Letter to the Editor

Comments on “The Historical Narrative of the Standard Temperature–Time Heating Curve for Structures” by Gales, et al.

Vytė Babrauskas, Fire Science and Technology Inc, Clarkdale, AZ, USA
and John Jay College of Criminal Justice, New York, NY, USA*

Accepted: 3 August 2021/**Published online:** 23 August 2021

Last year, Law and Bisby [1] published a review of the history of fire resistance test standards which focused on some of the less well known history of early developments in the UK. In a parallel effort, Prof. Gales and his colleagues at York University now provided a valuable review [2] of the history of some early developments in the US. Here I would like to offer some comments on the review by Gales et al. They build on my original efforts at the University of California in the 1970s [3–5] to reconstruct as much as possible of the early history of the development of the ASTM E119 [6] (originally, C19) fire resistance test. The research by Gales et al. will prove to be equally valuable to future researchers, since they ably identified a number of early studies which my research had not uncovered. I commend them for this important addition to the historical understanding of fire resistance testing concepts.

Here, I would like to focus on some of their subjective interpretations, several of which I do not agree with. First, I would like to mention that, when I was doing my research in the mid-1970s, the fire science profession, at least in the US, was in its infancy. As a result, even though we had no internet then and only very primitive (institutional, not personal) computers, the practitioners were infused with tremendous enthusiasm for the potential of the profession. Even though we did not explicitly state this, it was basically felt that, in the space of a few short years, fire resistance testing would become an obsolete anachronism. Practitioners, instead, would use numerical modeling for such purposes. Hindsight, of course, has shown otherwise. In fact, what happened is that two separate tracks emerged. For most buildings, ASTM E119 testing continues to be the basis of what shows

* Correspondence should be addressed to: Vytė Babrauskas, E-mail: vytob@doctorfire.com

up in the architectural plans. And the ASTM E119 test itself is different from its 1970s versions only in tiniest details.

But a separate track did emerge, and it also goes back to work at the University of California Berkeley, this time under the aegis of Prof. Boris Bresler. Already in the early 1970s he was convinced that the fire resistance of structural frames—notably reinforced concrete frames—could be designed by computer-based methods. For that purpose, he and his graduate students developed and released in 1974 two companion programs FIRES-T [7] and FIRES-RC [8]. This was the earliest significantly-developed effort at simultaneously doing two things: (1) Given certain prescribed temperature or heat flux boundary conditions, predict the thermal response of a reinforced concrete (RC) building frame. And, (2) given the thermal response of the frame, predict its structural performance. In other words, numerically compute the fire resistance by computer modeling. Prof. Bresler did not much elaborate on the fire which would constitute the boundary condition to his model, but, developed only slightly later, my COMPF [9] computer program could in fact do that. What would not have been anticipated then, was that during the rest of the 1970s and through the 1980s, Prof. Bresler's concept of providing fire resistance for building by means of thermostructural modeling went into a deep sleep. It was only in the 1990s that fire safety engineers started realizing that thermostructural design for fire resistance purposes is a viable engineering strategy. Today, of course, fire resistance for costly, innovative, non-standard buildings would be provided by exactly such engineering design. In today's language, this falls under the rubric of *performance-based design*. Buildings nowadays designed in this way may include atrium buildings, airport terminals, railway stations, sports arenas, and other high-cost structures where the design is not dominated by a regularly-spaced array of conventional beams and columns.

But the design of the majority of fairly conventional buildings remains rooted in prescriptive fire resistance testing. This is very simple and cost-effective. The architect determines the hourly fire resistance ratings required by the pertinent building code for various structural or separating members of the building. Designs which meet these requirements can then be selected from fire-test compilations or from manufacturers' literature. It is always risky trying to foresee the future, but at the moment, I do not see that this is likely to change in the next few decades. As I see it, there are three main reasons for this:

- (1) The scheme is cost-effective in terms of labor effort. The architect or engineer does not have to expend much effort to produce a compliant design.
- (2) This scheme is cost-effective with regards to product supply. Since only a single, simple variable is involved (hourly rating per the ASTM E119 test), products can be readily tested and catalogued. Establishing a supply chain involving a diversity of potential fire exposures would be significantly costlier.
- (3) The reliability is exceptionally high. It is very rare to come across structures which have failed due to inadequacies of the provided fire resistance. In fact, the scheme is so robust that it may be argued that some of the building code requirements should be reassessed to determine if they could be somewhat reduced, reducing societal costs [10].

Notwithstanding the above traditionally-established reasons why using a standard time–temperature curve is desirable, there have been efforts to the contrary, i.e., proposals why testing to some other time–temperature curve, or some other way of conducting fire-resistance testing might be desirable. The first such effort was, again, by Bresler, who in 1972 [11] proposed a short duration, high intensity (SDHI) curve. Since the 1970s were the first decade with widespread replacement of lignocellulosic materials by their synthetic polymer versions, concern was being raised that such fires could be “hotter.” Tests could indeed be found where such was the case. However, more systematic testing at the National Bureau of Standards (now, NIST) showed that, when averaged over a 1-h time period [12], such short, flashy fires did not at all represent a more rigorous performance criterion. In other words, the standard time–temperature curve, when evaluated over periods of 60 min,¹ or more, remained a conservative strategy. In the US, an alternative curve did eventually arise, emanating from the petrochemical industry. That industry is often faced with fires where equipment is subjected to impingement of high-velocity jets of fuel, which may create a very serious thermal challenge. The upshot was the creation of ASTM E1529 [13] for that industry. This differs from ASTM E119 in that it uses neither the standard time–temperature curve, nor does it control the heating of the furnace by means of thermocouples. Instead, heat flux instrumentation and control are utilized. Consistent with its history, this test is used only petrochemical industry testing, not for testing of normal building elements.

Gales et al. offer two subjective comments on fire resistance testing in their Abstract, and I have to disagree with those. He states that: “*This study identifies that no currently available historical literature can support the definition of the temperature points which describe the standard temperature–time heating curve.*” This conclusion, I believe, is not consistent with the history of the test method development. As I showed in my paper [Ref. [5], Fig. 4], the standard time–temperature curve is generally an upper-envelope curve to then-existing data, although not an absolute worst-case envelope. Gales et al., instead, illustrate this relationship by means of their Fig. 8. This I would consider to be misleading. There is a profusion of data points, but only from one test series, the 1896–1897 tests in New York City. It is notable that Gales et al. themselves then comment that this particular set of tests was alleged to be perfused with corruption, hardly the best basis for establishing benchmarks. By contrast, the graph I show compiles some 9 different test programs, including the one from NYC, which can be seen to be problematical. Furthermore, we can ask: What is being simulated here? In a narrow sense, thermal exposures in one furnace are being simulated in others. But the more relevant physics is that many of the early tests were conducted by manually stoking wood fires. This has a strong similitude to combustibles burning in a room fire, and the similitude was borne out initially by the work of Ingberg [14] and much later by Fang and Breese [12].

¹ Some countries use 30-min and other rating intervals shorter than 60-min. However, the rationale for those requirements is to provide a modest risk reduction over not having any fire resistance. It is not seen as a representation of the duration of short fires.

Perhaps most problematical is Gales et al.'s conclusion that "*This reinforces contemporary discussion that the heating curve lacks scientific basis in its representation of a real fire.*" My conclusion is the opposite. Over the decades, there has been a great deal of scientific research confirming that the *temperatures* on the ASTM E119 time–temperature curve describe a well-justified, near-upper-bound to experimental data.

Neither I, nor Law and Bisby [1], nor Gales et al., however, have presented clearly enough the rationale for the *time* component of the standard curve, i.e., how long should the test be continued? For the benefit of both novices and practitioners, this ought to be stated clearly, which I will endeavor to do here. While the temperature component of the curve is based on a conservative limit to room fires, the duration has no relation to any fire physics whatsoever. Instead, it represents a very early expression of a *risk* concept. This has continued to the present day. Building codes typically require columns, for example, to possess longer duration fire resistance ratings than partitions, due to the differences in risk of a column collapsing, versus a partition. A failing column might entail multiple storeys of a building collapsing. Meanwhile, the outcome of a partition collapse is likely to be much more limited in scope. While Sachs' proposal of 1903 [15] did not become the basis for subsequent UK or US testing, interestingly it can be viewed as a risk-based scheme, given how it established classes for 'temporary,' 'partial,' and 'full' protection. It is clear that, in this respect, both Sachs' scheme and the requirements of modern building codes use a very casual concept of risk, not based on any quantification thereof, nonetheless, they are risk concepts.

With regards to the latter, it bears emphasis that Ingberg [14] and some of his successors [16] *proposed* that the required duration of time during which the ASTM E119 criteria continued to be met should be related to test results interpreted in light of surveys of fuel loads of rooms of various types. But this notion was *never accepted* by any US building codes, even though his work was very well known to the building code community. This indicates that the building codes consider that a risk-based categorization for the required rating periods remains appropriate. In my view, this is reasonable, since the overwhelming portion of building fires are terminated by fire service intervention, not by burnout. Thus, a remote danger of collapse would only potentially exist for rare cases of fire service unavailability or ineffectiveness. And, for such cases, it seem appropriate to focus solely on categorizing the risk of collapse.

Gales et al. have hopes that more practitioners should participate in the ASTM standardization process, and that this would result in substantive, positive changes being made to ASTM E119. I am afraid that in this, he is much more sanguine than I am. Many things are possible, but having participated in that process since 1973, I do not see any obvious trends that would suggest that changes of philosophy are immanent. But more important, I do not see that the profession has a need for substantive changes to be made to ASTM E119. The alternative—performance-based design—is today readily used by designers in cases where this is more appropriate.

Another point Gales et al. raise is whether there should be a cool-down phase to the heating curve, since some constructions may fail during cool-down. Over the years, many smart structural engineering students have pointed out that classroom problems can be created where the structure performs acceptably during the heating period, then precipitously collapses during cool-down. My view, however, is that this is a non-problem, for two reasons: (1) Real-fire experience does not indicate this is a problem, assuming we are not dealing with 1880s facades made of wrought iron. (2) Such a view represents a misunderstanding of the meaning of the fire rating period. Fire-rated assemblies are only rated for a specified time period, and it is fully-well accepted that they may collapse after that time period. The fire resistance concept, after all, is intended to offer a useful measure of safety, not an absolute guarantee against collapse.

Finally, I point to some minor issues, which it might help to clarify. Gales et al. cite the 1927 study by UL as noting that real-fire temperatures had not been adequately studied up until that time. What is missing is the connection that Ingberg’s landmark study [14] which accomplished precisely that came barely one year later, in 1928.

Gales et al. cite as an example of more modern fire safety engineering the use of Parametric heating curves offered by the Eurocodes. While no doubt some designers work with these, in the US it is much more common for designers to use FDS [17] as the fire model and one of a number of commercially-available software packages for performing finite-element analysis to represent the thermostructural response of the structure.

Let me recapitulate. Testing products under standard ASTM E119 conditions is a suitable strategy for most situations, although not for all. For situations where a different fire exposure is needed, the viable strategy is not to petition ASTM to make revisions to E119. Instead, designers use FDS + ANSYS (or the desired models of their choice) to adequately treat the peculiarities of their particular design problem. And, if I may be permitted to speculate about the future, one change that I can foresee is that computer-modeling-based designs will gradually become less costly and, consequently, more structures will be getting designed on a performance basis.

References

1. Law A, Bisby L (2020) The rise and rise of fire resistance. *Fire Saf J* 116:103–118
2. Gales J, Chorlton B, Jeanneret C (2021) The historical narrative of the standard temperature-time heating curve for structures. *Fire Technol* 57:529–558
3. Babrauskas V (1976) Fire endurance in buildings. Ph.D. Dissertation, University of California, Berkeley
4. Babrauskas V, Williamson RB (1978) The historical basis of fire resistance testing, part I. *Fire Technol* 14:184–194, 205
5. Babrauskas V, Williamson RB (1978) The historical basis of fire resistance testing, part II. *Fire Technol* 14:304–316
6. Standard Test Methods for Fire Tests of Building Construction and Materials (ASTM E119), ASTM

7. Becker J, Bizri H, Bresler B (1974) FIRES-T: a computer program for the fire response of structures—thermal (UCB FRG-74-1). University of California, Berkeley
8. Becker JM, Bresler B (1974) FIRES-RC—a computer program for the fire response of structures—reinforced concrete Frames (UCB FRG 74-3). University of California, Berkeley
9. Babrauskas V (1975) COMPF: a program for calculating post-flashover fire temperatures (UCB FRG 75-2), Fire Research Group. University of California, Berkeley
10. Babrauskas V (2013) Some neglected areas in fire safety engineering. *Fire Sci Technol* (Tokyo) 32(1):35–48
11. Bresler B (1972) Reinforced concrete column response to fire. Discussion No. 9. In: International conference on planning and design of tall buildings, vol 1B, Bethlehem PA, pp 723–726
12. Fang JB, Breese JN (1980) Fire development in residential basement rooms (NBSIR 80-2120), [U.S.] Natl. Bur. Stand., Gaithersburg MD
13. Standard Test Methods for Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies (ASTM E1529), ASTM
14. Ingberg SH (1928) Tests of the severity of building fires. *Q NFPA* 22(3):43–61
15. Sachs EO (1903) Standards of fire resistance (On Behalf of the Executive of the British Fire Prevention Committee). In: The official congress report—first international fire prevention congress. Public Health Engineer, London, pp 166–168
16. Robertson AF, Gross D (1970) Fire load, fire severity, and fire endurance. In: Fire test performance (ASTM STP 464), ASTM, Philadelphia, pp 3–29
17. McGrattan K, Hostikka S, Floyd J, McDermott R, Vanella M (2020) Fire dynamics simulator user's guide, 6th edn. (SP 1019), NIST, Gaithersburg MD