

Research Objective

To Investigate mechanical properties of recycled and virgin concrete aggregates for use in rigid pavements

Secondary objectives are to investigate the:

- Effect of recycled coarse aggregate on concrete fracture and drying shrinkage properties
- Effect of synthetic fibers on recycled concrete aggregate concrete

Background

Recycling concrete is a viable option to decrease the use of natural resources and a way to limit the amount of construction waste disposal. Recycled materials such as concrete are typically used as unbound material layers in the base or subbase. However, there is no technical reason why recycled concrete cannot be used to construction concrete pavements. In fact, the state of Illinois has previously used recycled concrete in transportation projects. In 1986, the Illinois Department of Transportation (IDOT) used recycled concrete on two interstate construction projects. The first project was completed on a 4 mile stretch of I-57 near Effingham, Illinois. A 10-inch continuously reinforced concrete inlay with a widen lane was constructed. Approximately 80 percent of the aggregates used in the concrete surface were from recycled concrete. A second project also on I-57, south of Ullin, Illinois, used recycled concrete aggregates (RCA) for an asphalt concrete pavement inlay.

RCA Technical Issues

Decrease in strength and modulus

■Contributing factors are:

- Concrete mixture, blending percentage, water-cement ratio, RCA gradation

Greater moisture shrinkage potential (drying and autogeneous)

- Shrinkage may be same or reduced if RCA is presoaked to provide internal curing

Higher absorption capacity

- RCA 3% - 9%
- Virgin 1% - 2%

Lower bulk specific gravity

Workability can be reduced due to the greater absorption capacity

Virgin & Recycled Concrete Aggregate



This figure shows virgin aggregate (left) and RCA (right)

Methodology

The recycled concrete aggregate was sieved and meet IDOT CA-7 specifications

Sieve ID (in)	1 1/2	1	3/4	1/2	3/8	3/16
Cumulative Amount Passing (%)	100	96	68	33	20	0

The Bulk Specific Gravity and absorption capacity were determined

	BSG _{ssd}	Absorption Capacity
RCA	2.42	5.27%
Virgin	2.64	2.01%

Four different concrete mixtures were used. The first and second used virgin coarse aggregate with the addition of synthetic fibers to the second mix. The third and fourth used recycled concrete coarse aggregate with the addition of fibers in the fourth mix.

Virgin Coarse Aggregate Material	Plain Concrete	Synthetic Fiber Reinforced Concrete
Water	308 Lb/CY	308 Lb/CY
Type I Cement	607 Lb/CY	607 Lb/CY
Coarse aggregate	1645 Lb/CY	1645 Lb/CY
Fine aggregate	1360 Lb/CY	1360 Lb/CY
Synthetic Macrofibers	0 Lb/CY	3 Lb/CY

Recycled Coarse Aggregate Material	Plain Concrete	Synthetic Fiber Reinforced Concrete
Water	308 Lb/CY	308 Lb/CY
Type I Cement	607 Lb/CY	607 Lb/CY
Coarse aggregate	1508 Lb/CY	1508 Lb/CY
Fine aggregate	1360 Lb/CY	1360 Lb/CY
Synthetic Macrofibers	0 Lb/CY	3 Lb/CY

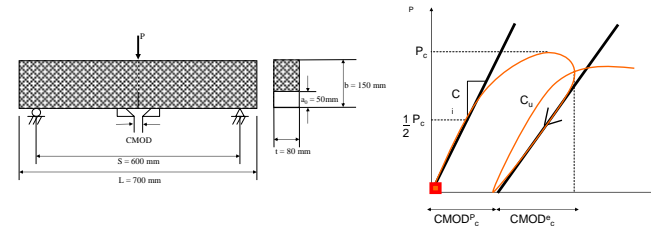


Compression and split tensile cylinders, drying shrinkage and three point bending samples were cast.



Experimental Procedure

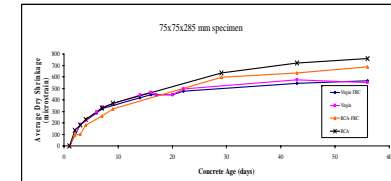
The compression and tensile split samples measured 8 inches in height and 4 inches in radius. The compression and split tension samples were tested in accordance to ASTM C39 and ASTM 496, respectively. ASTM 157-99 was used to test the drying shrinkage samples.



The figure on the top left is a schematic of the size of the beam that was used to test using the Two Parameter Fracture model. The dimensions are shown along with the locations of the load, pin, roller and the knife edges which are represented as trapezoids under the beam. An extensometer was placed on the knife edges so that it may measure the crack mouth open displacement (CMOD). The collected data was the used to plot a Load (P) vs. CMOD curve. The top right figure is a schematic representation of the first loop and beginning of the second loop of a P vs. CMOD curve. The P vs. CMOD plot was used to determine the peak load along with the loading and unloading compliances. These values were then used to determine the critical stress intensity factor (K_{IC}). The critical crack tip open displacement ($CTOD_c$) was calculated using reference [1]. The total fracture energy, G_F , was calculated as the area under the P vs CMOD curve [2].

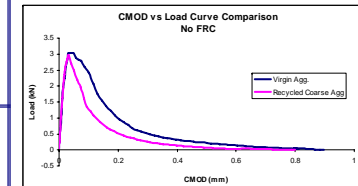
[1] Shah, S.P., Ouyang, C., Swatts, S.E., Fracture Mechanics of Concrete, John Wiley and Sons, New York, 1995
[2] Jenq, Y. and S.P. Shah, Two Parameter Model for Concrete, J. Engng Mech. 111 (10), 1227-1241, 1985

Results and Discussion (cont.) Drying Shrinkage



- Average of three samples from each concrete mixture
- After 14 days, free shrinkage of RCA samples became greater than virgin aggregate concrete

Plain Concrete

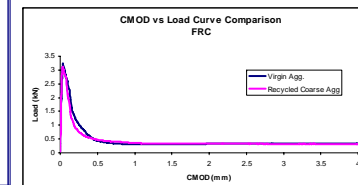


	Peak Load (kN)	E (GPa)	K_{IC} (MPa·m ^{1/2})	CTOD _c (mm)	G_F (N/m)	
VAC	Beam 1	2.92	27.2	0.87	0.015	78
	Beam 2	3.57	24.7	1	0.017	94
Average	3.25	26.0	0.94	0.016	86	
RCA	Beam 1	2.95	30.1	0.94	0.016	50
	Beam 2	3.01	25.8	0.88	0.016	62
Average	2.98	28.0	0.91	0.016	56	

- Similar peak load
- Virgin aggregate concrete fracture energy (G_F) is 1.5 times larger than G_F for RCA.



Fiber Reinforced Concrete



	Peak Load (kN)	E (GPa)	K_{IC} (MPa·m ^{1/2})	CTOD _c (mm)	G_F (N/m)	
VAC FRC	Beam 1	3.68	26.8	1.16	0.022	195
	Beam 2	3.00	25.2	1.03	0.024	174
Average	3.34	26	1.09	0.023	185	
RCA FRC	Beam 1	3.06	28.4	0.93	0.016	205
	Beam 2	3.20	28.0	0.96	0.016	158
Average	3.13	28.2	0.95	0.016	181	

- Similar peak loads
- Similar softening curves
- Similar G_F

Results and Discussion Compression and Split Tensile

	Compressive Strength (psi)	Tensile Strength (psi)
Virgin	4528	378
Virgin FRC	4396	425
RCA	4030	356
RCA FRC	3450	415

- Samples tested at 7 days
- Plain concrete had a higher compressive strength than RCA concrete

Conclusions

- RCAC has slightly lower strength and 40% less fracture energy
- Shrinkage of RCAC is greater at 28-days
 - w/o mix design adjustments
- Addition of FIBERS result in similar fracture behavior of RCAC and PCC