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# An Experimental Study on Reducing Fire Spalling Effect on Concrete– *A Review*

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***Abstract: Despite almost 100 years of research, the fundamentals of fire spalling of concrete are not yet fully understood. Many different theories exist, each trying to describe the coupling between different phenomenon leading to fire spalling. Some of these phenomenon have been investigated and are presented in this paper. Spalling of concrete at high temperature, mainly in the form of a violent breaking off of concrete layers, was already observed in the early research work on concrete at high temperatures. During the 1970s, research indicated different mechanisms leading to explosive spalling: High internal pore pressure due to the evaporation of moisture as well as thermal stresses caused by temperature gradients or a combination of both were proposed in literature to be the governing mechanisms leading to spalling. In this if we reduce pore water pressure without affecting other properties of concrete we can reduce the effect. From research it is studied that by adding fibres such as poly-propylene fibres (PPF), nylon fibres, poly-ethelyn fibres, steel fibres and PVC fibres etc. will melt at higher temperature with increasing permeability of concrete which results in releasing water pressure. In this experimental study PPF and nylon fibre is used and compared with standard concrete.***

***Keywords: spalling of concrete, pore water pressure, fibres, permeability.***

## I. INTRODUCTION

Spalling of concrete can be defined as "the violent or non-violent breaking off of layers or pieces of concrete from the surface of a structural element, when it is exposed to high and rapidly rising temperatures as experienced in fires".

Spalling of concrete is generally categorised as pore pressure induced spalling, thermal stress induced spalling or a combination of the two. Strong thermal gradients develop in concrete as it is heated, due to its low thermal conductivity and high specific heat. These thermal gradients induce compressive stresses close to the surface due to restrained thermal expansion and tensile stresses in the cooler interior regions. The surface compression may also be augmented by applied loading or prestress. Combined pore pressure and thermal stress induced spalling is most likely that spalling

Figure 1. Spalling of concrete

occurs due to the combination of tensile stresses induced by thermal expansion and increased pore pressure. Much debate still surrounds the identification of the key mechanism (pore pressure or thermal stress). However, it is noted that the key mechanism may change depending upon the section size, material and moisture content.

### A. *Types Of Spalling*

| Spalling | Usual time of occurrence | Nature | Sound | Influence on structure | Governing factors leading to spalling |
|---|---|---|---|---|---|
| Explosive | 7-30 min | Violent | loud bang | very serious | material, structural / mechanical and temperature related |
| Surface | 7-30 min | Violent | cracking | can be serious | mainly material related |
| Aggregate | 7-30 min | Splitting | popping | superficial | mainly material related |
| Corner | 30-90 min | non-violent | none | can be serious | mainly structural / mechanical related |
| Post-cooling | after cooling | non-violent | none | can be serious | structural / mechanical and material related |
| Sloughing-off | when concrete weakens | non-violent | none | can be serious | mainly structural / mechanical related |

Table 1 Types of spalling

### B. *Governing Factors Leading To Spalling*

Different factors affecting or influence spalling of concrete is categorised in mainly three categories. Each one is described below with its effect on spalling.

#### 1) *Material-related Parameters*

| Material related parameter | Increasing risk of spalling | Influence on spalling |
|---|---|---|
| silica fume | very high | Silica fume lowers the permeability and increases the possibility of explosive spalling due to the reduced release of high vapour pressure |
| permeability | high | Low permeability and insufficient temperature-dependent increase in permeability increases the risk of spalling due to insufficient release of pore pressure |
| porous / lightweight aggregates | variable | Higher porosity and permeability enables the release of high pore pressure and decreases the risk of spalling. The higher moisture content of lightweight aggregates promotes the risk of spalling. |
| cement content | high | High cement content increases the total amount of water added to the concrete, even with low w/c ratios. |

Table 2 Material related parameters affecting spalling of concrete

#### 2) *Structural / mechanical parameters*

| Structural / mech. Parameter | Increasing risk of spalling | Influence on spalling |
|---|---|---|
| tensile strength | lowering risk | A high tensile strength is considered as lowering the risk of explosive spalling since it offers a higher resistance: [against spalling due to a high pore pressure], [of high thermal gradients, stresses and expansion] and [of corner spalling or thermal stresses from two sides]. |
| applied load | applied load | The risk of spalling increases with applied higher load levels Preload as low as 5% of the cold strength increases the risk of spalling It remains unknown if a low preload minimizes the risk of spalling, since small cracks used for the release of vapour are pressed together. |
| cross section geometry | high | Round cross section, rounded corners, sufficient reinforcement cover and spacing and modified tie design lowers the likelihood of spalling or increases the remaining load bearing capacity of concrete members after spalling. |

Table 3 Mechanical parameters affecting spalling of concrete

#### 3) *Heating characteristics*

In terms of the parameters that depend on heating characteristics, the heating rate and the hereby caused temperature gradients have a strong influence on explosive spalling. High heating rates and thermal gradients increase spalling.

## II. OBJECTIVE OF STUDY

1) To study behaviour of concrete in fire with and without fibre ingredients.
2) To study damage to concrete in general and temperature dependent deterioration process during heating.
3) To study and determine the affecting parameters
4) To perform tests for strength and fire resistance of concrete.
5) To develop a mix design which can reduce or eliminate spalling characteristic of concrete.

### *A. Fibre*

Fibres used in this experimental study is described as follows:

### *B. Polypropylene Fibre (PPF)*

PPF have low specific gravity, because of that it yields significant volume of fibre for a given weight. It means it provides good bulk and cover, while being lighter in weight. PPF is the lightest of all fibres and it is also lighter than water. In comparison it is 34% lighter than polyester and 20 % lighter than nylon. In addition PPF is having less thermal conductivity. So it retains more heat for a longer period of time. And it is also resistant to bacteria like other fibres such as nylon, acrylic and polyester. PPF is a recyclable and eco-friendly material and does incinerate to trash ash with no hazard volatiles.

PPF starts melting at 165 °C to 170 °C and then starts degradation of fibres. In cold situations it remains flexible at -55 °C. It is also resistant to absorb water and water has no effect on the strength.

In this experimental study 10 mm length of fibre is been used. Following figure shows sample of PPF used in this experiment.

Fig 2 PPF Fibres

Fig 3 Nylon Fibre

### *C. Nylon Fibre*

Nylon fibre is also a light weight fibre compare to others. It has low absorbance characteristic and water doesn’t affect the strength of fibre. It has quietly similar quality as described for PPF.

It reduces water permeability. But in situation of fire it melts and reduces pore water pressure. Nylon fibre starts melting about 200 °C temperature. Figure no. shows sample of nylon fibre used in this experiment.

## III. EXPERIMENTAL TESTS

In this study M50 and M55 grade concrete has been used. There are total five tests were been conducted.

*A.* Compression test (at 7 days and 28 days)
*B.* Split tensile test
*C.* Porosity test (RCPT – Rapid Chloride Penetration Test)
*D.* Compression test after 500 °C heating
*E.* Time measurements for complete degradation at 900 °C constant heating

## IV. TEST RESULTS

Concrete used for this study is M50 grade and M55 grade concrete. So standard compressive strength and tensile strenghth test were performed and achieved satisfactory results. Now in this paper results of RCPT test, Compressive strength after heating at 500 °C temperature and direct heating at 900 °C temperature is described as follows:
Following notation is used for sample identification
For M50 grade concrete:
11) M50 grade standard concrete without any addition of fibre
12) M50 grade concrete with PPF
13) M50 grade concrete with Nylon fibre
For M55 grade concrete:
21) M55 grade standard concrete without any addition of fibre
22) M55 grade concrete with PPF
23) M55 grade concrete with Nylon fibre

### *A. Rcpt Test Result And Criteria*

In this study for porosity measurement of concrete, RCPT test was been carried out and its results are as shown in following table.

| Sr. No. | Coulombs | Porosity condition |
|---|---|---|
| 11 | 1540 | low |
| 12 | 1800 | moderate |
| 13 | 1510 | low |
| 21 | 1410 | low |
| 22 | 1730 | moderate |
| 23 | 1350 | low |

Table 4 RCPT test results

### *B. Compression Test After 500 °C Heating*

In this test standard compression test was carried out with 150 cm sixe cube specimen after oven heating of 500 °C temperature. Results are as shown in following table.

| Sr. No. | Average Compressive Strength in N/mm2 |
|---|---|
| 11 | 28.50 |
| 12 | 28.60 |
| 13 | 26.37 |
| 21 | 31.27 |
| 22 | 31.20 |
| 23 | 29.40 |

Table 5 Results of Compression test after 500 °C heating

### *C. Direct Heating At 900 °C At Constant Rate*

In this test standard concrete cube of size 150 cm was been applied with direct heating at constant rate of 900 °C temperature and time duration measured for its degradation stages. Results are as shown in following table.

| Sr. No. | Duration when cube started to breaking off (in minutes:seconds) |
|---|---|
| 11 | 08:21 |
| 12 | 10:30 |
| 13 | 08:35 |
| 21 | 08:40 |
| 22 | 12:37 |
| 23 | 09:10 |

Table 6 Duration of 900 °C heating to start degradation

| Sr. No. | Duration for complete degradation (in minutes:seconds) |
|---|---|
| 11 | 14:26 |
| 12 | 18:47 |
| 13 | 14:58 |
| 21 | 15:32 |
| 22 | 20:14 |
| 23 | 16:23 |

Table 7 Duration for complete degradation of concrete at 900 °C direct heating

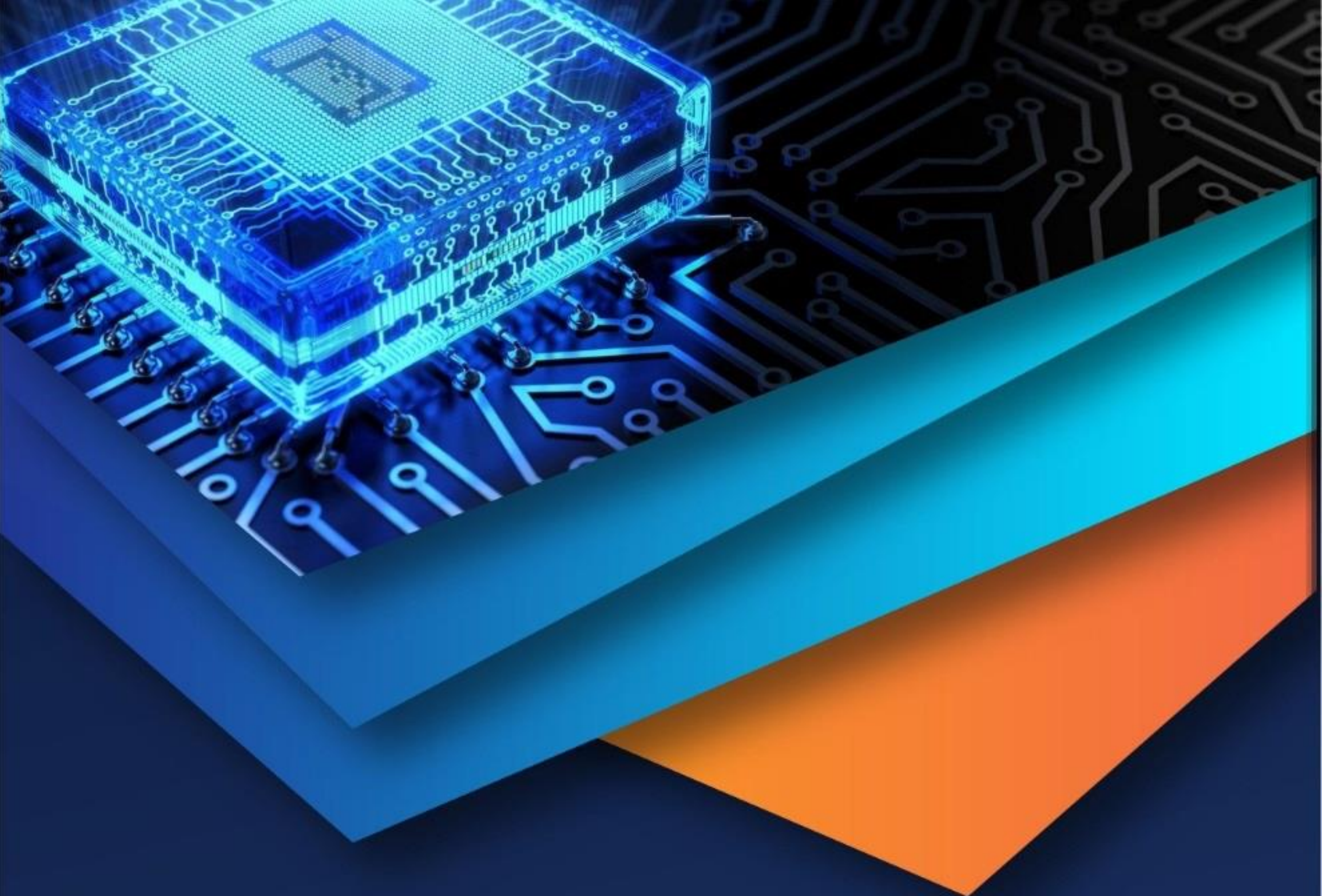
## V. CONCLUSION

From this study following points were concluded.

*A.* Fire spalling gives more effect on concrete for higher strength.
*B.* In this study PPF was effective to reduce fire spalling effect on concrete. And there was no change in compressive strength and tensile strength. So, we can use PPF without affecting the strength of concrete.
*C.* Use of PPF changes the porosity of concrete before and after experiencing the fire. For lower degree temperature PPF will remain same as a concrete ingredient but it will melt down when temperature crosses its melting point and makes concrete porous. Which will allow to release pore pressure induced by water vapour. This will increase durability of concrete against fire exposure.
*D.* Use of nylon fibre does not seems to be that much effective compared to PPF. It does not also affect compressive strength and tensile strength of concrete.

## REFERANCES

[1] Gabriel Alexander Khoury, "Fire and concrete", Encontro Nacional Betao Estrutural, November 2008.
[2] "Test method for spalling of fire exposed concrete", by K.D. Hertz, ELSEVIER Fire safety journal, 22nd June, 2005.
[3] "How do polypropylene fibres improve the spalling behaviour of in-situ concrete?" by Matthias Zeiml, ELSEVIER Cement and concrete research, 2006.
[4] "Fire spalling in concrete – The moisture effect, part II", by R. Jansson and L. Bostrom, Researchgate, Publication no. 270777, September 2013.
[5] "Fire Spalling of Concrete Members", by M. Hedayati, 6th International Conference on Structural Engineering and Construction Management, 11th – 13th December, 2015.
[6] "A Comprehensive Review of Spalling and Fire Performance of Concrete Members", by M. Hedayati, Electronic Journal of Structural Engineering, January 2015.
[7] "Fracture and explosive spalling of concrete slabs subjected to severe fire", by F. A. Ali, University of Ulster, 2014.
[8] Jansson R. & Boström L. "Spalling of concrete exposed to fire", SP Report, Licentiate thesis published in 2008.
[9] Khoury, "Effect of fire on concrete and concrete structures", Prog. Structural Engineering Matter, 2000
[10] Akhtaruzzaman A. A. and Sullivan P. J. E. (1970) "Explosive spalling of concrete exposed to high temperature", Concrete Structures Research Report, Imperial College, Great Britain, as cited by Malhotra H. L. (1984).
[11] Anderberg Y. (1997) "Spalling phenomena of HPC and OC", Proceedings from the International Workshop on Fire Performance of High-Strength Concrete, NIST, February 13-14, 1997, Gaithersburg, USA.
[12] Bangi M. R. (2010) "Study on Pore Pressure Spalling in Hybrid Fibre – High Strength Concrete at Elevated Temperatures" Master's Thesis No. EG-M 80_ Division of Environment and Resources Engineering Graduate School of Engineering, Hokkaido University September, Hokkaido, Japan.
[13] Phan L. T. (2008) "Pore pressure and explosive spalling in concrete" Materials and Structures Vol 41, pp 1623–1632.
[14] Persson B. (2004) "Fire resistance of self-compacting concrete, SCC" Materials and Structures, Vol. 37, November 2004, pp 575-584.
[15] Sundius N. (1931) "Investigation of fire exposed concrete by microscopy" Betong, No 2, 1931, (in Swedish).



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