SCM = supplementary cementitious materials

SG = specific gravity

TM = total mortar

TABLES AND FIGURES

Table 1 - Acronyms used while the mix-design of RCA concrete using the EMV.

Acronyms	Description
NA	Natural aggregate
CC (or NAC)	Conventional Concrete (Natural aggregate concrete)
RCA	Recycled concrete aggregate
OVA	Original virgin aggregate
RM	Residual mortar
RMC	Residual mortar content
EMV	Equivalent mortar volume
RMC_{max}	Maximum residual content permitted in the RCA
V^{NAC}	Volume of a constituent within the CC
V_{NA}^{NAC}	Unit volume of NA within the CC
V_{OVA}^{RCA}	Unit volume of OVA within the RCA
V_{NA}^{RCA}	Volume of new aggregate in the RCA mix
V_{RM}^{RCA}	Volume of residual mortar in the RCA
V_{NM}^{RCA}	Volume of new mortar in the RCA

Table 2 - Average physical properties of fine and coarse aggregates [3,43–45].

Aggregate	Moisture Content (%)	Absorption Content (%)	Specific Gravity			RMC (%)
			Bulk	SSD	Apparent	
RCA-M	1.10	5.40	2.31	2.42	2.64	41.0
RCA-V	1.30	3.30	2.42	2.50	2.64	23.0
Limestone	0.20	0.34	2.70	2.71	2.73	-
River Gravel	0.20	0.89	2.72	2.74	2.79	-
River Sand	4.00	0.54	2.70	2.72	2.76	-
RT	-	3.13	2.39	-	-	25.3
RU	-	3.43	2.36	-	-	41.0
NA	-	0.58	-	-	-	-
FA	-	0.50	-	-	-	-
RCA QG 25	0.85	4.45	2.45	-	-	34.3
RCA QG 35	1.20	5.17	2.42	-	-	39.6
RCA QG 45	1.00	4.23	2.47	-	-	36.9
RCA CL 25	0.97	5.40	2.40	-	-	40.0
RCA CL 35	1.10	5.09	2.41	-	-	45.6
RCA CL 45	1.30	4.88	2.43	-	-	52.1
Natural FA	-	0.91	2.60	-	-	-

Table 3 - Proportions of Mixes used by [3,43–45] for Conventional Mix Design, DR, EMV, EMV-mod and EV Methods.

Mix-ID	RCA (%)	Water (kg)	Cement (kg)	Fly Ash (kg)	BFS (kg)	Sand (kg)	RCA (kg)	NA (kg)	WRA (mL/m^3)	AE (mL/m^3)	A.Cont (%)
CM-C	100	156	349	-	-	888	792	-	1,396	35	6.9
CM-F	100	157	262	87	-	888	792	-	-	209	7.4
CM-B	100	155	227	-	122	888	792	-	523	35	6.0
EM-C	63.5	151	335	-	-	630	720	414	1,005	33	6.0
EM-F	63.5	151	251	84	-	630	720	414	606	201	5.7
EM-B	63.5	149	218	-	117	630	720	414	1,339	33	5.7
CL-C	-	193	430	-	-	808	-	833	-	86	6.3
CV-C	100	156	349	-	-	857	867	-	1,047	35	7.4
CV-F	100	157	262	87	-	857	867	-	-	209	6.0
CV-B	100	155	227	-	122	857	867	-	1,047	35	7.1
EV-C	74.3	161	358	-	-	645	813	281	1,075	36	6.0
EV-F	74.3	161	269	90	-	645	813	281	-	215	5.5
EV-B	74.3	160	233	-	125	645	813	281	1,792	36	6.8
CG-C	-	191	424	-	-	765	-	898	-	85	6.3
Mix designation nomenclature - E or C: mix proportioned based on EMV (E) or conventional method (C); M, V, L, or G: mix made with RCA-M (M), RCA-VA (V), natural limestone (L), or natural gravel (G); and C, F, or B: mix made with ordinary portland cement only (C),cement plus fly ash (F), or cement plus bfs (B).											
NA-25	-	192	314	-	-	790	-	1029	-	-	2.1-1.4
RU-25	50	135	220	-	-	555	887	515	-	-	2.0-3.0
RT-25	50	162	264	-	-	665	697	509	-	-	1.8-2.1
RU-25A	81	99	162	-	-	405	1440	193	-	-	12.5
RU-25B	81	134	219	-	-	405	1440	193	-	-	3.7
RT-25	100	132	215	-	-	542	1380	-	-	-	2.9-5.5
NA-35	-	174	370	-	-	790	-	1029	-	-	1.6-1.0
RU-35	50	122	260	-	-	555	887	515	-	-	x-5.1
RT-35	50	147	312	-	-	666	690	515	-	-	6.0-2.4
RU-35A	81	90	191	-	-	408	1440	193	-	-	6.1
RU-35B	81	118	250	-	-	408	1440	193	-	-	7.2
RT-35	100	119	254	-	-	542	1380	-	-	-	4.5-x
RTO-35A	100	125	277	-	-	614	1416	-	-	-	-
RTO-35B	100	191	322	-	-	521	1416	-	-	-	-
NA2-35	-	180	400	-	-	723	-	1056	-	-	-
RTM-35	100	135	322	-	-	547	1416	-	-	-	-
Mix designation nomenclature -Naming convention for batches is as follows: (Aggregate Source)-(Target Strength)(Batch Letter).											
RCA QG 25	100	153	341	-	-	695	1179	-	-	-	less than 2 for all mixes
RCA QG 35	100	149	332	-	-	691	1200	-	-	-	

Table 3 - Continued

RCA QG 45	100	151	336	-	-	693	1189	-	-	-
QG 35	-	192	370	-	-	730	-	1024	-	-
RCA CL 25	100	149	330	-	-	693	1200	-	-	-
RCA CL 35	100	145	321	-	-	686	1223	-	-	-
RCA CL 45	100	139	309	-	-	685	1247	-	-	-
CL 35	-	187	370	-	-	782	-	1024	-	-

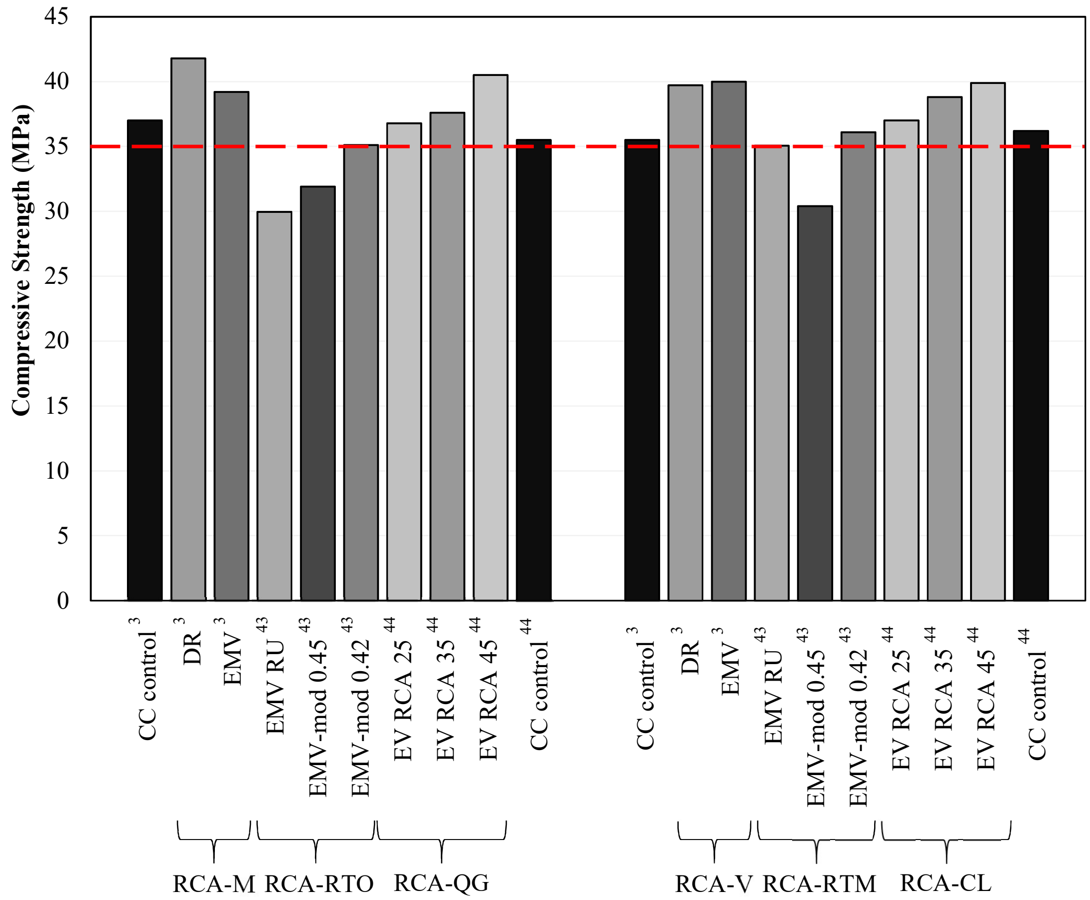
Mix designation nomenclature – type of aggregate – composition of the RCA aggregate (made with Quartzite Gravel or Crushed Limestone, and 3 different strengths, 25, 35 and 45 MPa)

Note: 1 lb = 0.45 kg; 1 fl. oz/yd^3 = 38.67 mL/m^3.

Table 4 - Effect of mixes proportioning methods on the slump test [3,43–45]

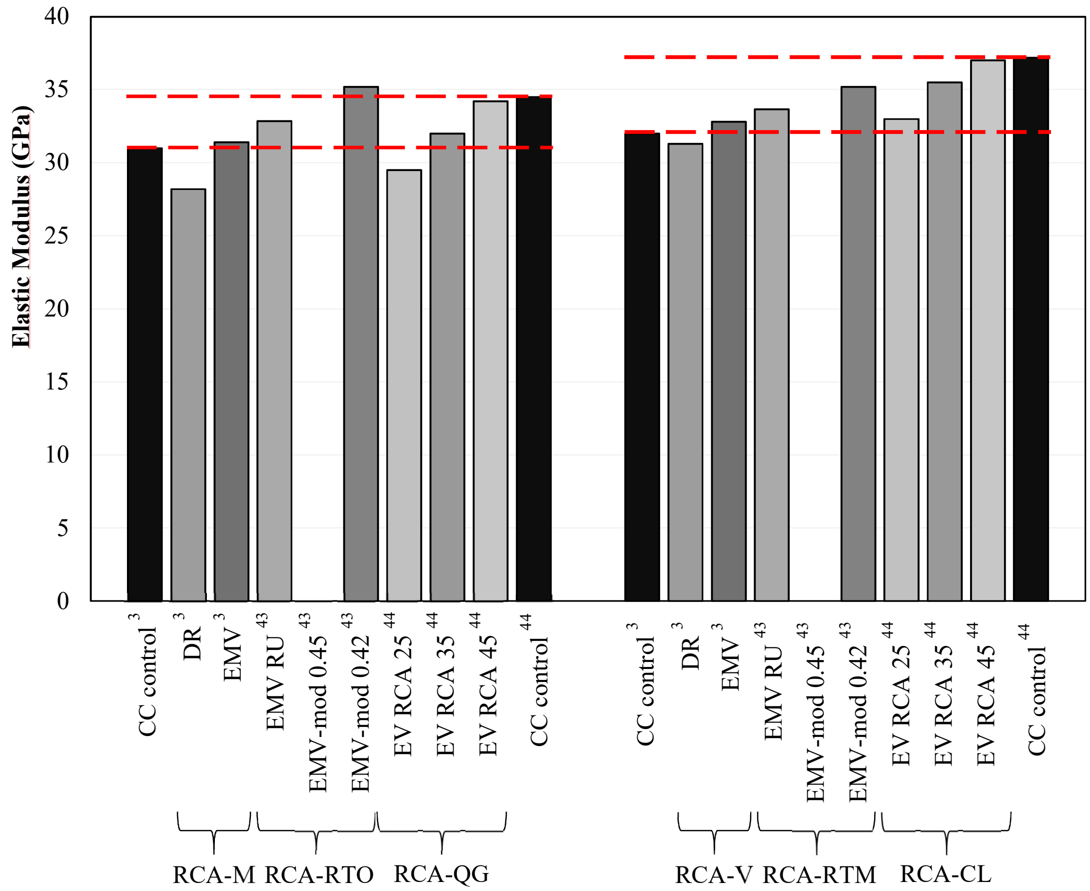
Mix-ID	Slump (cm)	Mix-ID	Slump (cm)	Mix-ID	Slump (cm)
CM-C	7,0	NA-25A	19,0	RCA QG 25	
CM-F	13,0	NA-25B	19,5	RCA QG 35	5.0 for all mixes
CM-B	5,5	RU-25A	4,5	RCA QG 45	
EM-C	10,5	RU-25B	3,0	QG 35	9.0
EM-F	12,0	RT-25A	13,5	RCA CL 25	
EM-B	8,0	RT-25B	11,0	RCA CL 35	5.0 for all mixes
CL-C	17,0	RU-25A	-	RCA CL 45	
CV-C	7,0	RU-25B	-	CL 35	9.0
CV-F	9,5	RT-25A	2,0		
CV-B	11,0	RT-25B	1,5		
EV-C	14,0	NA-35A	9,0		
EV-F	14,0	NA-35B	8,5		
EV-B	15,0	RU-35A	1,0		
CG-C	21,0	RU-35B	-		
		RT-35A	2,5		
		RT-35B	2,0		
		RU-35A	-		
		RU-35B	1,0		
		RT-35A	-		
		RT-35B	-		
		RTO-35A	1,0		
		RTO-35B	1,0		
		NA2-35	-		
		RTM-35A	-		
		RTM-35B	-		

Note: 1 in = 2.54 cm.



Note: 1 ksi = 6.89 MPa.

Figure 1 - Effect of mixes proportioning methods on the compressive strength results [3,43–45].



Note: 1 ksi = 6,890 GPa.

Figure 2 - Effect of mixes proportioning methods on the elastic modulus results [3,43–45].

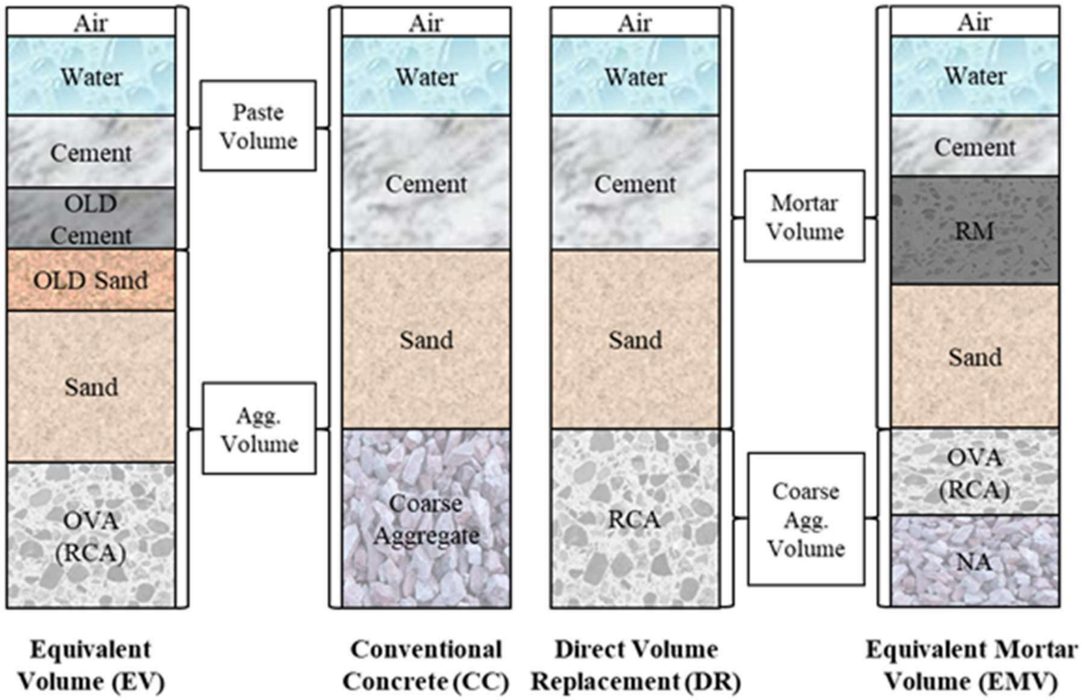


Figure 3 - Volumetric material volumes of RCA mixtures designed with EMV and EV methods when compared to their initial CC mixes [3,43–45].

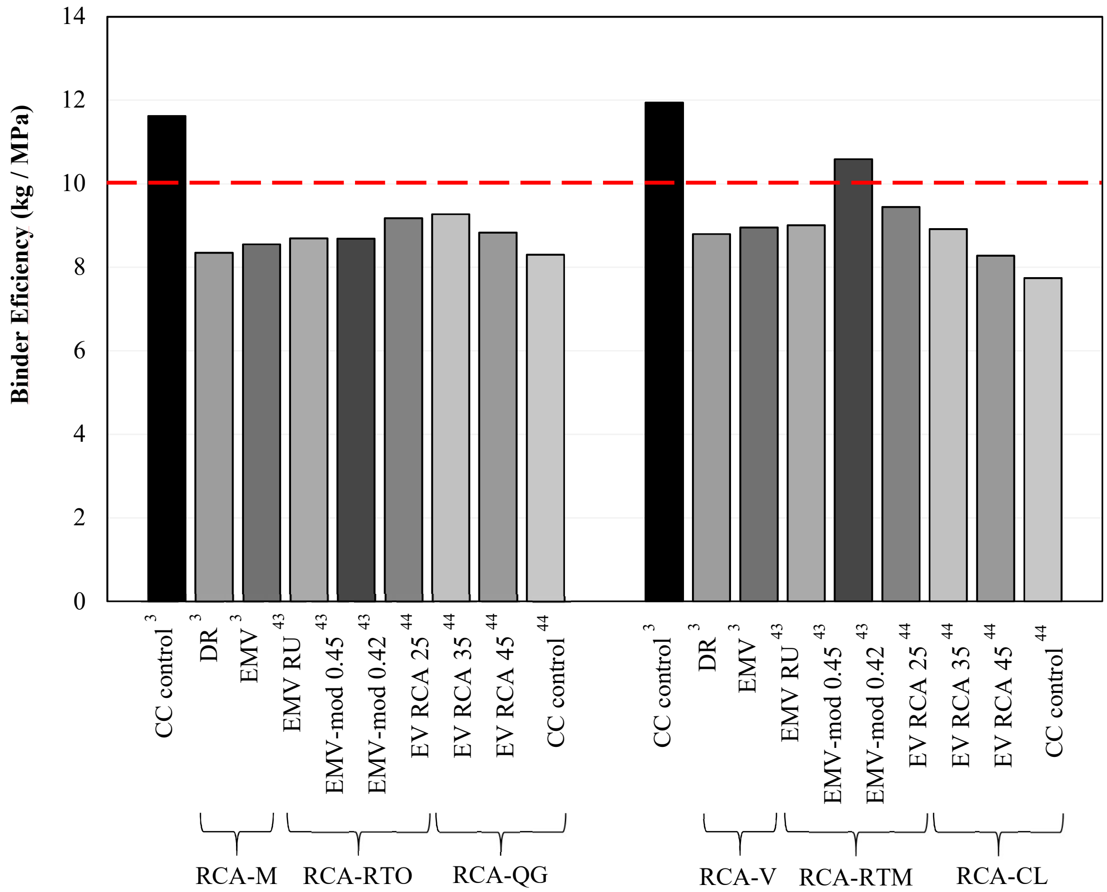


Figure 4 - Effect of mixes proportioning methods on the binder intensity.

Properties of Fly Ash-Based Geopolymer Mortars

A.M. Said, O. Saleh and A. Ayad

Synopsis: There is a growing need for alternative binders with smaller carbon footprint. The cement manufacture is an energy intensive process that is one of the major global contributors to carbon dioxide emission. Fly ash-based geopolymer binders represent one of these potential alternatives. Beside consuming a largely produced byproduct, fly ash-based geopolymers generally have better mechanical performance when exposed to elevated temperatures. This study evaluates the effect of the initial curing temperature and the alkaline activation solution proportions on the strength, pores structure and crystal structure of fly ash-based geopolymer mortars. The geopolymer was synthesized using Class F fly ash, potassium hydroxide solution and sodium silicate solution. The specimens were made using various ratios of sodium silicate to potassium hydroxide and were initially cured at different temperatures and their properties were studied in terms of mechanical and microstructural properties.

Keywords: Geopolymer; High temperature; Compressive strength; Alkali activated binder; Fly ash.

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INTRODUCTION

Although the use of ordinary portland cement (OPC) as the primary binder in concrete is convenient, it is well known that the production of OPC is associated with a significant emission of carbon dioxide through fuel burning and calcination. Previous studies reported that the production of one ton of OPC releases one ton of carbon dioxide [1]. Hence, the search for environmentally friendly alternatives became the target of several studies. Alkali-activation was discovered in the 1940's as a successful technique for enhancing the pozzolanic properties of calcium-rich aluminosilicate minerals [2]. Using similar concept, a new material called geopolymer was introduced by professor Joseph Davidovits in 1978 [3]. Geopolymer is known for its excellent mechanical properties, as well as its chemical and fire resistant [4]. Geopolymers can be used as cement for concrete and mortar, material for coating and adhesives, binder for fiber composites and waste encapsulation [5].

Geopolymers can be synthesized by reacting material rich in aluminum (Al) and silicon (Si) with high alkaline solution. Previous studies used various pozzolans (e.g. slag, fly ash, metakaolin, natural pozzolans, etc.) were considered as a source of Al and Si to synthesize the geopolymer [6]. The alkaline solution, in most cases, is a combination of alkaline silicate solution and alkali hydroxide solution. The polymerization is a fast reaction and the required curing period is within 48 hours. Although the geopolymer could be cured at ambient temperatures, higher curing temperatures (up to 90°C) enhance the polymerization and improve the compressive strength of the final product [7].

Fly ash is a byproduct of coal-burning power plants. In 2010, the United States generated 68 million tons of fly ash [8]. Although fly ash can be used in concrete, blended cement, and several other applications, a huge amount of the generated fly ash – more than 62% in 2010 – is accumulated as a waste material. A combination of silicon dioxide, aluminum oxide, and iron oxide should make at least 70% of the chemical composition of Class F fly ash [9]. Accordingly, many studies identified Class F fly ash as an ideal byproduct to synthesize geopolymer [1, 4, 7, 10-32].