Thickness for Passive Fire Protection Coatings

Why Extrapolated Data Won't Work on Small Structural Steel Sections

By Bob Glendenning

In a commercial building fire, the fate of the structure – and the safety of people in, on, or around the structure – may all come down to a layer of protective intumescent coating. However, how can structural engineers be sure they have used the right amount of coating material to provide the necessary fire protection? It all comes down to complying with available specification data, and not making assumptions when data for a specific steel section profile is unavailable.

Structural steel under load can quickly lose strength in a fire, eventually reaching a critical failure temperature at which it could collapse and possibly bring down large building sections or potentially the entire structure. To delay, and hopefully avoid such catastrophic losses, engineers and architects need to specify some form of passive fire protection, which usually includes cementitious fire-resistive materials, intumescent coatings, or a combination of both. These passive materials provide fire resistance, up to a certain number of minutes, while a fire is contained.

Cementitious materials provide a physical barrier of gypsum or cement to slow down the transfer of heat to the steel underneath.

Intumescent coatings work differently. They react chemically in fire, swelling to approximately 50 times their dry film thickness (DFT). The coatings form a char that expands with heat exposure and acts as insulation to reduce the rate of heat transfer to the structural steel. This extends the time for a given steel section to reach its critical failure temperature.

The required intumescent coating DFT to achieve a specified fire-resistance rating varies with the size of each structural steel member. Small, lightweight sections need a higher DFT to achieve the desired protection compared to larger, heavier sections. Underwriters Laboratories (UL) lists the required coating DFTs for structural steel members in its *Fire Tests of Building Construction and Materials* specification (ANSI/UL 263 (ASTM E-119)). However, the specification does not include every possible size, leaving data gaps for very small and very large sections.

To overcome the lack of sufficient UL 263-listed data for a particular steel section, some coatings suppliers engage in the potentially hazardous practice of extrapolating data to recommend an intumescent coating DFT. However, extrapolated DFT data is outside the UL certification program's scope, and using this noncompliant data could lead to two similarly dangerous scenarios:

1) The steel section may not have a sufficient coating DFT, which means it will not achieve its desired fire resistance.
2) The steel section may have a coating DFT that's too high, in which case the weight of the expanded char could cause the coating to delaminate and fall off, exposing the steel directly to fire with no protection in place.

Given these hazards, UL has stated that it is not safe to make assumptions about intumescent coating thicknesses. Therefore, when structural engineers encounter steel section sizes outside of UL's listing, they need to work with a coatings supplier to find a safe, workable alternative.

What Leads to Data Extrapolation

Building fire resistance requirements vary based on several considerations, including building codes, the structure's design, insurance regulations, and other factors. Common fire-resistance ratings include half-hour increments from 60 to 180 minutes.

While attempting to meet these ratings, engineers are also trying to minimize building material costs by creating sound designs with lightweight materials. In doing so, they may not realize that particular steel sections are smaller than those tested and listed in UL 263. No data exists to confirm whether those sections can meet the defined fire-resistance rating with a certain intumescent coating DFT applied. In such cases, some coatings suppliers may look at the closest size listed and assume that a correlative percentage of added coating provides sufficient protection. However, UL has determined that this extrapolated data is noncompliant, stating in its *The Fire & Security Authority* publication (2014, Issue 2) and its BXUV/CDWX guide for UL 263-compliant fire-resistance ratings that the average intumescent coating DFT "should not exceed the maximum thickness published in the individual [steel section] designs."

When faced with unavailable data, an engineer's best solution is to either consider an alternate steel size or profile or use more advanced fire engineering principles that consider how much of the steel strength supports the structure and how much reserve strength is available to resist fire. The latter option is deserving of a stand-alone article, so we will focus on specifying different steel sections.

UL 263 Steel Section Data Explained

It is important to remember two key points when determining intumescent coating DFT requirements: 1) Different UL listing categories have different test and pass criteria, and 2) different steel member shapes and orientations have different coating requirements. Therefore, it could be unsafe to use a maximum thickness from one UL category listing on another listing.

Each steel section has a "section factor" that helps to determine the intumescent coating DFT

*Bob Glendenning is Global Fire Engineering Manager for the Fire Engineering and Estimation Team at Sherwin-Williams Protective & Marine Coatings. He can be reached at **bob.glendenning@sherwin.com**.*

Table 1. Fire-resistance ratings for Column Y UL 263 listing (fully exposed I-beam column).

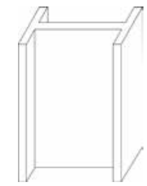
	Column Size	W/D	Required DFT (inches) for Fire Rating Duration		
			60 Minutes	90 Minutes	120 Minutes
	W6x12	0.45	0.129	0.247	N/A
	W10x39	0.78	0.072	0.134	0.198
	W10x49	0.84	0.067	0.126	0.185

Table 2. Fire-resistance ratings for Beam N UL 263 listing (I-beam covered by concrete on top flange).

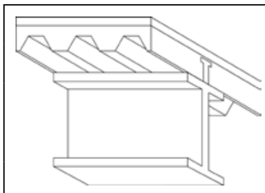
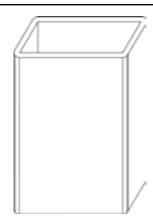
	Beam Size	W/D	Required DFT (inches) for Fire Rating Duration		
			60 Minutes	90 Minutes	120 Minutes
	W6x12	0.53	0.093	0.118	0.192
	W10x39	0.93	0.076	0.099	0.161
	W10x49	1.01	0.072	0.095	0.154

Table 3. Fire-resistance ratings for HSS Column Y UL 263 listing (fully exposed hollow column).

	HSS Tube Size	A/P	W/D Equivalent	Required DFT (inches) for Fire Rating Duration		
				60 Minutes	90 Minutes	120 Minutes
	3 x 2 x ¼	0.21	0.72	0.149	0.223	0.331
	10 x 10 x ¼	0.23	0.78	0.137	0.209	0.309
	10 x 4 x ⅜	0.34	1.157	0.099	0.162	0.239

required to meet various fire-resistance ratings. The section factor is a ratio that differs based on the style of the steel section and its exposure to fire. An I-beam (or H-beam) section uses the ratio "W/D," while a hollow structural section (HSS) uses "A/P." "W" is the weight of the section (in pounds/foot). "A" is the cross-sectional area of all sides of the HSS (in inches). "D" and "P" both represent the heated perimeter of the section (in inches), or the total square area that would be in contact with fire.

For a fully exposed I-beam (*Table 1*), D is the entire surface area of the section. For a similar section that's in contact with or partially encased by another material (e.g., a steel beam supporting a concrete ceiling/slab above (*Table 2*)), D only includes the surface area of the steel that is not in contact with the other material. The other material serves as a heat sink, which offers some fire resistance itself. For an HSS (*Table 3*), A is the entire surface area of the section, less any areas in contact with heat sinks.

Dividing the weight (W) or area (A) by the heated perimeter (D or P) provides a ratio (W/D or A/P) that represents how quickly the steel heats up in a fire. Converting A/P to W/D enables a direct comparison of I-beam and HSS sections. A larger ratio indicates that the steel section requires less fire protection (or mils of DFT). A smaller ratio means it needs more fire protection. *Tables 1*, *2*, and *3* include a few examples that show how the smaller W/D and A/P ratios at the top require a greater coating DFT, as well as how the DFT requirement increases with longer fire rating durations.

Let's make some direct comparisons to demonstrate why you cannot use W/D and DFT data from one category listing to the next, even when the steel section is the same size. Looking at the W10x39 Beam N size in *Table 2*, the required intumescent coating thickness for a 120-minute fire rating is 161 mils DFT. The same W10x39 Column Y size in *Table 1* has a smaller W/D ratio, which equates to higher DFT requirements. For the same 120-minute rating, the coating must have a DFT of 198 mils, which is 23% greater than the Beam N requirement. While the two sections are the same size, their heated perimeter is much different because Beam N is in contact with concrete on one face.

Moving to a similarly sized HSS column (*Table 3*), the requirements are drastically different, as HSS members usually require significantly higher intumescent coating DFTs due to their structural profile. The A/P ratio has been converted to W/D for comparison. Here, a 10.0 x 10.0 x ¼ HSS Column Y with the same column section factor and a similar size to a W10x39 Column Y (both are 10 inches deep and have a similar weight per foot) requires a 309-mil DFT for a 120-minute fire rating. This is 92% and 56% greater than the W10x39 Beam N and Column Y DFT requirements, respectively.

Why Data Extrapolation Doesn't Work

The available UL 263 data has limitations on the lower and upper ends of steel member sizes because UL has either not tested those sections or has determined they are not able to be protected using intumescent coatings. If a coatings supplier extrapolates data beyond those limits, it runs the risk of recommending a DFT that is either too low or too high. Both scenarios can result in having insufficient fire protection. Still, the UL 263 specification offers some flexibility in specifying coating thicknesses for any size steel sections in between the lower and upper limits.

In its revised fire-resistance rating guidance documents, UL notes that the following scenarios are acceptable:

- Using the minimum listed coating DFT for a specific beam size (specific W/D) on a larger steel section (greater W/D) that has a greater heat sink than the listed steel section
- Substituting a steel member for a heavier weight (greater W/D) section using the same specified coating thickness

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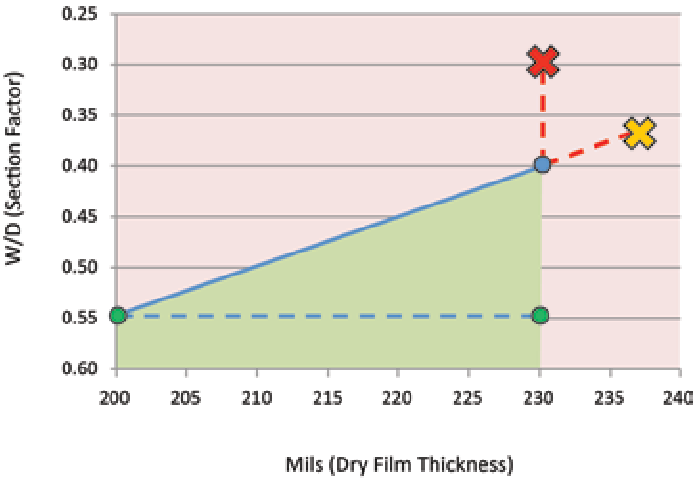

Figure 1. Intumescent Coating DFTs for 120-Minute Fire Rating. The lightest steel section listed in UL 263 has a W/D ratio of 0.40 W/D (blue dot). Use any point on the blue line or within the green area to determine the appropriate DFT for this and larger-sized steel members. Don't extrapolate data in the direction of the red or orange Xs.

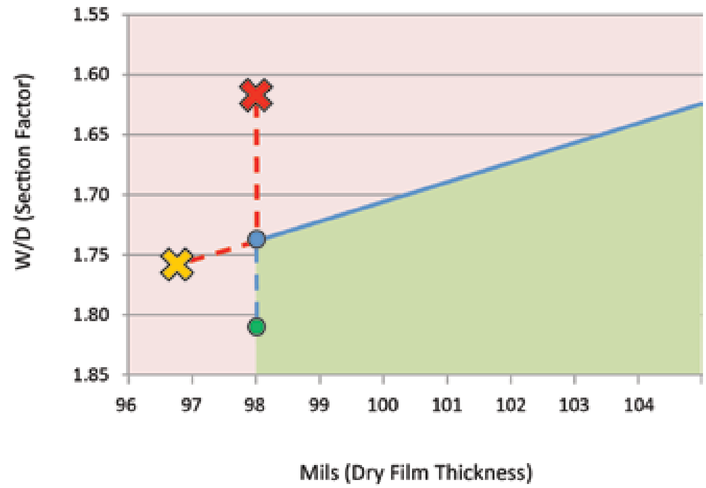

Figure 2. Intumescent Coating DFTs for 120-Minute Fire Rating. The heaviest steel section listed in UL 263 has a W/D ratio of 1.74 (blue dot). Any DFT on the blue line or within the green area is acceptable. It is not acceptable to extrapolate in the direction of the red or orange Xs.

UL also notes that the following scenarios are not acceptable:

- Using a coating DFT specified for a larger steel section to cover a smaller steel section that has a lower W/D than is listed
- Substituting a steel member for a lighter weight (lower W/D) section using the same specified coating DFT

Figures 1 and *2* demonstrate these points. In both diagrams, you need to stay within the green areas and keep out of the red areas when specifying the intumescent coating DFT for a given steel section W/D ratio. Any point on or below the blue lines is OK.

The blue lines represent the maximum allowed data points for steel sections listed in UL 263, based on what UL has tested. In *Figure 1*, the blue line terminates at a W/D ratio of 0.40, as that is the lightest steel listed in UL 263. The graph plots the required coating DFT on the X-axis against the steel section's W/D ratio on the Y-axis. A steel section with a W/D ratio of 0.40 requires a 230-mil DFT (see the blue dot) for a 120-minute fire resistance. A section with a 0.55 W/D ratio requires a minimum DFT of 200 mils (left-hand green dot), but it could be coated up to a 230-mil DFT without worry (right-hand green dot). For either of these sections, the DFT cannot exceed 230 mils because that data is not included in UL's listing. For this reason, specifiers cannot extrapolate the data to a lower W/D ratio (red X) or a higher DFT (orange X). Per UL guidelines, such extrapolation is not acceptable.

The same principle holds true when looking at stronger/heavier steel sections. In *Figure 2*, the W/D ratio of 1.74 (blue dot) is the lowest listed in UL 263. The 120-minute DFT requirement at this ratio is 98 mils. UL permits specifiers to coat sections with a greater W/D ratio – for example, 1.8 (green dot) – with the same minimum 98-mil DFT. However, because UL has not tested sections beyond the 1.74 W/D ratio, it does not permit specifiers to extrapolate a reduced DFT for stronger steel sections (orange X). Also, UL does not allow specifiers to extrapolate data for lighter steel sections (red X). Instead, specifiers must move up the blue line to match a lower W/D ratio with the correct minimum DFT.

Overcoming Data Extrapolation

UL does not condone the practice of extrapolating UL 263 data, and the organization is reminding the industry to avoid the practice. UL published an updated position on the issue in 2014 and added language to the UL 263 specification. Also, UL is scheduled to publish a new best practice guide in 2017 that will include even stronger language against using extrapolated data.

When designing a commercial building, structural engineers and architects may be unaware that they need to avoid using certain steel section sizes that are not tested for passive fire protection using intumescent coatings. The scenario is likely to happen, as building designers often choose steel beams and columns that are as lightweight as possible to save costs, yet UL's published data does not include a range of smaller, as well as larger, steel member sizes. When encountering this situation, engineers and architects need to examine the available UL 263 steel section sizes to come up with a solution. A credible coatings supplier can also assist in finding a safe, proven alternative solution.▪

A Point about Topcoats

After finalizing intumescent coating specifications for a structure, all structural steel members need to be coated with the appropriate material thickness. The coating process can take place off-site in a controlled facility or in the field. Applicators use a wet film gauge – a comb-like gauge with different depth prongs – to confirm the applied wet film thickness (WFT) per the coating manufacturer's guidelines. After curing, applicators can use an electronic gauge to determine the resulting DFT. If it is not sufficient, applicators apply more coating material to reach the specified DFT.

For exposed structural steel, architects often choose to apply a topcoat to intumescent coatings for a more aesthetically pleasing finish. They may also need to cover non-exposed steel sections with a protective coating in areas where durability is a concern, such as areas exposed to weathering or wet/dry cycling. Any cured topcoat added on top of an intumescent coating adds more DFT to the structure. However, because the intumescent coating material has already been built to the proper DFT, this added material does not push a steel section out of UL's specification. Still, it is important to note that a topcoat may eventually need to be recoated. Adding too many layers of topcoat material can create a situation in which the topcoat thickness is too much for the intumescent coating underneath to activate in a fire. The parties involved need to plan carefully to mitigate this situation.