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Issues Arising from Using Supplementary Cementing Materials in Cement Based Foams

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OUTLINE

- Introduction
- Production of Cement Based Foams
- Relevant Tests & Experimental Set up
- Results & Discussion
- Concluding Remarks

INTRODUCTION

- Cement Based Foams
- Supplementary Cementing Materials

What are Cement Based Foams?

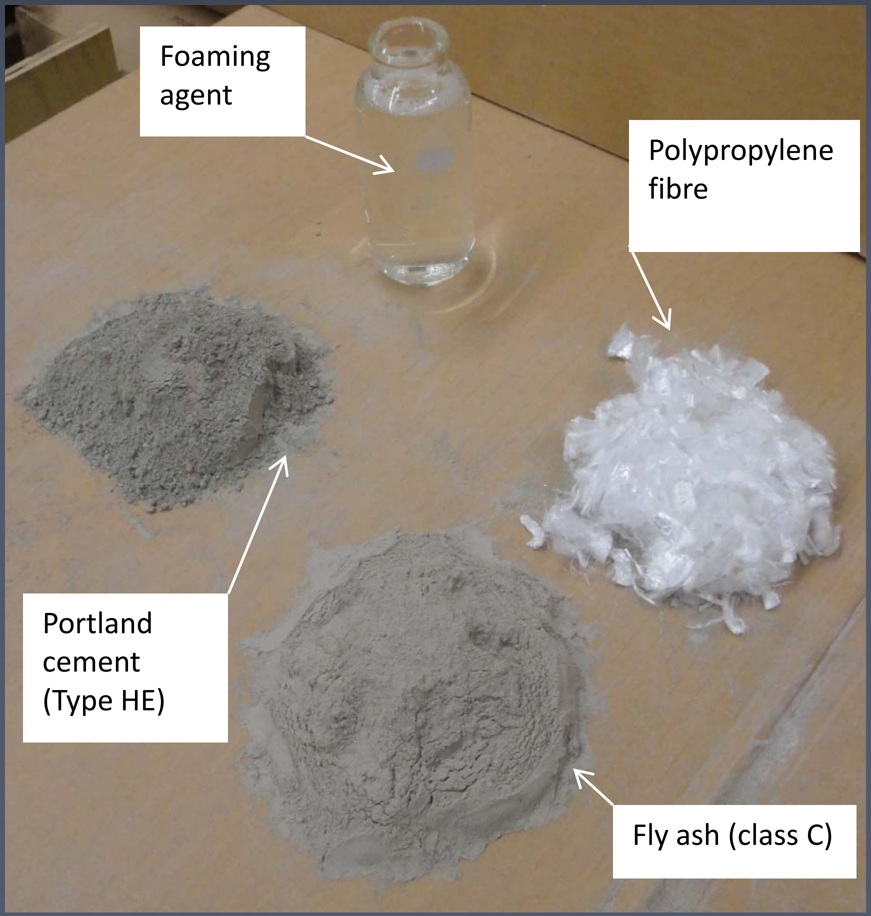
- Cement based foam is a light weight mixture of:
  - Cementitious material
  - Fine aggregate (for density higher than 800 kg/m^3)
  - Water
  - Stable foam
- Applications typically include:
  - Engineered, non-structural fill
  - Precast panels
  - Thermal and acoustic insulation
  - Refractory materials

Cement Based Foams In Alberta

- Principal advantages:
  - High strength to weight ratio
  - Low demolition cost
  - Favourable thermal properties

- Properties of Interest
  - Rheology (must be self-levelling)
  - Thermal Conductivity

Mix Constituents & Supplementary Cementing Materials



Typical Mix Constituents

Alternate SCM

Supplementary Cementing Materials

- Fly ash (class C) was introduced at 20%, 25% and 50% of the binder.
- Silica fume at 10% and 20%
- Metakaolin at 10% and 20% of the binder.

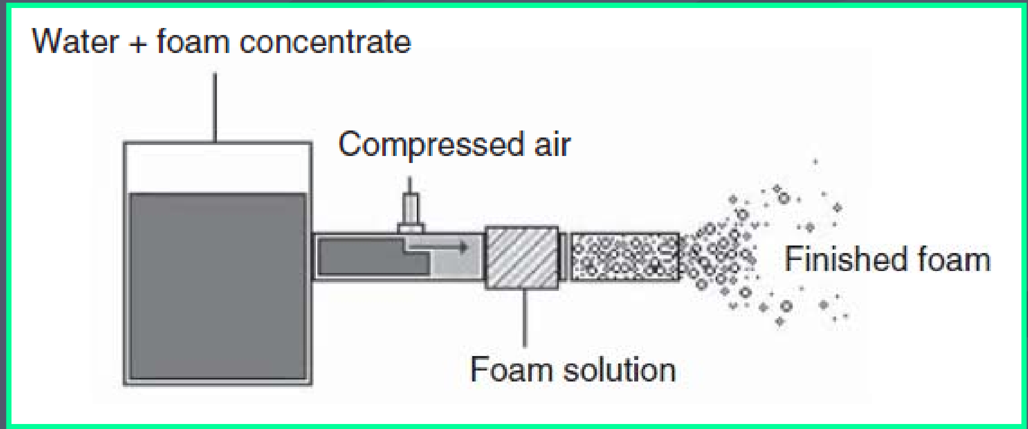
Chemical Composition%	Fly Ash (Class C)	Silica Fume	Metakaolin
Silicon Dioxide (SiO_2)	35	90	51
Aluminum Oxide (Al_2O_3)	20	2	42
Ferric Oxide (Fe_2O_3)	5	2	0.50
Calcium Oxide (CaO)	20	0	0.35

Production of Cement Based Foams

1. Foam Generation
- Diluted surfactant is aerated using compressed air.
- Liquid-air combine is then forced to pass through a nozzle.
2. Preparing the Slurry
3. Flow Check for Target Density
4. Adding the Foam to the Slurry

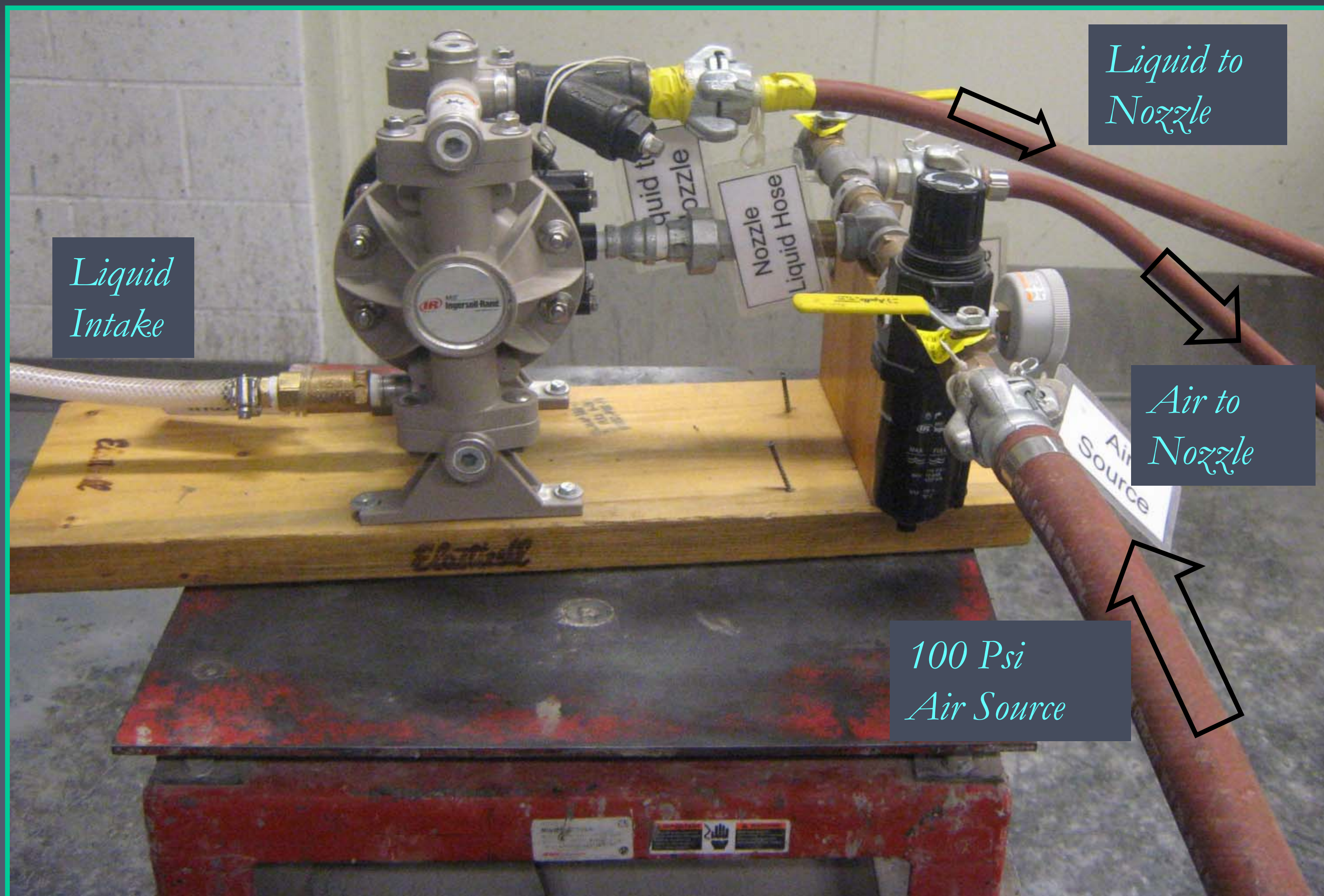
Ingredient	Weight (%)
Fatty Alcohol	1-10
Alcohol	6.5-35
Fatty Acid	10-65

Composition of synthetic foaming agent

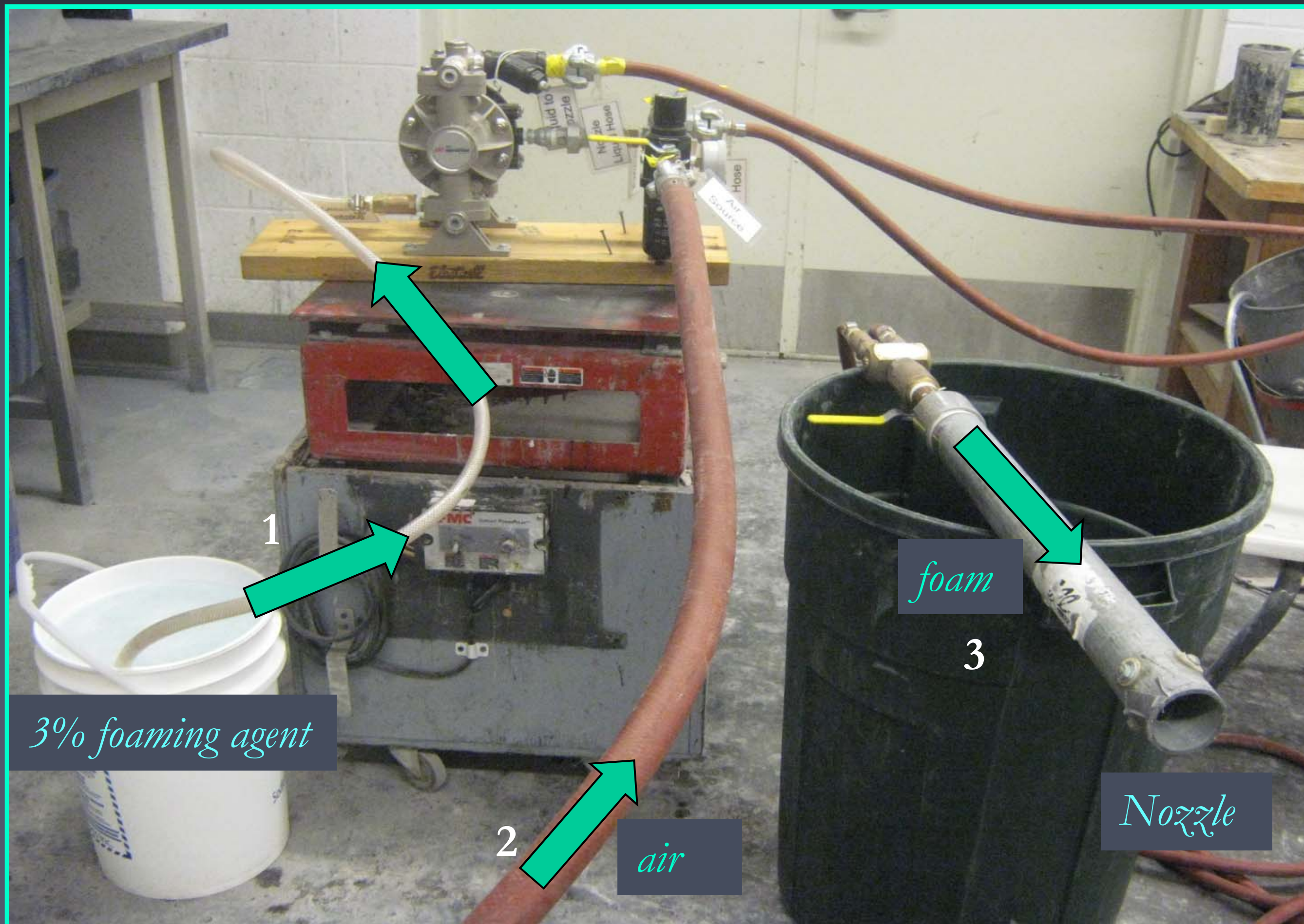


Schematic of a foam generator

Components of the Foam Generator



Sequence for Foam Generation



Step-1. Foam Production

Stable foam coming out from nozzle

Foam ready to be mixed with slurry

Step 2. Preparing the Slurry

- Dry Powder of Cement and SCM is Mixed with Water.

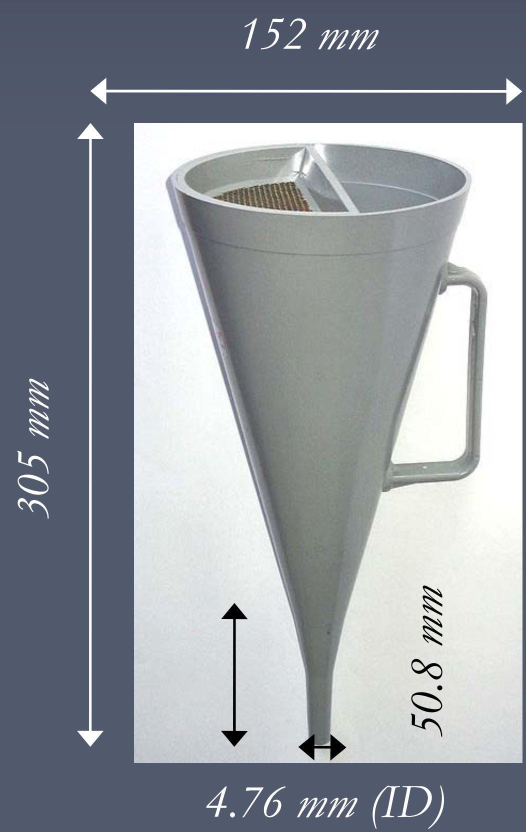
- Modified Drill (Paint Mixer) used for Mixing.

Cement, Water and SMC

Mixing with Drill

Step 3. Flow Check for Target Density

- Time taken for 350 ml of slurry to flow through the Marsh funnel relates to cast density.
- Besides density, this test also ensures flow-ability.



Marsh Funnel

Marsh Funnel Test

Step 4. Adding Foam to Slurry

- Gradual mixing of foam and slurry.
- Addition of fibre reinforcement, if any.
- Check for cast density of foam concrete intermittently.
    - Cast at 400, 600 and 800 kg/m^3

Slurry in rotary type mixer

Mixing foam with slurry

Polypropylene Fibres

Property	Value
Fibre Length (mm)	20
Density (kg/m^3)	910
Tensile Strength (MPa)	450
Modulus of Elasticity (MPa)	3450
Denier	3

Composition of Mixes Examined

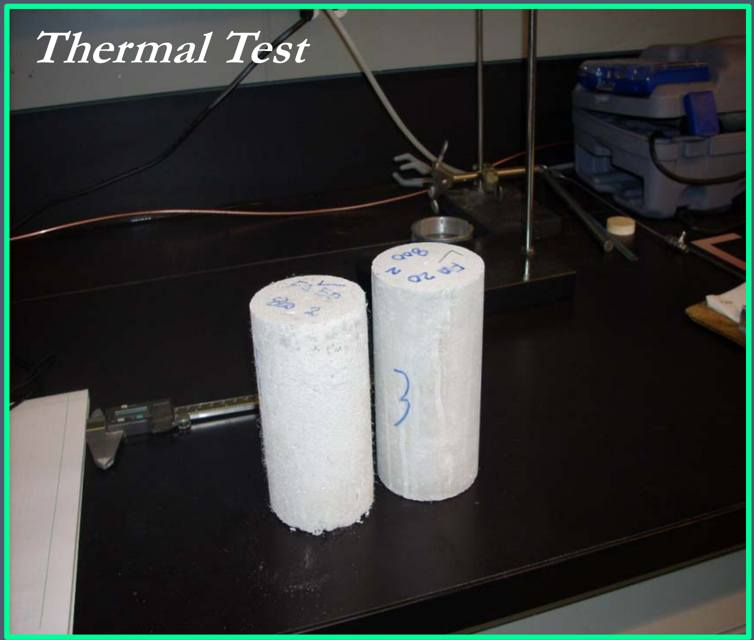
SCM	Cast Density kg/m³	Cement kg/m³	Water kg/m³	SCM kg/m³	Foam kg/m³	Fibre (0.2% V_f)
20%Fly Ash	800	425	291	85	18	23
	600	319	218	64	22	23
	400	213	146	43	28	23
25% Fly Ash	800	408	291	102	18	23
	600	306	218	77	22	23
	400	204	146	51	28	23
50% Fly Ash	800	340	291	170	17	23
	600	255	218	128	22	23
	400	170	146	85	27	23
10% Silica Fume	800	464	291	47	17	23
	600	348	218	35	22	23
	400	232	146	24	27	23
20% Silica Fume	800	425	291	85	16	23
	600	319	218	64	21	23
	400	213	146	43	26	23
10% Metakaolin	800	464	291	47	17	23
	600	348	218	35	22	23
	400	232	146	24	27	23
20% Metakaolin	800	425	291	85	16	23
	600	319	218	64	21	23
	400	213	146	43	27	23

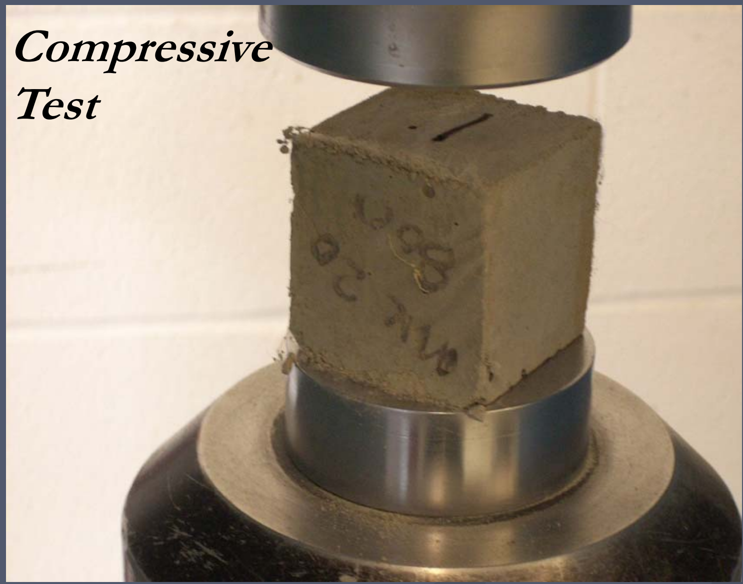
Tests Conducted

1. Compressive Test
   (ASTM C 39)

2. Thermal Conductivity
   (ASTM D5334)

Foam Concrete Specimens





- *Size of cylinders 3in x 6in (75 mm x 150 mm)*
- *Size of cube 50 mm x 50 mm x 50 mm*

Experimental Set Up

Thermal Probe Needle Test ASTM D 5334 method is:

- A transient heat method.
- Capable of determining the thermal conductivity & diffusivity of soil and soft rock.
- Suitable only for isotropic materials.

- Applicable to dry materials over a wide temperature range from <0 to >100°C, depending on the suitability of the thermal needle probe construction to temperature extremes.

- Also used for specimens containing moisture.

Thermal Conductivity

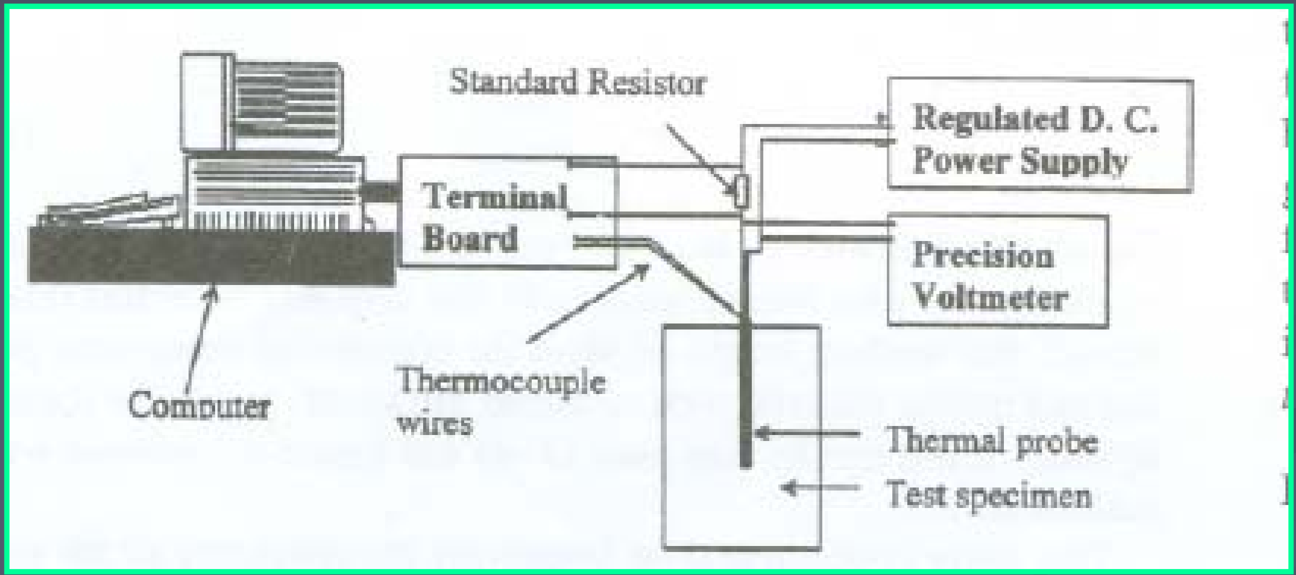
- Coefficeint of thermal expansion for cellular concrete varies directly with density

- Typically 5.0 to 7.0 x 10-6 per ° F (9.0 to 12.6 x 10-6 per ° C)

Oven Dry Density		**Thermal Conductivity, K**	
lb/ft^3	kg/m^3	BTU x in (h x ft^2 x °F)	*w*/(m x K)
20	320	0.75	0.11
30	480	0.91	0.13
40	640	1.11	0.16
50	800	1.36	0.20

Typical thermal conductivity values for oven dry cellular concrete

Transient Line Source Thermal Test (ASTM D 5334)



Schematic of electrical circuit and data acquisition system at the University of Alberta

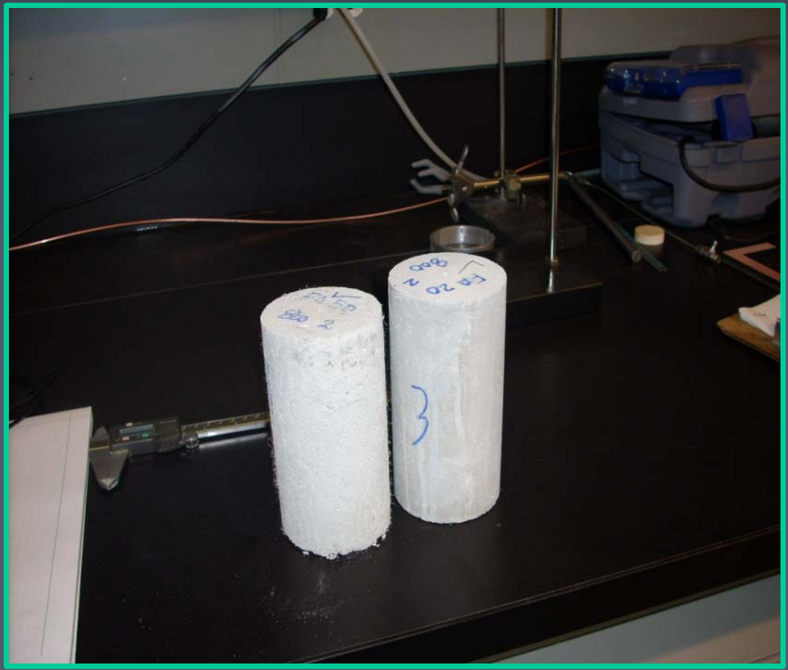
Components of the Thermal Probe Needle

Power Supply

Base platform with axial heating source

Computerized data-acquisition

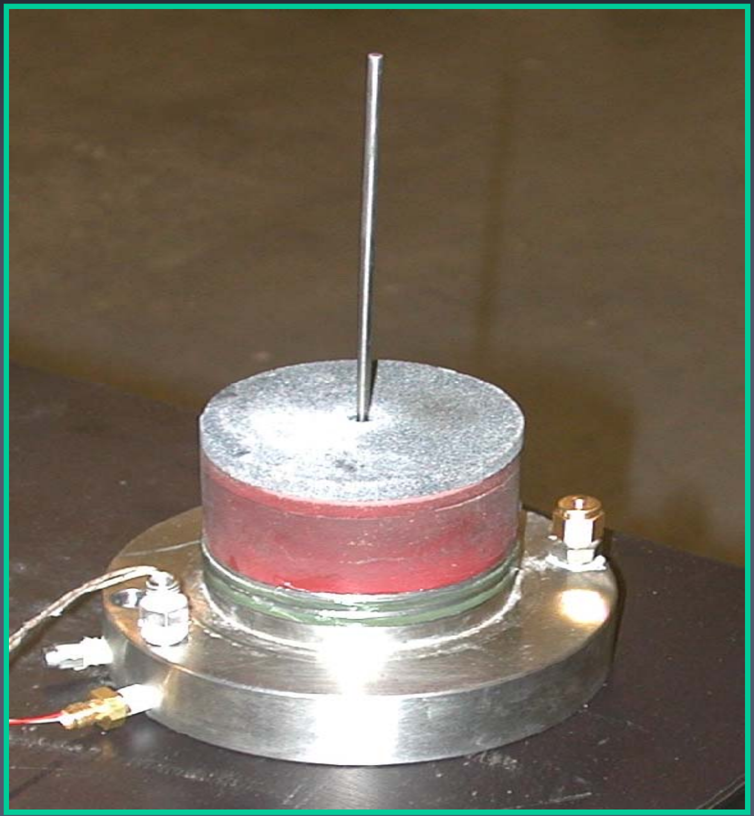
Sample Preparation



Foam concrete cylinders

Drilling the sample to accommodate the thermal probe

Testing of Specimens



Base platform with axial heating source

Sample mounted and ready for testing

Calculation of Thermal Conductivity

- Temperature of needle and time-history are recorded
- Power supply values were recorded
- Graph plotted between needle temperature and time (ln) in seconds
    - Slope of the plot is calculated
- Thermal conductivity K was calculated from the above

Results & Discussion

- Effects of SCM on:
  - a) Fresh Properties
  - b) Compressive Strength of Hardened Samples

- Effects of Thermal Conductivity on:
  - a) 20 to 50% of Fly Ash
  - b) 10 to 20 % of Silica Fume
  - c) 10 to 20 % of Metakaolin

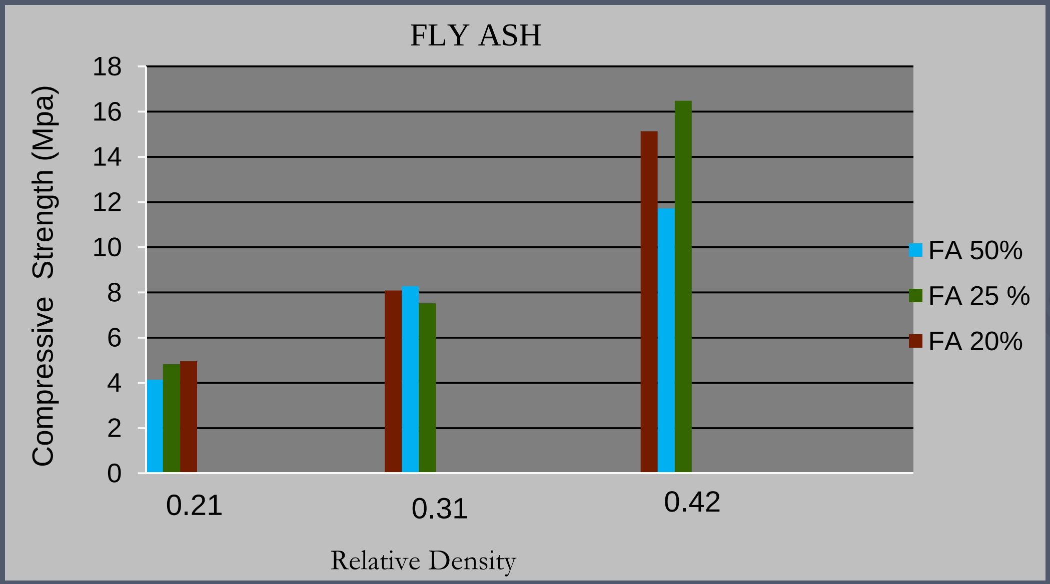
Effects of Supplementary Cementing Materials

Fresh Properties

- Time taken by slurry to flow through the funnel decreases with an increase in Fly Ash
- Silica Fume and Metakaolin registered higher time-to-flow for the same cast density
- In particular, Metakoalin showed a significant increases in time-to-flow compared with Silica Fume for identical dosage and density.
- Uneven fibre dispersion was observed with reduced flowability at higher dosage of SCM, in all cases.

SMC	% of Replacement Materials	Marsh Funnel Reading (s)
Fly Ash	20%	35-40
	25%	34-39
	50%	33-37
Silica Fume	10%	40-49
	20%	60-64
Metakoalin	10%	60-70
	20% (7 ml HRWRA)	90-120 54-60

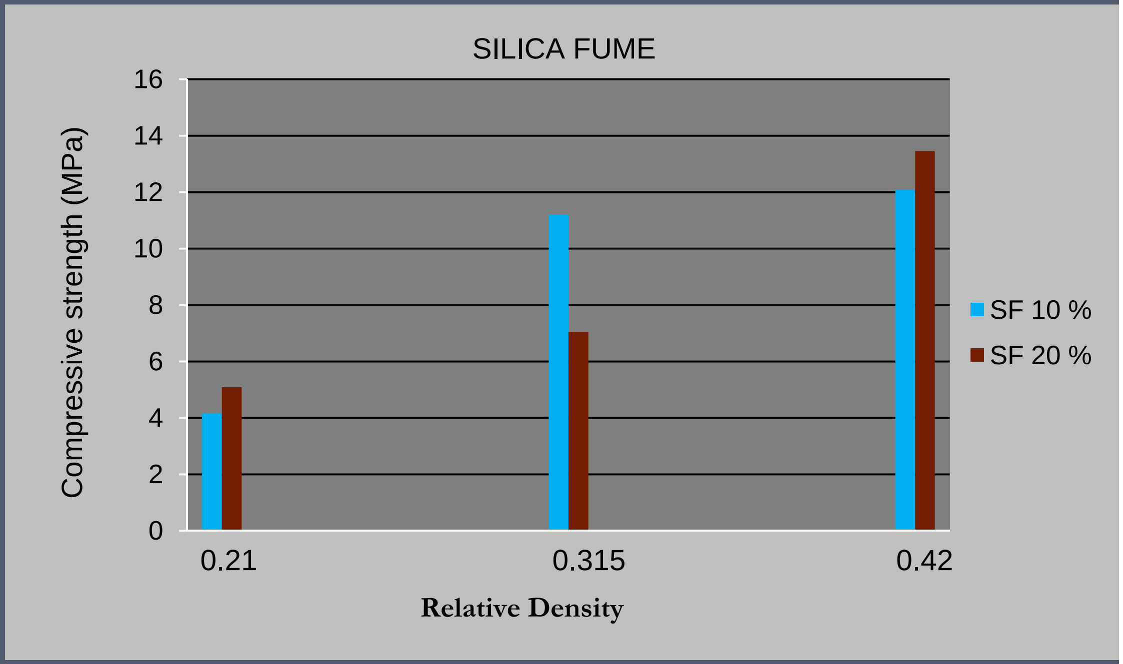
Compressive Strength (1)



- ➢Increased amount of Fly Ash reduces the compressive strength.
- ➢Difficult to minimize the difference between cast and dry density specially for < 600 kg/m3.

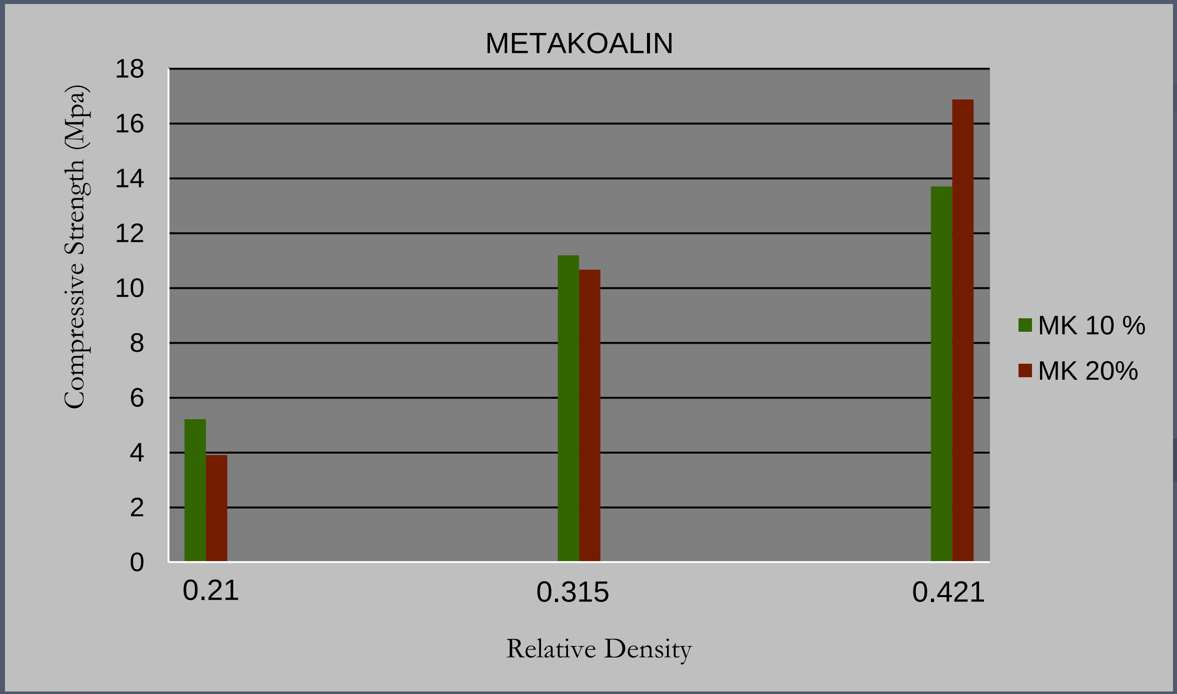
Compressive Strength (2)

- Increased amount of Silica Fume increases the compressive strength.



Compressive Strength (3)

- Higher Dosage of Metakoalin increases the compressive strength.
- Significant drop was noticed in the dry density specially for cast density less than 600 kg/m^3.
- Small sizes of samples should be avoided specially for lower density as it led to inconsistent dry density.

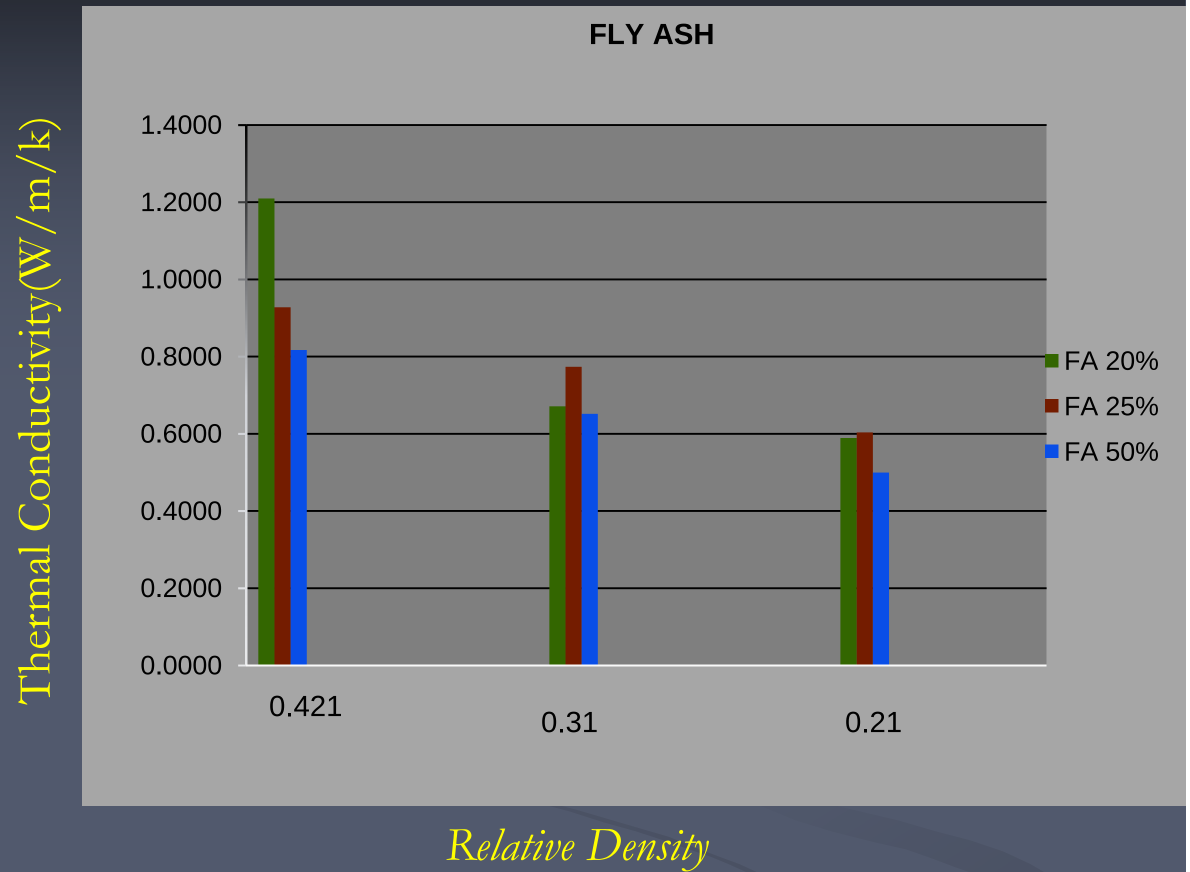


Effect on Thermal Conductivity

1. Fly Ash

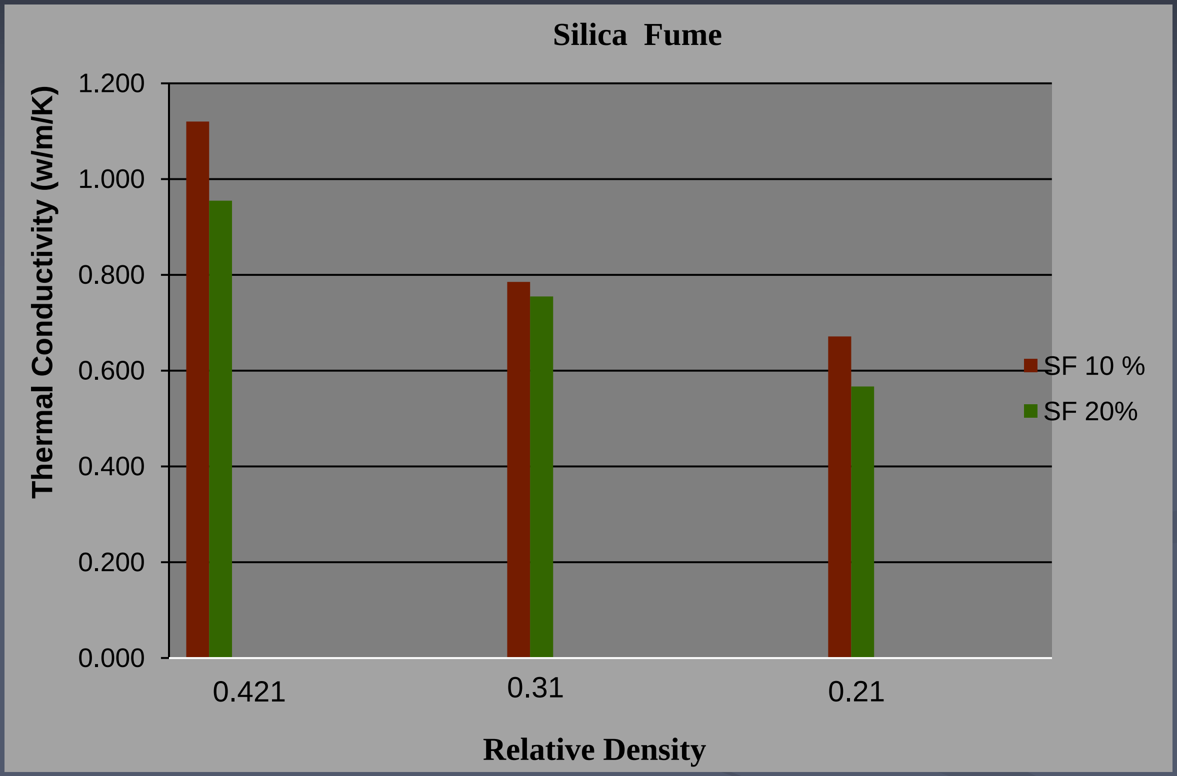
- The thermal conductivity decreased with an increase in the fly ash fraction in the binder.

- A linear relationship was obtained between thermal conductivity and dry-density as noted by other researchers.



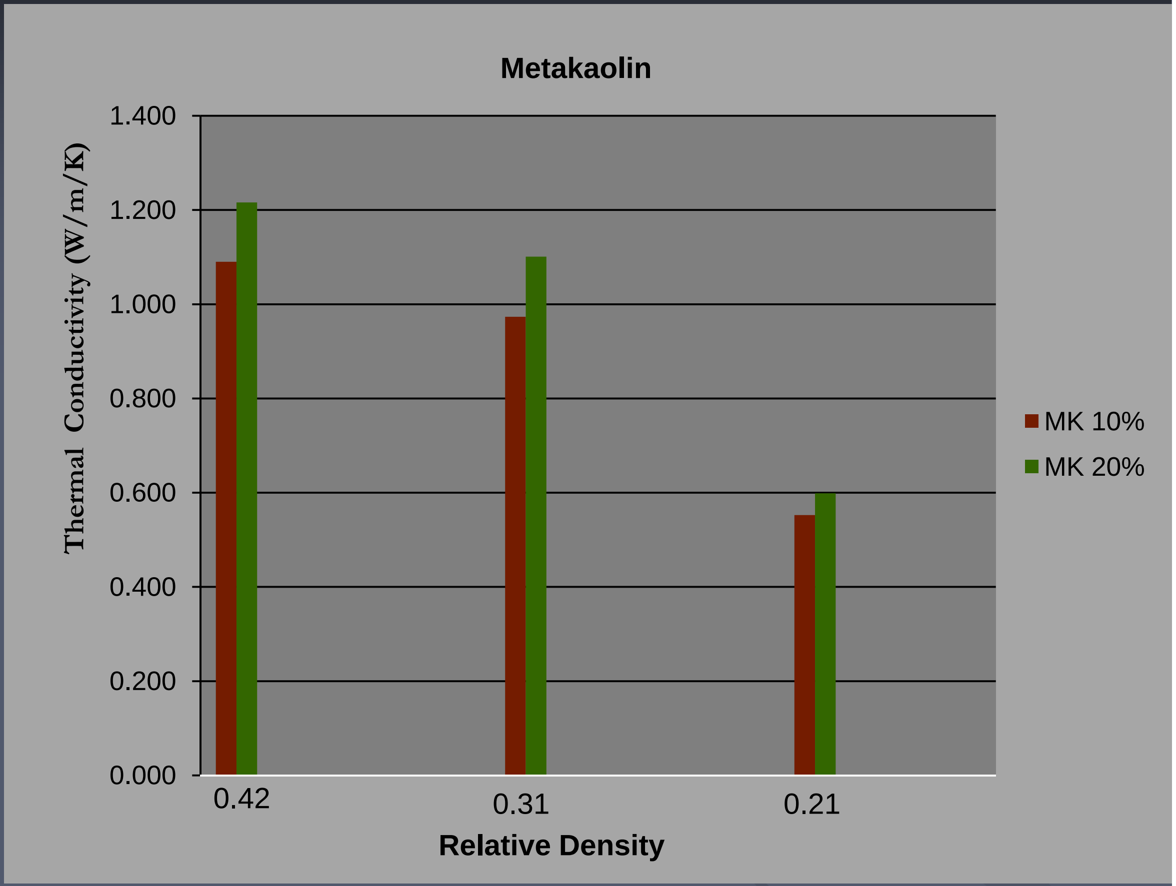
2. Silica Fume

- An increase in the Silica Fume fraction of the binder led to a drop in the thermal conductivity.



3. Metakoalin

- Thermal conductivity **increased** with an increase in Metakoalin dosage in the binder. (Could this be due to the *Al_2O_3* component?)



Thermal Conductivity vs Relative density

There was a linear relationship between thermal conductivity and dry density in all cases.

Concluding Remarks

- It is difficult to achieve desired dry density for cast density less than 600 kg/m^3
  - This was further compounded for smaller specimens

- Fly ash with 50% mix in general and 400 kg/m^3 in particular was difficult to cast.

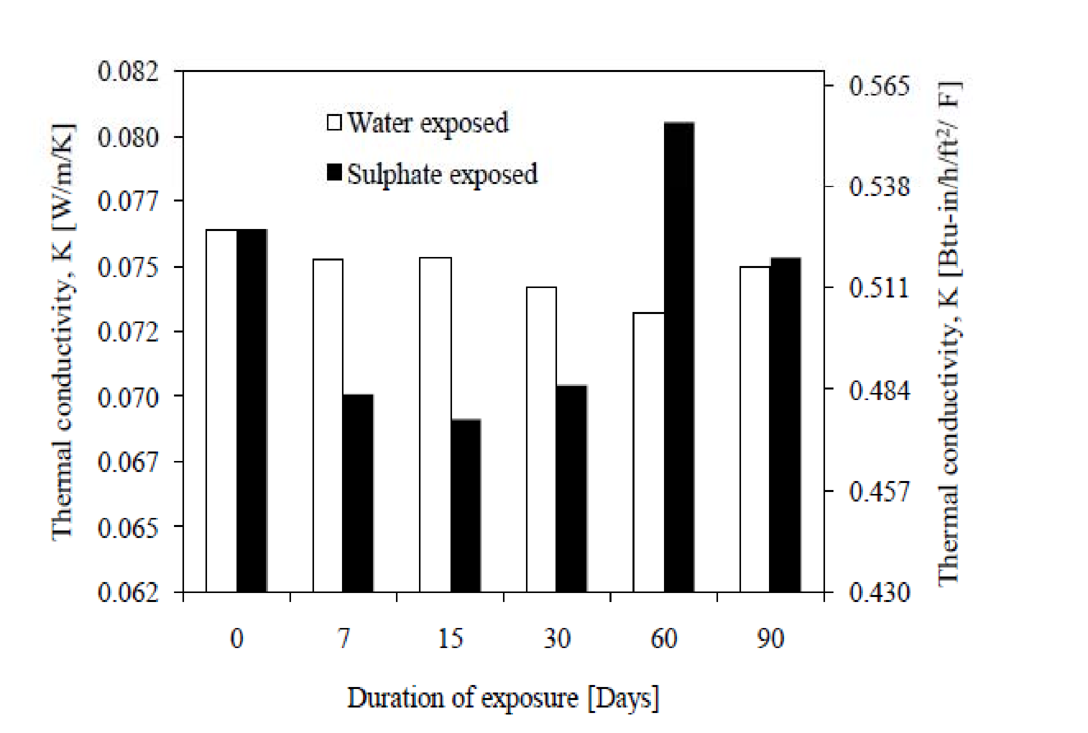
- Where as the compressive strength decreased with an increase in the dosage of fly ash, silica fume and metakoalin led to an increase in the compressive strength, for the levels examined.

- For Fly-Ash and Silica Fume, the thermal conductivity decreased with an increase in dosage. On the other hand, metakoalin when used as an SCM led to an increase in the thermal conductivity of the foamed composite.

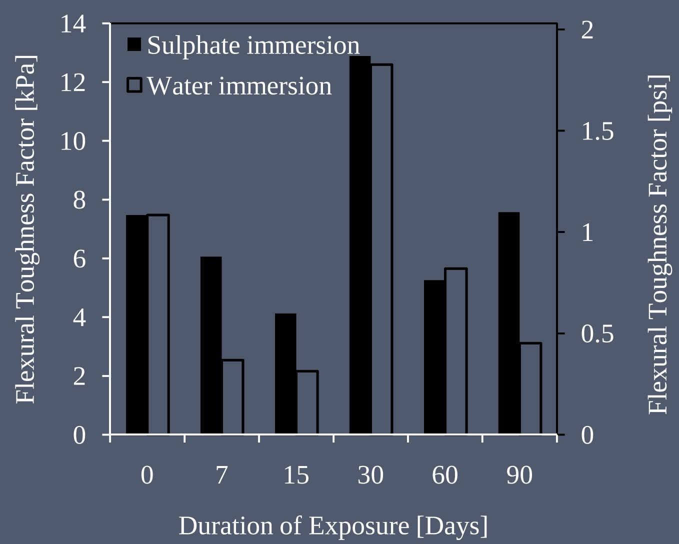
Exposure to Sulphates

Sulphate Exposed (no fibre)

➢Sulphate exposed samples exhibit a decrease in thermal conductivity immediately upon exposure due to onset of cracking. Sustained exposure to sulphates beyond 30 days led to an increase in the thermal conductivity. This is likely due to self-healing .

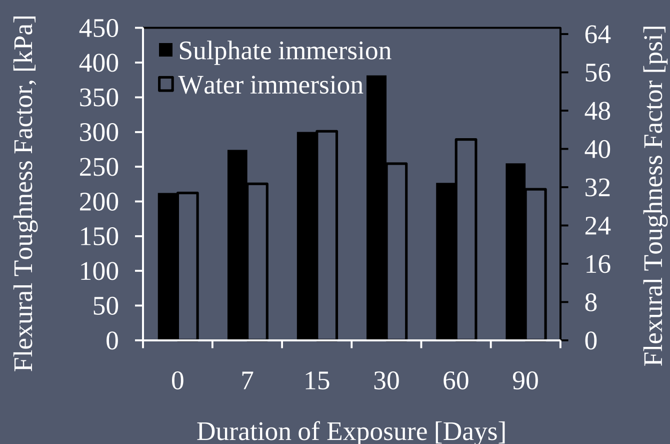


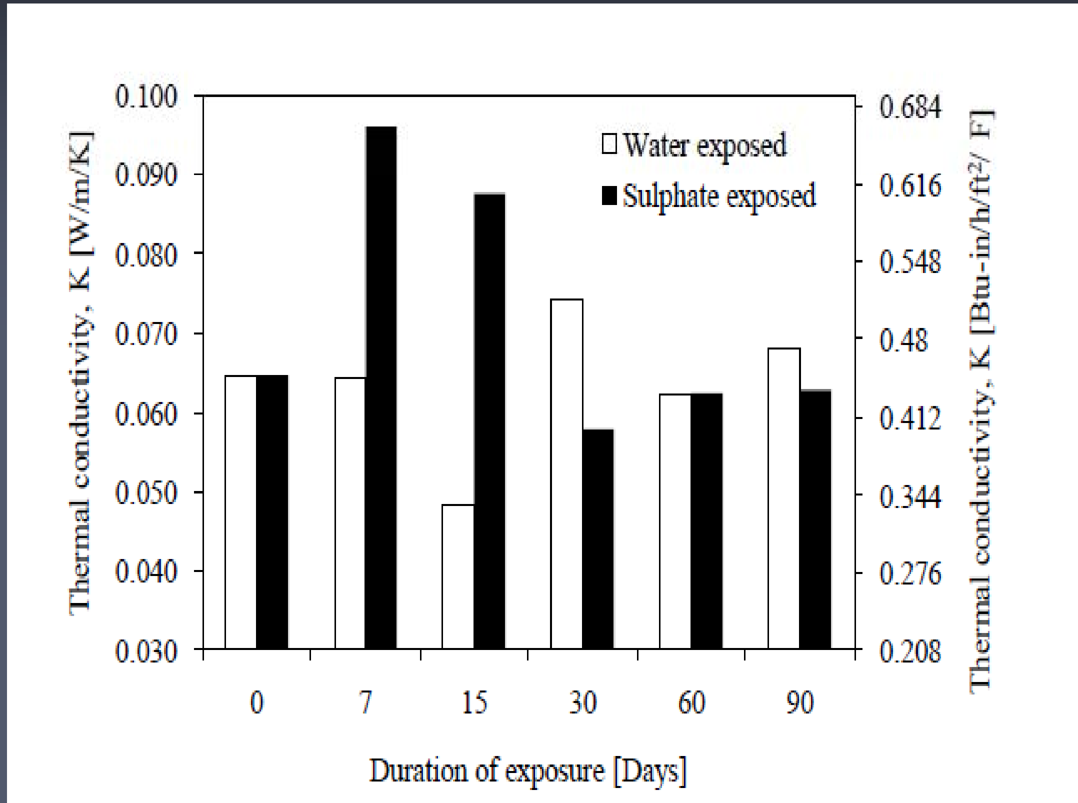
Thermal conductivity of plain (0.0% fibre) cement-based foams after immersion to sulphate bath and water bath for various duration of exposure(457kg/m^3).



Sulphate Exposed (with fibre reinforcement)

- Sulphate exposed samples with fibre reinforcement exhibit an increase in the thermal conductivity upon immediate exposure. This was attributed to crack arrest mechanisms effected through the presence of micro-fibres.





Thermal conductivity of fibre reinforced (0.2%) cement-based foams after immersion to sulphate bath and water bath for various durations of exposure. (cast density = 475kg/m³).

Effect of Sulphates

When exposed to a sulphate solution, specimens with fibres have higher flexural toughness factor and thermal conductivity compared to an unexposed sample. These parameters drop only after 30 days of sustained exposure.

This may have a bearing on the choice of SCM, since that will lead to improved fibre-matrix bond.

Acknowledgements

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THANK YOU!