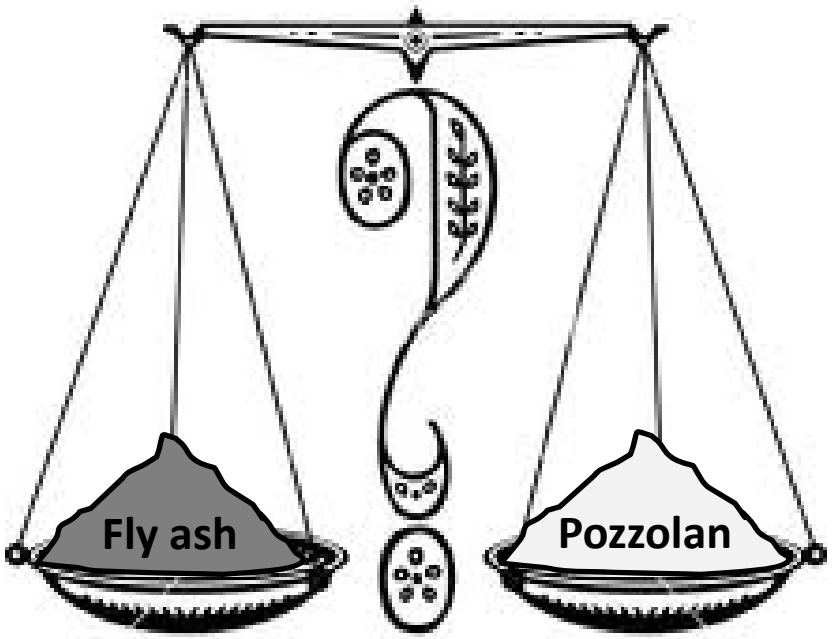
The Potential of Natural Pozzolans to be a Class F Fly Ash Replacement in Concrete



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Project sponsored by Texas Department of Transportation (TX 0-6717)

MOTIVATION

- Uncertain supply of fly ash in the future due to EPA regulations that propose to classify it as a special waste.
- Air pollution reduction incentives are making power plants switch to coal sources that do not produce good quality Class F fly ash.
- Estimated average annual cost of banning fly ash in the US is $5.23 billion (ARTBA, 2011).
- Imperative to find alternative SCMs (supplementary cementitious materials) that can provide similar strength and durability benefits to concrete as Class F fly ash.

OUR RESEARCH

- Looks at the performance of natural pozzolans found in US:
  - ASTM C 618 requirements for Class N pozzolan
  - Compression Strength
  - Durability *(Alkali Silica Reaction & Sulfate Attack)*
  - Fresh State Properties

- 8 different pozzolans used in our research:
  - *Unaltered Volcanic Pozzolans*: Pumice, Perlite, Vitric Ash
  - *Altered Volcanic Pozzolans:* Three Zeolites (1 fine, 2 coarse)
  - *Sedimentary Pozzolans:* Metakaolin, Shale

POZZOLAN PROPERTIES

- All the pozzolans were rich in silica and alumina, having a $SiO_2+Al_2O_3+Fe_2O_3$ quantity of over 74%.
- Other than the three zeolites, all the pozzolans passed the ASTM C 618 requirements for a Class N pozzolan.
- The three zeolites that did not pass the ASTM C 618 mostly failed due to problems with water demand and moisture content.
- Two of the coarser zeolites also had problems with fineness requirement and showed a lower Strength Activity Index (SAI).

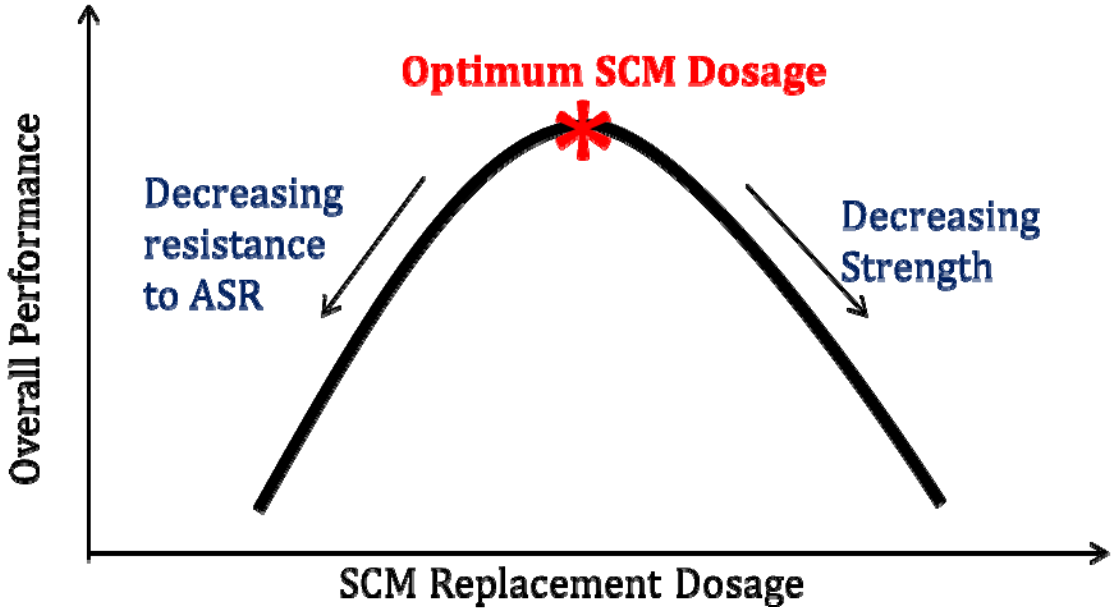
ASTM C 618

	SiO_2+ Al_2O_3+ Fe_2O_3	Moisture Content	LOI	Fineness	SAI, 7 day	SAI, 28 day	Water Requirement	Passes ASTM C 618?
Pumice-D	**82.9**	**1.5**	**4.4**	**2**	**82**	**93**	**104**	**YES**
Perlite-I	84.3	0.6	3.4	2	86	94	100	YES
Metakaolin-D	**88.9**	**0.9**	**1.0**	**7**	**94**	**108**	**102**	**YES**
Shale-T	85.7	0.3	0.4	30	72	81	103	YES
Vitric Ash-S	**76.9**	**2.3**	**5.9**	**15**	**72**	**83**	**102**	**YES**
Zeolite-Z	78.6	**5.1**	2.5	0	71	100	**116**	NO
Zeolite-T	**75.2**	**11.6**	**4.6**	**43**	**47**	**61**	**132**	**NO**
Zeolite-A	74.6	**4.8**	4.8	**61**	**60**	**64**	**118**	NO
Criteria in ASTM C 618	**70 % min**	**3% max**	**10% max**	**34% max**	**75% min**	**75% min**	**115% max**	

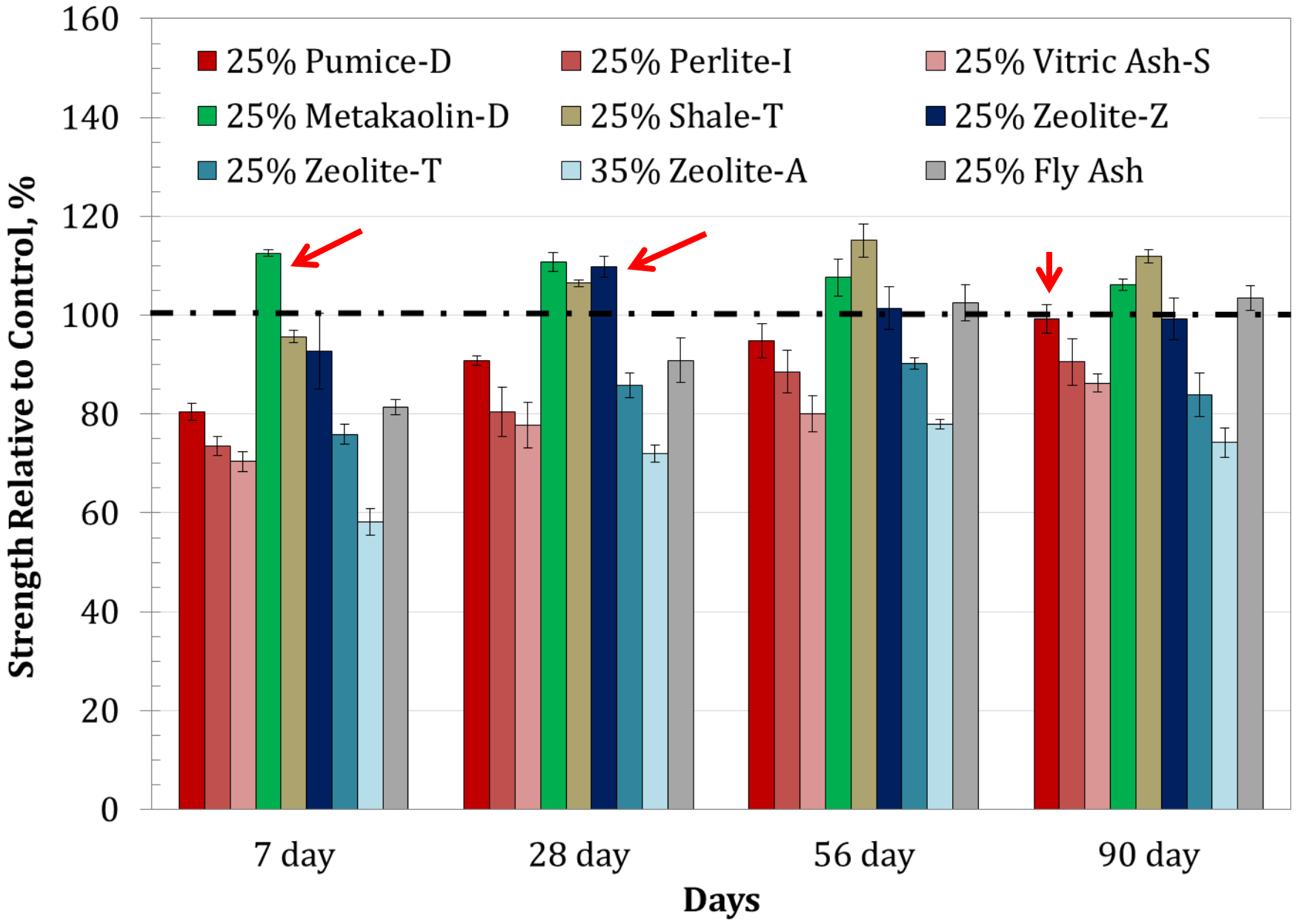
** Values in red do not meet the ASTM C 618 requirements

FINDING THE RIGHT DOSAGE

- Percentage of SCM replacement in concrete and mortar mixes determined by amount needed to mitigate expansions from ASR.
- Found using ASTM C 1567, the Accelerated Mortar-Bar Test Method for measuring resistance to Alkali Silica Reaction (ASR).
- Most of the mixtures needed an SCM replacement dosage of 25%.
- Exception: Zeolite-A mixture, which needed a 35% dosage

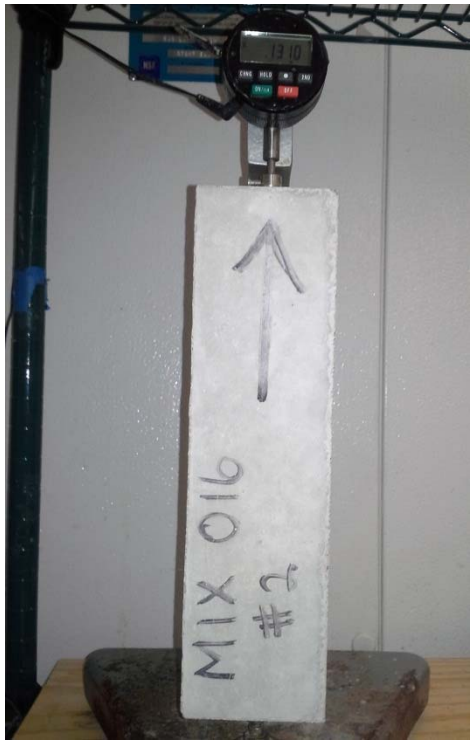


CONCRETE STRENGTH–ASTM C 39

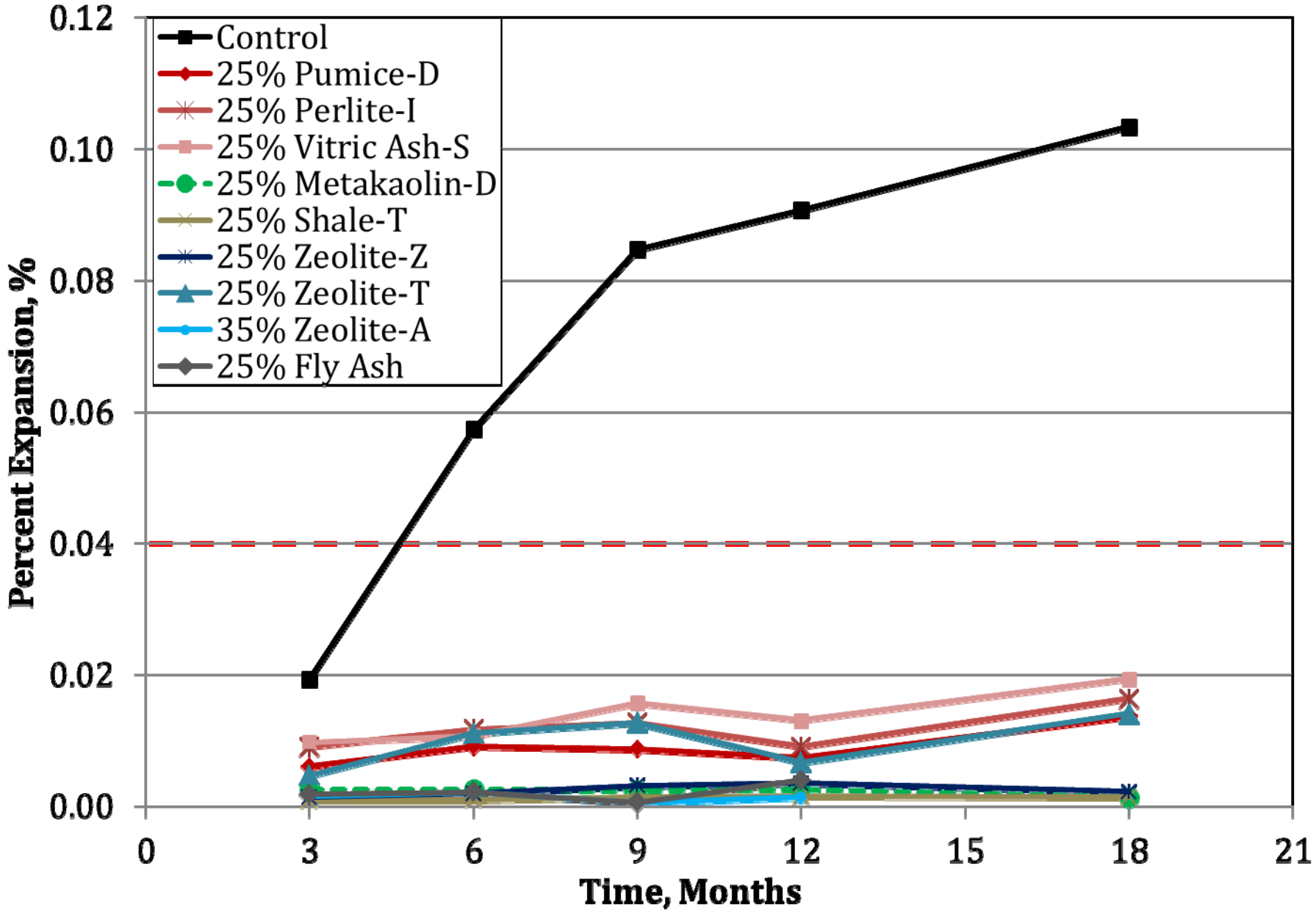


RESISTANCE TO ASR

- Preliminary percentages found using ASTM C 1567, the Accelerated Mortar-Bar Method for measuring ASR resistance.
- Currently, the pozzolans are being tested for resistance to ASR using ASTM C 1293, which uses concrete prisms (3” x 3” x 11 ¼”)
- ASTM C 1293 states that if average expansion is less than 0.04% at 2 years, then amount of SCM used is enough to prevent excessive expansion in field concrete from ASR.



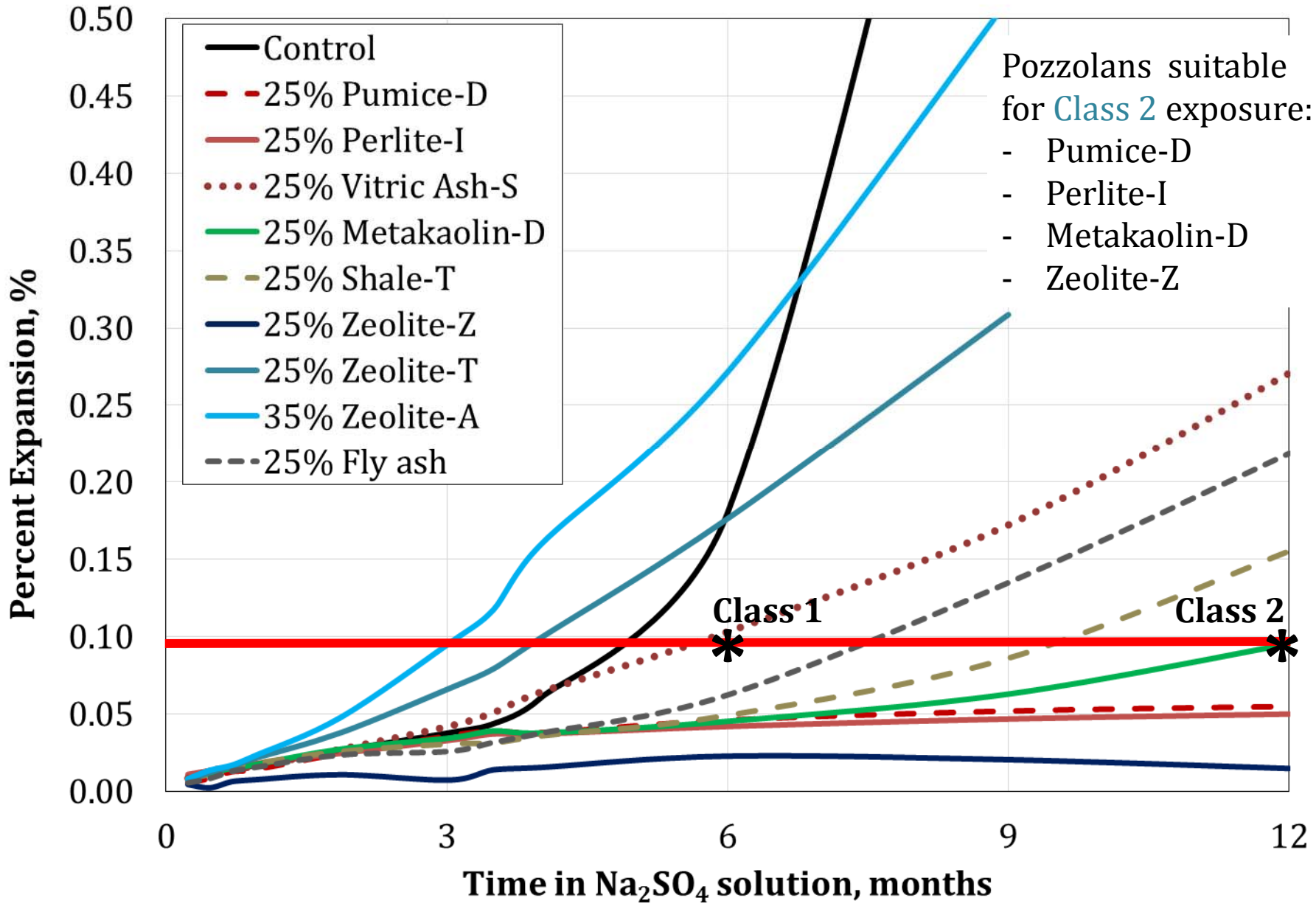
ASR CONCRETE PRISM TEST–ASTM C 1293



SULFATE ATTACK

- The procedures from ASTM C 1012 is being used to test the ability of the pozzolans to mitigate expansions from sulfate attack.
- ASTM C 1012 measures the length change of mortar bars (1"x 1"x 11¼" in dimension) submerged in Na_2SO_4 solution.
- According to ACI 201, Guide to Durable Concrete, natural pozzolans can be qualified for sulfate resistance by demonstrating an expansion less than 0.10% in 1 year, using ASTM C 1012.

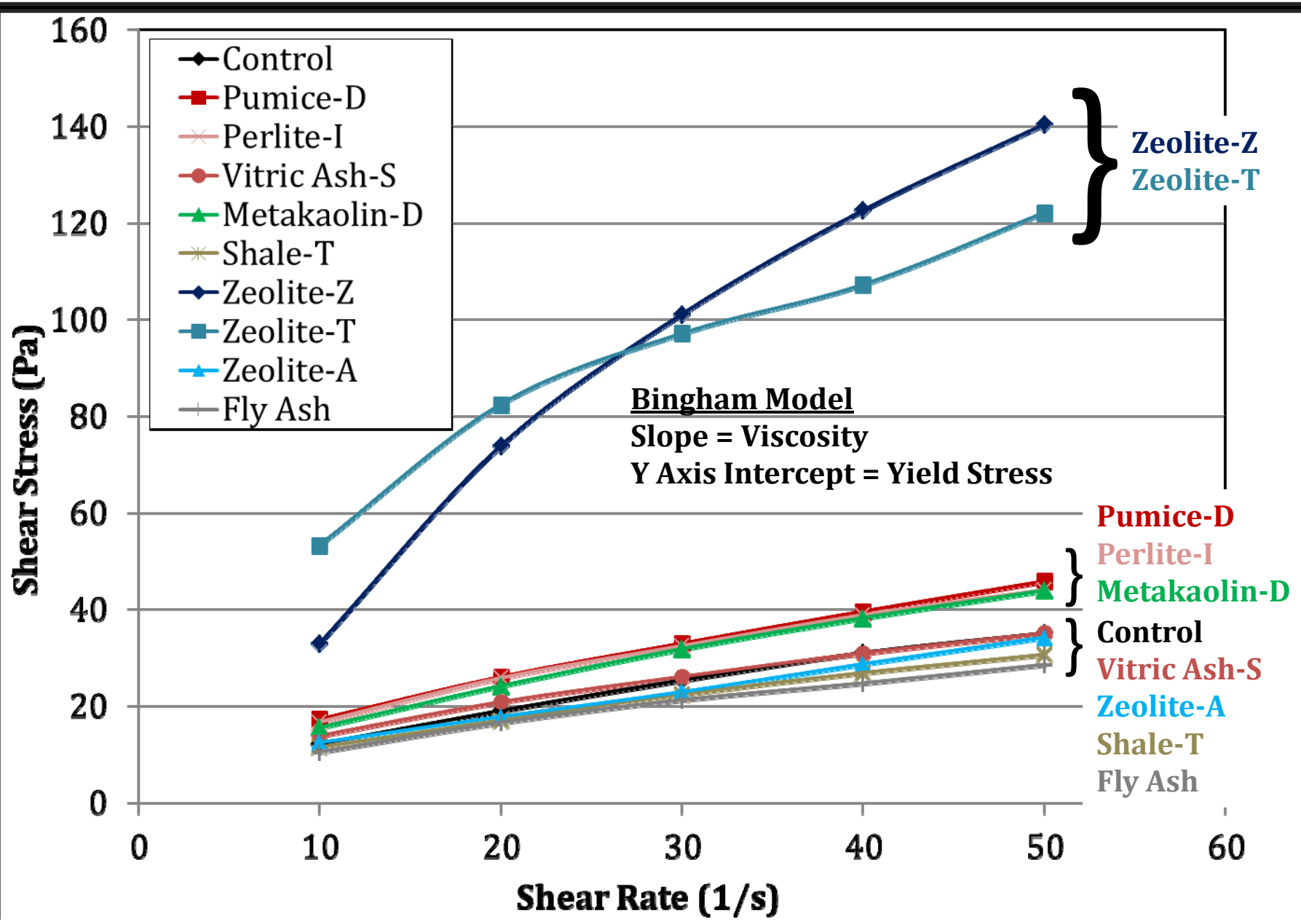
SULFATE RESISTANCE – ASTM C 1012



FRESH STATE PROPERTIES

- **Setting Time using a penetrometer (ASTM C 403)**
  - No significant delay in set time.
  - Concrete with SCM had a final set between 4.5 - 6 hours.
  - Control had a final set of 4.5 hours.
  - Fly ash had a final set of 5.3 hours.
- **Slump (ASTM C 143)**
  - Target slump was set between 3-5".
  - All mixtures able to achieve this with superplasticizer, except for the concrete mixture with Zeolite-Z and Zeolite-T.
  - Workability problems with these zeolites were expected:
    - Failed water requirement test from ASTM C 618.
    - Rheological tests on pastes showed high viscosities.

RHEOLOGY FLOW CURVE OF PASTE



RESEARCH IN PROGRESS

- **Understanding why one SCM is working better than others**
- **Linking performance to the physical properties of the SCMs**
  - *Surface area analysis with BET*
  - *Finding crystalline content using XRD*
- **Determining the pozzolanic potential of the SCM**
  - *Finding the $Ca(OH)_2$ content of pastes using TGA*
- **Can properties can be modified to enhance performance?**
  - *Modifying zeolites to improve workability*
  - *Understanding why modifications improve/deteriorate performance*

CONCLUSIONS

- Other than the two coarse zeolites, Zeolite-T and Zeolite-A, all the pozzolans tested can be a suitable replacement for Class F fly ash.
- In terms of ***compressive strength***, the best performers were Pumice-D, Metakaolin-D, Shale-T and Zeolite-Z, having strengths higher than or similar to the control concrete at 90 days.
- In terms of resistance to ***ASR***, all the pozzolan concrete mixtures are well below the 0.04% expansion limit at 18 months.
- For resistance to ***sulfate attack***, the best performers were Pumice-D, Perlite-I, Metakaolin-D and Zeolite-Z, having expansions less than 0.10% at 1 year (Class 2 exposure).
- Zeolite-Z is a good performer, but it has some ***workability issues***.