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Thermophysical behaviour of reinforced concretes

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Thermal conductivity – standard values

Standard	Material	Density ρ [kg/m ³]	Thermal conductivity λ [W/mK]
MSZ 04-140/2:1991	reinforced concrete	2400	1.55
	concrete	2200	1.28
MSZ 24140:2015	reinforced concrete	2400	2.5
	concrete	2200	2.0
	medium density concrete	1800	1.15
		2000	1.35
MSZ EN ISO 10456:2008	high density concrete	2200	1.65
	high density concrete	2400	2.0
	reinforced concrete (with 1% of steel)	2300	2.3
	reinforced concrete (with 2% of steel)	2400	2.5
	steel	7800	50

EN 1992-1-2:2013 and EN 1993-1-2:2013

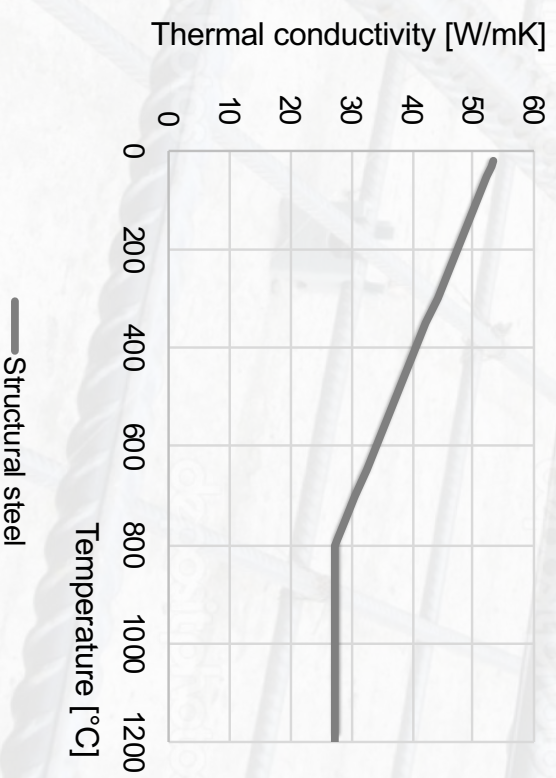
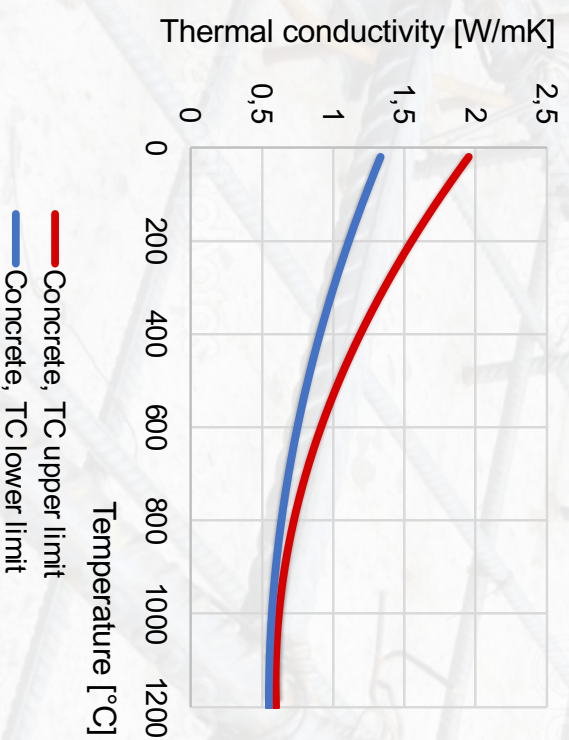
Thermal conductivity of concrete and structural steel

$$\lambda_{c,upper} = 2 - 0.2451 \cdot (\theta/100) + 0.0107 \cdot (\theta/100)^2$$

$$\lambda_{c,lower} = 1.36 - 0.136 \cdot (\theta/100) + 0.0057 \cdot (\theta/100)^2$$

$$\lambda_s = 54 - 0.0333 \cdot \theta_s$$

$$\lambda_{s,800} = 27.3$$





Thermal conductivity – European standards

Standard	Material	Density ρ [kg/m ³]	Design thermal conductivity λ [W/mK]
ČSN 730540- 3:2005	concrete	2100	1.23
		2200	1.30
		2300	1.36
	reinforced concrete	2300	1.43
		2400	1.58
	steel	2500	1.74
	steel	7800	58

Standard	Denomination	Density ρ [kg/m ³]	Internal thermal conductivity λ_{int} [W/mK]	External thermal conductivity λ_{ext} [W/mK]
NBN B 62- 002:2001	concrete	2000-2100	1.44	1.86
	concrete	2100-2200	1.57	2.04
	concrete	2200-2300	1.72	2.24
	steel	7800	45	45

Concrete specimens



- steel fibre reinforced concrete:
 - Humix 50 cold formed steel fibres with different amount (20 kg/m³ – 27.5 kg/m³ – 35 kg/m³)
- rebar reinforced concrete:
 - 1:2 scale miniature element of slabs with different diameters of bars (4-5-6 mm)

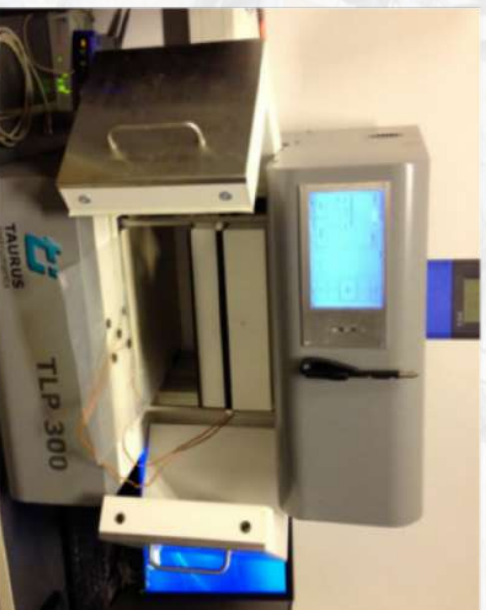
Each concrete mixture was distributed to six standard 15x15x15 cm cubes and three 20x20x10 cm cuboids.

The specimens made for thermal conductivity measurements were stored in water for 7 days, then stored in a temperature and humidity conditioning chamber at 23 °C and 50 %RH.



Thermal conductivity measurements

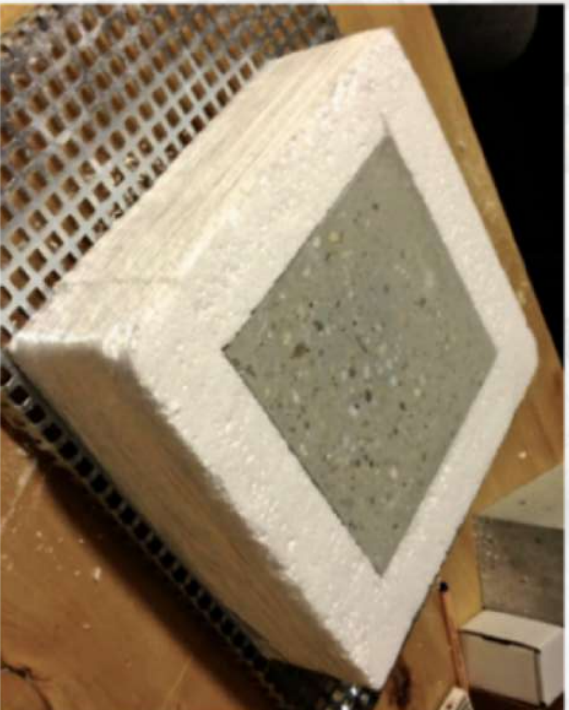
Thermal conductivity was measured using a Taurus TLP 300 DTX guarded hot plate instrument according to MSZ EN 12664:2001



- steel fibre reinforced concrete:
 - tested once after the conditioning with still moist samples and once after one year of storing them in laboratory conditions
- rebar reinforced concrete:
 - samples were dried out artificially before the measurements



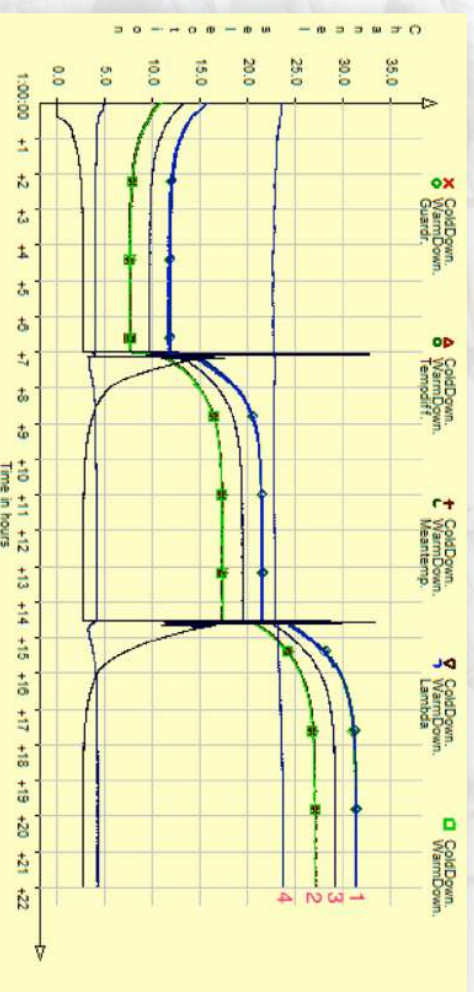
Thermal conductivity measurements



The specimens were framed using 10 cm thick EPS foam stocks, ensuring that the temperature or humidity in the lab do not affect the results of the measurements and in the specimens measured intermediate 10x10 cm area, one-dimensional steady state heat flow can develop during all three measured temperature stages



Thermal conductivity measurements



1. warm side
2. cold side
3. temperature in the specimen
4. temperature in the chamber

We measured the thermal conductivities at three stages around 10 °C, 20 °C and 30 °C and the tests ended when relative error in thermal conductivity was under 0.2 %.

Measurement results

Type	Name	Measured TC after 28 days moist samples @ 23 °C λ [W/mK]	Measured TC of dried samples @ 23 °C λ [W/mK]
steel fibre reinforced concrete	REF	1,79	1,68
	S35	1,87	1,75
	S27,5	2,11	1,99
reinforced concrete	S20	2,16	2,03
	REF	-	1,46
	P1 - 6mm	-	1,47
reinforced concrete	P2 - 5mm	-	1,48
	P4 - 4mm	-	1,48

- steel fibre reinforced concretes had higher thermal conductivity compared to reinforced concretes
- reinforcement bars in concrete only slightly changed the thermal conductivity
- randomly oriented steel fibres could increase the thermal conductivity of a sample by up to 20%
- increasing the amount of steel fibre (e.g. from 20 kg/m³ to 35 kg/m³) decreases the thermal conductivity

The measured values remained below the MSZ EN ISO 10456:2008 standard values, but we should highlight that the density of concrete, the concrete mixture or the porosity can greatly influence the thermal conductivity.



Thermal diffusivity

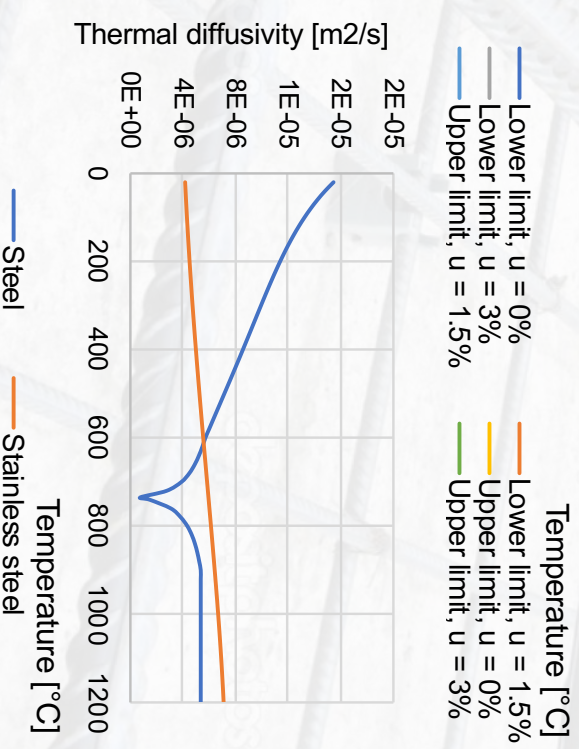
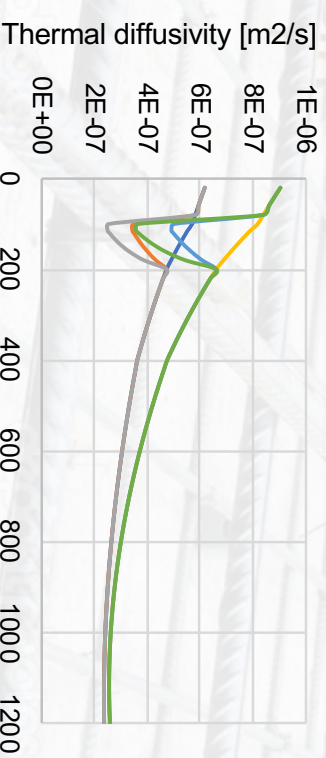
Thermal diffusivity measures the rate of heat transfer in a material, and is mandatory to know for transient heat transfer calculations, such as calculating the reinforced concrete structure's momentary temperatures in fire resistance design.

$$a = \lambda / (\rho \cdot C_p) \text{ [m}^2\text{/s]}$$

λ – thermal conductivity [W/mK]

ρ – bulk density [kg/m³]

C_p – specific heat capacity [J/kgK]





Thermal properties of reinforced concretes

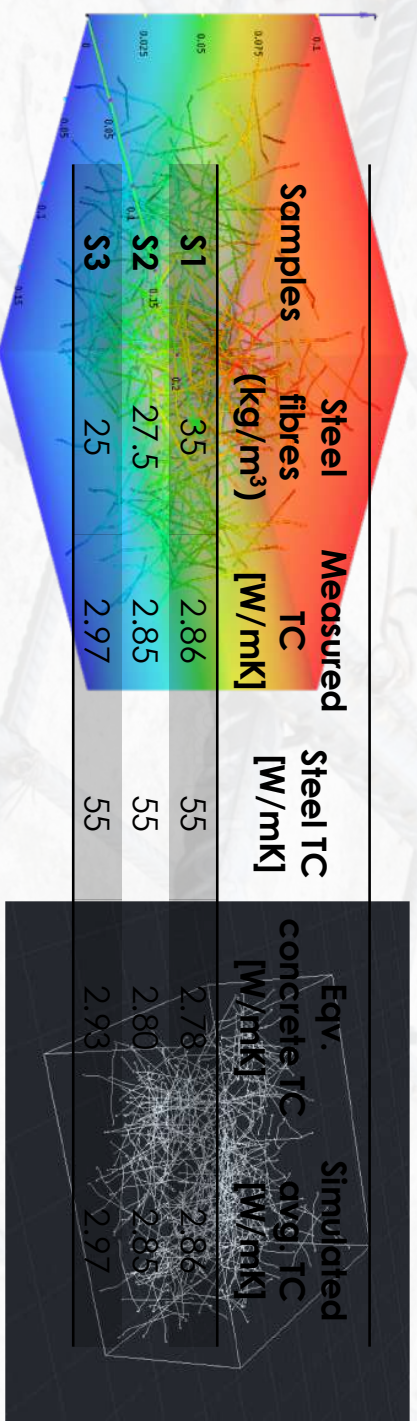
Type	Sample	Density ρ [kg/m ³]	Specific heat capacity C_p [J/kgK]	Thermal conductivity λ [W/mK]	Thermal diffusivity $[\cdot 10^{-7}$ m ² /s]
steel fibre reinforced concrete	REF	2401	880	1.68	7.95
	S35	2429	873.8	1.75	8.25
	S27,5	2419	875.1	1.99	9.40
reinforced concrete	S20	2414	876.4	2.03	9.59
	REF	2280	880	1.46	7.28
	P1 - 6mm	2311	874.2	1.47	7.28
	P2 - 5mm	2315	886.8	1.48	7.21
	P4 - 4mm	2306	885.2	1.48	7.25
MSZ EN ISO 10456	Reinforced 2 % steel	2400	1000	2.5	10.40
	Reinforced 1 % steel	2300	1000	2.3	10.00

Numerical simulations

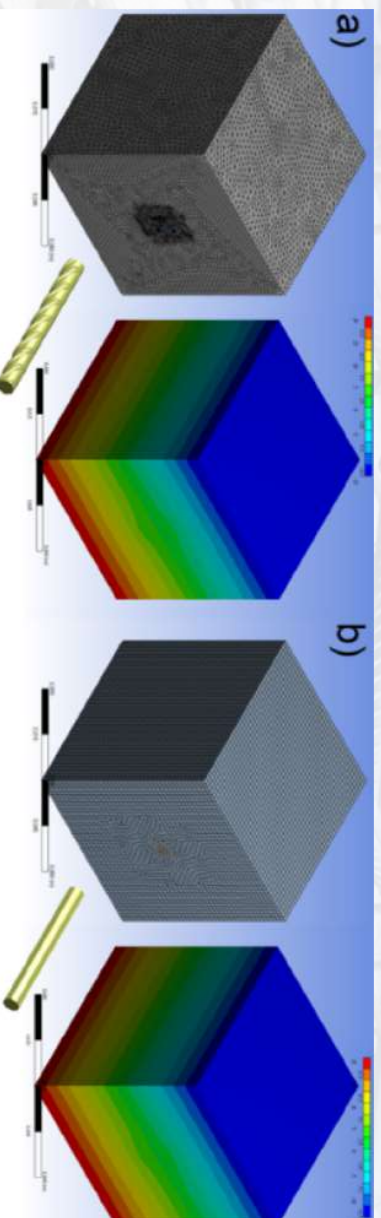
Our first target was to model and predict the thermal conductivity of concretes with different amount of randomly oriented steel fibres in it.



- thermal conductivity of steel fibres was set to 55 W/mK
- the equivalent thermal conductivity of concrete was iterated and chosen to get the measured thermal conductivities of each sample



Numerical simulations



- simplification of rebars was necessary
- models with octagonal-based prism showed less than 1% difference, however both FE mesh and running time is reduced dramatically
- six different 6 m x 6 m x 0.2 m roof slab parts using different diameters (8 mm, 10 mm and 12 mm) for the reinforcement bars
- in the case of slabs, the distribution of the rebars are not alternate significantly the thermal conductivity of the concrete slab
- in any case, the difference between the heat fluxes was below 2%
- there is connection between the placed amount of reinforcement bars and the heat fluxes, even if the difference is insignificant
- solid reinforced concrete slabs can be modelled using concrete's thermal properties only

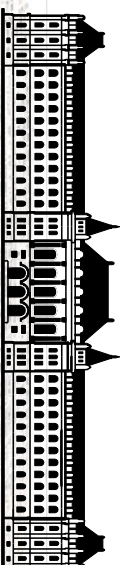


Summary

- we reviewed European Standards on thermal conductivities of concrete, reinforced concrete and steel, and this paper shows that there is substantive difference between the measured thermal conductivities and the standard's values
- in case of steel fibre reinforced concretes increasing the amount of steel fibre does not necessarily increase the thermal conductivity
- reinforced concrete slabs can be modelled using only the concrete's thermophysical properties if the mandatory minimum concrete covering is applied
- after we measured and simulated specimens of bar reinforced concretes, we showed that the measured values are different than the operative standard's, but similar to the Czech or old Hungarian standard's values
- opposed to this, fibre reinforced concretes have significantly different thermophysical properties compared to reference concretes
- with the measurements and simulations, in the field of building physics and energy design we are able to calculate more accurately the reinforced concrete's thermal behaviour



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