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The composite action of the OSB-CFS composite beam in fire

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Contents

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Background- benefits

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- OSB (Oriented Strand Board) + CFS (Cold-Formed Steel) composite beams are lightweight and high-strength

- Suitable for modular construction

- The composite action can increase in load-bearing capacity of 75%-120% and flexural stiffness of up to 40% (Kyvelou et al., 2015; Kyvelou et al., 2017(a); Loss and Davison, 2017; Raffoul et al., 2019; Zhou et al., 2019)

(Far, 2020)

Practical cases

(Stratco (Australia) Pty Ltd.)

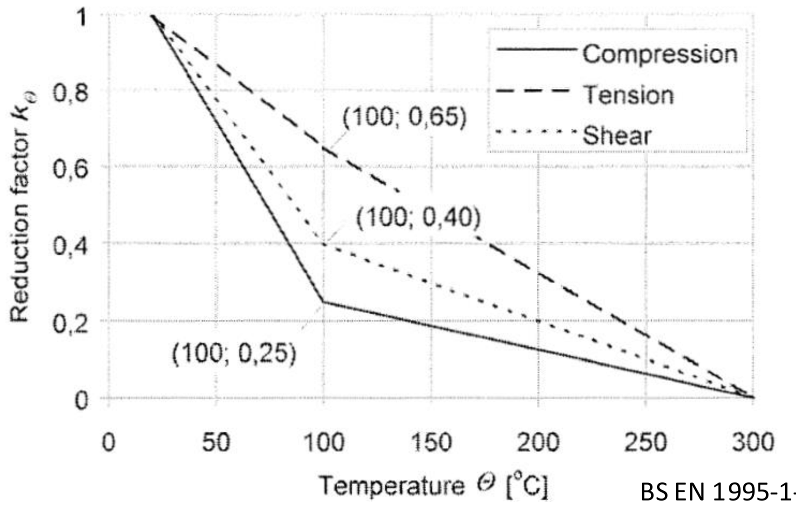
Background- issues

- Lack of fire studies

- Whether the composite action existing?

- Timber is combustible and temperature-sensitive (König, 2000; BS EN 1995-1-2, 2009; Xu et al., 2017)

- Local charring



BS EN 1995-1-2

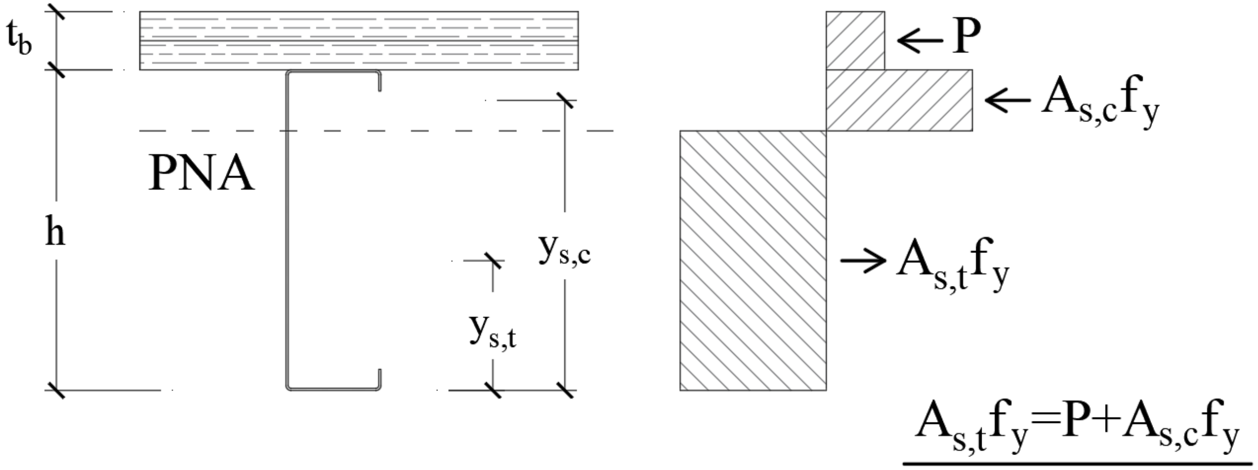
Local charring of timber around a metal shear connector

Design methods- ambient

- Ambient plastic design methods has been verified (Kyvelou et al. (2017(b))

- An example (partial shear connection):

- A few uncertainties for fire application

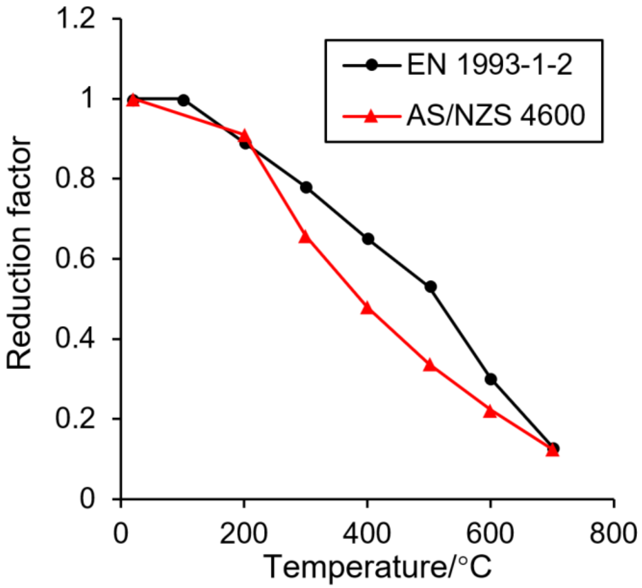


$$M_{pl} = P \times \left(\frac{t_b}{2} + h - y_{s,t}\right) + T_{s,c} \times \left(y_{s,c} - y_{s,t}\right)$$

Design methods- four uncertainties for fire application

- Local charring >> location of the temperatures (local or remote)?
- Steel with higher temperatures >> plastic assumptions ?
- Elevated temperature mechanical property models of CFS
- Complex buckling effects

Relatively low temperatures



Local charring

Aim & Objectives

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The existence of the composite action and the extension of the design method to the fire condition

- Fire tests

- Evaluate the effectiveness of possible options for these issues

- Recommend the best choice for design

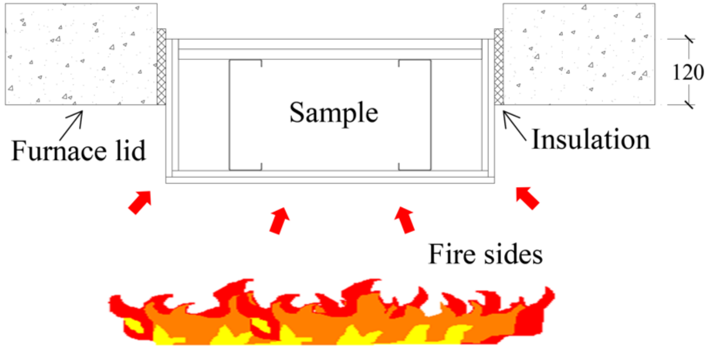
Experiments

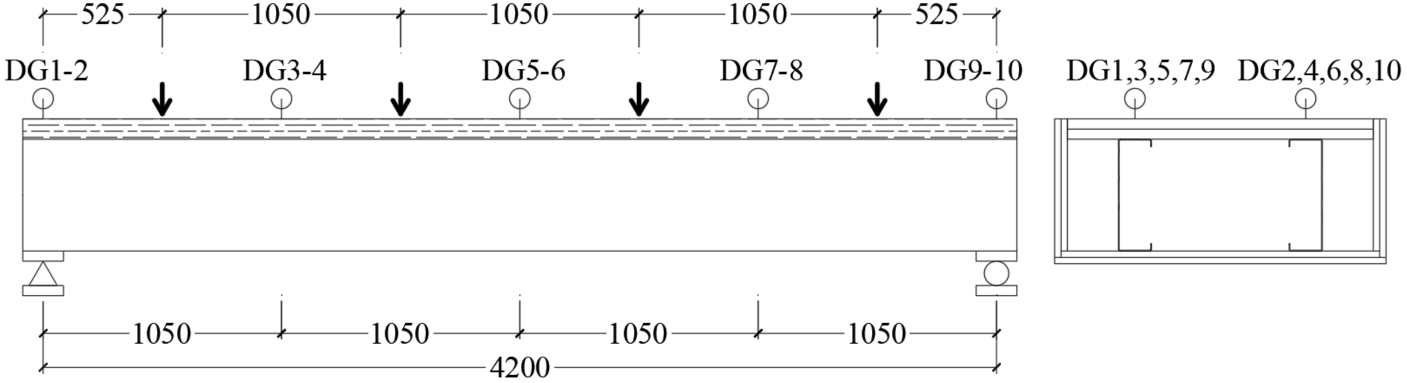
A group of 8 beam (2 ambient, 6 fire) tests

- Three-side exposure

- Gypsum protected

No	Spacing/mm	Plasterboard layer	Load ratio
1	80	-	-
2	160	-	-
3	80	1	0.35
4	80	1	0.70
5	80	2	0.35
6	80	2	0.70
7	160	2	0.35
8	160	2	0.70





Units in mm

Experiments results- fire

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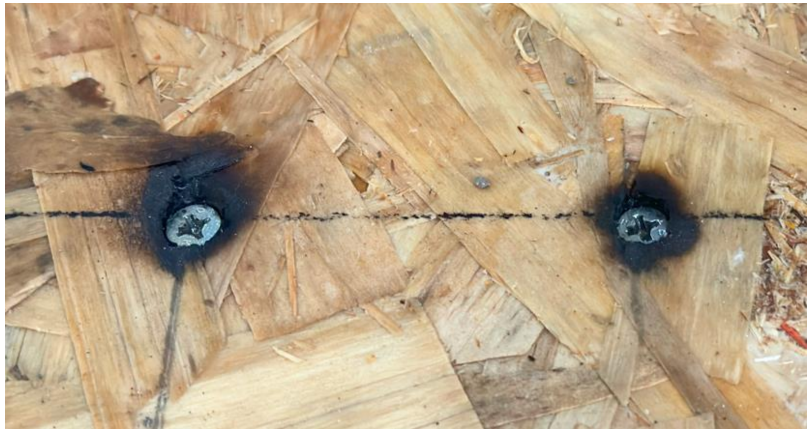
A group of 8 beam (2 ambient, 6 fire) tests

- Buckling

- Local charring

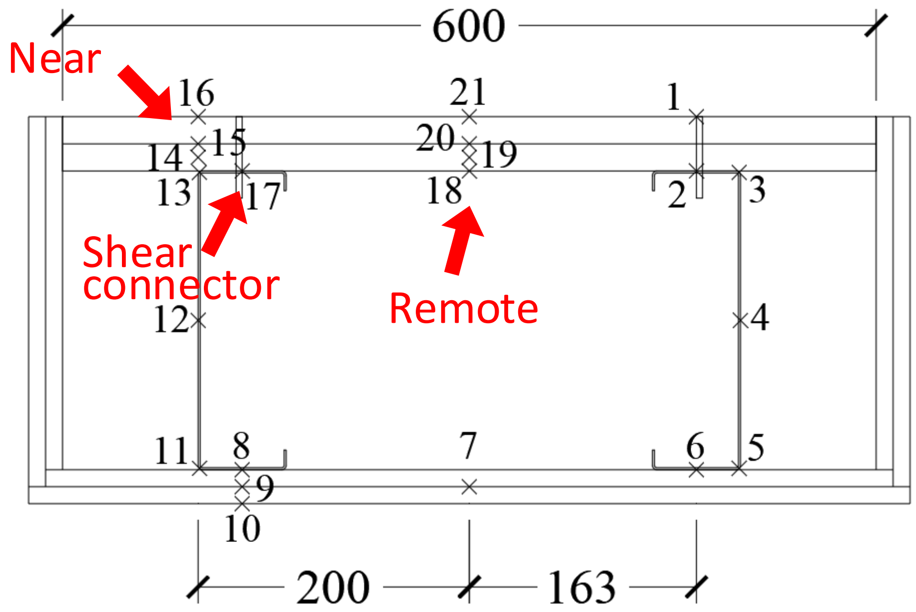


No	Spacing /mm	Plasterboard layer	Load ratio	Fire resistance /min	Max steel temperature at mid-span/^{o}C
1	80	1	0.35	51.4	597
2	80	1	0.70	30.4	403
3	80	2	0.35	121.3	580
4	80	2	0.70	79.2	401
5	160	2	0.35	138.5	640
6	160	2	0.70	83.7	433

Assessment- Four main issues & options

- **CFS mechanical property models at elevated temperatures**
  - EN 1993-1-2 model (BS EN 1993-1-2, 2005)
  - AS/NZS 4600 model (AS/NZS 4600, 2018)

- **Temperatures to be used to calculate shear connector resistance**
  - Temperatures of timber "remote" away from the shear connector
  - Temperatures of timber "near" the shear connector
  - Shear connector temperatures, taken as the upper flange of the steel section



Layout of thermocouple

Assessment- Four main issues

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- **Shear force distribution along the beam effective length**
  - Plastic distribution: uniform distribution
  - Elastic distribution: linear variation

- **Local buckling**
  - Whole cross-section effective: no consideration
  - Only the upper flange, applying the effective width according to EN 1993-1-5 (BS EN 1993-1-5, 2006)
  - Apply the effective flange width and discard the upper half web

Assessment- Options

No.	Reduction factor of CFS	Shear connector capacity	Shear distribution	Buckling
1				No
2			Elastic	Effective width of the top flange
3		Temperature in remote timber for timber bearing		Effective width (top flange) + half web
4				No
5			Plastic	Effective width of the top flange
6				Effective width (top flange) + half web
7				No
8			Elastic	Effective width of the top flange
9		Temperature near shear connectors (SCs) for timber bearing		Effective width (top flange) + half web
10				No
11	EN 1993-1-2		Plastic	Effective width of the top flange
12				Effective width + ignore a half web
13				No
14			Elastic	Effective width of the top flange
15		Temperature of SCs (steel flange) for timber bearing		Effective width (top flange) + half web
16				No
17			Plastic	Effective width of the top flange
18				Effective width + ignore a half web
19				No
20		CFS sections only		Effective width of the top flange
21				Effective width (top flange) + half web
22				No
23			Elastic	Effective width of the top flange
24		Temperature in remote timber for timber bearing		Effective width (top flange) + half web
25				No
26			Plastic	Effective width of the top flange
27				Effective width (top flange) + half web
28				No
29			Elastic	Effective width of the top flange
30		Temperature near SCs for timber bearing		Effective width (top flange) + half web
31				No
32	AS/NZS 4600		Plastic	Effective width of the top flange
33				Effective width (top flange) + half web
34				No
35			Elastic	Effective width of the top flange
36		Temperature of SCs (steel flange) for timber bearing		Effective width (top flange) + half web
37				No
38			Plastic	Effective width of the top flange
39				Effective width + ignore a half web
40				No
41		CFS sections only		Effective width of the top flange
42				Effective width (top flange) + half web

36 combinations with composite action, 6 for CFS section only

Assessment- Results-Calculation/test result ratios

No.	Factors	Temp	Shear force	Buckling	B-1-F-1	B-1-F-2	B-2-F-1	B-2-F-2	B-2-F-3	B-2-F-4	Ave	CoV %
22	AS/NZS 4600	"Remote" TCs	Elastic	No	0.95	0.94	0.98	0.90	0.87	0.90	0.92 (1.15)	4.16 (8.17)
23				Top flange	0.92	0.88	0.93	0.84	0.81	0.82	0.87 (1.06)	5.36 (9.27)
24				Flange + web	0.73	0.73	0.79	0.68	0.69	0.63	0.71 (0.85)	6.79 (13.38)
25			Plastic	No	1.03	1.03	1.07	0.98	0.91	0.95	0.99 (1.23)	5.47 (7.59)
26				Top flange	1.01	0.99	1.02	0.93	0.87	0.88	0.95 (1.17)	6.27 (8.40)
27				Flange + web	0.79	0.86	0.83	0.83	0.72	0.74	0.80 (0.98)	6.42 (10.42)
28		"Near" TCs	Elastic	No	0.96	0.94	0.99	0.90	0.88	0.89	0.93 (1.15)	4.22 (8.32)
29				Top flange	0.92	0.88	0.94	0.84	0.82	0.82	0.87 (1.07)	5.47 (9.47)
30				Flange + web	0.73	0.74	0.79	0.68	0.69	0.63	0.71 (0.85)	6.87 (13.74)
31			Plastic	No	1.03	1.03	1.07	0.98	0.91	0.95	1.00 (1.24)	5.50 (7.81)
32				Top flange	1.01	0.99	1.03	0.94	0.88	0.88	0.96 (1.18)	6.32 (8.48)
33				Flange + web	0.80	0.87	0.84	0.83	0.73	0.74	0.80 (0.99)	6.36 (10.57)
34		SCs	Elastic	No	0.88	0.87	0.91	0.85	0.84	0.86	0.87 (1.09)	2.90 (7.94)
35				Top flange	0.82	0.80	0.84	0.77	0.76	0.78	0.80 (1.02)	3.57 (9.80)
36				Flange + web	0.67	0.60	0.68	0.57	0.63	0.57	0.62 (0.72)	7.25 (11.81)
37			Plastic	No	0.90	0.92	0.92	0.89	0.84	0.89	0.89 (1.13)	3.08 (6.58)
38				Top flange	0.85	0.86	0.85	0.82	0.77	0.81	0.83 (1.05)	3.77 (7.83)
39				Flange + web	0.69	0.70	0.70	0.66	0.64	0.62	0.67 (0.78)	4.84 (9.10)
40		CFS sections only		No	0.68	0.52	0.65	0.51	0.61	0.53	0.58 (0.68)	-
41				Top flange	0.44	0.35	0.43	0.35	0.40	0.36	0.39 (0.46)	-
42				Flange + web	0.13	0.11	0.13	0.11	0.12	0.12	0.12 (0.15)	-

Results in brackets- EC3

Assessment- Results

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- **Composite action**

- Predictions of considering CFS sections only >> only 0.5-0.7
- The improvement of the capacity could be over 100%
- The composite action in the fire test beams was substantial and can be reliably utilised in the fire design

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Assessment- Evaluation of four issues

- **Effects of mechanical property models of CFS**

• The AS/NZS 4600 mechanical property model gives much lower coefficient of variation (CoV) values (ranging from 2.90% to 7.25%) than using the Eurocode 3 mechanical property model (ranging from 6.58% to 13.74%)

• AS/NZS 4600 model is preferred

- **Local buckling**

• No consideration of the buckling is unsafe (many predictions >1.0 for calculation/test result ratio)

• Discarding the flange and the beam is not correct (predictions 0.6-0.8), UDL in practice

• Only the upper flange buckling is preferred

Assessment- Evaluation of four issues

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- **Temperature distributions**

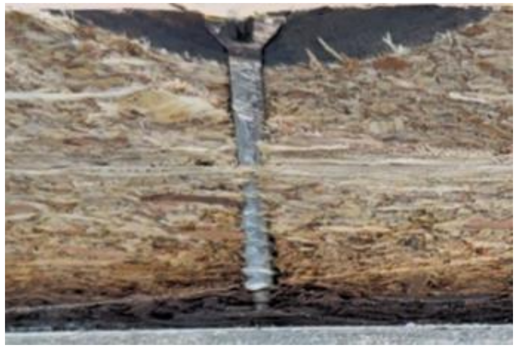
- "Remote" >> 0.95 in average >> accurate and temperatures independent to the steel >> cut into >> preferred
- "Near" >> 0.96 in average
- Shear connector >> 0.83 in average >> safe but inaccuracy

- **Shear force distribution**

- Elastic >> 0.87 in average
- Plastic >> 0.95 in average >> preferred

  with experimental evidence

(i) Near the support



(ii) Near the mid-span

Conclusions

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A number of issues of extending the ambient design methods are solved:

- The benefits of the composite action were reliable in fire conditions
- Recommend combination (average ratio of 0.95, CoV of 6.27%):
- The AS/NZS 4600 yield strength model at elevated temperatures for low-strength cold-formed steel gives better accuracy than the Eurocode 3 model
- For buckling effects, the simplistic assumption of the effective contribution of the top flange only is acceptable
- The remote timber temperature can be used
- Plastic analysis can still be assumed for fire design.

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Thank you for your attention

Any questions?

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