



# Effect of GGBF slag on CSA-based ternary binder hydration, and concrete performance

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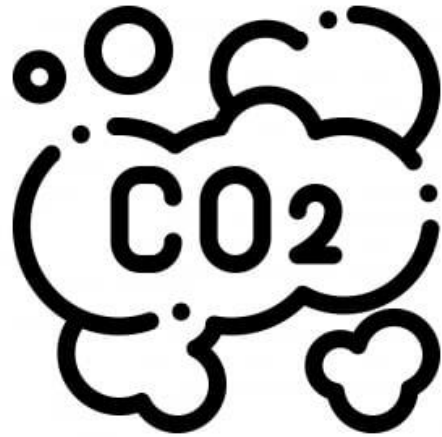


ACI Concrete Convention  
April 3<sup>th</sup>, 2022

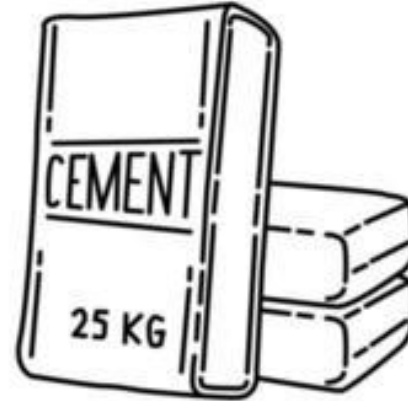
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# A search for alternative cement

## Portland cement



0.59 ton per ton cement  
manufactured



95 million metric tons  
In the USA 2022



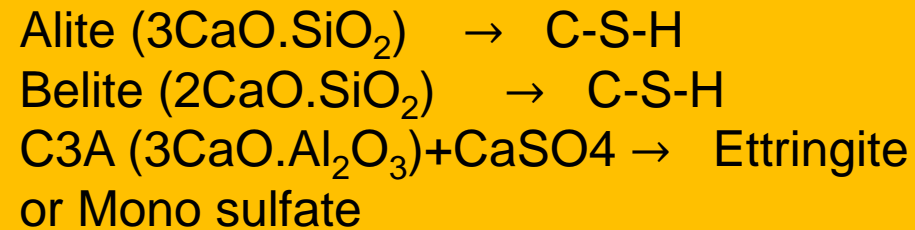
91% energy comes from  
fossil fuel

## Alternative solution?

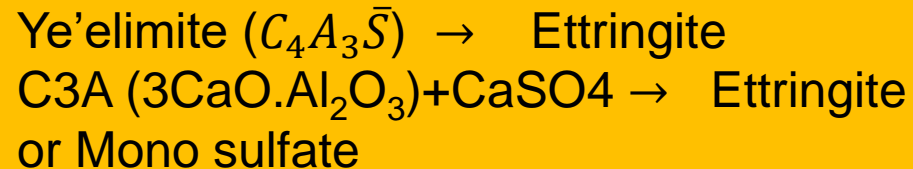
Calcium Sulfo-Aluminate cement

# Difference in mineralogy and hydration process

Portland cement  
(Type III)



Calcium sulfo-  
aluminate  
cement



## Hydration Controlling Parameter

w/b ratio, addition of SCMs,  
Ca/Si Ratio

Gypsum to Ye'elimite ratio

$$\text{M value} = \frac{\text{quantity of CaSO}_4 (\text{mole})}{\text{quantity of C}_4\text{A}_3\bar{\text{S}} (\text{mole})}$$

impacts hydration, setting time  
and shrinkage

# Research questions

- i. The controlling hydration reaction in calcium sulfo-aluminate (CSA) cement based composite binder with ground granulated blast furnace slag (GGBFS) and Ordinary Portland cement (OPC)
- ii. Potential chemical parameters influencing the fresh and mechanical performance of composite
- iii. Assess the influence of the chemical parameters on setting time, and compressive strength of the composite binders

## **Binder composition**

5 CSA-Type III cement (OPC) composite

5 CSA-GGBFS composite

19 OPC-CSA-GGBFS composite

## **Binder identification:**

$TxCySz$  ;

X,Y,Z = % of Type III cement, CSA, and Slag

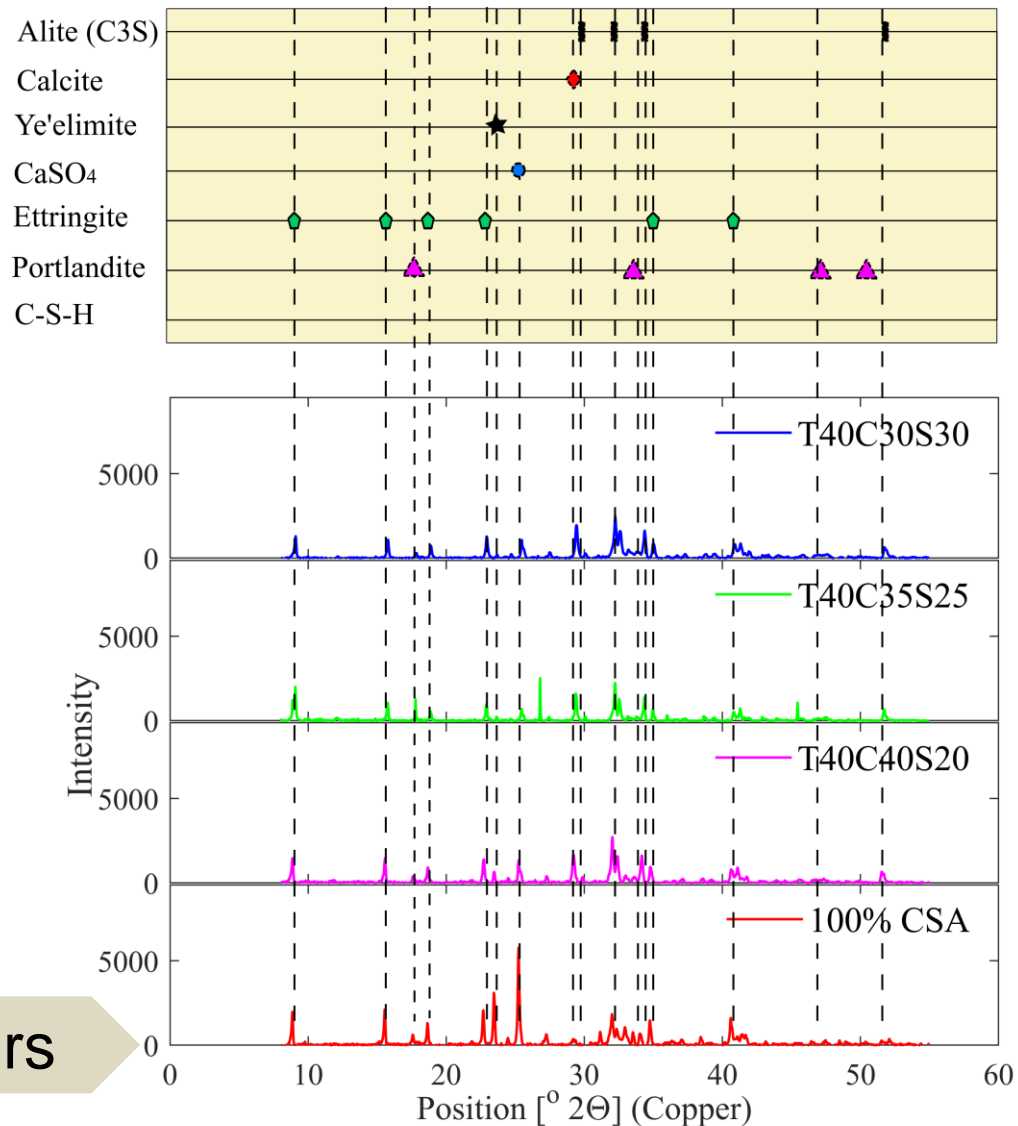
## **Binder performance**

Workability – ASTM C1437 (Flow table test)

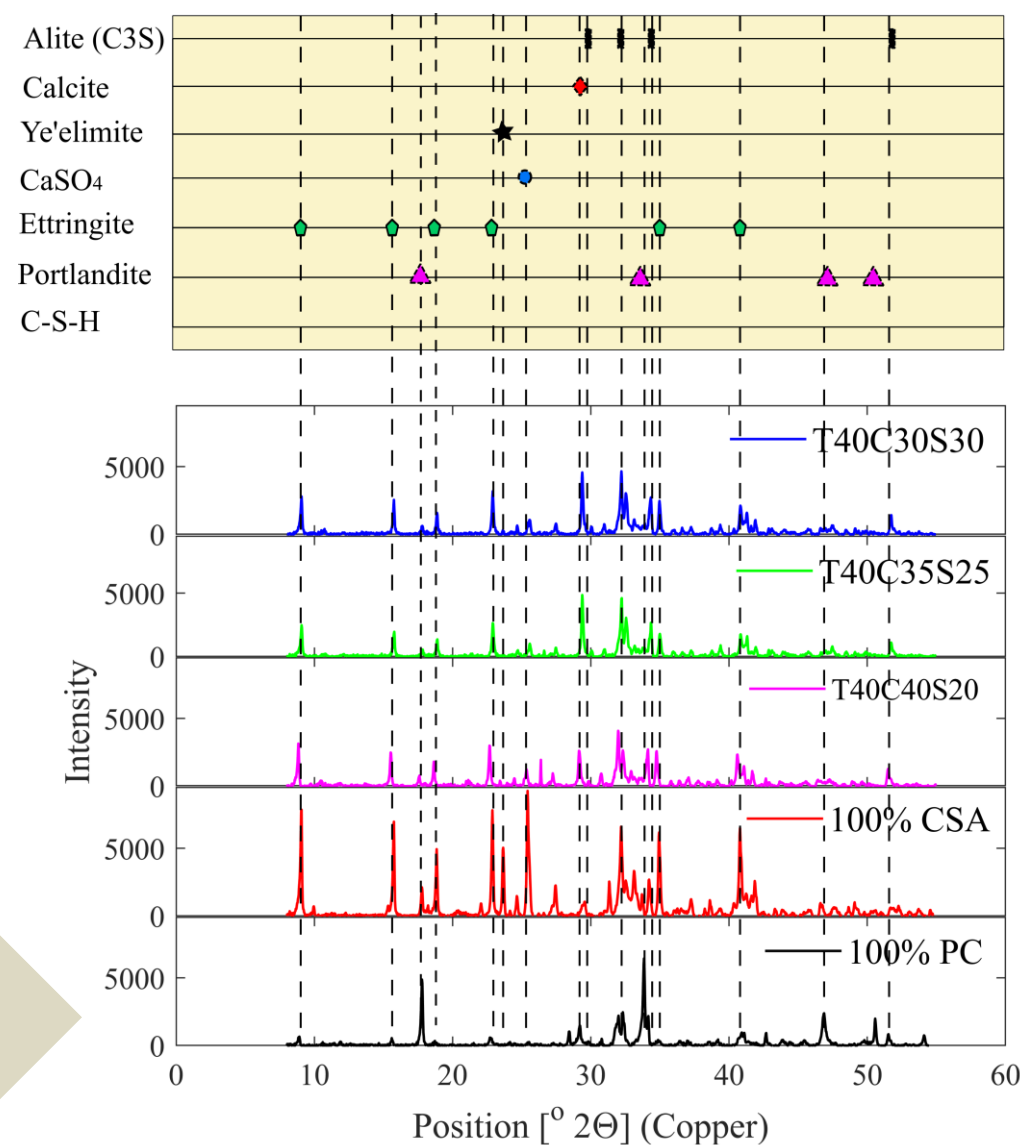
Setting time – ASTM C403 (Penetration resistance test)

Compressive strength – ASTM C 109

# Identifying key hydration process for CSA based composite binders

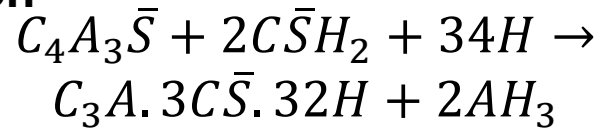


28 days

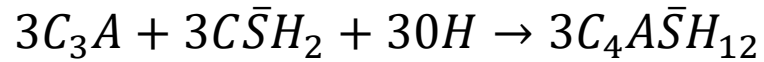


# Identifying controlling hydration reactions

Ye'elite hydration controlling early reaction

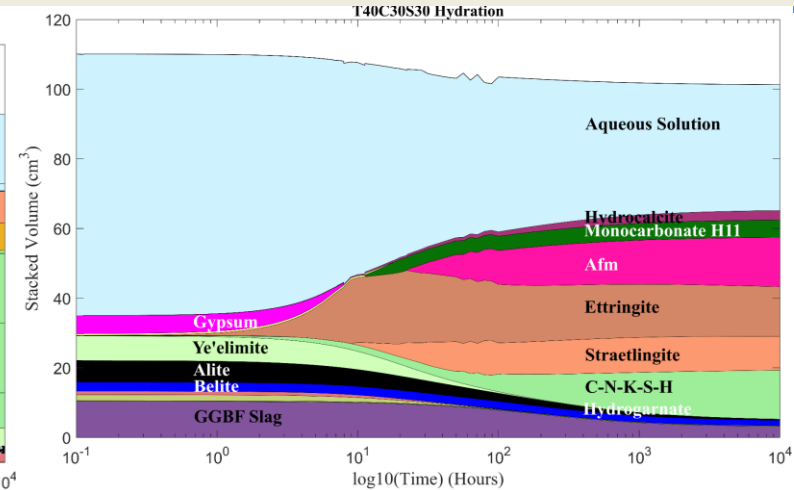
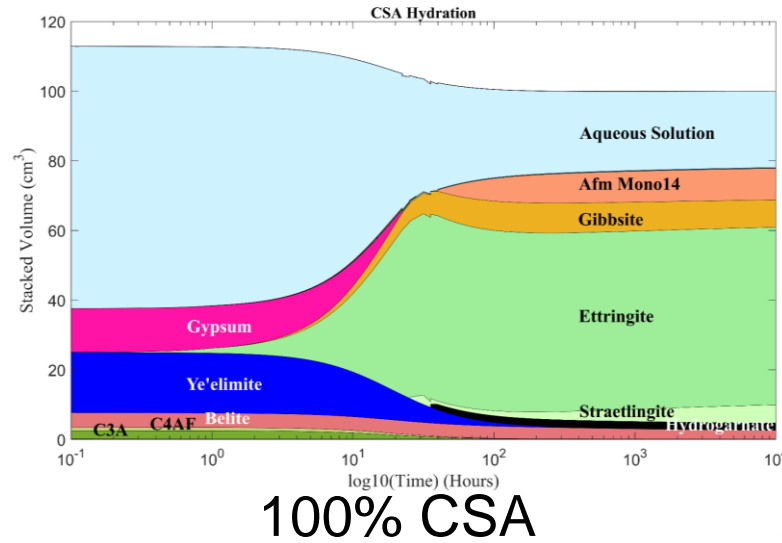


In composite, C3A with inadequate CaSO<sub>4</sub>

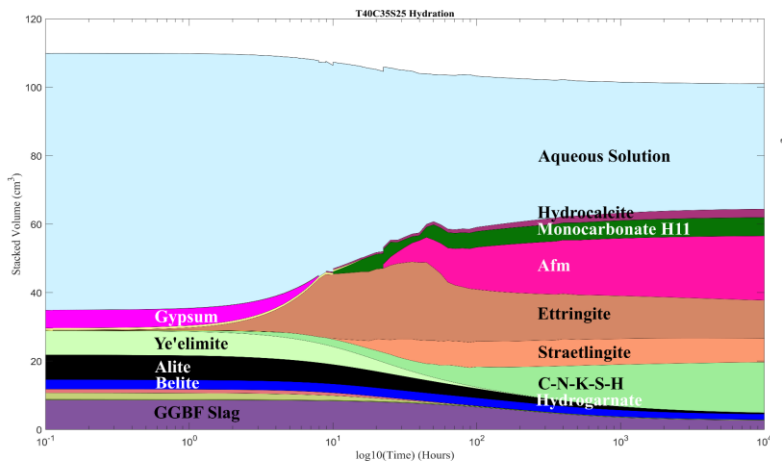


Modified M-value

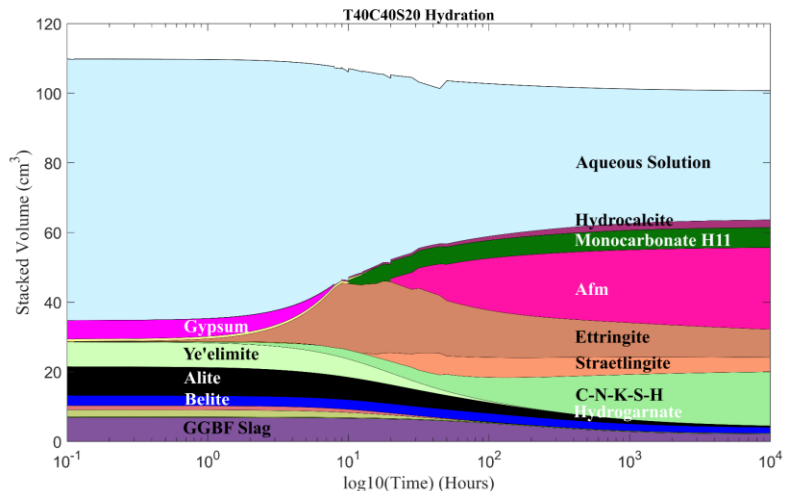
$$\frac{CaSO_4(mole)}{C_3A(mole) + 2 \times C_4A_3\bar{S}(mole)}$$



T40C30S30 composite

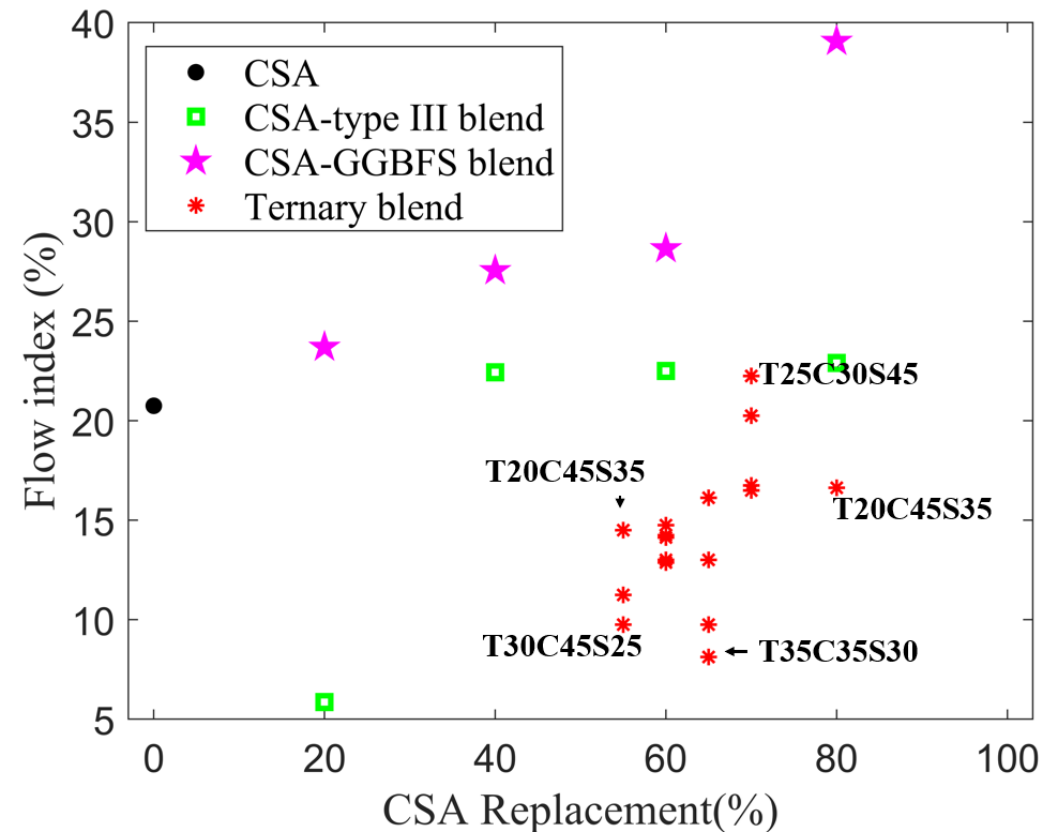
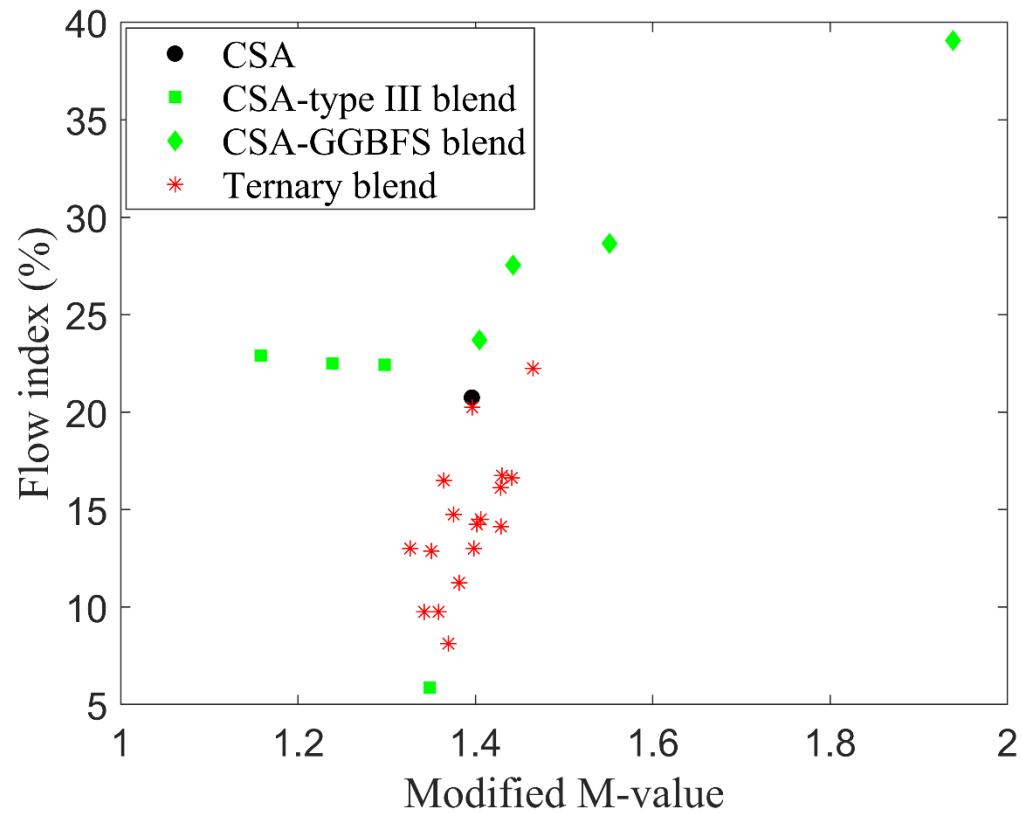


T40C35S25 composite



T40C40S20 composite

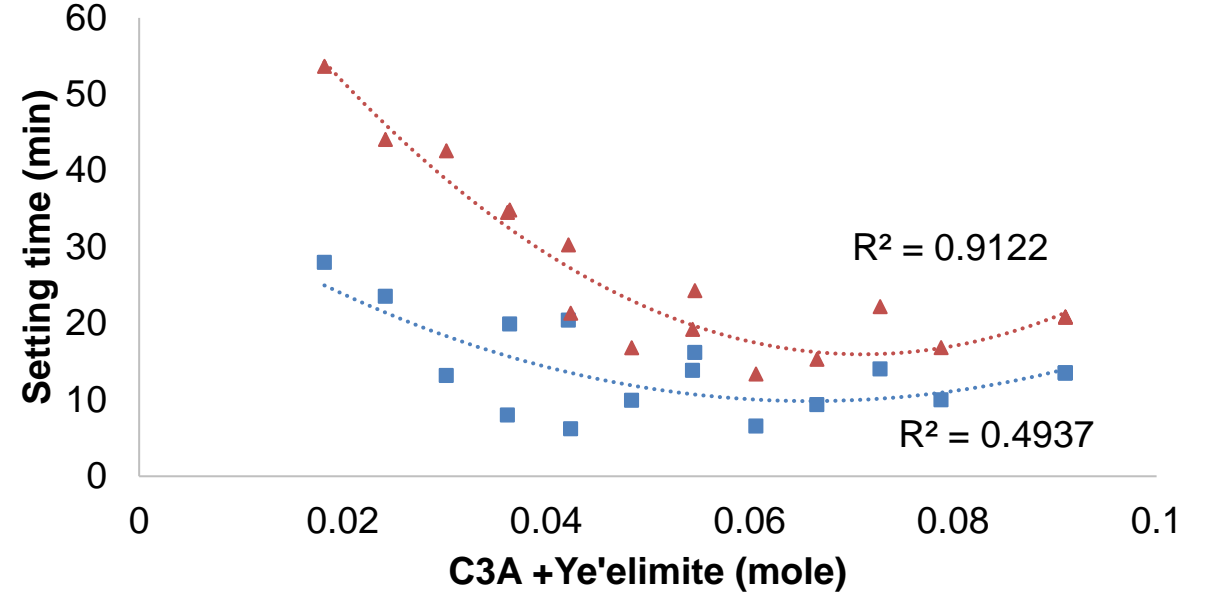
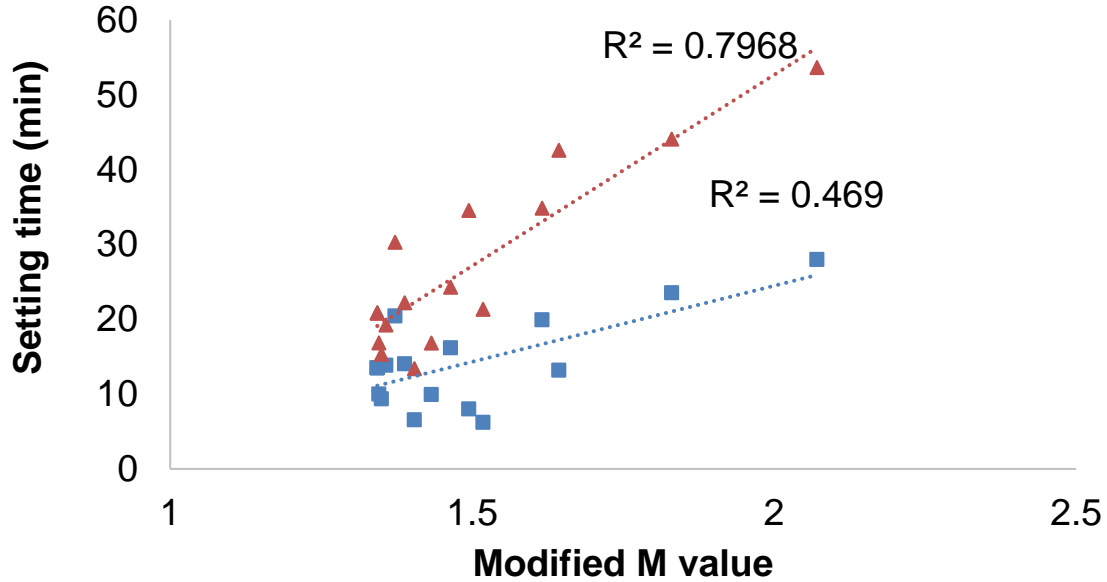
# Effect of binder parameter on workability



Increased slag quantity improves workability



# Effect of binder parameter on setting time

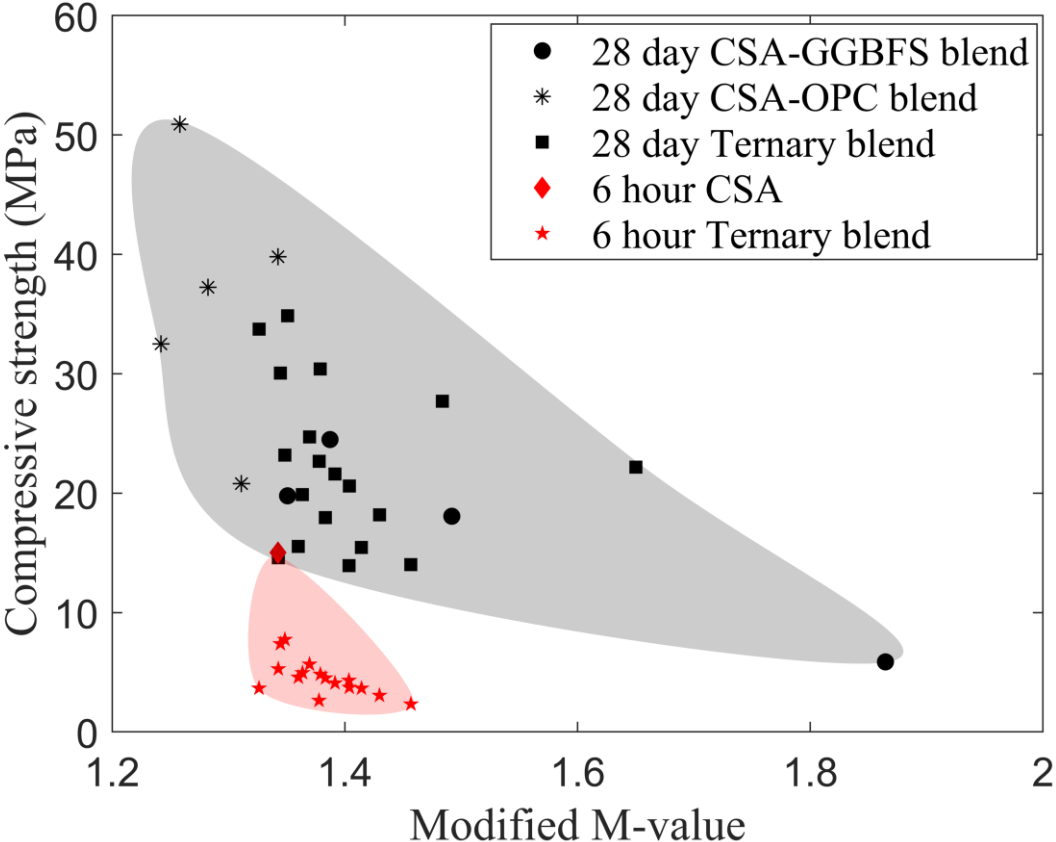
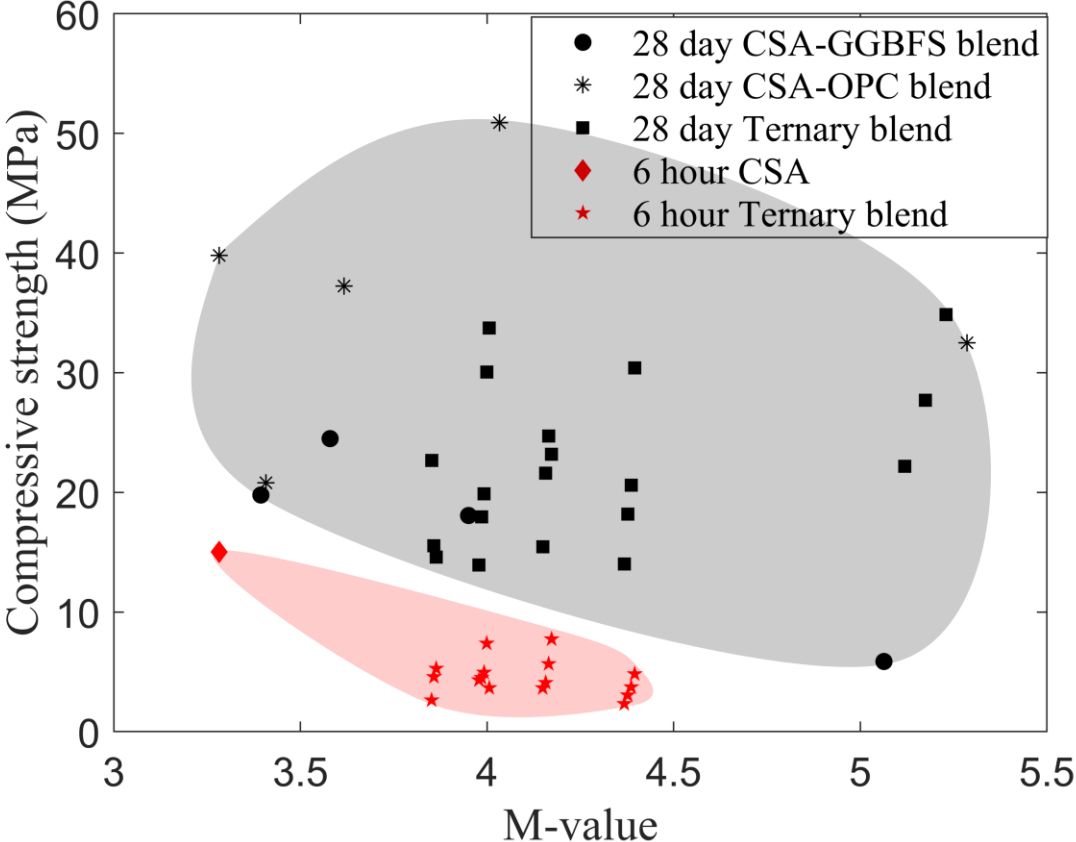


■ Initial Set      ▲ Final Set  
..... Linear (Initial Set)      ..... Linear (Final Set)

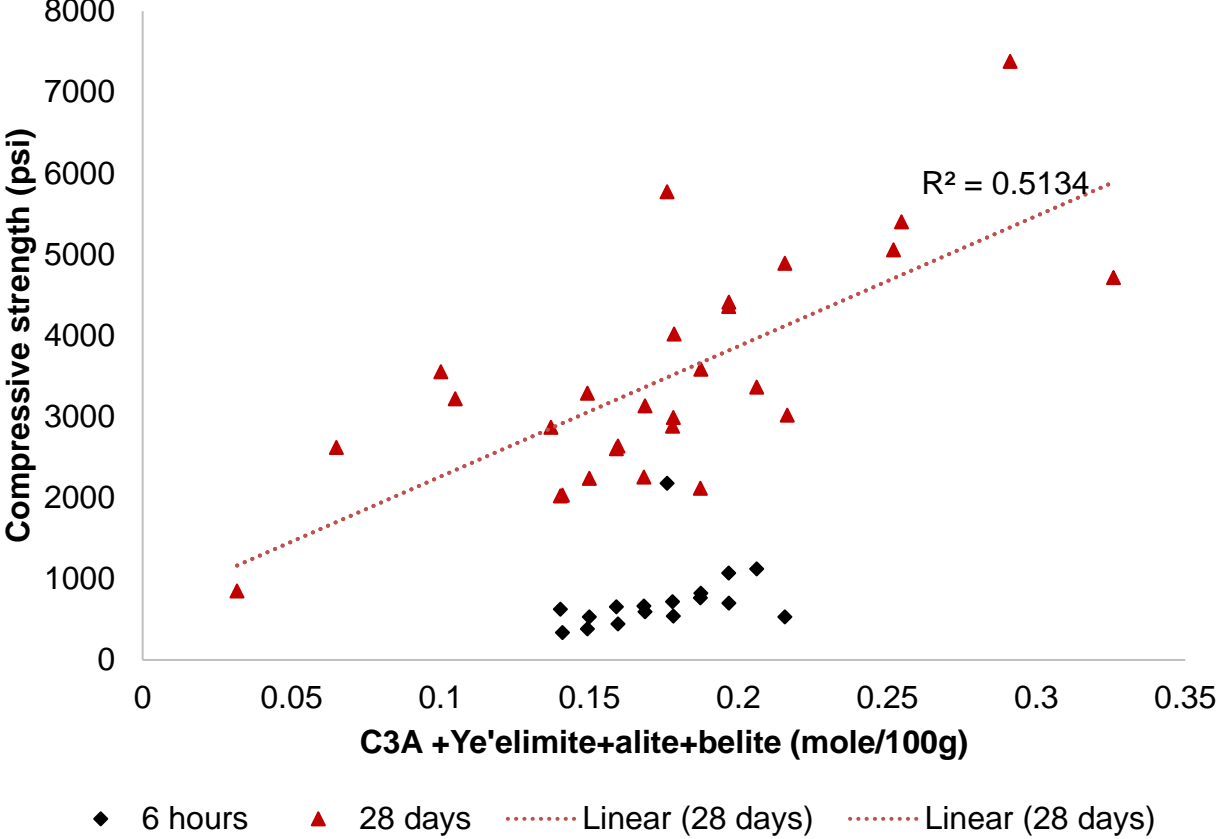
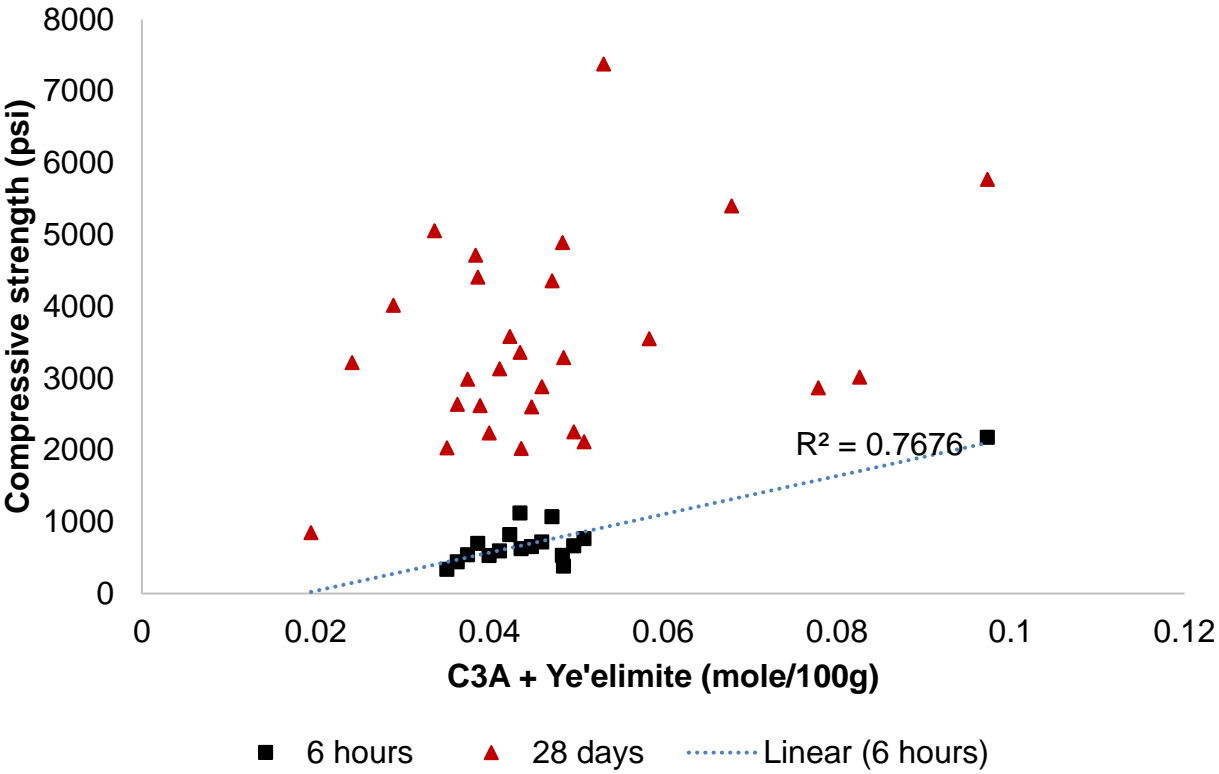
■ Initial Set      ▲ Final Set  
..... Poly. (Initial Set)      ..... Poly. (Final Set)

**Setting time increases with higher modified M-value and decrease in (C3A + Ye'elinite) quantity**

# Effect of binder parameter on compressive strength



# Effect of binder parameter on compressive strength



Quantity of total reacting clinker phases affects the compressive strength at 6 hours and 28 days

# Conclusions

- 1) Early hydration and early properties like setting time and 6 hour compressive strength is controlled by the hydration of ye'elimite and C3A
- 2) Hydration and compressive strength at 28 days rely on quantity of other phases like Alite, Belite along with C3A and ye'elimite
- 3) For composite binder there is a need to consider other phases along with ye'elimite. Hence, M value is needed to modified
- 4) Use of ternary binder can provide the middle ground between early mechanical strength, workable time and cost

## Acknowledgement:

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# Thank You!



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