DEVELOPMENT OF PERFORMANCE PROPERTIES OF TERNARY MIXTURES

Executive Summary

October 6, 2009 St. Louis, MO

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Goal #1

- Quantitative Guidance to DOT's
  - Ternary Mixture Design Optimization
    - Technical Properties
    - Life Cycle Value
    - Constructability
  - Effects of Constituents on Concrete Behavior
    - Slump, Entrained Air, Admixture Dosage

Goal #2

- Provide Solutions to Cold Weather Issues
  - Setting Time
  - Early age strength development
  - Deicing salt scaling of ternary mixtures

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Goal #3

- Define Optimal Use of Ternary Mixture in Rapid Strength Applications
  - Early Opening
  - Repair and Restoration
  - Prestressed Concrete

Goal #4

- Performance Specifications for Concrete
  - Guidelines for Engineers to define performance
  - Performance Measures for Contract Documents
    - Mixture design performance
    - In-situ performance
    - Economic incentives for performance
    - Environmental performance measure
  - Use of Field Implementation Studies to Improve Specifications and Guidelines

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Progress

- Phase I (completed 12/07)
  - Planning of Scope
  - Defining Tests and Data
  - Identification of past work
  - Materials Acquisition
  - Materials Characterization
  - Mortar Testing
  - Preliminary Modeling
  - Scoping for Phase II

Development of Performance Properties of Ternary Mixtures: Phase I Final Report

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Final Report
December 2007

Sponsored through
Federal Highway Administration;
FHWA Pooled Fund Study TPF-5(117):
California, Illinois, Iowa (lead state), Kansas, Mississippi, New Hampshire, Pennsylvania, Wisconsin, and Utah;
the Portland Cement Association;
Headwaters Resources;
the American Coal Ash Association; and
the Slag Cement Association

ctre
Center for Transportation Research and Education

Iowa State University

The University of Utah

XRF Results for Cements

		Type I	TIPM	TISM	TIP
Chemical Composition, %	CaO	61.62	59.15	58.23	50.88
	SiO_2	19.79	24.91	23.51	28.88
	Al_2O_3	6.19	4.38	5.27	8.19
	Fe_2O_3	2.50	3.12	2.99	3.70
	MgO	2.76	1.36	4.33	1.60
	K_2O	0.75	0.56	0.59	0.90
	Na_2O	0.34	0.22	0.13	0.35
	SO_3	2.58	3.33	2.87	2.74
	TiO_2	0.28	0.29	0.41	0.44
	P_2O_5	0.21	0.11	0.10	0.22
	SrO	0.24	0.10	0.04	0.20
	Mn_2O_3	0.11	0.18	0.50	0.20
Fineness (m^2/kg)		388	450	378	433

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XRF Results for SCM's

Chemical Composition, %		Class C	Class F (F1)	Class F (F2)	GGBFS	Metakaolin
	CaO	27.24	3.78	13.26	36.78	0.07
	SiO_2	34.21	45.06	51.31	36.83	52.42
	Al_2O_3	18.31	23.73	16.11	9.65	44.42
	Fe_2O_3	6.60	16.33	6.74	0.62	0.42
	MgO	5.04	0.91	4.44	10.04	0.04
	K_2O	0.35	1.46	2.32	0.36	0.14
	Na_2O	1.55	0.81	2.86	0.31	0.16
	SO_3	2.71	0.69	0.80	-	0.02
	TiO_2	1.57	1.16	0.63	0.49	1.45
	P_2O_5	1.30	0.25	0.15	0.01	0.08
	SrO	0.51	0.18	0.33	0.05	<0.01
	Mn_2O_3	0.06	0.03	0.05	0.39	<0.01
	S	-	-	-	1.10	-
	LOI, %	0.25	5.38	0.04	-	0.30

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Pozzolanic Index

Material	Water requirement %	Strength activity index (%)		Slag activity index (%)		Pozzolanic activity index (%)	
		7 day	28 day	7 day	28 day	7 day	28 day
Class C fly ash	86.8	112	108				
Class F fly ash	97.9	85	86				
Class F2 fly ash	90.5	108	107				
Silica fume	--					125	--
Grade 100 slag	--			60	97		
Grade 120 slag	--			80	112		
Metakaolin (20%)	121.9	114	121				
Metakaolin (10%)	104.0	141	144				

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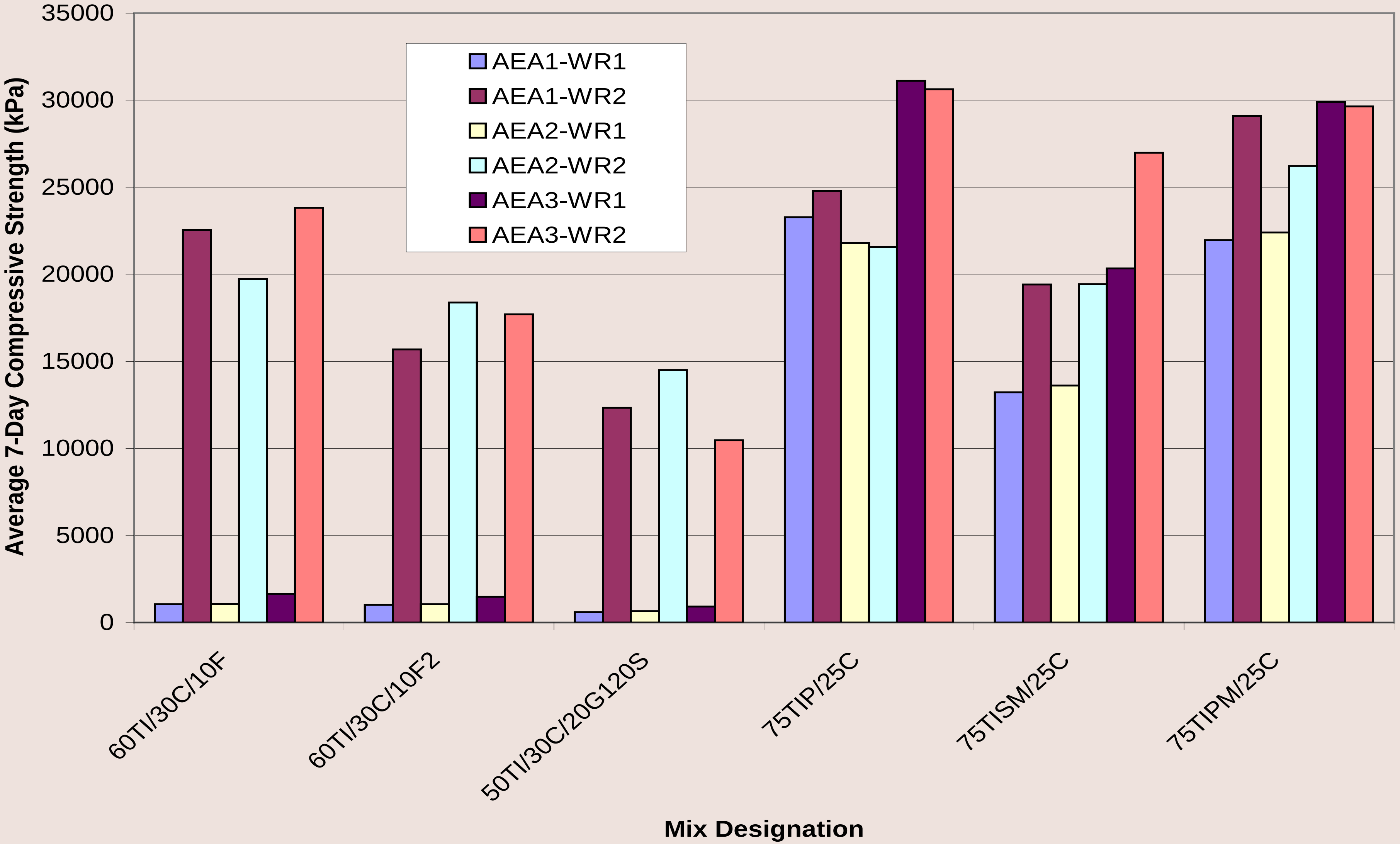
Observations for Phase I

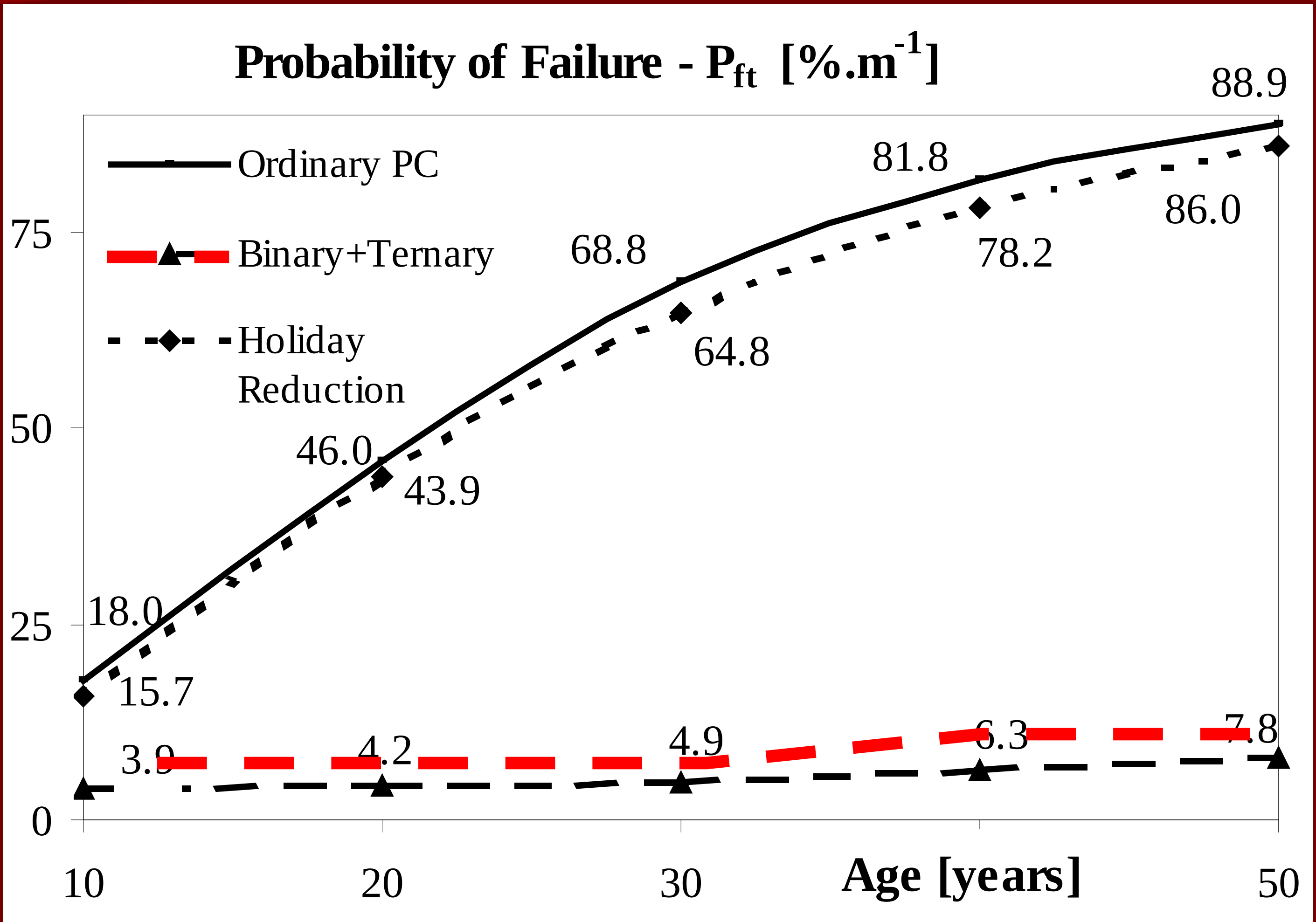
- Ternary mixtures with Class C fly ash and Sucrose based water reducers were incompatibility with low 7-day compressive strength results. The issues were relieved by polycarboxylate water reducers.
- No other admixture compatibility issues were seen in 150+ ternary combinations

Class C Fly Ash vs. Admixtures



SBRA Corrosion Model

Probability of corrosion initiation P_f [%.m^{-2}]



Observations for Phase I

- Ternary Combinations with pozzolans between 40-50% of total cementitious materials performing well in moderate to hot weather environments.
- Small quantities of silica fume and metakaolin provide early age boost to cold weather applications.
- Lignitic based fly ash has not performed well in ternary blends

Phase II - Progress

- Finalize Phase II concrete mixtures
- Define concrete performance test and data

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Phase II Properties

Property	Range of Acceptable Values	Desirable Values	Test method(s)
Slump loss	0-2”	<1”	ASTM C 143
Bleeding			ASTM C 232
Initial Setting Time	45-420 minutes	90-360 minutes	ASTM C 403
Strength Development 28/7 Day F_c ratio	1.20-1.67	1.25-1.35	AASHTO T29 & Maturity
Shrinkage	<500 με	200-400 με	Concrete prism ASTM C 157
Freeze-Thaw Durability	80-100 DF	85-100 DF	Freeze-thaw C666
Rapid Ion Permeability	200-2000 Coulombs	800-1500 Coulombs	AASHTO T277
Electrical Resistivity	30-100 kΩ/cm	>50 kΩ/cm	4-probe Array

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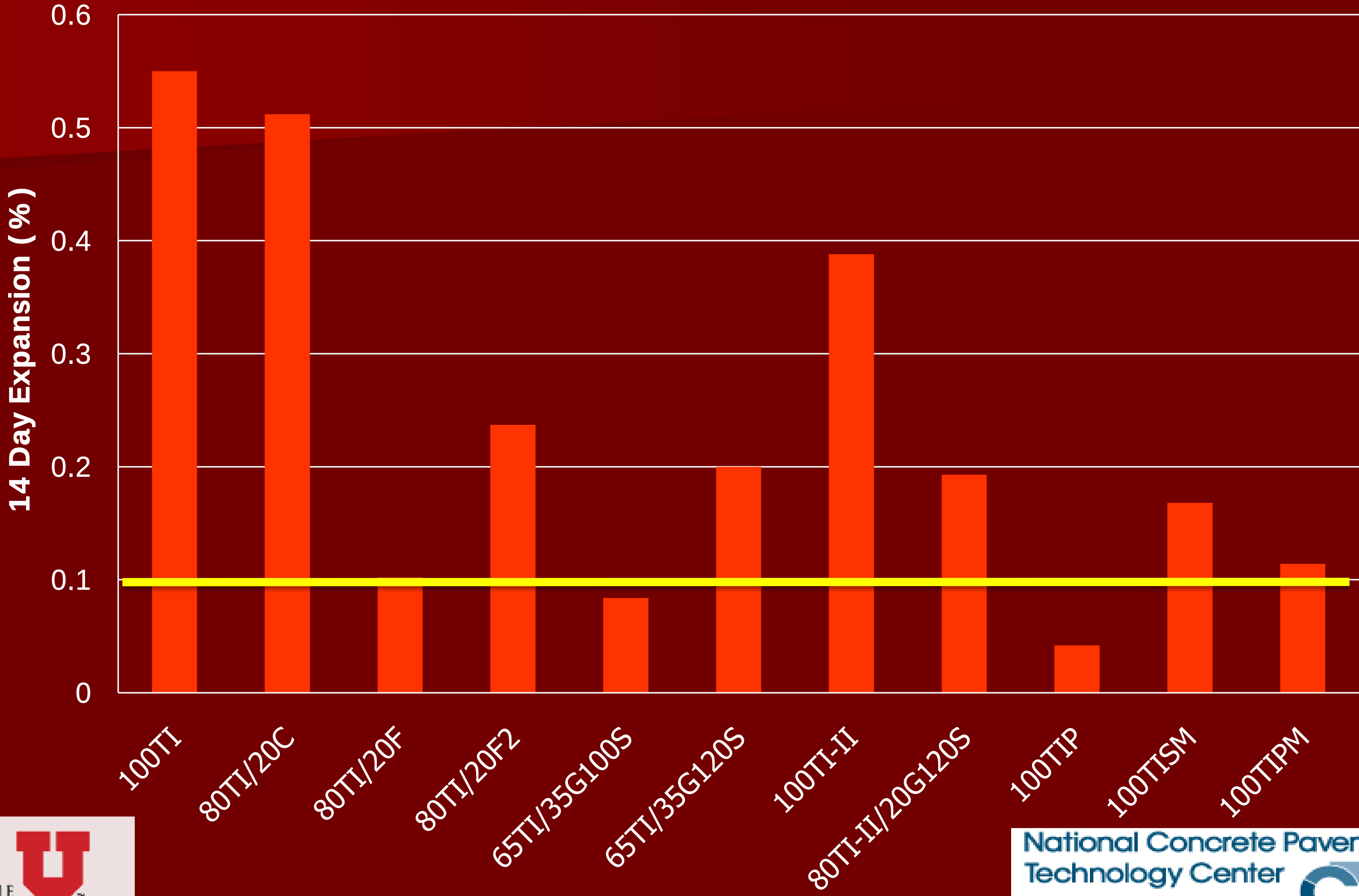
ASR of CONTROL MIXTURES



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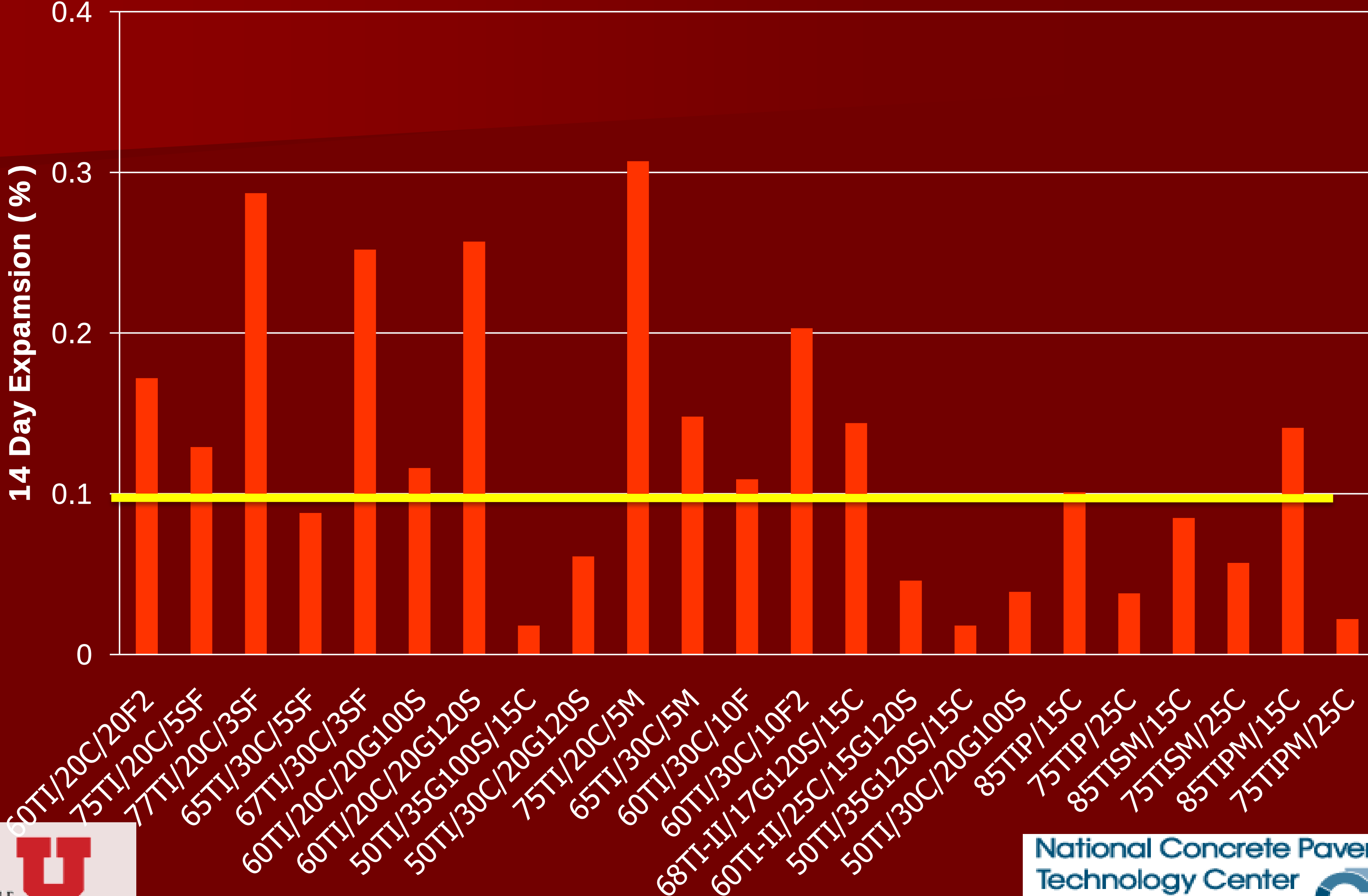
ASR with CLASS C FLY ASH



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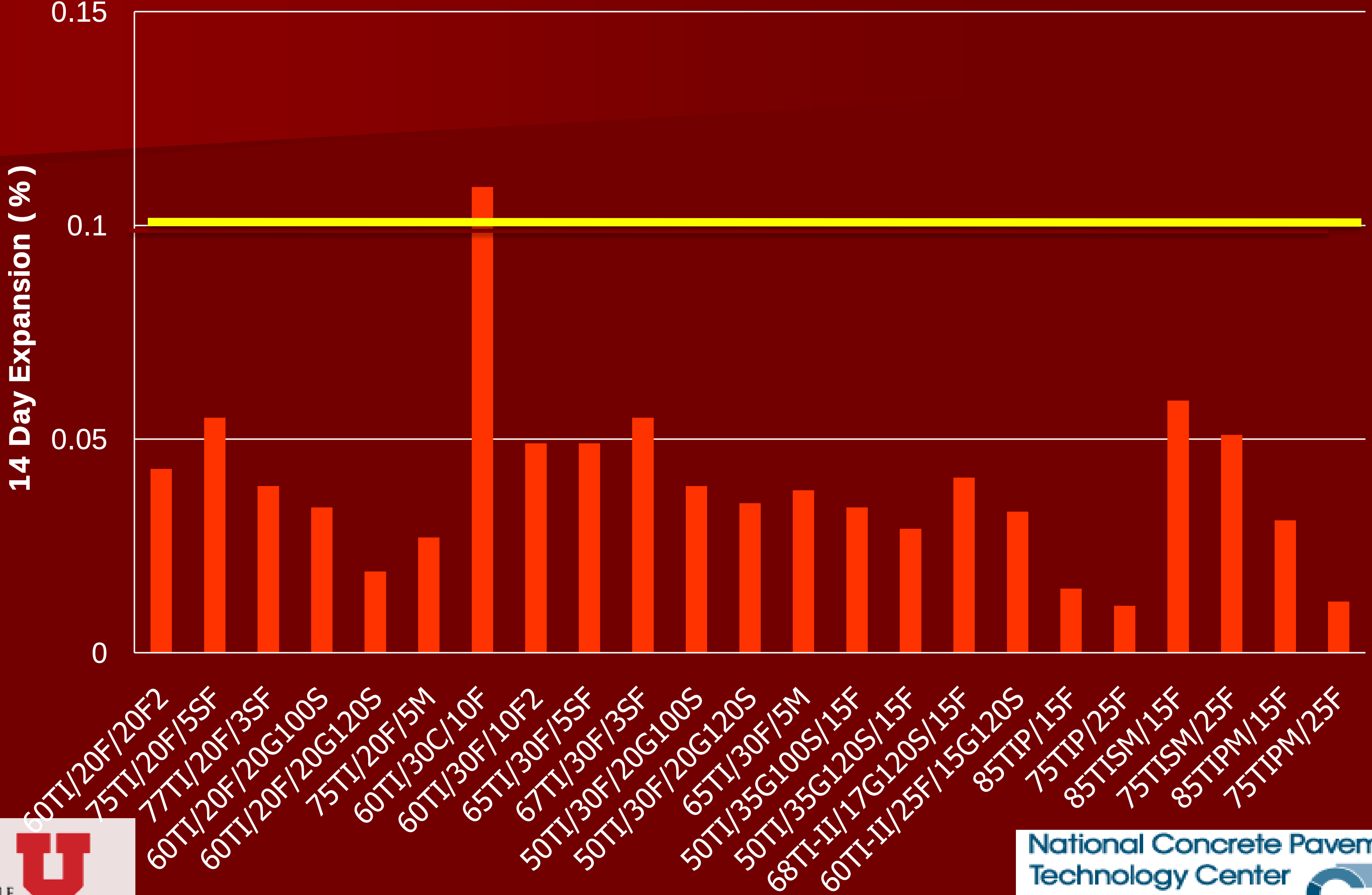
ASR with CLASS F FLY ASH



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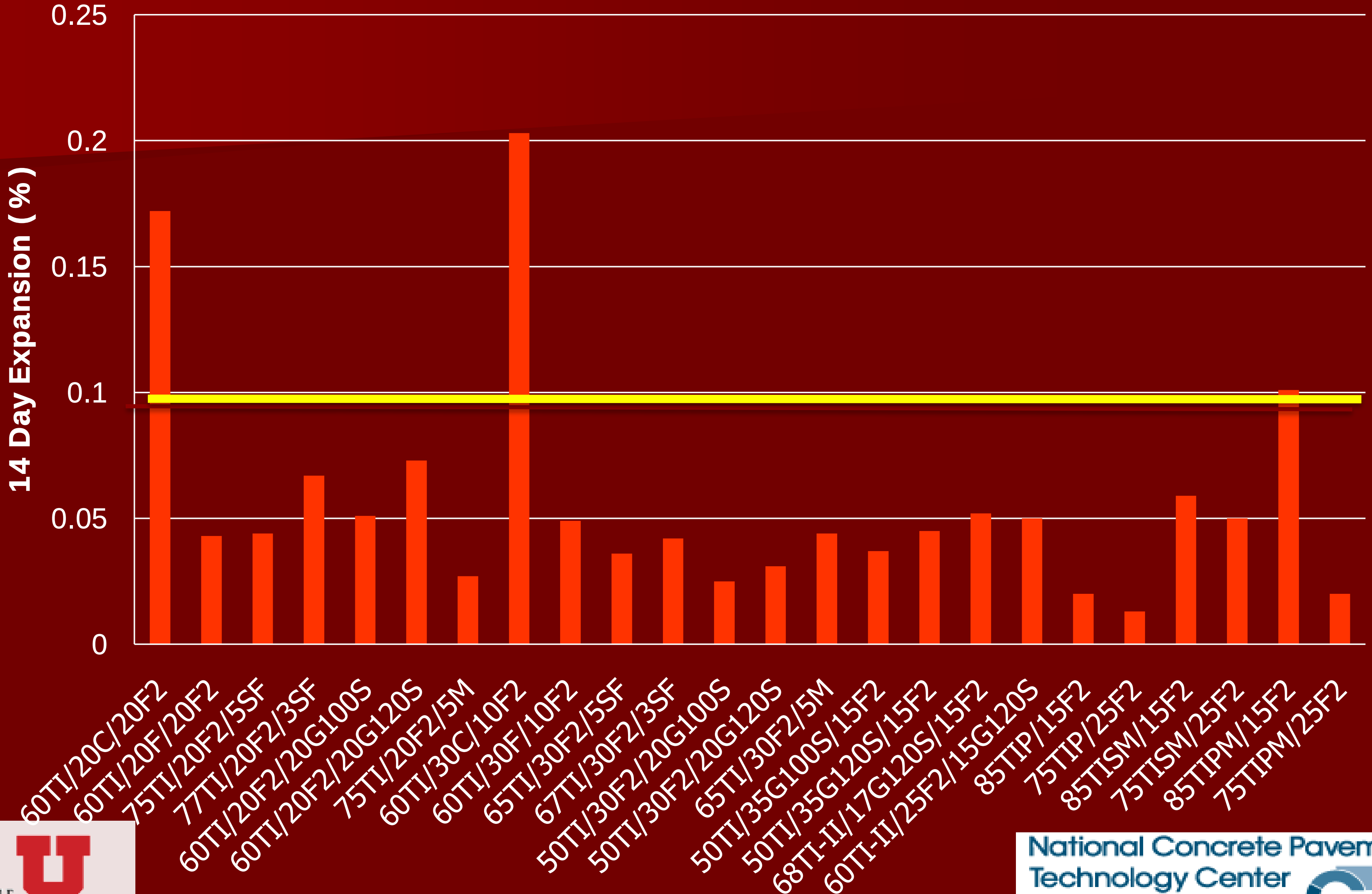
ASR with CLASS F2 FLY ASH



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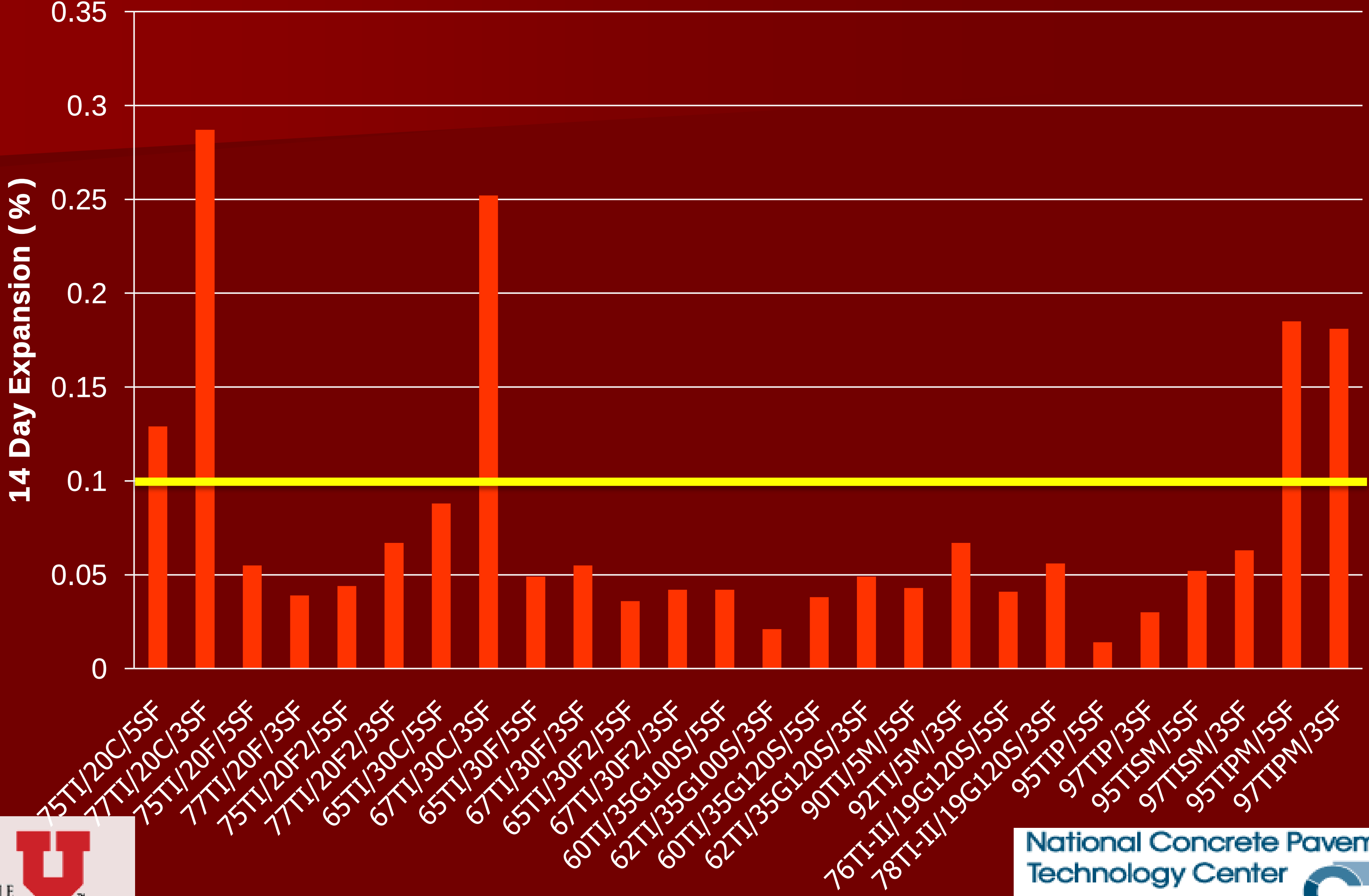
ASR with Ternary SILICA FUME



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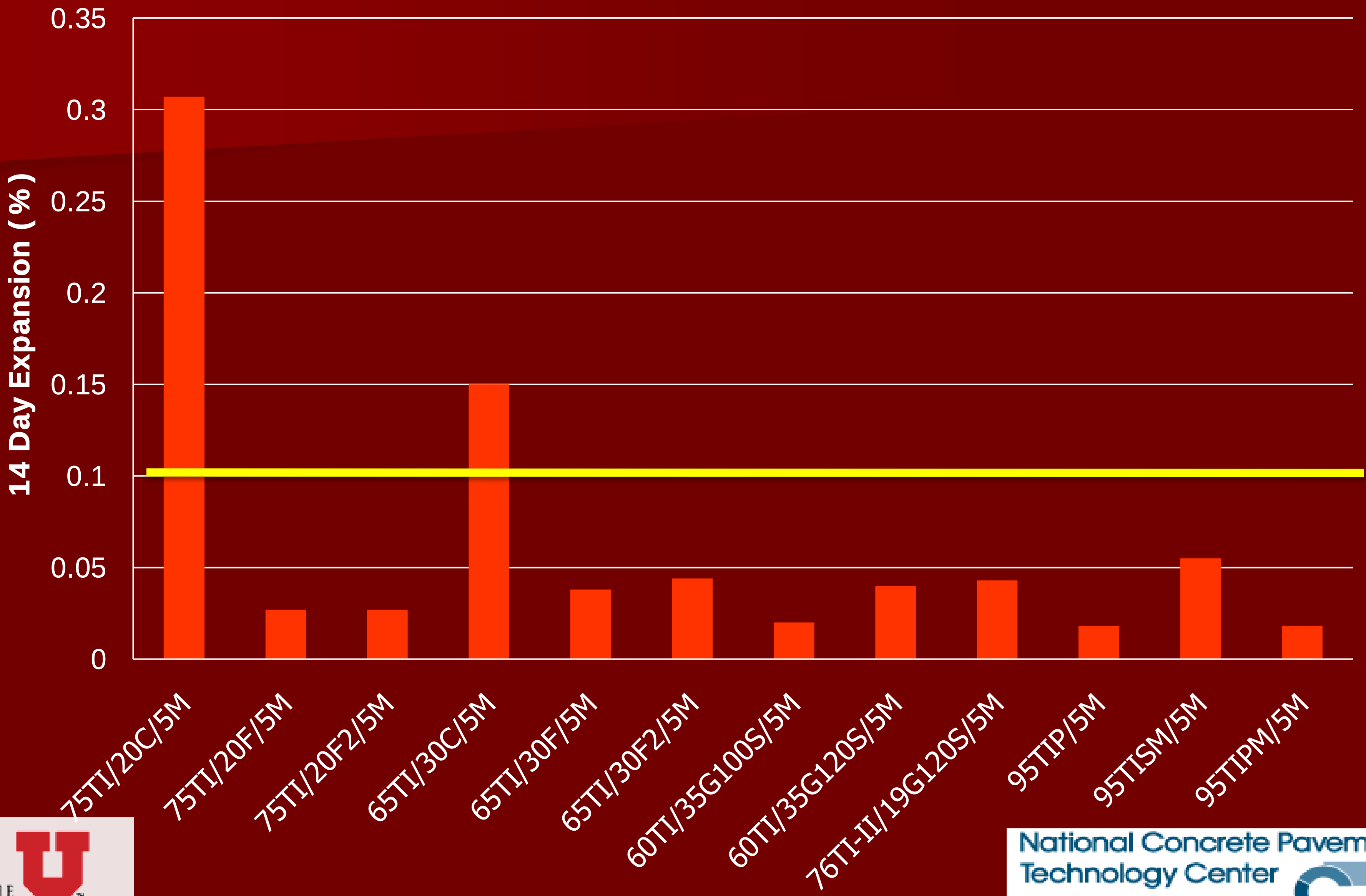
ASR with Ternary METAKAOLIN



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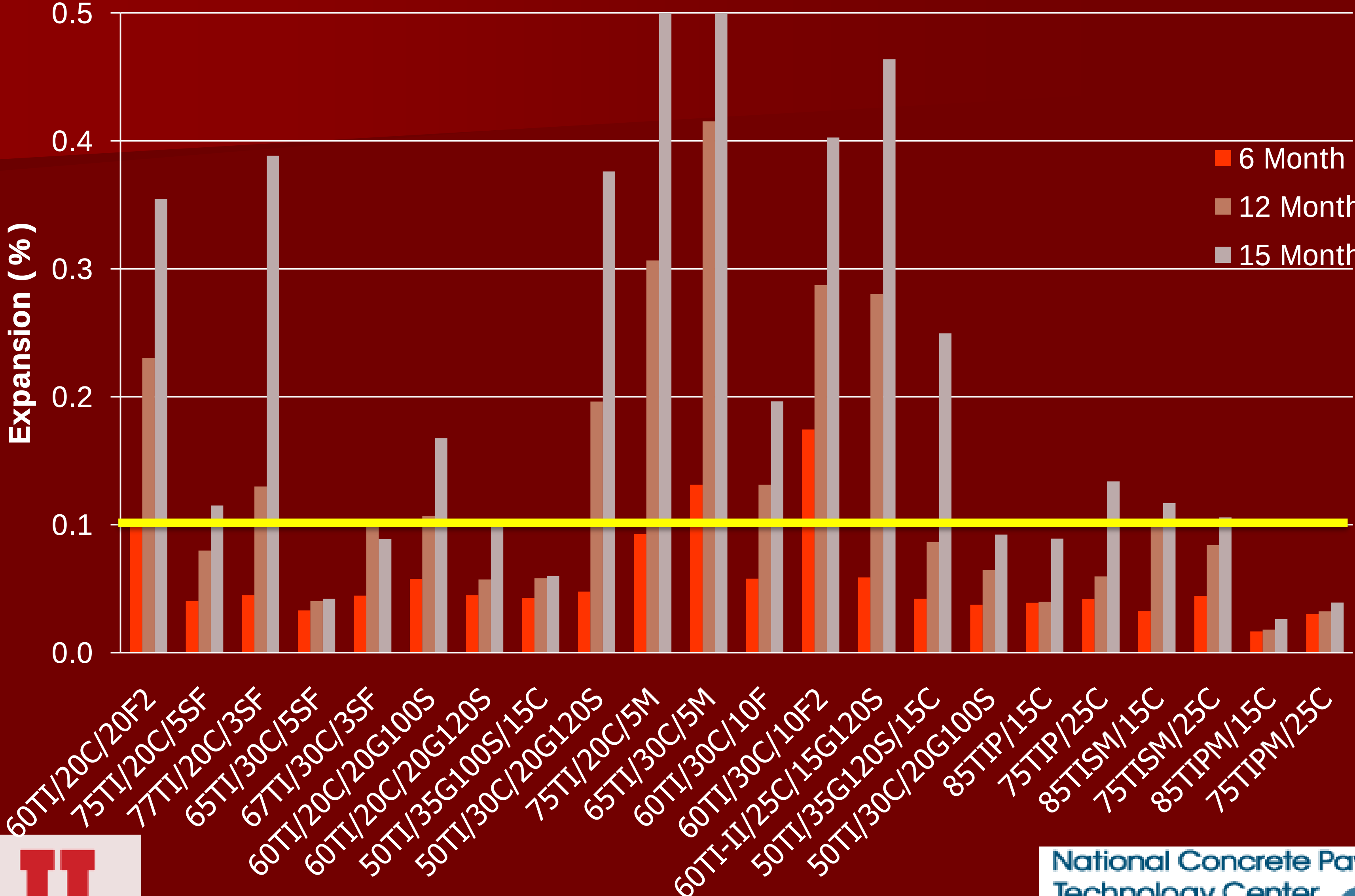
SULFATE with ternary CLASS C FLY ASH



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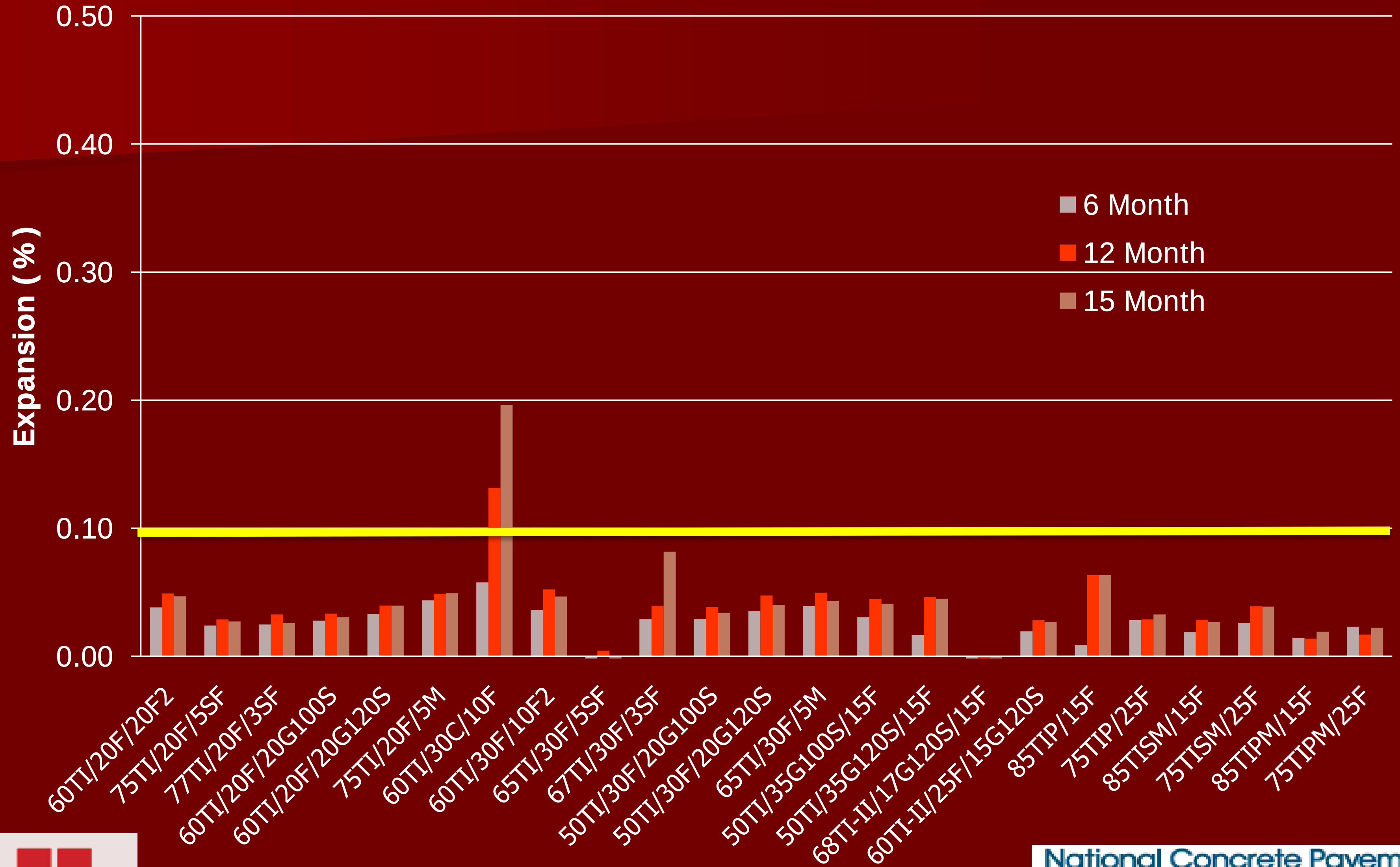
SULFATE with Ternary CLASS F FLY ASH



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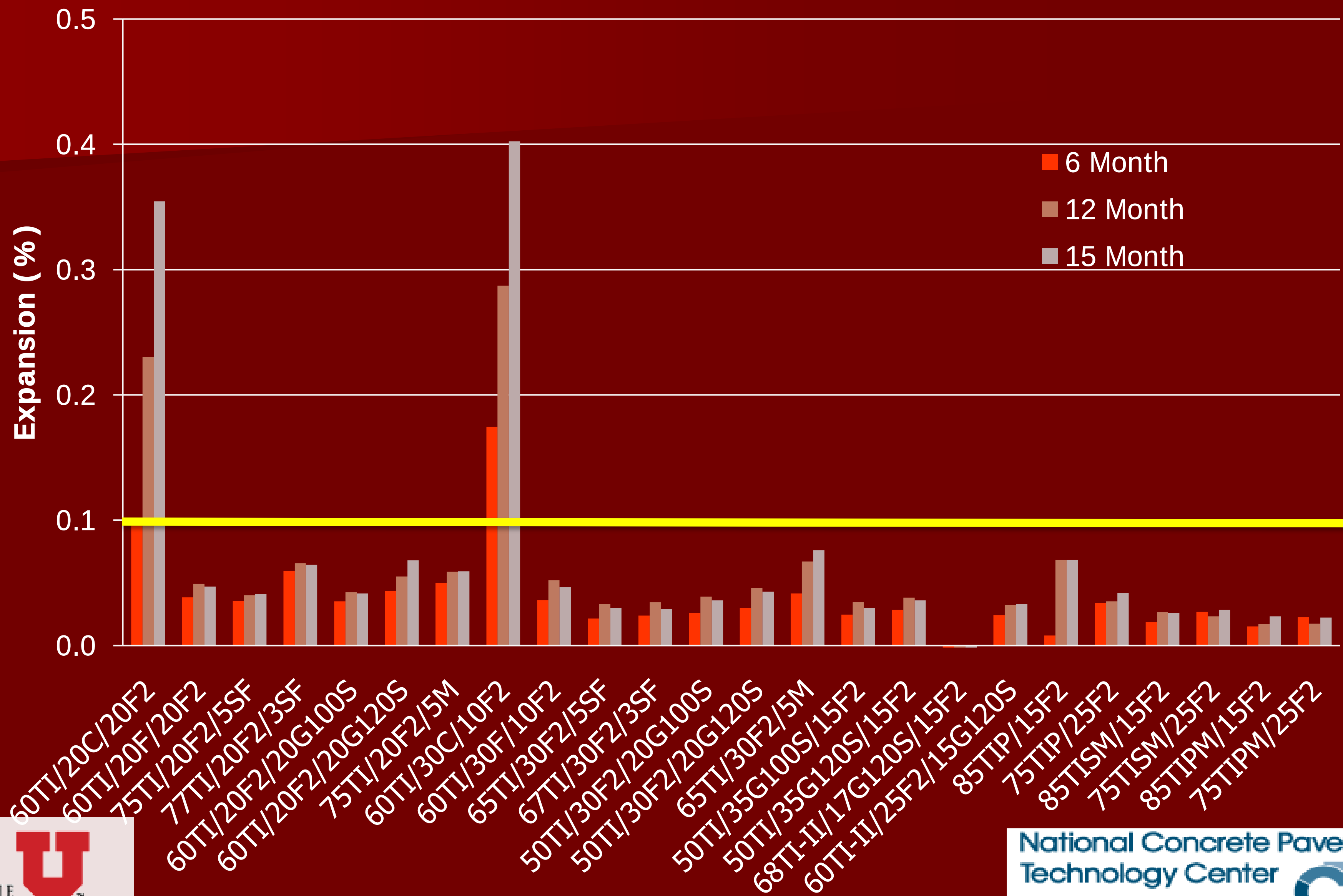
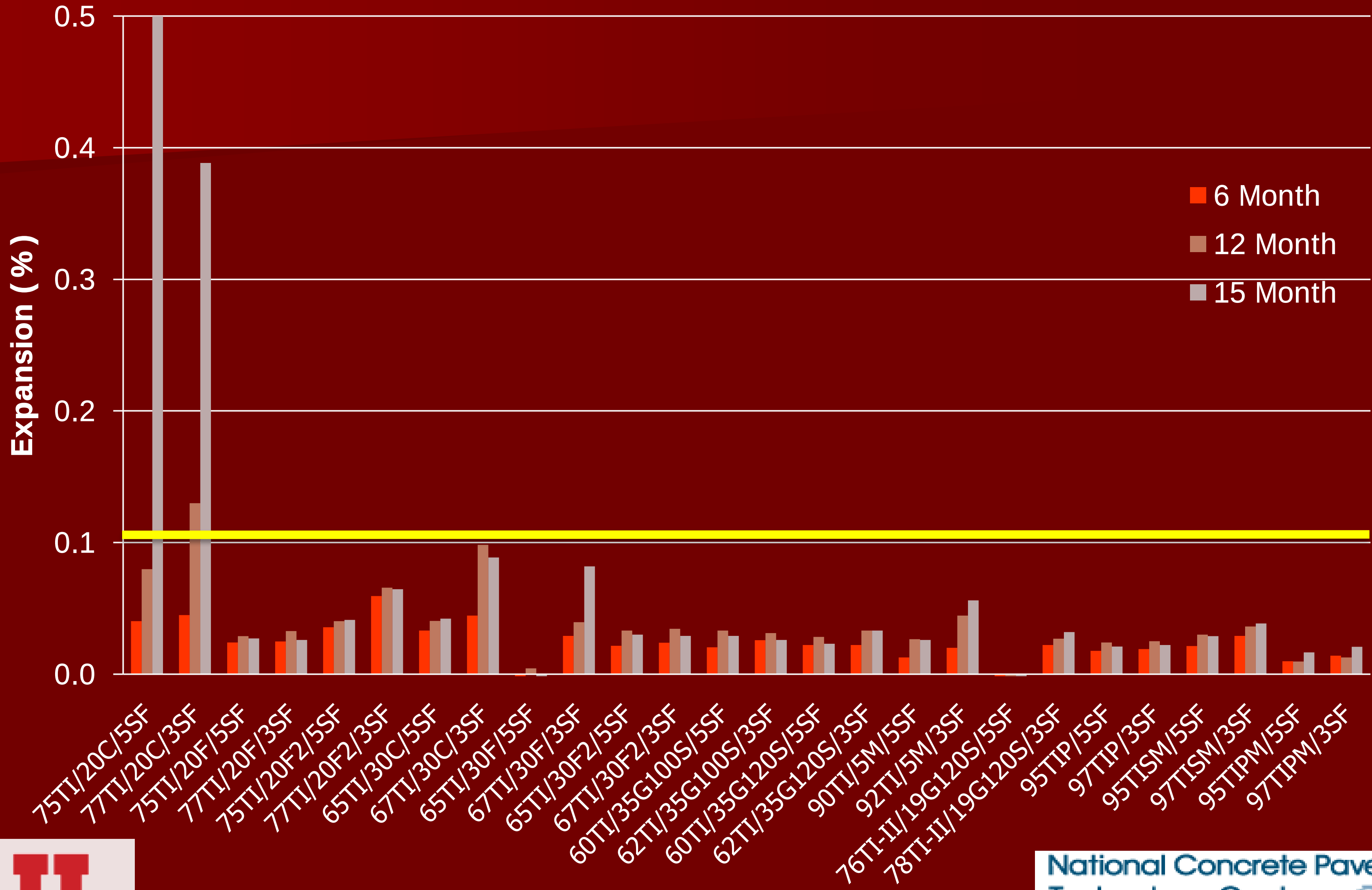
SULFATE with Ternary CLASS F2 FLY ASH



SULFATE with Ternary SILICA FUME



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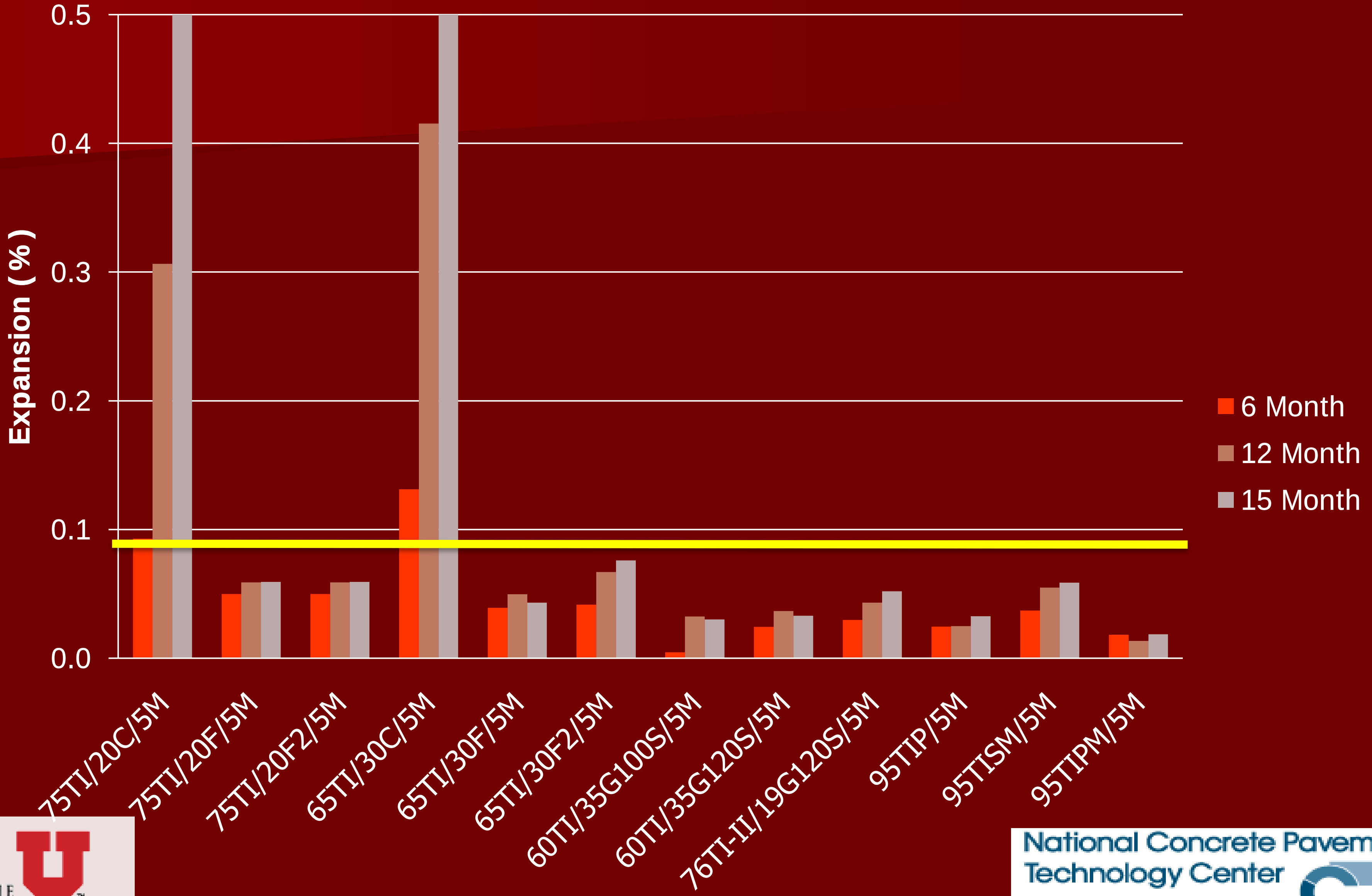
SULFATE with Ternary METAKAOLIN



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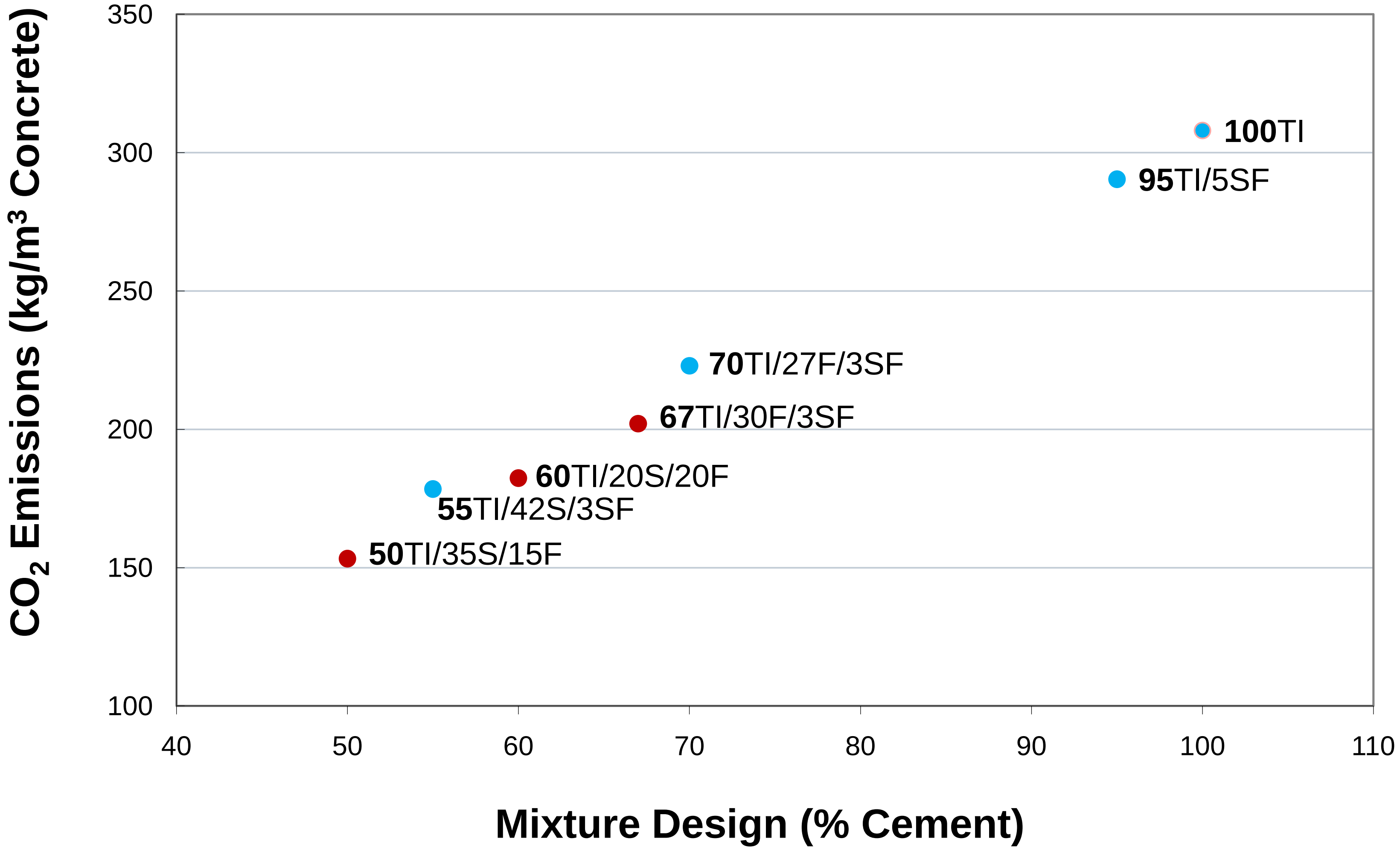
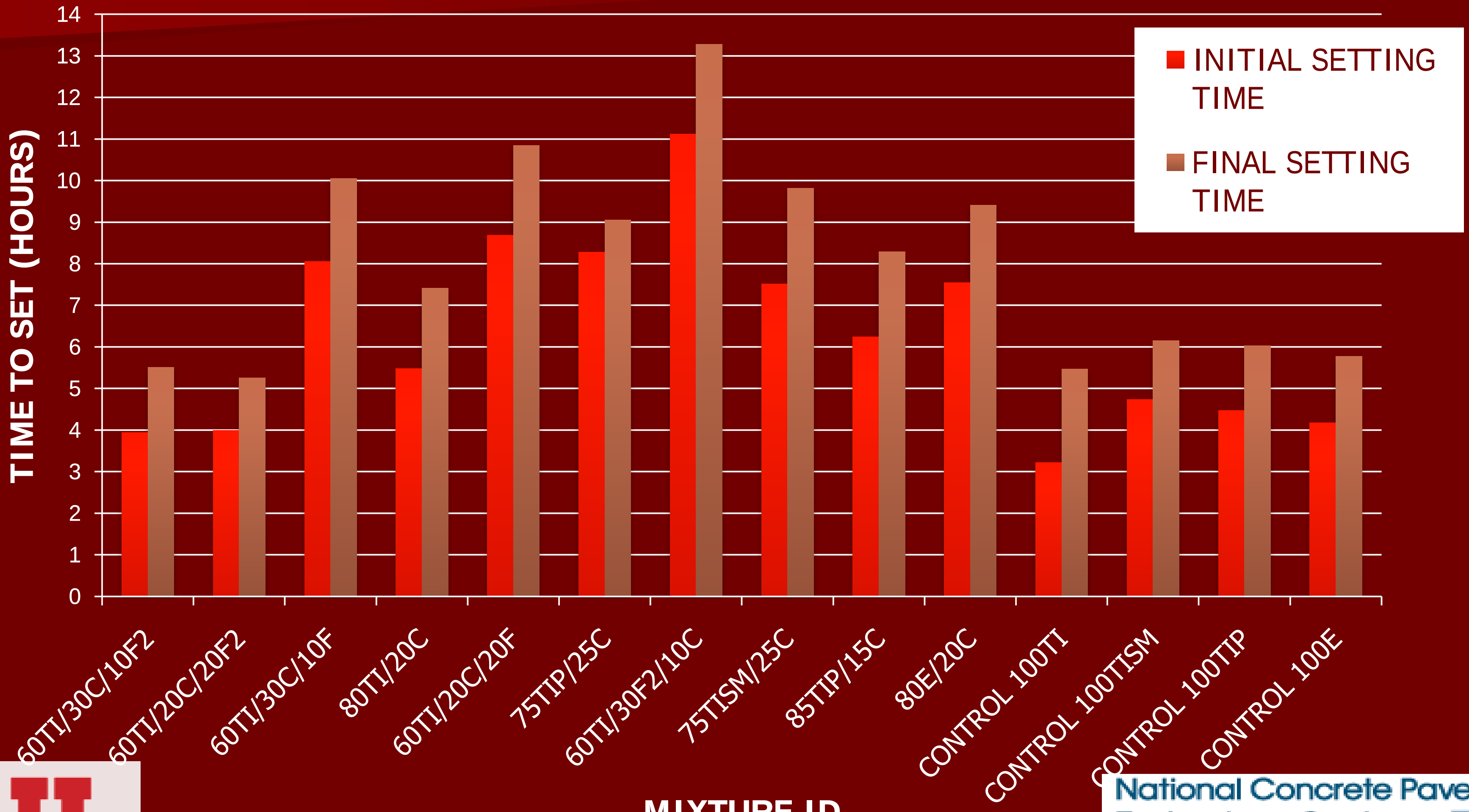
CO_2 Emissions and % Cement



SETTING TIME
MIXTURES WITH CLASS C FLY ASH



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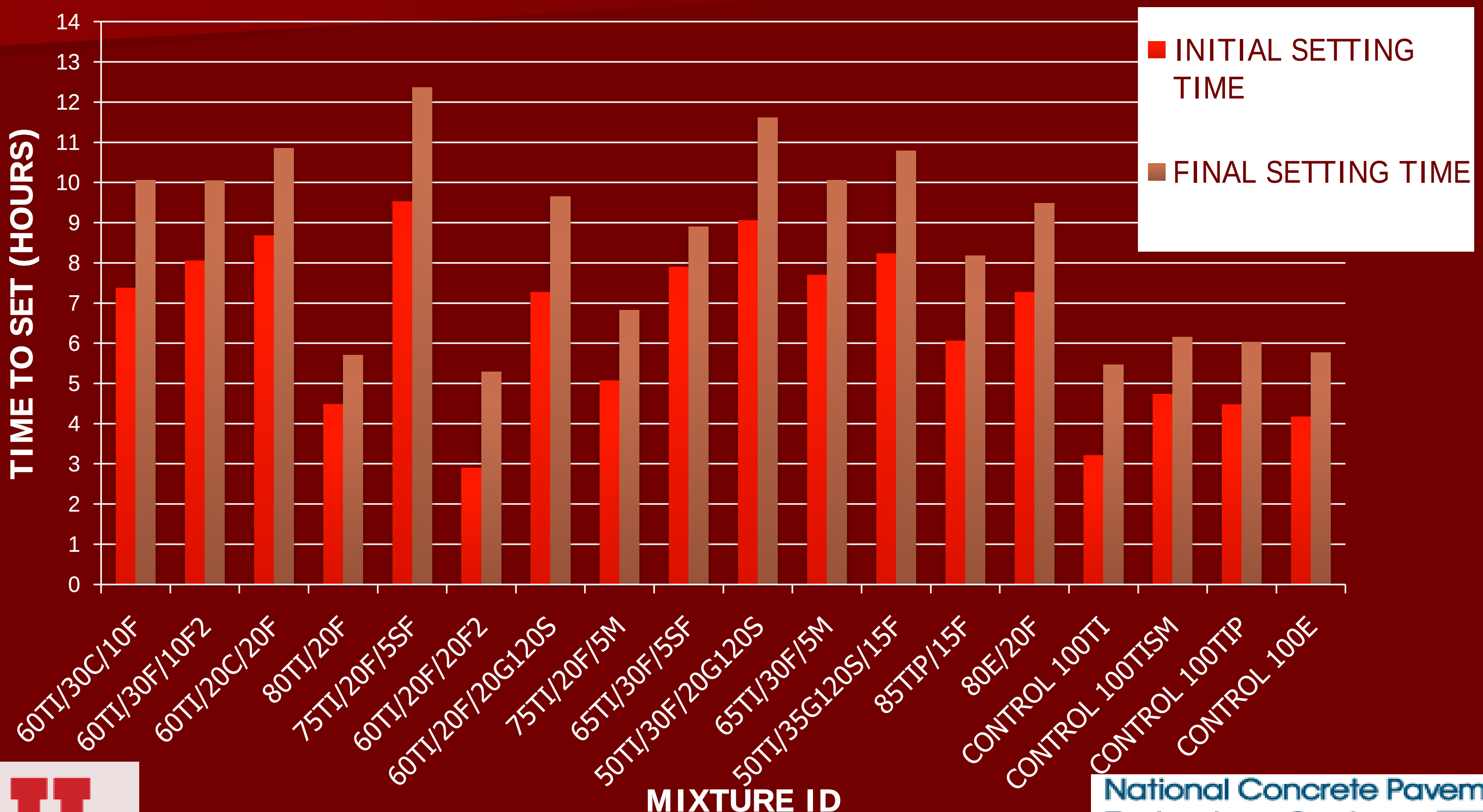
SETTING TIME
MIXTURES WITH CLASS F FLY ASH



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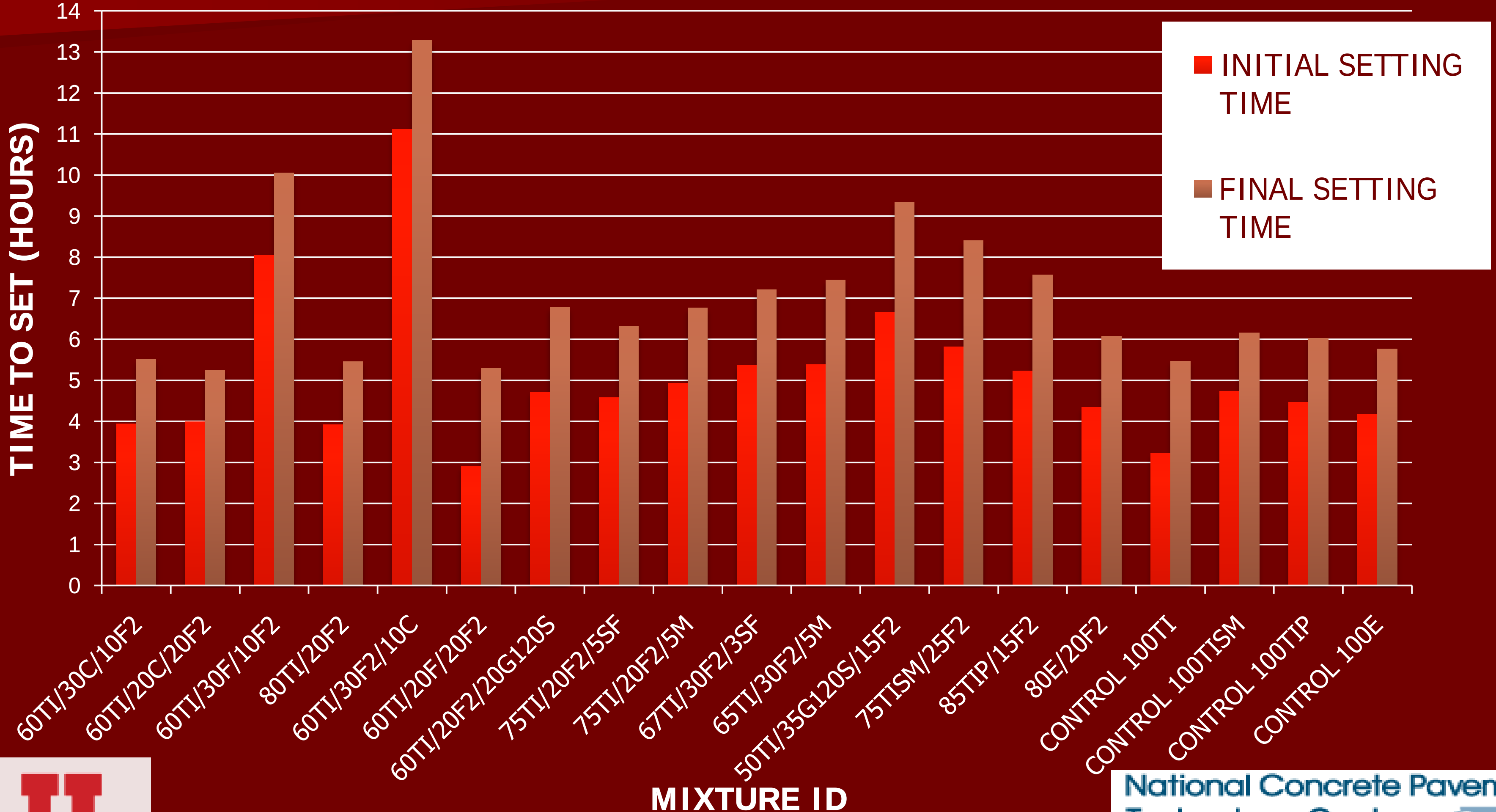
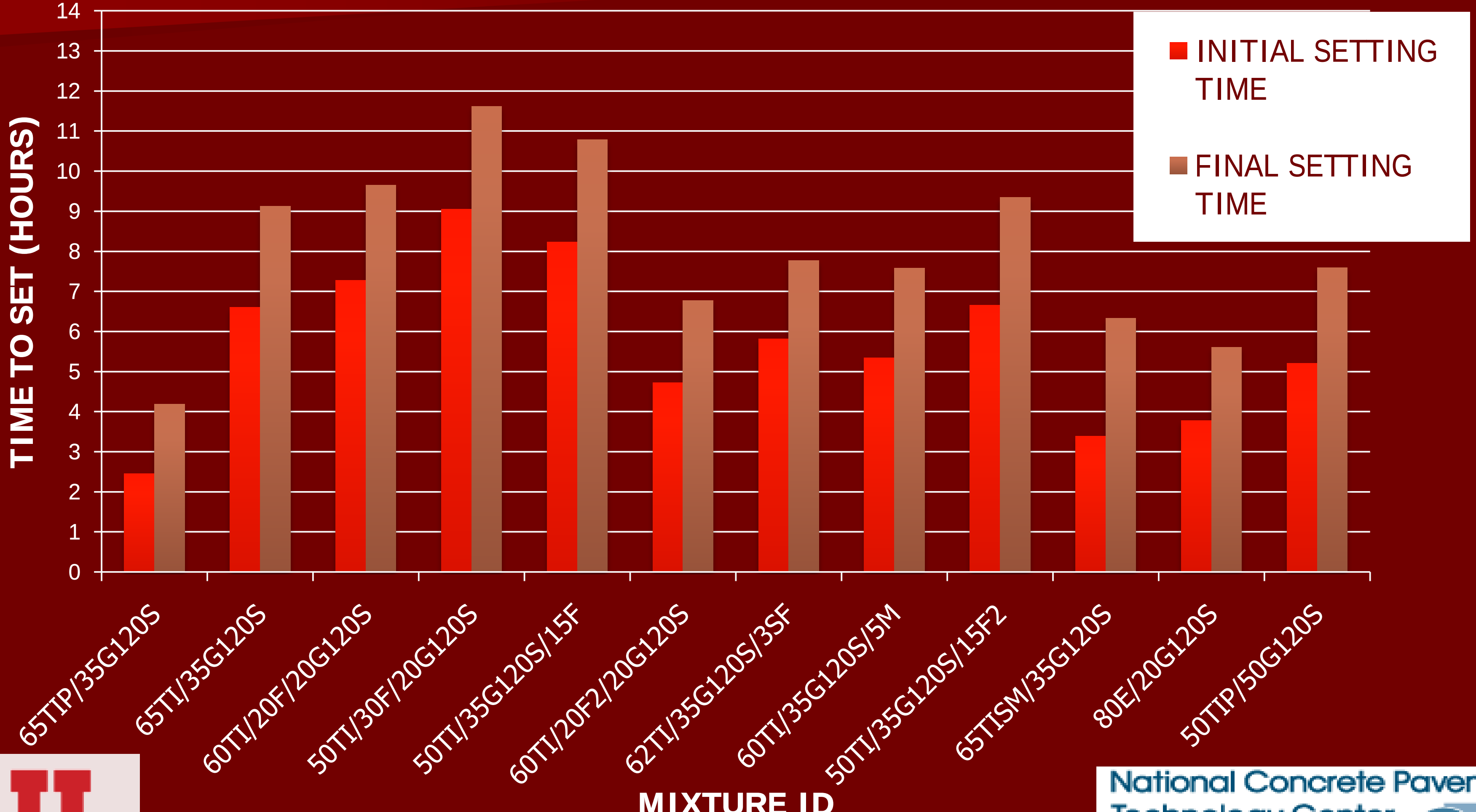
SETTING TIME
MIXTURES WITH CLASS F2 FLY ASH



SETTING TIME
MIXTURES WITH GRADE 120 SLAG



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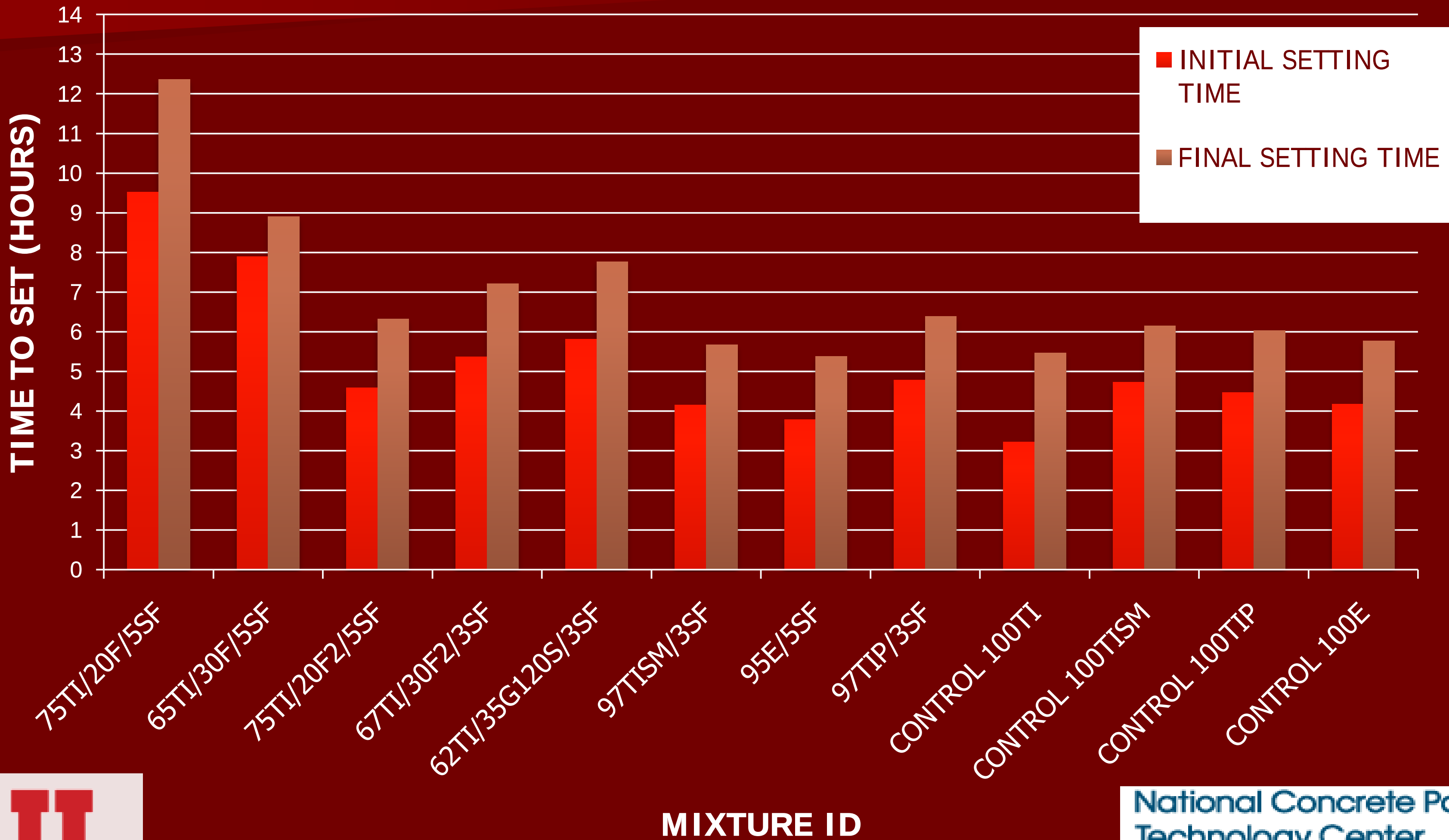
SETTING TIME
MIXTURES WITH SILICA FUME



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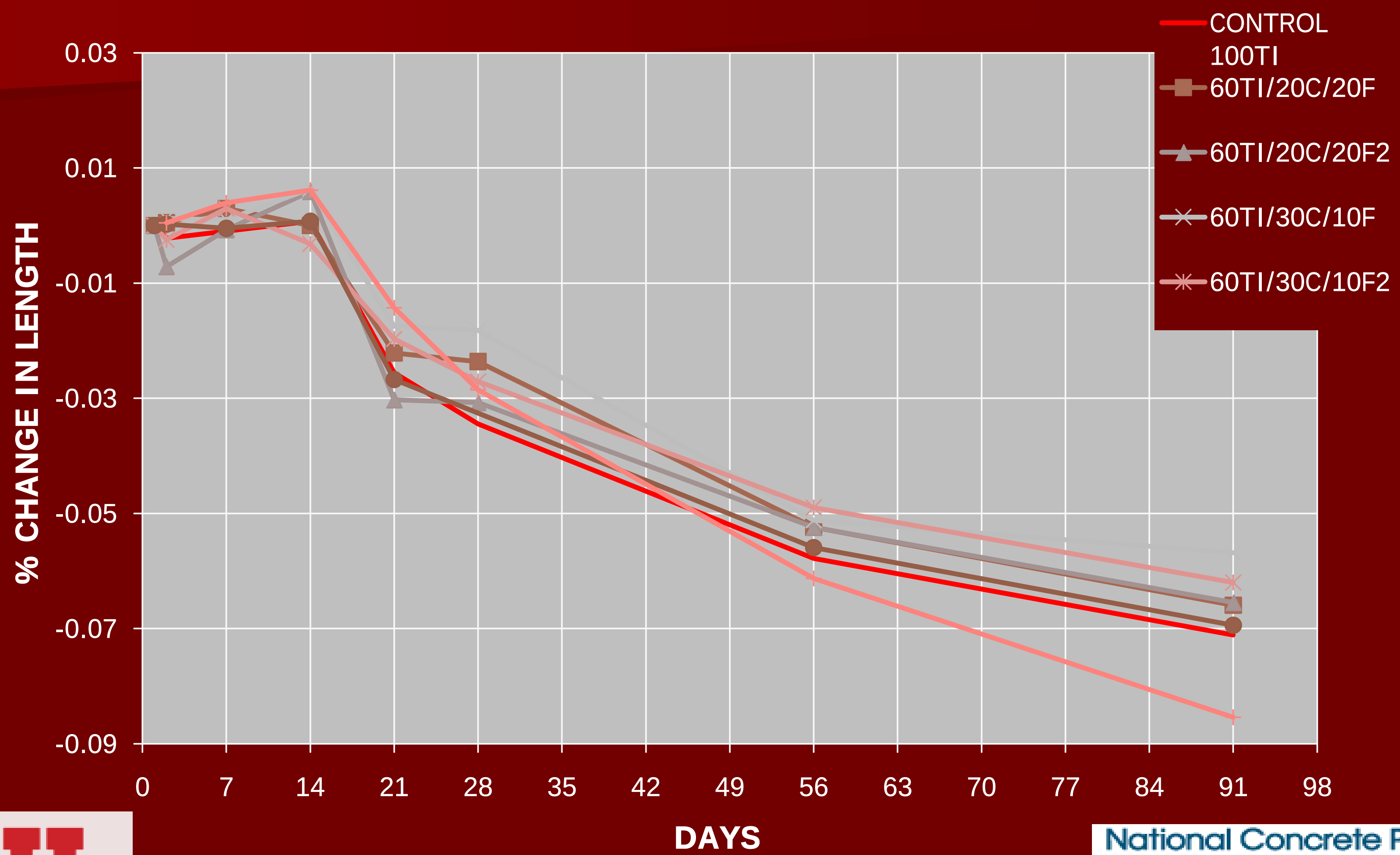
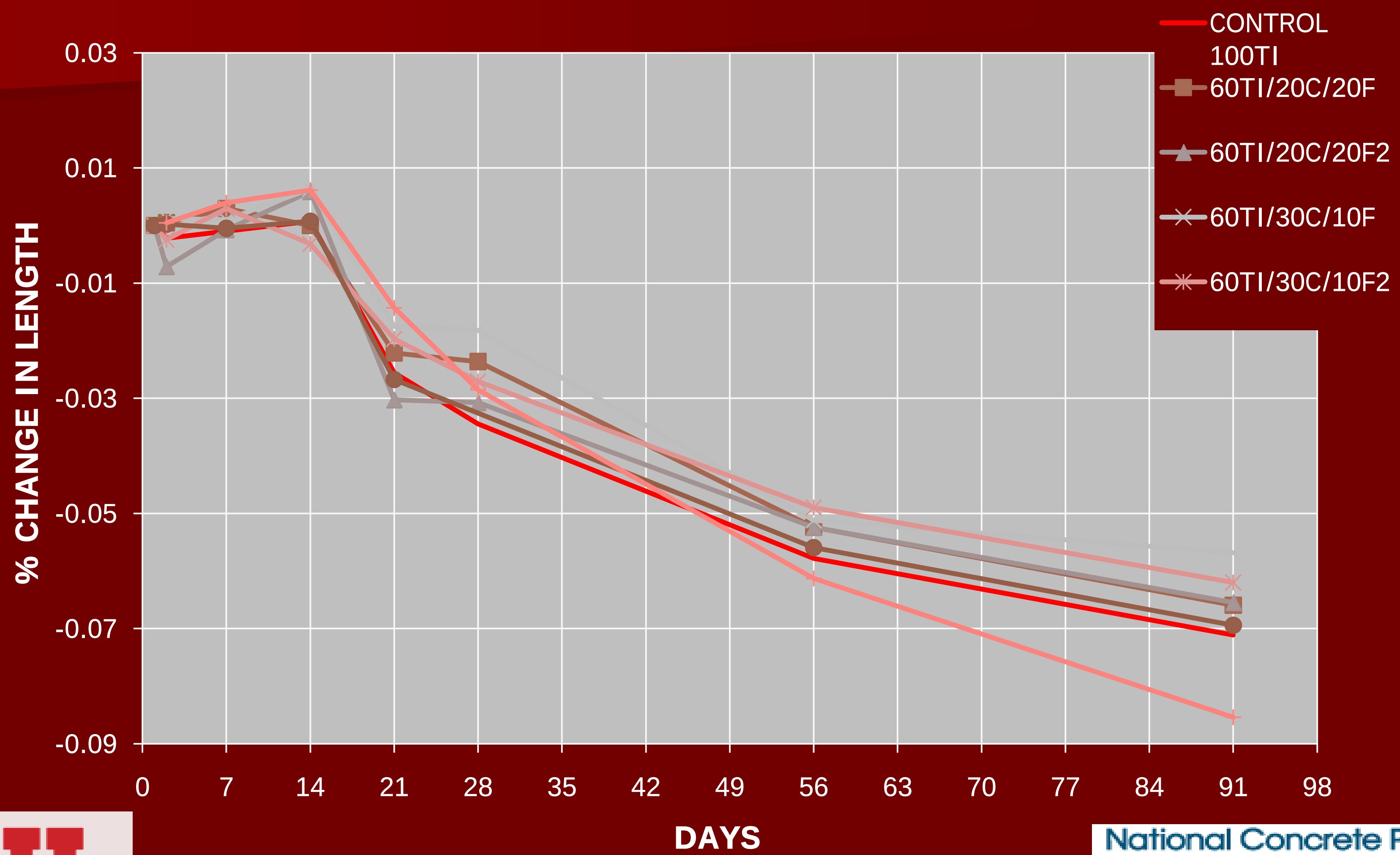
SHRINKAGE FOR MIXTURES CONTAINING CLASS C FLY ASH



SHRINKAGE FOR MIXES CONTAINING CLASS C FLY ASH



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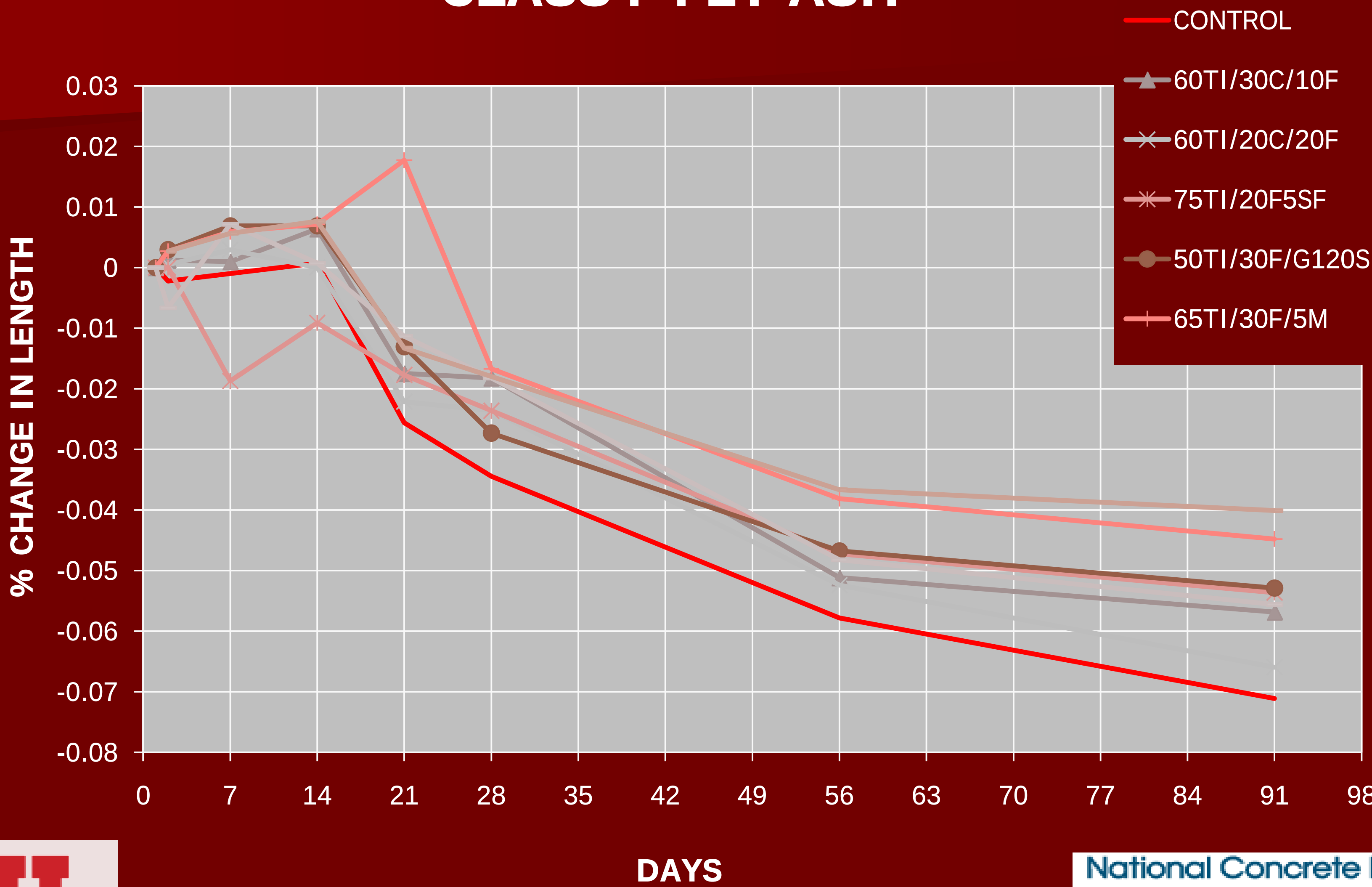
SHRINKAGE FOR MIXTURES CONTAINING CLASS F FLY ASH



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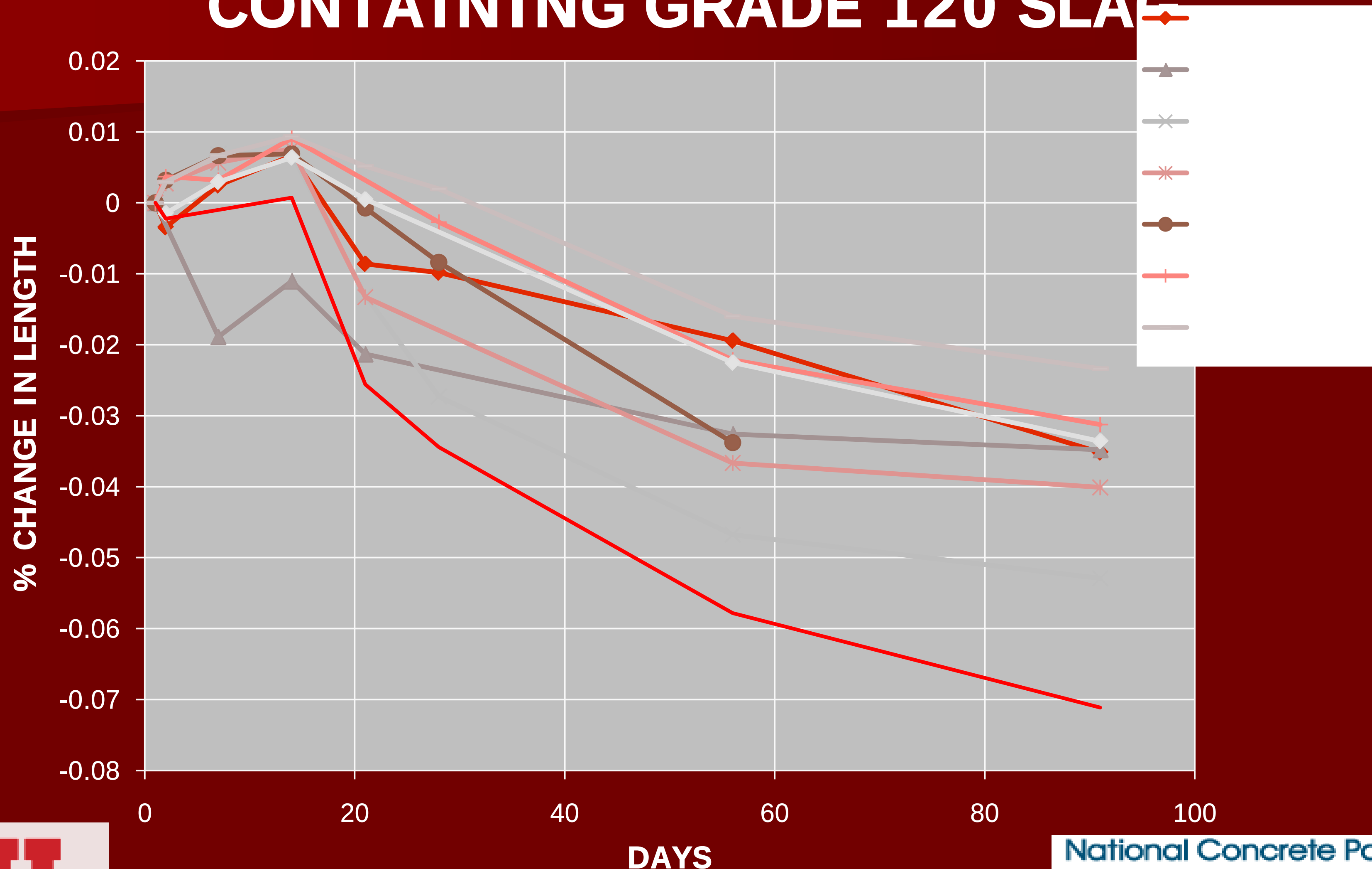
SHRINKAGE FOR MIXTURES CONTAINING GRADE 120 SLAG



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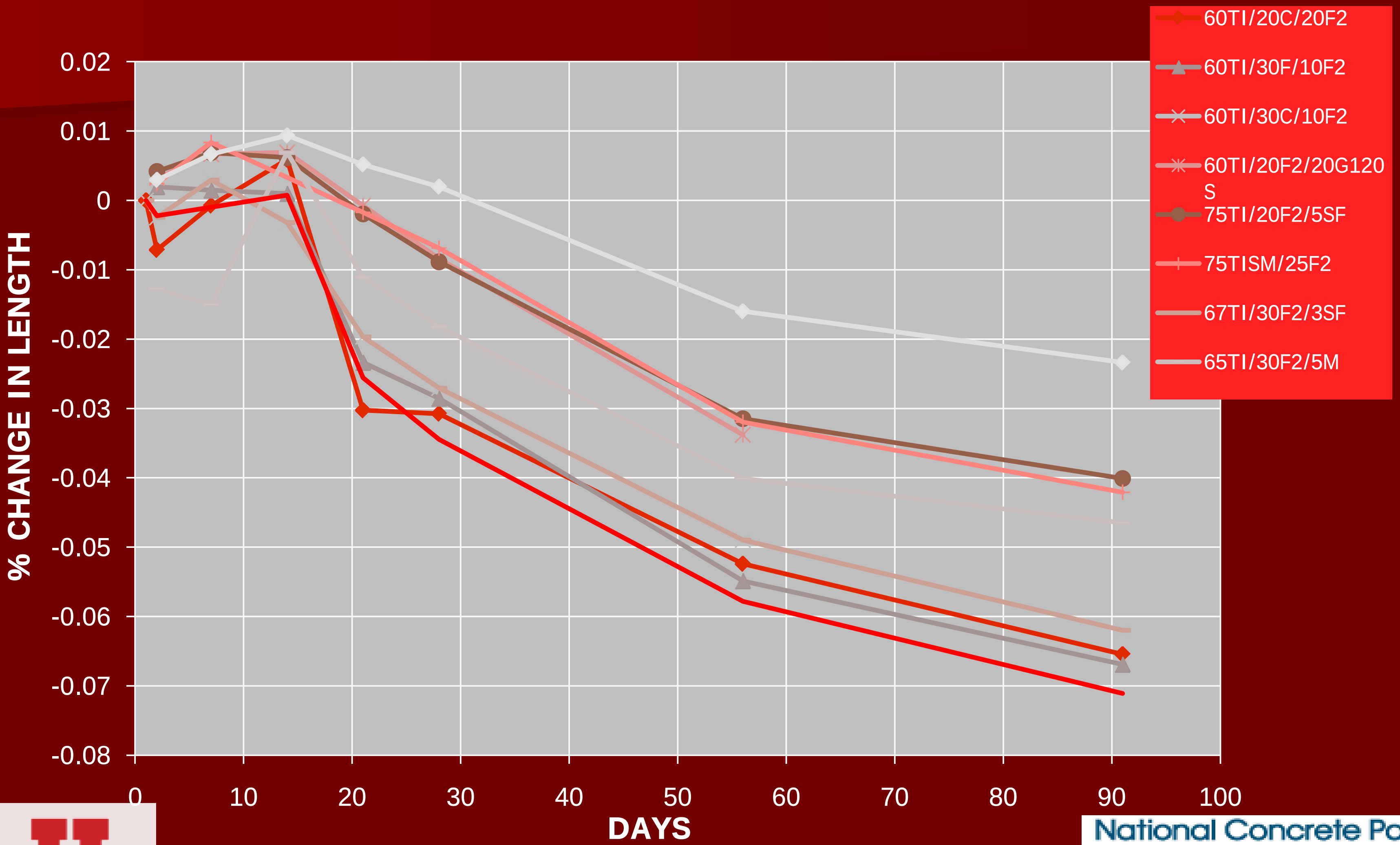
SHRINKAGE FOR MIXTURES CONTAINING CLASS F2 FLY ASH



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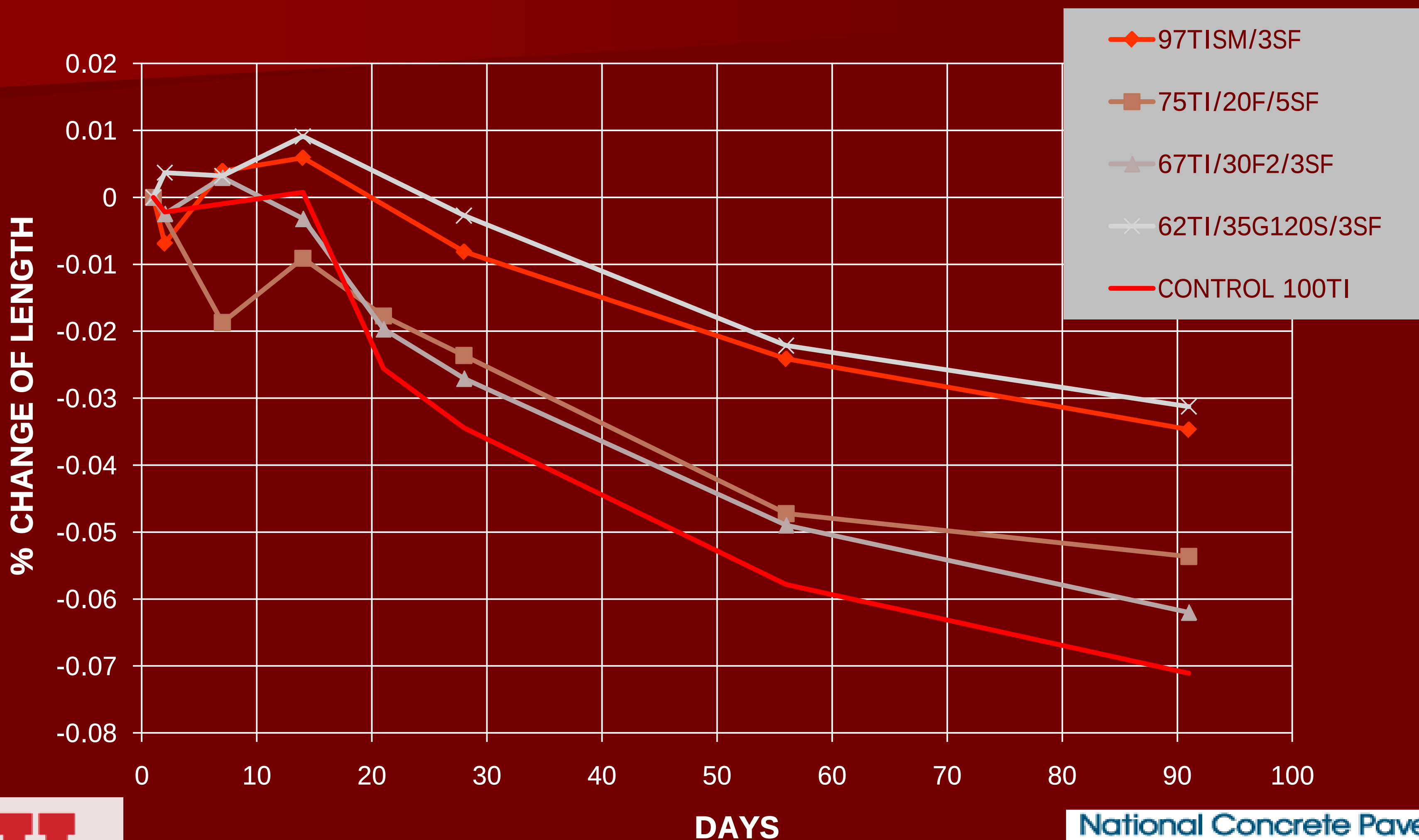
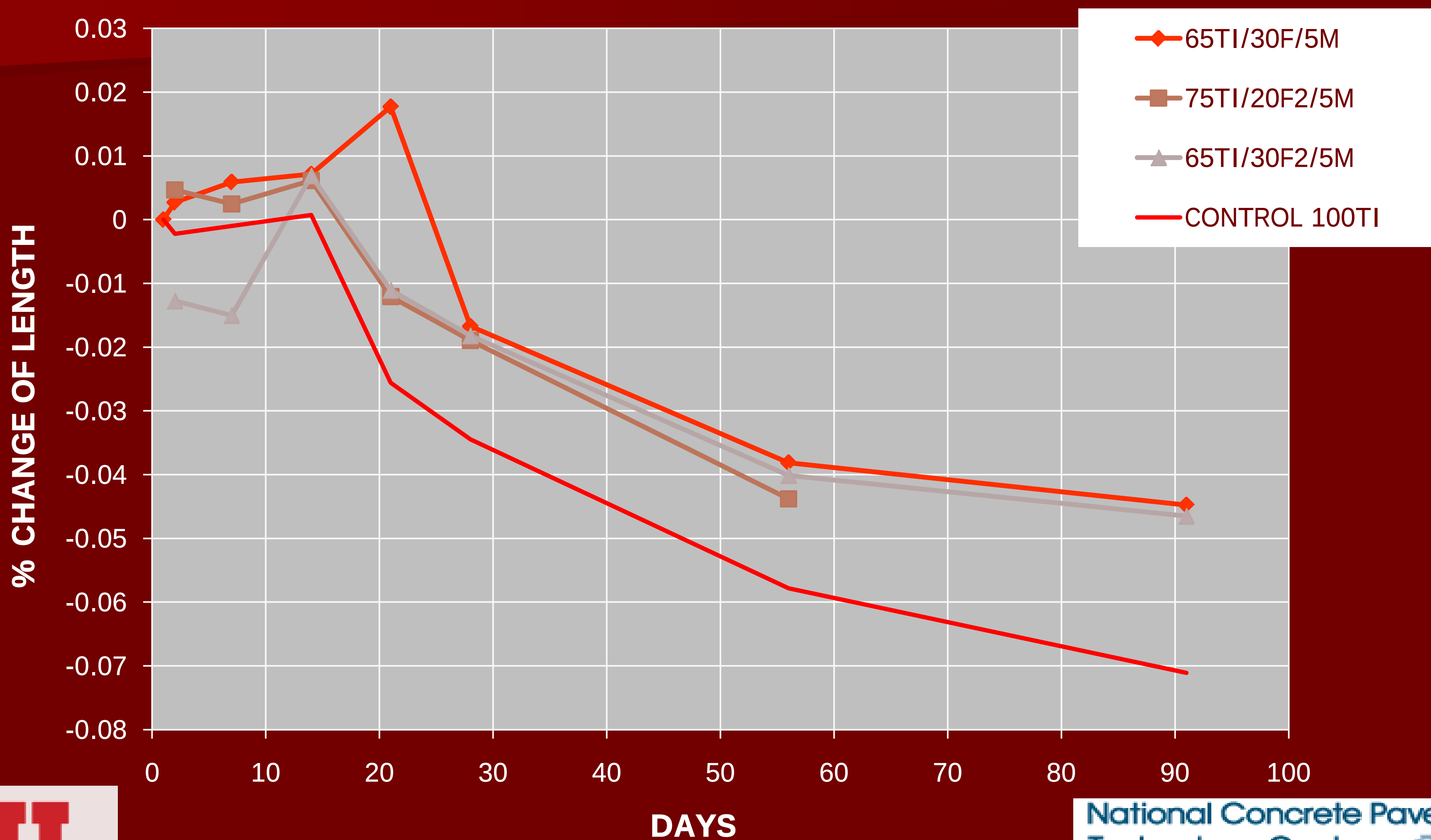
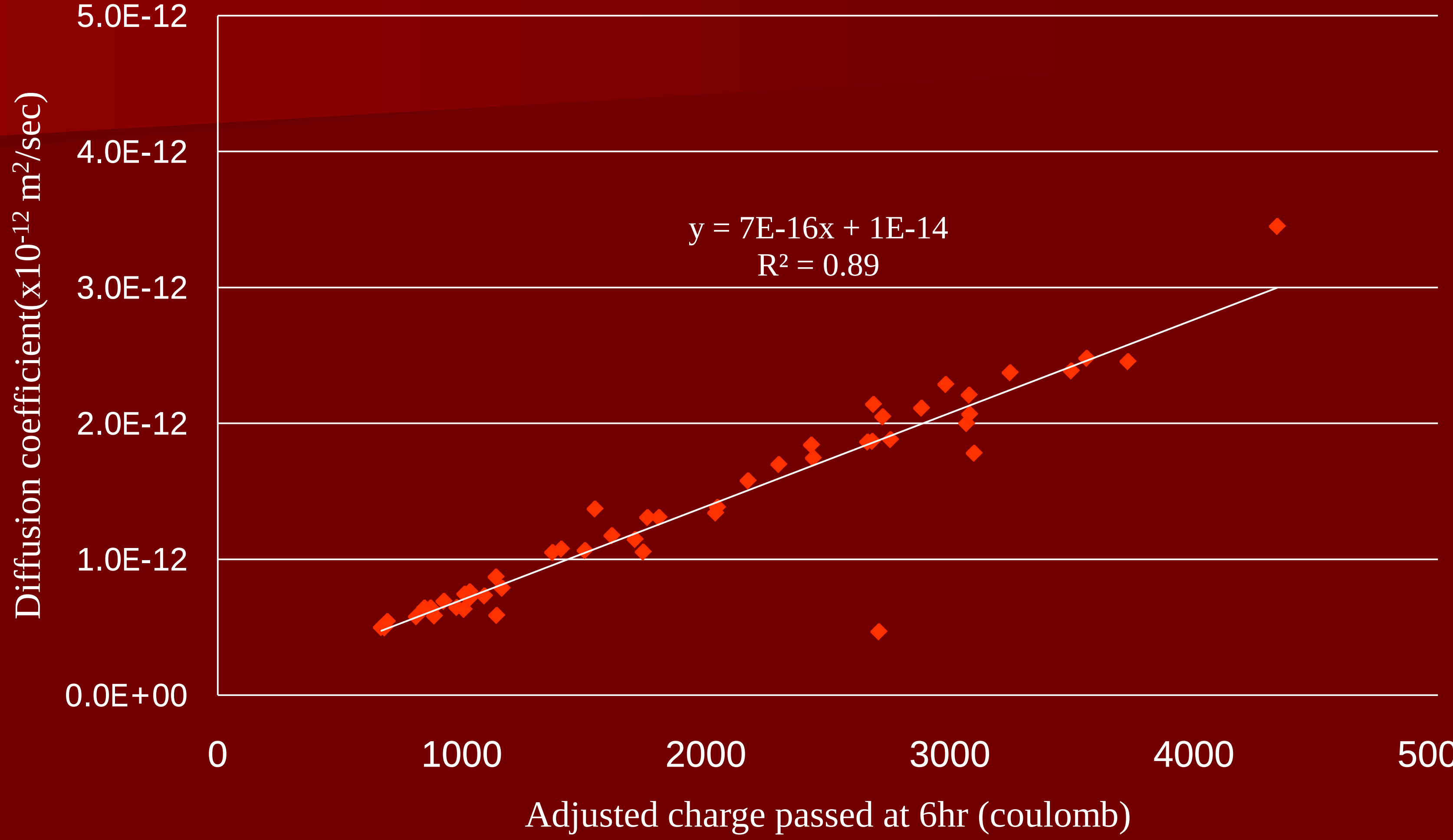
SHRINKAGE FOR MIXTURES CONTAINING SILICA FUME



SHRINKAGE FOR MIXTURES CONTAINING METAKAOLIN



Diffusion coeffcient at 360 min vs adjusted charge passed at 6 hr (Nernst-Einstein)



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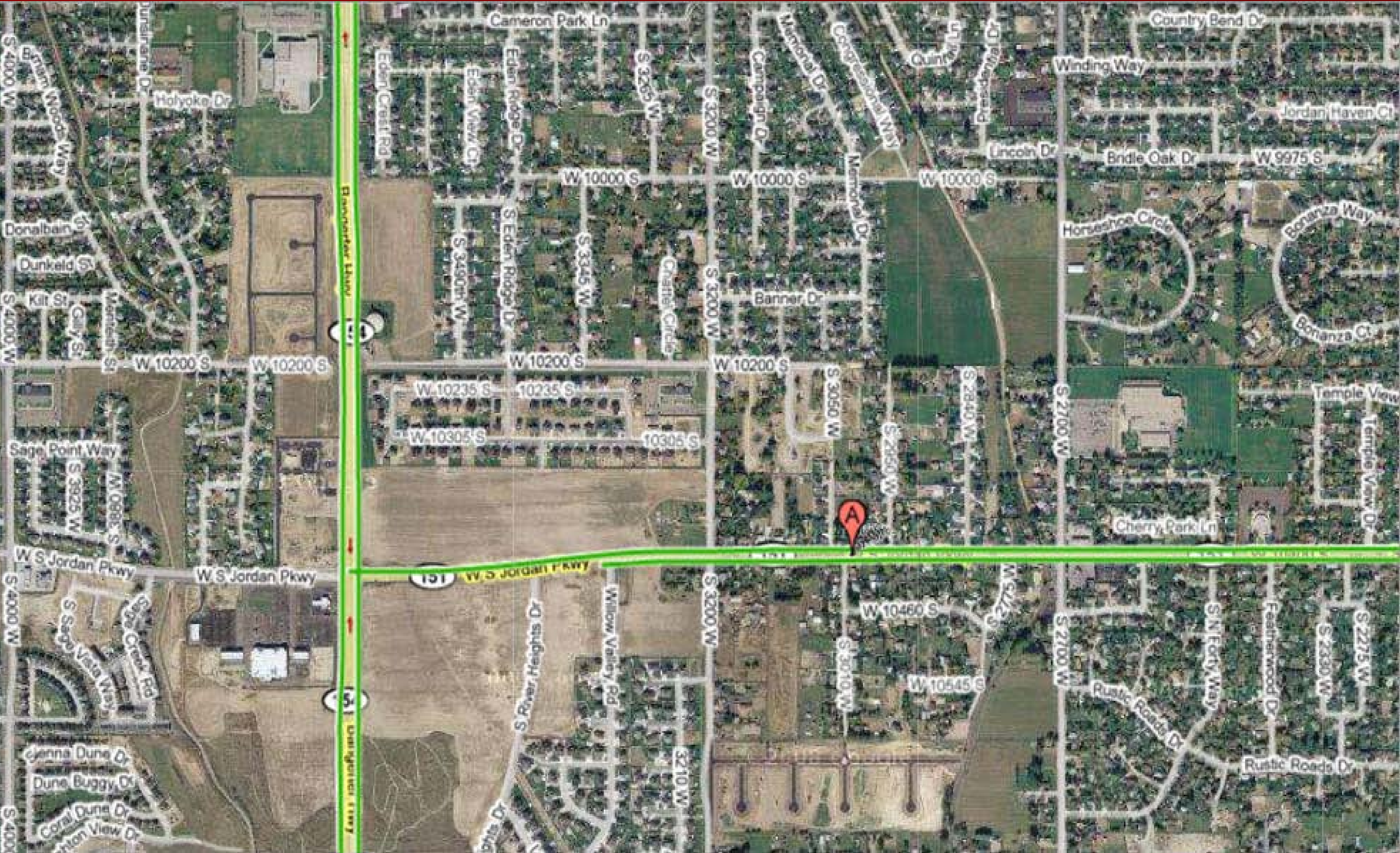
Phase III - Progress

- Phase III (Started 6/09)
  - – Utah SR201 Concrete Paving (2009)
  - – Pennsylvania Bridge Decks (2010)
  - – New Hampshire (?) (2010-2011)
  - – Illinois, Mississippi, California, Iowa, Kansas, Wisconsin (TBD)

UDOT 10400 S (Redwood-Bangerter)



Salt Lake County, Utah (UDOT)

- 1000 cubic yards of control pavement
  - C150 Type II/V with 25% class F fly ash
- 1000 cubic yards of 10% limestone blended with control clinker C1157 MS with 25% class F fly ash
- No cracking at 100 days
- Nearly identical strength development
- Ternary blend has substantially better finish

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PennDoT District 9-0 Pennsylvania

District 9-0 Pennsylvania

- Both bridge decks constructed by same contractor with different ternary mixtures
- PennDOT & PACA cooperation
- Performance based ternary mixture
  - <2000 coulombs AASTOTO T277
  - < 500με shrinkage ASTM C157
  - F_c' > 4,000 psi

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INTERNATIONAL CONFERENCE ON OPTIMIZING PAVING CONCRETE MIXTURES & ACCELERATED CONCRETE PAVEMENT CONSTRUCTION AND REHABILITATION
November 7 to 9, 2007 – Atlanta, Georgia

Effects of Different Air Entraining Agents (AEA), Supplementary Cementitious Materials (SCM), and Water Reducing Agent (WR) on the Air Void Structure of Fresh Mortar

T.D. Rupnow, V.R. Schaefer, K. Wang, and P.J. Tikalsky

Second International Symposium on Ultra-High Performance Concrete, Kassel, Germany, March 5-7, 2008

Environmental Advantages of Ternary Cement Combinations

Stephanie Márquez, Shannon Hanson, and Paul J. Tikalsky
University of Utah

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NINTH CANMET/ACI INTERNATIONAL CONFERENCE ON FLY ASH, SILICA FUME, SLAG AND NATURAL POZZOLANS IN CONCRETE

Warsaw, May 20-25, 2007

EFFECT OF BINARY AND TERNARY CEMENTITIOUS SYSTEMS ON THE PERFORMANCE OF CONCRETE BRIDGES

Paul J. Tikalsky [2] Petr Konečný [1]

[1] University of Utah, U.S.A.

[2] VŠB -Technical University of Ostrava, Czech Rep.

Thank You

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