By John Rakic

Introduction

As I sit at my trusty laptop, on Sunday morning, watching the sun rise through my window, I take a moment to stop and pay my respects to the 2750 people or more that died almost 19 years ago in the World Trade Centre terrorist attacks. Time flies and quite often we get too busy to stop, just take a moment, to pause, reflect and review what we are doing.

Image depicts bent steel after a building fire.

It's true, COVID19 has given some of us time in our home offices. Maybe some of you readers will have had time in between the Zoom & Team Viewer mania, to get to things you might not have got to if you were still working 70 hours a week in your offices?

This article is going to look at the legal or regulatory requirements for passive fire protection of steel structures here in Australia; that is the requirements of our own National Construction Code (NCC) encompassing fire testing requirements of AS1530 Part 4 or an equivalent fire test method, along with the strict requirements contained in AS4100 for data analysis and calculation of the thicknesses of fire protection materials required to provide a compliant FRL.

Sadly, it would be remiss of me, not to question the thousands of square metres of pink and so-called fire rated plasterboard, which is used in my humble opinion, incorrectly as cladding to provide an FRL to steel columns and beams in construction of our buildings here in Australia. I will stand corrected if I am wrong, and it would not be the first time, but I urge readers to educate themselves by way of this article on how the NCC and FRL's MUST work for steel structures, and check to see if the materials you see being used, should in fact be being used? It there might be a few more than a couple of pink faced moments, and not the plasterboard, but you the reader????

Please enjoy……………………..Happy to receive comments to jr@tgroup.com.au

What happens to steel structures in fires

Structural steel, by definition, is a steel structure that is helping to hold up a building. The steel structure, might consist of vertical columns, and horizontal beams, along with some bracing for example? The beams might be supporting a composite concrete slab for example.

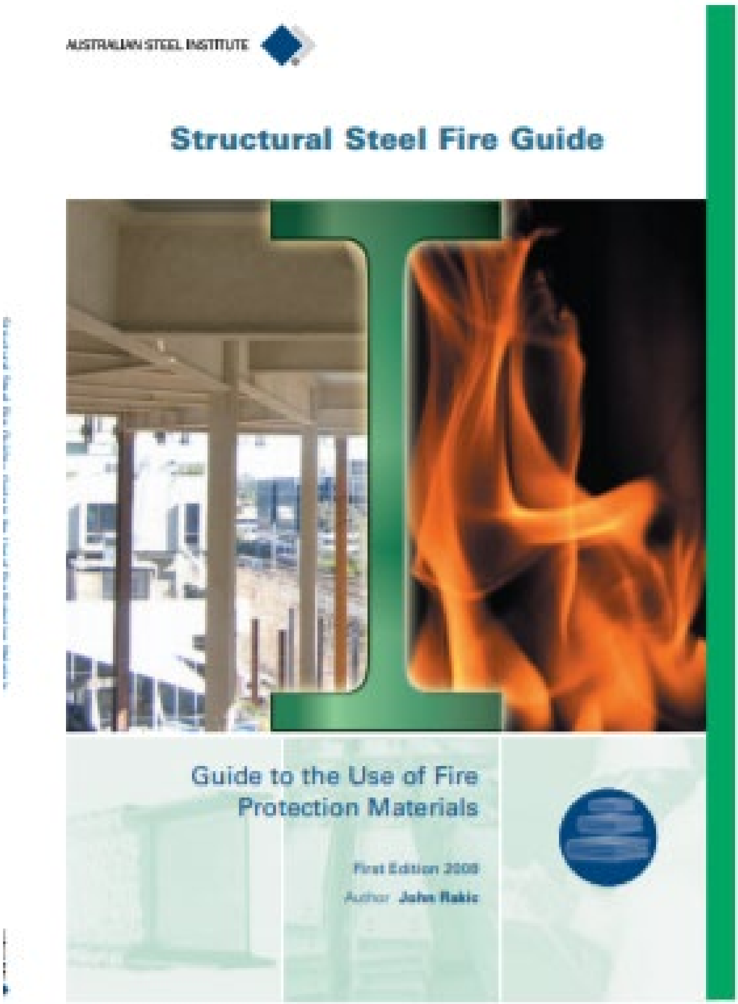
In a building fire, the temperatures can quickly rise within a compartment space to 500 deg C, and without sprinkler intervention, the temperature can continue to rise significantly, as long of course as there remains sufficient fuel and oxygen to allow sustained combustion.

Without adequate passive fire protection applied to these steel structure, at these elevated temperatures, the steel under load, does lose some of its strength and start to bend and twist and in extreme cases result in collapse of part of or all the building.

Passive fire protection isn't hard to understand, you apply some material over the steel, to help provide some insulation to keep the steel, under the applied material, at below the temperature where it can start to lose strength.

Déjà vu or not?

I was asked in 2008 to write a technical guide for the Australian Steel Institute (ASI) about passive fire protection for Steel Structures. I can't believe that was over 10 years ago……



If you Google it, you might find a copy on the internet for FREE, or you can buy it from the ASI?

NCC DtS provisions and FRL's

Sorry for the acronyms.

This section will provide a brief overview of the technical requirements under the National Construction Code, NCC (formerly the Building Code of Australia, BCA), and how one can provide a compliant fire rating or FRL, and therefore are protected as having provided a Deemed to Satisfy Building Solution to meet the performance requirements under the NCC.

If this is confusing, don't stress, if you do the following, you should be fine!

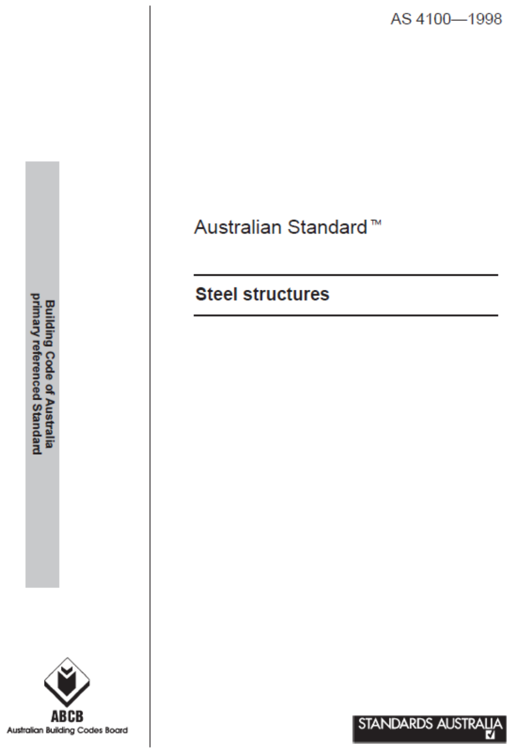
FRL requirements

The fire ratings required where steel structures as being used, and determined under the NCC, based on the Class of Building & the Type of Construction and manifest themselves as FRL's (Fire Resistance Levels).

For structures, only the first criteria of the FRL applies, so some common fire rating would be:

- One hour, FRL 60/-/-
- 90 minutes, FRL 90/-/-
- Two hours, FRL 120/-/-
- Three hours, FRL 180/-/-
- Four hours, 240/-/-

AS4100, our Australian Standard for Steel Structures


AS 4100—1998

Building Code of Australia
primary referenced Standard

Australian Standard™

Steel structures

ABCB
Australian Building Codes Board

STANDARDS AUSTRALIA

The NCC correctly requires that all steel structures need to comply with AS4100.

AS4100 deals with loads and other actions, which a structural engineer gets excited about. Terms like dead & live loads, bending moments, compression, tension, buckling and restraint conditions come to mind. Along with fabrication and erection guidance.

What readers might not realise, is that both **FIRE** and Earthquake are included in AS4100 and the design criteria are very important to adhere to, in case of a fire or an earthquake.

AS4100 and the technical requirements for determining FRL's

AS4100 allows a structural engineer to calculate the FRL of an *unprotected* steel member.

The FRL is defined as the time in minutes, for the limiting temperature to be reached; that is the time in minutes it takes for the steel temperature to increase to a dangerous level for design purposes.

We know enough about the properties of steel and elevated temperatures to allow calculation for unprotected steel members.

In most cases, unless the steel is very thick and under very low loads, and the fire rating is very short, steel members will need additional passive fire protection materials added to insulate the steel and keep it relatively cooler under fire conditions.

First principals or common sense tells us that we would need some fire test data for any material being used to protect steel structure for fire exposure.

Any fire testing should show that any passive fire protection material or systems will:

- provide the required high temperature thermal insulation properties to keep the steel under pre-determined limiting steel temperatures for the fire rating times required
- *stay in place around the steel* during exposure to elevated temperatures (applicable for cladding systems), or stay stuck to the steel (applicable to coating such as sprays and paints), and be able to cater for thermal expansion and not crack, spall, fall off or result in openings through which hot gases can get to the underlying steel

………………

AS4100 requires a *series of fire tests to the requirements outlined AS1530 Part 4* including:

- *full scale load bearing fire tests*, on steel beam sections of 3 metres long
- additional *small or pilot scale fire tests* or thermal fire tests on 1 metre long sections

This fire testing is expensive and time consuming and therefore, in a small market like Australia one might expect to be only a handful of product or system options available?

AS4100, has a strict procedure for determining the thickness of a proprietary passive fire protection material or systems which is proposed to be used to protect structural steel members and provide an NCC compliant FRL or fire rating; *it requires a detailed mathematically based linear regression analyses*, which provide for an area of applicability for stability and provides the requisite thickness of passive fire protection material requires for steel sections based on the Exposed Surface to Mass Ratio (ESA/m).

Please note, in the UK for example, the Heated Perimeter to Cross Sectional Area, (Hp/A) is typically used for describing steel section properties and one can easily convert from ESA/m to Hp/A or vice versa mathematically.

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AS 4100—1998 140

12.6.2.1 *Regression analysis* The relationship between temperature (T) and time (t) for a series of tests on a group shall be calculated by least-squares regression as follows:

$$t = k_0 + k_1 h_i + k_2\left(\frac{h_i}{k_{sm}}\right) + k_3 T + k_4 h_i T + k_5\left(\frac{h_i T}{k_{sm}}\right) + k_6\left(\frac{T}{k_{sm}}\right)$$

where

t = time from the start of the test, in minutes

k_0 to k_6 = regression coefficients

h_i = thickness of fire protection material, in millimetres

T = steel temperature, in degrees Celsius, $T > 250°C$

k_{sm} = exposed surface area to mass ratio, in sqaure metres/tonne.

12.6.2.2 *Limitations and conditions on use of regression analysis* Test data to be utilized in accordance with Clause 12.6.2.1 shall satisfy the following:

(a) Steel members shall be protected with board, sprayed blanket or similar insulation materials having a dry density less than 1000 kg/m^3.

NOTE: Standards Australia is not prepared to make recommendations on interpolation for members protected with other materials such as intumescent coatings.

(b) All tests shall incorporate the same fire protection system.

(c) All members shall have the same fire exposure condition.

(d) The test series shall include at least nine tests.

(e) The test series may include prototypes which have not been loaded provided that stickability has been demonstrated.

(f) All members subject to a three-sided fire exposure condition shall be within a group in accordance with Clause 12.9.

The regression equation shall only be used for interpolation. The window defining the limits of interpolation shall be determined as shown in Figure 12.6.2.2.

The regression equation obtained for one fire protection system may be applied to another system using the same fire protection material and the same fire exposure condition provided that stickability has been demonstrated for the second system.

A regression equation obtained using prototypes with a four-sided fire exposure condition may be applied to a member with a three-sided fire exposure condition provided that stickability has been demonstrated for the three-sided case.

12.6 DETERMINATION OF TIME AT WHICH LIMITING TEMPERATURE IS ATTAINED FOR PROTECTED MEMBERS

12.6.1 Methods The time (t) at which the limiting temperature (T_l) is attained shall be determined by calculation on the basis of a suitable series of fire tests in accordance with Clause 12.6.2 or from the results of a single test in accordance with Clause 12.6.3.

For beams and for all members with a four-sided fire exposure condition, the limiting temperature (T_l) shall be taken as the average of all of the temperatures measured at the thermocouple locations shown in AS 1530.4.

For columns with a three-sided fire exposure condition, the limiting temperature (T_l) shall be taken as the average of the temperatures measured at the thermocouple locations on the face farthest from the wall. Alternatively, the temperatures from members with a four-sided fire exposure condition and the same surface area to mass ratio may be used.

12.6.2 Temperature based on test series Calculation of the variation of steel temperature with time shall be by interpolation of the results of a series of fire tests using the regression analysis equation specified in Clause 12.6.2.1 subject to the limitations and conditions of Clause 12.6.2.2.

Abstracts from AS4100 and the required mathematical analyses used to determine the thickness of a passive fire protection material used on different steel section sizes.

An example of a NCC compliant fire test assessment report using AS4100 linear regression

You will have seen, or you can see, if you look at the AS4100 abstract I provided above, that there is a complicated linear regression coefficient one MUST use to achieve AS4100 compliance. It is called a 7 coefficient analyses, as there is 7 co-efficient k_o to k_6 respectively.

It looks like this:

$$t = k_0 + k_1 h_i + k_2\left(\frac{h_i}{k_{sm}}\right) + k_3 T + k_4 h_i T + k_5\left(\frac{h_i T}{k_{sm}}\right) + k_6\left(\frac{T}{k_{sm}}\right)$$

I am going to use some abstracts from my own Trafalgar FyreBOARD Maxilite™ product to show what a compliant AS4100 fire test assessment report looks like.

Shown below are the 7 coefficients as calculated using the strict requirements of AS4100, for Trafalgar FyreBOARD Maxilite™ based on both full scale loaded steel sections and unloaded steel pilot or small-scale sections.

The assessment process used is that specified in AS 4100, Steel Structures, Section 12, Fire. This requires a fit to an expression, based on calculations using least squares regression as :

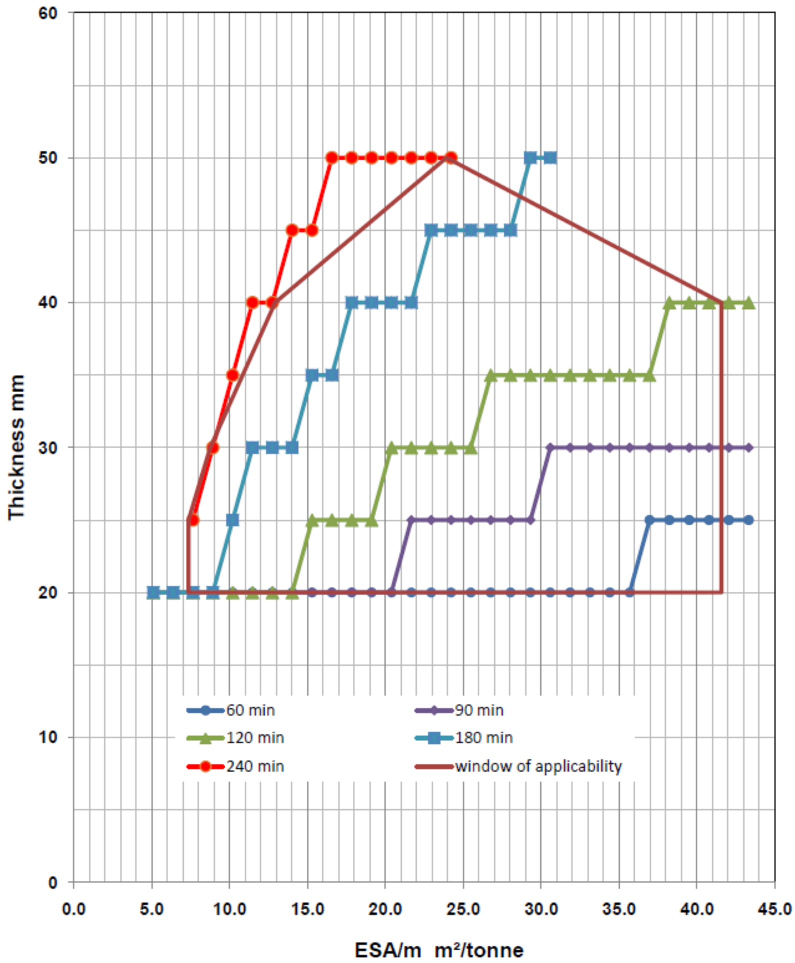
$$t = k_0 + k_1.h_i + k_2.(h_i/k_{sm}) + k_3.T + k_4.h_i.T + k_5.(h_i.T/k_{sm}) + k_6.(T/k_{sm}) \quad (4.1)$$

where:
t = time from the start of the test, in minutes
k_0 to k_6 = regression coefficients
h_i = thickness of fire protection material, in millimetres
T = steel temperature, in degrees Celsius, $T > 250°C$
k_{sm} = exposed surface area to mass ratio, in square metres/tonne (m^2/tonne), or
k_{sm} may be expressed in m^{-1} or heated perimeter to surface area (Hp/A) and is used in this report.

The regression analysis resulted in the following coefficients:

k_0	0.648
k_1	0.496
k_2	-8.07
k_3	-0.0808
k_4	0.0049
k_5	0.0781
k_6	1.38

If you are mathematically inclined, and remember how to solve simultaneous equations, for a given FRL ('t' in the above equation in minutes), and for a critical steel temperature ('T'), you can calculate the minimum thickness of Trafalgar FyreBOARD Maxilite™ required using the formula above (making sure the data falls within the *window of applicability* for stickability



The data will also be provided in a tabular format providing the ESA/m and thickness of material required for a given limiting steel temperature

Limiting steel temperatures

It is commonplace to use 550 deg C for vertical steel section, whether columns, beams (beam sections used vertically) and for hollow steel sections for example

For beam supporting concrete slabs, where the concrete slab provides a good heat sink, a higher temperature of 620 deg C is often used.

Table 2: Maxilite Thickness (mm).
I-Columns, Beams and Hollow Sections at 550°C

Section Factor		Fire Resistance				
ESA/m	Hp/A	60	90	120	180	240*
1.3	10	20	20	20	20	25
2.5	20	20	20	20	20	25
3.8	30	20	20	20	20	25
5.1	40	20	20	20	20	25
6.4	50	20	20	20	20	25
7.6	60	20	20	20	20	25
8.9	70	20	20	20	20	30
10.2	80	20	20	20	25	*40*
11.5	90	20	20	20	30	*40*
12.7	100	20	20	20	30	*40*
14.0	110	20	20	20	30	*40*
15.3	120	20	20	25	35	*40*
16.6	130	20	20	25	35	*50*
17.8	140	20	20	25	40	*50*
19.1	150	20	20	25	40	*50*
20.4	160	20	20	30	40	*50*
21.7	170	20	25	30	40	*50*
22.9	180	20	25	30	45	*50*
24.2	190	20	25	30	45	
25.5	200	20	25	30	45	
26.8	210	20	25	35	45	
28.0	220	20	25	35	45	
29.3	230	20	25	35	50	
30.6	240	20	30	35	50	
31.8	250	20	30	35	50	
33.1	260	20	30	35	50	
34.4	270	20	30	35	50	
35.7	280	20	30	35	50	
36.9	290	25	30	35	50	
38.2	300	25	30	40	50	
39.5	310	25	30	40	55	
40.8	320	25	30	40	55	

Note*: Values at 240 minutes in italics are the direct application of test results

An abstract of ESA/m and thicknesses for Maxilite using a limiting steel temperature of 550 deg C

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As Trafalgar, for FyreBOARD Maxilite™, we have compiled a technical manual which can be downloaded along with our fire test assessment report at www.tfire.com.au

You can search by Application for Steel Protection and you will get the option below and in the technical manual all the thicknesses of Trafalgar FyreBOARD Maxilite™ are provided for given FRL's pertaining to most local available steel section types and size designations.

FyreBOARD MAXILITE

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Fight Fire with Fyre

FyreBOARD Maxilite™ is a lightweight high performance fire rated board. It is a calcium silicate product and joined together with non-organic binders and is completely free from asbestos, VOC and ODP compounds. FyreBOARD Maxilite™ is available in 30mm, 40mm and 60mm thicknesses for use in fire protection of structural steel. FyreBOARD Maxilite™ has been tested to various international test standards and is suitable for a large range of steel sizes and types. FyreBOARD Maxilite™ provides thermal insulation and heat sinking capacity for steel.

Required Maxilite Thickness

Universal Columns

Steel Size		Hp/A 1/m	Required Maxilite Thickness – 3 Sided Encasement – Fire Resistance Level: 30	60	90	120	180	240
310UC	283	30	20	20	20	20	20	20
	240	35	20	20	20	20	20	20
	198	40	20	20	20	20	20	20
	158	50	20	20	20	20	20	20
	137	55	20	20	20	20	20	25
	118	60	20	20	20	20	20	25
	97	75	20	20	20	20	20	30
250UC	90	70	20	20	20	20	20	30
	73	80	20	20	20	20	25	35
200UC	60	80	20	20	20	20	25	35
	52	95	20	20	20	20	30	40
	46	105	20	20	20	20	30	40
150UC	37	100	20	20	20	20	30	40
	30	120	20	20	20	25	35	45
	23	155	20	20	20	25	40	50
100UC	15	160	20	20	20	30	40	55

Compliance checklist for passive products used for protecting steel

CONFUSED?

Yes, don't worry, if you just appreciate that NCC and AS4100 compliance requires of the following:

- Full scale fire testing of loaded steel structures
- 7 coefficients and linear regression analysis
- A window of applicability graph
- Tables of ESA/m or Hp/A verses thickness of material

So, if you don't find the expression below in a current report from your supplier of passive fire protection material for protection of structural steel, you might not be using a compliant product

$$t = k_0 + k_1 h_i + k_2\left(\frac{h_i}{k_{sm}}\right) + k_3 T + k_4 h_i T + k_5\left(\frac{h_i T}{k_{sm}}\right) + k_6\left(\frac{T}{k_{sm}}\right)$$

Conclusions

- NCC requires strict use of AS4100 and 7 coefficient linear regression for determination of FRL's
- Fire testing must include full scale load bearing elements
- All fire test assessment report MUST include the 7 coefficients, k_0, k_1……………………..k_7
- Don't be fooled by the BIG NAME suppliers; ask for their fire test assessment report and double check compliance yourself
- The fire test assessment report should be readily available on the product suppliers web sites
- Be afraid of pink plasterboard…just saying….happy to write a public retraction if and when I receive an AS4100 complaint report at jr@tgroup.com.au
- Fire test laboratories are culpable in part for some confusion in the market by way of writing assessments that do not include the NCC requirements for AS4100 and the 7 coefficient linear regression analyses MANDATORY requirement
- If it says in the assessment report it MAY instead of it DOES; be concerned as you might not be installing compliant steel passive protection systems under the so called Deemed to Satisfy Provisions
- If in doubt ask, we are happy to review report and point you in the right direction
- TRUST Trafalgar; we believe SAFETY should never be taken for granted