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Numerical calculations of vapour pressure in concrete exposed to fire

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The paper presents a simple method of calculating vapour pressure developed in concrete when exposed to fire. Compared with other models reported in literature (see for example, reference [6] as cited in the paper,^{10–14}) the advantage of the presented method is its simplicity. For a complicated problem, adequate simplification is necessary and is essential for solving the problem efficiently.

The method presented in the paper was developed based on the conservation of energy and mass for heat and water vapour. Equation (1) for the heat transfer may be acceptable, provided that the coefficients of specific heat and conductivity are not for the ‘dried concrete’ but have been modified by taking into account the energy consumption during phase exchanges and the convection owing to moisture flow. The correct form of equation (1) should be as follows because k is temperature dependent

$$\frac{\partial T}{\partial t} = \frac{1}{\rho c} \nabla \cdot (k \nabla T) \quad (\text{A1})$$

The focus of this discussion, however, is mass transfer rather than heat transfer. It is well known that there are two mechanisms for the transfer of water vapour in

concrete. One is diffusion owing to mass gradient and the other is convection owing to pressure gradient. In addition, water vapour is generated from the vaporisation of liquid water when temperature becomes high. Equation (10) was derived based only on diffusion. This is clearly not right. It has been demonstrated that the mass transfer owing to convection is even more important than that owing to diffusion.^{10–14}

The inaccuracy of equation (10) can be easily explained by the example used in the paper. For a fixed temperature of 500°C on the fire surface, the density of water vapour on the fire surface can be calculated as follows

$$w \Big|_{x=0} = w_o = \frac{Mp}{RT} = \frac{0.018 \times 10^5}{8.314 \times (273 + 500)} = 0.28 \text{ kg/m}^3 \quad (\text{A2})$$

Assume that the wall is thick enough and the temperature on the other side of the wall remains unchanged. Therefore, the density of water vapour on the other side can be obtained by

$$w \Big|_{x=L} = w_L = \frac{Mp}{RT} = \frac{0.018 \times 10^5}{8.314 \times (273 + 20)} = 0.74 \text{ kg/m}^3 \quad (\text{A3})$$

The solution of equation (10) with boundary conditions of equation (A2), equation (A3) can be expressed as follows

$$\frac{w(t, x) - w_L}{w_o - w_L} = 1 - \operatorname{erf} \left(\frac{x}{2\sqrt{D_o t}} \right) \quad (\text{A4})$$

The above solution shows that $w(t, x)$ decreases with time and is independent of temperature and vapour pressure. Moreover, if the fire surface is sealed there is no movement of water vapour. Therefore the vapour pressure distribution will be exactly the same as the temperature distribution. These features contradict the findings of experiments and other models.^{10–14}

Also, the temperature distribution profile given in Fig. 5(a) is rather strange. It is surprising that the temperature still remains unchanged at 35 mm away from the fire surface after 1 h exposure. Design charts prepared by Institution of Structural Engineers and Concrete Society¹⁵ indicate that temperatures should be in the order of 200–300°C. On the other hand, the vapour pressure shown in Fig. 5(b) at 20 mm away from the fire surface for 1 h exposure is incredibly high (about 1.5 MPa) although the temperature there is only 75°C.

It is not known how such high vapour pressures are obtained in the model, since there was no vapour generation and the water vapour decreases with time as is

demonstrated by equation (A4). As the vapour pressure was assumed to be linearly proportional to the product of water vapour density and temperature (see equation (5)), and assuming water vapour does not decrease, the increase of temperature from 20°C to 250°C can only increase the vapour pressure by about 1.8 times, that is, $(250 + 273)/(20 + 273)$. Therefore it is unlikely that the peak pressure can reach the order of 1–2 MPa if the initial vapour pressure is 0.1 MPa.

References

10. ABDEL-RAHMAN A. K. and AHMED G. N. Computational heat and mass transport in concrete walls exposed to fire. *Numerical Heat Transfer (Part A)*, 1996, **29**, No. 4, 373–395.
11. SELIH J., SOUSA A. C. M. and BREMMER T. W. Moisture and heat flow in concrete walls exposed to fire. *Journal of Engineering Mechanics*, ASCE, 1994, **120**, No. 10, 2028–2043.
12. TENCHEV R. T., LI L.Y., PURKISS J. A. and KHLALAFALLAH B. H. Finite element analysis of coupled heat and mass transfer in concrete when it is in a fire. *Magazine of Concrete Research*, 2001, **53**, No.2, 117–125.
13. TENCHEV R.T., LI L.Y. and PURKISS J. A. Finite element analysis of coupled heat and moisture transfer in concrete subjected to fire. *Numerical Heat Transfer*, 2001, **39**, No. 7, 685–710.
14. LI L.Y., PURKISS J. A. and TECHCHEV R. T. An engineering model for coupled heat and mass transfer analysis in heated concrete. *Proceedings of the Institute of Mechanical Engineers Part C, Journal of Mechanical Engineering Science*, 2001, **216**, No. 2, 213–224.
15. INSTITUTION OF STRUCTURAL ENGINEERS AND CONCRETE SOCIETY. *Design and Detailing of Concrete Structures for Fire Resistance*. ISE, London, 1978.