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# Thermal and mechanical properties of 19th century fireproof flooring systems at elevated temperatures

C. Maraveas, Y.C. Wang *, T. Swailes

*School of Mechanical, Aerospace and Civil Engineering, The University of Manchester, Manchester M13 9PL, UK*

## HIGHLIGHTS

- Comprehensive collection of thermal and mechanical properties for 19th century fireproof flooring systems.
- Correlation of thermal and mechanical properties with values in Eurocodes for modern materials.
- Proposal of safe values for use in fire resistance assessment.

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## ABSTRACT

Two types of fireproof flooring systems commonly encountered in the 19th century are the "jack arch floor" and "the filler joist floor". A proper evaluation of their fire resistance requires reliable information of the thermal and mechanical properties of their construction materials, namely cast iron, wrought iron, mild steel, "early" concrete and masonry, at elevated temperatures. This paper collates temperature-dependent thermal (i.e., thermal conductivity and specific heat) and mechanical properties (i.e., yield strength, tensile or compressive strength, Young's elastic modulus and thermal expansion) of the metals as well as the temperature dependent thermal properties of the "insulation" from literature. The collated data are then compared with Eurocode's mathematical expressions for contemporary materials to assess the applicability of the Eurocode expressions for the 19th century fireproof flooring systems.



## 1. Introduction

For preservation of historic 19th century buildings, an understanding of their constructional material properties at elevated temperatures is required so that they can be demonstrated to possess sufficient fire resistance in their new uses. The flooring systems of such historical structures consist of wrought iron/cast iron/mild steel embedded within early concrete or masonry.

Wrought iron, cast iron and mild steel (which will be referred to as metals in this paper) are the main load-bearing elements so it is clearly important that their mechanical properties, including thermal expansion, at elevated temperatures be determined with good accuracy. However, it should be borne in mind that the varying and often primitive manufacturing processes compared to the modern steel making process means that there will inevitably be many uncertainties with regard to their chemical compositions and geometrical dimensions. Furthermore, these are specialist structures. A lack of interest from the mainstream construction industry means that there is no detailed and systematic study to provide a comprehensive database of their mechanical properties to allow the effects of different influential parameters to be fully appreciated. The purpose of this research is to conduct an exhaustive search through open literature to obtain their mechanical properties from different sources and to identify the main parameters that have profound effects on them. Comparison with modern steel (whose properties can be obtained from relevant expressions given in the Eurocode) will be made.

Their thermal properties consist of thermal conductivity and thermal capacitance (the product of density and specific heat). The thermal conductivity of these materials will be similar to that of normal carbon steel and is expected to have a high value. Such a high thermal conductivity allows the so-called lumped mass assumption to be made so that the material can be assumed to have uniform temperature distribution when exposed to fire. It is expected that this assumption will hold true regardless of the thermal conductivity value used.

* Corresponding author.
*E-mail address:* yong.wang@manchester.ac.uk (Y.C. Wang).

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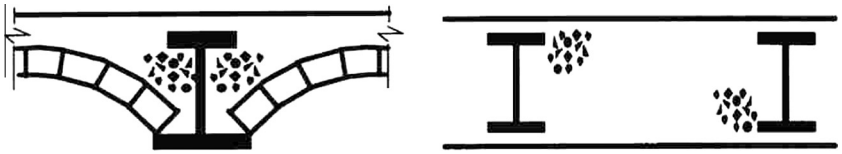

**Fig. 1.** "Arch jack" floor (left) and "filler joist" construction (right) [1].

**Table 1**
Experimental data referring to the thermal properties of cast iron.

| Source | Properties provided | Specific materials |
|---|---|---|
| Angus [2] | Thermal conductivity<br>Specific heat | High carbon iron, blackheart malleable, whiteheart malleable, pure iron<br>White iron, grey iron, pure iron, high and low phosphorus iron |
| Holmgen [3] | Thermal conductivity | Cast irons with different graphite morphology (flake, nodular, compacted irons) |
| Donaldson [4] | Thermal conductivity | Various cast irons, including blackheart malleable and whiteheart malleable |

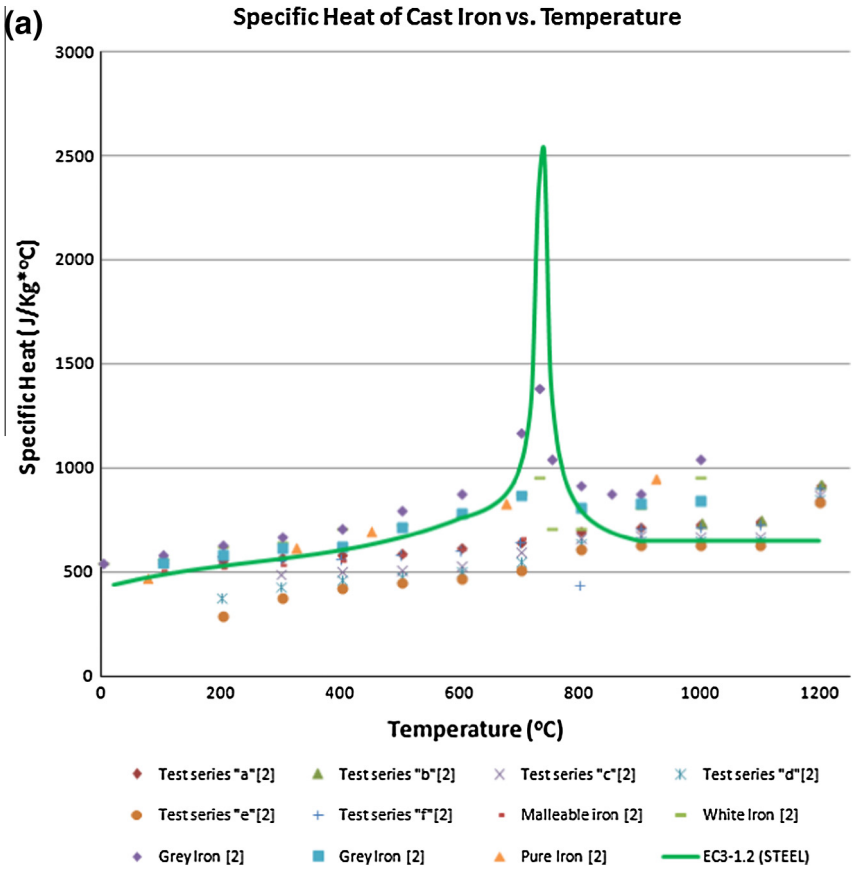


**Fig. 2.** Variations of specific heat (plot a) and thermal conductivity (plot b) of cast iron with temperature.

On the other hand, the thermal properties of the "insulating" materials will play a critical role in affecting the fire resistance of the 19th century building structures through influencing the temperatures of the load-bearing elements. This paper will also report the results collated from literature regarding the variation of thermal conductivity and specific heat of the "insulating" materials. Comparison with the properties of contemporary materials will also be made.

## 2. Fireproof flooring systems of the 19th century buildings

The concept of fireproof flooring is linked with encasing the fire-susceptible structural element (metal) within fire-resistant materials (concrete or masonry). In 19th century construction, two types of fireproof flooring systems are typically encountered. In the first type, the "jack arch floor", asymmetrical cast iron beams were encased in "early concrete" underlain by masonry (Fig. 1, left). The bottom flange would not be encased and would serve as support for the overlaying masonry. The second type, called "filler joist", involved pouring the "early concrete" slab in such a way that the beams were completely embedded (Fig. 1, right). In the "filler joist" construction, however, the beams were made out of wrought iron or mild steel and rarely out of cast iron. In certain cases, the soffit of the cast floor was level with the lower flange of the beam which was, therefore, unprotected. The term "early concrete" mentioned above refers to concrete made with various