Feasibility of Using High-alkali Natural Pozzolans and Reclaimed Fly Ash as Alternative Supplementary Cementitious Materials in Concrete

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Introduction

Previously - Reasons why not

- If SCMs contain significant qua… n the concrete pore solution, con… n be very challenging.

Now - Reasons why we should

- The demand for alternative … s increased significantly.
- There is no specification for limiting the threshold value of alkali content of SCMs.
- Not all alkalis of SCMs are readily available for release into concrete pore solution. It is important to distinguish available alkalis from total alkalis in SCMs.

ASTM C618

TABLE 1 Chemical Requirements

	N
Silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3), min, %	70.0
Calcium oxide (CaO), %	report only
Sulfur trioxide (SO_3), max, %	4.0
Moisture content, max, %	3.0
Loss on ignition, max, %	10.0

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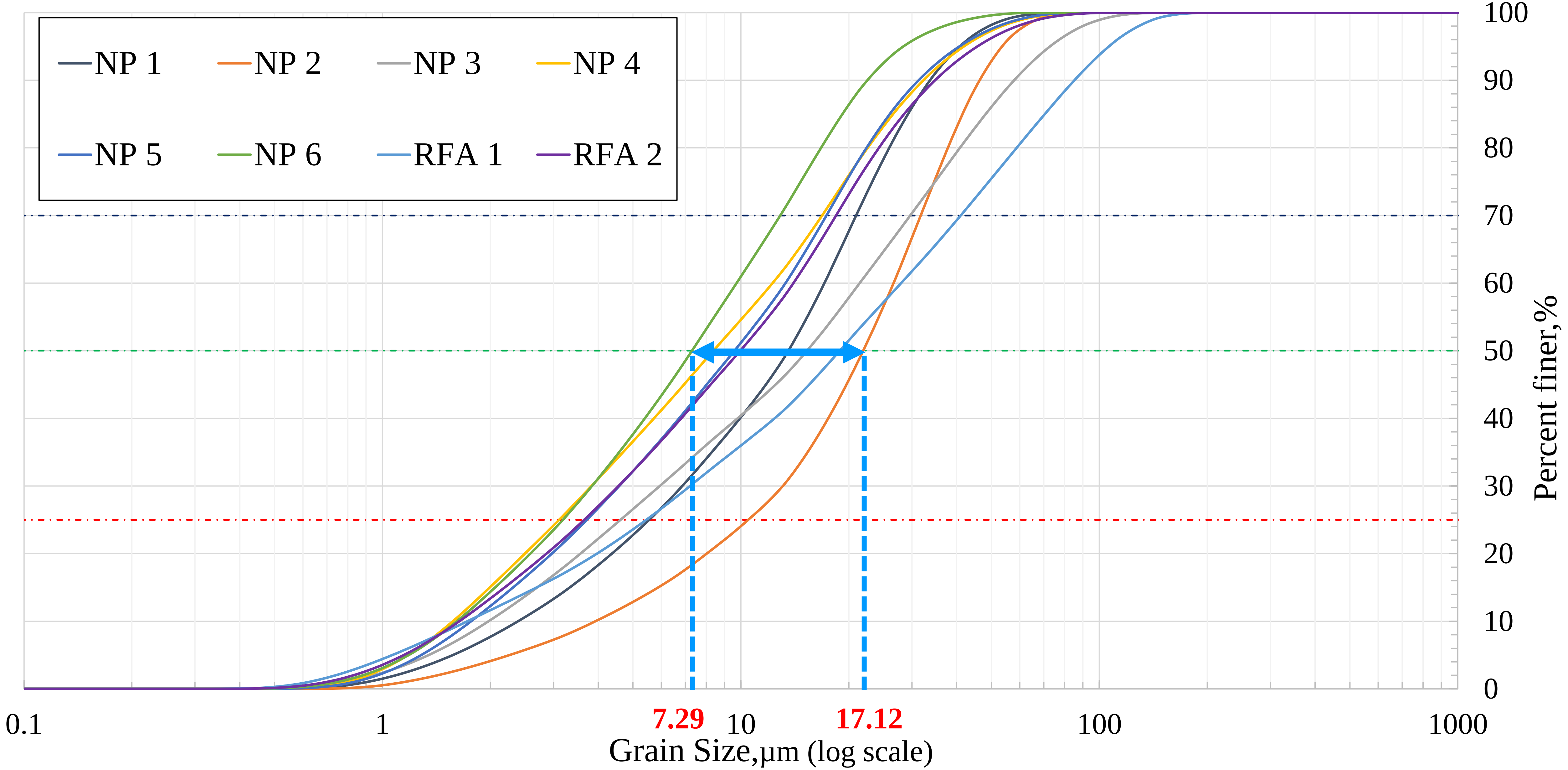
High Alkali SCMs

		SiO_2	Al_2O_3	Fe_2O_3	S+Al+Fe	CaO	MgO	Na_2O	K_2O	Na_2O_e	LOI	SG	Amorphous Level (%)
	Low-alkali Portland cement	19.93	4.77	3.13	27.83	62.27	2.70	0.06	0.48	0.37	2.6	3.15	NA
	High-alkali Portland cement	19.00	4.99	2.11	26.1	62.45	2.84	0.31	1.05	1.0	NA	3.15	NA
Volcanic rhyolitic tuff	NP 1	68.62	13.14	1.91	83.67	1.73	1.43	2.7	3.2	4.82	7.18	2.53	37.67
Pumice	NP 2	73.42	12.30	1.41	87.13	0.79	0.23	2.9	4.2	5.61	4.72	2.35	98.55
Pumice	NP 3	65.48	11.19	1.75	78.42	2.99	0.33	3.6	3.4	5.85	10.87	2.26	3.38
Volcanic rhyolitic tephra	NP 4	71.95	12.26	1.50	85.71	0.93	0.39	3.9	4.0	6.51	4.88	2.35	87.76
Volcanic glass	NP 5	71.21	12.99	0.90	85.1	0.56	0.13	3.9	4.1	6.57	5.95	2.40	100
Pumice	NP 6	71.91	11.68	2.18	85.77	0.32	0.09	5.5	4.2	8.28	3.94	2.34	91.17
Reclaimed fly ash	RFA 1	53.06	15.13	6.88	75.07	13.70	4.53	3.4	1.9	4.69	0.55	2.56	82.48
Reclaimed fly ash	RFA 2	56.81	14.20	2.69	73.7	10.13	1.41	2.8	2.7	4.56	8.42	2.42	88.88

Particle Size Distribution



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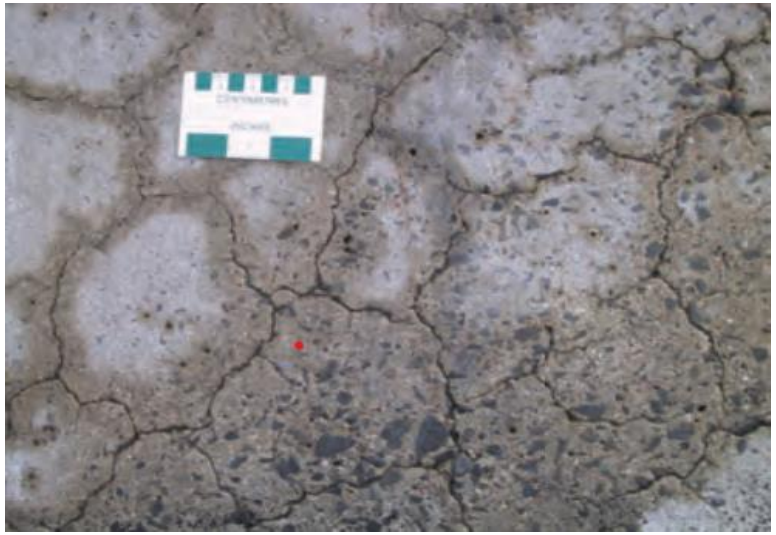
Alkali-Silica Reaction

Alkali-Silica Reaction

Alkali–silica reaction (ASR) is a concrete durability problem that results from deleterious reactions between alkali hydroxides in pore solution of concrete and reactive forms of silica, typically present in aggregates. ASR can result in significant maintenance and reconstruction costs.



Role of SCMs in Mitigating ASR

- Clinker dilution
- Reduce the permeability
- Consume calcium hydroxide (CH)
- Alkali-binding and lowering the pH

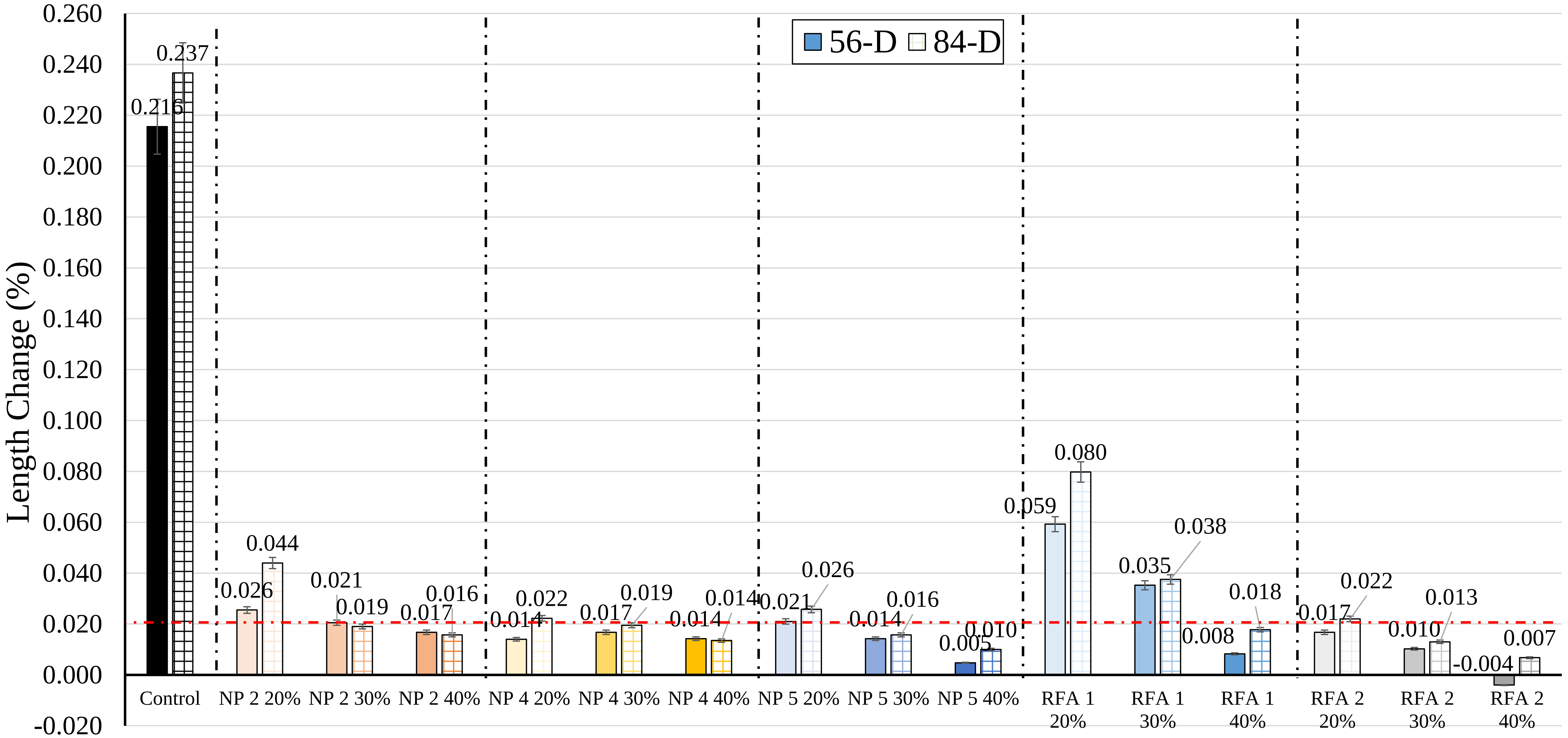
Experimental Method

Methods	ASTM C1567 (AMBT)	ASTM C1293 (CPT)	AASHTO T380 (MCPT)
Duration	14 days	2 years	56 days (or 84 Days)
Sample Size	1 in. ×1 in. ×1.25 in.	3 in. ×3 in. ×11.25 in.	2 in. ×2 in. ×11.25 in.
Materials	Mortar	Concrete	Concrete
Exposure Environment	1 N NaOH Solution, 80^{o}C	100% RH, 38^{o}C	1N NaOH Solution, 60^{o}C
Criteria for Effective ASR Mitigation (With SCMs)	1. Innocuous, <0.10 % at 14-day 2. Potentially Reactive, 0.10% -0.20% at 14 -day 3. Reactive, >0.20 % at 14-day	Effective, < 0.040% at 2-year	1. Effective ≤ 0.020% at 56-day 2. Uncertain 0.020 -0.025% at 56-day 3. Not Effective > 0.025% at 56-day 4. Expansion rate < 0.010% in 2-week between 56-day to 84-day

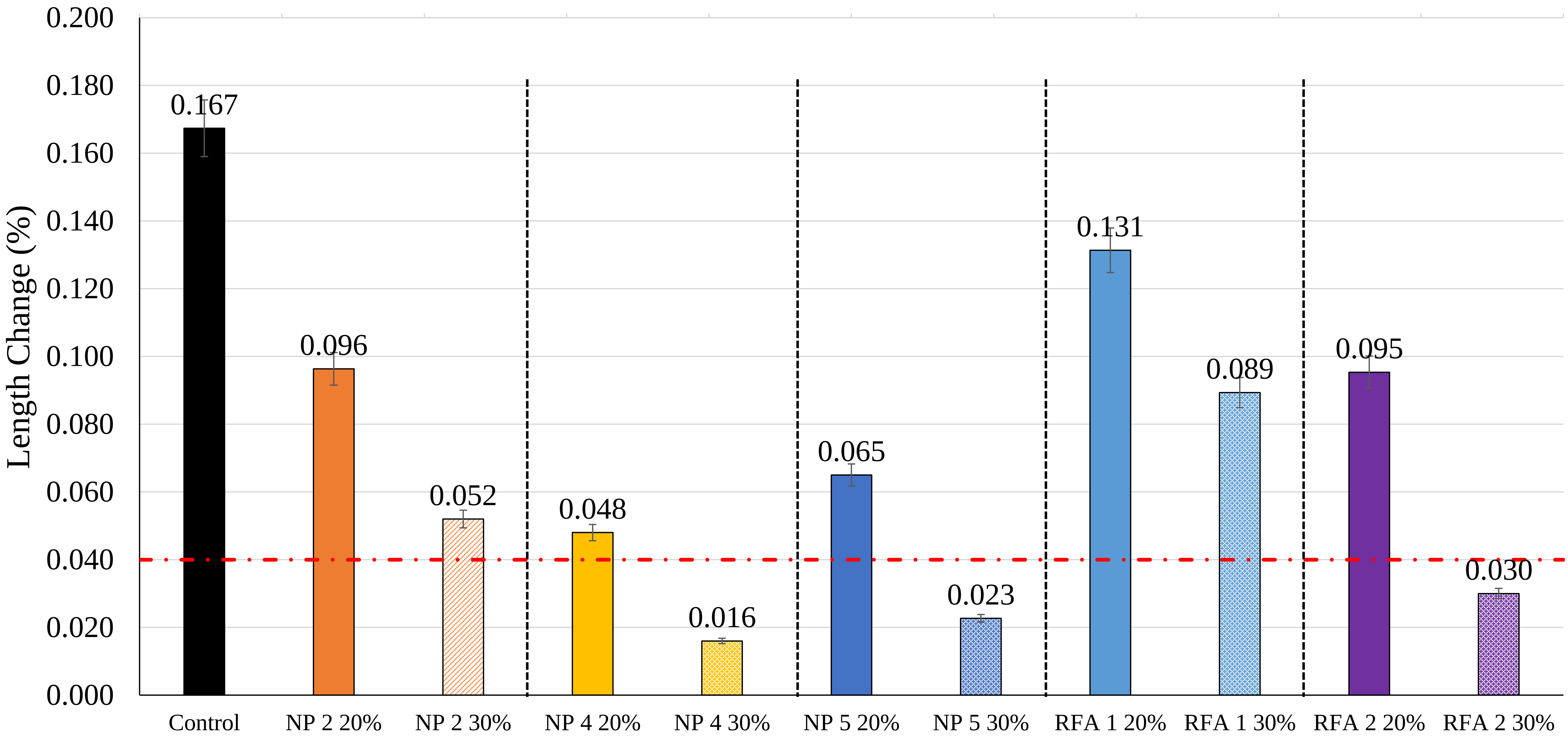
Comparison of Results from Different Test Methods (20% Dosage)

		ASTM C1567 (14-D) Effective<0.10 % in 14-D		ASTM C1293 (2-Y) Effective<0.040% in 2-Y		AASHTO T380 Effective (P) < 0.020 % at 56 Days Not Effective (F) > 0.025% at 56 days			
NP Type	Na_2Oeq	Expansion	P or F	Expansion	P or F	Expansion (56-D)	P or F	Expansion (84-D)	P or F
Control		**0.49**	F	**0.167**	F	**0.216**	F	**0.237**	F
NP 1	4.82	0.03	P	0.109	F	0.019	P	0.036	F
NP 2	5.61	0.03	P	0.096	F	0.026	F	0.044	F
NP 3	5.85	0.02	P	0.084	F	0.017	P	0.021	P
NP 4	6.51	0.03	P	0.048	F	0.014	P	0.022	P
NP 5	6.57	0.02	P	0.058	F	0.021	F	0.026	F
NP 6	8.28	0.02	P	0.091	F	0.017	P	0.018	P
RFA 1	4.69	0.07	P	0.131	F	0.059	F	0.08	F
RFA 2	4.56	0.04	P	0.095	F	0.017	P	0.022	P

AASHTO T380 Replacement Level



ASTM C1293 Replacement Level---18-month



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Experimental Method

Rigaku XRD Analyzer

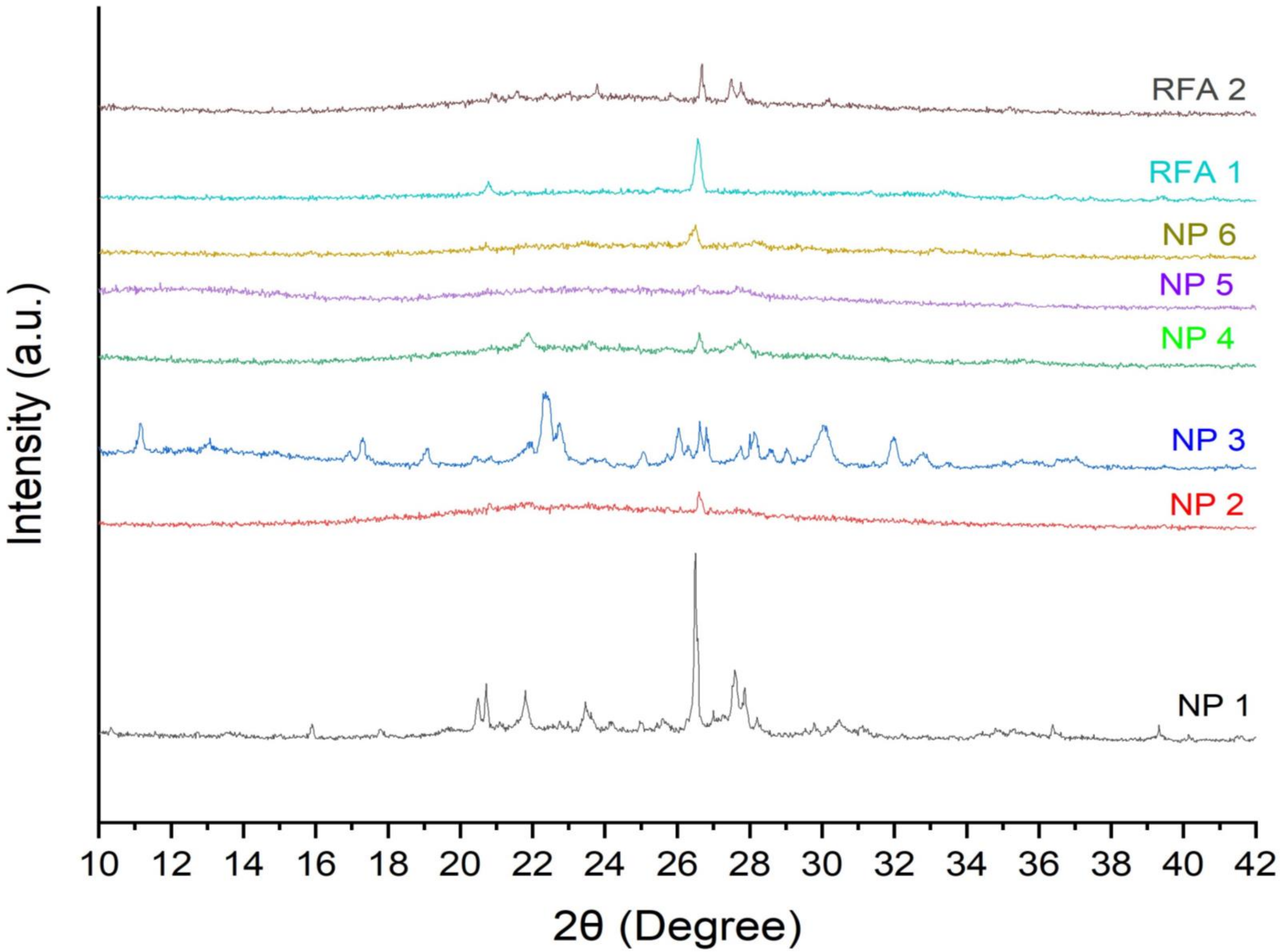
Strength Activity Index (SAI)

Isothermal Calorimetry
(Rapid, Relevant and Reliable (R^3) Test)

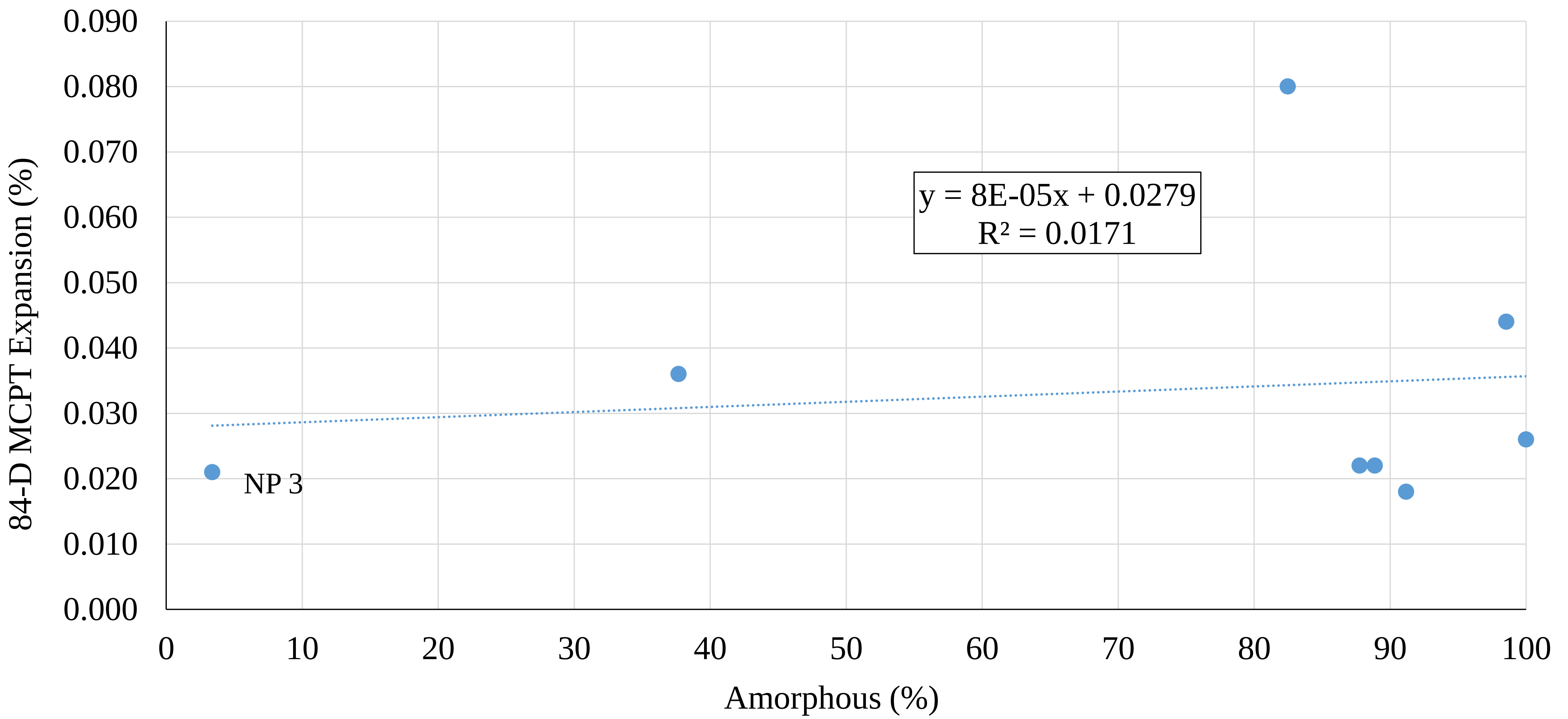
Thermogravimetric analysis (TGA)

Inductively Coupled Plasma Spectroscopy (ICP)

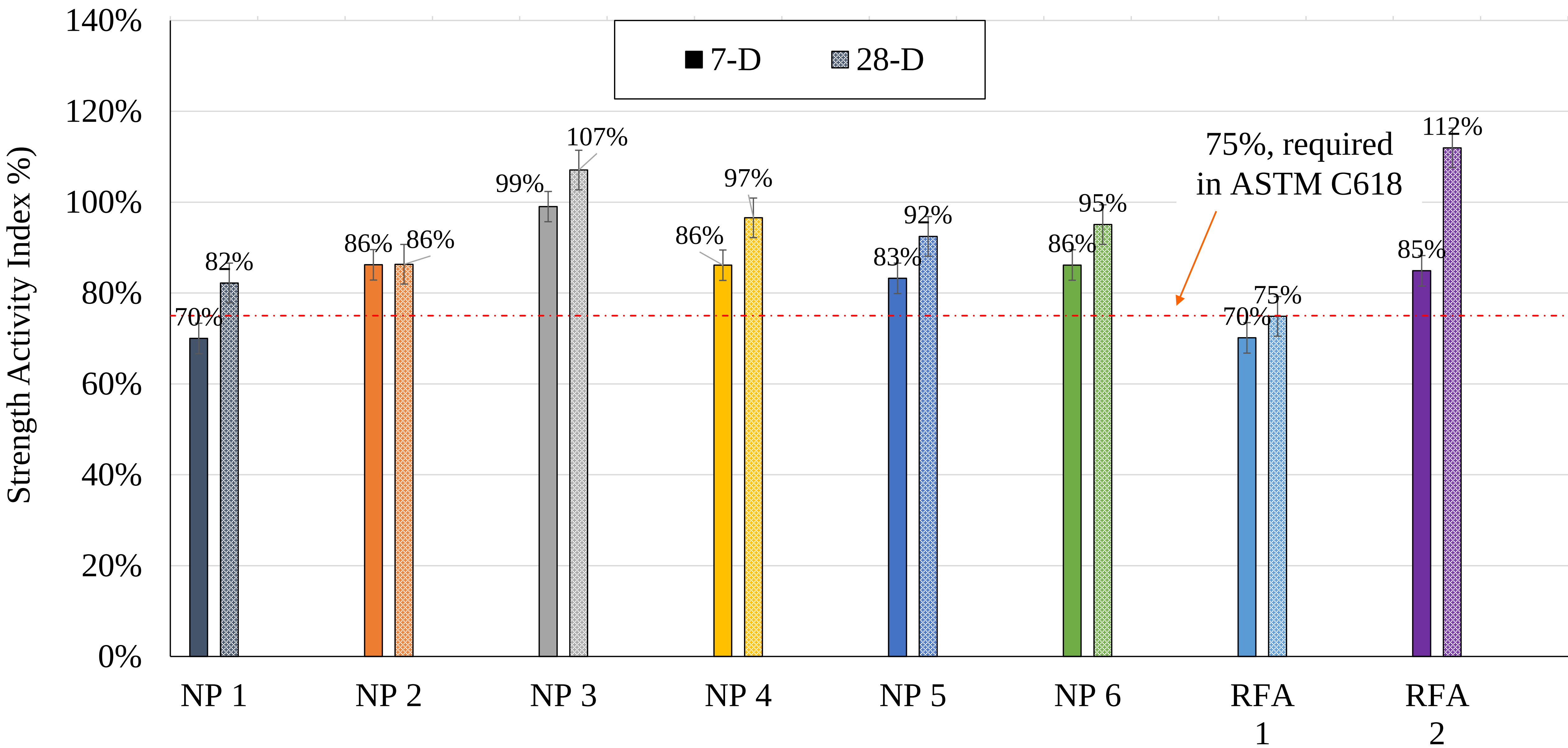
X-Ray Diffraction



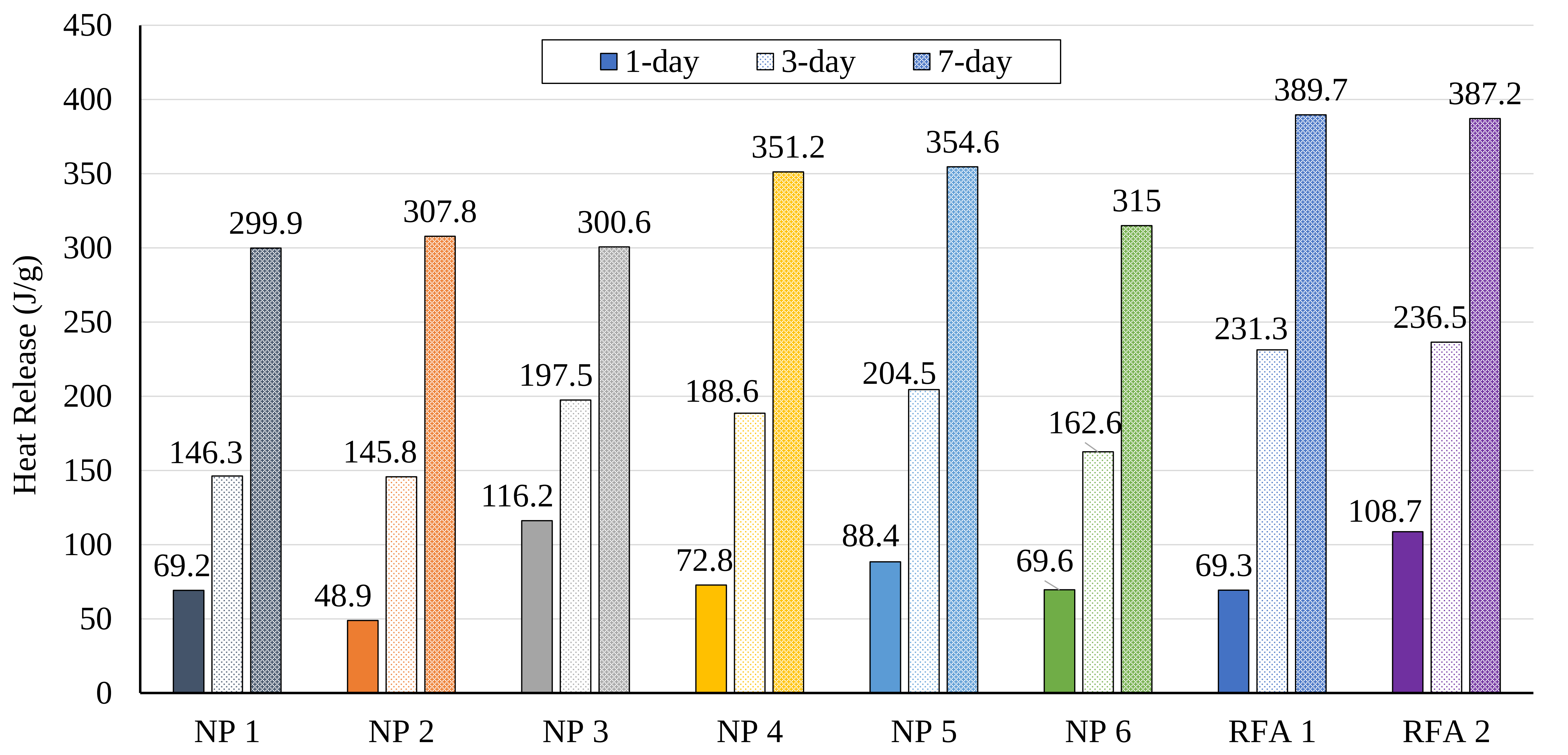
SCMs Amorphous Level vs 84-D MCPT Expansion



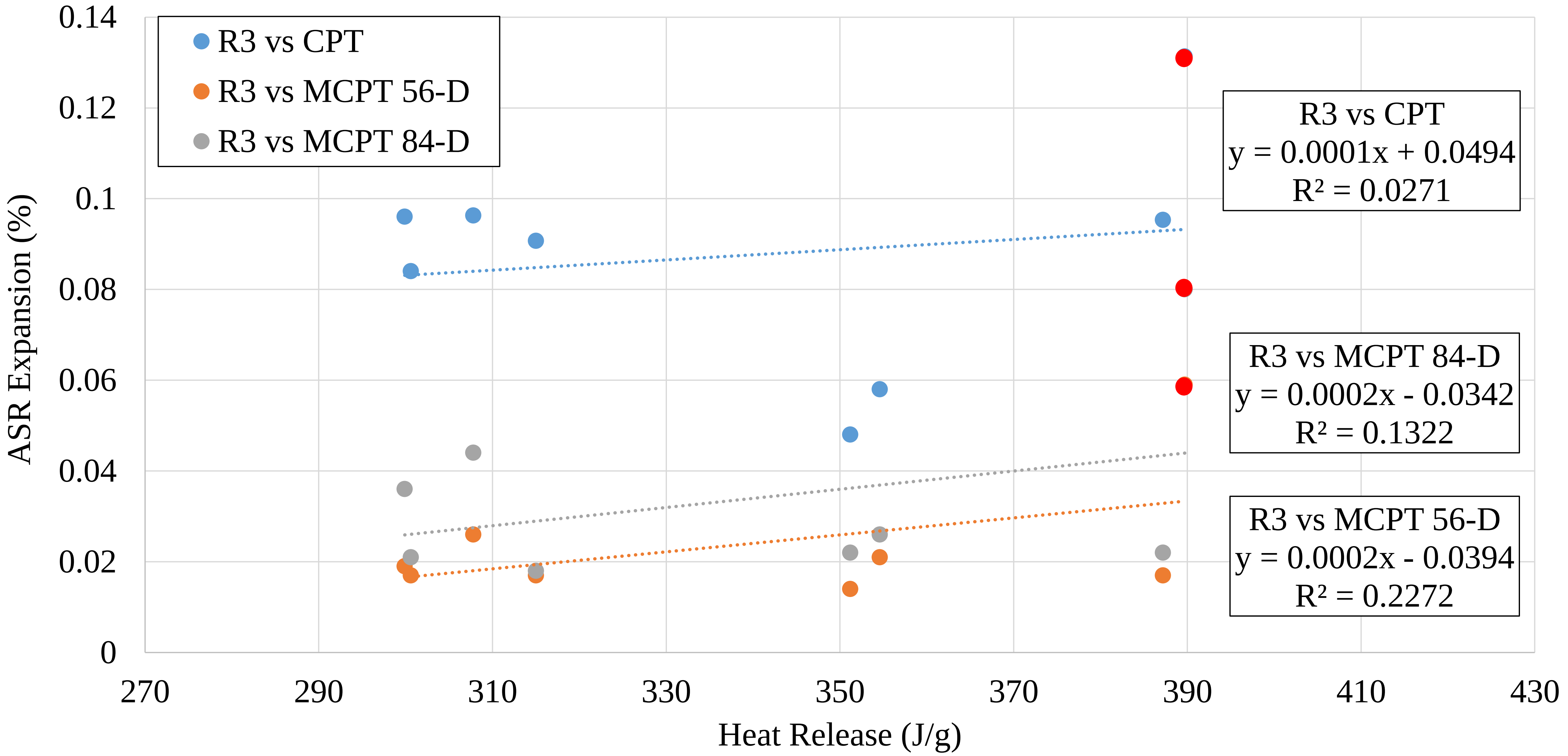
ASTM C311 – Strength Activity Index (SAI)



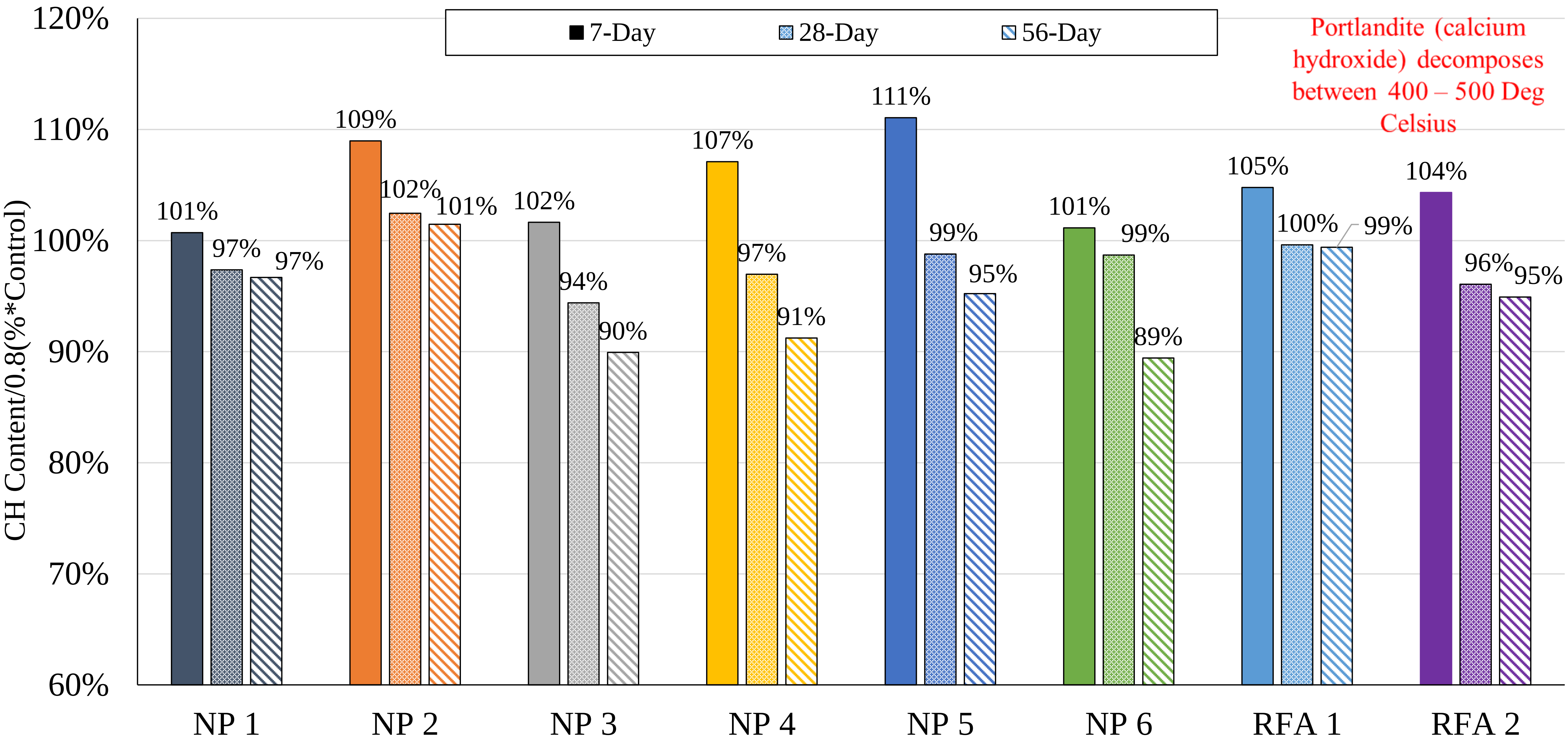
ASTM C1897 – R^3 Test Results



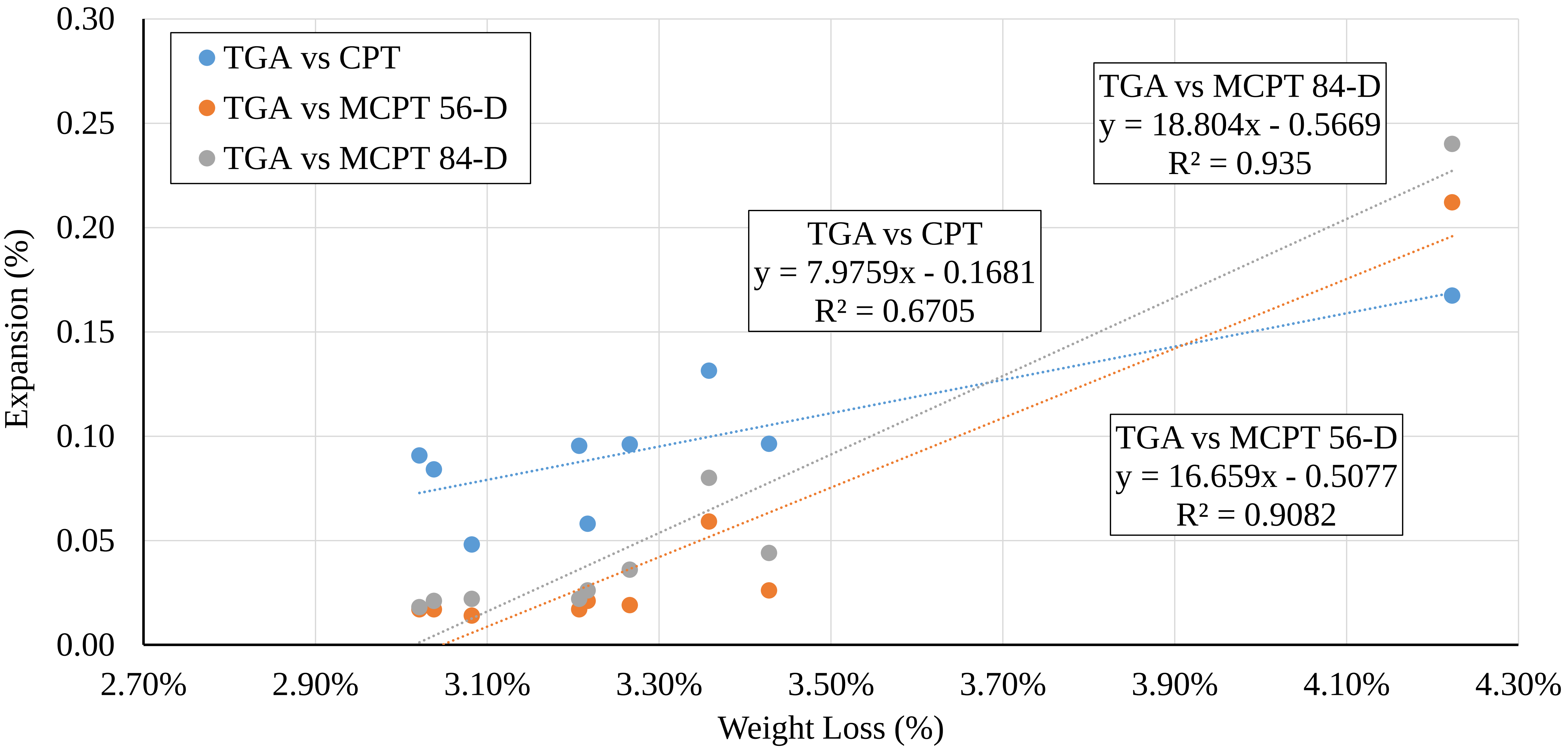
R^3 vs ASR Results



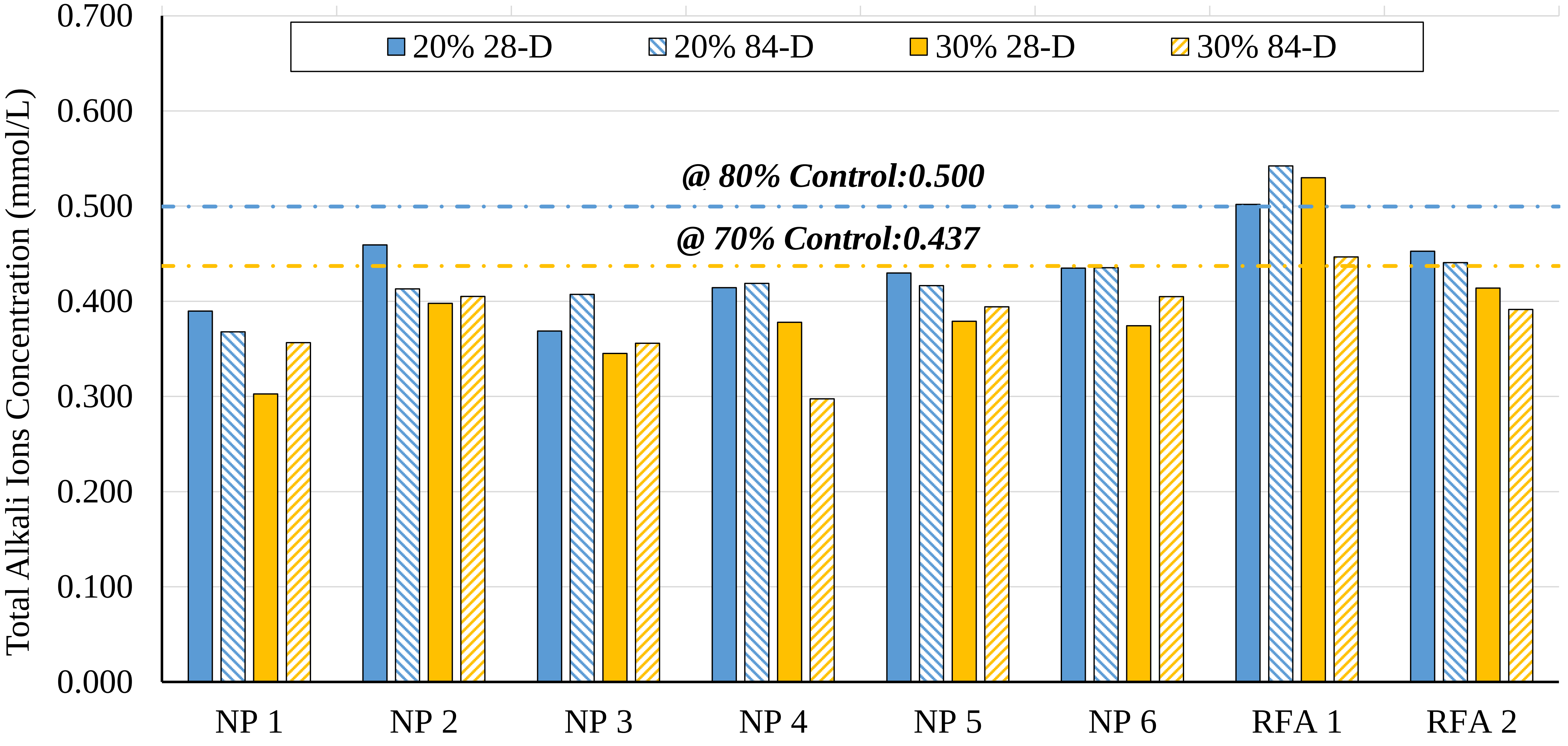
TGA – $Ca(OH)_2$ g/g of Cement as Percentage to Control



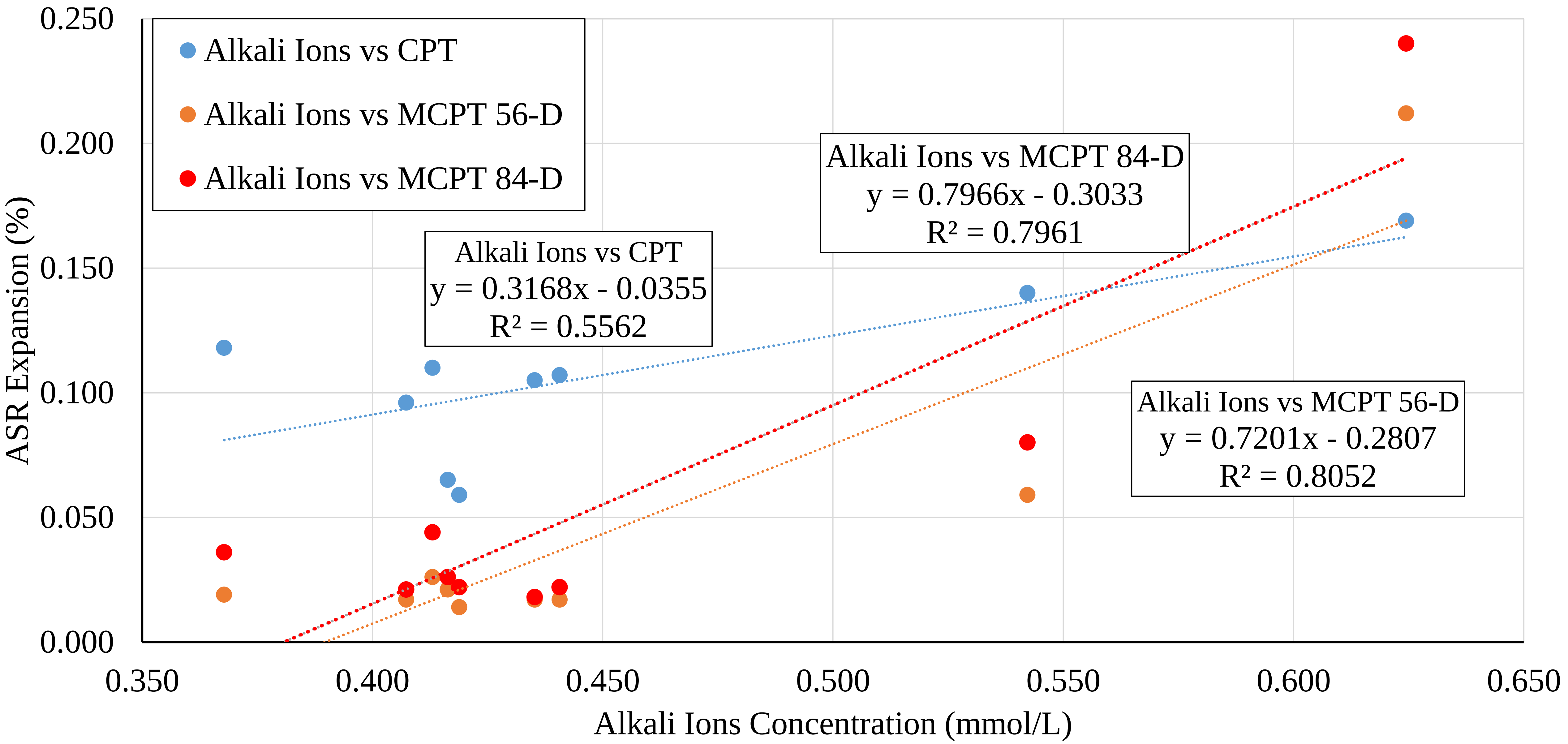
TGA vs ASR Results



Alkali Ions Concentration



Alkali Ions vs ASR Results



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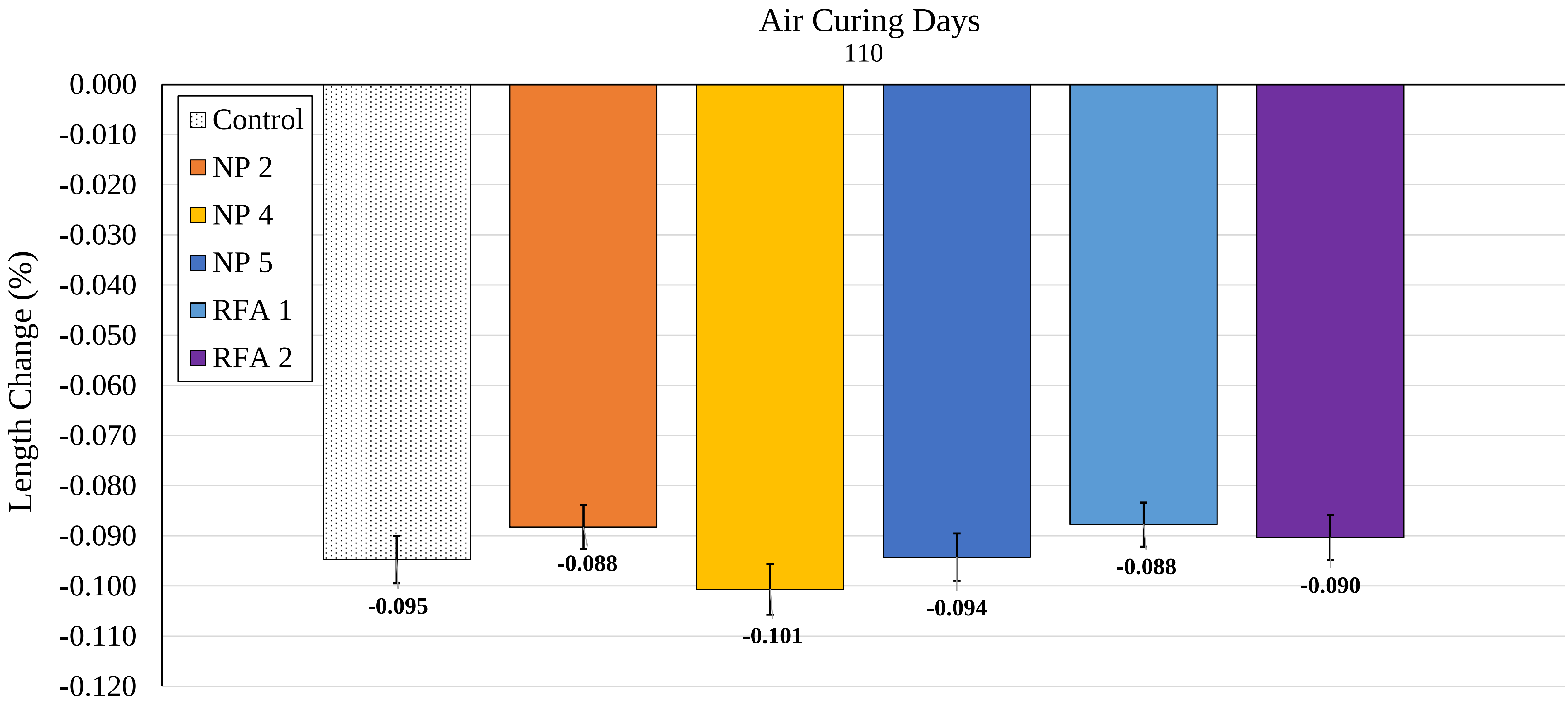
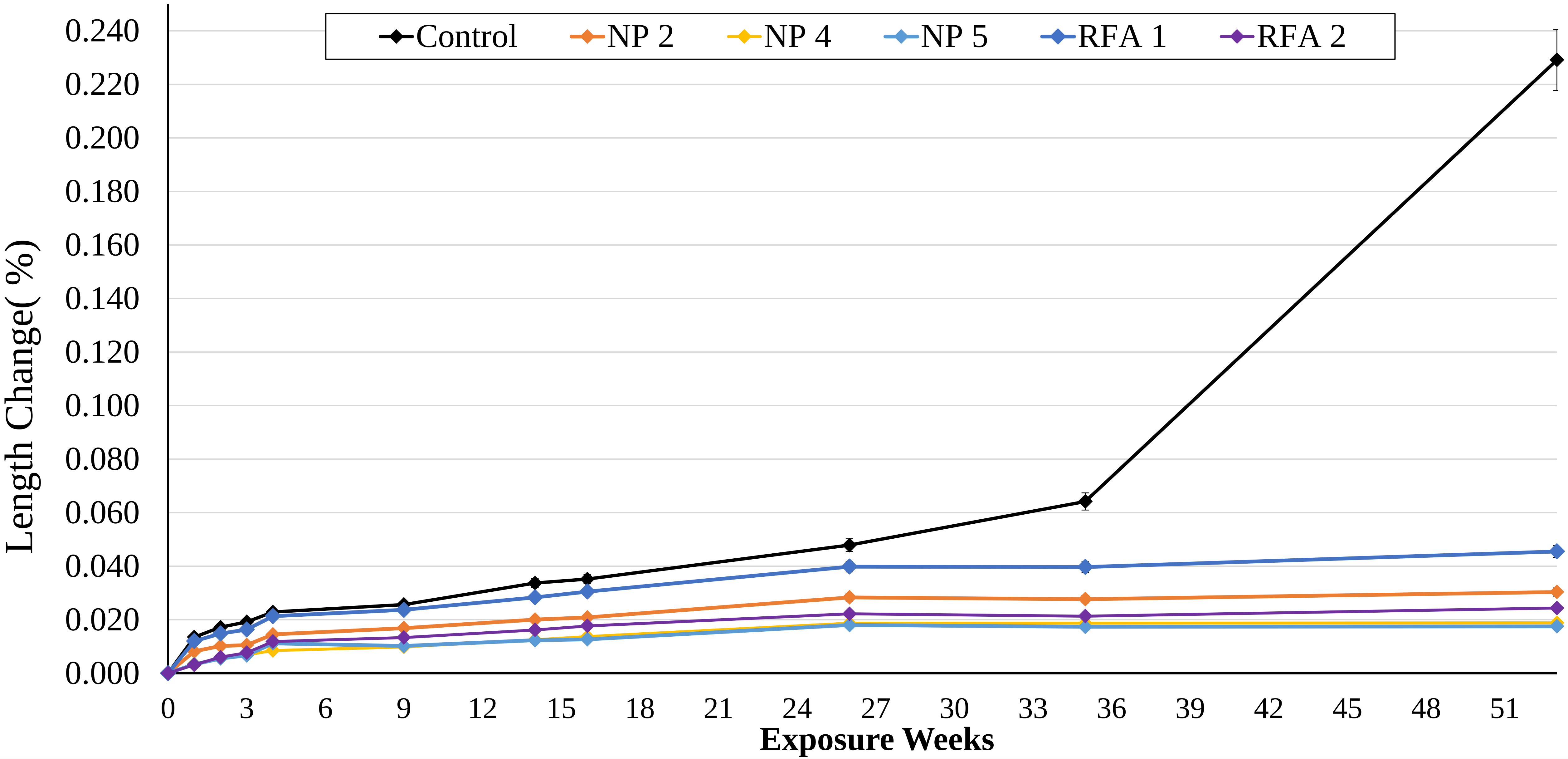
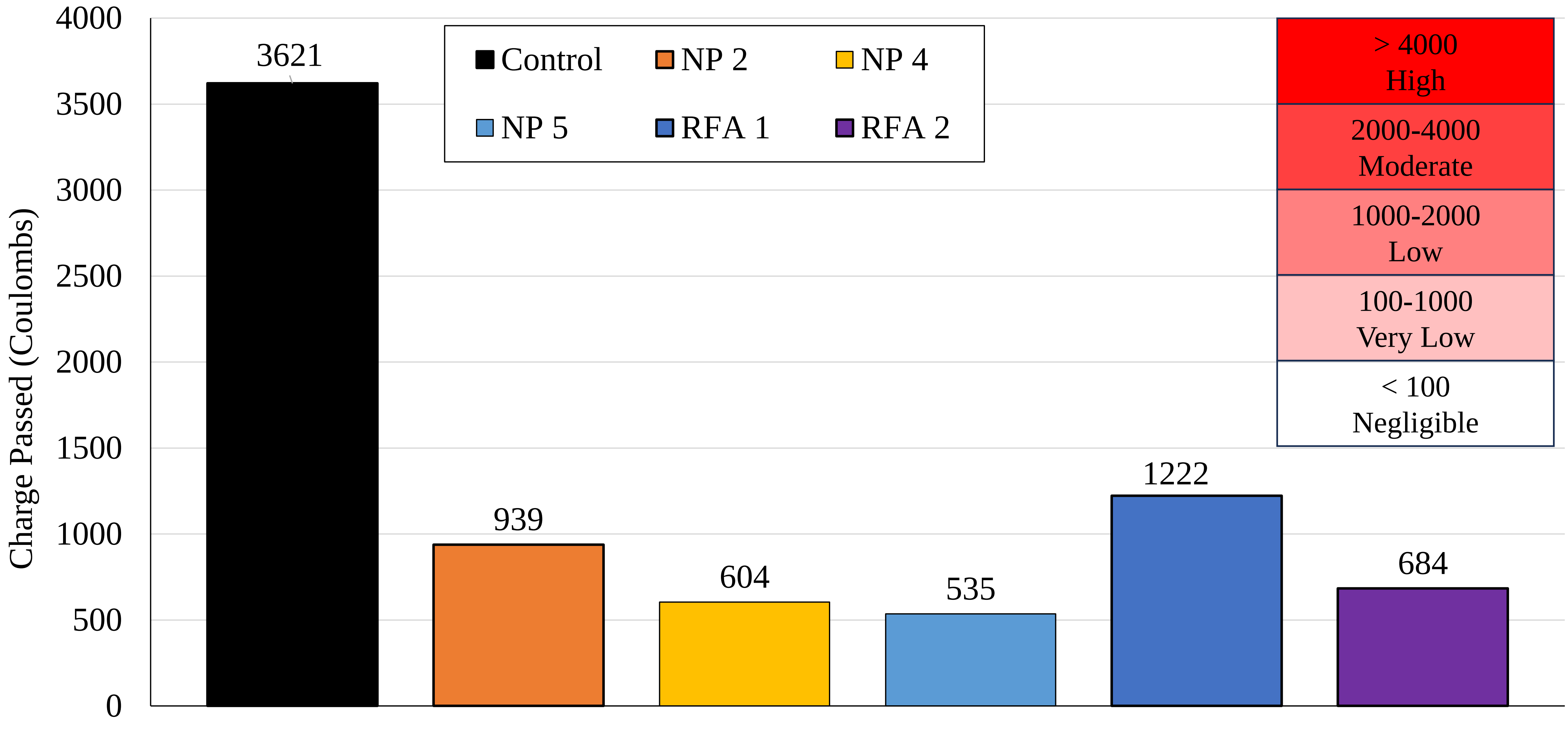
ASTM C596 – Drying Shrinkage



ASTM C1012 – Sulfate Resistance



ASTM C1202 – Rapid Chloride Penetration Test



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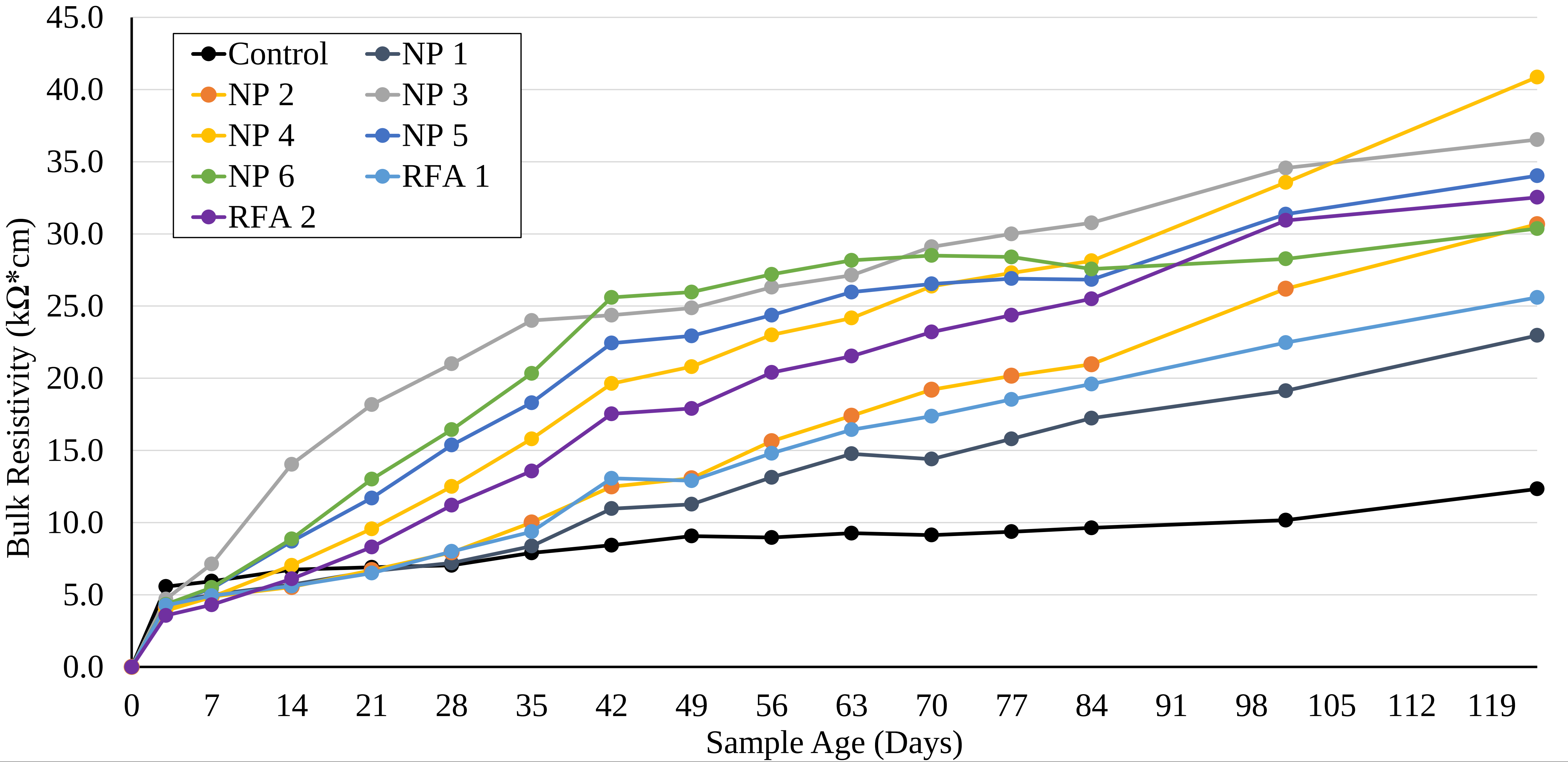
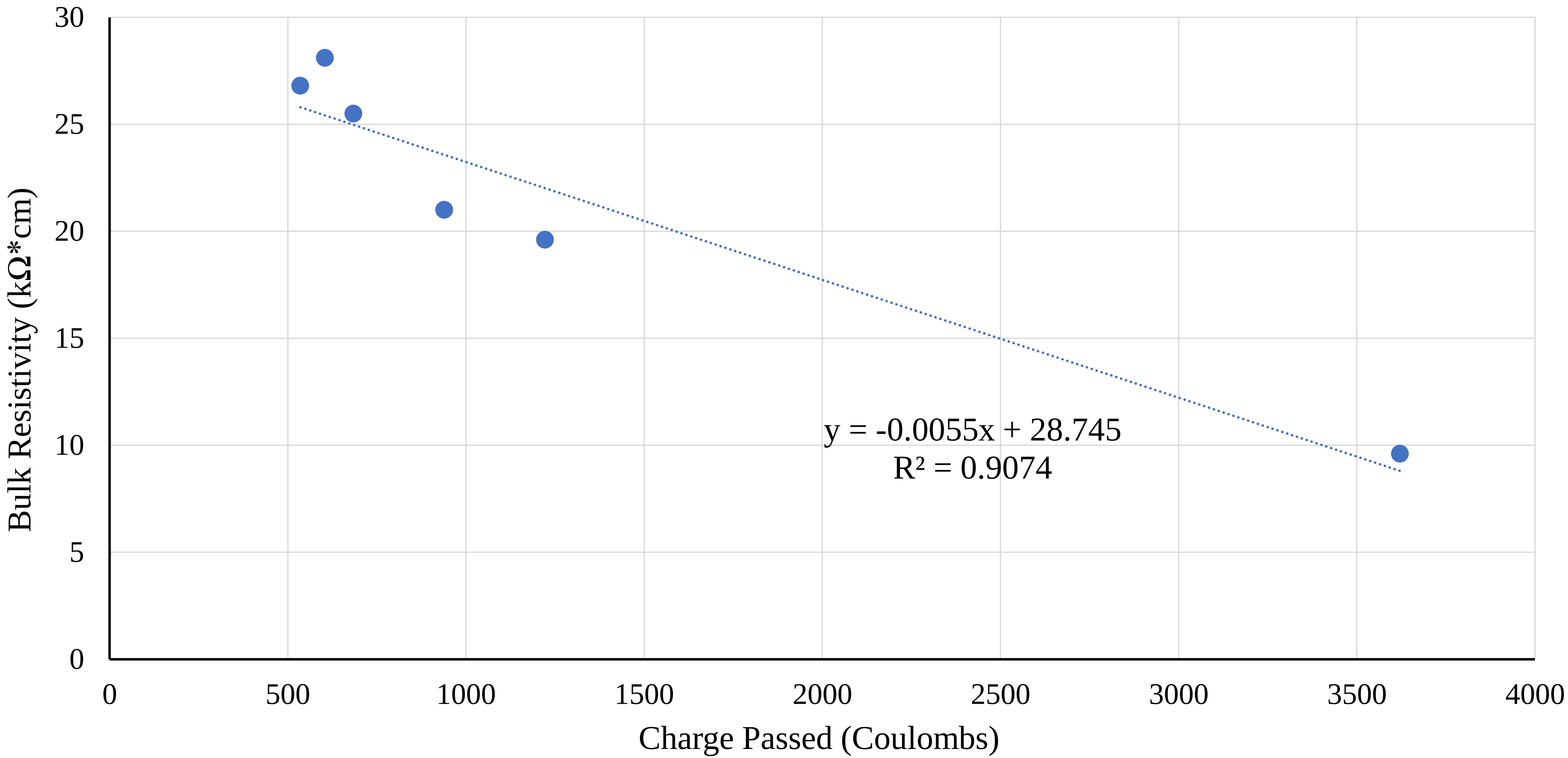
Electrical Bulk Resistivity

SMART CENTER
Sustainable Materials Research and Technology Center
CLEMSON
GLENN DEPARTMENT OF CIVIL ENGINEERING



Bulk Resistivity vs RCPT (84-D)



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Conclusions

- Different ASR test methods yield different characterizations of high-alkali SCMs. Per ASTM C1567 all the high-alkali SCMs materials passed the test, but all of them failed in ASTM C1293 (even at 1 year) at 20% dosage level. Using the amount of alkali content of SCMs to predict their ASR mitigation performance is not comprehensive.
- Results indicate that at higher replacement levels (30% and 40%) high-alkali SCMs are performing much more effectively in mitigating ASR.
- ASR expansion results from ASTM C1293 and AASHTO T380 show a good correlation with amount of calcium hydroxide, determined by TGA.
- SCMs' amorphous level and R3 test does not correlate well with ASR expansion very well.
- SAI results are not persuasive to represent the pozzolanic reactivity of SCMs.

Conclusion

- Pore solution chemistry in these systems support the results from ASR experiments. All SCMs effectively lower the alkali ions concentration in the pore solution. Higher SCMs replacement further decreases concentration. The alkali content of SCMs does not indicate the proportional relationship with alkali ions concentration in pore solution.
- Results obtained from RCPT and bulk resistivity indicate that cooperating high-alkali SCMs in the concrete makes concrete matrix denser compared to the control.
- High-alkali SCMs improve the sulfate resistance.
- Based on the findings in this study, high-alkali SCMs can have a solid potential to be alternative SCMs for the concrete industry, provided the alkalis are not readily available.

Acknowledgements

We acknowledge the support of National Pozzolan Association (NPA),and its member companies for providing the materials for this study.

Thanks for Listening

Any Questions?

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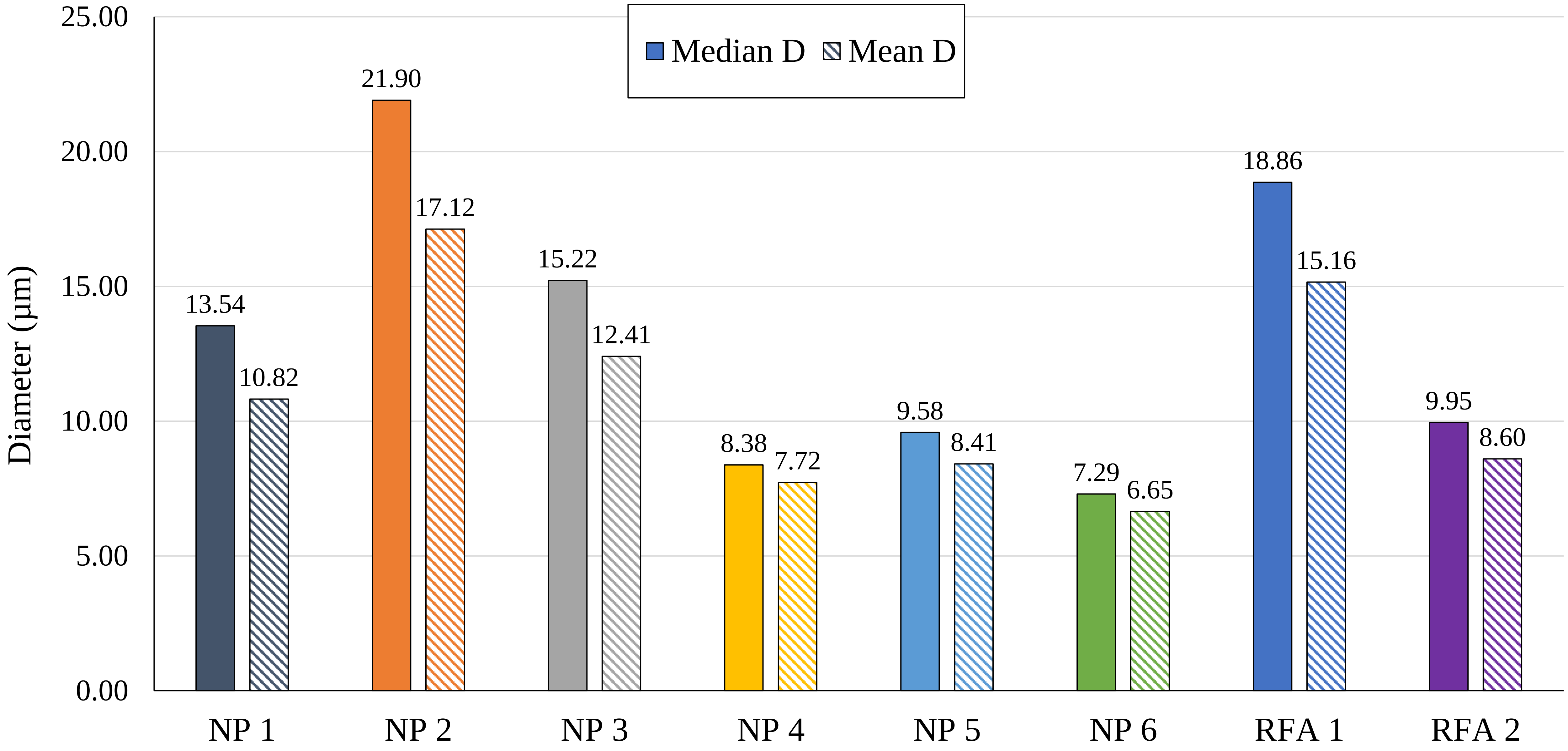
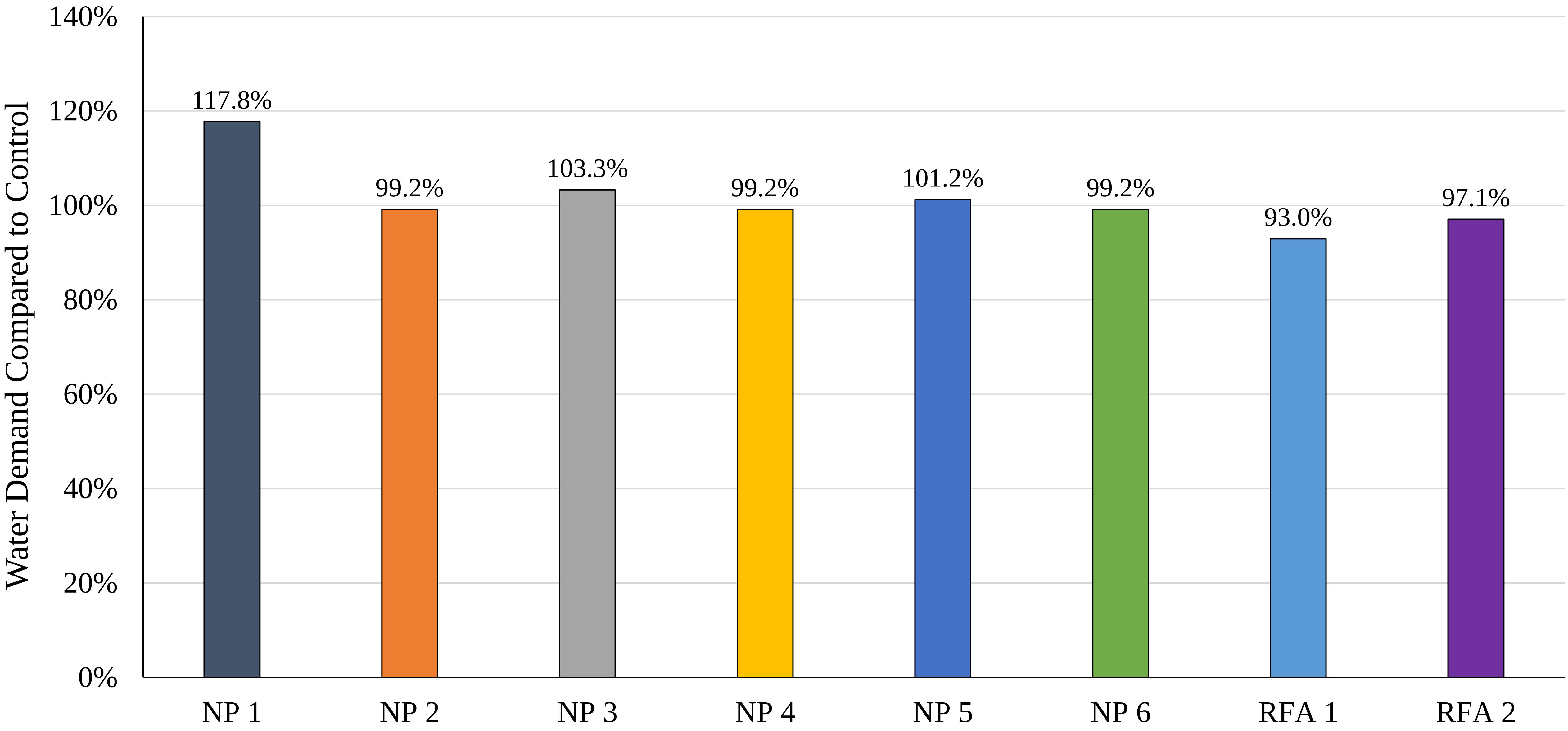
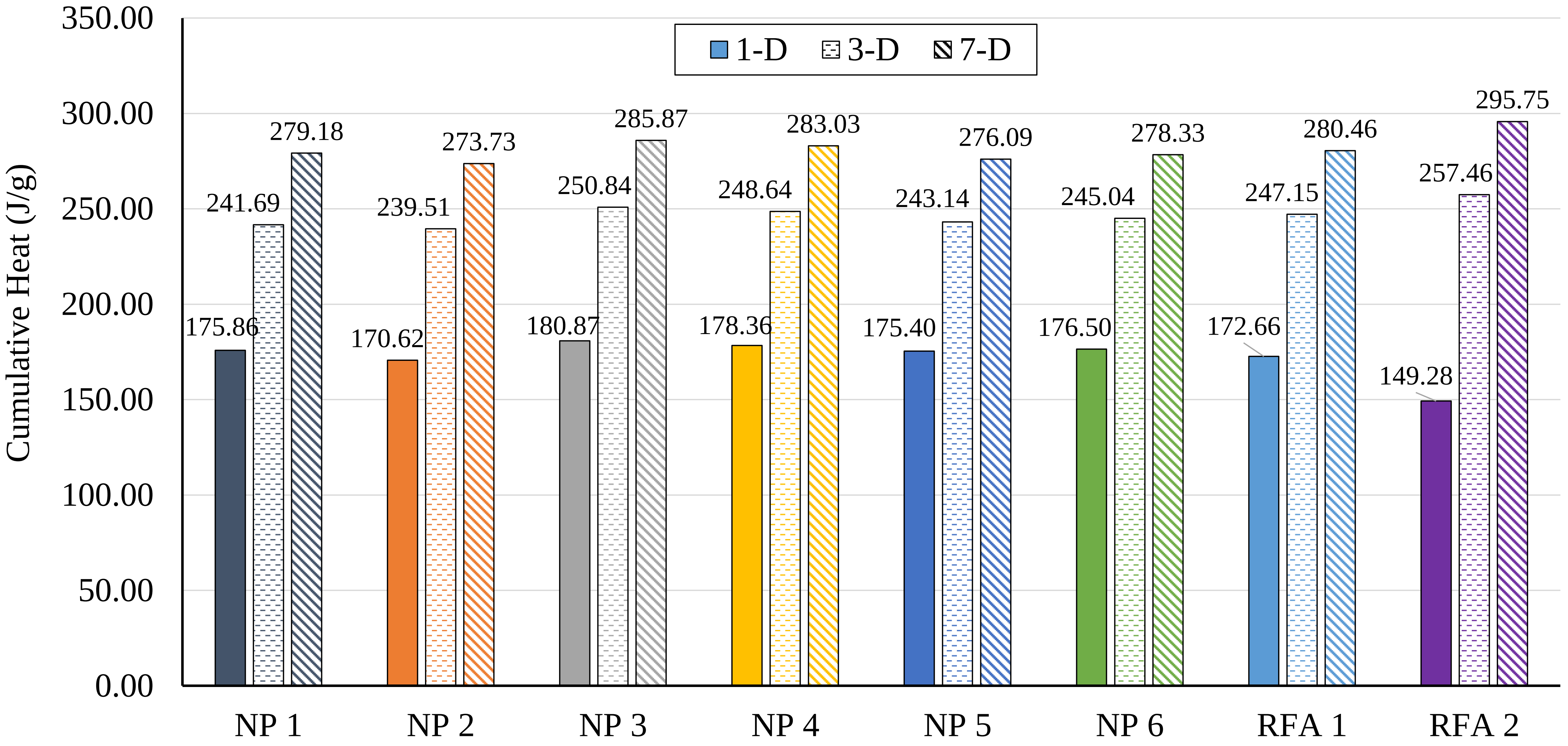
Particle Diameter



Water Demand Compared to Control (± 5%) (ASTM C311)



Isothermal Calorimetry 20% Dosage



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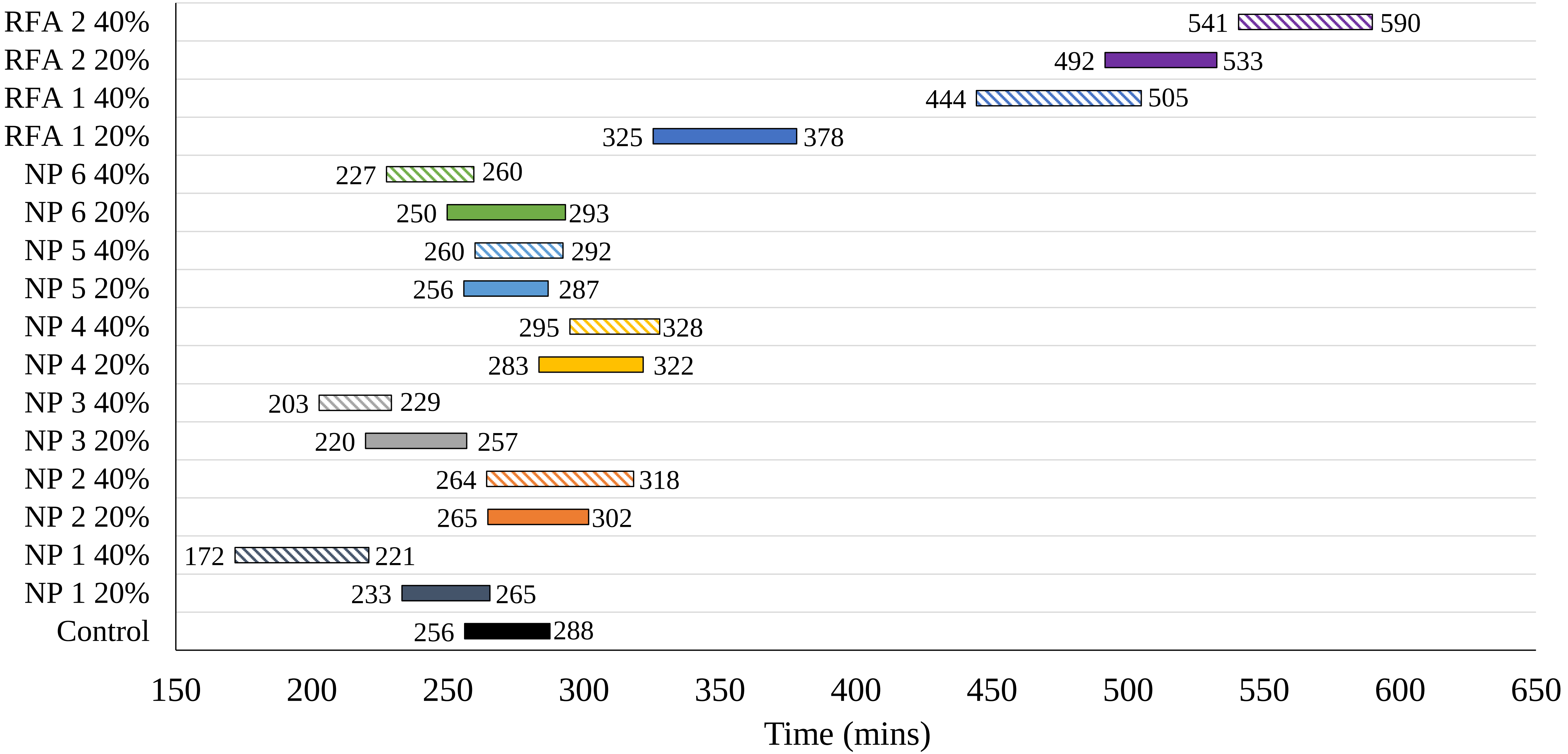
Automatic Setting Time



Ultrasonic-Pulse Velocity