minnesota concrete council
Dedicated to Cast-in-Place Concrete

Performance of Recycled Aggregate Concrete

Presented by Dan Vruno, P.E.
For the MCC Research Committee

Presentation Outline

I. History of MCC Research
II. History of Use of Recycled Aggregate Concrete
III. Current Research on Recycled Aggregate Concrete
IV. Recap

MCC Research

MCC Surface Popout Project
by John Amundson

MCC Optimum Durability Study

MCC Late Season Placement Study

MCC Recycled Aggregate Performance

History of Use

A. WWII
B. Minnesota Paving

Minnesota Paving

- Between 1983 and 1992, many pavements were placed with recycled aggregates in the State of Minnesota

Minnesota Paving

Back then the MnDOT pavement selection process looked at four different pavement types.

1. Full depth asphalt
2. Asphalt over aggregate base
3. Concrete with recycled aggregate
4. Concrete with virgin aggregate

Minnesota Paving

The MnDOT specification allowed only the ¾ to #4 to be used resulting in many recycled fines piled up at the locations of the pavers portable batch plants.

Minnesota Paving

Highway 59 north of Worthington
Others:
- I-90 Western Minnesota
- Highway 169
- Highway 60
- I-35 Owatonna to Lakeville
- I-94 North of Metro
- US-52 near Pine Island
- Highway 5 in Chanhassen

Minnesota Paving

After a decade of placing pavements with recycled concrete as coarse aggregate, the contractors pushed to be given the option of going back to the use of virgin aggregates.

Current Use

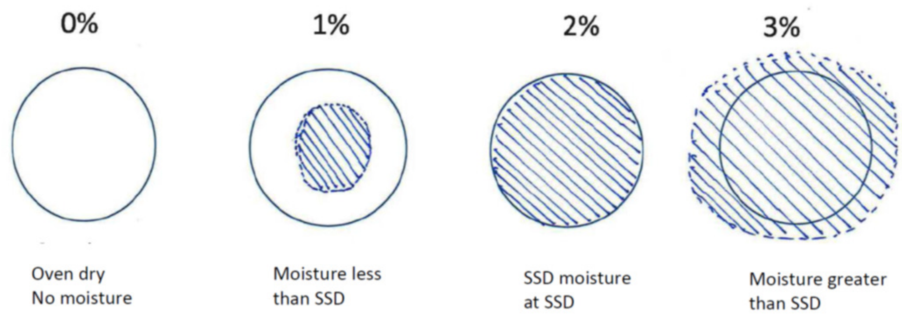
Currently, no pavements being placed in Minnesota are using recycled concrete as coarse aggregate.

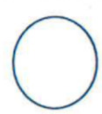
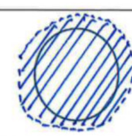
Current Use

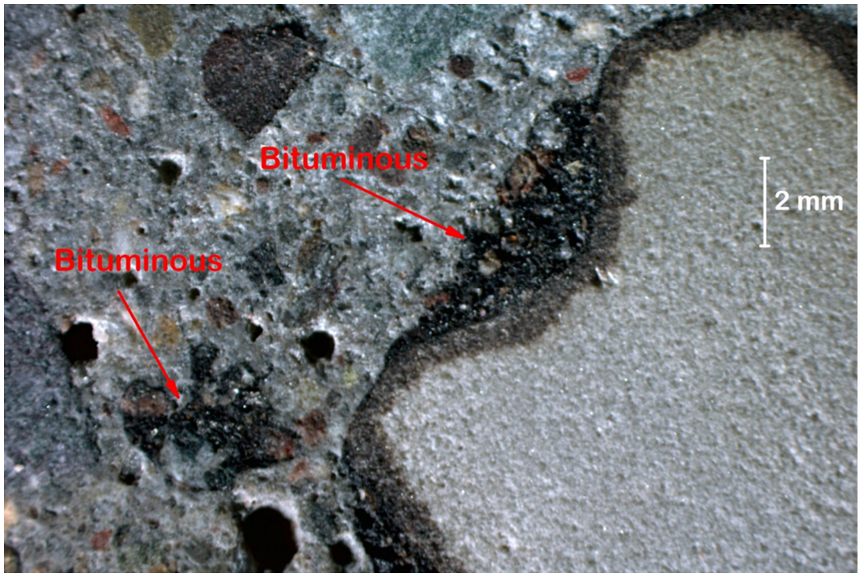
The use of 20% crushed coarse aggregate in structural concrete is now a practice accepted by codes in many European countries.

The two highest hurdles with regard to using recycled concrete as aggregate in concrete are:

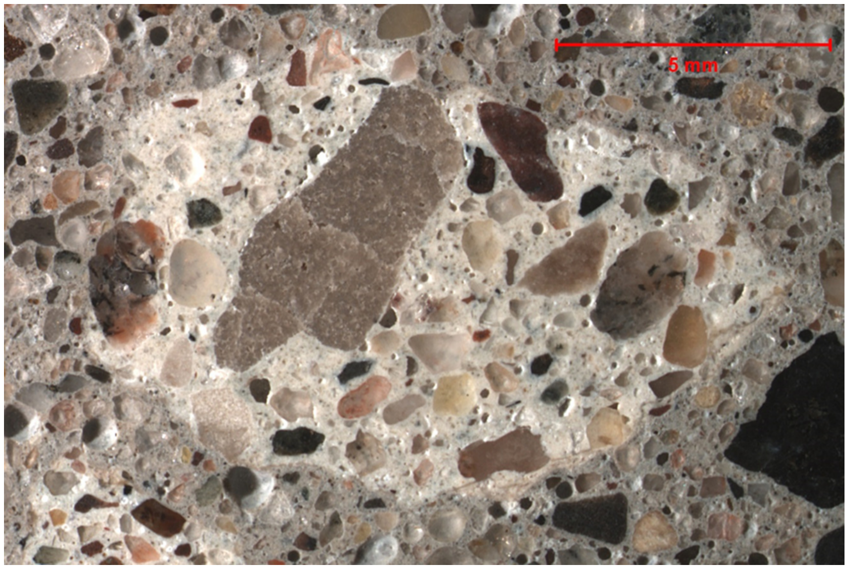
1. High absorption
2. Increased paste content



			OVEN DRY	SSD 2%	3%
					
Cement	水泥	(shray knee)	564	564	564
Sand	沙	(sha)	1,287	1,300	1,300
Stone	石	(shi)	1,765	1,800	1,818
Water	水	(shuī)	13+35+254	254	254-18 = 236



Countries like Japan have limits on contaminants allowed when recycled concrete is used as coarse aggregate.


5 mm


0.5 mm

Two types of recycled concrete are considered:

CCA is from concrete returned to the plant in the ready mix truck

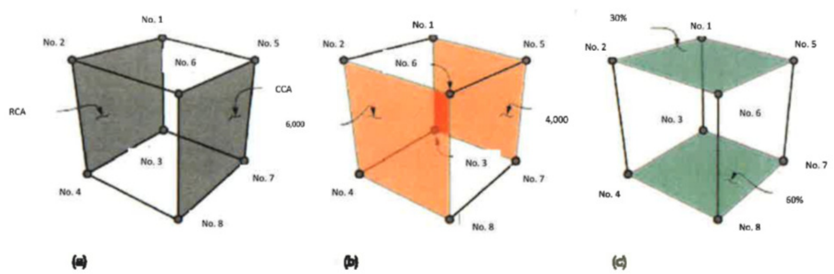
RCA is from demolished concrete after it's service life.

Independent Variables

The three (3) independent variables tested are:

1. Source of recycled coarse aggregate
2. Recycled aggregate replacement percentage
3. Design strength of concrete

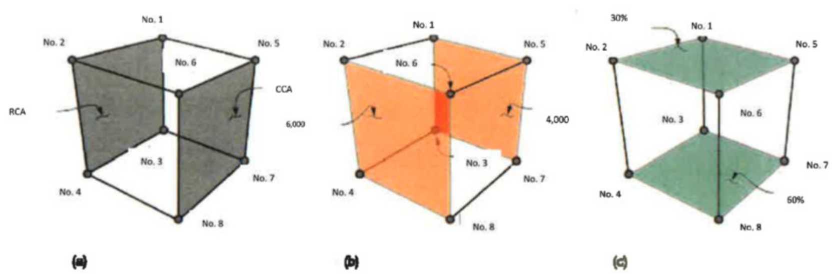
2^3 Factorial Design



Independent Variables for Performance of Recycled Aggregate Concrete

Factorial Points	Aggregate Source	Replacement Percentage	Design Strength (psi)
1	RCA	30%	4,000
2	RCA	30%	6,000
3	RCA	60%	4,000
4	RCA	60%	6,000
5	CCA	30%	4,000
6	CCA	30%	6,000
7	CCA	60%	4,000
8	CCA	60%	6,000
9	RCA	45%	4,000
10	RCA	45%	6,000
Control	–	0%	4,000
Control	–	0%	6,000

2^3 Factorial Design



Independent Variables for Performance of Recycled Aggregate Concrete

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6	CCA	30%	6,000
7	CCA	60%	4,000
8	CCA	60%	6,000
9	RCA	45%	4,000
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Control	–	0%	4,000
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Dependent Variables

There are a total of eight (8) dependent variables that were tested for each factorial point and controls. These are listed below with relevant testing standard.

#1 Slump

ASTM C143/C143/M-15, "Standard Test Method for Slump of Hydraulic Cement Concrete."

#2 Air Content

ASTM C231/C231M-14, "Standard Test Method for Air Content of Freshly Mix Concrete by the Pressure Method."

#3 Finishability

Subjective evaluation by three experienced finishers who applied a magnesium and wood float finish to a 24x24-inch test slab.

Finishing Scale

1. Very difficult
2. Difficult
3. Moderate
4. Easy
5. Very easy

#4 Setting Time

ASTM C403/C403M-08, "Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance."

#5 Shrinkage

ASTM C157/C157M-08 (2014), "Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete."

#6 Compressive Strength

ASTM C39/C39M-15, "Standard Test Method for Compression Strength of Cylindrical Concrete Specimens."

#7 Flexural Strength

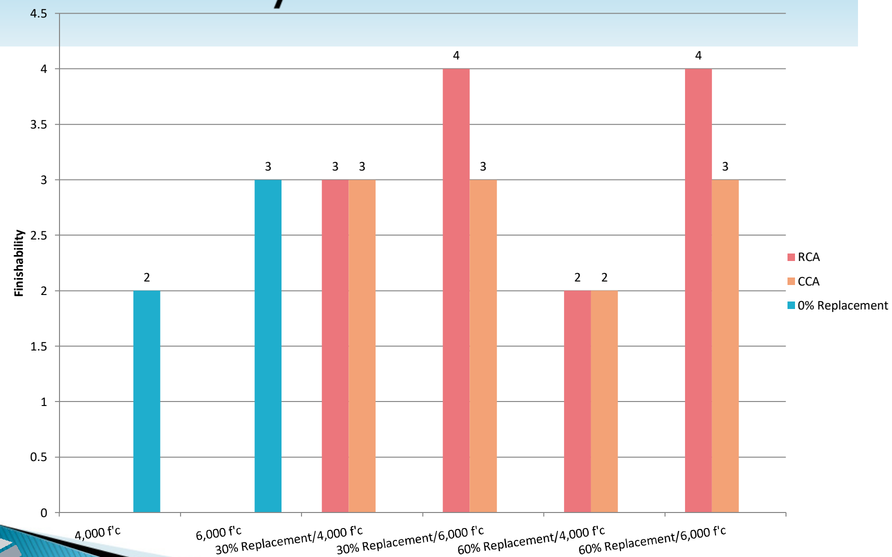
ASTM C78/C78M-15a, "Standard Test Method for Flexural Strength of Concrete (using Simple Beam with Third-Point Loading)."

Chloride Penetration (Wenner Probe Method) – AASHTO T358-15, "Standard Method of Test for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration."

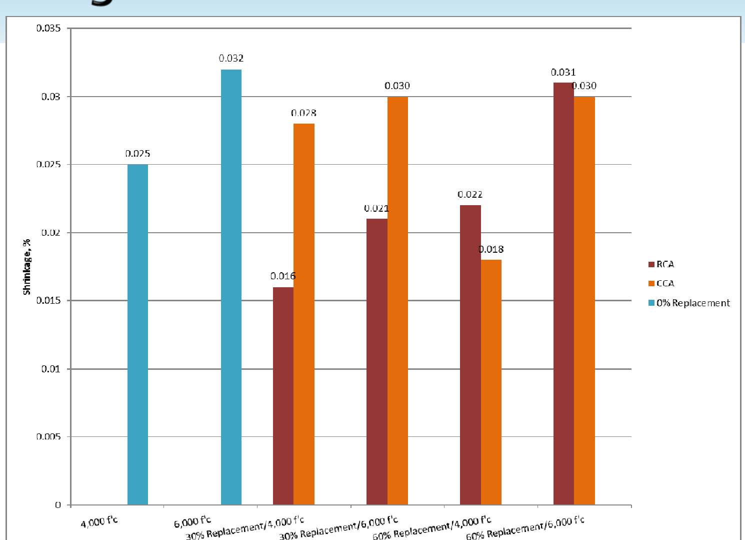
Surface Resistivity Test

Chloride Ion Penetration	4x8-in cylinder kΩ-cm
High	<12
Moderate	12-21
Low	21-37
Very low	37-254
Negligible	>254

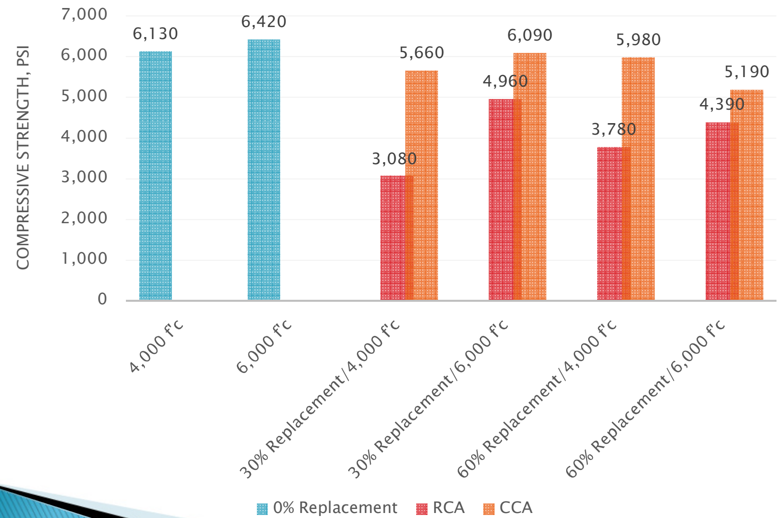
Finishability

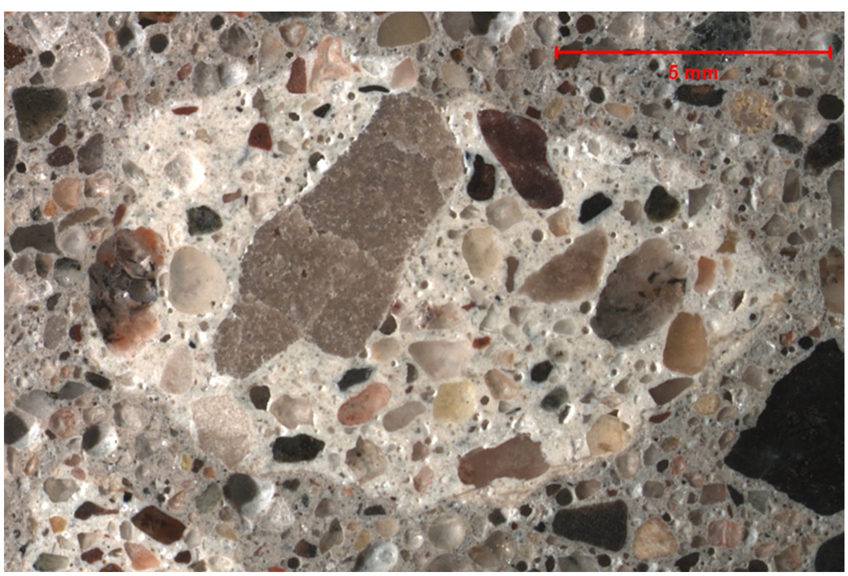


Shrinkage

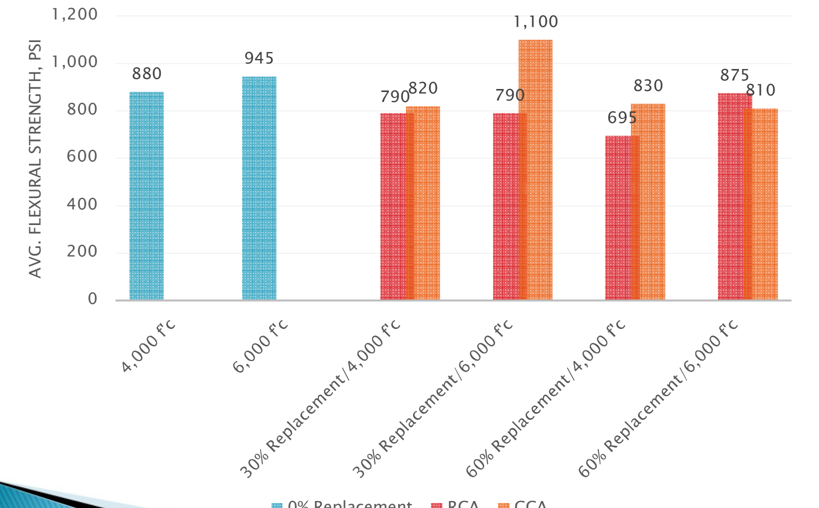


Compressive Strength @ 28 days

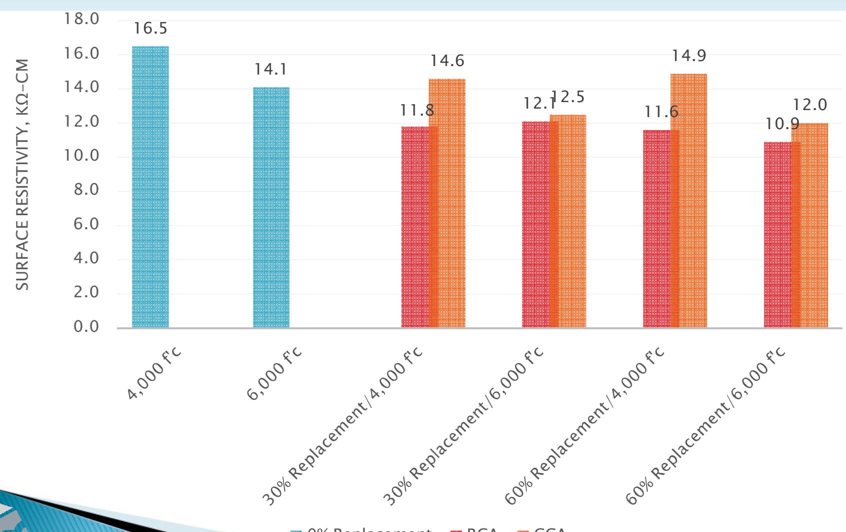




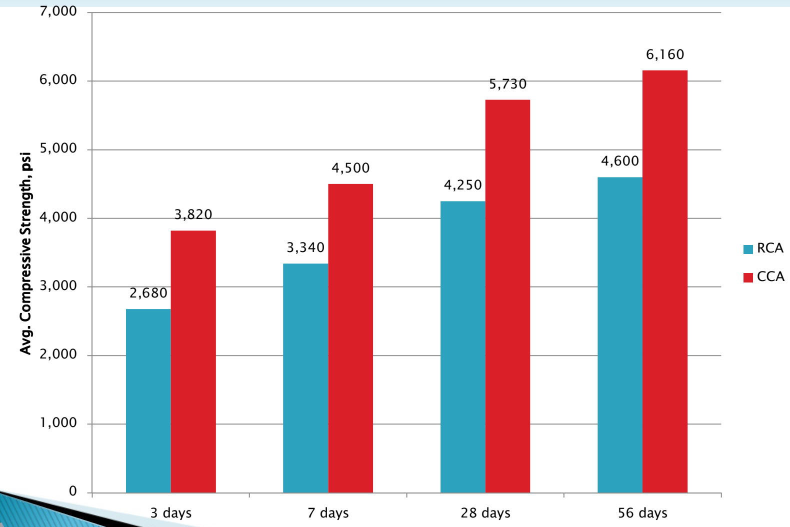
Flexural Strength @ 28 days



Surface Resistivity



Aggregate Type vs Compressive Strength



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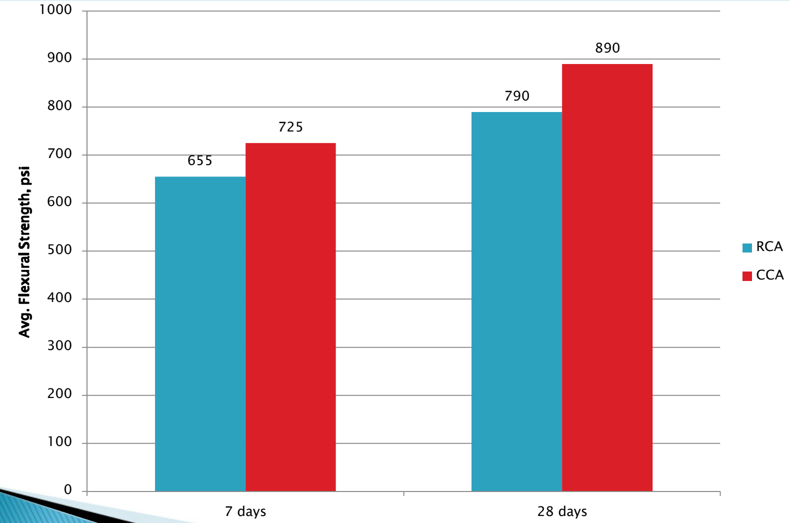
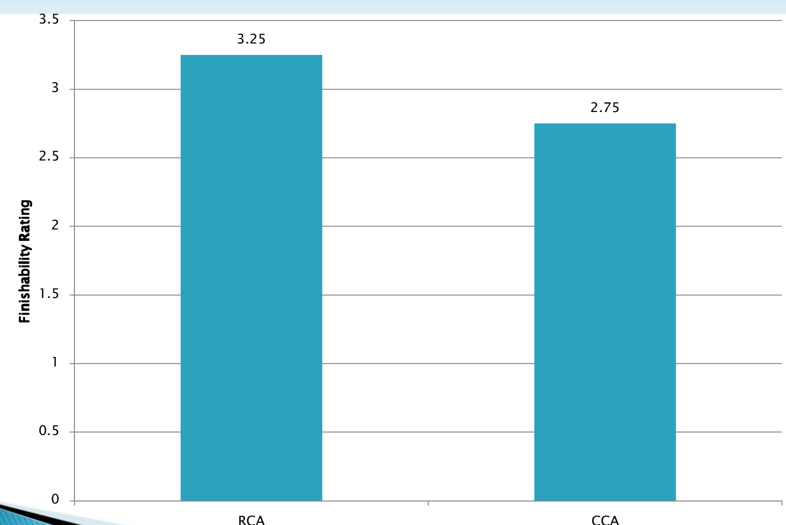
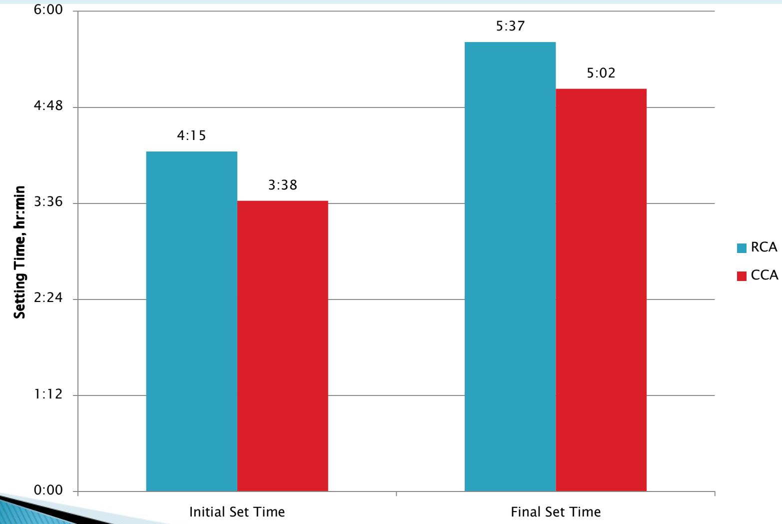
Aggregate Type vs Flexural Strength



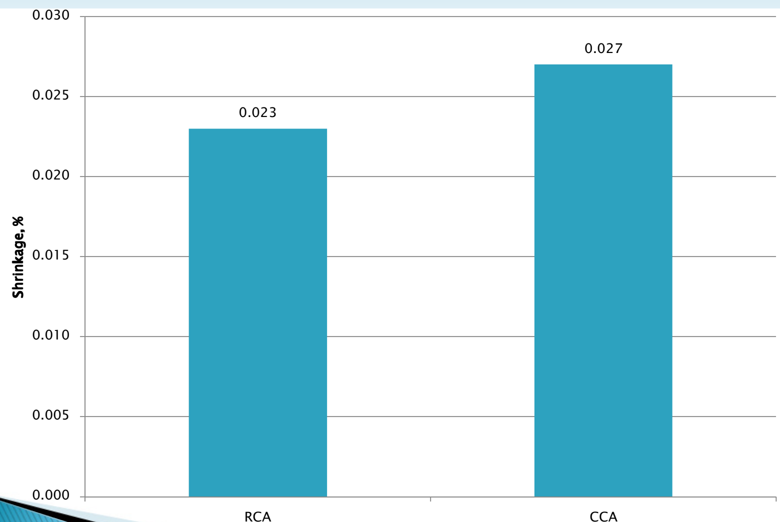
Aggregate Type vs Finishability



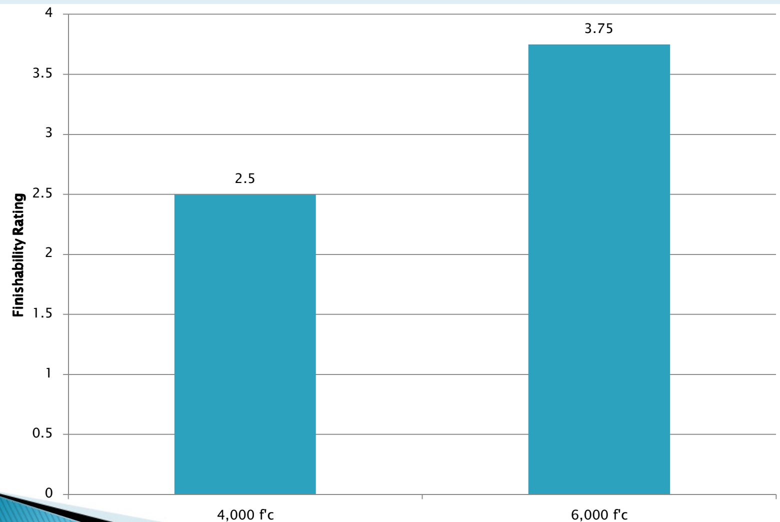
Aggregate Type vs Setting Time



Aggregate Type vs Shrinkage



Design Strength vs. Finishability



Recommendations

The two driving forces to use recycled concrete as aggregate replacement are:

- Cost of virgin aggregate
- Cost of transportation and disposal of CCA and RCA

Recommendations

The NRMCA recommends 10% replacement for structural concrete and 30% for non-structural.

RECAP

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II. History of Use of Recycled Aggregate Concrete
III. Current Research on Recycled Aggregate Concrete

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