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**Indicative fire test on a cellular and  
solid web steel beam**

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## **Summary**

Concern has been raised that the temperature of the web-post in a cellular beam with intumescent coating increases at a faster rate compared to a similar size web in a solid beam. If the temperature of the web-post increases faster than expected premature failure of the cellular beam could occur due to instability of the web-post.

To investigate whether the web-post temperatures increase, at a faster rate than expected, a series of tests were derived on unloaded, protected and unprotected, indicative beams. This report presents the results from the first of the series of tests on an unloaded, unprotected, cellular beam and an identical solid web beam. Both the cellular and solid beams were placed in the same furnace and thus subjected to the same temperature environment.

The test showed that the flange and web temperatures of the cellular beam were slightly lower than the equivalent temperatures of the solid beam. It was also shown that the web-post temperature did not increase at a faster rate compared to the temperature of the web of the solid beam.

The variation of temperatures between the web-post and bottom flange of the cellular beam was similar to the variation of temperatures between the web and bottom flange of the equivalent solid beam.

It is currently unknown why the solid beam was slightly hotter than the cellular beam. One possible reason is due to the flow of hot gases in the furnace, but this requires further investigation.



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## 1. Introduction

Following a meeting between the Steel Construction Institute (SCI), Westok, and a number of Intumescent Manufacturers on 24<sup>th</sup> April 2003, a series of tests were defined to investigate the thermal performance of cellular beams with intumescent coatings.

The tests were developed due to SCI's concern, following recent fire tests, that higher temperatures than expected were experienced in the web-post of cellular beams, which may influence web-post shear and buckling behaviour. Unfortunately, the tests on which SCI base their concerns are commercially confidential and cannot be peer reviewed.

The only public available information on the previous fire tests is published in a Technical Note in *The Structural Engineer*<sup>(1)</sup>. This Note states that *'It was evident from the results of the fire tests on cellular plated beams test pieces that the temperature, and hence strength, of the web post was critical to its ability to withstand the forces to which it was subject. Indeed, a comparison of varying width web posts shows marked variations in temperature profile both horizontally and vertically through the web post. Closely spaced openings, giving narrow web posts, consistently exhibited 'higher' temperatures horizontally through the post than those measured near the flanges'*. The Note concludes that limits on the d/t ratio of the web and minimum cell spacing should be specified for all castellated and cellular beams with intumescent coatings. However, no technical details are provided on how these limits are derived.

As stated in the Technical Note<sup>(1)</sup> the conclusions, and limits on the geometry of the beam, are based on five loaded fire resistance tests on protected composite beams and numerous unloaded tests. All the tested sections were protected with Firetex FB120 intumescent coating.

Before general geometric limits are specified for all castellated and cellular beams with intumescent coatings the cause of the web-post temperatures being higher than expected in the previous fire tests needs to be investigated. The process of this investigation should include:

- Investigation of whether placing a hole in the web of a beam causes the temperature of the web to increase at a faster rate compared to an identical web thickness without holes.
- Investigation of whether the rate of increase of the web-post temperature is due to the type of protection adopted and whether this is generic or product specific.

Based on these criteria a series of unloaded tests were derived on unprotected and protected beams (Table 1). For each proposed test two beams are placed in the same furnace, one beam being cellular and the other beam being solid. Both the cellular and solid beams are fabricated from the same tee section so that they are identical in geometry. By testing the two beams in the same furnace a comparison can be made between web-post and solid web temperatures in an identical temperature environment.

Two types of intumescent coatings were chosen for the protected beams of varying thickness (Table 1). The purpose of varying the type of intumescent and thickness is to investigate whether the temperature of the web-post compared to an identical solid web is governed by the generic nature of the protection or is product specific.

Test	Size of web-post	Thickness of Protection	Notes
1a	120mm	None	To investigate whether the temperatures in the web are dependent on hole size and spacing
1b	Solid	None	
2a	120mm	0.8mm	Product 'A' intumescent coating used to investigate whether web-post temperatures are governed by the protection.
2b	Solid	0.8mm	
3a	120mm	2.1mm	
3b	Solid	2.1mm	
4a	200mm	None	To investigate difference between protected (Product 'A') and unprotected cellular beams.
4b	200mm	0.8mm	
5a	120mm	0.8mm	Product 'B' intumescent coating used to investigate whether any increase in web-post temperatures compared to a solid beam is generic or product specific (by comparison with tests 2 and 3)
5b	Solid	0.8mm	
6a	120mm	2.1mm	
6b	Solid	2.1mm	
7a	200mm	0.8mm	Investigate influence of varying protect thickness (Product B) on web-post temperatures
7b	200mm	2.1mm	
8a	120mm	0.8mm	Test on asymmetric beam using either Product 'A' or 'B'
8b	120mm	2.1mm	

*Note: Beams cut from 406×178×60UB with 300mm diameter openings*

*Asymmetric beam comprises 406×140×39UB top tee and 406×178×60UB bottom tee.*

Table 1: Summary of proposed tests

This report presents the test results from Test 1 where an unprotected cellular and solid beam was tested in the same furnace. The aim of the test is to investigate whether the web-post temperatures increase at a faster rate compared to an equivalent solid web.

## 2. Test Procedure

Two indicative beams were fabricated from 406×178×60UB tees. For the cellular beam a 300mm diameter hole and a 300mm diameter half circle were cut from the two tees. The tees were welded back together forming a web-post between the holes of 118mm. The solid beam, used for comparison, was also fabricated from two 406×178×60UB tees welded together to form an identical beam without any holes in the web.

The measured geometry of the two beams is shown in Figure 1 and the location of the thermocouples is shown in Figure 2.

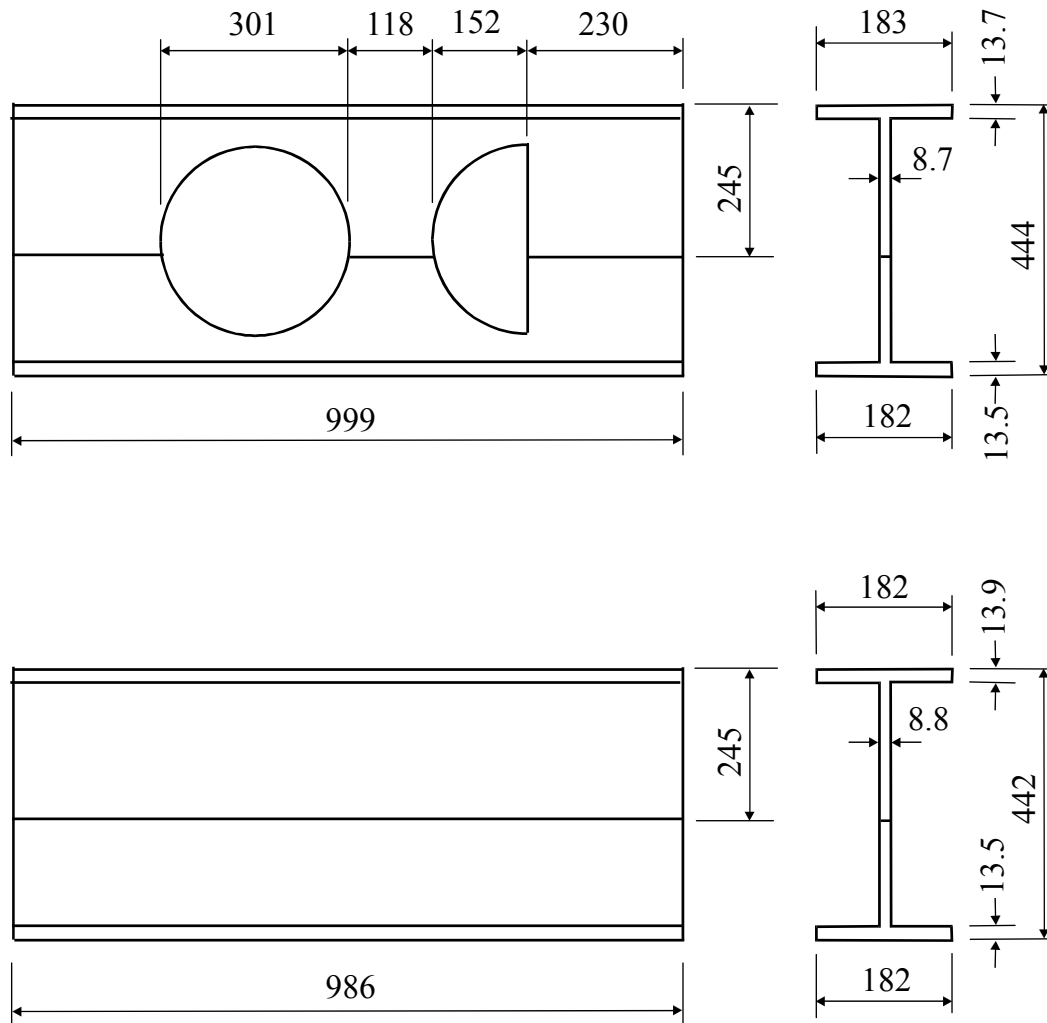
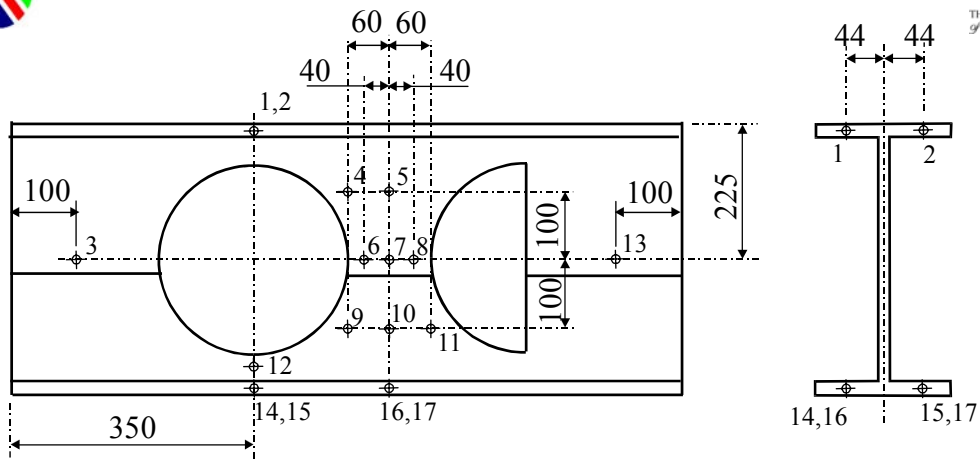
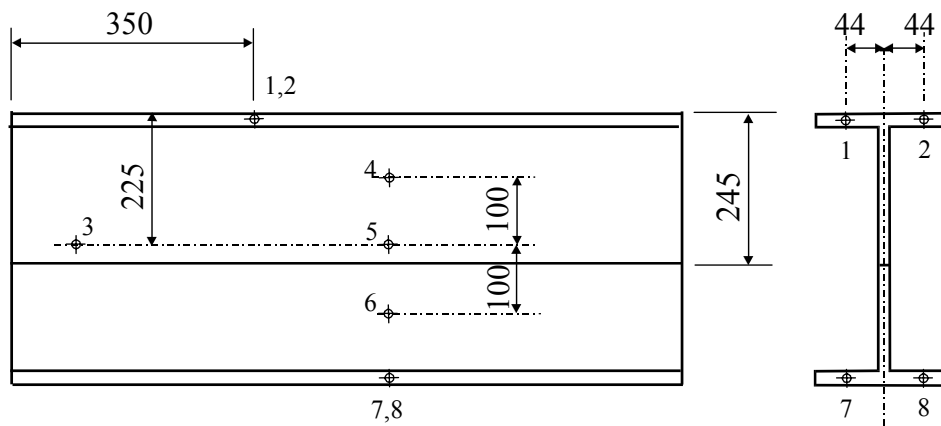


Figure 1: Geometry of tested beams

*Note: Thickness of web and flange were measured to the nearest 0.1mm  
Width, depth and length of beam were measured to the nearest 1.0mm*



Beam 1A



Beam 1B

Figure 2 Location of thermocouples

Both beams were fixed to the roof of a 1.5m<sup>3</sup> furnace. The position of the beams within the furnace is shown in Figure 3. The time-temperature relationship of the furnace followed the BS476 curve. Figure 4 shows a photograph of the beams placed in the furnace and Figure 5 shows a photograph of the cellular beam with the thermocouples attached.

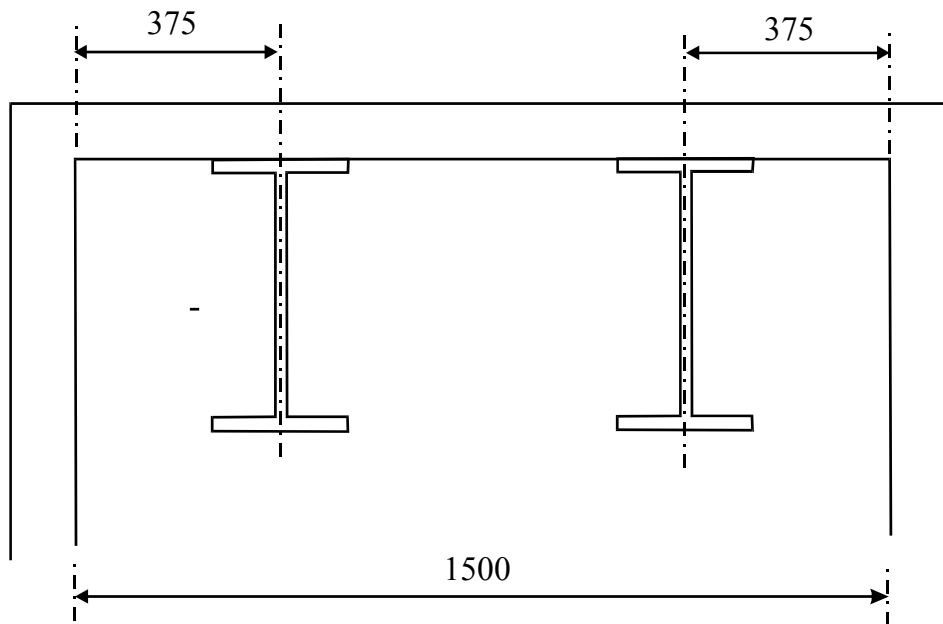


Figure 3 Position of beams within furnace.



Figure 4 Photograph showing beams fixed to the roof of the furnace



Figure 5 Photograph showing location of thermocouples on cellular beam.

### 3. Test Results

The test was carried out on 8<sup>th</sup> May 2003 and witnessed by Professor Bailey of the Manchester Centre of Civil and Construction Engineering.

Figure 6 shows the recorded temperature at the centre of the web-post (position 7) of the cellular beam and the temperature at the corresponding position on the solid beam (position 5). It can be seen that the temperature of the web of the solid beam is higher than the temperature of the centre of the web-post for the duration of the test. Up to steel temperatures of 900°C the temperature at the centre of the web of the solid beam is 30°C hotter than the temperature at the centre of the web-post of the cellular beam. At 90 minutes, the temperature at the centre of the web of the solid beam is still 10°C hotter than the middle of the web-post on the cellular beam.

Figure 7 shows the average temperature of the bottom flange on the solid beam compared to the average temperature of the bottom flange of the cellular beam, measure below the web-post. Once again it can be seen that the solid beam is hotter than the cellular beam. Figure 8 shows the difference in temperatures between the two beams for the average flange temperatures and the temperatures at the web-post and mid-height of the solid beam. It can be seen that after 20 minutes the difference in the solid web and web-post temperatures is greater than the difference between the average temperatures measured in the flange of both beams.

The recorded temperatures at positions 7, 10, and an average of positions 16 and 17 on the cellular beam are shown in Figure 9. Up to 600°C the average flange temperature is lower than the web temperature. Above 600°C the flange temperature is hotter than the web temperature. The difference in temperature between position 7 and 10 on the cellular beam is nominal indicating that the temperature of the web-post is fairly constant from its mid-height and to the bottom flange. Similar behaviour in temperature was observed in the solid beam, as shown in Figure 10.

Figure 11 shows the recorded temperatures at positions 6,7 and 8 on the cellular beam, representing the thermal gradient horizontally across the web-post. It can be seen from this figure that there is no significant variation of temperature across the web-post. The temperature at mid-height of the web of the solid beam (position 5) is also shown in Figure 10, which was hotter than the temperatures of the web-post.

Figure 12 shows the recorded temperatures at the mid-height of the cellular beam at positions 3 (end of beam), 7 (centre of web-post) and 13 (end of beam). It can be seen that temperatures at position 7 are hotter than the temperatures at positions 3 and 13, with the temperatures recorded at position 13 being significantly cooler. Recorded temperatures at position 3 on the solid beam (corresponding to position 3 on the cellular beam) and position 5 (corresponding to position 7 on the cellular beam) are also shown in Figure 11. It can be seen that the corresponding temperatures on the solid beam are hotter. It is of interest to note that temperatures recorded at positions 3 and 5 on the solid beam are similar except between 10 and 20 minutes where the temperatures at position 3 (end of the beam) are higher than temperatures at position 5 (centre of the beam).



Figure 13 shows the recorded temperatures at positions 4-11 on the cellular beam, representing the measured temperatures throughout the web-post. Also shown in this figure is the temperature of the web at mid-height of the solid beam. It can be seen that the temperature of the web of the solid beam is hotter than the temperatures measured at positions 4-11 in the web-post of the cellular beam.

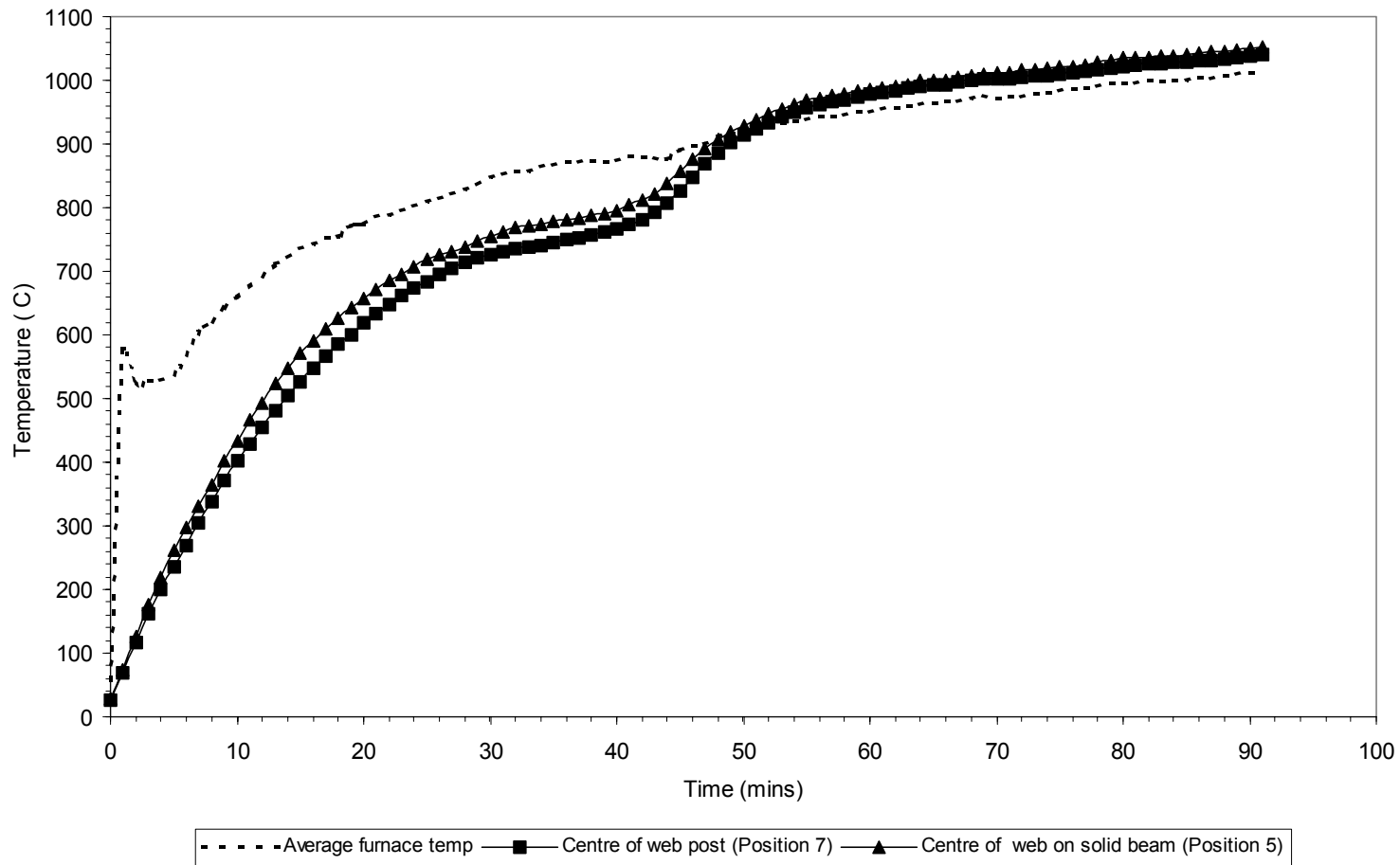


Figure 6 Comparison between recorded temperatures at mid-height and mid width of the web-post (position 7) on the cellular beam with temperatures at mid-height on solid beam (position 5)

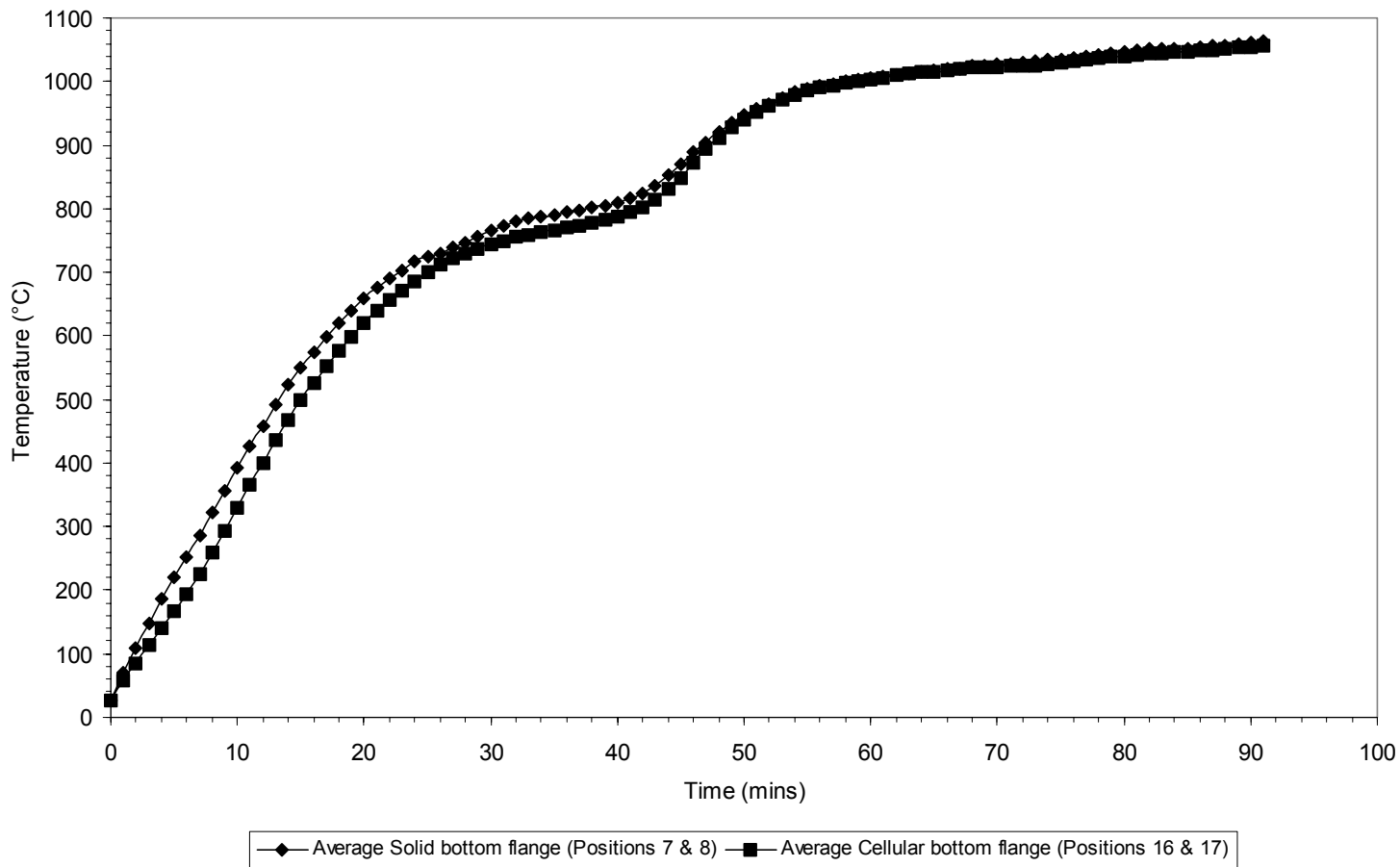


Figure 7 Comparison between recorded average temperatures on the bottom flange of the cellular beam (Positions 16 and 17) with average temperatures on the bottom flange of the solid beam (Positions 7 and 8)

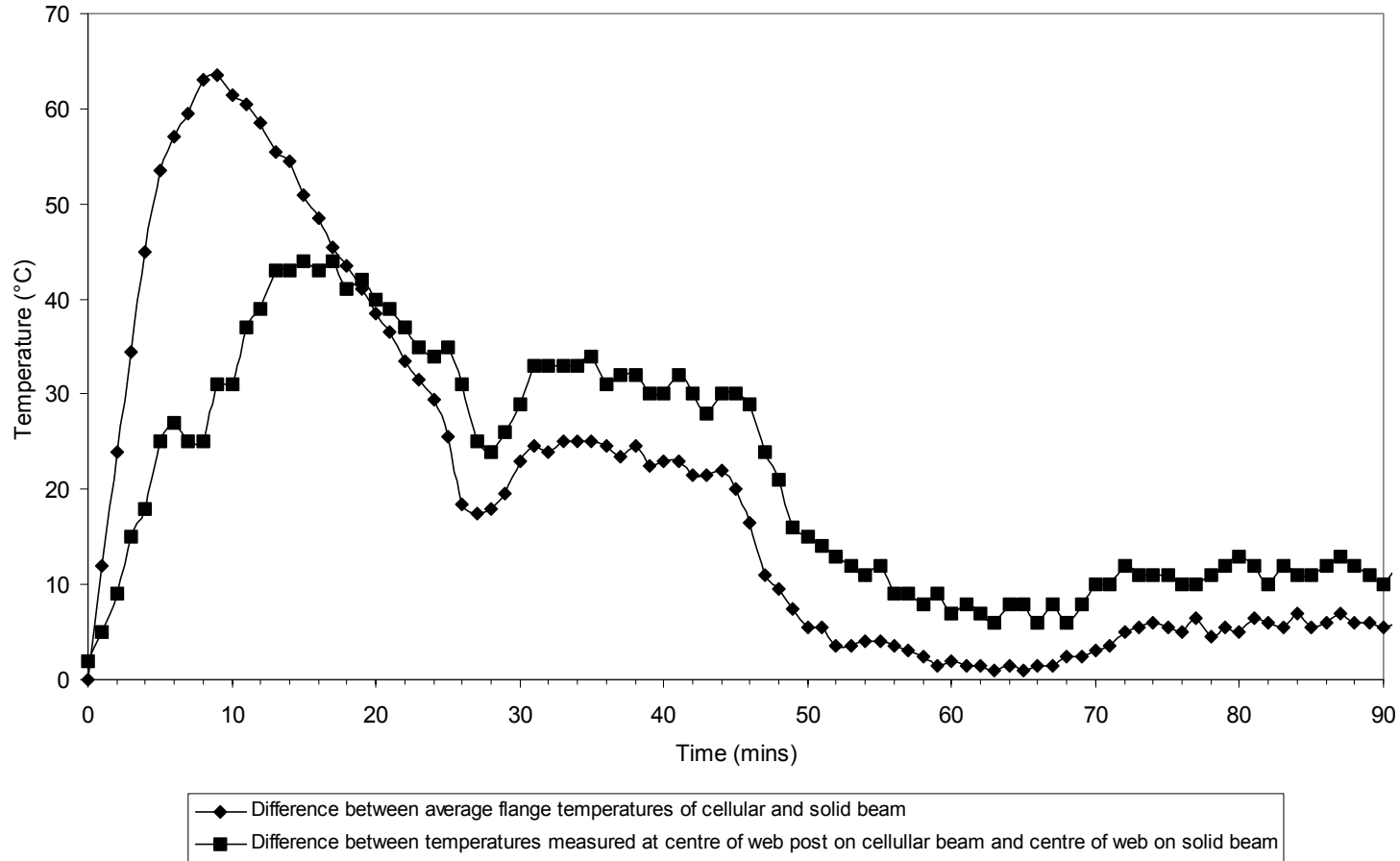


Figure 8 Comparison between difference in recorded flange and web temperatures between cellular and sold beam

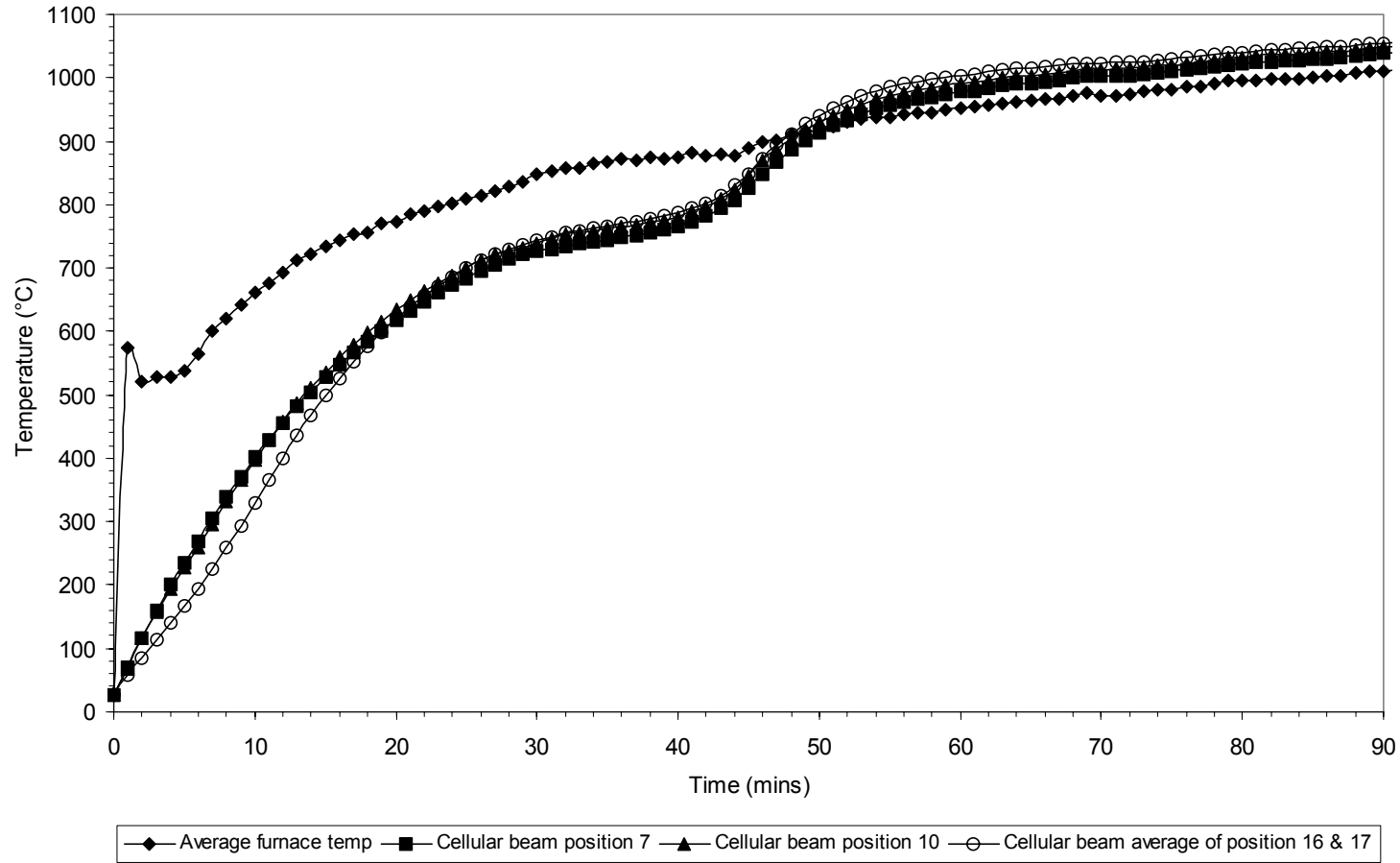


Figure 9 Comparison of measured temperatures at position 7, 10 and average of 16 and 17 on the cellular beam

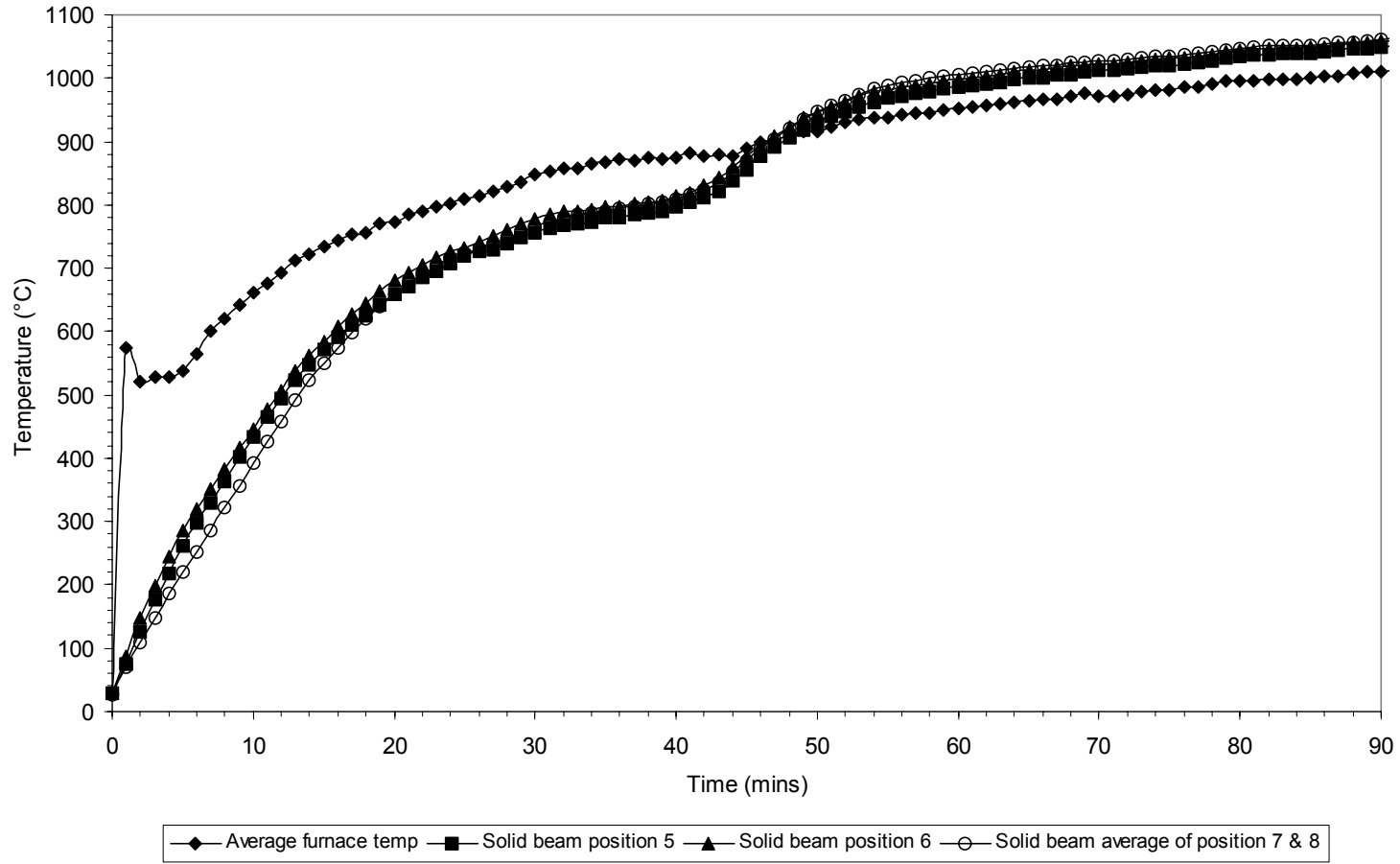


Figure 10 Comparison of measured temperatures at position 5,6 and an average of 7 and 8 on the solid beam

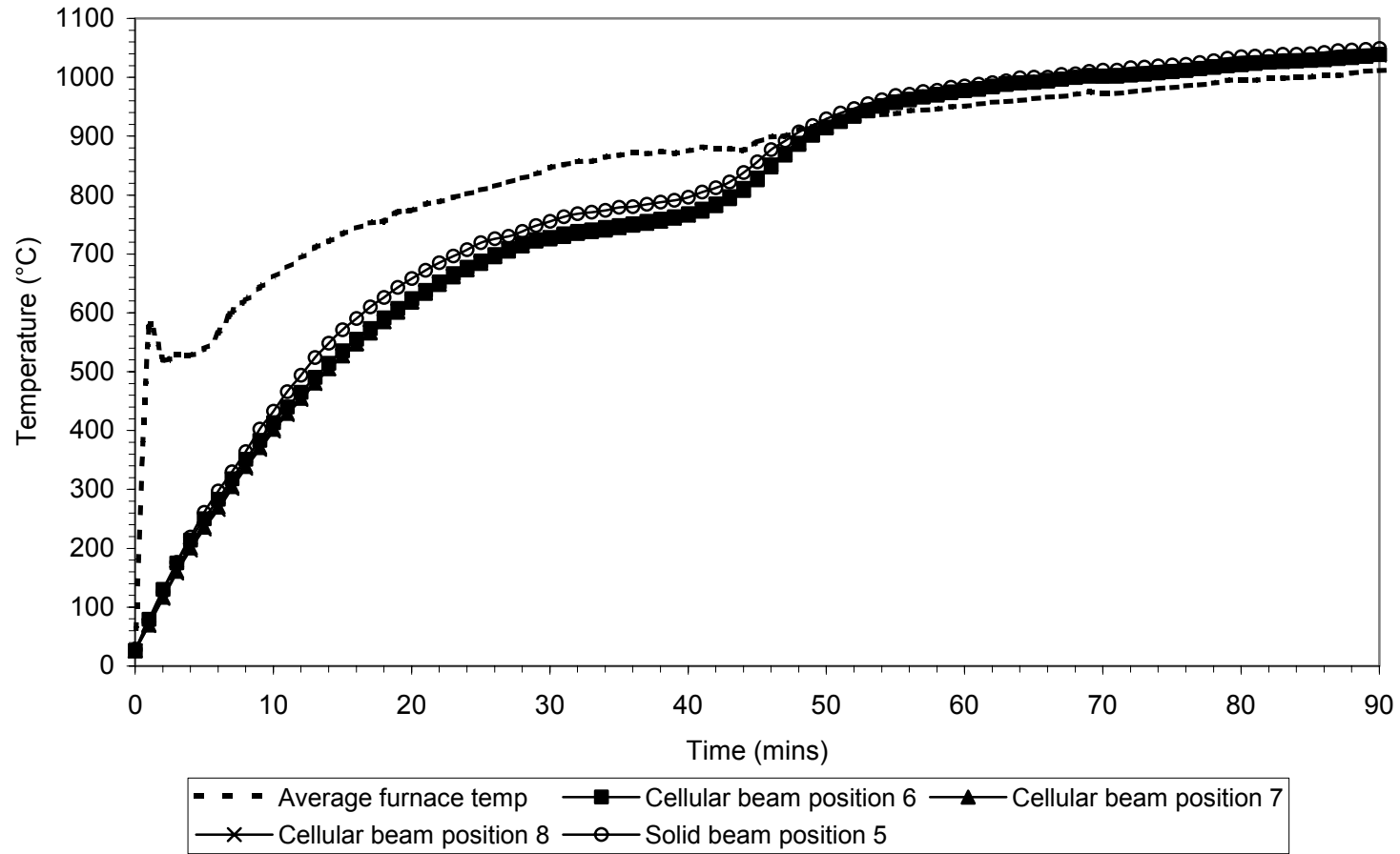


Figure 11 Comparison of measured temperatures at position 6,7 and 8 on the cellular beam and temperature at position 5 on the solid beam

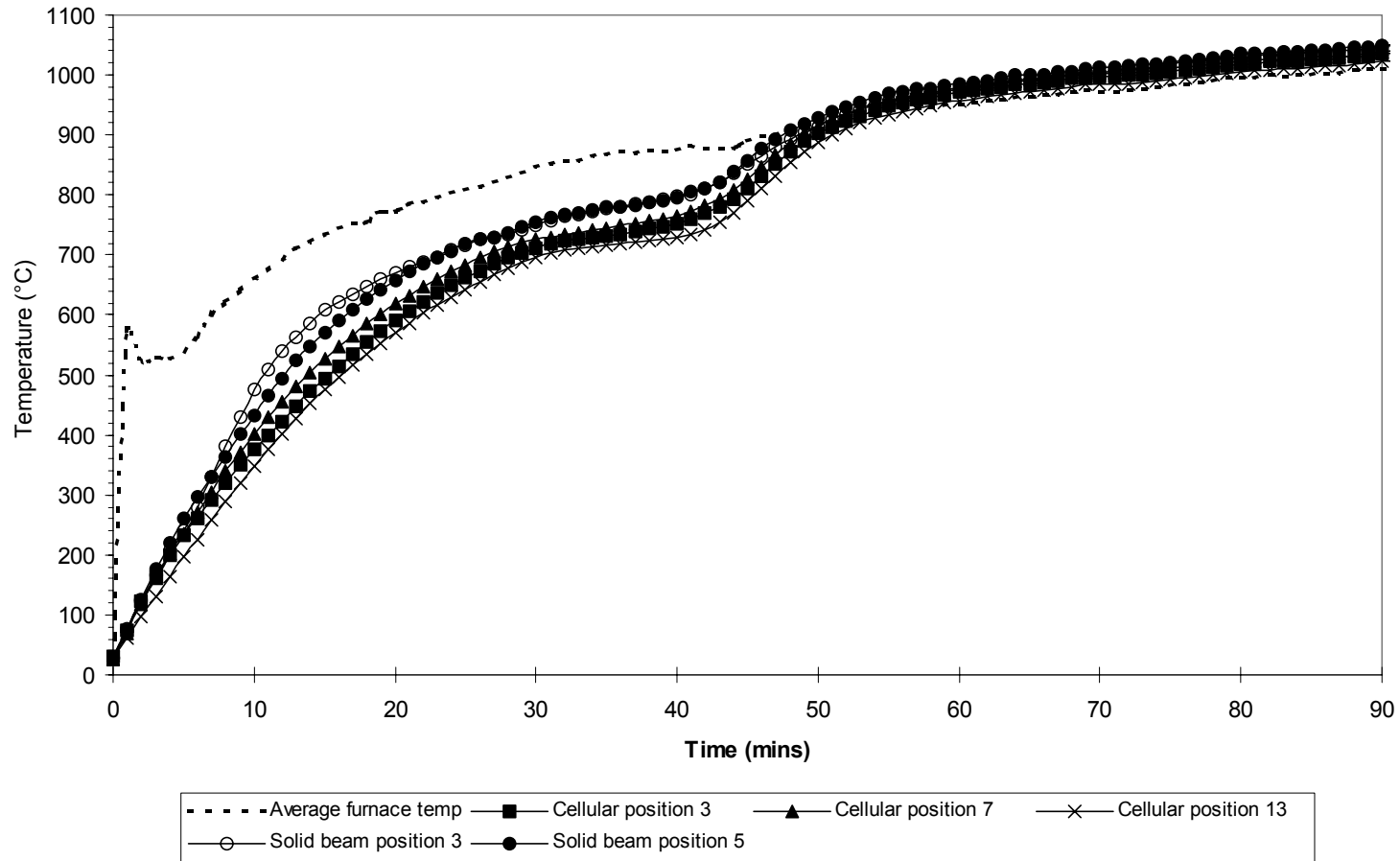


Figure 12 Comparisons of recorded temperatures at mid-height of cellular and solid beam (refer Figure ? for location of thermocouples)

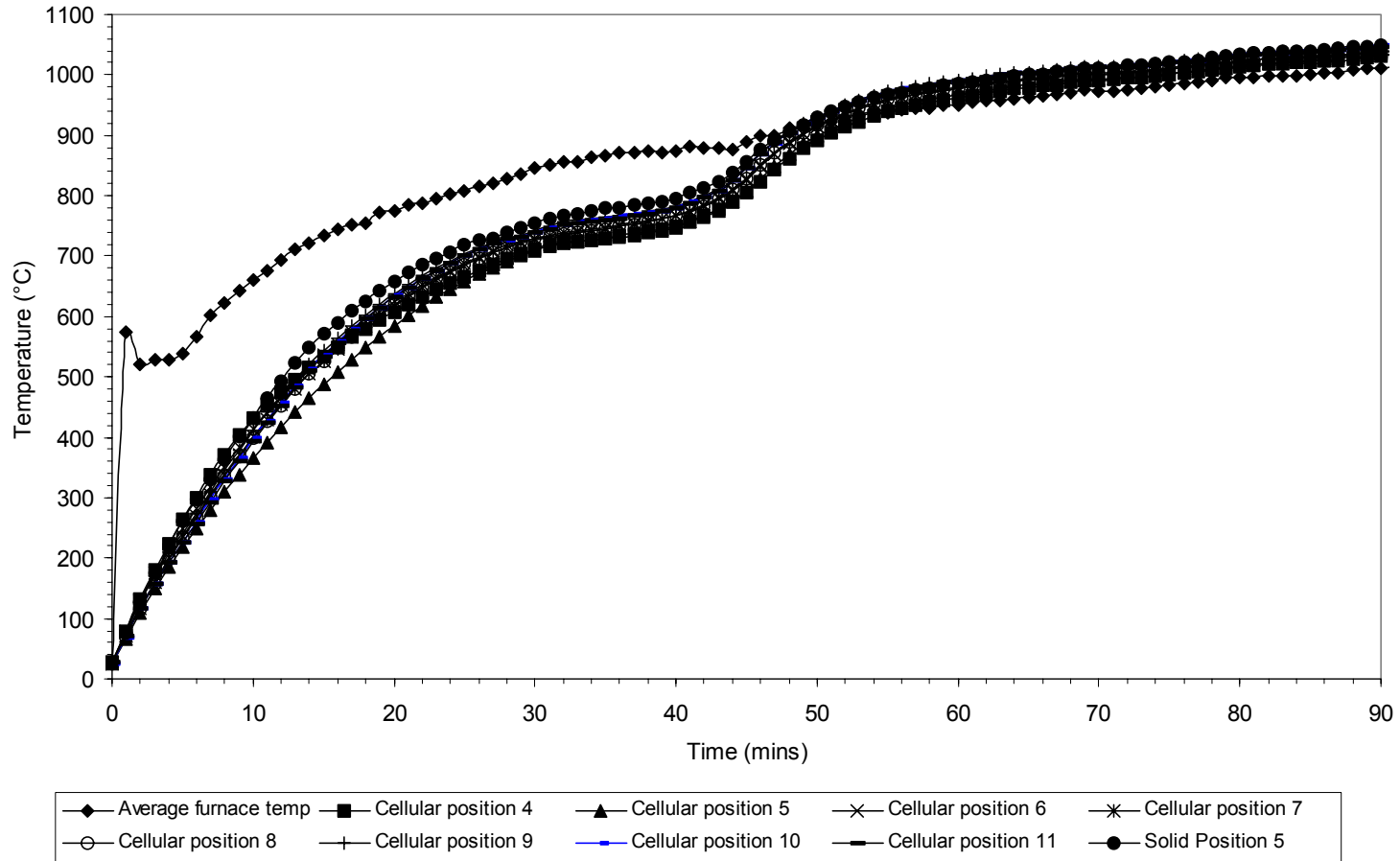


Figure 13 Comparison of web-post measured temperatures (positions 4 to 11) with measured web temperature at mid-height of solid beam



## 4. Conclusions

Two identical unprotected beams were placed in a furnace, one with a solid web the other with one and a half holes cut into the web to form a web-post 118mm wide. The primary aim of the test was to investigate whether the web-post of an unprotected cellular beam heats up at a faster rate than an identical beam without holes.

Comparison of the temperatures measured at the middle of the web-post with the temperatures measured at the middle of the web of the solid beam showed that the solid web was hotter than the web-post for the duration of the test.

It was found by comparing all recorded temperatures, measuring both the flange and web temperatures, that the solid beam was hotter than the cellular beam. Since the beams were geometrically similar (except for the holes in the cellular beam) the reason why the solid beam was hotter is currently unknown. It is possible that the temperatures of the beams were influenced by the flow of hot gases in the furnace, but this requires further investigation.

The temperatures measured at mid-height of the web-post were similar to the temperatures measured 100mm below the mid-height towards the bottom flange. There was no significant variation of temperature distribution across the mid-height of the web-post. The flange temperature of the cellular beam was lower than the mid-height web-post temperature for the first 20 minutes of the test (Figure 9). After 20 minutes the flange temperature was higher than the web-post temperature. The similar behaviour in temperature distribution between the flange and web was observed in the solid beam (Figure 10).

The test indicates that for an unprotected, unloaded, steel beam the temperatures in the web-post do not increase compared to an equivalent solid web.

Further tests are now required on protected beams to see if the performance of the protection influences the temperatures in the web-post compared to an equivalent unprotected beam.



## **5. References**

1. Technical Note: Fire engineering of cellular beams using intumescent coatings. The Structural Engineer – 1<sup>st</sup> October 2002,pp24-25.