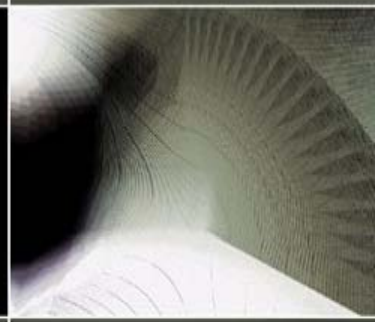
OPPORTUNITIES FOR RECYCLED CONCRETE AGGREGATE (RCA) IN CONCRETE PAVEMENTS

Sponsored by Indiana Department of Transportation (INDOT)



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INTRODUCTION

Background

- Aggregates occupy 70% to 80% of the volume of concrete and have considerable influence on it's properties
- Concerns related to naturally mined aggregates:
  →Depletion of existing sources
  →Availability of new sources
  →Restrictions on development of new sources
- Crushing and reusing of existing concrete to produce recycled concrete aggregate (RCA) should help to address some of these concerns

On-site crusher
(http://www.dfwconnector.com/images/pictures/sized/onsite_crusher_gallery.jpg)

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INTRODUCTION

Literature Findings

Recycled aggregate properties vs. natural aggregate properties

Author	Specific gravity (coarse aggregate)	
	Recycled aggregate	Natural aggregate
ACPA (2)	2.1-2.4	2.4-2.9
Gomez, Soberon, J.M.V. (8)	2.35-2.42 (SSD)	2.59-2.67 (SSD)
Gomez, Soberon, J.M.V. (8)	2.17-2.28 (air dry)	2.57-2.64 (air dry)
Poon,C.S. (13)	2.33-2.37	2.62
Ann, K.Y. (10)	2.48	2.63
Xiao et al. (33)	2.52	2.82
Fathizal, G. (12)	2.42-2.5 (SSD)	2.71-2.74 (SSD)
Kou et al. (7)	2.49-2.57	2.62
Olorunsogo, F.T., Padayachee, N. (24)	5.13	5.32

Author	Absorption (%)	
	Recycled aggregate	Natural aggregate
ACPA (2)	3.7-8.7	0.8-3.7
Gomez, Soberon, J.M.V. (8)	5.83-8.16	0.88-1.49
Poon,C.S. (13)	6.28-7.56	1.24-1.25
Ann, K.Y. (10)	4.25	0.73
Xiao et al. (33)	9.25	0.4
Fathizal, G. (12)	3.3-5.4	0.54-0.89
Kou et al. (7)	3.52-4.26	1.11-1.12

RCA can have :

- Up to 16% lower specific gravity than that of natural aggregate
- Up to more than 20 times higher absorption than that of natural aggregate

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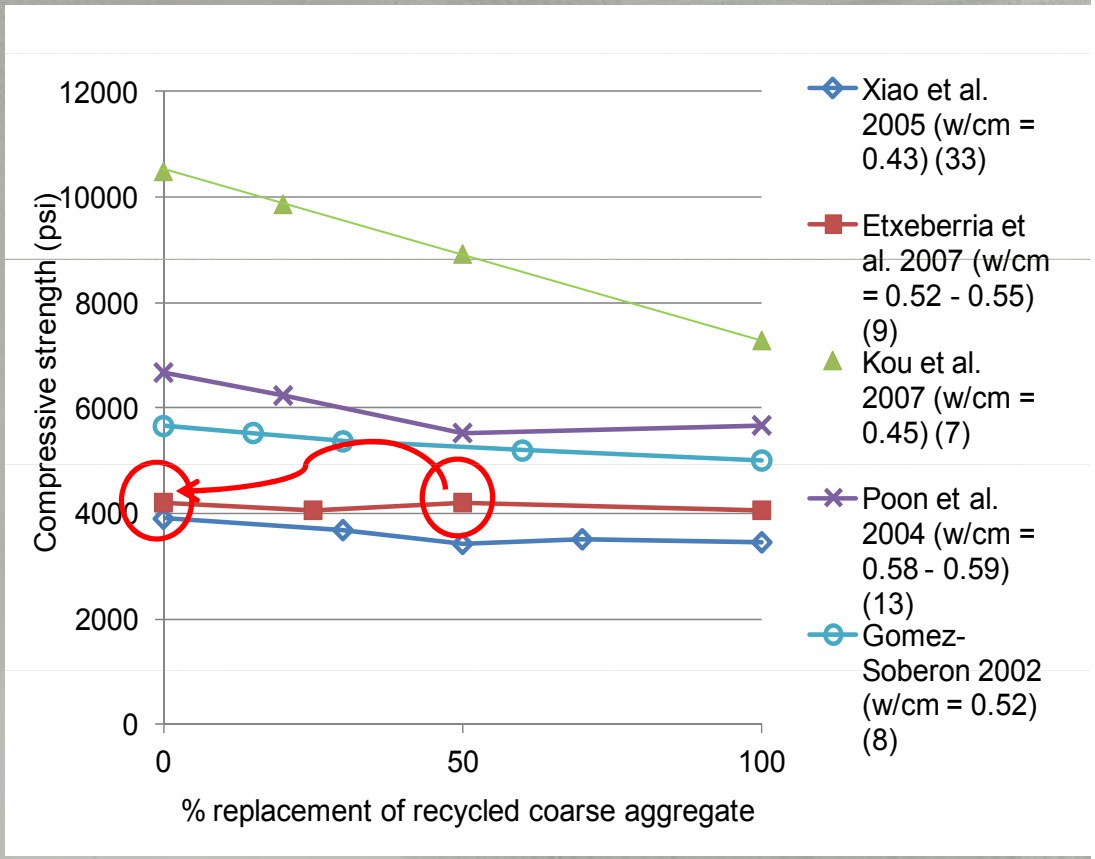
INTRODUCTION

Literature Findings

Compressive strength vs. % recycled coarse aggregate

- The compressive strength of RCA concrete typically 2%-25% lower than that of concrete with natural aggregate.
- However, concrete with 50% RCA can have similar compressive strength to concrete with natural aggregate only (Etxeberria et al. 2007).



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INTRODUCTION

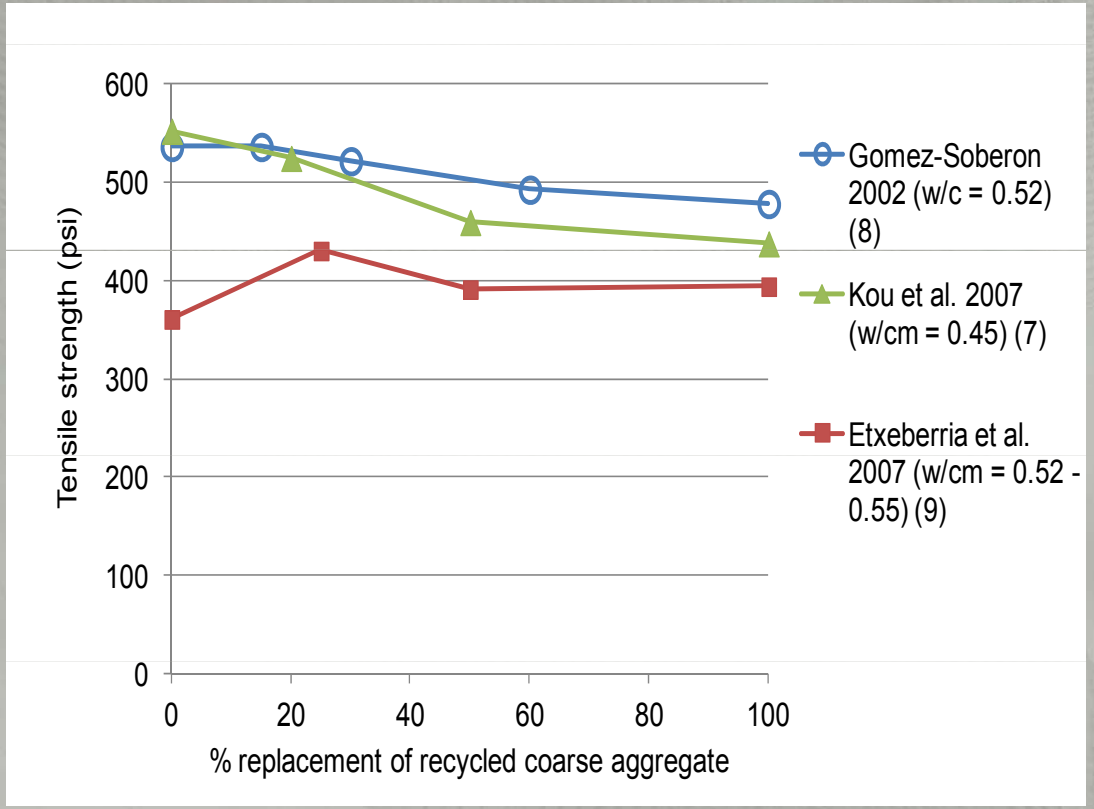
Literature Findings

Tensile strength vs. % recycled coarse aggregate

The tensile strength of RCA concrete:

- 8-21% lower
- 8-20% higher

than the tensile strength of natural aggregate (Etxeberria et al. 2007)



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INTRODUCTION

Objective of the Study

- To evaluate the effects of using aggregate produced from recycled concrete as a replacement for natural (virgin) coarse aggregate in pavement concrete mixtures.

Scope of the Study

- Evaluation and comparison of several properties of RCA and natural aggregates.
- Evaluation and analysis of the effects of RCA on concrete properties.

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MATERIALS

- Portland Cement → Type I (ASTM C 150)
- Fly ash → Class C (ASTM C 618) 20% weight replacement
- Aggregates:
  - Coarse aggregates → three types of #8 coarse aggregates (dmax = 1 inch)
    - #8N1 - #8 dolomitic limestone 1, obtained from Delphi Plant, IN.
    - #8N2 - #8 dolomitic limestone 2, obtained from Newton County quarry , Kentland, IN.
    - #8R - #8 RCA (Recycled Concrete Aggregate), crushed from old concrete pavement removed from State Road 26 Indiana, mostly gravel
  - Fine aggregate → #23 natural sand

AGGREGATES PROPERTIES

Specific gravity, Absorption, L.A. Abrasion and Soundness (Brine Freeze Thaw)

Aggregates properties	Coarse aggregate					Fine aggregate
	#8 N1	#8 N2	#8 R	#11R	INDOT limit	#23 Natural Sand
Bulk Specific Gravity (SSD)	2.74	2.69	2.42	2.45	--	2.61
Absorption , %	1.8	2.7	5.3	5.4	5%, max	1.4
% mass loss (L.A. Abrasion test)	29	31	36	34	40%, max	NA
% mass loss (Soundness Brine F/T)	0.1-0.5*	0.9	16.4	--	30%, max	0.9-9.5* (max. 12%)

NA: Not Applicable

*INDOT historical data

Verian, K. P., 2012

#8 N1

#8 N2

#8 RCA

All coarse aggregates satisfied INDOT maximum allowable % mass loss for L.A. abrasion and Soundness (Brine F/T).

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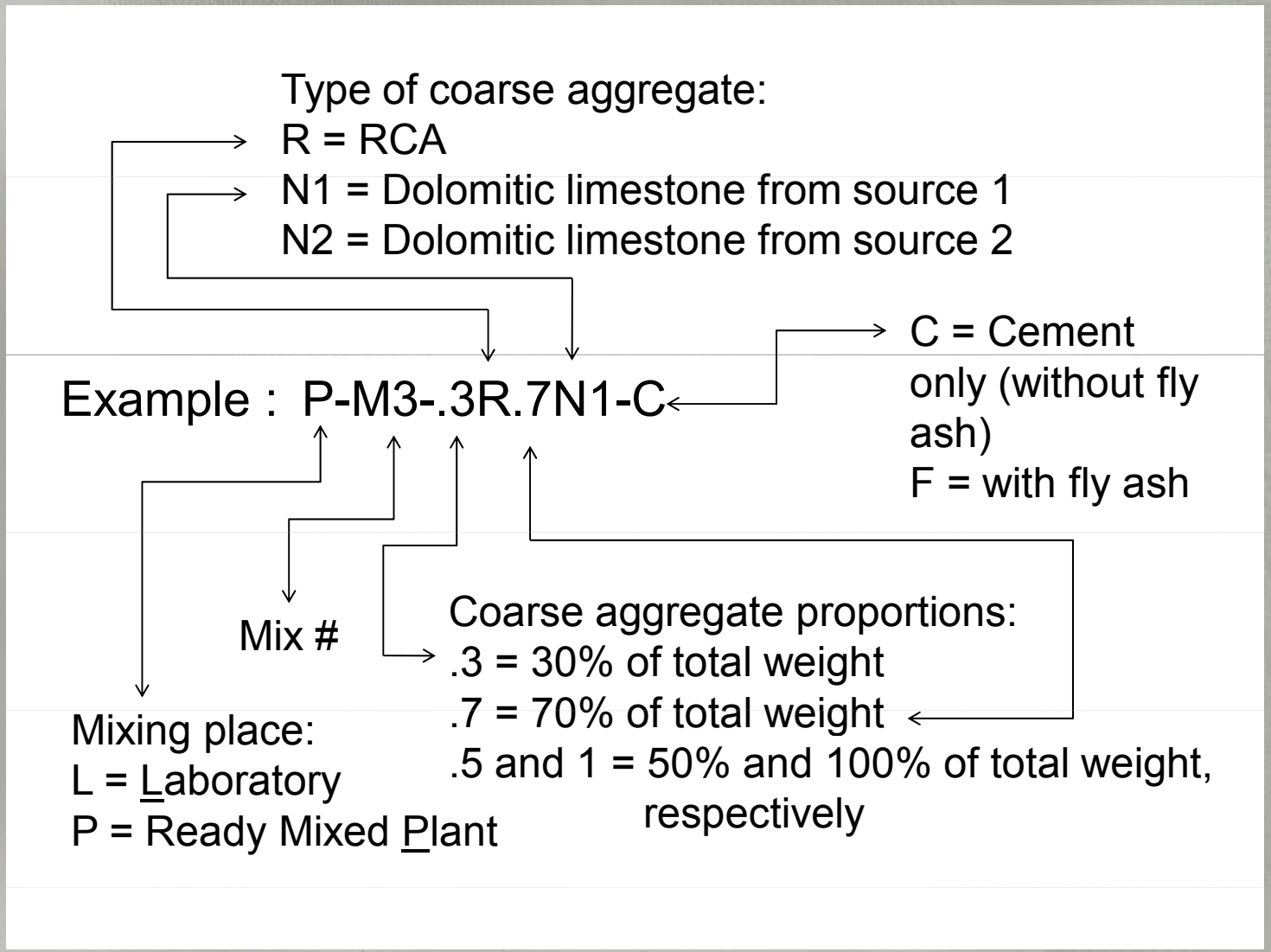
#8 N1

#8 N2

#8 RCA

Labelling of the mixtures



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CONCRETE MIXTURES

Mixture Proportions

Mixtures designations		P-M1-1N1-C	P-M2-1R-C	P-M3-.3R.7N1-C	P-M4-.5R.5N2-F	P-M5-.3R.7N1-F	P-M6-.5R.5N2-C	P-M7-1R-F	P-M8-.3R.7N2-F	P-M9-1N2-F	P-M10-1N1-C
Cement		522.5	510	512.5	432.5	432.5	515	445	437.5	437.5	512.5
FA		--	--	--	100	100	--	105	100	110	--
Water		232	239	219	212	220	224	220	227	214	214
Fine Agg.		1570	1480	1520	1510	1480	1480	1420	1450	1480	1580
Coarse Agg.	#8 N1	1690	--	1190	--	1130	--	--	--	--	1730
	#8 N2	--	--	--	800		830		1130	1700	--
	#8 RCA	--	1610	510	820	480	830	1580	490	--	--
Air entraining agent, fl oz		1.1	1.6	1.2	1.2	1.2	1.1	1.5	1.2	1.3	1.3
Water reducer, fl oz		1.9	2.0	2.0	2.1	1.9	1.7	2.4	2.1	1.8	2
w/cm		0.44	0.47	0.43	0.40	0.41	0.43	0.40	0.42	0.39	0.42

Cem-ent

Fly ash

0% RCA

30% RCA

50% RCA

100% RCA

Air entraining agent & Water reducer: fl oz/100 lbs cementitious

CONCRETE MIXTURES

- Ten types of concrete mixtures were produced at commercial ready mixed concrete plant
- All concrete mixtures were based on the Indiana Department of Transportation (INDOT) approved QC/QA pavement concrete mixture design

Drum mixer at commercial ready mixed concrete plant

Verian, K. P., 2012

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MIXING PROCESS

Specimens Production at Ready Mixed Plant

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EXPERIMENTS

Mechanical properties:

- Compressive strength (AASHTO T 22)
- Flexural strength (AASHTO T 97)

Durability properties:

- Rapid chloride permeability test ~ RCP (AASHTO T 277).
- Electrical impedance spectroscopy test ~ EIS
- Freezing and Thawing (ASTM C 666)
- Scaling (ASTM C 672)

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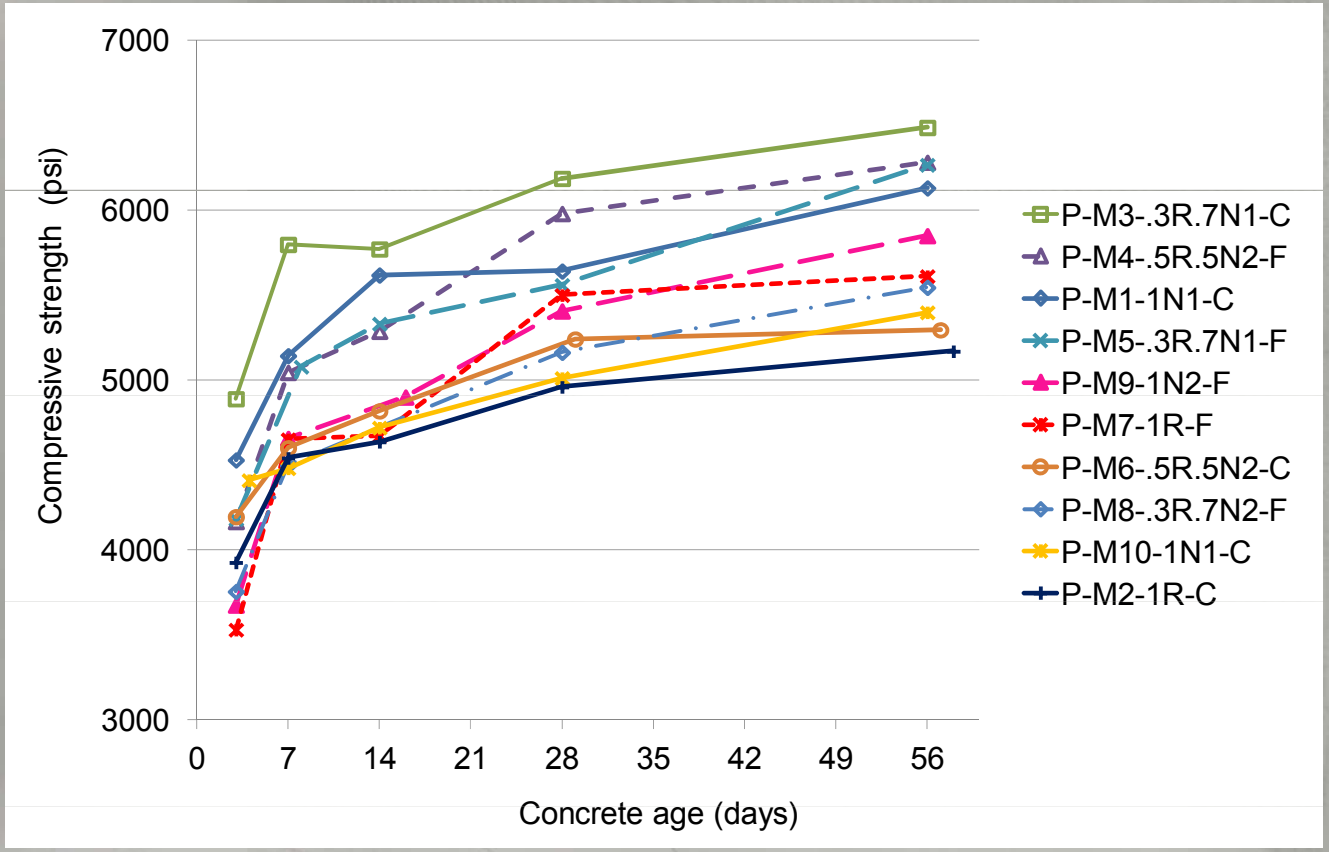
RESULTS AND ANALYSIS

- Compressive strength ~ Test Results

The compressive strength was obtained by testing 100×200 mm (4×8 in) cylindrical specimens in accordance with AASHTO T 22 and determined after 3, 7, 14, 28, and 56 days of moist curing.



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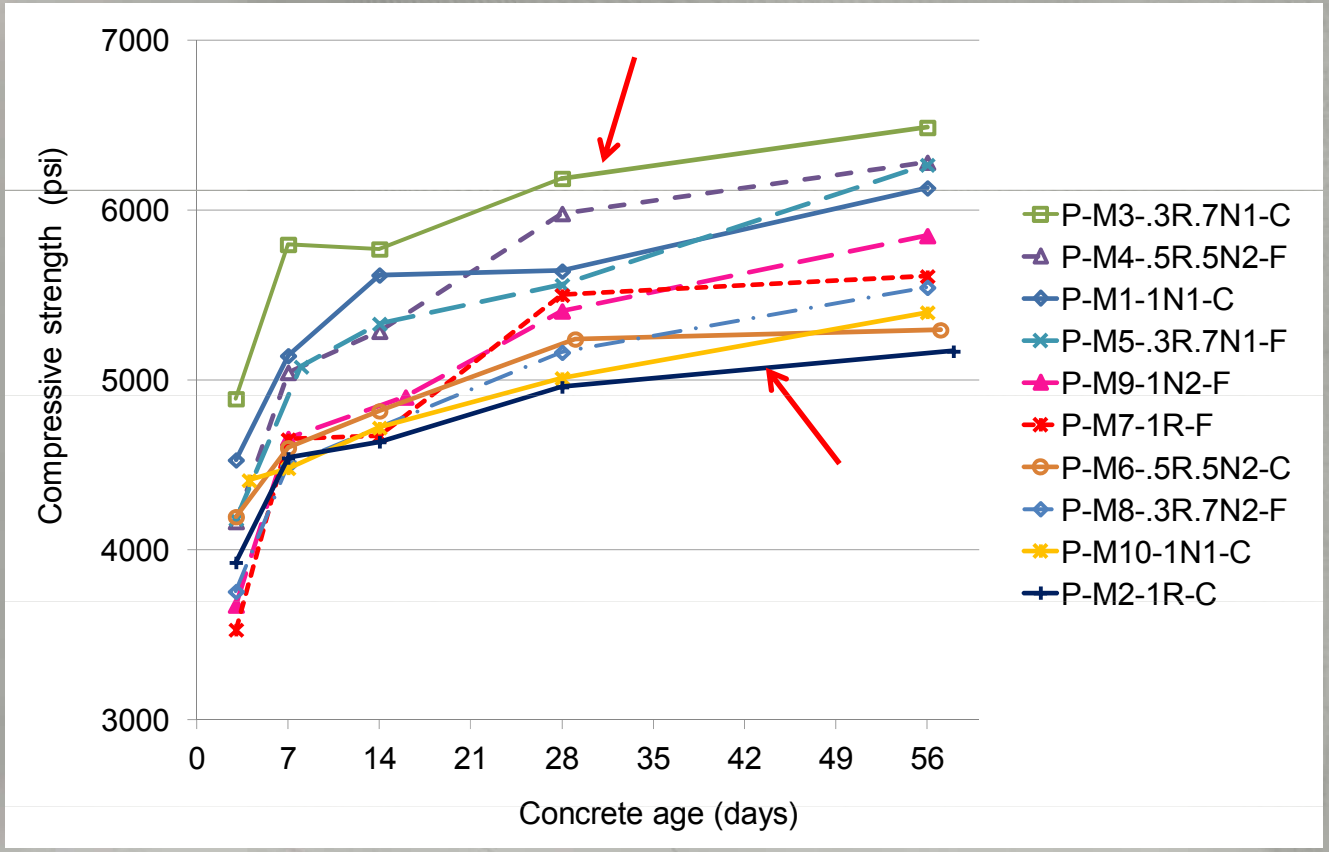
RESULTS AND ANALYSIS

- Compressive strength ~ Test Results

The concrete mixture with 30% RCA (P-M3-.3R.7N1-C) had the highest compressive strength at all ages while the mixture with 100% RCA and no fly ash (P-M2-1R-C) had the lowest compressive strength at all ages beyond 3 days.



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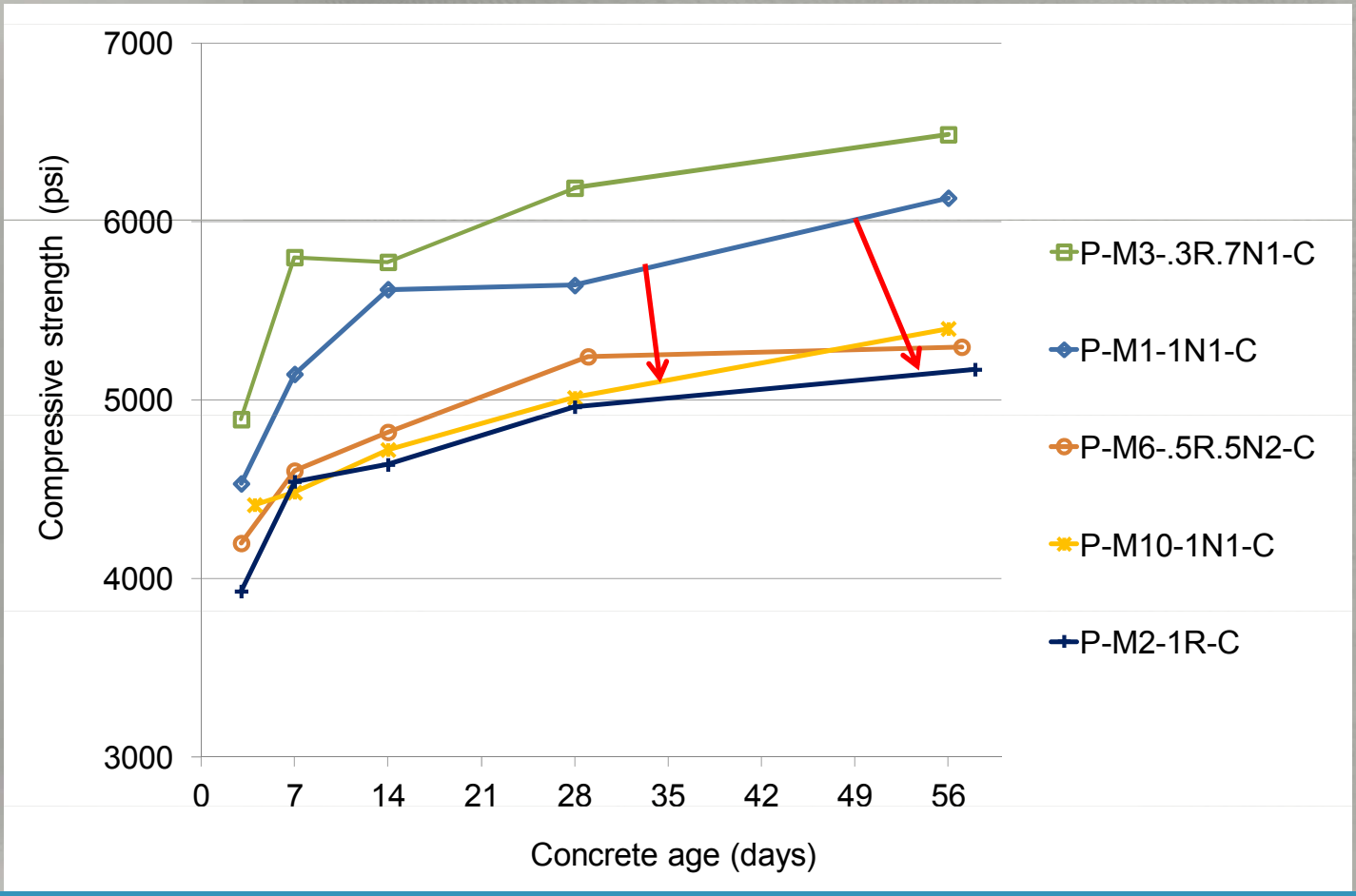
RESULTS AND ANALYSIS

- Compressive strength ~ Test Results

The increase in RCA content beyond 30% resulted in decrease in the compressive strength values (P-M6-.5R.5N2-C) and 100% (P-M2-1R-C).



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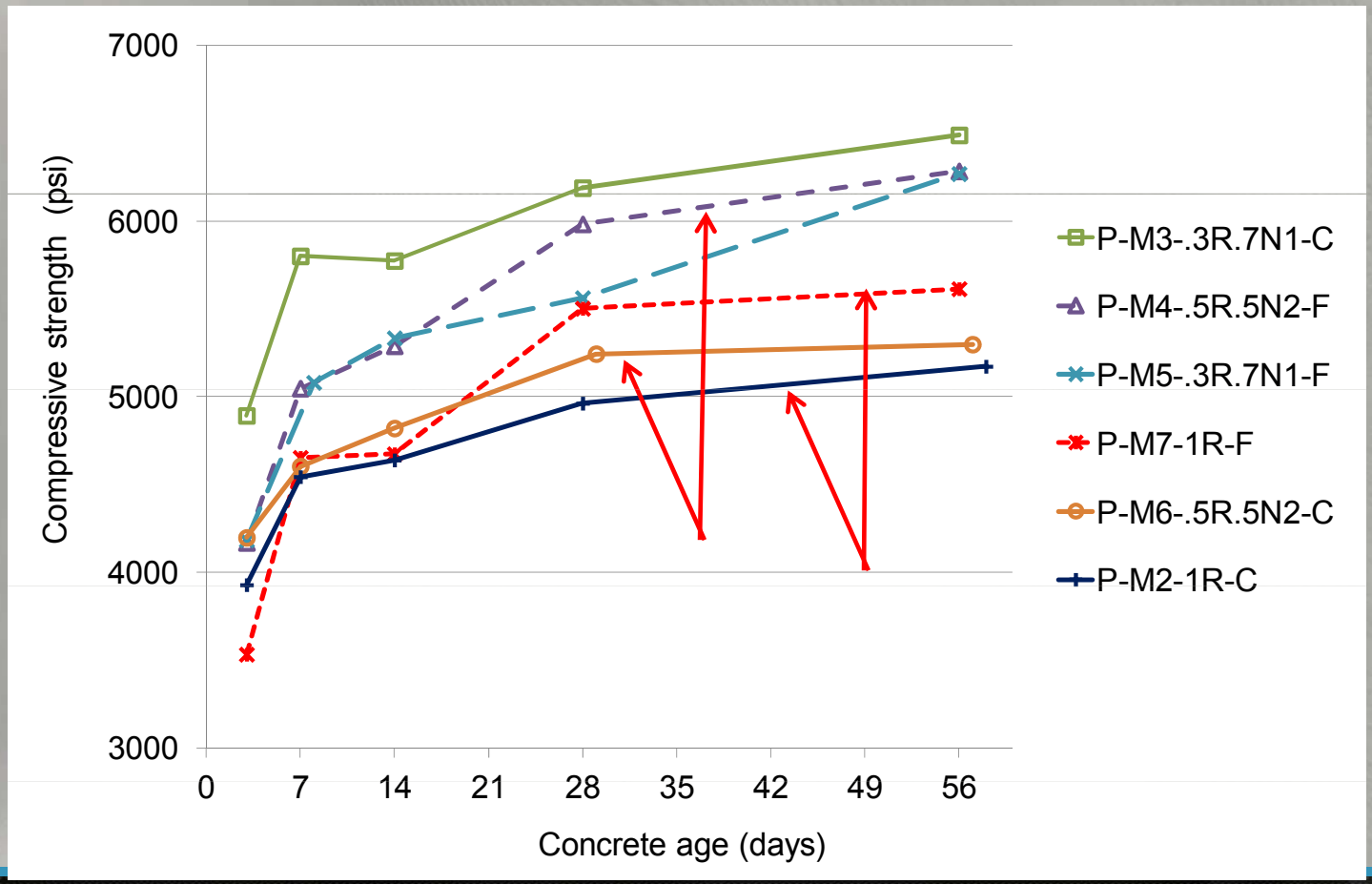
RESULTS AND ANALYSIS

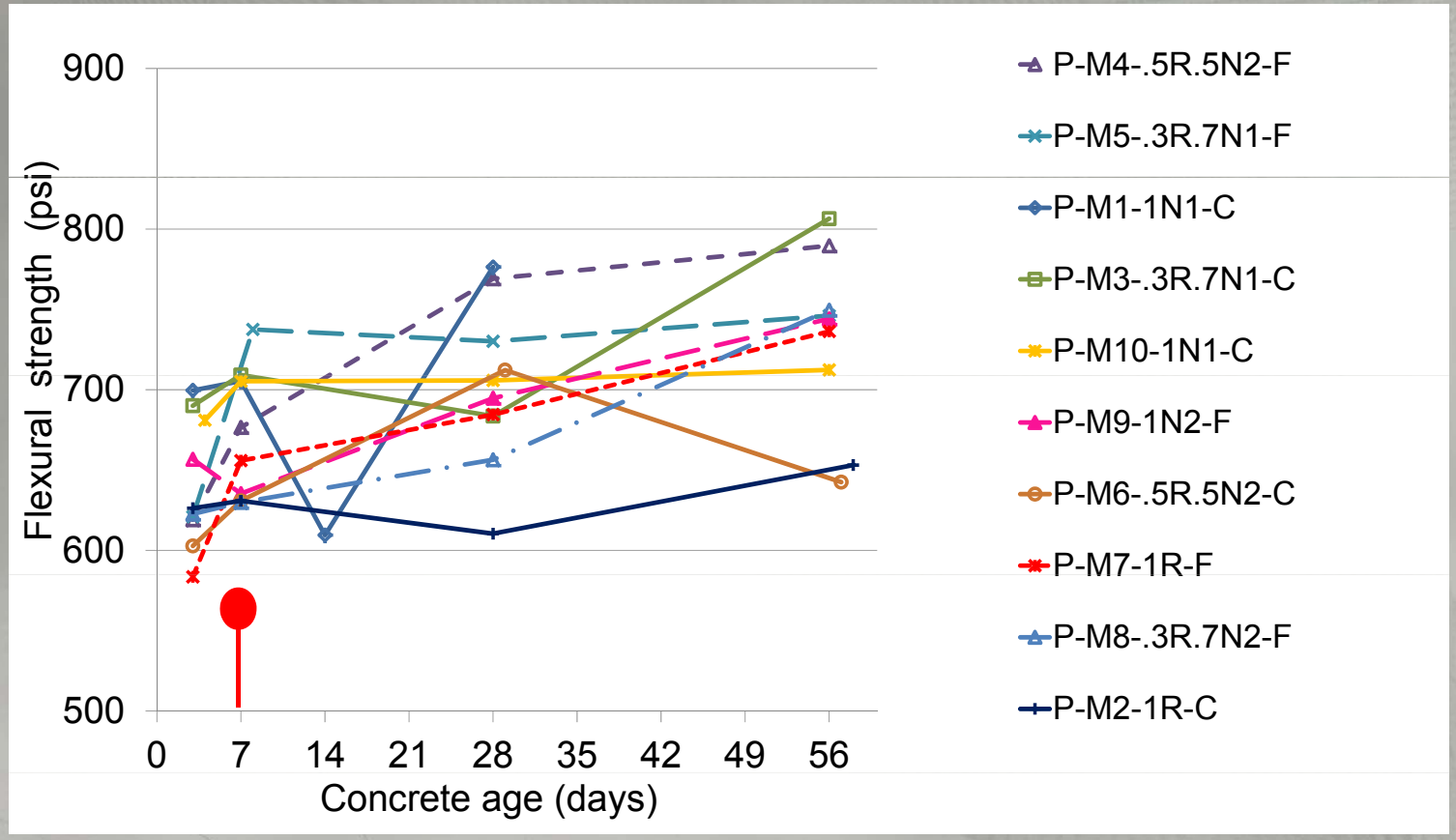
- Compressive strength ~ Test Results

Although adding more than 30% RCA reduces compressive strength, this trend can be offest by replacing part of cement with fly ash (compare M2 to M7 and M6 to M4).



RESULTS AND ANALYSIS

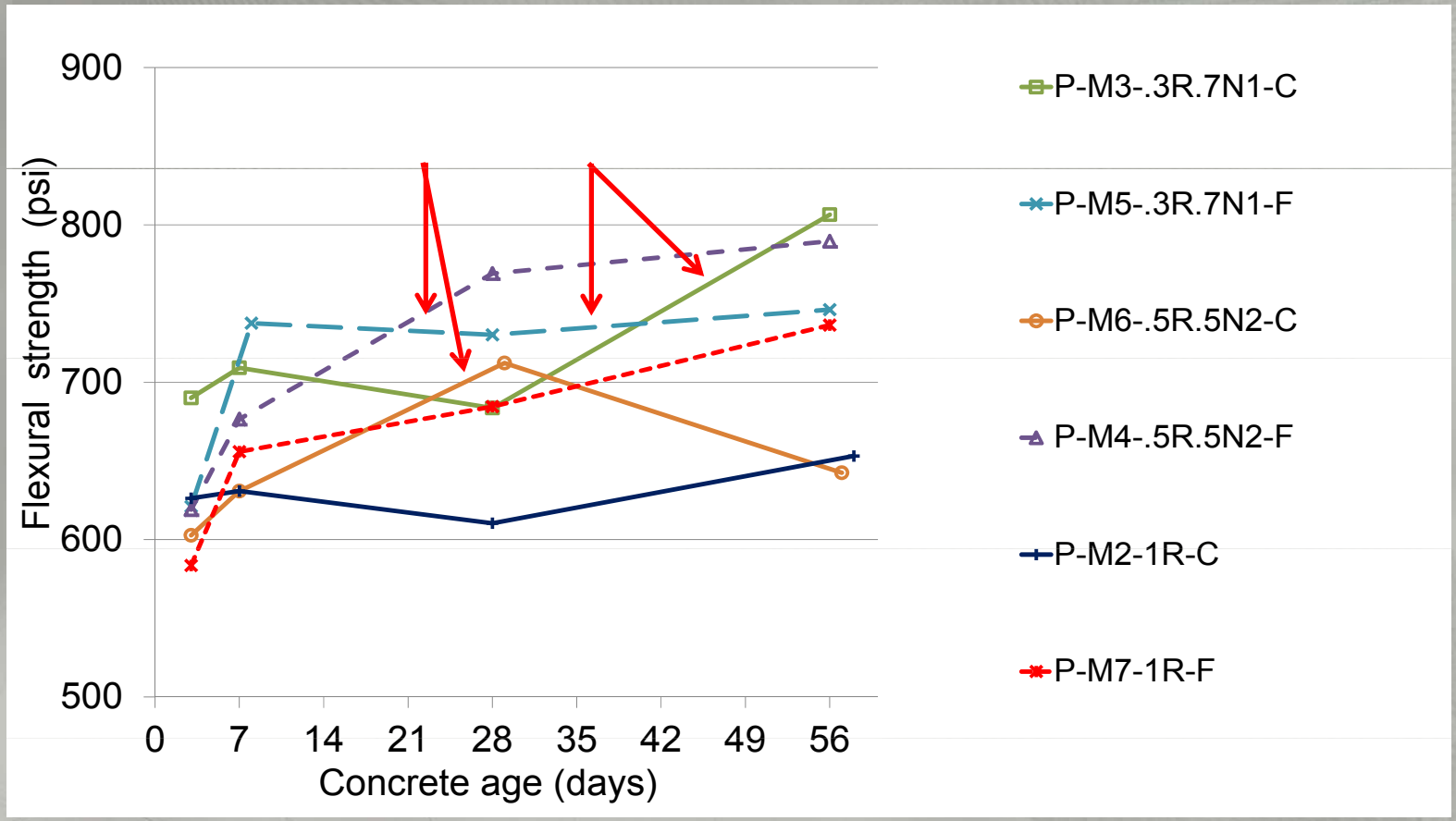
- Flexural strength ~ Test Results
  - •The flexural strength values were obtained following AASHTO T97. The prismatic specimens (6×6×21 in.) were tested after 3, 7, 28, and 56 days of moist curing.
  - •All mixes satisfied INDOT's minimum requirement for flexural strength at 7 days (4.0 MPa/570 psi).



RESULTS AND ANALYSIS

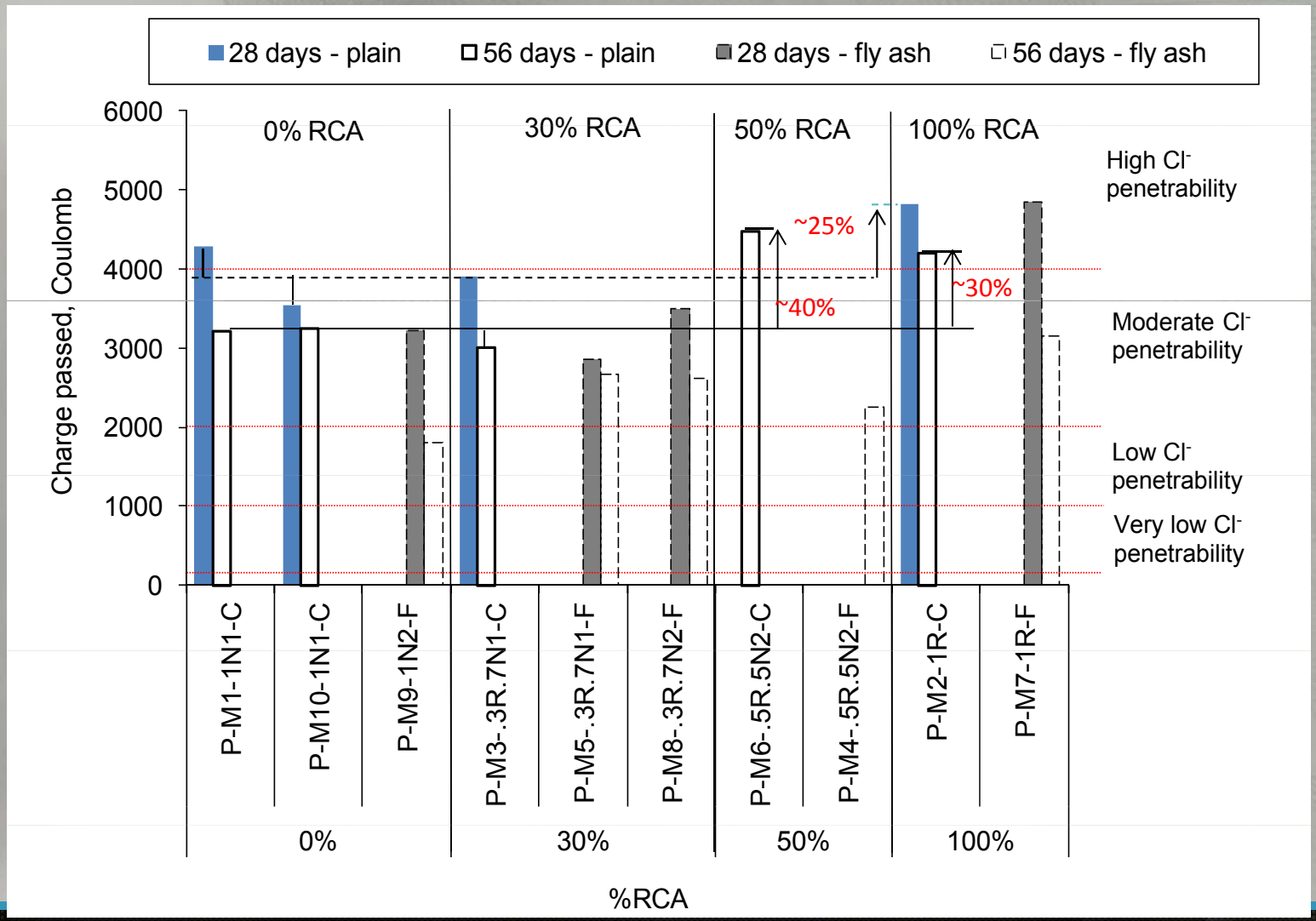
- Flexural strength ~ Test Results

  Similar to what was observed for compressive strength, replacing cement by the fly ash helps to offset the flexural strength loss due to the use of RCA (beyond 30% replacement level)



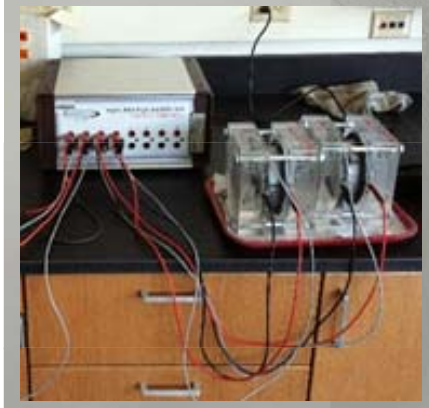
RESULTS AND ANALYSIS

- Rapid chloride permeability (RCP) ~ Test Results

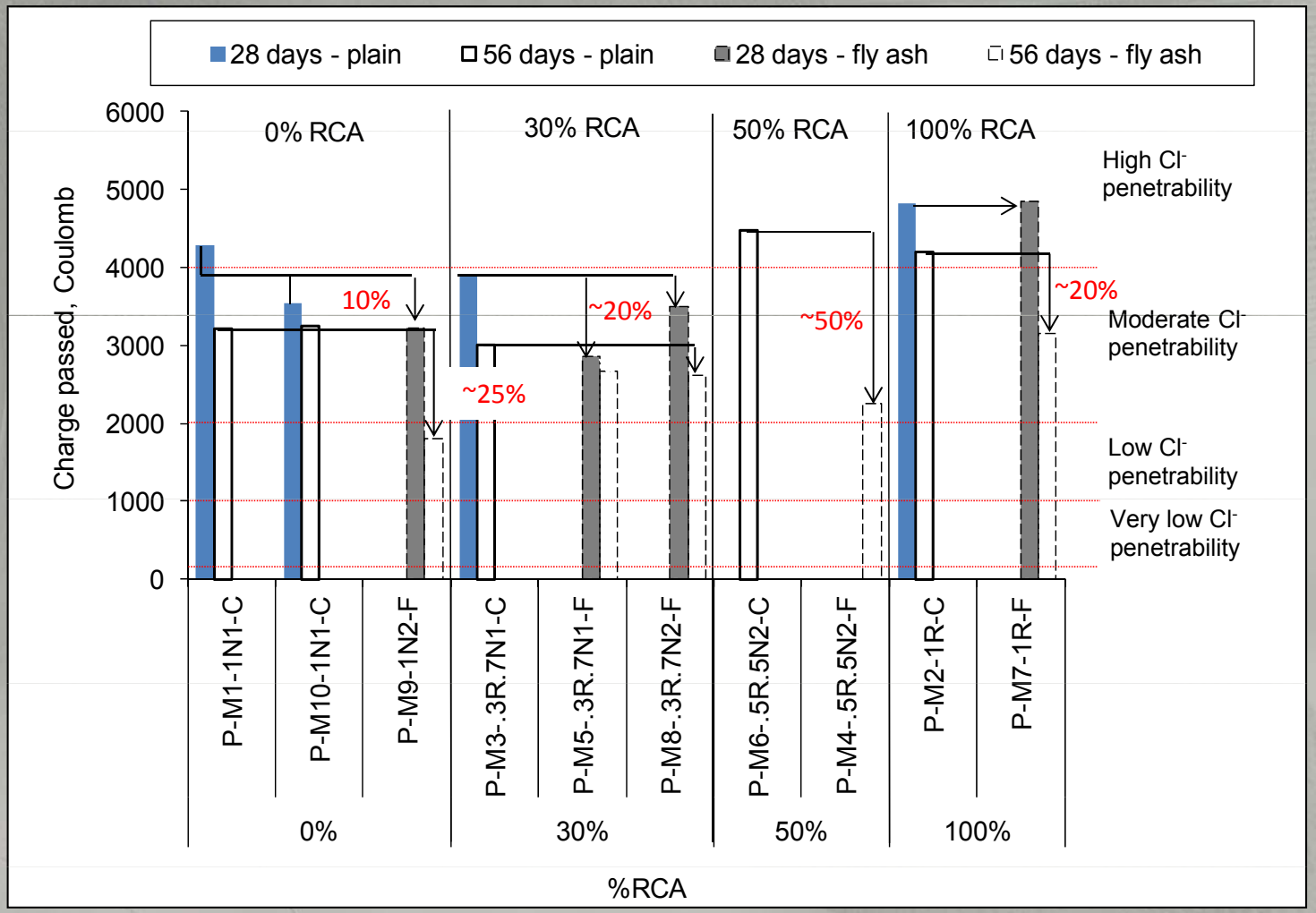


RESULTS AND ANALYSIS

- Rapid chloride permeability (RCP) ~ Test Results



RCP test setup



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RESULTS AND ANALYSIS

- Electrical Impedance Spectroscopy (EIS) ~ Test Results

Concrete's resistivity increased (up to 85%) along with the age of the concrete.

Fly ash concrete had higher increase in resistivity (25% to 85%) than plain concrete (14% to 24% increase).

Mixture designations	Resistivity, Kohm-cm		
	28-day	56-day	% increase
P-M1-1N1-C	5.6	6.4	14
P-M2-1R-C	4.0	4.8	19
P-M3-.3R.7N1-C	5.3	6.5	24
P-M4-.5R.5N2-F	6.0	7.5	25
P-M5-.3R.7N1-F	6.0	8.7	45
P-M6-.5R.5N2-C	--	5.3	
P-M7-1R-F	4.5	7.0	55
P-M8-.3R.7N2-F	4.8	8.8	82
P-M9-1N2-F	5.9	10.9	85
P-M10-1N1-C	5.9	7.0	18

-- data missed

% increase fly ash mixture

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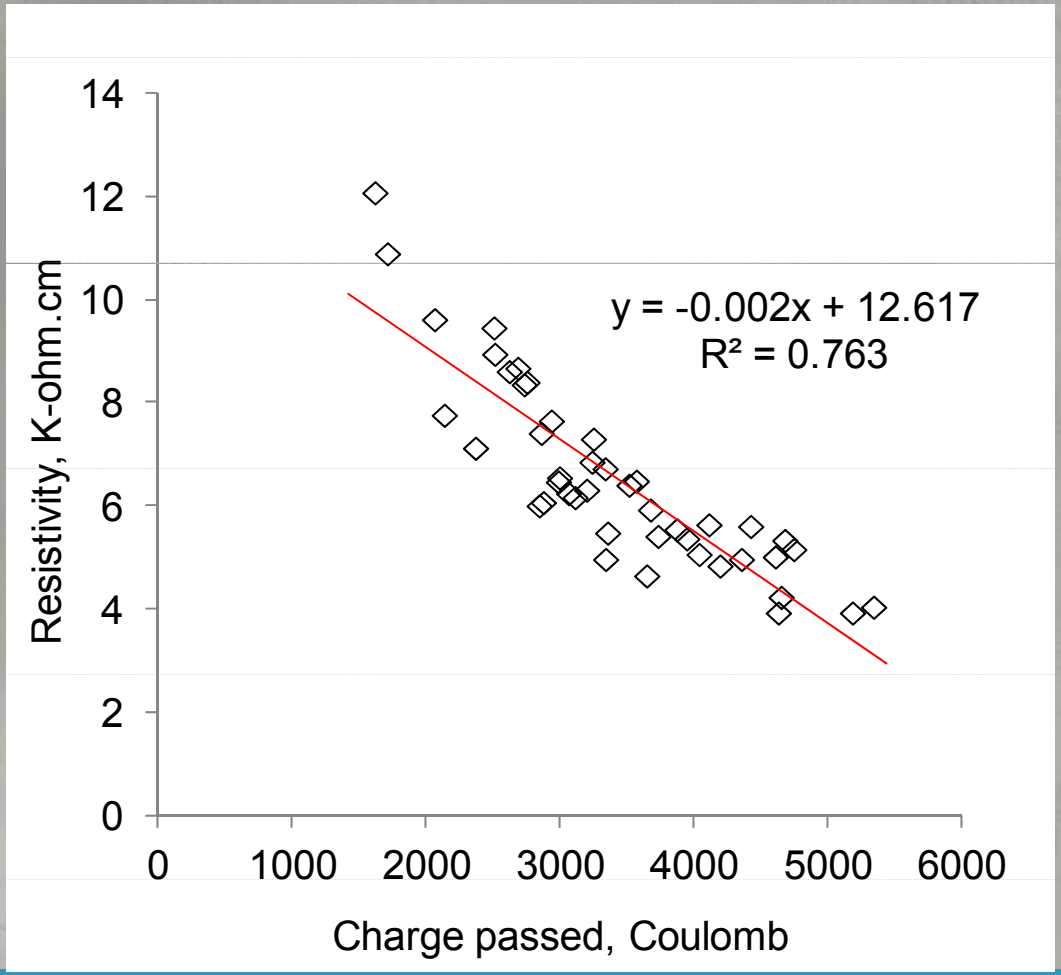
RESULTS AND ANALYSIS

Correlation between concrete resistivity from EIS test, charge passed and chloride ion penetrability based on RCP test results



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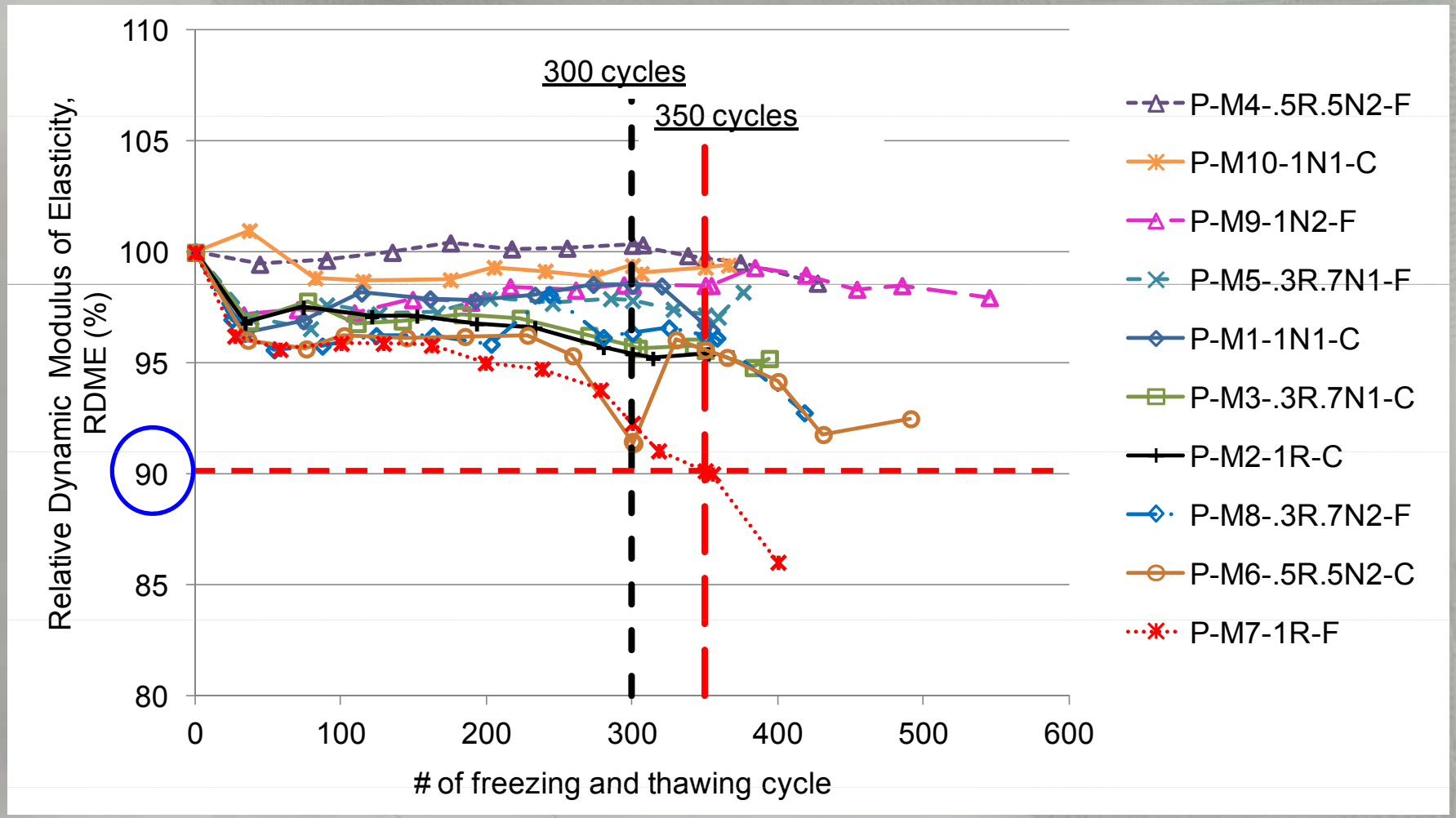
RESULTS AND ANALYSIS

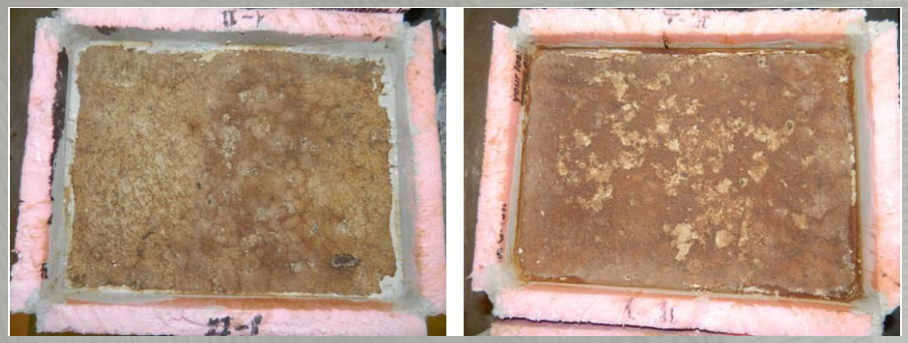
- Freezing and Thawing ~ Test Results



RESULTS AND ANALYSIS

- Scaling ~ Test Results

-Standard scaling rating (ASTM C 672)



-Mix-2 after 50 cycles of scaling

The test results indicated that all concretes showed only very slight scaling (rating #1) when subjected to F/T cycles in the presence of calcium chloride

Placing 30% RCA mix

- 10:00 am, STA 654+00: Began placing 30%RCA.

- Pavement stamped "1 30" to indicate sublot 1 that had 30%RCA

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- Samples tested from one of the first 3 truck loads:
  - Air = 5.2%
  - Slump = 1.5"

- Finishers commented that it closed well and finished very nicely, better than the 100% gravel. Edge was looking very good, clean and sharp.

End of 30% RCA placement (R-30)

End of 30% RCA placement looking north, back at job

100% Gravel

Placing 50% RCA concrete as part of the shoulder of new US 231 near the intersection of S. River Road.


GOMACO
GOMACO


SLOW

Recycled concrete aggregate (RCA) replaced 50% of the coarse aggregate in the concrete used for part of the shoulder of the new US 231 near the intersection with River Road.

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CONCLUSIONS

- All concretes produced in the ready mixed plant satisfied INDOT's requirements (QC/QA) for concrete pavements.
  - Slump (1.25 – 3.00 in)
  - Target air content 6.5% (allowable range: 5.7% - 8.9%)
  - 7-day flexural strength, min. 570 psi
- RCA (used in this study) can be used as an alternative for natural coarse aggregate for concrete pavements at Indiana.
- At 30% replacement level, RCA concrete had properties which were comparable to (and in some cases even better) than the properties of control concrete (plain-0% RCA)
- Concretes with 50% and 100% RCA tend to have lower strengths and lower durability (as indicated by most of the properties tested) than the control concrete
- Replacing part of cement with fly ash (Class C, ~20% by weight) helped in bringing the properties to the level comparable to control concretes

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RECOMMENDATIONS

- The determination of moisture content of RCA is critical for proper adjustments of the mix water. Further adjustments (i.e. in the amount and time of introduction of admixtures) may be required to achieve the desired target slump
- The replacement levels of RCA is suggested to be not higher than 30% for plain concrete and not higher than 50% for fly ash concrete
- The use of fly ash is recommended in RCA concrete since it has been proven that fly ash improves the mechanical and durability properties

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Thank you