Effect of Slag Characteristics on Adiabatic Temperature Rise of Blended Concrete

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Introduction

- Cement hydration is an exothermic chemical reaction that, along with the relatively low thermal conductivity of concrete and low rate of heat dissipation, causes high concrete member temperatures, thermal stresses, and early-age thermal cracking
- Ground-granulated blast-furnace slag (slag) is a supplementary cementitious material (SCM) widely used in mass concrete to reduce concrete temperature rise and increase resistance to thermal cracking
- The temperature rise of concrete mixtures containing different slag compositions is not well studied to establish their effects on heat generation

Introduction

Research Significance

- This study investigated the adiabatic temperature rise of several cement-slag combinations of varying chemical and physical characteristics and related the findings to the measured adiabatic temperature rise.
- The findings of this study will supplement the current massive concrete specifications by implementing the provided data in the design of thermal control plans for slag-blended concrete.
- This will ultimately lead to minimizing high temperature rise issues experienced in the field and subsequently minimizing the potential for thermal cracking.

Experimental Approach

- Adiabatic Temperature Rise Tests
  - Hydration Parameters
- Isothermal Calorimetry
  - Activation Energy
- Sensitivity Analysis
  - Varying placement temperatures
  - Varying member size

Materials

I/II IL Slags

Analyte	Z	GILOP	S8	S10C	S10F	S14B	S17
SiO_2	19.4	18.4	38.4	36.3	36.7	33.4	30.5
Al_2O_3	4.64	4.56	7.82	10.7	10.1	13.8	17.1
Fe_2O_3	3.06	3.29	0.47	0.79	1.06	0.84	0.46
CaO	62.8	62.3	39.2	39.2	38.3	42	35.5
MgO	3.01	0.91	10.7	10.7	10.8	5.6	11
SO_3 as sulfate	3.25	2.93	0.18	0.05	0.11	1.22	1.39
Na_2O	0.02	0.18	0.28	0.26	0.3	0.23	0.48
K_2O	0.95	0.32	0.42	0.22	0.33	0.28	0.3
TiO_2	0.35	0.21	0.39	0.44	0.41	0.53	1.63
P_2O_5	0.05	0.43	0	0	0	0	0
Mn_2O_3	0.09	0.06	0.53	0.28	0.28	0.19	0.35
LOI (550°C)	0.75	1.62	—	—	—	—	—
LOI (950°C)	2.53	5.86	–0.77	–1.20	–0.06	0.09	0.17
Total	100	99.6	99.7	99.8	100	100	100
Na_2O_{eq}	0.65	0.4	0.56	0.4	0.52	0.41	0.68

Slags selected for:

- Al2O3 contents
- Fineness (10C vs 10F)

Materials

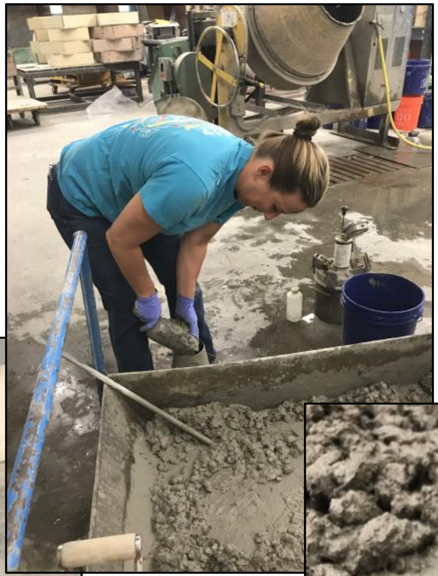
	I/II	IL	Slags				
Analyte	Z	GILOP	S8	S10C	S10F	S14B	S17
C_3S	54	44.5	—	—	—	—	—
C_2S	7.2	16.5	—	—	—	—	—
C_3A	5.6	3.7	—	—	—	—	—
C_4AF	7.7	8.9	—	—	—	—	—
Calcite	3.4	9.2	0.9	0.2	0.2	1.4	0.2
Gypsum	0.3	3.9	—	—	—	2	2.6
Hemihydrate	2.5	—	—	—	—	—	—
Portlandite	—	1.5	—	—	—	—	—
Quartz	0.2	0.4	—	—	—	—	0.1
Dolomite	0.5	0.7	—	—	—	—	—
Periclase	1.8	—	—	—	—	—	—
Syngenite	1.1	—	—	—	—	—	—
Melilite	—	—	0.4	0.4	0.3	0.3	1.4
Merwinite	—	—	—	1.1	1.1	0.1	—
Amorphous	15.7	10.6	98.7	98.3	98.4	96.1	95.7
MP), µm	13.5	13.1	9.49	10.3	9.03	12.6	9.79
Blaine fineness, m²/kg	412	469	617	485	600	553	510

Adiabatic Temperature Rise Testing - USBR

- 10 mixtures
- Two Cements (Type II and Type IL)
- Five Slags (60% replacement by mass)

Material	Cement Mixtures	Slag Mixtures
Cement, lb (kg)	665 (395)	266 (158)
Slag, lb (kg)	0	399 (237)
Coarse aggregate #57 limestone SSD, lb (kg)	1719 (1020)	1719 (1020)
Fine aggregate – SSD, lb (kg)	1174 (697)	1174 (697)
Water, lb (kg)	267 (158)	267 (158)
Air entraining admixture, fl oz (ml)	0.06 (2.3)	0.06 (2.3)
Water reducing admixture, fl oz (ml)	27.39 (1059)	27.39 (1059)
w/cm	0.404	0.404

Adiabatic Temperature Rise Testing - USBR



Fresh Properties – Type II(MH) Cement

Cement	Z					
Slag	--	S8	S10C	S10F	S14B	S17
Unit Weight (lb/ft³)	141.4	142.8	141.6	140.3	142.6	142.0
Slump (in)	5.00	5.00	4.25	6.50	2.75	3.5
Air Content (%)	3.6	3.2	--	4.5	3	4.4
Temperature (°F)	62.4	59.5	59.2	60.0	61.3	58.9

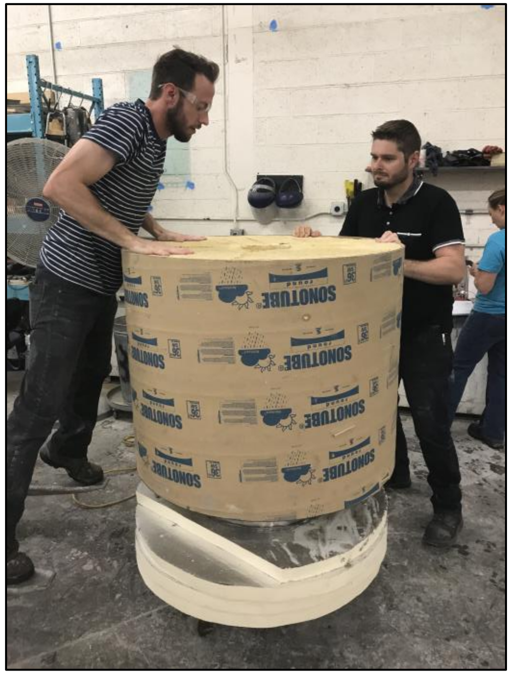
Fresh Properties – Type IL Cement

Cement	G1LOP			
Slag	--	S8	S14B	S17
Unit Weight (lb/ft³)	--	--	142.3	142.7
Slump (in)	3.25	4.00	2.00	4.75
Air Content (%)	--	--	2.8	2.9
Temperature (°F)	60.3	59.8	60.0	62.0

Adiabatic Temperature Rise Testing - USBR

- USBR 4911 – Procedure for Temperature Rise of Concrete

Sample Size = 4.62 ft^3



Polyurethane Insulation
R = 31.8

Moved to calorimeter
chamber within 30 minutes
from start of mixing time

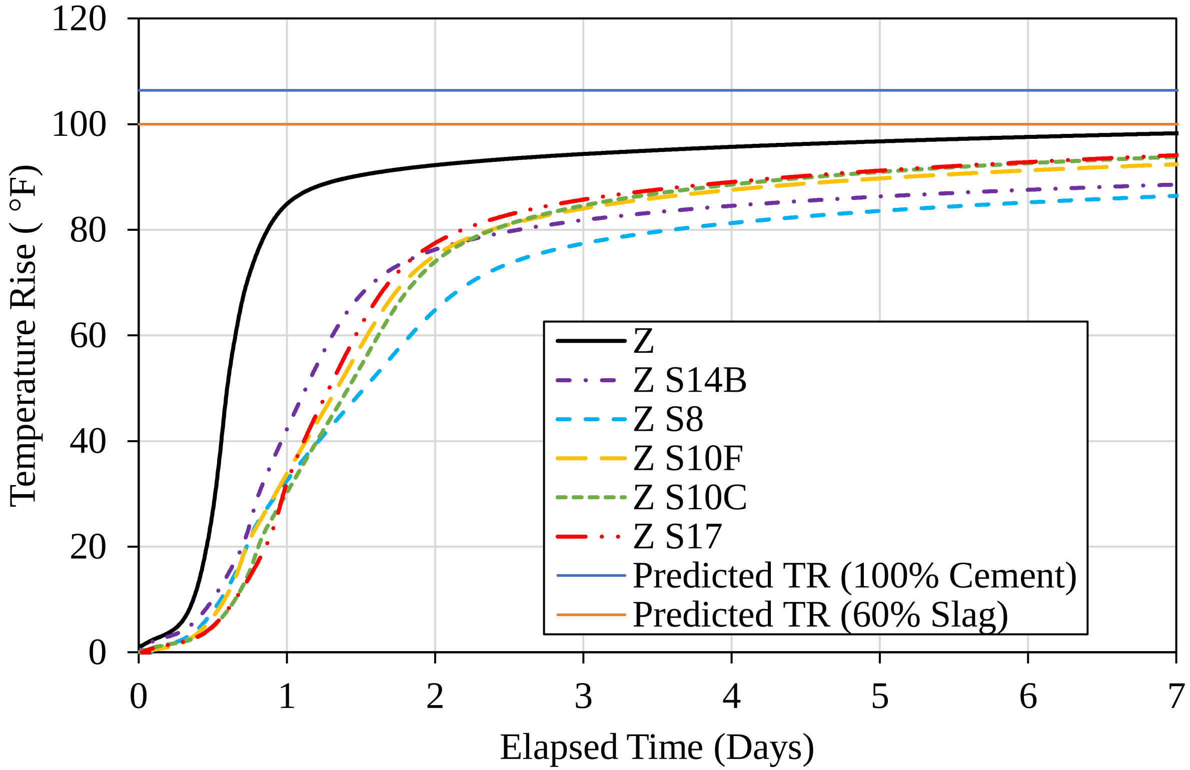
Two platinum RTD probes
at center of sample

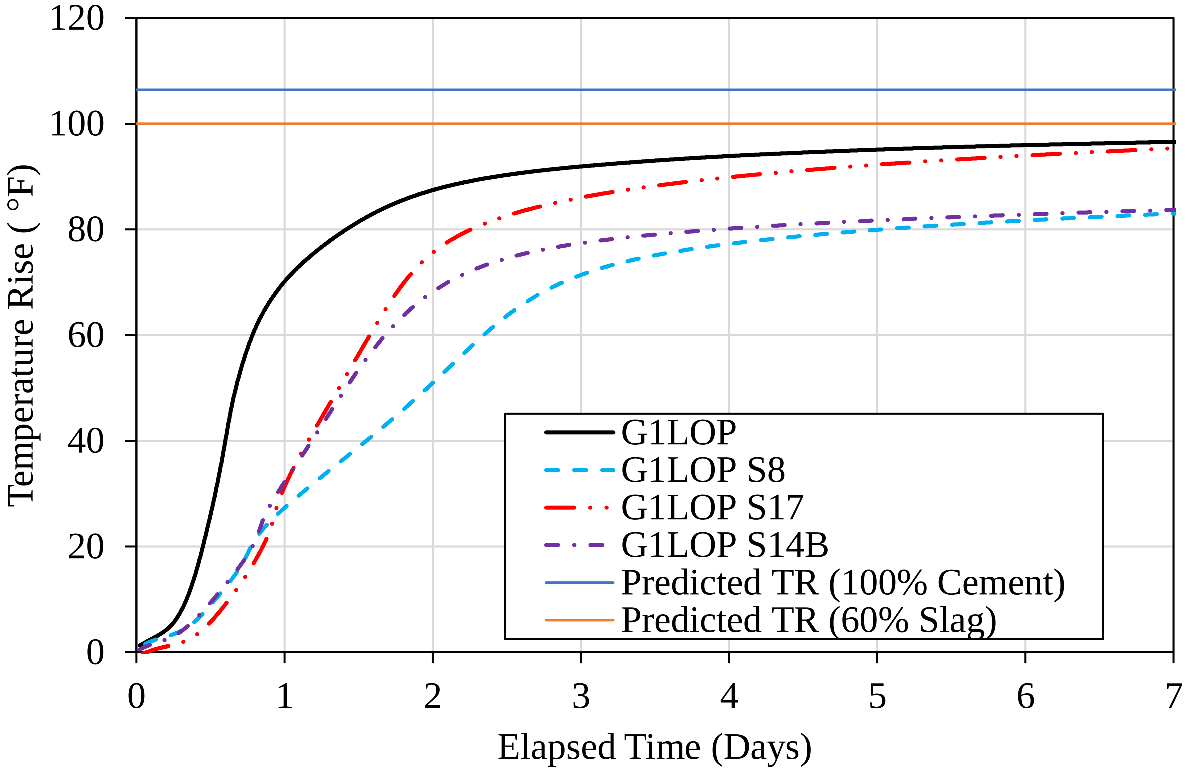
Adiabatic Temperature Rise Testing - USBR

- Six Environmental Chambers
  - 10 ft by 10 ft by 8 ft
  - -20 °F to 180 °F

- Adiabatic Calorimetry
  - Room temperature set to sample temperature within 0.01 °F
  - Records room temperature and sample temperature every 5 minutes

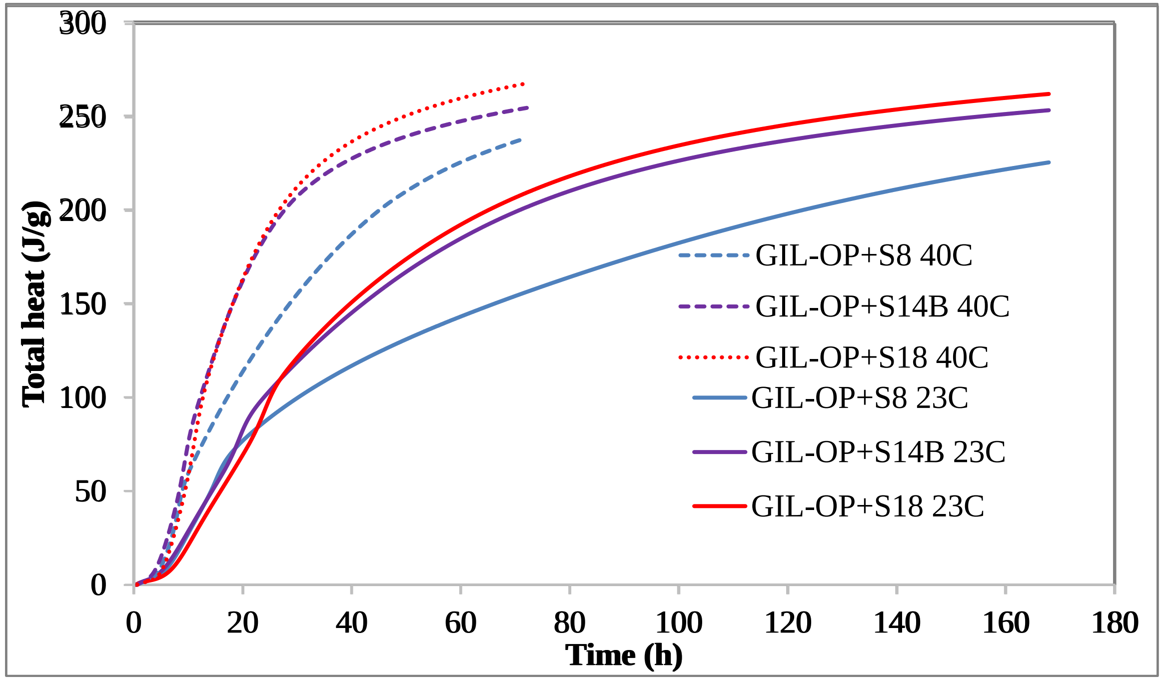
Adiabatic Temperature Rise Testing - USBR





Isothermal Calorimetry

- Measured at 20, 30, 40°C in 8-channel isothermal calorimeter
- Used to calculate activation energy

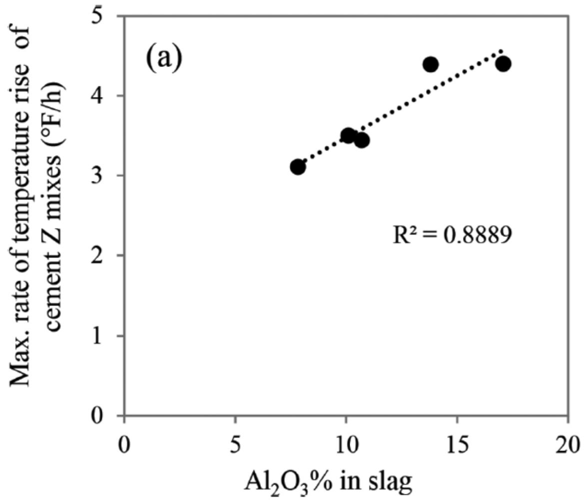


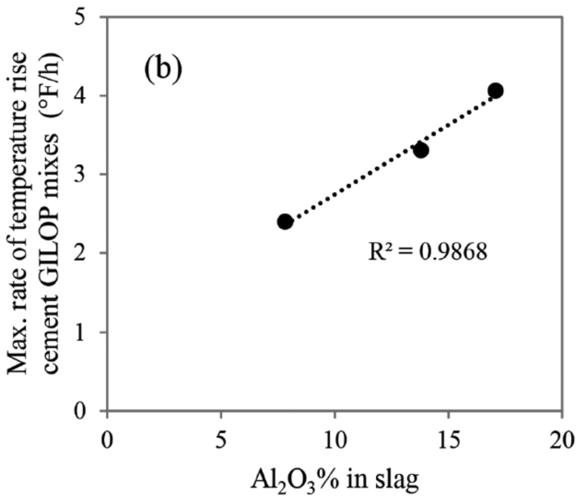
Mix ID	E_a (kJ/mol)
Control Z	28.3
Control GILOP	31. 5
Z-S8	43. 8
Z-S10C	45.5
Z-S10F	40.0
Z-S14B	37.6
Z-S17	30.2
GILOP-S8	38.7
GILOP-S14B	39.3
GILOP-S17	34.5

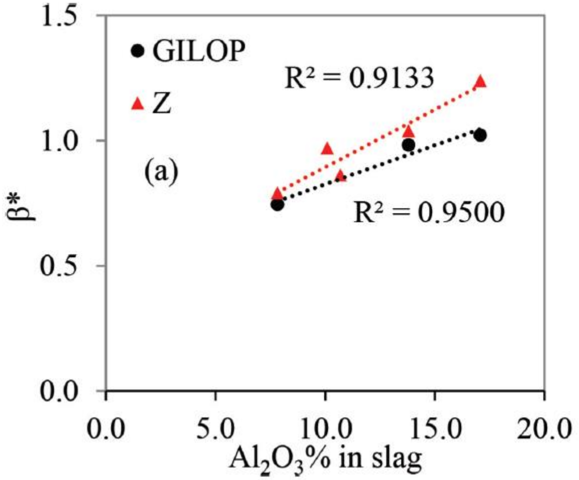
Results and Discussion

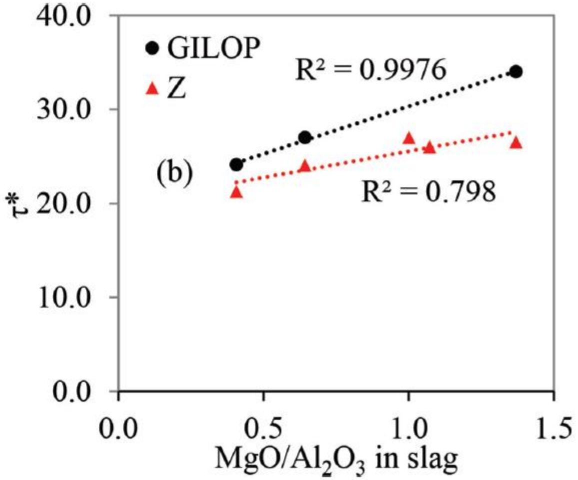
- Adiabatic temperature rise data fit

$$Q_h(t) = H_u \cdot W_c \cdot \left(\frac{\tau}{t_e}\right)^{\beta} \cdot \left(\frac{\beta}{t_e}\right) \cdot \alpha(t_e) \cdot \exp\left(\frac{E_a}{R}\left(\frac{1}{T_r} - \frac{1}{T_c}\right)\right)$$





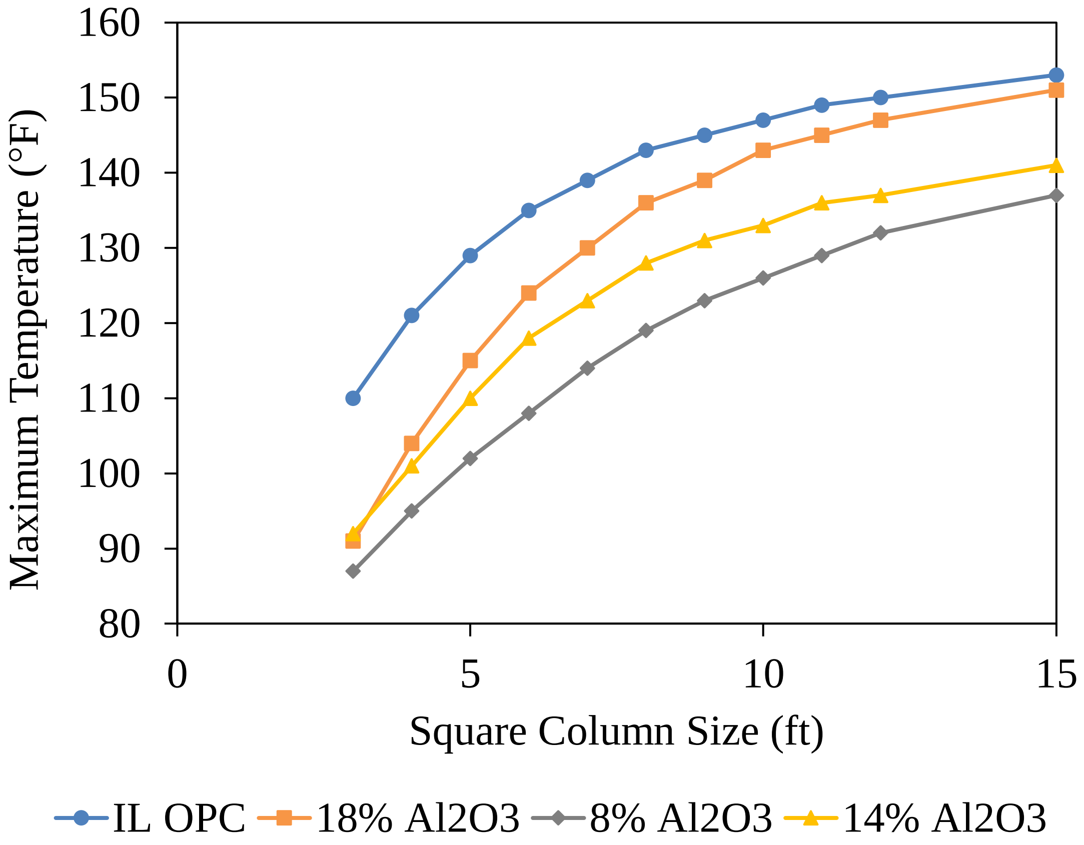


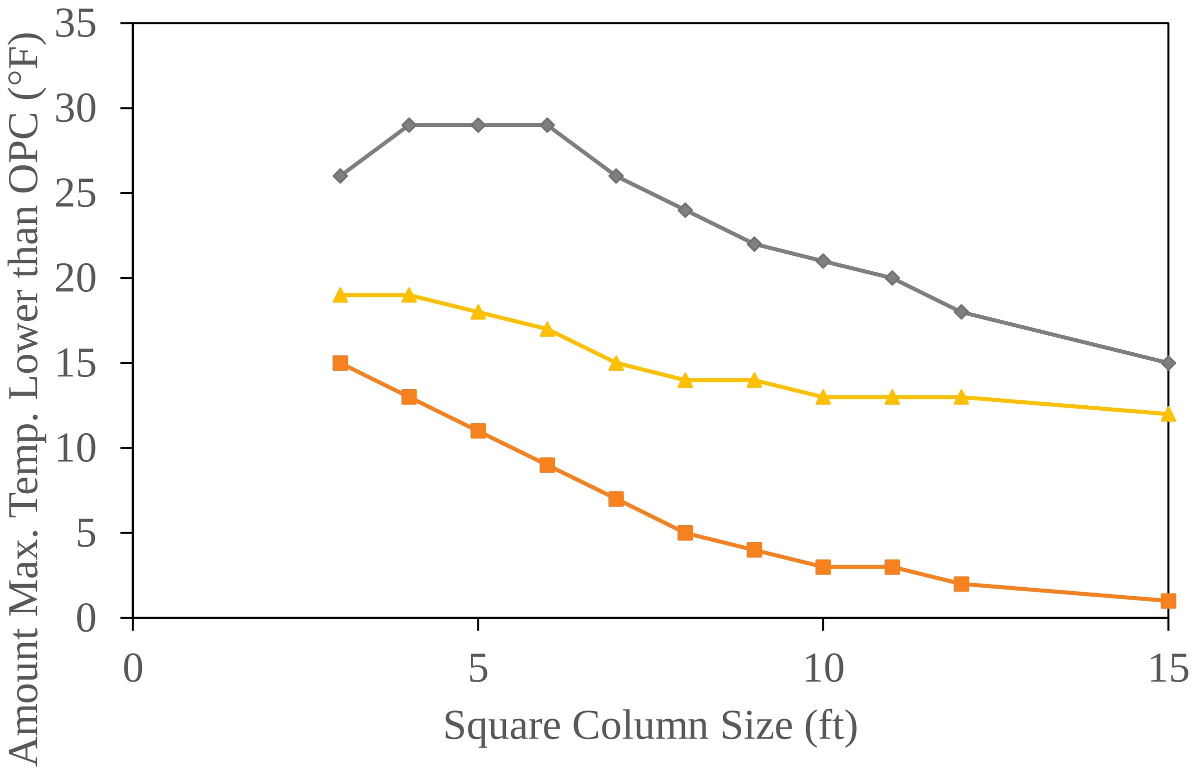


Impact of Slag on Concrete Temperature Development

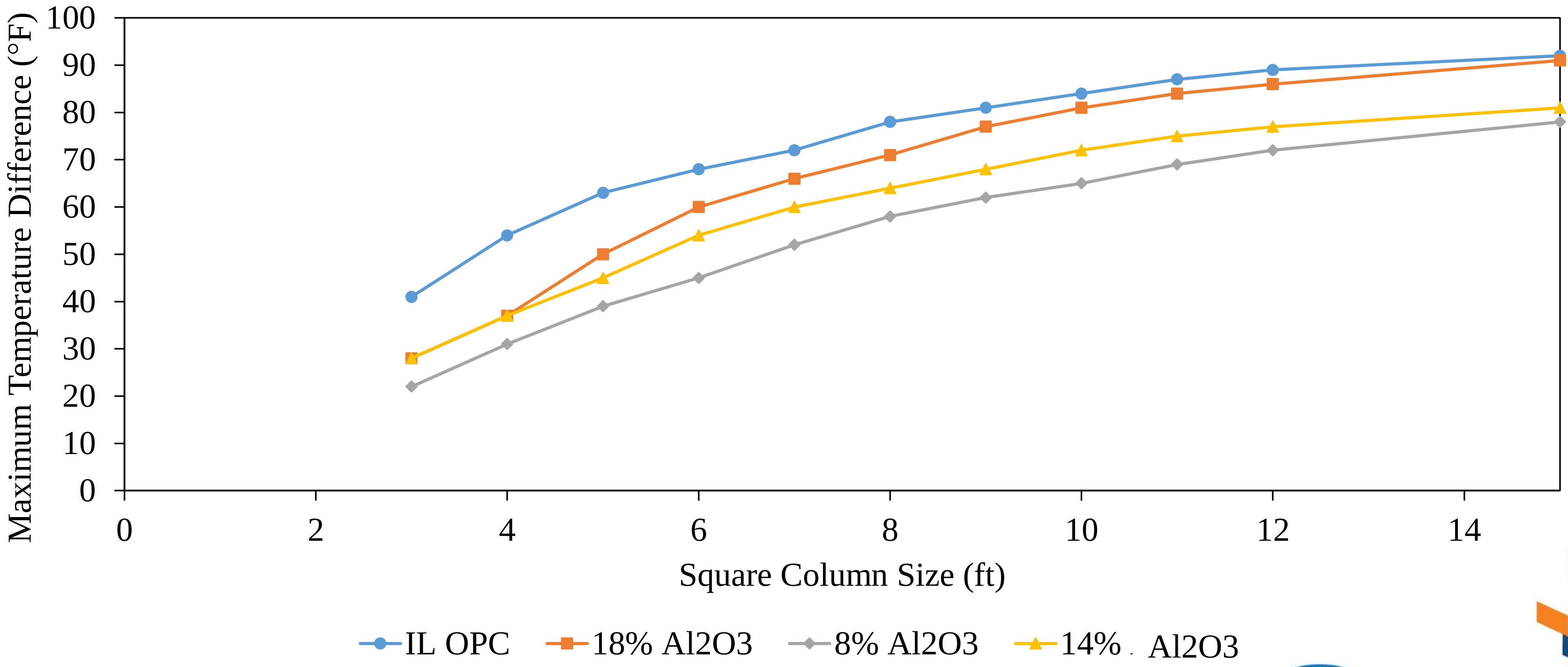
- Adiabatic temperature rise data used in simulations of concrete temperature development in concrete columns to determine sensitivity to slag
- Simulations examined:
  - Location: Jacksonville, FL
  - Steel forms
  - Square columns with increasing dimensions
  - Aug. 1 placement with 90°F placement temperature
  - Dec. 1 placement with 61°F placement temperature

Dec. 1 Placement, 61°F Placement Temperature

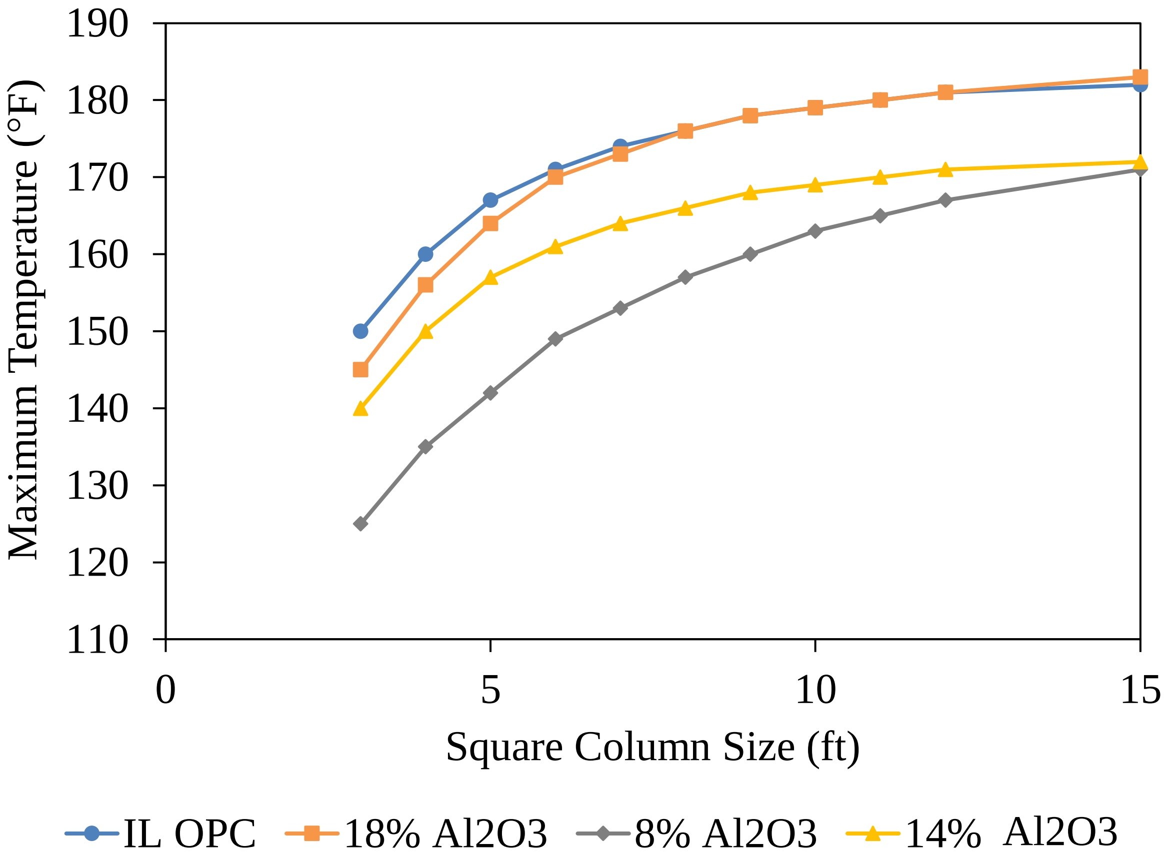


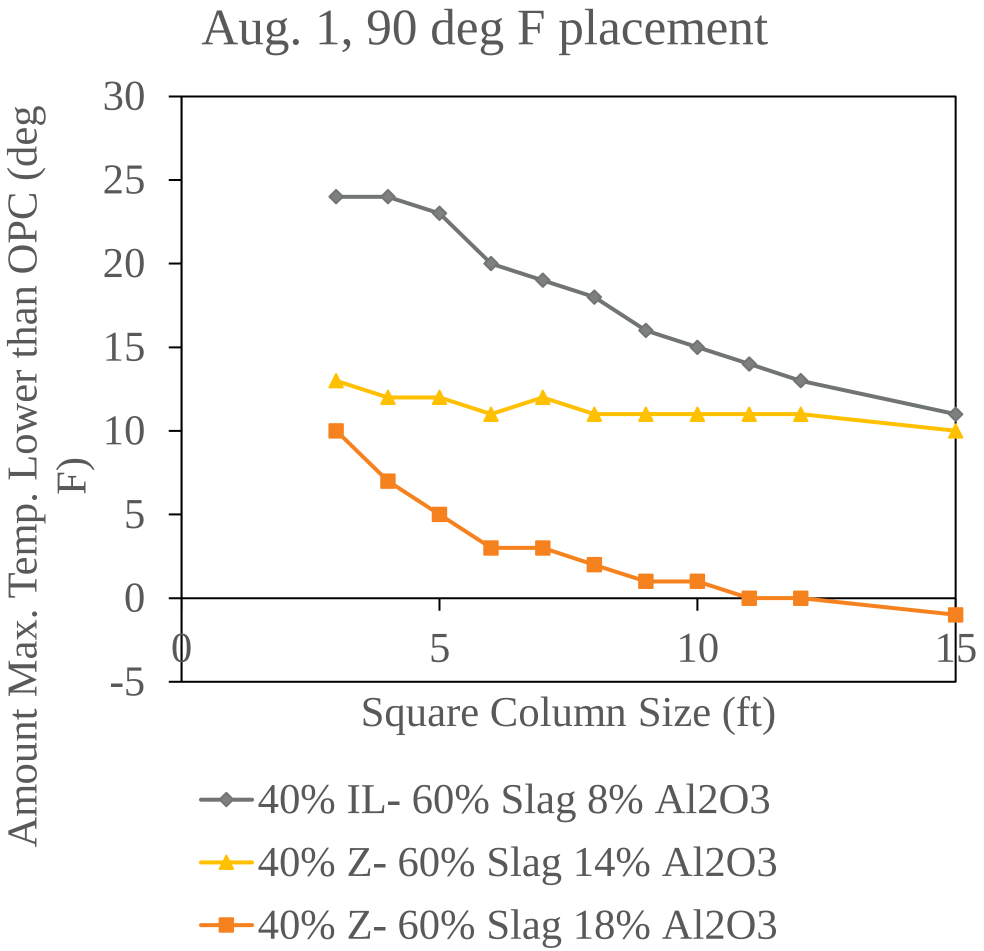


Dec. 1 Placement, 61°F Placement Temperature

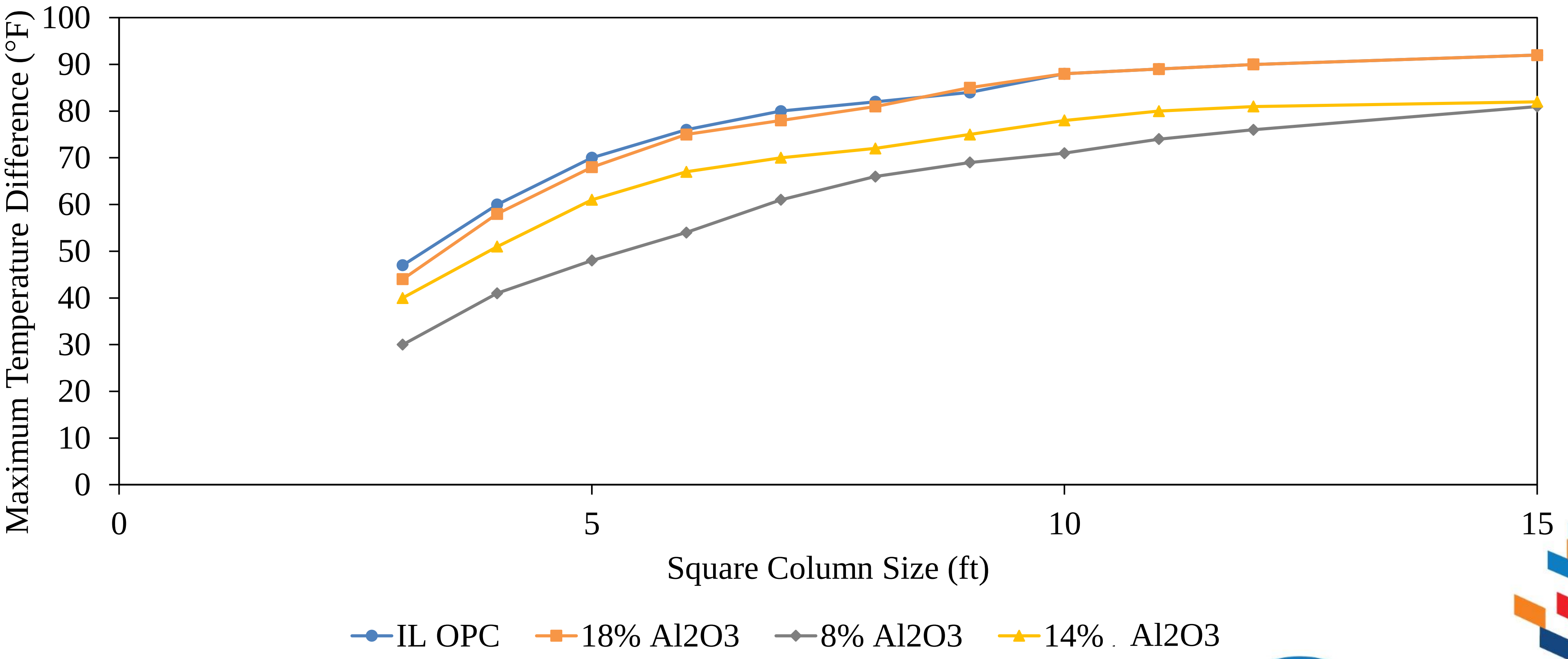


Aug. 1 Placement, 90°F Placement Temperature





Aug. 1 Placement, 90°F Placement Temperature



Conclusions

- Slag cement adiabatic temperature rise is dependent on the slag composition, with the Al_2O_3 and MgO contents being important
- Slag cement is slower reacting than OPC, but can produce higher adiabatic temperature rise in concrete than OPC after 7 days
- Slag cement can reduce the temperature rise in mass concrete, and is particularly effective for the size of structures typically used in many bridges and buildings