Eco-Efficient Self Consolidating Concrete (Eco-SCC) with Low Powder Content and Recycled Concrete Aggregate

Jiong Hu

Department of Civil and Environmental Engineering
University of Nebraska-Lincoln

Nebraska Lincoln

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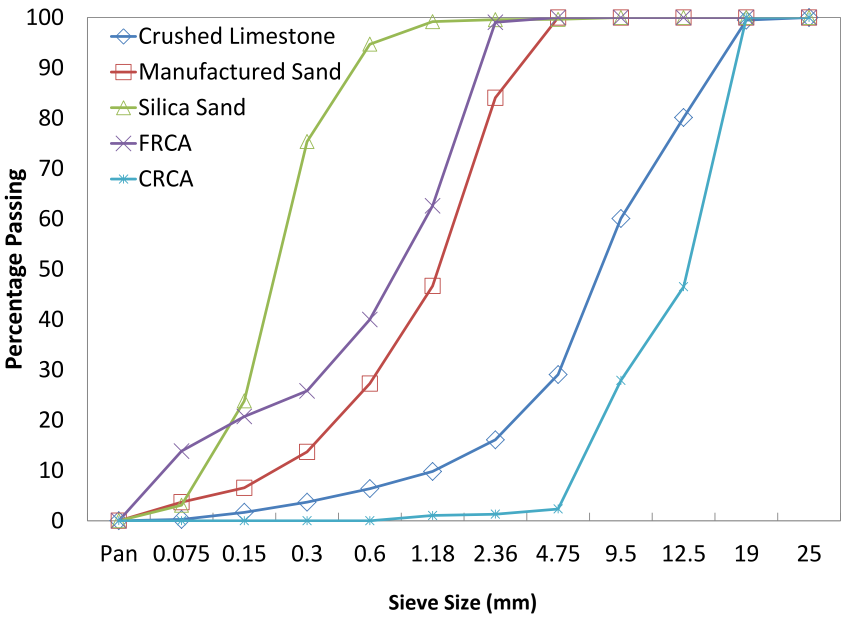
aci CONCRETE CONVENTION
THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

OUTLINE

- SCC with RCA
- Eco-SCC with RCA
  - Introduction
  - Materials
  - Results and Discussions
    - Effect of binder contents
    - Effect of RCA contents
    - Optimum packing
    - Global warming potential index comparison
- Conclusions and Looking Forward

SCC WITH RCA

MATERIALS - AGGREGATE



CRCA

FRCA

MIX PROPORTIONS – SERIES A

	A FRCA0	A FRCA25	A FRCA50	A FRCA75	A FRCA100
Cement	390(657)	390(657)	390(657)	390(657)	390(657)
Fly ash	83 (140)	83 (140)	83 (140)	83 (140)	83 (140)
Water	160(270)	160(270)	160(270)	160(270)	160(270)
w/c	0.41	0.41	0.41	0.41	0.41
w/b	0.34	0.34	0.34	0.34	0.34
Cr. limestone	917(1546)	917(1546)	917(1546)	917(1546)	917(1546)
Man sand	555(935)	402(678)	253(427)	103(173)	0(0)
Silica sand	98(165)	73(123)	44(75)	18(30)	0(0)
FRCA	0(0)	163(275)	326(550)	489(825)	600(1012)
HRWR	1043(16)	1043(16)	1043(16)	1043(16)	1043(16)
VMA	652(10)	652 (10)	652(10)	652(10)	652 (10)

Note: Cement, fly ash, water, and aggregates at kg/m^3 (pcy), HRWR and VMA at ml/100lb (fl oz/cwt).

MIX PROPORTIONS – SERIES B

	B FRCA0	B FRCA25	B FRCA50	B FRCA75	B FRCA100
Cement	415(700)	415(700)	415(700)	415(700)	415(700)
Fly ash	0 (0)	0 (0)	0 (0)	0 (0)	0(0)
Water	170(287)	170(287)	170(287)	170(287)	170(287)
w/c	0.41	0.41	0.41	0.41	0.41
w/b	0.41	0.41	0.41	0.41	0.41
Cr. limestone	831(1400)	831(1400)	831(1400)	831(1400)	831(1400)
Man sand	659(1111)	480(809)	301(507)	123(207)	0(0)
Silica sand	116(196)	85(143)	53(90)	21(36)	0(0)
FRCA	0(0)	194(327)	388 (654)	581(980)	714(1203)
HRWR	978(15)	978(15)	978(15)	978(15)	978(15)
VMA	522(8)	522(8)	522(8)	522(8)	522(8)

Note: Cement, fly ash, water, and aggregates at kg/m^3 (pcy), HRWR and VMA at ml/100lb (fl oz/cwt).

MIX PROPORTIONS – SERIES C

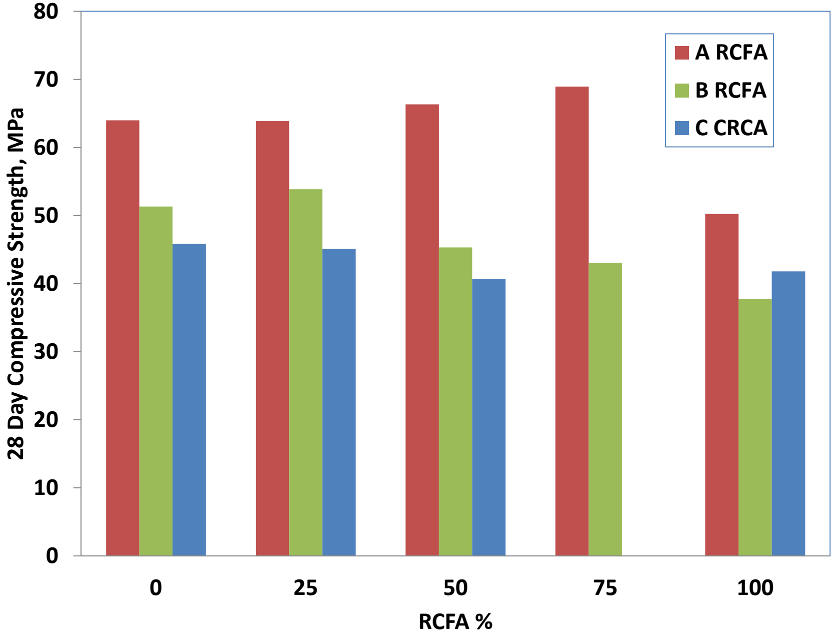
	C CRCA0	C CRCA25	C CRCA50	C CRCA100
Cement	276 (608)	277 (608)	278 (608)	279 (608)
Fly ash	77 (170)	78 (170)	79 (170)	80 (170)
Water	142 (314)	143 (314)	144 (314)	145 (314)
w/c	0.52	0.52	0.52	0.52
w/b	0.40	0.40	0.40	0.40
Cr. limestone	583 (1286)	432 (953)	284 (627)	0 (0)
Man sand	572 (1262)	573 (1262)	574 (1262)	575 (1262)
CRCA	0 (0)	143 (317)	284 (627)	555 (1223)
HRWR	784 (12)	785 (12)	786 (12)	787 (12)
VMA	404 (6.2)	405 (6.2)	406 (6.2)	407 (6.2)

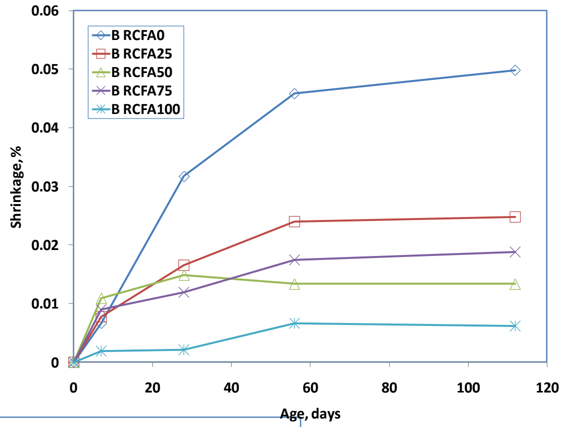
Note: Cement, fly ash, water, and aggregates at kg/m^3 (pcy), HRWR and VMA at ml/100lb (fl oz/cwt).

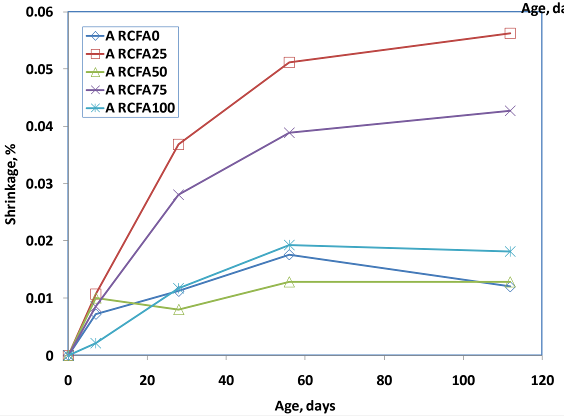
FRESH CONCRETE PROPERTIES

	Slump flow Diameter, mm (in)	Slump flow T_{50}, sec	J-ring flow, mm (in)	Flow difference, mm (in)	VSI	L-Box t_{final}, sec	L-Box t_{final}, sec	L-Box Blocking Ratio	V-funnel, T_v, sec
A RCFA0	673 (26.50)	5.0	606 (23.88)	67 (2.63)	0	7.0	7.0	0.85	10.0
A RCFA25	743 (29.25)	4.0	727 (28.63)	16 (0.63)	0	4.0	4.0	0.94	8.0
A RCFA50	711 (28.00)	2.8	686 (27.00)	25 (1.00)	0	6.0	6.0	0.94	10.2
A RCFA75	654 (25.75)	3.0	616 (24.25)	38 (1.50)	0	12.0	12.0	0.74	15.5
A RCFA100	845 (33.25)	1.3	775 (30.50)	70 (2.75)	0	1.0	1.0	1.00	4.0
B RCFA0	762 (30.00)	1.5	713 (28.06)	49 (1.94)	0	0.0	0.0	0.52	7.2
B RCFA25	775 (30.50)	1.7	768 (30.25)	06 (0.25)	1	3.0	3.0	0.25	7.0
B RCFA50	806 (31.75)	1.7	768 (30.25)	38 (1.50)	1	2.0	2.0	1.00	7.0
B RCFA75	775 (30.50)	2.4	673 (26.50)	102 (4.00)	0	7.0	7.0	0.74	4.2
B RCFA100	711 (28.00)	1.1	686 (27.00)	25 (1.00)	0	6.0	6.0	0.81	3.7
CRCA0	667 (26.25)	2.1	594 (23.38)	73 (2.87)	0	--	--	--	6.7
CRCA25	715 (28.13)	2.1	622 (24.50)	92 (3.63)	0	--	--	--	2.8
CRCA50	768 (30.25)	1.0	759 (29.88)	9 (0.37)	2	--	--	--	2.0
CRCA100	812 (32.75)	1.6	867 (34.13)	0 (0)	1	--	--	--	4.0

HARDENED CONCRETE PROPERTIES





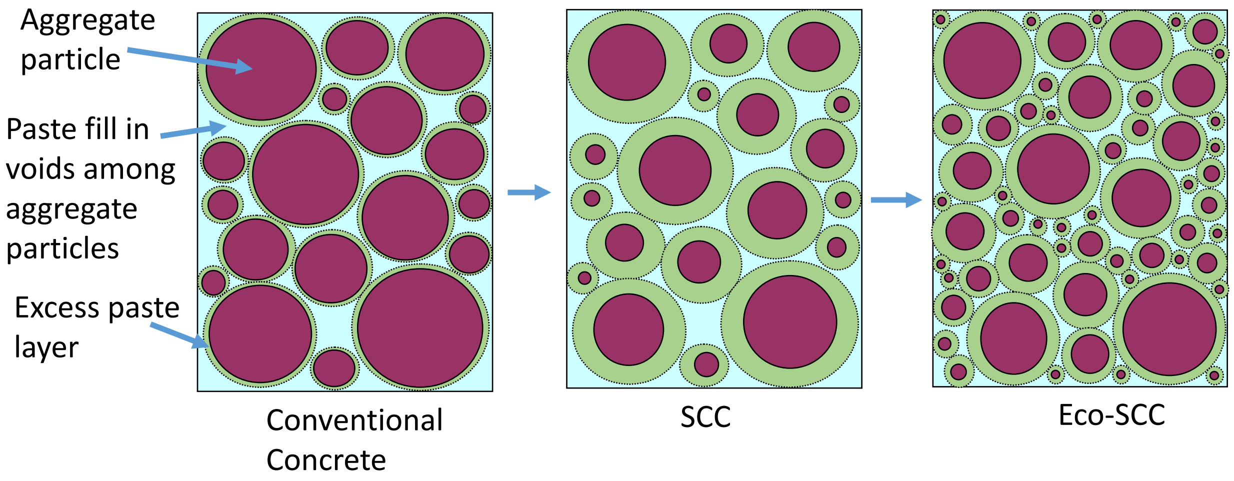


ECO-SCC WITH RCA

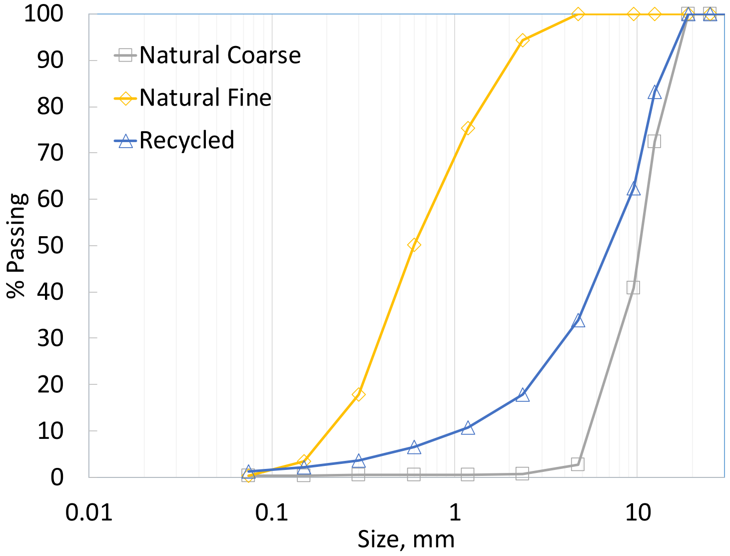
ECO-EFFICIENT (ECO-SCC)

- The high material cost due to the high cement and cementitious material content has become an obvious obstacle of the wide application of SCC, particularly in ready-mixed concrete (RMC) production
- Eco-SCC: The optimization of aggregate gradation and particle packing, as well as the use of viscosity modify agent (VMA) allows the effective reduction of cement and cementitious materials content, so as to reduce cost as well as to minimize technical issues such as high drying shrinkage.

ECO-SCC DESIGN



MATERIALS - AGGREGATE



Coarse Agg.

Fine Agg.

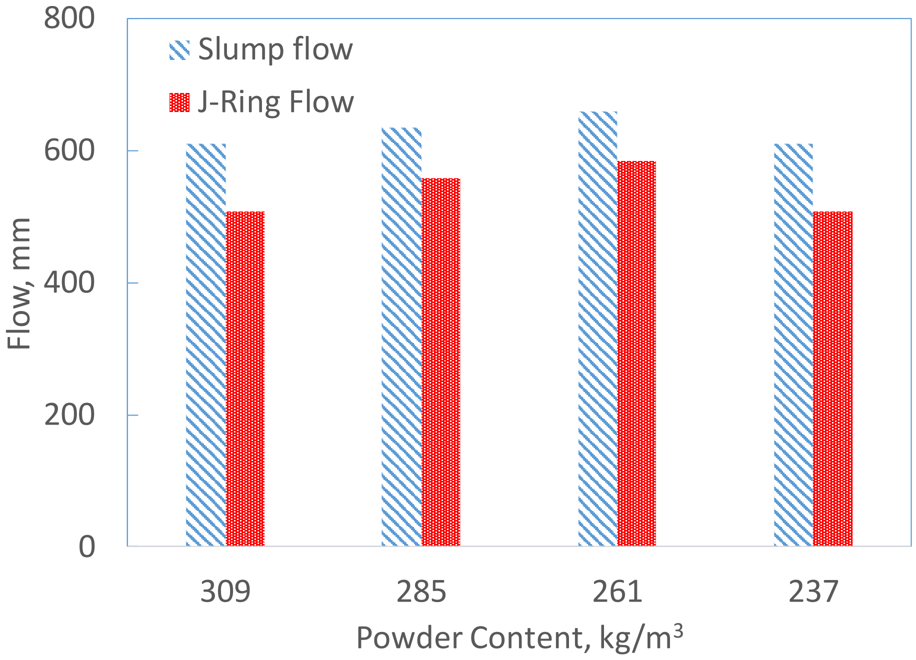
RCA

	$G_{sb, SSD}$	Absorption	F.M.
Natural coarse aggregte (Dolomite)	2.83	0.7%	6.54
Natural fine aggregte (River sand)	2.64	0.6%	2.59
Recycled aggregte	2.25	5.6%	5.63

EFFECT OF BINDER CONTENTS - MIXTURE DESIGNS

Mix ID	P-1	P-2	P-3	P-4
Cement, kg/m^3 (pcy)	309 (520)	285 (480)	261 (440)	237 (400)
Fly Ash, kg/m^3 (pcy)	78 (131)	71 (120)	65 (110)	59 (100)
Binder, kg/m^3 (pcy)	386 (651)	356 (600)	326 (550)	297 (500)
Natural Co. Agg. , kg/m^3 (pcy)	1011 (1705)	1036 (1746)	1060 (1787)	1084 (1828)
Natural Fine, kg/m^3 (pcy)	758 (1278)	775 (1307)	795 (1340)	813 (1370)
Recycled Agg. , kg/m^3 (pcy)	0 (0)	0 (0)	0 (0)	0 (0)
Water (kg/m^3)	93 (156)	95 (160)	86 (146)	78 (131)
w/b	0.240	0.266	0.265	0.263
HRWR, ml/100kg (fl oz/cwt)	1006 (15.4)	1091 (16.7)	1190 (18.3)	1905 (29.2)
VMA, ml/100kg (fl oz/cwt)	366 (5.6)	397 (6.1)	433 (6.6)	714 (11.0)

EFFECT OF POWDER CONTENT ON SLUMP FLOW AND J-RING FLOW

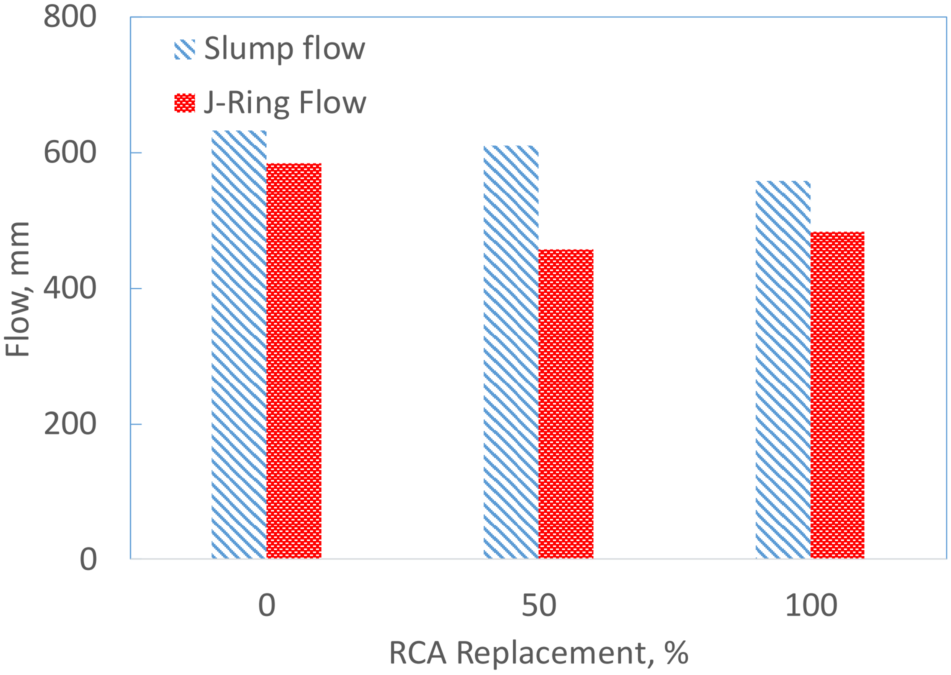


Mix ID	P-1	P-2	P-3	P-4
Slump flow, mm (in.)	610 (24)	635 (25)	660 (26)	610 (24)
T_{50} (s)	4.5	5.5	3.9	4.5
J-ring flow, mm (in.)	508 (20)	559 (22)	584 (23)	508 (20)
VSI	0	0	0	1
$f'_{c,7}$, MPa (psi)	50.5 (7,324)	37.8 (5,477)	40.5 (5,876)	40.5 (5,876)
HVSI	0	0	0	0

EFFECT OF RCA CONTENTS - MIXTURE DESIGNS

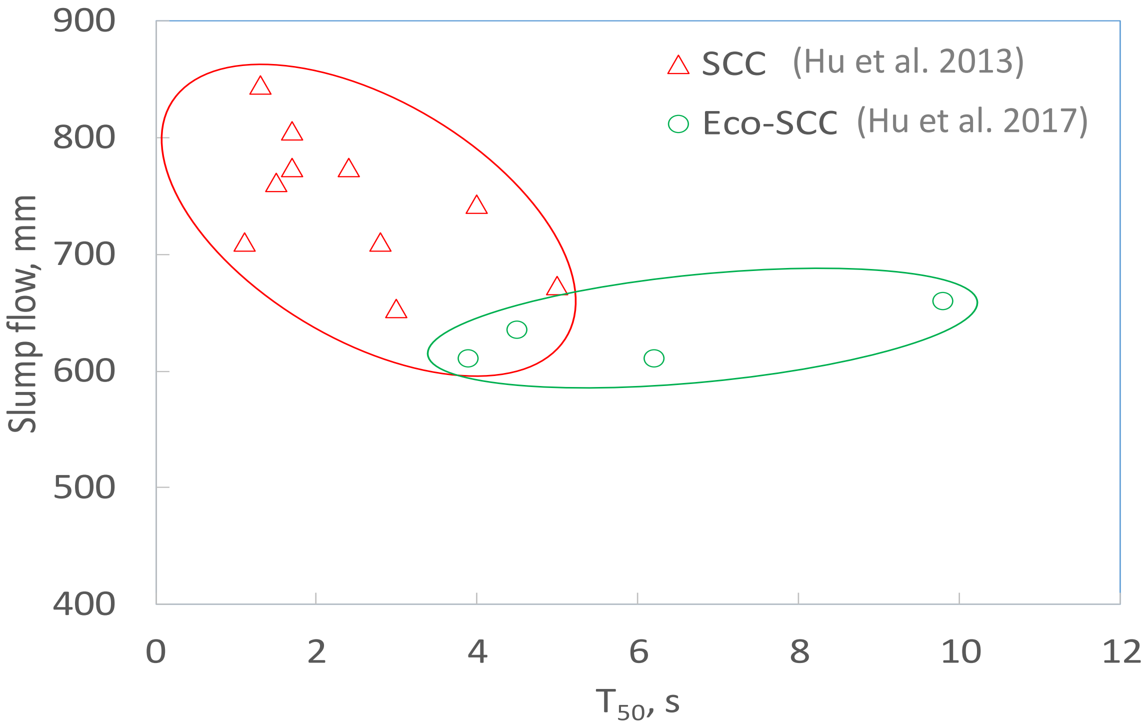
Mix ID	R-1 (P-3)	R-2	R-3
Cement, kg/m^3 (pcy)	261 (440)	261 (440)	261 (440)
Fly Ash, kg/m^3 (pcy)	65 (110)	65 (110)	65 (110)
Binder, kg/m^3 (pcy)	326 (550)	326 (550)	326 (550)
Natural Co. Agg. , kg/m^3 (pcy)	1060 (1787)	477 (806)	0 (0)
Natural Fine, kg/m^3 (pcy)	795 (1340)	794 (1339)	794 (1339)
Recycled Agg. , kg/m^3 (pcy)	0 (0)	501 (844)	891 (1502)
Water (kg/m^3)	86 (146)	111 (187)	116 (195)
w/b	0.265	0.339	0.355
HRWR, ml/100kg (fl oz/cwt)	1190 (18.3)	1190 (18.3)	1190 (18.3)
VMA, ml/100kg (fl oz/cwt)	433 (6.6)	433 (6.6)	433 (6.6)

EFFECT OF RCA ON SLUMP FLOW AND J-RING FLOW



Mix ID	R-1 (P-3)	R-2	R-3
Slump flow, mm (in.)	660 (26)	610 (24)	559 (22)
T_{50} (s)	3.9	9.8	6.2
J-ring flow, mm (in.)	584 (23)	457 (18)	483 (19)
VSI	0	0	0
$f'_{c,7}$, MPa (psi)	40.5 (5,876)	46.7 (6,779)	38.4 (5,565)
HVSI	0	0	0

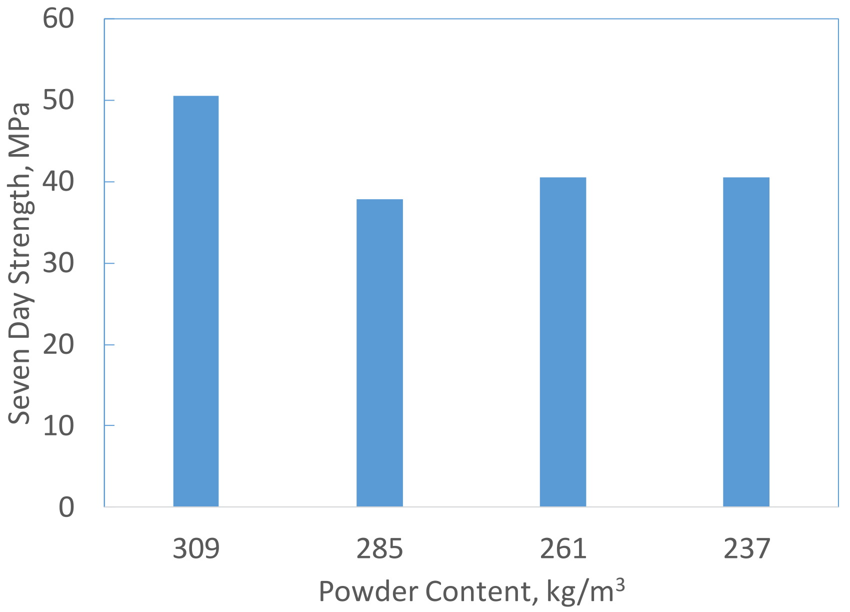
RHEOLOGICAL BEHAVIOR

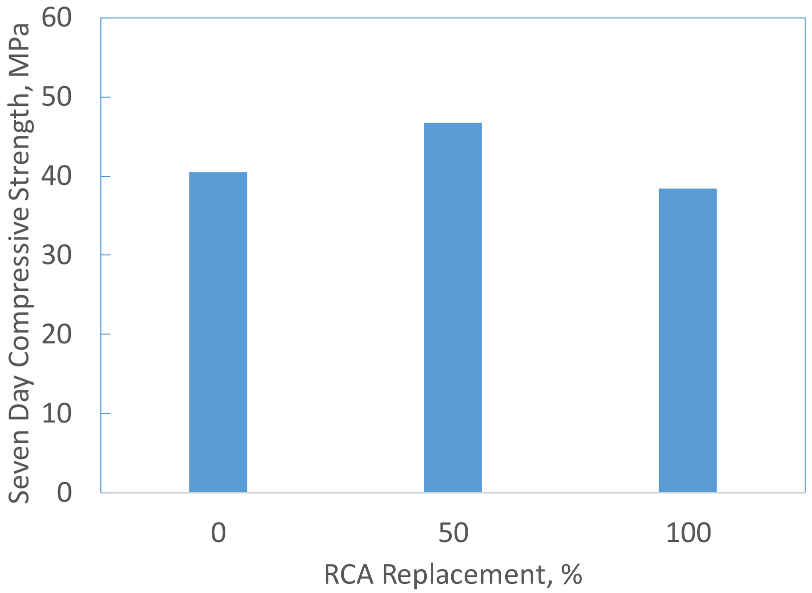


J. Hu, I. Levi Souza and F. Cortês Genarini, *Engineering and Environmental Performance of Eco-Efficient Self Consolidating Concrete (Eco-SCC) with Low Powder Content and Recycled Concrete Aggregate*, Journal of Sustainable Cement-Based Materials, Vol. 6, No. 1, 2017.

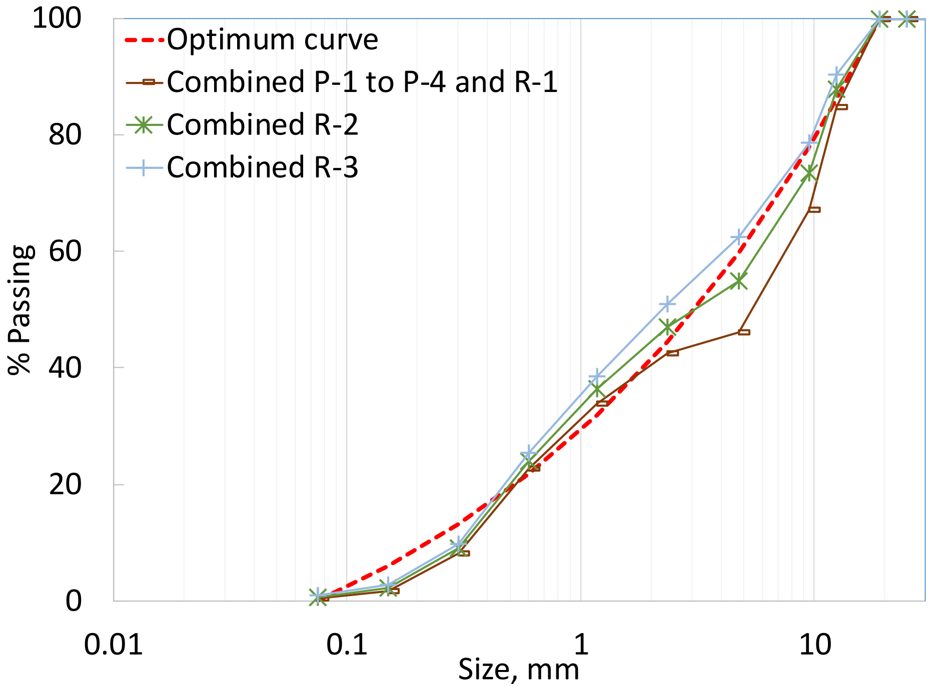
J. Hu, Z. Wang, Y. Kim, *Feasibility Study of using Fine Recycled Concrete Aggregate in Producing Self-Consolidation Concrete*, Journal of Sustainable Cement-Based Materials, Vol. 2 (2013), pp. 20-34.

EFFECT OF POWDER CONTENT AND RCA CONTENT ON STRENGTH





OPTIMUM PACKING CURVE AND COMBINED AGGREGATE PARTICLE DISTRIBUTIONS.

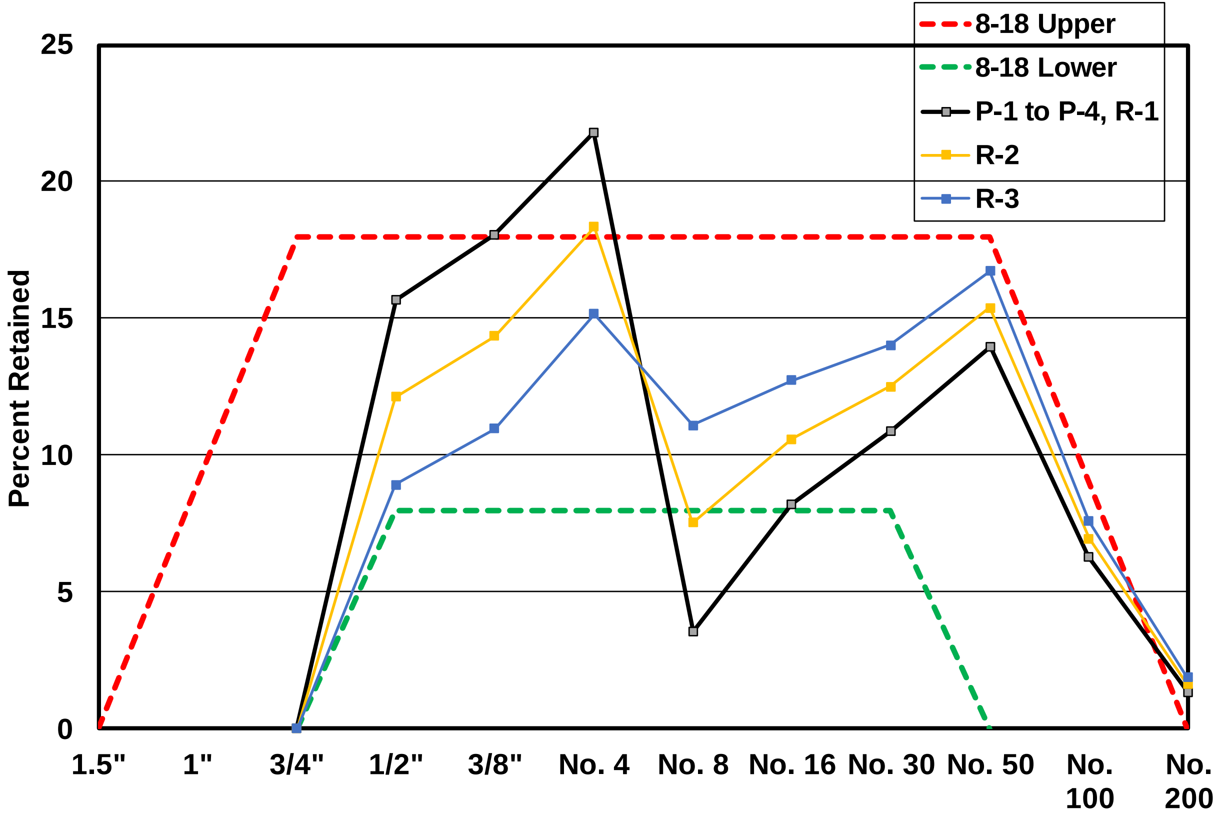


Modified Andreasen and Andersen model

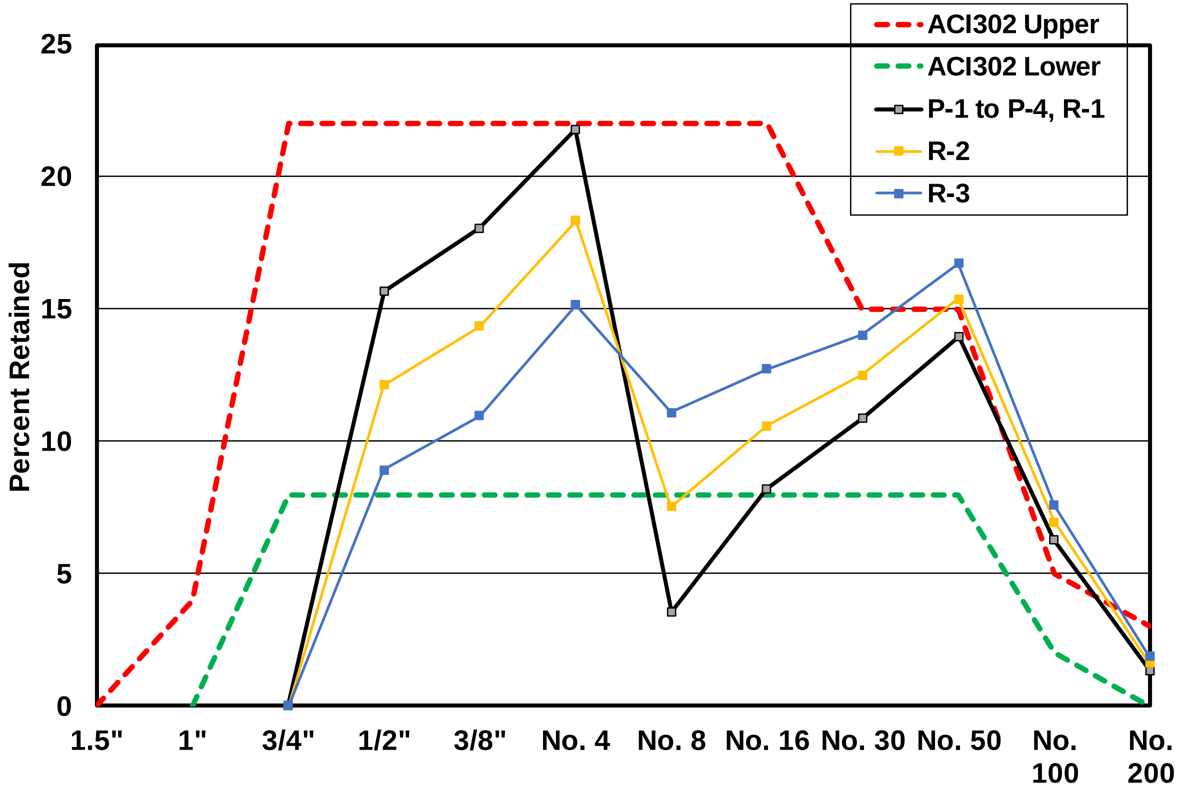
$$P_i = \frac{D_i^q - D_{min}^q}{D_{max}^q - D_{min}^q}$$

Where P_i = cumulated percentage passing of particle on the current sieve; D_{max} = maximal size of particle under analysis; D_{min} = minimum size of particle under analysis, D_i = diameter of the current sieve, and q = exponent of the equation. a maximum particle size of 19mm and a minimum particle size of 0.075mm were used based on the aggregate used. A q of 0.27 was used for Eco-SCC.

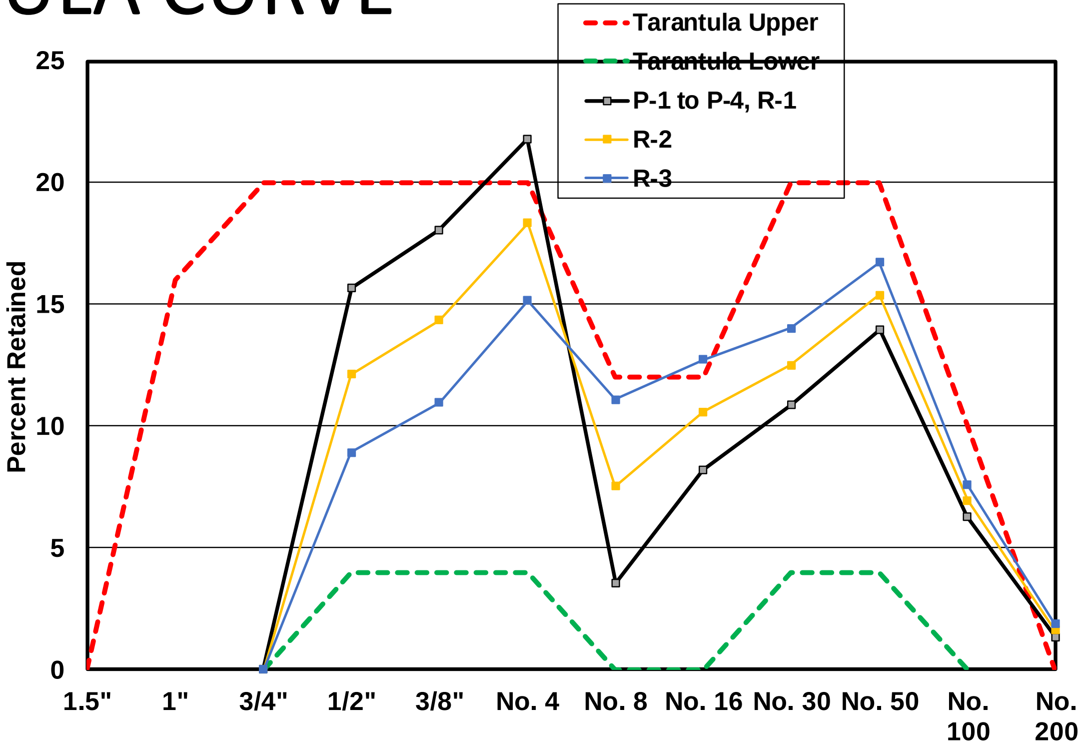
COMBINED AGGREGATE GRADATION - 8-18



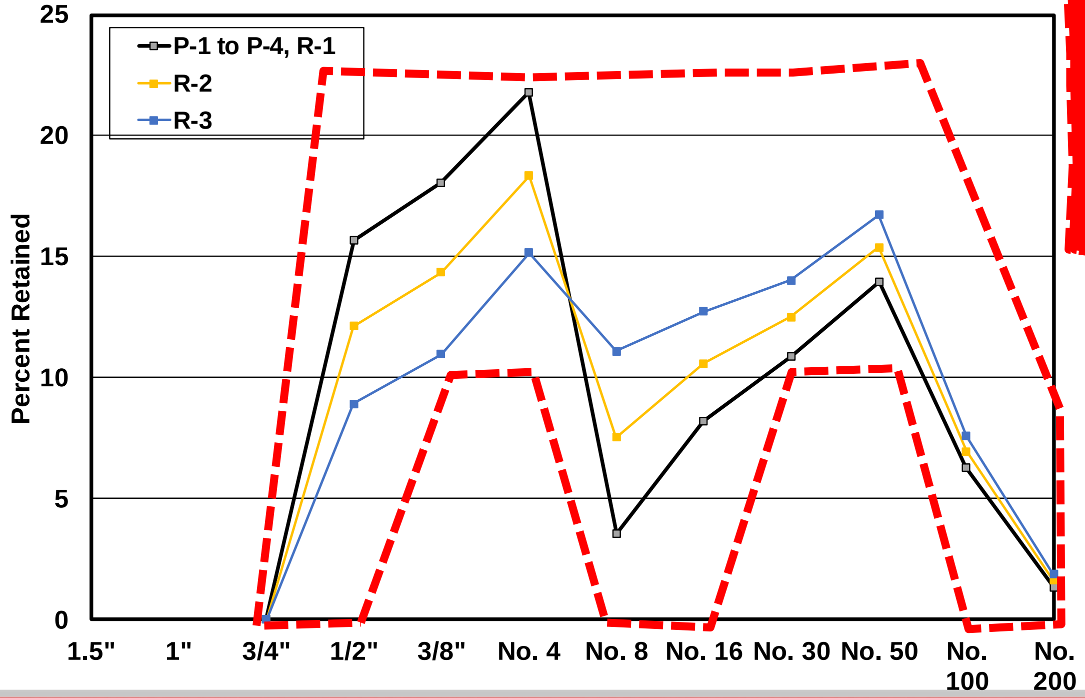
COMBINED AGGREGATE GRADATION - ACI 302



COMBINED AGGREGATE GRADATION - TARANTULA CURVE



COMBINED AGGREGATE GRADATION - ECO-SCC CURVE?



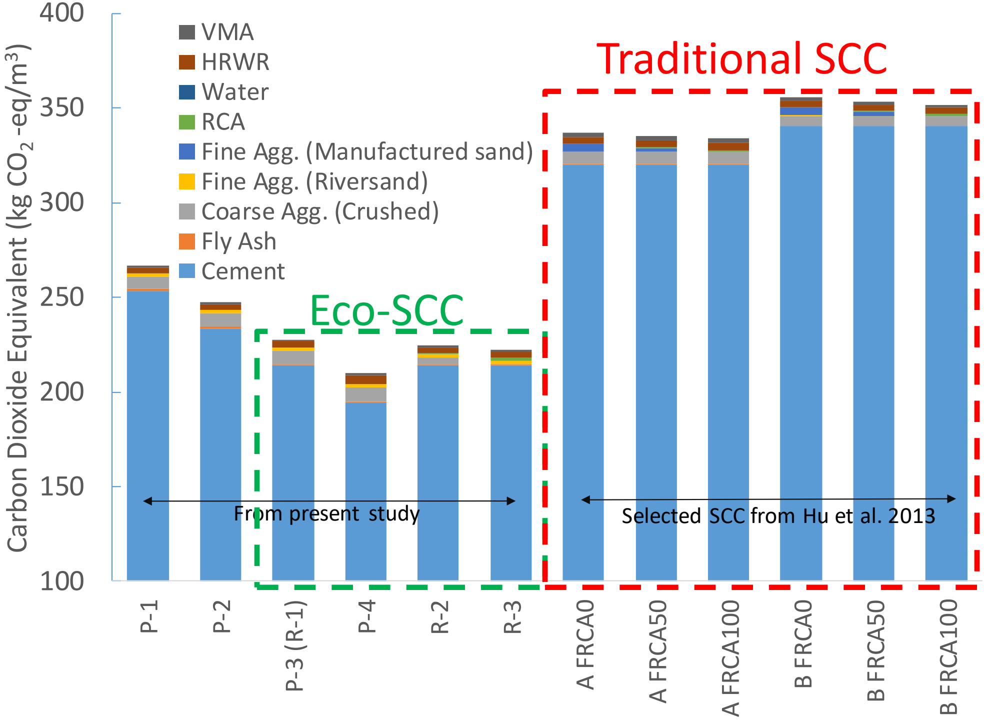
BASIC DATA FOR ENVIRONMENTAL PERFORMANCE EVALUATION

Constituent	Reference unit	GWP ($kg\ CO_2$-eq)
Cement	kg	0.8198
Fly Ash	kg	0.011
Coarse Agg. (Crushed)	kg	0.0068
Fine Agg. (Riversand)	kg	0.0023
Fine Agg. (Manufactured sand)	kg	0.0068
RCA	kg	0.0017
Water	kg	0
HRWR	kg	0.7721
VMA	kg	0.7721

PE Europe GmbH (Hrsg.): *Manual GaBi 6*. Leinfelden-Echterdingen, 2016.

S. Marinković, V. Radonjanin, M. Malešev, I. Ignjatović, Comparative Environmental Assessment of Natural and Recycled Aggregate Concrete, Waste Management, Vol. 30 (2010), pp. 2255-2264.

COMPARISON OF GLOBAL WARMING POTENTIAL INDEX OF ECO-SCC AND SCC



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CONCLUSIONS

- The developed Eco-SCC mixtures included in this study, including the two RCA provide concrete with good flowability, passing ability and stability and well satisfy criteria of SCC.
- The study demonstrated that it is possible to obtain Eco-SCC with lower cement content comparing to conventional SCC, through the optimization of aggregate gradation and the use of viscosity modifying agent.
- Global warming potential can also be reduced dramatically in Eco-SCC. A reduction of over 30% in CO2 equivalent compared with traditional SCC mixtures was calculated.
- Further study is needed to optimize mixture design and to study effect of cement content and VMA in SCC behaviour, both in fresh and hardened concrete stage.

FINAL REMARKS

Expected Changes in SCC Mix Design Due to Sustainability

- ✓ Decrease clinker dosage
- ✓ Use more crushed aggregate
- ✓ Use of recycled crushed demolished concrete

Eco-SCC for ready mixed concrete

a) Develop Eco-SCC and improve the performance and robustness of Eco-SCC through detailed evaluation of particle packing and concrete rheological performance;

b) Investigate the technical feasibility, cost effectiveness and sustainability of producing Eco-SCC for the RMC industry; and

c) Develop guidelines for mixture design of Eco-SCC for RMC producers.

Questions and Comments?

Jiong Hu
Department of Civil and Environmental Engineering
University of Nebraska-Lincoln
Email: jhu5@unl.edu

Nebraska Lincoln