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Fire resistance of 19th century fireproof flooring systems: A sensitivity analysis

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HIGHLIGHTS

- Evaluation of fire resistance of 19th century fireproof systems.
- Comprehensive data of high temperature thermal and mechanical properties.
- Sensitivity of fire performance to material property uncertainties.
- High temperature material property models for 19th century fireproof systems.

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ABSTRACT

Typical fireproof flooring systems of the 19th century comprise of metal beams embedded within insulation materials that span between them, sometimes in the form of arches. The limited or non-existent fire resistance requirement of that era demands a thorough understanding of their structural fire response when dealing with their conservation. This requires suitable material property models. Historical records from different sources contain large variations in the thermal (insulation and metals) and mechanical (for metals) properties of the materials. In this research, the variations were placed within lower and upper boundary curves. A sensitivity study of the thermal behaviour of typical flooring systems was conducted. The results of this study were used to indicate the level of uncertainty in the thermal properties of the metals (cast iron, wrought iron and mild steel) and the "insulation" materials ("early concrete" and masonry) that may be tolerated without introducing large inaccuracy (>10%) in the structural temperature results. To assess the applicability of the proposed boundary curves for the mechanical properties of the metals, the second series of sensitivity analyses of structural performance was performed, using the temperature profiles from the thermal sensitivity study.

1. Introduction

In typical 19th century fireproof flooring systems, metal beams (made out of cast iron, wrought iron or mild steel) were used as the main load-bearing elements. To provide the necessary fire protection, a common practice was to encase the metal members of the floor with insulation materials ("early concrete" or masonry). It should be noted that "early concrete" was made from various constituents (broken brick, crushed tile, cinders, limestone etc.) different from those in modern concrete production. The two predominant types of such flooring systems are the "filler joist" (Fig. 1a) and the "arch jack" (Fig. 1b) floors. In a typical "filler joist", wrought iron or mild steel girders are completely encased in "early concrete". The "arch jack" floor commonly consists of asymmetric cast iron girders embedded in "early concrete" and masonry in an arch form supported by the lower flanges of the metal beams which remain unprotected.

In order to investigate the behaviour of 19th century fireproof flooring systems under fire exposure and evaluate their fire resistance, it is critical to establish the thermal and mechanical properties of the constituent materials (metal beam and insulation) at elevated temperatures. The authors [2] have recently presented the results of a thorough literature review which has yielded an extensive experimental database of the required thermal and mechanical properties. The collected results showed that considerable scatter existed in some cases. However, it can be argued that if the structural performance of the metal beams is not sensitive to the scatter, it would be acceptable to use some nominal (such as the mean) values for the material properties. Whether or not this is the case can be answered by performing a sensitivity study

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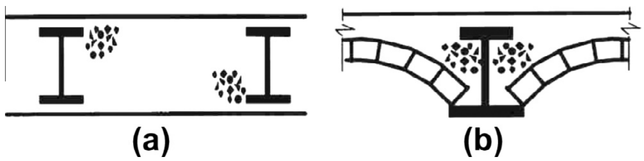

Fig. 1. Typical (a) "Filler joist" and (b) "Arch jack" floor [1].

and this is the overall aim of the this paper. Specifically, this research will investigate the sensitivity of the fire resistance performance of the metal beams to variations in the following relevant material properties:

(1) Thermal properties (thermal conductivity, thermal capacitance = specific heat $*$ density) of the metals.
(2) Thermal properties of the insulation materials.
(3) Mechanical properties of the metals.

The variations in the relevant properties collected from literature by the authors [2] are represented by the lower bound and upper bound values fitted to the collected data. These boundary curves (usually straight lines) provide an envelope to the collected experimental data. Because the collected data were from different sources, some dating back a long time ago, they do not always follow a consistent pattern. Hence some boundary curves contain spikes within some specific temperature regions.

The criteria for deciding sensitivity of the fire resistance performance results to variations in the material properties are: for the thermal properties, the fire performance of the metal beams is considered not sensitive to the variations of the properties if the calculated structural temperature does not vary by more than 10% from the mean value; for the mechanical properties of the metals, the fire performance of the metal beams is considered not sensitive to the properties if the load carrying capacity of the metal beam does not vary by more than 10% from the mean value.

2. Lower and upper bound values of relevant material properties

2.1. Metals

2.1.1. Thermal properties

Fig. 2a shows the relevant graphs for thermal conductivity, while Fig. 2b is for specific heat. The respective expressions for modern steel, as given in EN1993-1-2 [3], are also included for comparison. It should be noted that the thermal conductivity data for wrought iron and mild steel have negligible scatter so they are described by single "average" curves in Fig. 2a. The equations for these boundary curves are presented in Table 1.

2.2. Mechanical properties

Table 2 presents the lower and upper bound equations for the mechanical properties of cast iron, wrought iron and mild steel. These equations are plotted in Fig. 3. For comparison, the data for carbon steel in EN 1993-1-2 [3] are also presented in the figures.

2.3. Insulation materials

The role of the insulating materials is to limit the temperature increase of the load-bearing metal elements [2]. For this reason, determining the thermal properties (thermal conductivity and specific heat) of these materials at elevated temperatures is of the utmost importance. Fig. 4 shows relevant plots of the derived lower and upper bound curves based on the collated data by the authors [2]. The mathematical expressions for these boundary curves are given in Table 1.

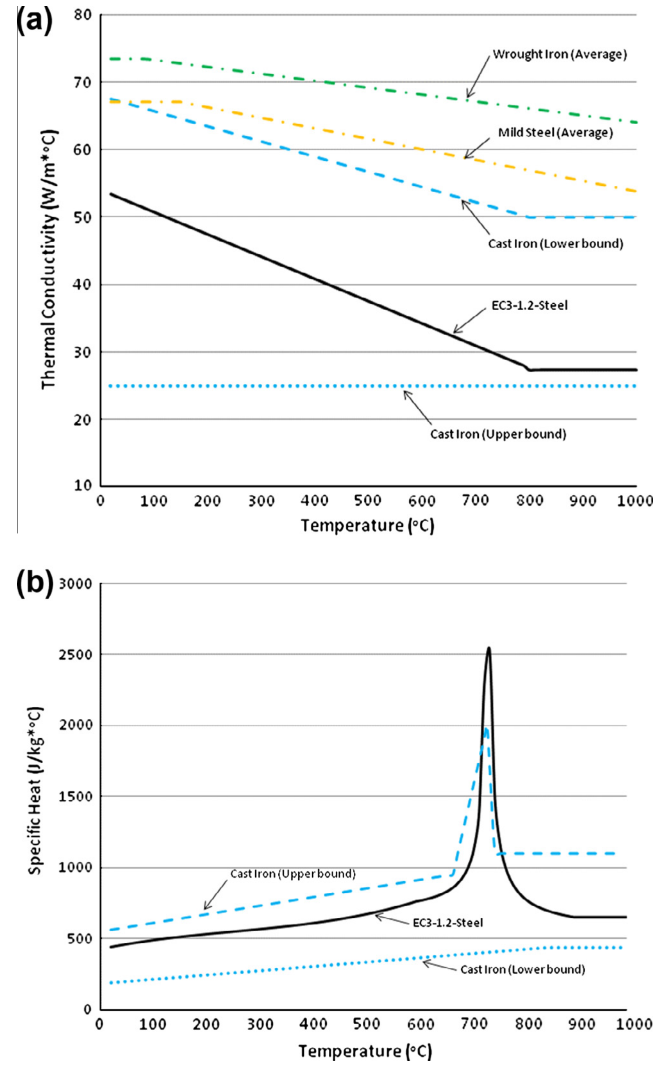

Fig. 2. Variations of: (a) thermal conductivity and (b) specific heat with temperature for the metals of 19th century fireproof floors.

2.4. Masonry

The data presented in the previous section include those for masonry units and for mortar. However, masonry construction is made of both masonry units and mortar. Therefore, it is necessary to combine the results for masonry units and for mortar to obtain those for masonry construction.

2.4.1. Thermal conductivity

The experimental data collated by the authors [2] suggest that the thermal conductivities of mortar and bricks vary in a similar pattern, with the exception of temperatures ranging from 400 °C to 800 °C, in which mortars display a drop in thermal conductivity [2]. For heavyweight bricks, the measured values show minor differences. Furthermore, according to Brown and Wilson [4], the thermal conductivities of masonry walls and bricks tend to be almost identical for brick units with densities of 1600–2200 kg/m^3. Therefore, the thermal conductivity of masonry walls at elevated can be sufficiently described by that of the brick unit.