THERMAL CONDUCTIVITY OF GYPSUM AT HIGH TEMPERATURES

A Combined Experimental and Numerical Approach

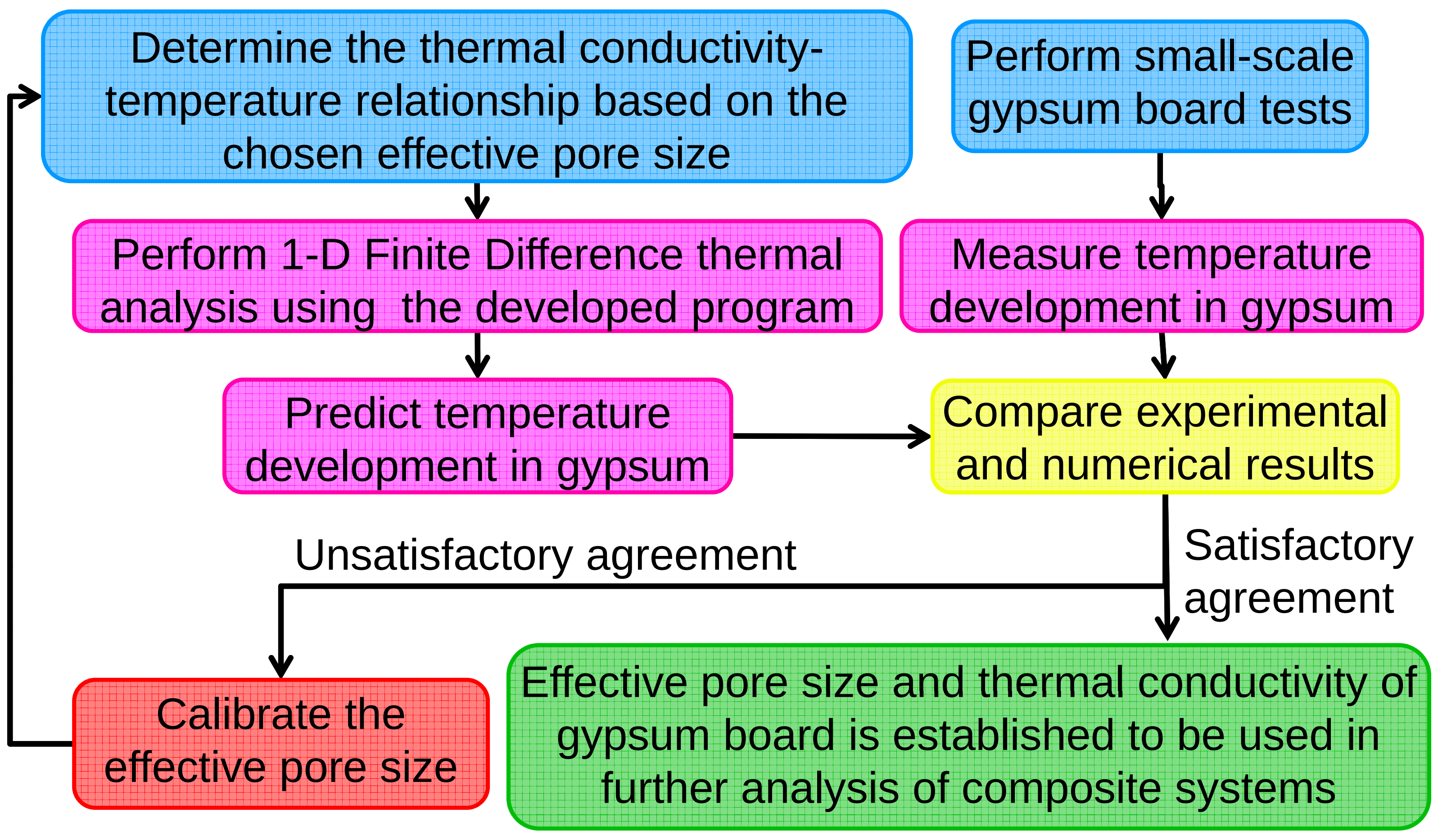
IMA RAHMANIAN[a], **YONG WANG**[a]

[a] School of Mechanical, Aerospace and Civil Engineering, The University of Manchester, UK

1. Introduction

Gypsum board based systems obtain their fire resistance through the low thermal conductivity and evaporation of water content of gypsum, which delays the temperature rise through the system.

Thermal properties of gypsum are temperature-dependent. Among them, thermal conductivity has a critical influence, yet there is a wide difference in reported values in literature (*Fig. 1*). Given the effects of porosity, non-homogeneity and moisture in gypsum, direct experimental measurement of thermal conductivity of gypsum at high temperatures is not an easy task. As an alternative, proposed here is a hybrid numerical and experimental method to extract thermal conductivity of gypsum, as summarised in the chart below.



Determine the thermal conductivity-temperature relationship based on the chosen effective pore size

Perform small-scale gypsum board tests

Perform 1-D Finite Difference thermal analysis using the developed program

Measure temperature development in gypsum

Predict temperature development in gypsum

Compare experimental and numerical results

Unsatisfactory agreement

Satisfactory agreement

Calibrate the effective pore size

Effective pore size and thermal conductivity of gypsum board is established to be used in further analysis of composite systems

2. Thermal Conductivity – Temperature Relationship

Being a porous material, heat transfer through gypsum is a combination of conduction through the solid and convection and radiation through the pores. The effective thermal conductivity of gypsum may be calculated using the following equation [1]:

$$k^* = k_s \frac{k_g \varepsilon^{\frac{2}{3}} + (1-\varepsilon^{\frac{2}{3}})k_s}{k_g(\varepsilon^{\frac{2}{3}} - \varepsilon) + (1-\varepsilon^{\frac{2}{3}} + \varepsilon)k_s} \quad (1)$$

Where k^* is the effective thermal conductivity of gypsum
k_s is the thermal conductivity of the solid
ε is the porosity of the material
k_g is effective thermal conductivity of gas to account for heat transfer in the pores

$$k_g = 4.815\times10^{-4}T^{0.717} + \frac{2}{3}\times 4d_e\sigma T^3 \quad (2)$$

T is absolute temperature
d_e is the effective diameter of the pores

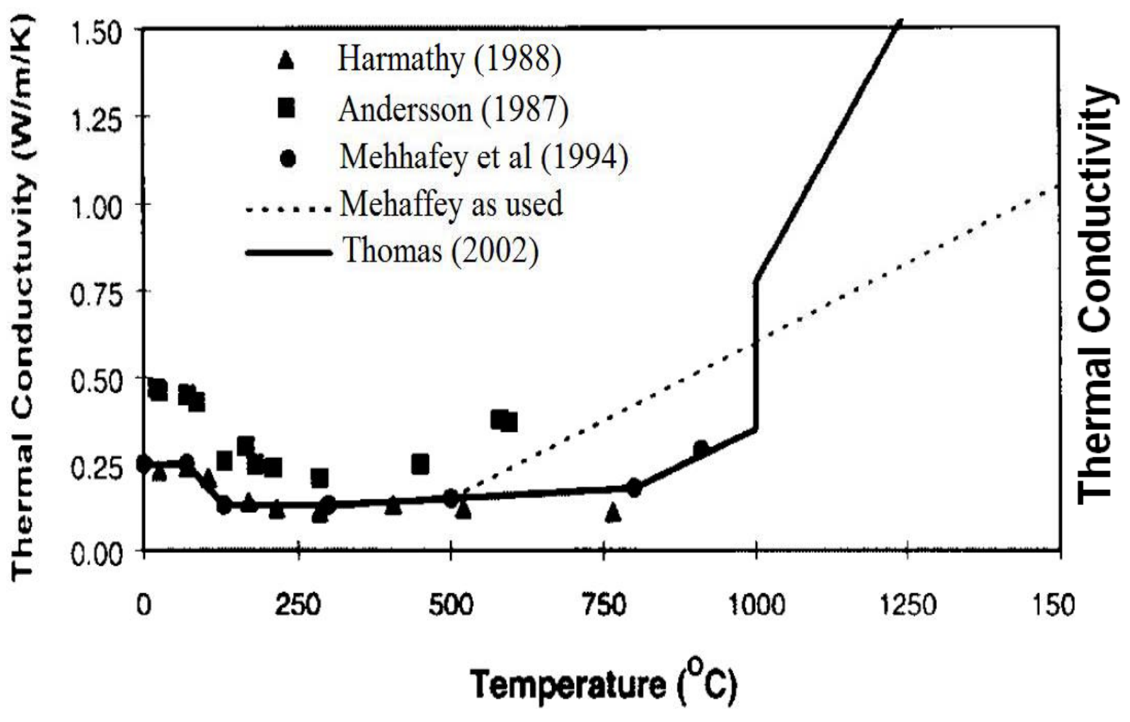


Fig. 1. Thermal conductivity of gypsum as reported by various researchers [2]

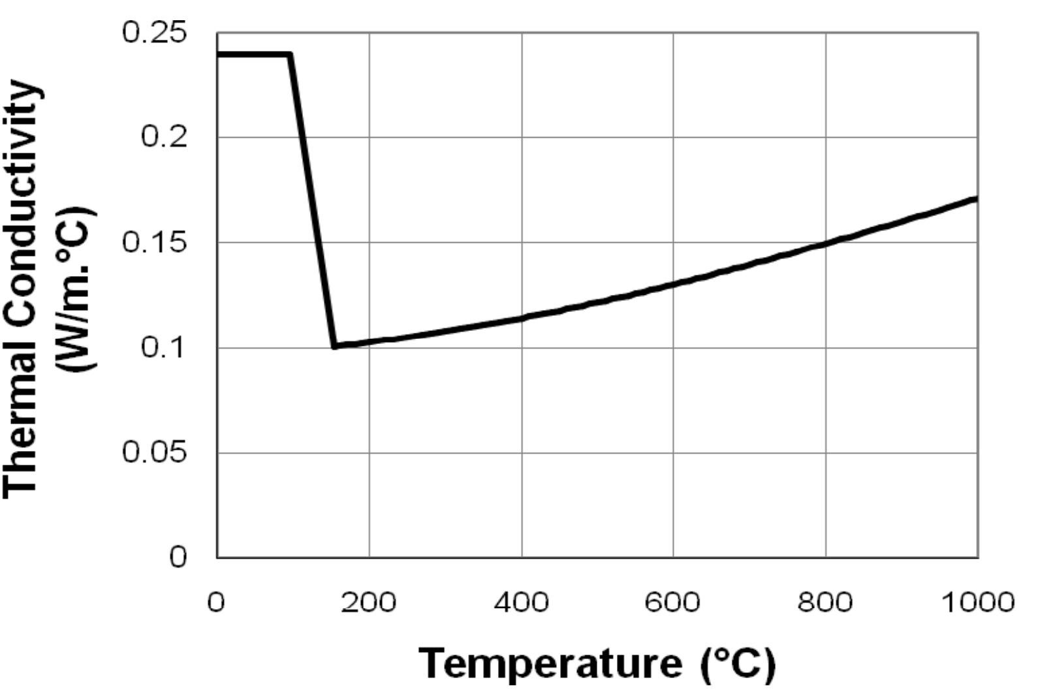


Fig. 2. Effective thermal conductivity of gypsum as used in this study

Hence, the effective thermal conductivity-temperature relationship consists of three parts as demonstrated in *Fig. 2*: 1) Constant thermal conductivity up to 95°C before water evaporation, equal to that at ambient temperature reported by the manufacturer; 2) Linear reduction of conductivity up to 155°C due to evaporation of water; 3) Non-linear increase in thermal conductivity based on equations 1 and 2.

3. Test Results

Some small-scale experiments have been performed on gypsum board panels of two different types; *Gyproc Fireline* and *Gyproc Wallboard* plasterboards, *British Gypsum* products. 400x400mm specimens were placed horizontally on top of an electric kiln so that one side of the panel was subjected to elevated kiln temperature and the other side faced up to room temperature (*Fig. 3). Fig. 4* shows the heating curve achieved in the kiln as compared to a standard fire [3].

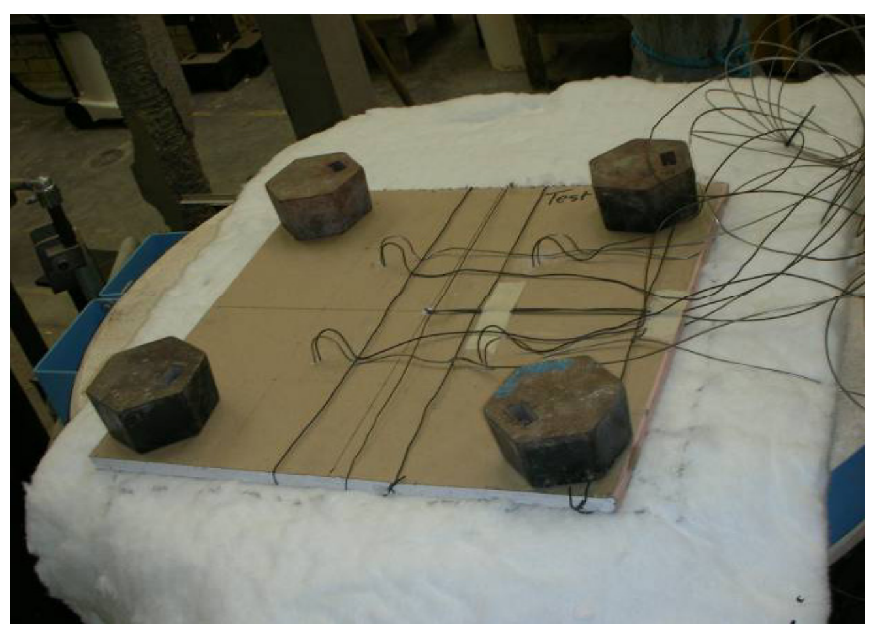


Fig. 3. Typical set-up for the small-scale fire tests

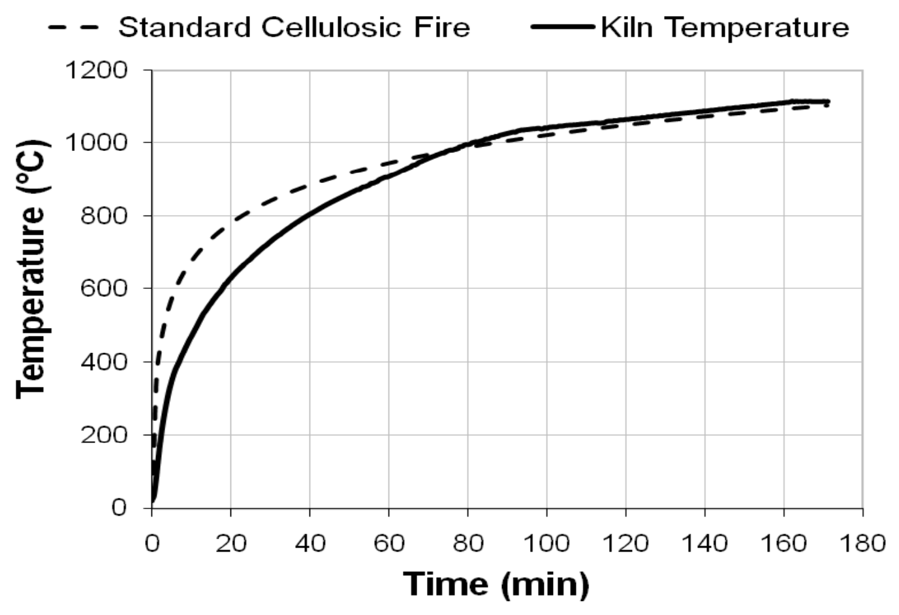


Fig. 4. Time-temperature curve for the kiln against standard cellulosic fire curve

In *Figs. 5* to *8*, the temperature histories measured from the tests and calculated by the program using pore size of 1mm are compared. Also plotted in these figures are the numerical results utilizing thermal conductivity of gypsum as used by Mehaffey *et al* [4] .

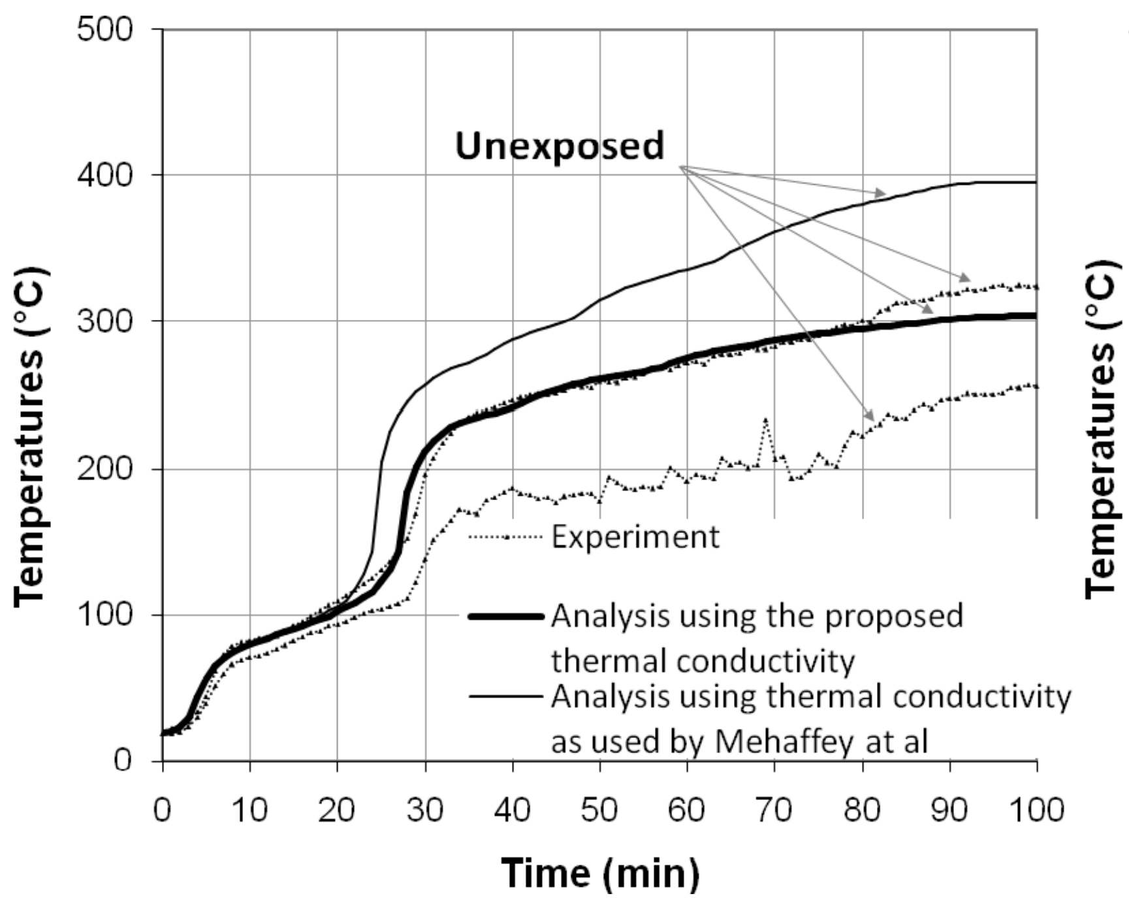


Fig. 5. Temperature history for 12.5mm Fireline gypsum panel

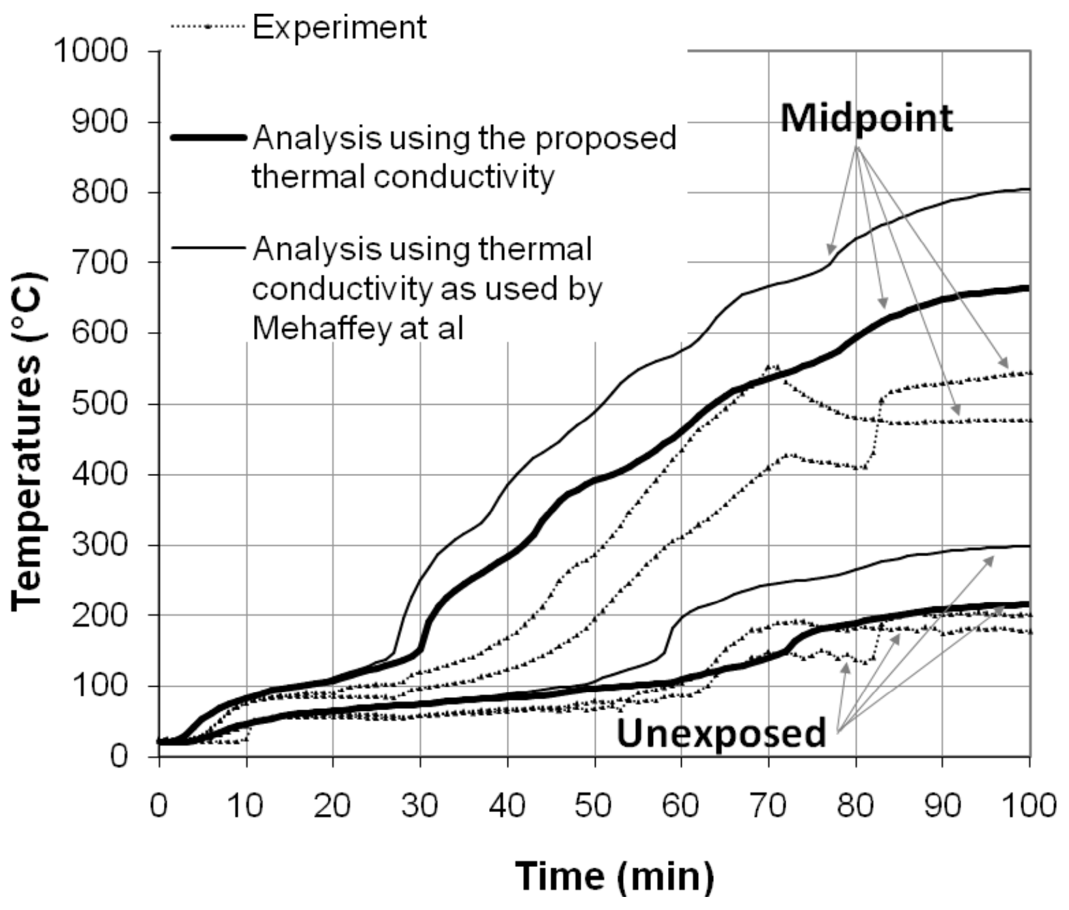


Fig.6. Temperature history for 25mm Fireline gypsum panel

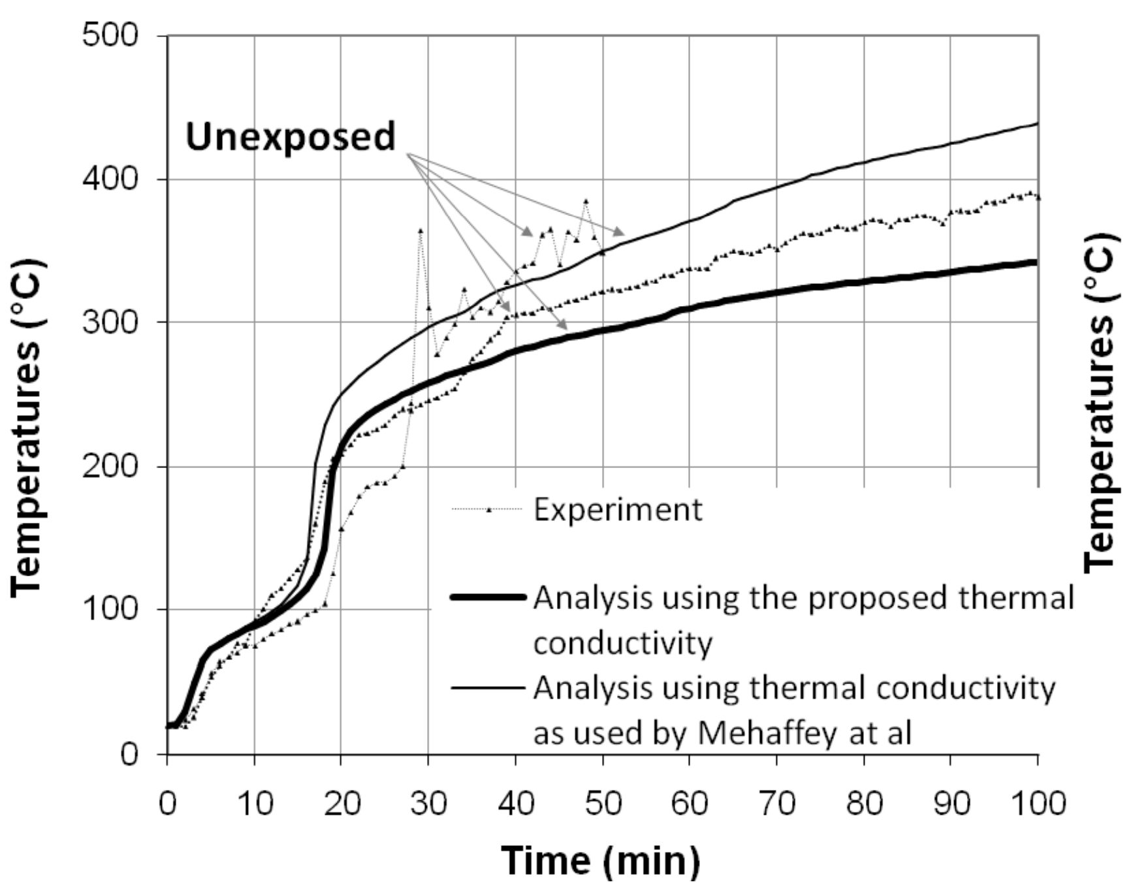


Fig. 7. Temperature history for 9.5mm Wallboard gypsum panel

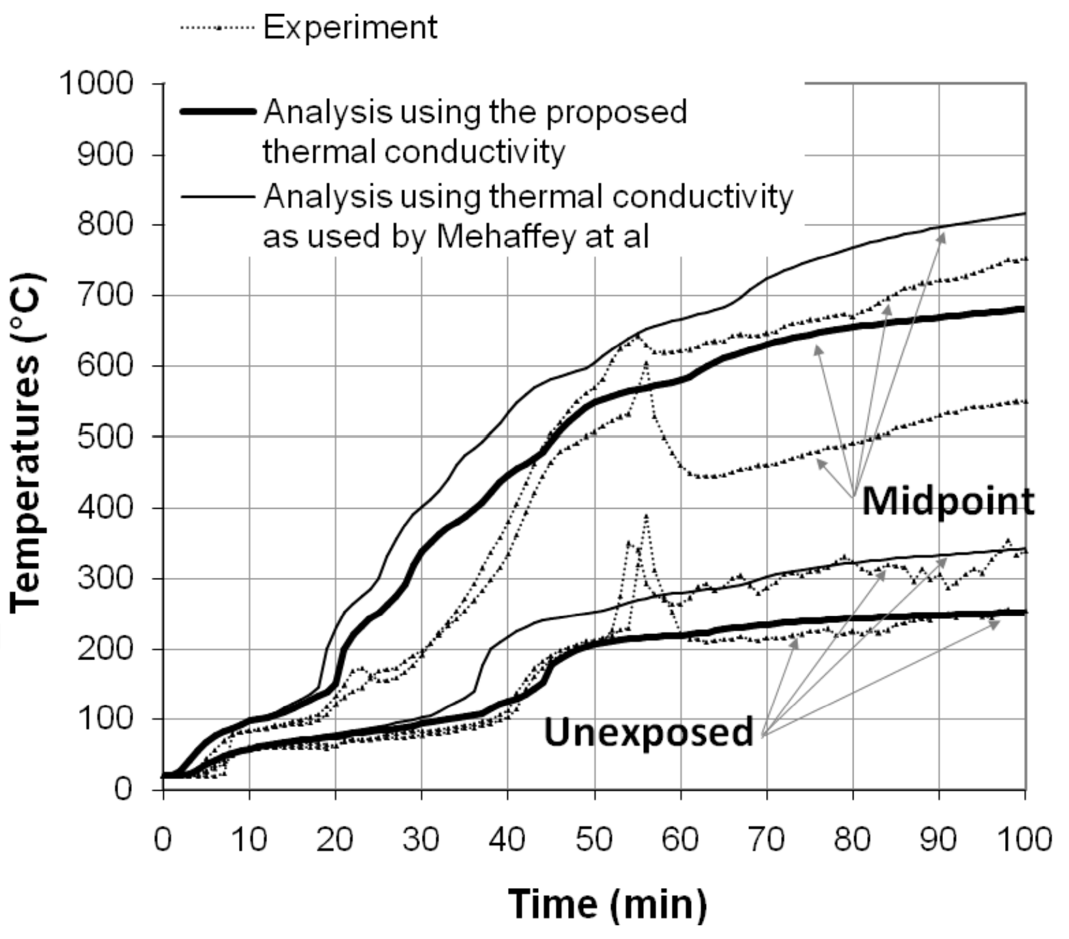


Fig. 8. Temperature history for 19mm Wallboard gypsum panel

4. Conclusions

This paper has presented a hybrid method to determine the effective thermal conductivity of gypsum at high temperatures, based on using small-scale experimental results and a thermal conductivity model which includes the effects of radiation in voids. Despite the simplicity of the method, the results are in good agreement with test measurements and show great improvement when compared to those produced using thermal conductivity values reported in literature.

5. Acknowledgement

The authors would like to thank British Gypsum for their financial support and Drs. Kane Ironside and Jan Rideout for their interest and technical support. The technical assistance by the laboratory staff at the University of Manchester is greatly appreciated.

References

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International Conference Applications of Structural Fire Engineering

Prague 2009