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The utilization of recycled concrete aggregate to produce controlled low-strength materials without using Portland cement

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ABSTRACT

This paper reports the results of an experimental study that investigated the feasibility of using fine and coarse recycled concrete aggregate (RCA) with slag or fly ash to produce Controlled Low-Strength Materials (CLSM). The main objective was to produce CLSM using only recycled and by-product materials without the need to add Portland cement. In addition to the hydraulic activity of slag and high-calcium fly ash (HCFA), their pozzolanic reaction was activated by the alkalis and calcium hydroxide present in the residual paste of the RCA. Preliminary tests showed mixtures with slag to have 7-day compressive strengths 70% higher than mixtures with fly ash.

Two types of CLSM with slag were investigated in further detail: one with fine and the other with fine/coarse RCA. The results showed that the developed CLSMs are suitable for a wide range of applications particularly those requiring structural support and fast hardening.

1. Introduction

The concept of sustainable development in construction has been gaining increasing attention at the present time [1]. The most immediate and obvious way to achieve more sustainable construction is by conserving new raw materials such as natural aggregates, and reusing construction and industrial wastes. Recycled concrete aggregate (RCA) is an example of a common construction waste that is produced from demolishing concrete structures as they approach the end of their service life. Supplementary cementing materials (SCM) such as fly ash and slag are industrial by-products, which have a long history of use with Portland cement (PC) in concrete. This paper presents the results of a study that investigated the feasibility of using RCA and SCM, without the use of PC, to produce Controlled Low-Strength Materials (CLSM) for different applications.

Generally, concrete accounts for nearly 75% by weight of all construction materials [2]. Construction and demolition waste in Canada amounts to 15–20% of all landfill materials [3]. By finding new applications for waste concrete and creating a market for its use, we can bypass the need to consume virgin natural aggregate and simultaneously conserve landfill space. Until now, RCA has primarily been used as granular base in road works or in conjunction with natural aggregate in concrete applications. In terms of using RCA in structural concrete, research has shown that the use of 30% RCA and 70% natural aggregate in high strength concrete produces concrete of similar strength as that containing only natural aggregates [4]. However, concrete mixtures made with laboratory crushed RCA as the only source of aggregate show a strength reduction of 10% when compared to conventional concrete [5]. For some types of commercially crushed RCA, research has shown negligible variation from concrete made from virgin materials in terms of compressive and tensile strength [6]. However, drying shrinkage is of concern when using RCA in concrete. New concrete made with RCA experiences creep and drying shrinkage that is 10–30% greater than that of concrete made from natural aggregate [2]. The high porosity of RCA increases drying shrinkage [6] and creep especially when fine RCA is used [7,8]. In addition, RCA generally has a lower elastic modulus than natural aggregate, which also contributes to drying shrinkage and creep.

Fine RCA has been found to have limited use in structural concrete as it is angular and coarser than natural aggregate [7] which affects the workability and ease of finishing. In addition, fine RCA was found to reduce the resistance to freezing and thawing [7,9] and sulphate attack when used with PC of 10.1% C_3A [10]. Research showed substantial improvement in the properties of concrete containing RCA when the fine portion was replaced by natural sand [7,11]; other research work suggested limiting the fine RCA content in concrete to 30% [12] or 50% [13] of the fine aggregate content in the mix.

From the sustainability standpoint, and based on the above review, it is important to develop more construction materials that incorporate RCA. This is of special importance for fine RCA and low-quality coarse RCA, which have limited use in structural concrete. Finding more uses of RCA helps reduce its disposal in

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landfills and conserves the consumption of natural aggregates. One of the possible construction materials where RCA can be utilized is CLSM.

CLSMs are construction materials that consolidate under their own weight making them ideal substitutes for compacted soil [14]. Unlike soil, CLSMs do not settle once they are hardened. CLSMs can be used in a variety of applications including backfills, structural fills, pavement bases, conduit beddings and void fillings [14]. Materials used in the production of CLSM are usually the same as those used in traditional concrete; however, the mix proportion is different as the strength of CLSM is much less than that of traditional concrete. CLSMs can also incorporate supplementary cementing materials such as high-calcium fly ash (HCFA) [15,16] and co-generated products such as cement kiln dust [17,18]. The strength of CLSMs varies depending on the application. For backfills with possible future excavation such as some utility fills, the 28-day strength should not exceed 2.1 MPa [14]. For road bases and structural fills, such as foundation support above weak or uneven soil, the required compressive strength can reach 8.3 MPa [14]. The flowability of CLSM can be measured using the traditional slump cone test (ASTM C 143) or slump flow test as per ASTM D 6103, as will be described under the Materials and Experimental Work subsection. CLSM is required to have a slump flow of at least 200 mm without segregation using the ASTM D 6103 or a slump value of at least 150 mm using ASTM C 143 [14]. Although CLSM is not usually designed to resist freezing/thawing or wetting/drying, it is recommended to design CLSM to withstand these conditions, if the material is intended for use as road bases [14]. The hardening time of CLSM is measured using the penetration test as per ASTM C 403 [14] or the Ball Drop Test as per ASTM D 6024 [19].

This paper aims at utilizing RCA and SCM's, with emphasis on slag, to produce sustainable CLSM without PC. The sustainability of such materials is achieved by using only recycled and industrial waste materials. An important contributor to the sustainability is that the developed material incorporates RCA that has limited applications in structural concrete such as fine RCA and low-strength coarse RCA. The idea is to make use of the available alkalis and calcium hydroxide from the residual pastes in the RCA to fuel the pozzolanic reaction of the slag and fly ash (HCFA in this study). This pozzolanic reaction coupled with some hydraulic activities of slag and HCFA are believed to help in hardening and strength development of the CLSM. The developed CLSM are designed to have a wide range of applications as follows:

1. CLSM containing fine RCA for use in trench backfilling, and conduit bedding. This is specifically applicable to trenches that are narrow with some congested areas or conduits with small spacing. CLSM with fine RCA is also useful in situations where future excavation is expected, such as utility fills, as the lack of coarse aggregates facilitates the digging operations [14].
2. CLSM containing fine/coarse RCA for use in road bases and structural fills. This material is expected to have higher strength and shorter hardening time compared to CLSM with fine RCA.

2. Materials and experimental work

Two types of RCA were investigated in this study: (a) fine RCA with nominal maximum size of 10 mm and (b) coarse/fine RCA with nominal maximum size of 28 mm. The gradation curves for both types are shown in Fig. 1. The slag used in this study was slag 80 with the chemical composition listed in Table 1. HCFA was tested with fine RCA but only for cube compressive strength to obtain a comparison between slag and HCFA in terms of strength development. The rest of the experimental program was conducted on CLSM containing slag.

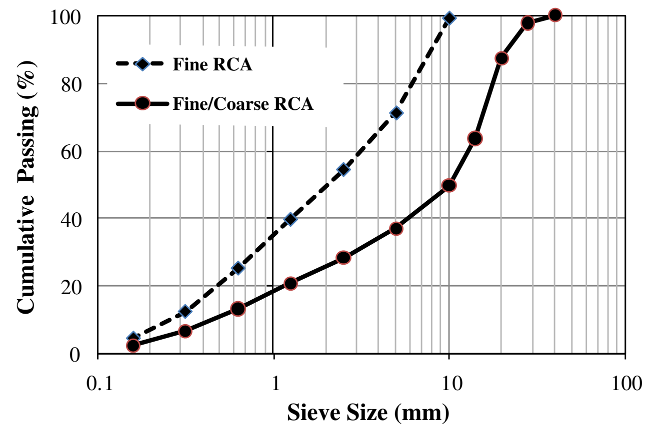

Fig. 1. Grain size distribution of the fine and fine/coarse RCA.

Table 1
Chemical composition of the fly ash and slag.

Sample	CaO (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	SO_3 (%)	K_2O (%)	Na_2O (%)	TiO_2 (%)
Slag	43.20	34.40	7.40	0.94	9.30	0.83	0.58	0.57	0.44
Fly ash	31.81	32.42	16.92	5.80	5.81	2.11	0.57	1.62	1.34

To evaluate the amount of alkalis contributed form RCA to the CLSM mixtures, a sample of RCA particles in the size range between 9.5 and 12.5 mm was soaked in distilled water at a solid-to-water ratio of 1:10. After 28 days, the water was analyzed and the concentrations of alkali cations (Na^+ and K^+) were determined using Induction-Coupled Plasma (ICP). The alkalis released from the RCA to the water were then calculated as a percentage Na_2O_e (equivalent sodium oxide) per dry mass of RCA.

A preliminary study was conducted on slag and HCFA samples to investigate the strength development when each of them was used with fine RCA. Fine RCA passing 5 mm sieve was mixed with slag or HCFA at different levels expressed as % of RCA mass. The water content was adjusted to obtain mixtures of similar workability as determined by visual examination. Table 2 lists the mix proportion as well as the flow obtained for each mix using the flow table as per ASTM C230. The cube samples were tested for compressive strength at the ages of 3 and 7 days as listed in Table 2. In addition, cube samples were also prepared and tested without SCM (only fine RCA and water). These cubes were tested to evaluate the strength resulting from the hydration of unreacted cement in the RCA.

A detailed study was then conducted on CLSM with slag and fine or fine/coarse RCA. The CLSM mixtures containing fine RCA were prepared using slag contents of 5%, 10%, 20% and 30% expressed as a percentage of dry mass of RCA. The levels of slag tested

Table 2
Properties of fine RCA/SCM mortar samples.

Slag					Fly ash				
Slag (%)	w/b	Flow (mm)	Strength (MPa)		Fly ash (%)	w/b	Flow (mm)	Strength (MPa)	
			3-day	7-day				3-day	7-day
5	3.00	118	0.70	0.55	5	2.65	120	0.36	0.20
10	1.63	165	1.44	2.10	10	1.25	119	0.81	0.56
15	1.00	135	3.08	4.98	15	0.83	132	0.93	0.74
20	0.75	152	4.67	5.84	20	0.63	108	1.21	1.54
30	0.54	135	5.21	6.54	30	0.50	141	1.17	1.77