EFFECT OF FIBRES ON FIRE RESISTANCE OF CONCRETE STRUCTURES

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Abstract:

In the paper, the influence of polymer and steel fibres on fire resistance of concrete structures is discussed. An emphasis is placed on concrete spalling. It is shown that the effect of polymer fibres on the reduction of damage caused by concrete spalling is significant and it is generally accepted. On the other hand, the addition of steel fibres in concrete is not suitable to prevent respectively to limit a risk of spalling during intensive temperature exposure of concrete. However, the steel fibres can significantly improve a bond between steel reinforcement and concrete in the case of fire.

Keywords: Fire Resistance; Concrete; Fibre; Spalling; Bond

1 Introduction

In comparison with other common construction materials, concrete provides superior performance for all relevant high-temperature resistance criteria [1]. However, this does not mean that concrete or reinforced concrete (RC) structures are not adversely affected by extreme temperatures. When exposed to severe temperature conditions, concrete and RC structural members lose their structural capacity due to the reduction of mechanical properties of concrete and steel and loss of bond between reinforcing steel and concrete [2-4]. Moreover, rising temperatures induce additional strains, thermal and transient creep that might also result in spalling or loss of structural integrity [4].

Scientific and professional community must deal with the fact that the risk related to extreme temperature conditions is high for some structures (high-rise buildings, underground car parks, tunnels). Therefore, behaviour of concrete and reinforced concrete structures subjected to extreme temperature conditions is an urgent and important research topic. Many national and international research organizations focus on the analysis of concrete structures under elevated temperatures, especially during fire.

Previous experience and different studies have shown that an addition of fibres in concrete may have significant benefits to its fire resistance, especially to the reduction of spalling and to the improvement of bond between concrete and reinforcing steel [2-3, 5-9].

In this paper, the most interesting works and research studies focused on the contribution of fibres to fire resistance of concrete structures are summarized.

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2 Spalling

As noted previously, when concrete is subjected to high temperatures, especially during fire, a spalling of concrete may occur. Spalling involves the breaking off of layers or pieces of concrete from the surface during thermal exposure [10].

Fig. 1 Spalling of concrete after high temperature exposition [3, 11]

Spalling is influenced by a number of parameters; rare of heating, temperature, moisture content, strength, permeability and porosity of the concrete, presence of cracks, chemical composition of the cement, aggregate type and size, stress conditions in the structural element, order of the reinforcement, cross-sectional shape and size, restrain to the thermal expansion [5, 10-11]; and it can be classified into several different types: explosive spalling, surface spalling, aggregate spalling (or splitting), corner spalling (or separation) and spalling due to chemical deterioration of cement paste [5, 10-11]. Explosive spalling is generally considered to be the most critical form of spalling for the performance of concrete exposed to fire [10]. The other forms of spalling are therefore not described further here.

2.1 Mechanism of spalling

Spalling is a very complex phenomenon and its physical causes are still not fully understood. However, there are two main explanations [5, 10-11].

One is the *Anderberg hypothesis* based on the low permeability of concrete. According this hypothesis, the spalling is caused due to the pore pressure (so called *pore-* or *vapour pressure induced spalling*), see **Fig. 2a**. The migration of evaporate free water from the heated surface leads to the increased pore pressure at some distance from the heated surface. Continued heating will result in the pore pressure reaching the tensile strength of concrete, causing explosive local failure [10-11]. This explanation seems consist with the experimental observation and numerical results [5, 11].

The other one is the *Bažant hypothesis* considering that spalling occurs due to the steep thermal gradients which are developed in the heated concrete (so called *thermal stress-* or *thermal dilatation induced spalling*), see **Fig. 2b**. These gradients induce compressive stress at the surface due to restrained thermal expansion and tensile stress in the cooler interior [10]. It is most likely that spalling is caused by a combination of these two described phenomena (pore pressure and thermal stress) [10].

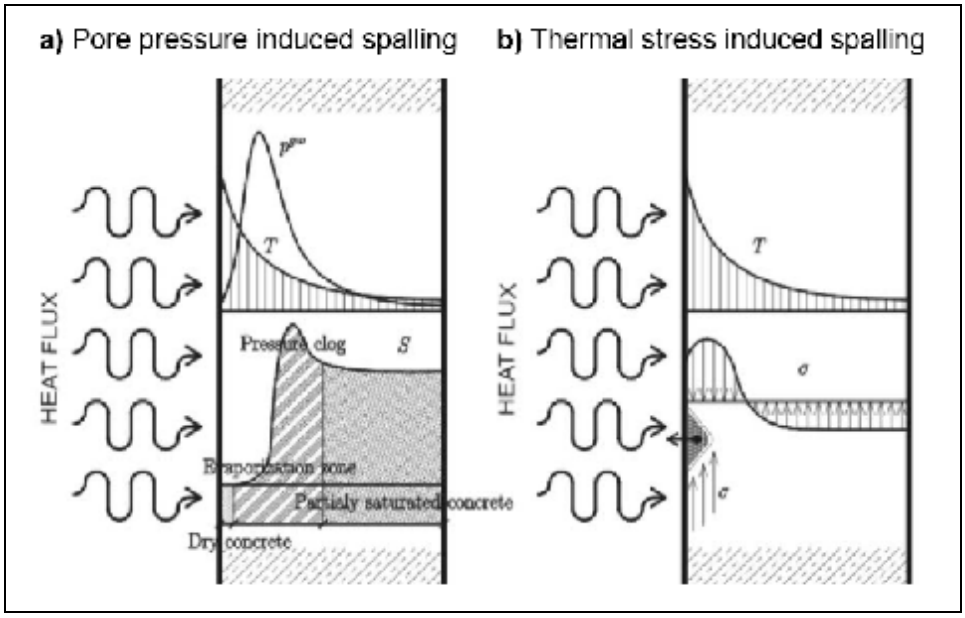

Fig. 2 Anderberg (a) vs. Bažant (b) hypothesis [11]

2.2 Explosive spalling

Explosive spalling occurs during the early stages of a fire, usually within the first 30 minutes when the rate of heating is high and it can occur just once or at intervals even from the previously spalled parts [10-11]. It is characterised by large or small pieces of concrete being violently expelled from the heated surface. The significant loss of concrete during the explosive spalling leads to a more rapid rise in temperature within the remaining cross-section and it reduce the structural integrity and stability of the structural element [11].

According to the Eurocode 2 [9], the explosive spalling shall be avoided, or its influence on performance requirements shall be taken into account in the structural design. For normal strength concrete, in the Eurocode 2 [9] is noted that the explosive spalling is unlikely to occur when moisture content of concrete is less than 3 % by weight. Above 3 % a more accurate assessment of moisture content, type of aggregate, permeability of concrete and heating rate should be considered. For high strength concrete (HSC), Eurocode 2 [9] requires an application of one of 4 recommended methods for the prevention or reduction of the spalling amount. One of these methods is an addition of propylene fibres in the concrete mix.

2.3 Effect of fibres on spalling

During the last decade, many works and research studies focused on prevention or reduction of explosive spalling using fibres have been published. The results of these studies have shown that an addition of fibres from polymers (for example from polypropylene) in the concrete mix can reduce the damage incurred by the concrete spalling [5-8]. However, the mechanisms underlying this benefit are not sufficiently understood. For a better understanding of this phenomenon, the international research project NewCon [8] has been initiated. The results of this project are shortly summarized below.

Water and polypropylene are grossly dissimilar in polarity causing poor interfacial adhesion between the polypropylene fibres and concrete which allows capillarity transport of water between the fibre and concrete by the PITS (Pressure Induced Tangential Space) mechanism. PITS is the tangential space that is created between the poorly wetted fibre and the surrounding concrete due to the steam pressure. This allows steam to travel along the space even before the fibre is melted. Hitherto, it has normally been assumed that water vapour is transported through the "vacated" channels after melting of the fibres.

From the results of the NewCon [8] project follows that, contrary to common belief, the high molecular weight and dimensions combined with the high viscosity of the melted fibre do not allow an easy transport of the melted fibre trough the concrete pores. It is only when the melted fibres vaporise to low molecular size hydrocarbons of irrelevant polarities that flow of the hydrocarbon becomes easy through the concrete pore structure [8].

This theory is not the only explanation that has been published. In [6-7], the effect of fibres to reduction of spalling damage is described as follows:

- Improvement of the permeability due to formation of capillary pores when the fibres melt and burn (*still disputable, see above*).
- Improvement of the permeability caused by the development of diffusion open transition zones near the fibres.
- Improvement of the permeability due to additional micro pores, which develop during the addition and mixing of fibres in the concrete mix.
- Improvement of the permeability due to additional micro cracks at the tip of the polypropylene fibres which develop during heating up and melting.

All the above theories indicate that in some way the drying process, i.e. moisture transfer, is somehow facilitated by the presence of polypropylene fibres [6].

Effect of polymer fibres on reduction of the damage caused by concrete spalling is significant and it is generally accepted. However, in the case of addition of steel fibres the influence is not so far-reaching. As stated in [5], the addition of steel fibres in concrete is not suitable to prevent respectively to limit a risk of spalling during intensive temperature exposure of concrete. The addition of steel fibres may partially prevent concrete pieces to fall down. This effect may protect the not destroyed concrete against direct fire attack but represent only a temporary limited barrier. During a continuous fire attack, this protection effect gets lost, because the thin steel fibres reach very quickly high temperatures [5]. However, as state in [2], the steel fibres can significantly improve a bond between steel reinforcement and concrete in the case of fire.

3 Conclusions

When exposed to severe temperature conditions, concrete and RC structural members lose their structural capacity due to the reduction of mechanical properties of concrete and steel and loss of bond between reinforcing steel and concrete. Moreover, rising temperatures induce additional strains, thermal and transient creep that might also result in spalling or loss of structural integrity.

Explosive spalling is generally considered to be the most critical form of spalling for the performance of concrete exposed to fire.

All theories explaining the effect of fibres to reduction of spalling damage indicate that in some way the drying process, i.e. moisture transfer, is somehow facilitated by the presence of polypropylene fibres.

Effect of polymer fibres on reduction of the damage caused by concrete spalling is significant and it is generally accepted. On the other hand, the addition of steel fibres in concrete is not suitable to prevent respectively to limit a risk of spalling during intensive temperature exposure of concrete. However, the steel fibres can significantly improve a bond between steel reinforcement and concrete in the case of fire.

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