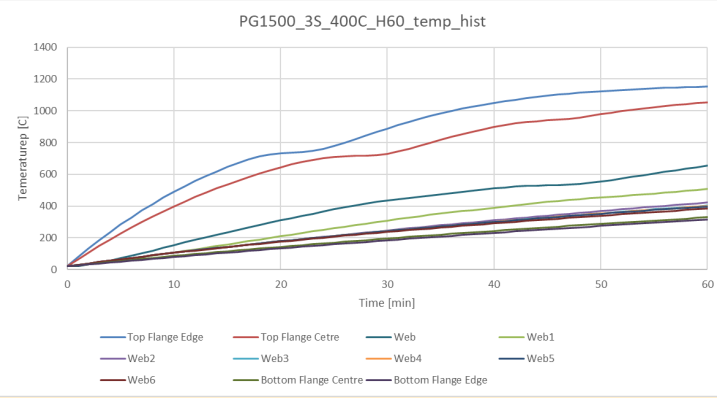
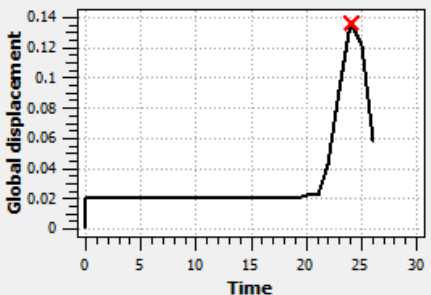
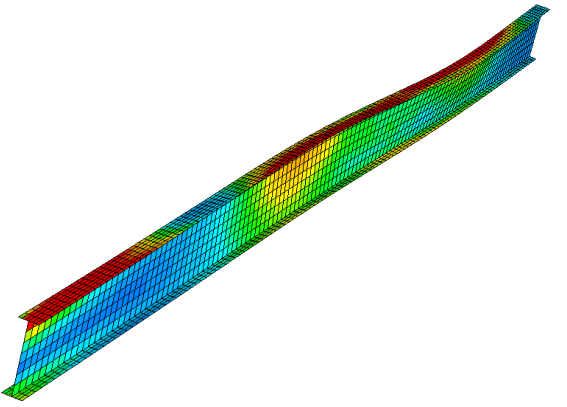
# W10x22 4-Sided 538°C H60

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism																																																																																																
	<p data-bbox="901 619 1156 639">W10x22_4S_538C_H60_temp_hist</p>  <table border="1"><caption>Heatup Curve Data (Approximate)</caption><thead><tr><th>Time [min]</th><th>Top Flange Edge [C]</th><th>Top Flange Centre [C]</th><th>Web1 [C]</th><th>Web2 [C]</th><th>Web3 [C]</th><th>Web4 [C]</th><th>Web5 [C]</th><th>Bottom Flange Centre [C]</th><th>Bottom Flange Edge [C]</th></tr></thead><tbody><tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr><tr><td>10</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td></tr><tr><td>20</td><td>250</td><td>250</td><td>250</td><td>250</td><td>250</td><td>250</td><td>250</td><td>250</td><td>250</td></tr><tr><td>30</td><td>350</td><td>350</td><td>350</td><td>350</td><td>350</td><td>350</td><td>350</td><td>350</td><td>350</td></tr><tr><td>40</td><td>450</td><td>450</td><td>450</td><td>450</td><td>450</td><td>450</td><td>450</td><td>450</td><td>450</td></tr><tr><td>50</td><td>500</td><td>500</td><td>500</td><td>500</td><td>500</td><td>500</td><td>500</td><td>500</td><td>500</td></tr><tr><td>60</td><td>538</td><td>538</td><td>538</td><td>538</td><td>538</td><td>538</td><td>538</td><td>538</td><td>538</td></tr></tbody></table>	Time [min]	Top Flange Edge [C]	Top Flange Centre [C]	Web1 [C]	Web2 [C]	Web3 [C]	Web4 [C]	Web5 [C]	Bottom Flange Centre [C]	Bottom Flange Edge [C]	0	0	0	0	0	0	0	0	0	0	10	150	150	150	150	150	150	150	150	150	20	250	250	250	250	250	250	250	250	250	30	350	350	350	350	350	350	350	350	350	40	450	450	450	450	450	450	450	450	450	50	500	500	500	500	500	500	500	500	500	60	538	538	538	538	538	538	538	538	538	<p data-bbox="1549 539 1727 582">+60mins</p>  <table border="1"><caption>Global displacement Data (Approximate)</caption><thead><tr><th>Time [min]</th><th>Global displacement</th></tr></thead><tbody><tr><td>0</td><td>0.0000</td></tr><tr><td>10</td><td>0.0005</td></tr><tr><td>20</td><td>0.0010</td></tr><tr><td>30</td><td>0.0015</td></tr><tr><td>40</td><td>0.0020</td></tr><tr><td>50</td><td>0.0025</td></tr><tr><td>60</td><td>0.0030</td></tr></tbody></table>	Time [min]	Global displacement	0	0.0000	10	0.0005	20	0.0010	30	0.0015	40	0.0020	50	0.0025	60	0.0030	<p data-bbox="2142 539 2226 582">N/A</p> 
Time [min]	Top Flange Edge [C]	Top Flange Centre [C]	Web1 [C]	Web2 [C]	Web3 [C]	Web4 [C]	Web5 [C]	Bottom Flange Centre [C]	Bottom Flange Edge [C]																																																																																										
0	0	0	0	0	0	0	0	0	0																																																																																										
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20	250	250	250	250	250	250	250	250	250																																																																																										
30	350	350	350	350	350	350	350	350	350																																																																																										
40	450	450	450	450	450	450	450	450	450																																																																																										
50	500	500	500	500	500	500	500	500	500																																																																																										
60	538	538	538	538	538	538	538	538	538																																																																																										
Time [min]	Global displacement																																																																																																		
0	0.0000																																																																																																		
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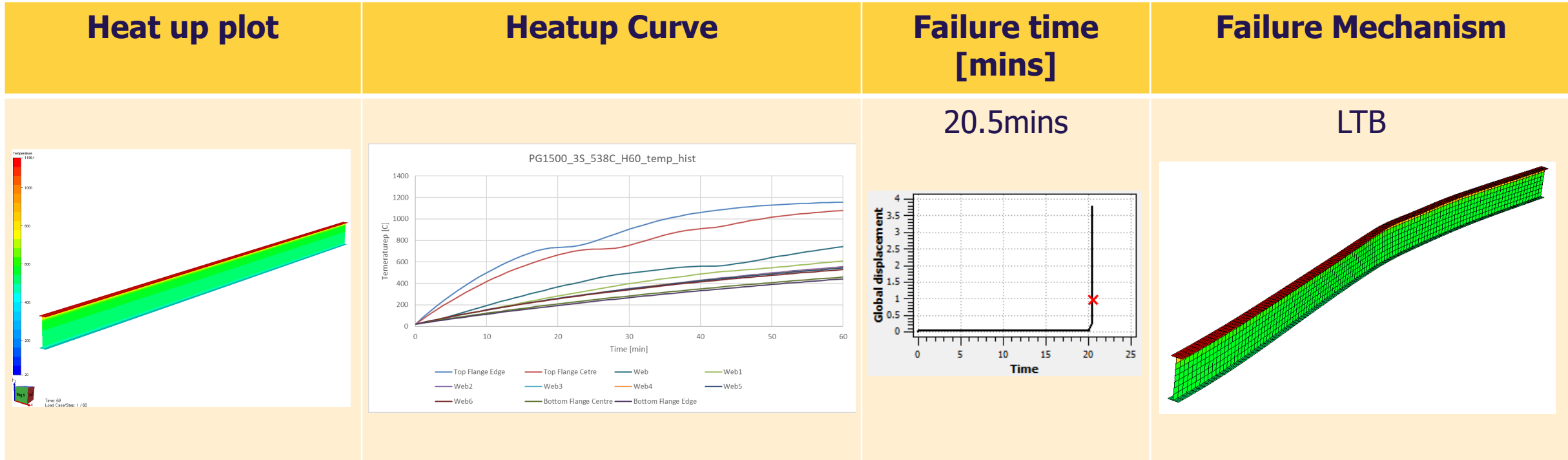
# PG1500 3-Sided 400°C H60

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism
		<p>22mins</p> 	<p>LTB</p> 

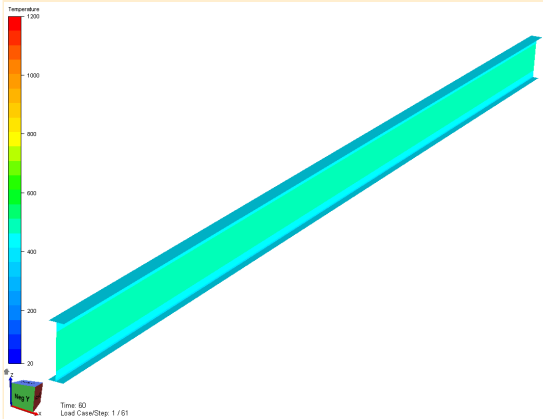
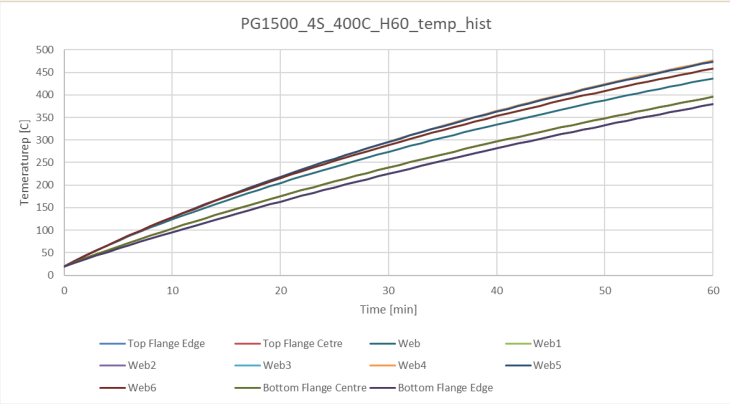
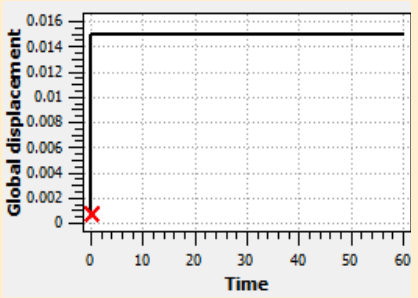
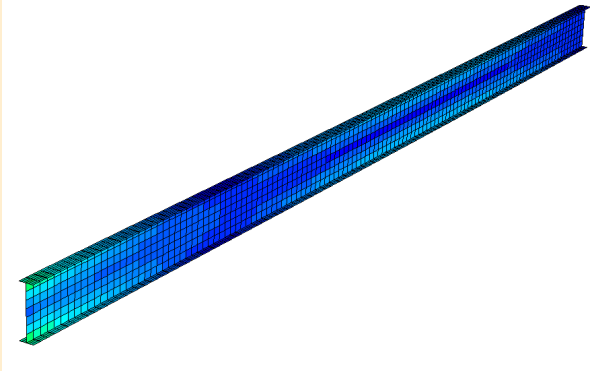
# PG1500 3-Sided 538°C H60

- The following results were obtained for this beam



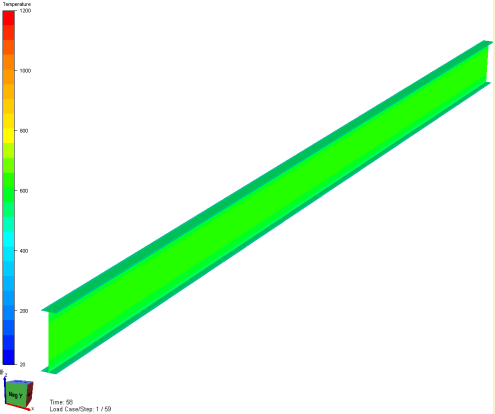
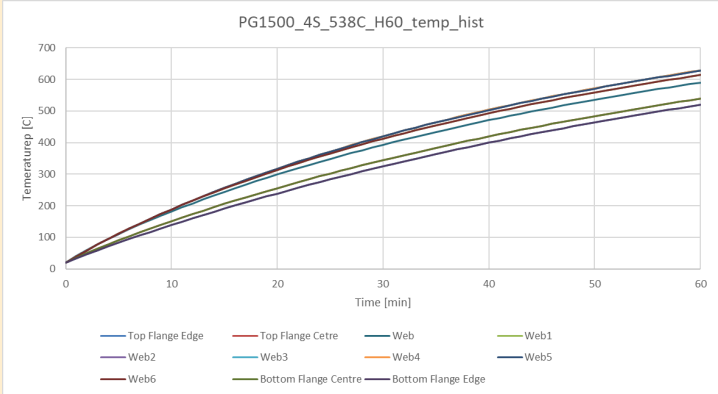
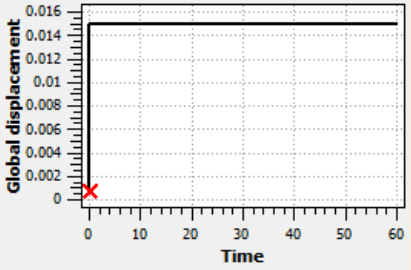
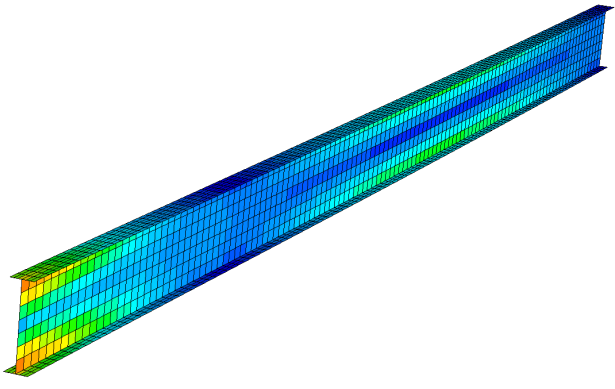
# PG1500 4-Sided 400°C H60

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism																																																																																																
 <p>A 3D visualization of a beam cross-section showing a temperature gradient. The color scale on the left ranges from -20°C (blue) to 1200°C (red). The beam is oriented diagonally, with the top flange showing higher temperatures (yellow/red) and the bottom flange showing lower temperatures (blue/cyan).</p>	 <p>PG1500_4S_400C_H60_temp_hist</p> <table border="1"><caption>Approximate data from Heatup Curve graph</caption><thead><tr><th>Time [min]</th><th>Top Flange Edge [C]</th><th>Top Flange Centre [C]</th><th>Web [C]</th><th>Web1 [C]</th><th>Web2 [C]</th><th>Web3 [C]</th><th>Web4 [C]</th><th>Web5 [C]</th><th>Web6 [C]</th><th>Bottom Flange Centre [C]</th><th>Bottom Flange Edge [C]</th></tr></thead><tbody><tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr><tr><td>10</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td></tr><tr><td>20</td><td>200</td><td>200</td><td>200</td><td>200</td><td>200</td><td>200</td><td>200</td><td>200</td><td>200</td><td>200</td><td>200</td></tr><tr><td>30</td><td>300</td><td>300</td><td>300</td><td>300</td><td>300</td><td>300</td><td>300</td><td>300</td><td>300</td><td>300</td><td>300</td></tr><tr><td>40</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td></tr><tr><td>50</td><td>450</td><td>450</td><td>450</td><td>450</td><td>450</td><td>450</td><td>450</td><td>450</td><td>450</td><td>450</td><td>450</td></tr><tr><td>60</td><td>500</td><td>500</td><td>500</td><td>500</td><td>500</td><td>500</td><td>500</td><td>500</td><td>500</td><td>500</td><td>500</td></tr></tbody></table>	Time [min]	Top Flange Edge [C]	Top Flange Centre [C]	Web [C]	Web1 [C]	Web2 [C]	Web3 [C]	Web4 [C]	Web5 [C]	Web6 [C]	Bottom Flange Centre [C]	Bottom Flange Edge [C]	0	0	0	0	0	0	0	0	0	0	0	0	10	100	100	100	100	100	100	100	100	100	100	100	20	200	200	200	200	200	200	200	200	200	200	200	30	300	300	300	300	300	300	300	300	300	300	300	40	400	400	400	400	400	400	400	400	400	400	400	50	450	450	450	450	450	450	450	450	450	450	450	60	500	500	500	500	500	500	500	500	500	500	500	<p>+60mins</p>  <p>Global displacement vs Time graph. The y-axis is Global displacement (0 to 0.016) and the x-axis is Time (0 to 60). A red 'X' is marked at the origin (0,0). The displacement remains at 0 until approximately 1 minute, then jumps to approximately 0.015 and remains constant thereafter.</p>	<p>N/A</p>  <p>A 3D finite element model of the beam cross-section. The model is colored with a gradient from blue (low stress/displacement) to red (high stress/displacement). The beam is oriented diagonally, showing the top and bottom flanges and the web.</p>
Time [min]	Top Flange Edge [C]	Top Flange Centre [C]	Web [C]	Web1 [C]	Web2 [C]	Web3 [C]	Web4 [C]	Web5 [C]	Web6 [C]	Bottom Flange Centre [C]	Bottom Flange Edge [C]																																																																																								
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60	500	500	500	500	500	500	500	500	500	500	500																																																																																								

# PG1500 4-Sided 538°C H60

- The following results were obtained for this beam

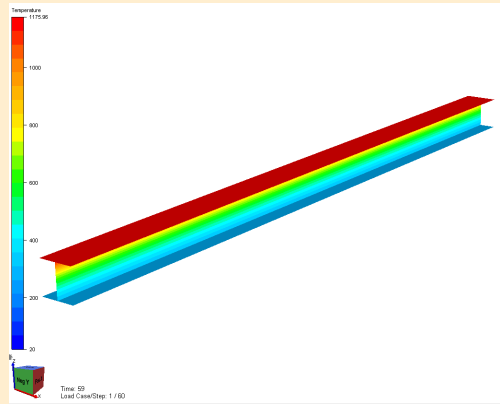
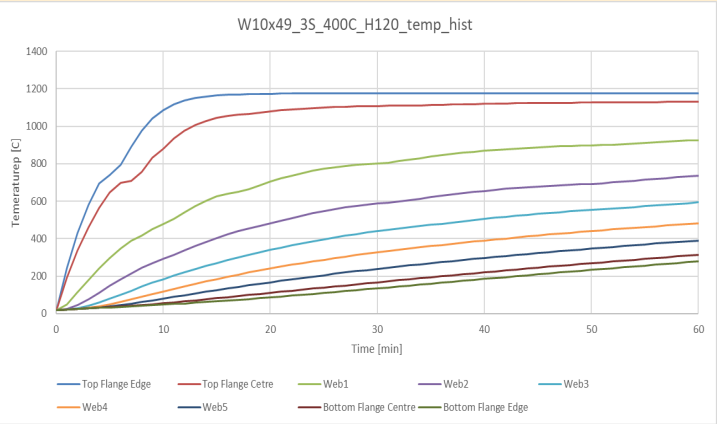
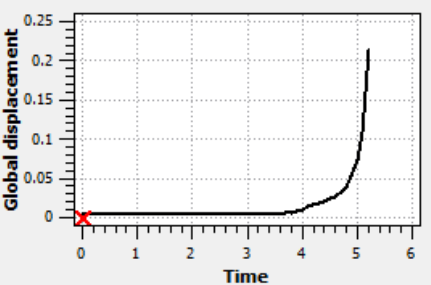
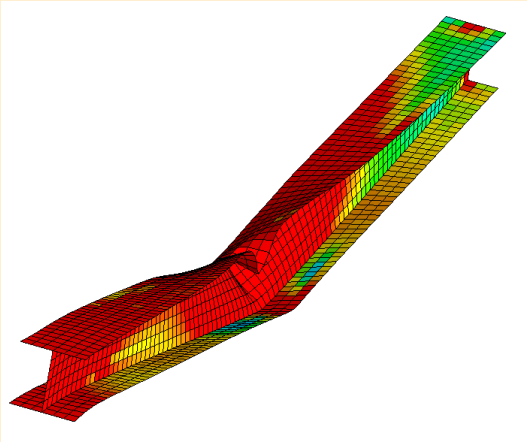
Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism																																																																																																																
	 <p>PG1500_4S_538C_H60_temp_hist</p> <table border="1"><caption>Approximate data from Heatup Curve graph</caption><thead><tr><th>Time [min]</th><th>Top Flange Edge [C]</th><th>Top Flange Centre [C]</th><th>Web [C]</th><th>Web1 [C]</th><th>Web2 [C]</th><th>Web3 [C]</th><th>Web4 [C]</th><th>Web5 [C]</th><th>Web6 [C]</th><th>Bottom Flange Centre [C]</th><th>Bottom Flange Edge [C]</th></tr></thead><tbody><tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr><tr><td>10</td><td>150</td><td>180</td><td>120</td><td>100</td><td>110</td><td>130</td><td>140</td><td>150</td><td>160</td><td>170</td><td>180</td></tr><tr><td>20</td><td>250</td><td>300</td><td>200</td><td>180</td><td>190</td><td>210</td><td>220</td><td>230</td><td>240</td><td>250</td><td>260</td></tr><tr><td>30</td><td>350</td><td>400</td><td>280</td><td>260</td><td>270</td><td>290</td><td>300</td><td>310</td><td>320</td><td>330</td><td>340</td></tr><tr><td>40</td><td>450</td><td>500</td><td>360</td><td>340</td><td>350</td><td>370</td><td>380</td><td>390</td><td>400</td><td>410</td><td>420</td></tr><tr><td>50</td><td>550</td><td>600</td><td>440</td><td>420</td><td>430</td><td>450</td><td>460</td><td>470</td><td>480</td><td>490</td><td>500</td></tr><tr><td>60</td><td>650</td><td>700</td><td>520</td><td>500</td><td>510</td><td>530</td><td>540</td><td>550</td><td>560</td><td>570</td><td>580</td></tr></tbody></table>	Time [min]	Top Flange Edge [C]	Top Flange Centre [C]	Web [C]	Web1 [C]	Web2 [C]	Web3 [C]	Web4 [C]	Web5 [C]	Web6 [C]	Bottom Flange Centre [C]	Bottom Flange Edge [C]	0	0	0	0	0	0	0	0	0	0	0	0	10	150	180	120	100	110	130	140	150	160	170	180	20	250	300	200	180	190	210	220	230	240	250	260	30	350	400	280	260	270	290	300	310	320	330	340	40	450	500	360	340	350	370	380	390	400	410	420	50	550	600	440	420	430	450	460	470	480	490	500	60	650	700	520	500	510	530	540	550	560	570	580	<p>+60mins</p>  <p>Global displacement</p> <table border="1"><caption>Approximate data from Global displacement graph</caption><thead><tr><th>Time [min]</th><th>Global displacement</th></tr></thead><tbody><tr><td>0</td><td>0</td></tr><tr><td>10</td><td>0</td></tr><tr><td>20</td><td>0</td></tr><tr><td>30</td><td>0</td></tr><tr><td>40</td><td>0</td></tr><tr><td>50</td><td>0</td></tr><tr><td>60</td><td>0.015</td></tr></tbody></table>	Time [min]	Global displacement	0	0	10	0	20	0	30	0	40	0	50	0	60	0.015	<p>N/A</p> 
Time [min]	Top Flange Edge [C]	Top Flange Centre [C]	Web [C]	Web1 [C]	Web2 [C]	Web3 [C]	Web4 [C]	Web5 [C]	Web6 [C]	Bottom Flange Centre [C]	Bottom Flange Edge [C]																																																																																																								
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30	350	400	280	260	270	290	300	310	320	330	340																																																																																																								
40	450	500	360	340	350	370	380	390	400	410	420																																																																																																								
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# H120 PFP Results

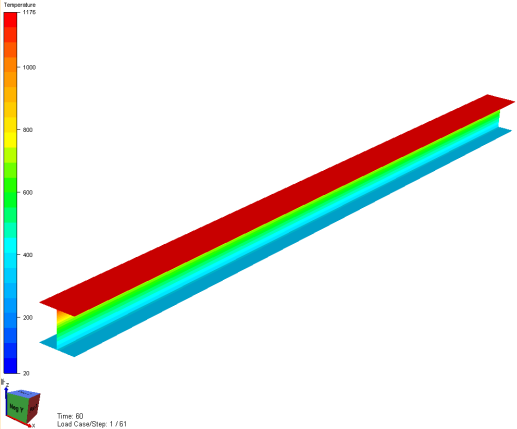
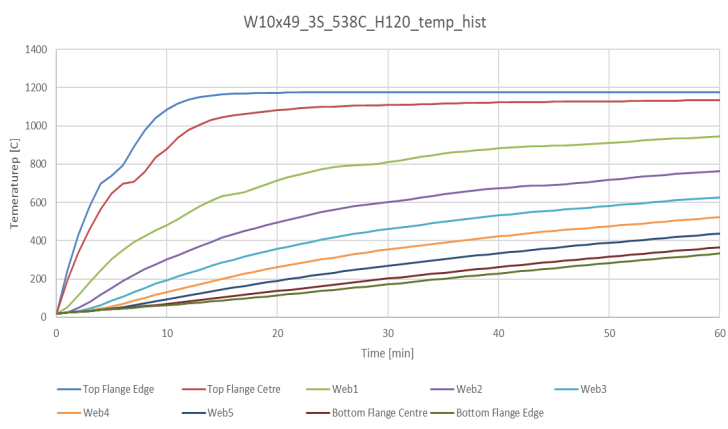
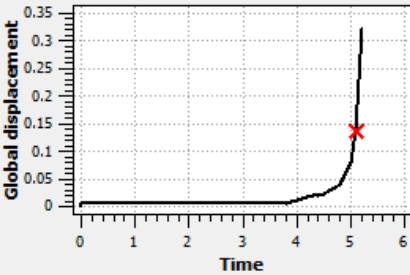
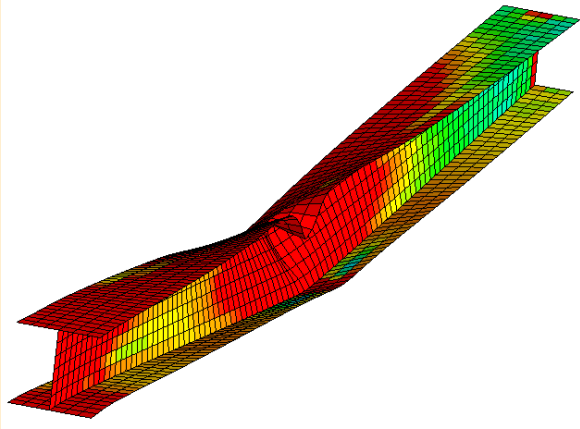
# W10x49 3-Sided 400°C H120

- 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

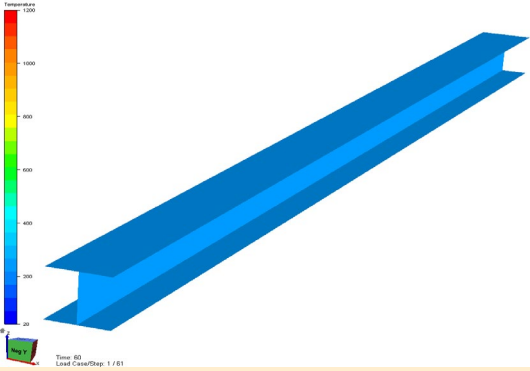
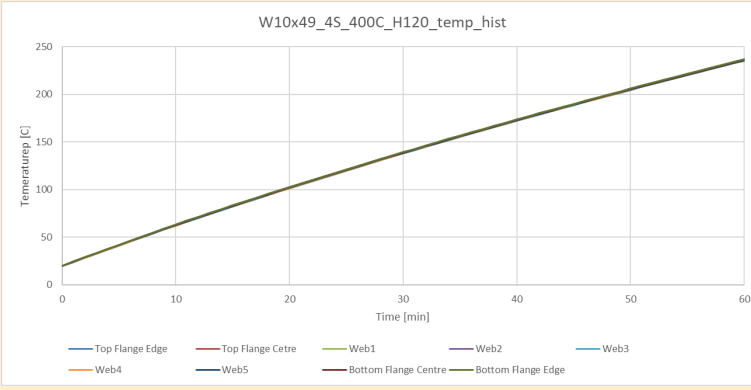
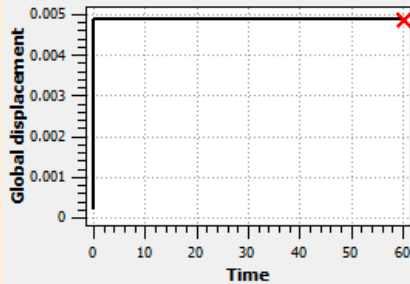
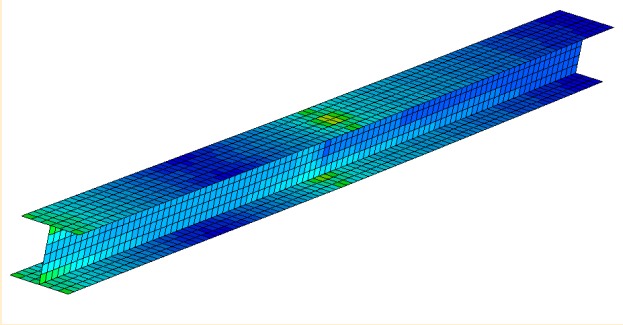
- The following results were obtained for this beam

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



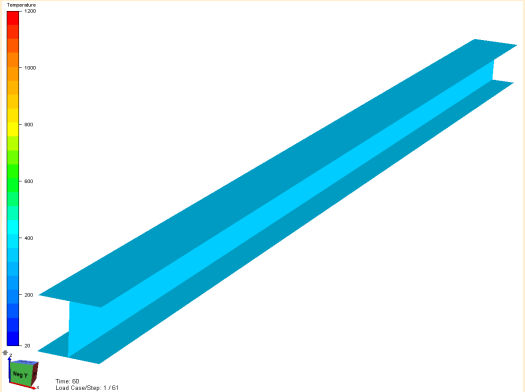
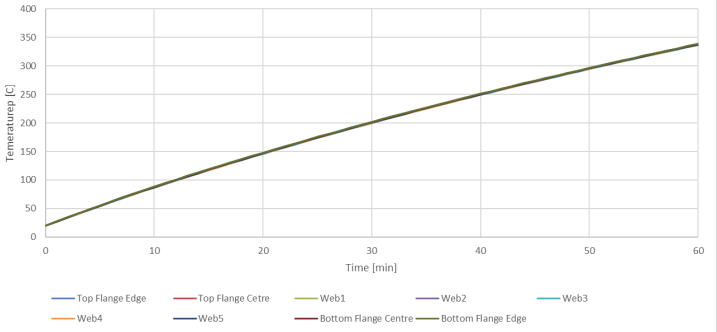
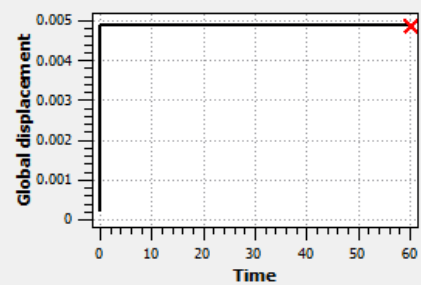
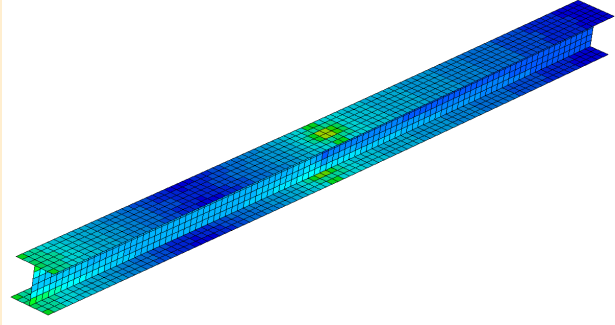
# W10x49 4-Sided 400°C H120

- The following results were obtained for this beam

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

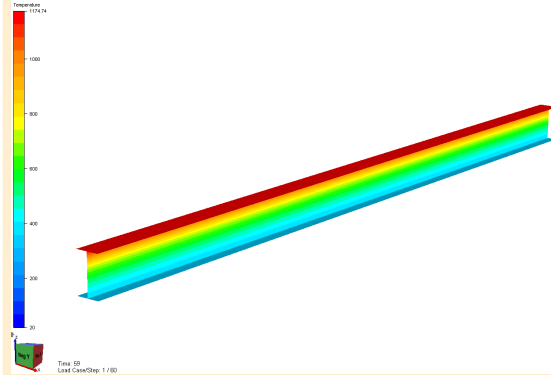
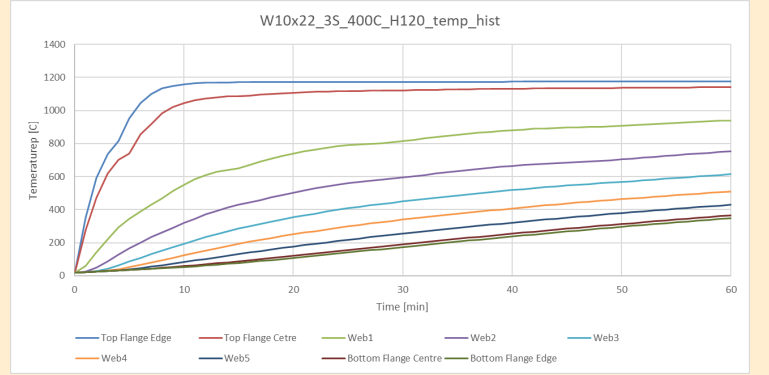
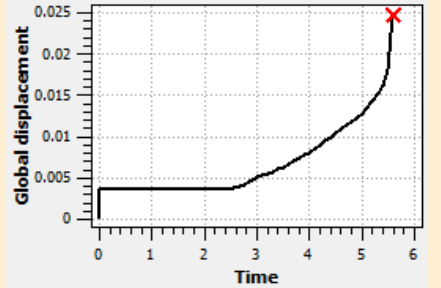
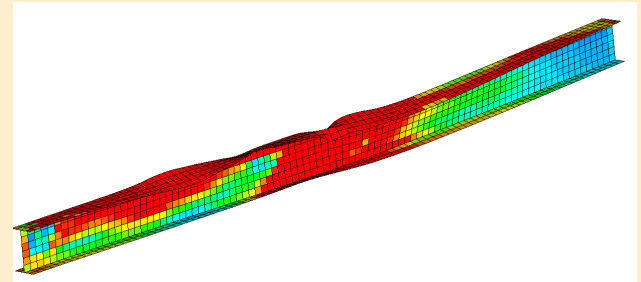
# W10x49 4-Sided 538°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism																																																																																																		
	<p data-bbox="894 625 1136 644">W10x49_4S_538C_H120_temp_hist</p>  <table border="1"><caption>Heatup Curve Data (Estimated)</caption><thead><tr><th>Time [min]</th><th>Top Flange Edge [C]</th><th>Top Flange Centre [C]</th><th>Web1 [C]</th><th>Web2 [C]</th><th>Web3 [C]</th><th>Web4 [C]</th><th>Web5 [C]</th><th>Bottom Flange Centre [C]</th><th>Bottom Flange Edge [C]</th></tr></thead><tbody><tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr><tr><td>10</td><td>80</td><td>80</td><td>80</td><td>80</td><td>80</td><td>80</td><td>80</td><td>80</td><td>80</td></tr><tr><td>20</td><td>160</td><td>160</td><td>160</td><td>160</td><td>160</td><td>160</td><td>160</td><td>160</td><td>160</td></tr><tr><td>30</td><td>240</td><td>240</td><td>240</td><td>240</td><td>240</td><td>240</td><td>240</td><td>240</td><td>240</td></tr><tr><td>40</td><td>320</td><td>320</td><td>320</td><td>320</td><td>320</td><td>320</td><td>320</td><td>320</td><td>320</td></tr><tr><td>50</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td></tr><tr><td>60</td><td>480</td><td>480</td><td>480</td><td>480</td><td>480</td><td>480</td><td>480</td><td>480</td><td>480</td></tr></tbody></table>	Time [min]	Top Flange Edge [C]	Top Flange Centre [C]	Web1 [C]	Web2 [C]	Web3 [C]	Web4 [C]	Web5 [C]	Bottom Flange Centre [C]	Bottom Flange Edge [C]	0	0	0	0	0	0	0	0	0	0	10	80	80	80	80	80	80	80	80	80	20	160	160	160	160	160	160	160	160	160	30	240	240	240	240	240	240	240	240	240	40	320	320	320	320	320	320	320	320	320	50	400	400	400	400	400	400	400	400	400	60	480	480	480	480	480	480	480	480	480	<p data-bbox="1544 539 1727 579">+60mins</p>  <table border="1"><caption>Global displacement Data (Estimated)</caption><thead><tr><th>Time [min]</th><th>Global displacement</th></tr></thead><tbody><tr><td>0</td><td>0.005</td></tr><tr><td>10</td><td>0.005</td></tr><tr><td>20</td><td>0.005</td></tr><tr><td>30</td><td>0.005</td></tr><tr><td>40</td><td>0.005</td></tr><tr><td>50</td><td>0.005</td></tr><tr><td>60</td><td>0.005</td></tr><tr><td>60</td><td>0</td></tr></tbody></table>	Time [min]	Global displacement	0	0.005	10	0.005	20	0.005	30	0.005	40	0.005	50	0.005	60	0.005	60	0	<p data-bbox="2142 539 2224 579">N/A</p> 
Time [min]	Top Flange Edge [C]	Top Flange Centre [C]	Web1 [C]	Web2 [C]	Web3 [C]	Web4 [C]	Web5 [C]	Bottom Flange Centre [C]	Bottom Flange Edge [C]																																																																																												
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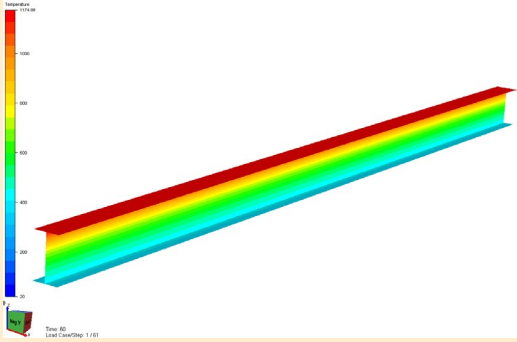
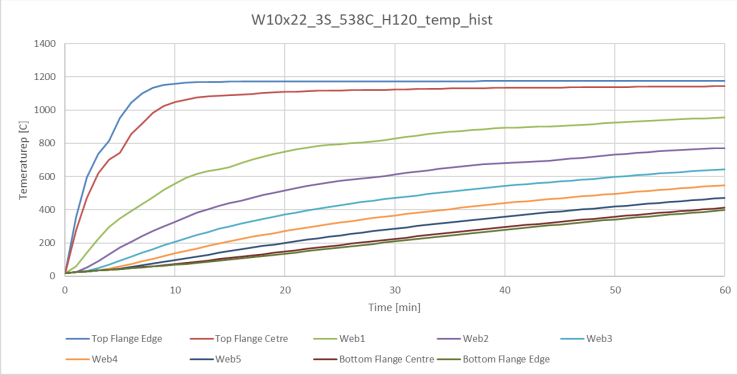
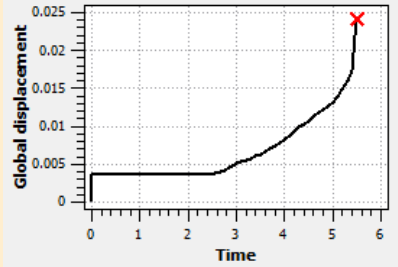
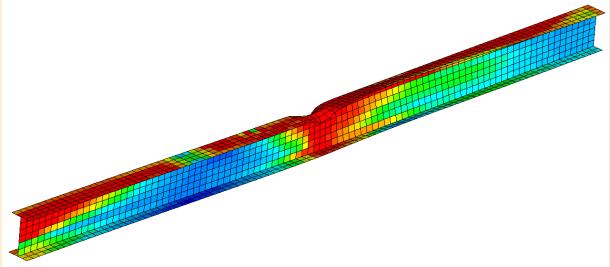
# W10x22 3-Sided 400°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism																																																																																																
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Time [min]	Top Flange Edge [C]	Top Flange Centre [C]	Web1 [C]	Web2 [C]	Web3 [C]	Web4 [C]	Web5 [C]	Bottom Flange Centre [C]	Bottom Flange Edge [C]																																																																																										
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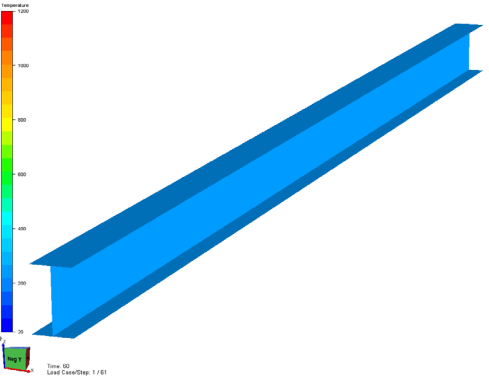
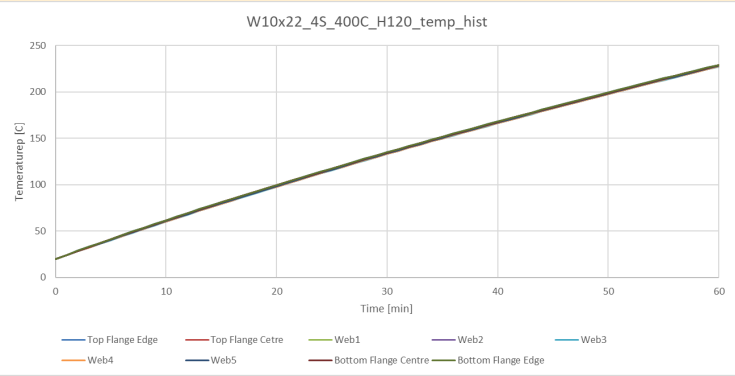
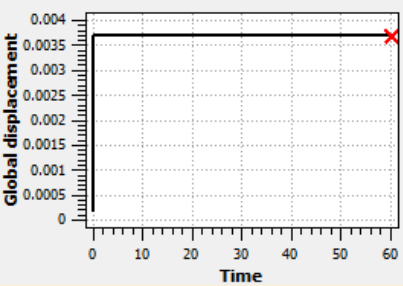
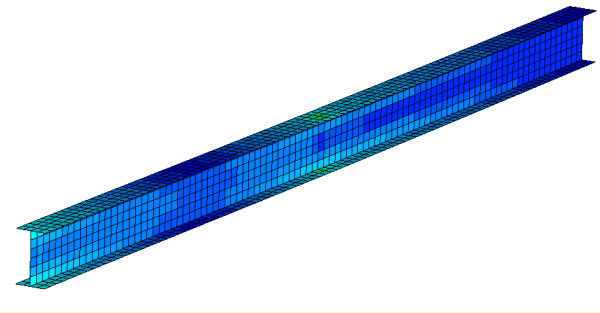
# W10x22 3-Sided 538°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism																																																																																																
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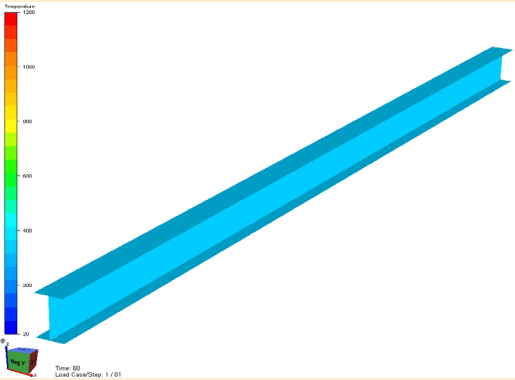
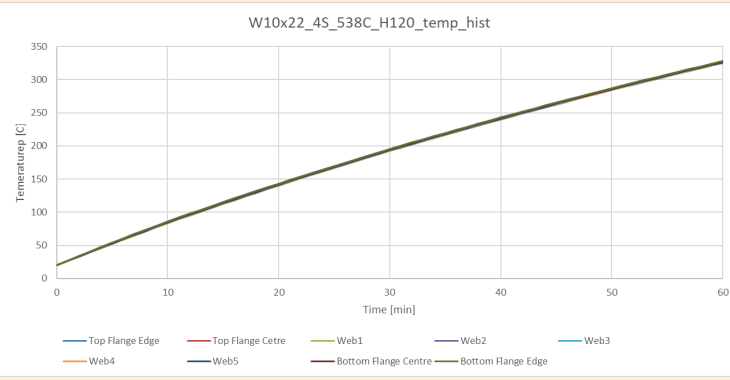
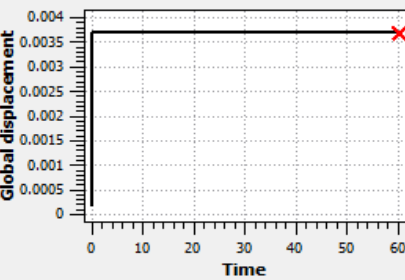
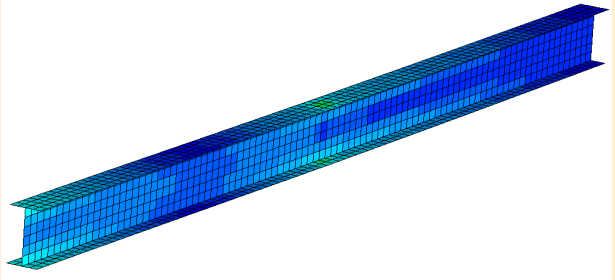
# W10x22 4-Sided 400°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism																																
	 <p>W10x22_4S_400C_H120_temp_hist</p> <table border="1"><caption>Heatup Curve Data</caption><thead><tr><th>Time [min]</th><th>Temperature [C]</th></tr></thead><tbody><tr><td>0</td><td>0</td></tr><tr><td>10</td><td>38</td></tr><tr><td>20</td><td>76</td></tr><tr><td>30</td><td>114</td></tr><tr><td>40</td><td>152</td></tr><tr><td>50</td><td>190</td></tr><tr><td>60</td><td>228</td></tr></tbody></table>	Time [min]	Temperature [C]	0	0	10	38	20	76	30	114	40	152	50	190	60	228	<p>+60mins</p>  <p>Global displacement</p> <table border="1"><caption>Global displacement Data</caption><thead><tr><th>Time</th><th>Global displacement</th></tr></thead><tbody><tr><td>0</td><td>0.00375</td></tr><tr><td>10</td><td>0.00375</td></tr><tr><td>20</td><td>0.00375</td></tr><tr><td>30</td><td>0.00375</td></tr><tr><td>40</td><td>0.00375</td></tr><tr><td>50</td><td>0.00375</td></tr><tr><td>60</td><td>0.00375</td></tr></tbody></table>	Time	Global displacement	0	0.00375	10	0.00375	20	0.00375	30	0.00375	40	0.00375	50	0.00375	60	0.00375	<p>N/A</p> 
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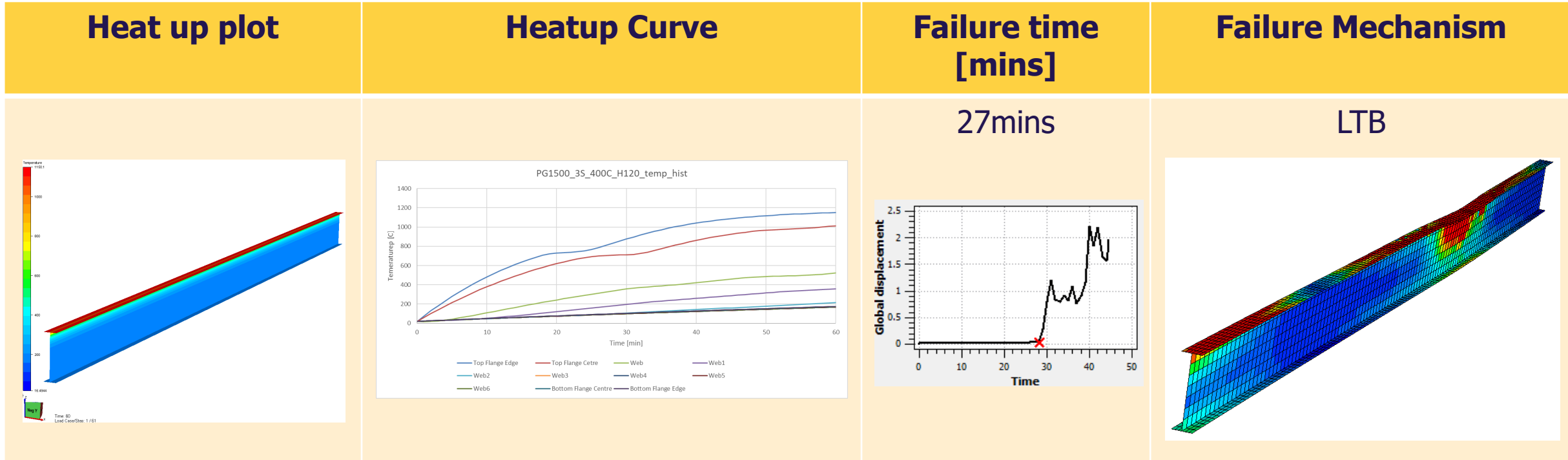
# W10x22 4-Sided 538°C H120

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Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism																																
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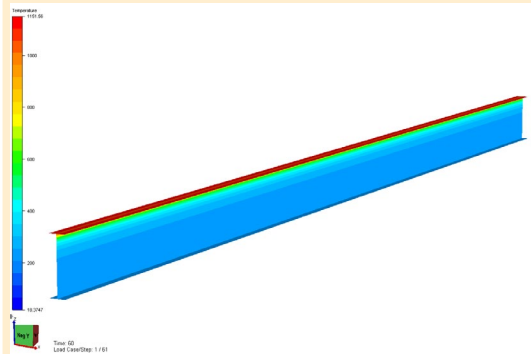
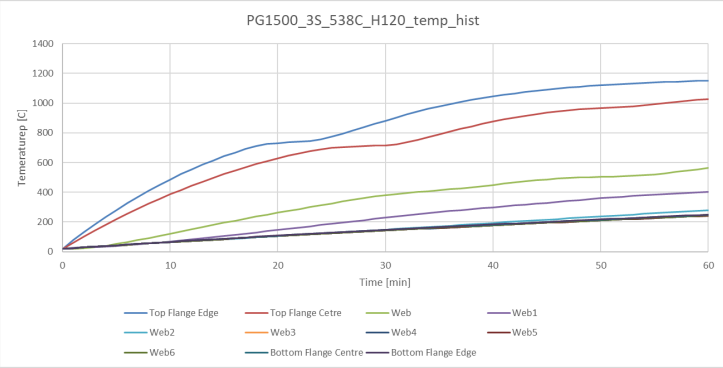
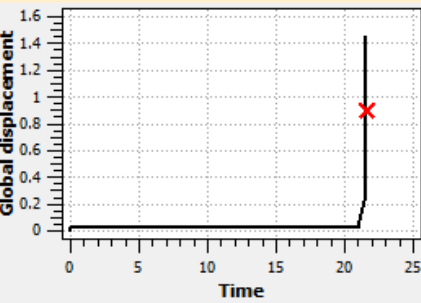
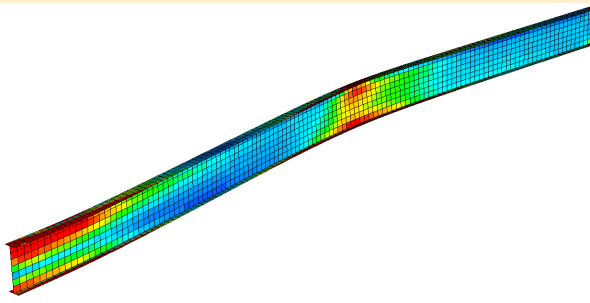
# PG1500 3-Sided 400°C H120

- The following results were obtained for this beam



# PG1500 3-Sided 538°C H120

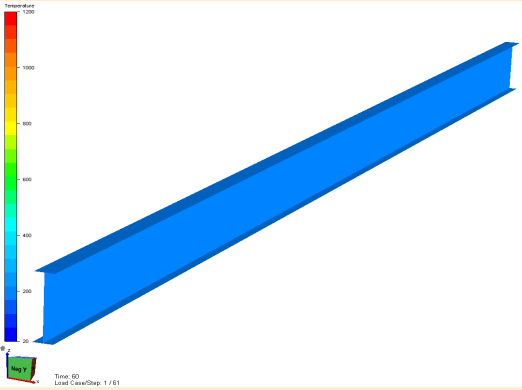
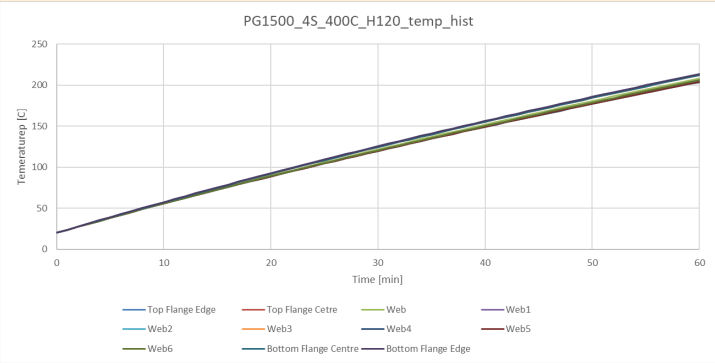
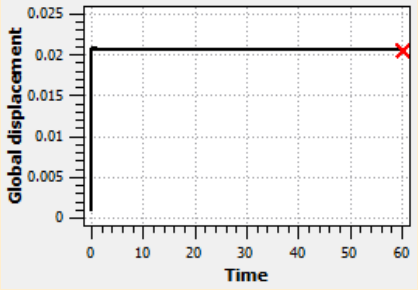
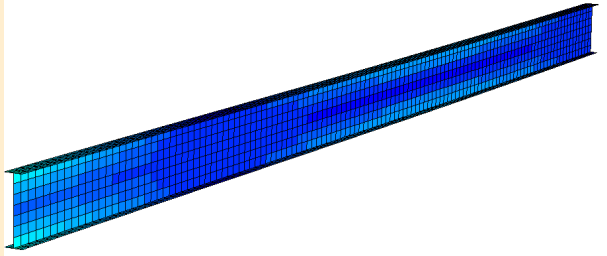
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Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism																																																																																																
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Time [min]	Top Flange Edge [C]	Top Flange Centre [C]	Web [C]	Web1 [C]	Web2 [C]	Web3 [C]	Web4 [C]	Web5 [C]	Web6 [C]	Bottom Flange Centre [C]	Bottom Flange Edge [C]																																																																																								
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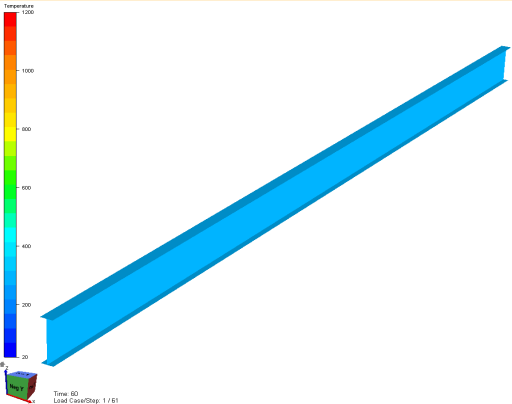
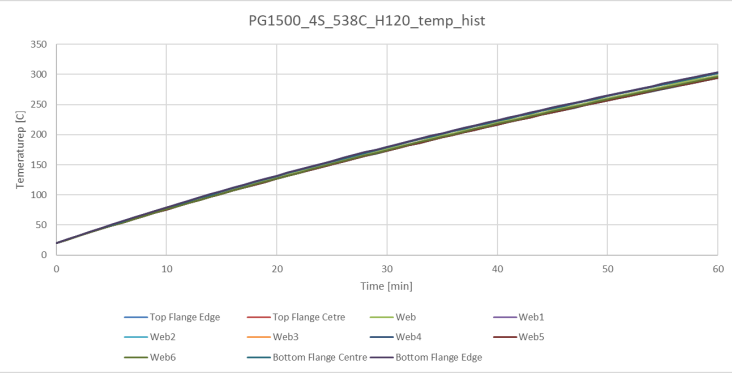
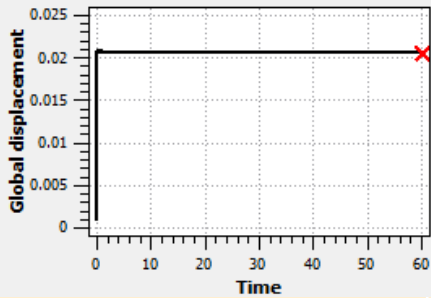
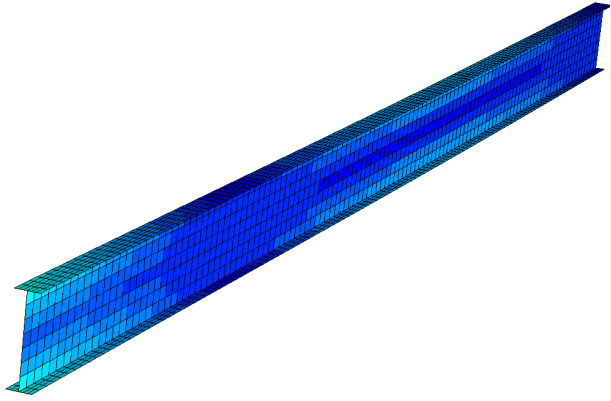
# PG1500 4-Sided 400°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism																																
	 <p>PG1500_4S_400C_H120_temp_hist</p> <table border="1"><caption>Approximate data from Heatup Curve graph</caption><thead><tr><th>Time [min]</th><th>Temperature [C]</th></tr></thead><tbody><tr><td>0</td><td>0</td></tr><tr><td>10</td><td>50</td></tr><tr><td>20</td><td>100</td></tr><tr><td>30</td><td>150</td></tr><tr><td>40</td><td>200</td></tr><tr><td>50</td><td>250</td></tr><tr><td>60</td><td>300</td></tr></tbody></table>	Time [min]	Temperature [C]	0	0	10	50	20	100	30	150	40	200	50	250	60	300	<p>+60mins</p>  <table border="1"><caption>Approximate data from Global displacement vs Time graph</caption><thead><tr><th>Time</th><th>Global displacement</th></tr></thead><tbody><tr><td>0</td><td>0</td></tr><tr><td>10</td><td>0.021</td></tr><tr><td>20</td><td>0.021</td></tr><tr><td>30</td><td>0.021</td></tr><tr><td>40</td><td>0.021</td></tr><tr><td>50</td><td>0.021</td></tr><tr><td>60</td><td>0.021</td></tr></tbody></table>	Time	Global displacement	0	0	10	0.021	20	0.021	30	0.021	40	0.021	50	0.021	60	0.021	<p>N/A</p> 
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# PG1500 4-Sided 538°C H120

- The following results were obtained for this beam

Heat up plot	Heatup Curve	Failure time [mins]	Failure Mechanism																																																																																																																
	 <p>PG1500_4S_538C_H120_temp_hist</p> <table border="1"><thead><tr><th>Time [min]</th><th>Top Flange Edge</th><th>Top Flange Centre</th><th>Web</th><th>Web1</th><th>Web2</th><th>Web3</th><th>Web4</th><th>Web5</th><th>Web6</th><th>Bottom Flange Centre</th><th>Bottom Flange Edge</th></tr></thead><tbody><tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr><tr><td>10</td><td>25</td><td>25</td><td>25</td><td>25</td><td>25</td><td>25</td><td>25</td><td>25</td><td>25</td><td>25</td><td>25</td></tr><tr><td>20</td><td>50</td><td>50</td><td>50</td><td>50</td><td>50</td><td>50</td><td>50</td><td>50</td><td>50</td><td>50</td><td>50</td></tr><tr><td>30</td><td>75</td><td>75</td><td>75</td><td>75</td><td>75</td><td>75</td><td>75</td><td>75</td><td>75</td><td>75</td><td>75</td></tr><tr><td>40</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td></tr><tr><td>50</td><td>125</td><td>125</td><td>125</td><td>125</td><td>125</td><td>125</td><td>125</td><td>125</td><td>125</td><td>125</td><td>125</td></tr><tr><td>60</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td></tr></tbody></table>	Time [min]	Top Flange Edge	Top Flange Centre	Web	Web1	Web2	Web3	Web4	Web5	Web6	Bottom Flange Centre	Bottom Flange Edge	0	0	0	0	0	0	0	0	0	0	0	0	10	25	25	25	25	25	25	25	25	25	25	25	20	50	50	50	50	50	50	50	50	50	50	50	30	75	75	75	75	75	75	75	75	75	75	75	40	100	100	100	100	100	100	100	100	100	100	100	50	125	125	125	125	125	125	125	125	125	125	125	60	150	150	150	150	150	150	150	150	150	150	150	<p>+60mins</p>  <p>Global displacement</p> <table border="1"><thead><tr><th>Time</th><th>Global displacement</th></tr></thead><tbody><tr><td>0</td><td>0.021</td></tr><tr><td>10</td><td>0.021</td></tr><tr><td>20</td><td>0.021</td></tr><tr><td>30</td><td>0.021</td></tr><tr><td>40</td><td>0.021</td></tr><tr><td>50</td><td>0.021</td></tr><tr><td>60</td><td>0.021</td></tr></tbody></table>	Time	Global displacement	0	0.021	10	0.021	20	0.021	30	0.021	40	0.021	50	0.021	60	0.021	<p>N/A</p> 
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# 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**

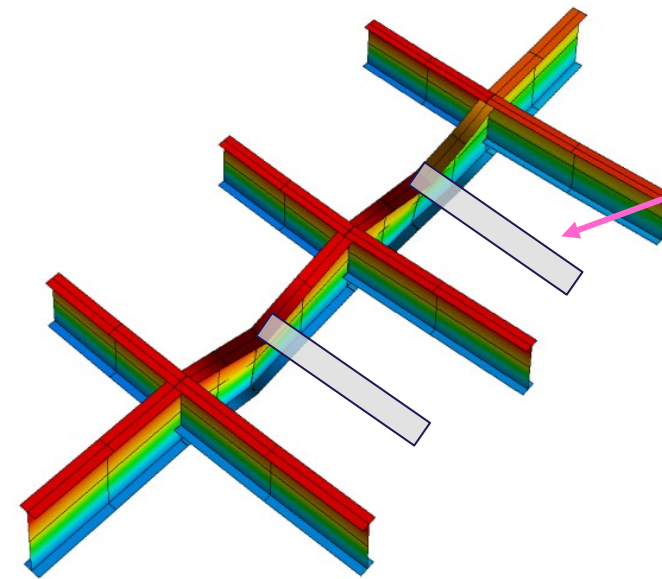
## **Effect of Lateral Support**

# 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 restraint 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.



Additional members to be protected providing lateral support

# 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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