

Structures in Fire Forum

29th September – London

Role of Polypropylene fibres in heat induced spalling

Hussein Cadosch



THE UNIVERSITY of EDINBURGH
Institute for Infrastructure
and Environment



STRUCTURES IN FIRE FORUM



Empa

Materials Science and Technology

Objective of the presentation

- Demystifying spalling
- Explain the role of Polypropylene as a mitigating factor (out of many recommended ones)
- Demonstrate the potential misconceptions about the use of PP fibre!



What is spalling?

- The earliest paper on spalling is by Kaplan and Linan [Spalling of concrete due to fire] in 1954.
- No standardised test available (yet)
- No unanimous agreement on the causes of it!



Spalling, and its mechanism

- Pressure induced
- Thermal gradient & restraint conditions
- Deterioration of matrix
- Shear stress induced by moving vapour!
- A combination of all, or some, of the above



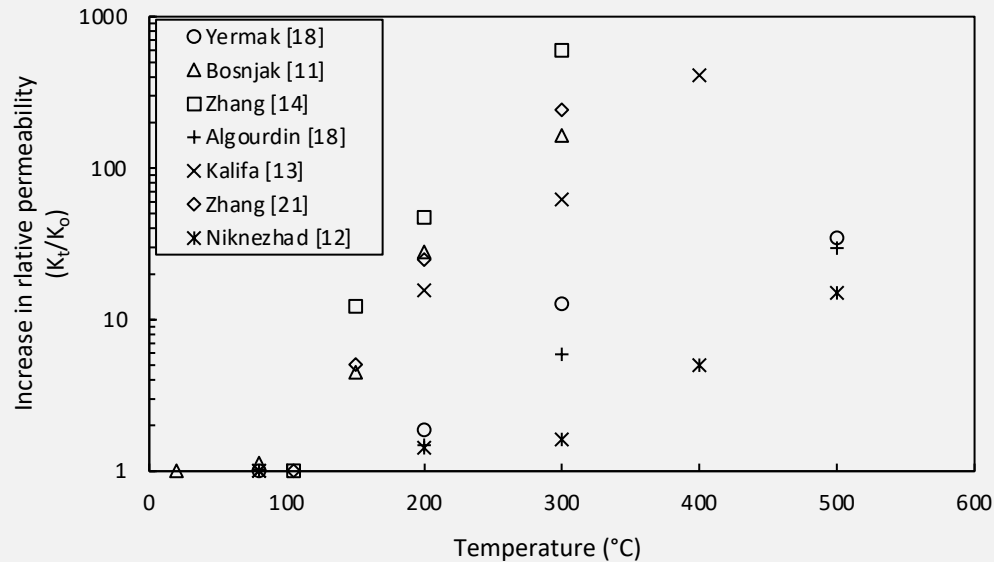
PP fibres as a solution

- The mechanism is still not fully known

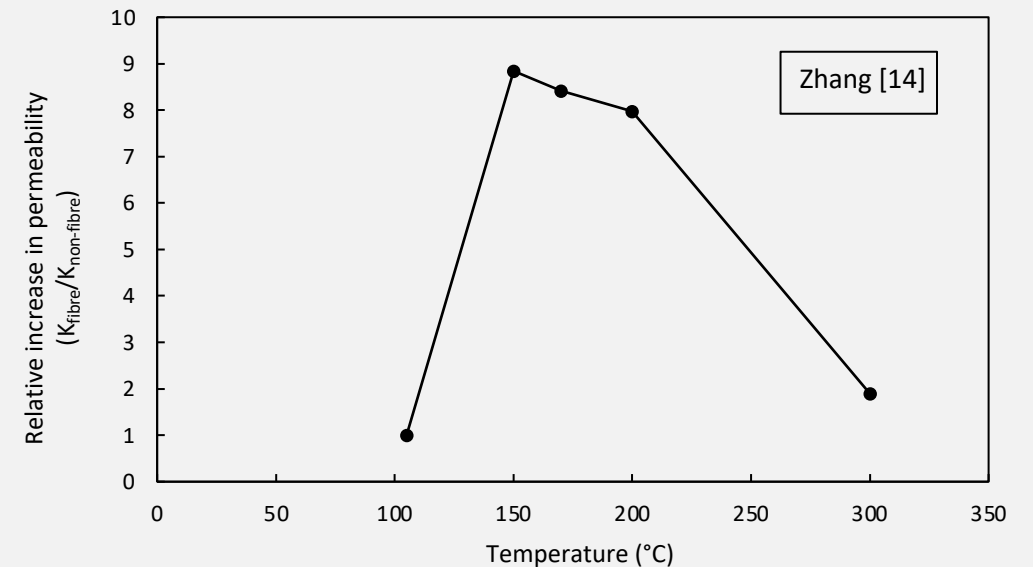


PP fibres ... what do they do?

- Permeability increase with heat



- PP fibres increase the rate



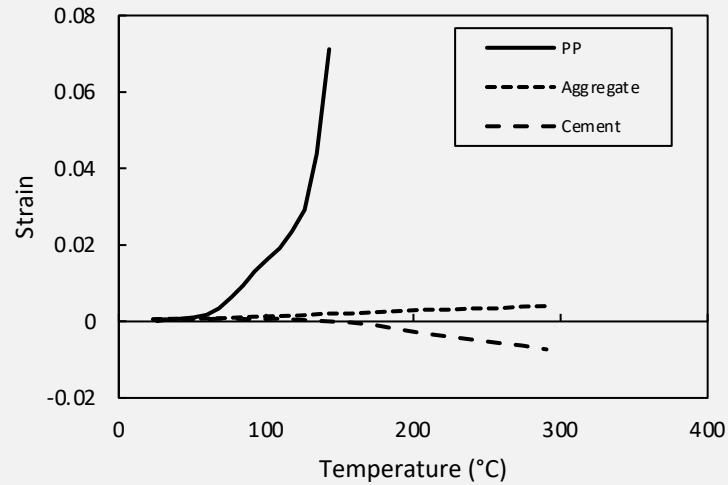
- [11] J. Bošnjak, J. Ožbolt, and R. Hahn, "Permeability measurement on high strength concrete without and with polypropylene fibers at elevated temperatures using a new test setup," *Cem. Concr. Res.*, vol. 53, pp. 104–111, 2013, doi: 10.1016/j.cemconres.2013.06.005.
- [12] D. Niknezhad, S. Bonnet, N. Leklou, and O. Amiri, "Effect of thermal damage on mechanical behavior and transport properties of self-compacting concrete incorporating polypropylene fibers," *J. Adhes. Sci. Technol.*, vol. 33, no. 23, pp. 2535–2566, Dec. 2019, doi: 10.1080/01694243.2019.1650427.
- [13] P. Kalifa, G. Chéné, and C. Gallé, "High-temperature behaviour of HPC with polypropylene fibres," *Cem. Concr. Res.*, vol. 31, no. 10, pp. 1487–1499, Oct. 2001, doi: 10.1016/S0008-8846(01)00596-8.
- [14] D. Zhang, A. Dasari, and K. H. Tan, "On the mechanism of prevention of explosive spalling in ultra-high performance concrete with polymer fibers," *Cem. Concr. Res.*, vol. 113, no. August, pp. 169–177, 2018, doi: 10.1016/j.cemconres.2018.08.012.
- [18] N. Algourdin, P. Pliya, A. L. Beaucour, A. Simon, and A. Noumowé, "Influence of polypropylene and steel fibres on thermal spalling and physical-mechanical properties of concrete under different heating rates," *Constr. Build. Mater.*, vol. 259, p. 119690, 2020, doi: 10.1016/j.conbuildmat.2020.119690.
- [21] Y. Shen, M. Dai, W. Pu, and Z. Xiang, "Effects of content and length / diameter ratio of PP fiber on explosive spalling resistance of hybrid fiber-reinforced ultra-high- performance concrete," *J. Build. Eng.*, vol. 58, no. August, p. 105071, 2022, doi: 10.1016/j.job.2022.105071.



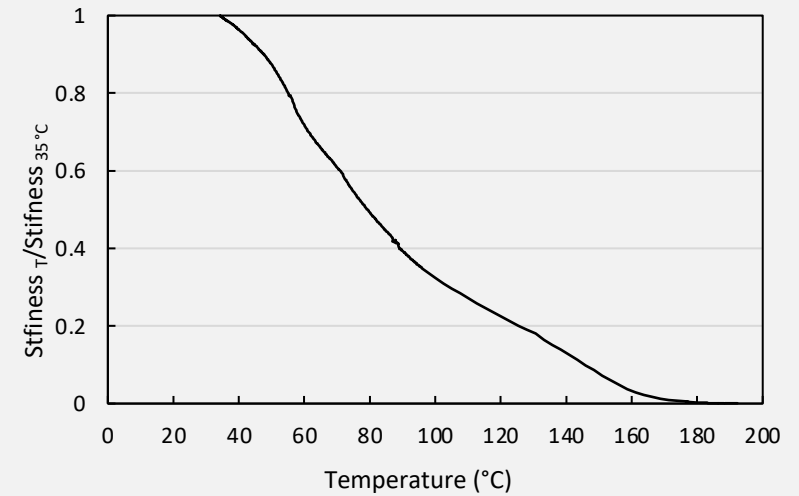
Why?

PP is well defined with melting temp ≈ 172 °C

But...



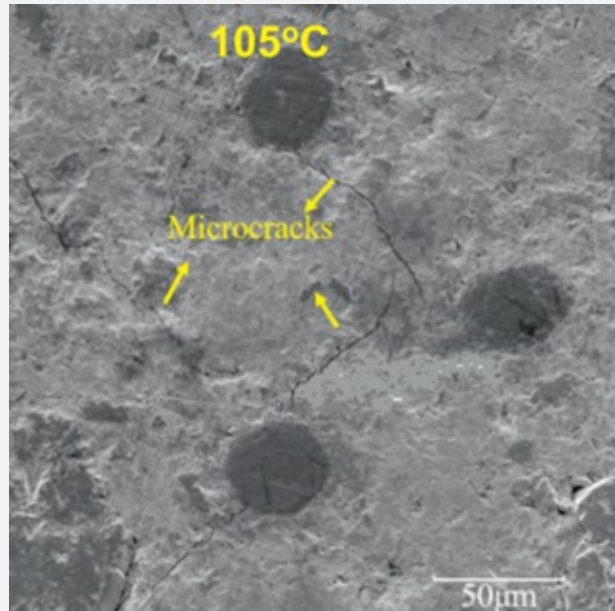
Also...



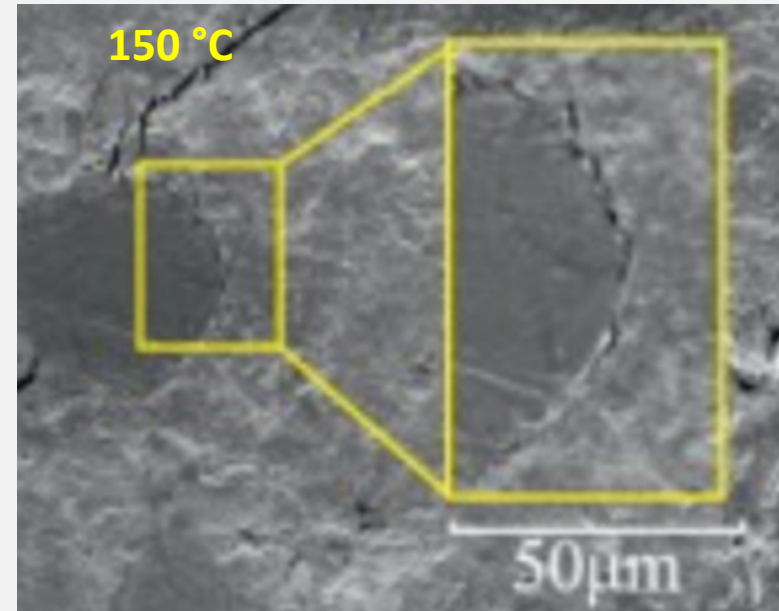
[14] D. Zhang, A. Dasari, and K. H. Tan, "On the mechanism of prevention of explosive spalling in ultra-high performance concrete with polymer fibers," *Cem. Concr. Res.*, vol. 113, no. August, pp. 169–177, 2018, doi: 10.1016/j.cemconres.2018.08.012.

Results?

Cracks at early age



And debonding



- [14] D. Zhang, A. Dasari, and K. H. Tan, "On the mechanism of prevention of explosive spalling in ultra-high performance concrete with polymer fibers," *Cem. Concr. Res.*, vol. 113, no. August, pp. 169–177, 2018, doi: 10.1016/j.cemconres.2018.08.012.

So ... what is the issue?

BS EN 1992-1-2:2004+A1:2019
Incorporating corrigendum July 2008



BSI Standards Publication

4.5 Spalling

4.5.1 Explosive spalling

(1)P Explosive spalling shall be avoided, or its influence on performance requirements (R and/or EI) shall be taken into account.

(2) Explosive spalling is unlikely to occur when the moisture content of the concrete is less than k % by weight. Above k % a more accurate assessment of moisture content, type of aggregate, permeability of concrete and heating rate should be considered.

Note: The value of k for use in a Country may be found in its National Annex. The recommended value is 3.

(3) It may be assumed that where members are designed to exposure class X0 and XC1 (see EN 1992-1-1), the moisture content of that member is less than k % by weight, where $2,5 \leq k \leq 3,0$.

6.2 Spalling

(1) For concrete grades C 55/67 to C 80/95 the rules given in 4.5 apply, provided that the maximum content of silica fume is less than 6% by weight of cement. For higher contents of silica fume the rules given in (2) apply.

(2) ^(AC1) For concrete grades $80/95 < C \leq 90/105$ at least one of the following methods should be provided: ^(AC1)

Method A: A reinforcement mesh with a nominal cover of 15 mm. This mesh should have wires with a diameter ≥ 2 mm with a pitch $\leq 50 \times 50$ mm. The nominal cover to the main reinforcement should be ≥ 40 mm.

58

BS EN 1992-1-2:2004+A1:2019

EN 1992-1-2:2004/A1:2019 (E)

Method B: A type of concrete for which it has been demonstrated (by local experience or by testing) that no spalling of concrete occurs under fire exposure.

Method C: Protective layers for which it is demonstrated that no spalling of concrete occurs under fire exposure.

Method D: Include in the concrete mix more than 2 kg/m^3 of monofilament propylene fibres.



THE UNIVERSITY of EDINBURGH
Institute for Infrastructure
and Environment



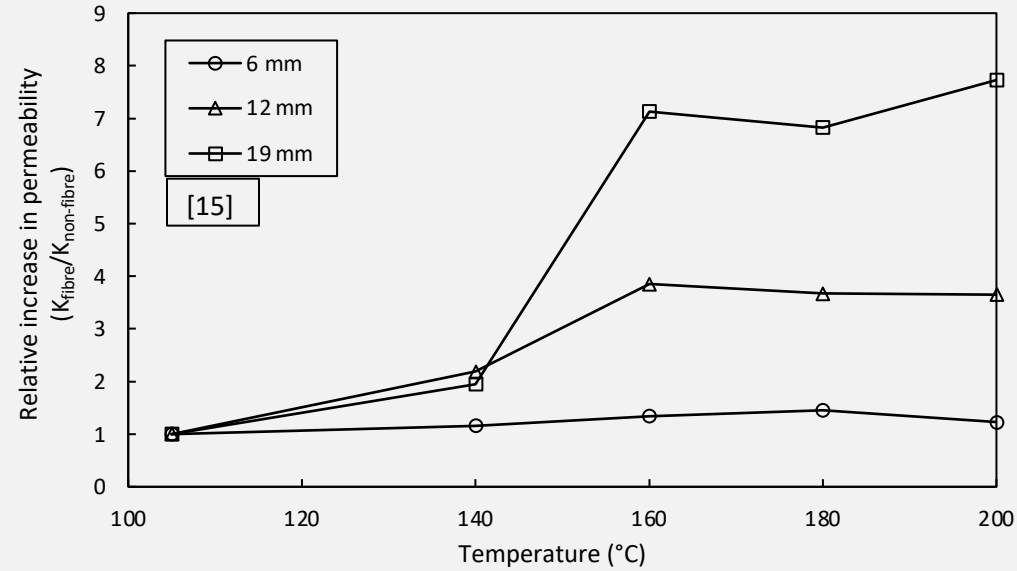
STRUCTURES IN FIRE FORUM



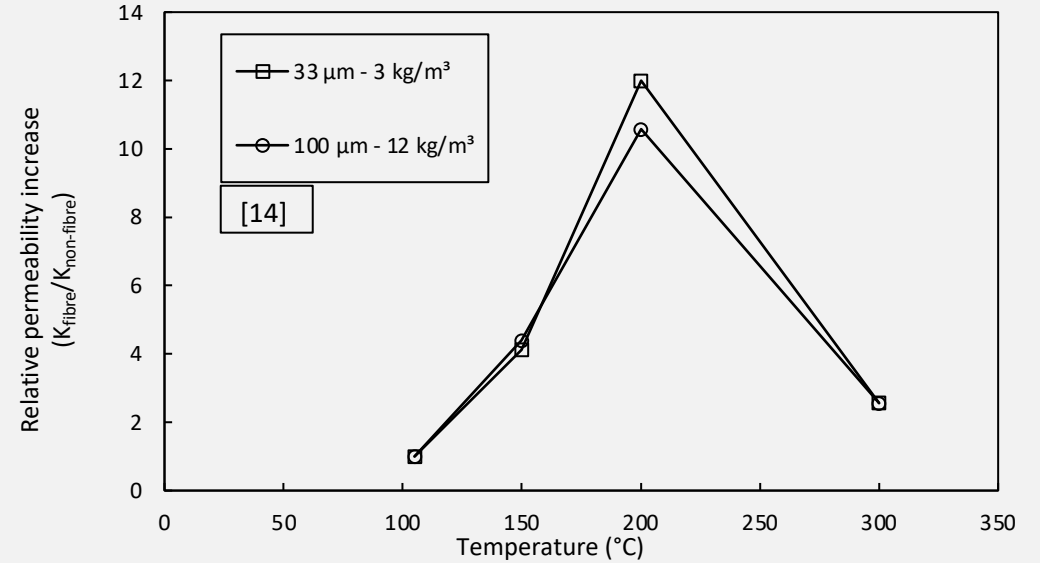
Empa

Materials Science and Technology

The geometry effect!



Length as variable



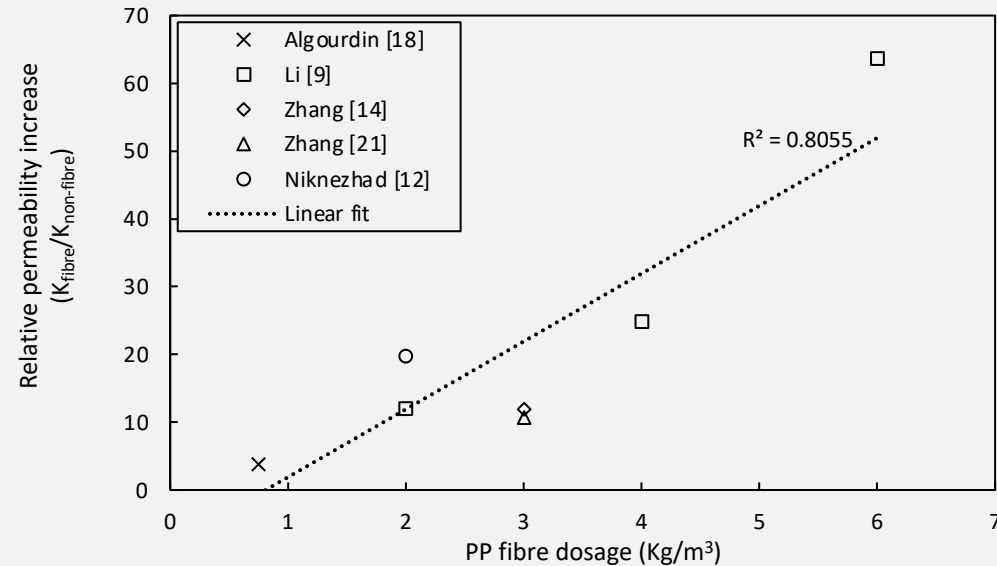
Diameter as variable

[14] D. Zhang, A. Dasari, and K. H. Tan, "On the mechanism of prevention of explosive spalling in ultra-high performance concrete with polymer fibers," *Cem. Concr. Res.*, vol. 113, no. August, pp. 169–177, 2018, doi: 10.1016/j.cemconres.2018.08.012.

[15] I. Hager, K. Mróz, and T. Tracz, "Contribution of polypropylene fibres melting to permeability change in heated concrete-the fibre amount and length effect," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 706, no. 1, 2019, doi: 10.1088/1757-899X/706/1/012009

Dosage ...

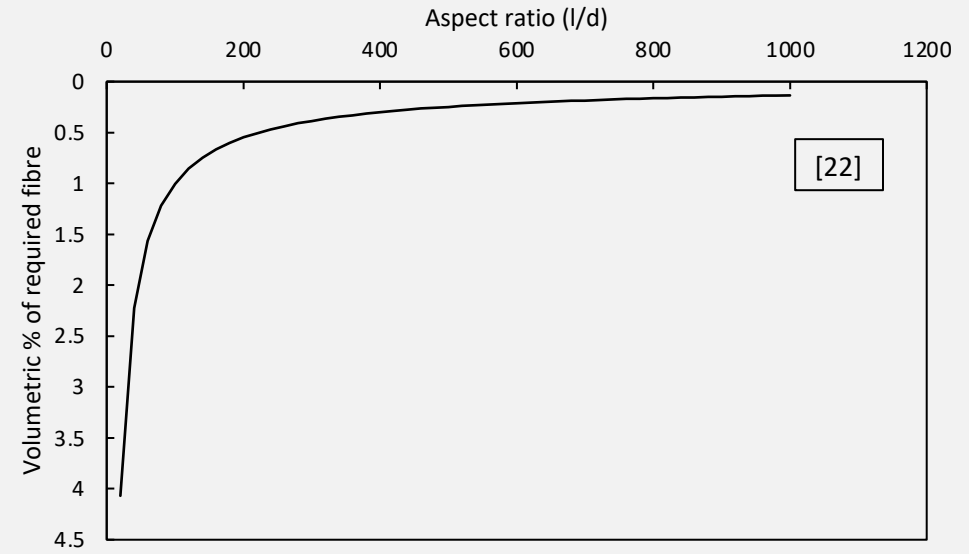
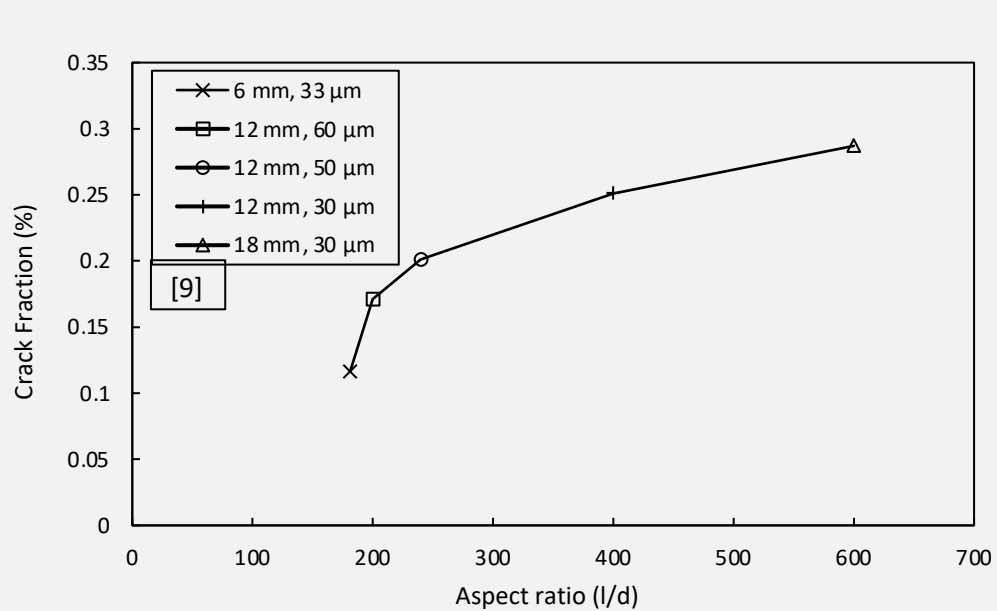
For 12 mm long, 33 μm diameter fibres ...



- [9] Y. Li, Y. Zhang, E. H. Yang, and K. H. Tan, "Effects of geometry and fraction of polypropylene fibers on permeability of ultra-high performance concrete after heat exposure," *Cem. Concr. Res.*, vol. 116, no. November 2018, pp. 168–178, 2019, doi: 10.1016/j.cemconres.2018.11.009.
- [12] D. Niknezhad, S. Bonnet, N. Leklou, and O. Amiri, "Effect of thermal damage on mechanical behavior and transport properties of self-compacting concrete incorporating polypropylene fibers," *J. Adhes. Sci. Technol.*, vol. 33, no. 23, pp. 2535–2566, Dec. 2019, doi: 10.1080/01694243.2019.1650427.
- [14] D. Zhang, A. Dasari, and K. H. Tan, "On the mechanism of prevention of explosive spalling in ultra-high performance concrete with polymer fibers," *Cem. Concr. Res.*, vol. 113, no. August, pp. 169–177, 2018, doi: 10.1016/j.cemconres.2018.08.012.
- [18] N. Alourdin, P. Pliya, A. L. Beaucour, A. Simon, and A. Noumowé, "Influence of polypropylene and steel fibres on thermal spalling and physical-mechanical properties of concrete under different heating rates," *Constr. Build. Mater.*, vol. 259, p. 119690, 2020, doi: 10.1016/j.conbuildmat.2020.119690.
- [21] Y. Shen, M. Dai, W. Pu, and Z. Xiang, "Effects of content and length / diameter ratio of PP fiber on explosive spalling resistance of hybrid fiber-reinforced ultra-high- performance concrete," *J. Build. Eng.*, vol. 58, no. August, p. 105071, 2022, doi: 10.1016/j.job.2022.105071.



What to do then?



[9] Y. Li, Y. Zhang, E. H. Yang, and K. H. Tan, "Effects of geometry and fraction of polypropylene fibers on permeability of ultra-high performance concrete after heat exposure," *Cem. Concr. Res.*, vol. 116, no. November 2018, pp. 168–178, 2019, doi: 10.1016/j.cemconres.2018.11.009.

[22] D. Zhang, Y. Zhang, A. Dasari, K. H. Tan, and Y. Weng, "Effect of spatial distribution of polymer fibers on preventing spalling of UHPC at high temperatures," *Cem. Concr. Res.*, vol. 140, no. October 2020, p. 106281, 2021, doi: 10.1016/j.cemconres.2020.106281



Concluding remarks

- Appreciating how the end user utilises guidance documents (i.e., Structural engineers)
- Importance of the geometry of fibres
- Fundamental understanding of the mechanism of PP work
- Prescribing is not (or should not be) the end of the line



Thank you for
listening!



THE UNIVERSITY *of* EDINBURGH
Institute for Infrastructure
and Environment



STRUCTURES IN FIRE FORUM



Empa

Materials Science and Technology