Effect of recycled crushed concrete fines on density, slump, strength and accelerated shrinkage of concrete

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ABSTRACT
This paper discusses the effect of recycled crushed concrete fines (RCCF) with particle sizes less than 75 μm on concrete properties. Specifically, the effect of RCCF at 10% and 20% by mass of cement on the density, slump, compressive strength and accelerated drying shrinkage of laboratory-made concrete mixes was investigated. The mixes were cast with a fixed water:binder ratio of 0.50. The incorporation of RCCF reduced strength, density, slump and accelerated drying shrinkage. There was no statistically significant difference in the magnitude of accelerated drying shrinkage across the specimens with RCCF. Generally, the performance of the mix cast using 20% RCCF was significantly lower than the control mix. The incorporation of 10% RCCF, in comparison with the control mix, did not result in a significant reduction in density, compressive strength and accelerated shrinkage.

Keywords: recycled crushed concrete fines, construction and demolition waste, concrete, cement replacement.

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This paper discusses the effect of recycled crushed concrete fines (RCCF) with particle sizes less than 75 μm on concrete properties. Specifically, the effect of RCCF at 10% and 20% by mass of cement on the density, slump, compressive strength and accelerated drying shrinkage of laboratory-made concrete mixes was investigated. The mixes were cast with a fixed water:binder ratio of 0.50. The incorporation of RCCF reduced strength, density, slump and accelerated drying shrinkage. There was no statistically significant difference in the magnitude of accelerated drying shrinkage across the specimens with RCCF. Generally, the performance of the mix cast using 20% RCCF was significantly lower than the control mix. The incorporation of 10% RCCF, in comparison with the control mix, did not result in a significant reduction in density, compressive strength and accelerated shrinkage.

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1. INTRODUCTION

Notable strategies that have been used globally to mitigate the negative effects of increased cement consumption comprise the use of supplementary cementitious materials (SCMs) such as ground granulated blast furnace slag (GGBS) and fly ash (FA). SCMs produce concrete with improved durability and mechanical performance. Despite their superior performance, the declining steel production in Cape Town has resulted in fluctuations in the quantity of slag available for construction. Also, FA has become uneconomical due to high costs involved in freighting over long distances and the high carbon impact of coal combustion. It is evident, therefore, that the demand for fly ash and slag in Cape Town outstrips the supply - a situation that could potentially increase the cost of construction significantly in future. There is a need, therefore, to identify and investigate alternative cementitious materials that are affordable, readily available and in significant quantities to meet the long-term demand for construction with a minimum negative impact on the environment. Recycled crushed concrete fines (RCCF) from construction and demolition waste (C&DW) is such a material. The use of RCCF in concrete would also contribute to the efficient management of municipal solid waste [1–7].

Research on, and the use of, C&DW in concrete has been ongoing since the early 1940s [4, 5,7–12]. Limited research, however, has been done on the use RCCF in concrete production [3, 5,7,12–14]. Shui et al [9], Oksri-Nelfia et al [3] and Prošek et al [6,7] specifically report that sub-sieve recycled concrete fractions are yet to be adopted in construction. Studies [1–3, 6, 7, 11–13, 15] have reported that the incorporation of RCCF in concrete and cement-based composites results in: reduced water demand for normal consistency, accelerated hydration of cement, negligible heat production during hydration, increased porosity and slump and reduced carbonation resistance and compressive strength. Contradictions have been reported on the effect of RCCF on slump, tensile strength and the overall fluidity of concrete [1, 3, 12, 13].

This paper presents the preliminary results from an ongoing study on the effect of RCCF on the following concrete properties: slump, density, compressive strength and accelerated drying shrinkage. The primary objective of this feasibility study is to assess the potential of RCCF as an SCM in concrete. This is one of the pioneer feasibility studies on the effect of RCCF in concrete cast using materials that are locally available in Cape Town and South Africa. The findings from this study will, therefore, inform future studies on the effect of RCCF on concrete cast using locally-available materials and the development of future guidelines on the use of RCCF in concrete.

2. METHODOLOGY

Three concrete mixes were designed and tested. The following materials were used:

i. CEM II B-M (L), 42.5 N: limestone content = 20%, clinker content = 80%, fineness = 3500 cm2/g; density = 2790 kg/m^3.
ii. Dune sand: Fineness Modulus = 1.88, compacted bulk density = 1670 kg/m^3.
iii. Greywacke crusher sand: Fineness Modulus = 3.09, compacted bulk density = 1890 kg/m^3.
iv. 13 mm Greywacke stone: bulk density = 1500 kg/m^3, relative density = 2.71.
v. Recycled crushed concrete fines (abbreviated as RCCF hereafter): density = 2590 kg/m^3, particle size < 75 μm.

The mix designs are summarised in Table 1.

Discarded laboratory-made concrete specimens of varying ages (older than 1 year) were mechanically crushed into small pieces using a hammer and a hydraulic compression machine. Utmost care was taken to minimise the inherent variability in the chemical composition of the discarded concrete by ensuring that they were from one source. The crushed concrete pieces were pulverised using a laboratory jaw crusher

Table 1: Concrete mix designs

Mix component	Mix ID		
	Control (0% RCCF)	10% RCCF	20% RCCF
CEM II B-M(L) (kg/m^3)	450	405	360
RCCF (kg/m^3)	0	45	90
Water (l/m^3)	225	225	225
Dune sand (kg/m^3)	402.5	402.5	402.5
Greywacke crusher sand (kg/m^3)	402.5	402.5	402.5
13 mm greywacke stone (kg/m^3)	850	850	850
Water:binder ratio	0.50	0.50	0.50

into fine powder. The powder extracts that passed through the 75 μm sieve – i.e., RCCF - were collected for subsequent testing. The RCCF, dune sand and greywacke crusher sand were oven-dried at 105 oC for 48 hours. Oven-drying was used to remove moisture. The oven-dried sands were left to cool for at least 4 hours and thereafter stored in cylindrical steel containers. The fineness modulus and grading of the dune and greywacke crusher sands was done according to ASTM C 136 [16]. The dune and greywacke crusher sands were blended at a ratio of 1:1. The density of aggregates was determined according to ASTM C 29 [17]. A water to binder (i.e., CEM II B-M(L) and RCCF) ratio – abbreviated as water:binder or w:b hereafter - of 0.50 was used. This water:binder ratio was deemed to be representative of conventional concrete. Three concrete mixes were cast: a control mix and two test mixes containing RCCF at replacement levels of 10% and 20% by mass of binder. The maximum replacement level of 20% was informed by past studies [1, 3, 9, 12, 15].

The dry materials – 13 mm greywacke stone, greywacke crusher sand, dune sand, cement and RCCF - were mass-batched and put in a 50-litre pan mixer. Thereafter, water was added to the dry mix in small increments after the mixer was switched on. The materials were mixed for five minutes. The slump of the freshly-cast concrete mixes was tested according to ASTM C 143 [18]. The test for slump was repeated thrice and the mean of three test results calculated. The slump test results are presented in Section 3.1. Test specimens were cast in standard moulds depending on the specifications for the particular test. A vibrating table was used to compact the freshly cast concrete mixes. The mixes, after compaction, were covered in a dark polythene sheet and left to harden in an undisturbed state in the laboratory (temperature = 21 ± 2 oC; relative humidity 60 ± 5%) for 24 ± 8 hours. The hardened specimens were demoulded and water-cured in a bath maintained at 21 ± 3 oC for 3, 7 or 28 days depending on the test. Three replicate specimens were cast and tested for each material property under investigation. Tests for density and compressive strength were done on 100 mm cube specimens while those for accelerated shrinkage were done on 100 x 100 x 200 mm prisms.

3. RESULTS AND DISCUSSIONS

3.1 Slump

The effect of RCCF on the slump of fresh concrete mixes is presented in Figure 1.

It can be observed, from Figure 1, that the incorporation of RCCF reduced slump significantly. The reduction in slump increased with an increase in RCCF content. This reduction has also been observed by other researchers [7,12]. The observed reduction in slump could be attributed to the reduction in the volume of spherical cement particles due to their replacement with coarser RCCF particles. The coarse RCCF particles increase inter-particle friction during mixing and a corresponding reduction in slump. The reduction in slump could also be attributed to the high absorption of RCCF particles which would reduce the volume of water available for the lubrication of the concrete mix [3,5]. Ma and Wang [1], while referring to other researchers, report that the surface of RCCF particles have pores which absorb water. The absorption of water in a mix would increase interparticle friction among the particles due to the reduction in water which acts as a lubricating agent. The increased friction would manifest as a reduction in slump. Prošek, et al [7] further attribute the reduction in slump in concrete containing RCCF to their high adhesion which results from their high specific surface area.

3.2 Density

The effect of RCCF on the density of the concrete is presented in Figure 2.

It can be observed, from Figure 2, that the incorporation of RCCF in concrete reduced its density. This observation is consistent with the findings of Lidmula et al [11]. The reduction in density, however, is not statistically significant. The observed reduction in density can be attributed to the reduction in the volume of cement paste. Cement particles were found to be denser (2790 kg/m^3) than RCCF particles (2590 kg/m^3). The partial replacement of cement with RCCF would thus result in a reduction in the density of concrete. Body et al [2, 13] and Prošek et al [7] also report that the incorporation of RCCF increases porosity; with the porosity increasing with an increase in RCCF content. An increase in porosity due to the incorporation of RCCF would result in a reduction in density. From this result, it can be inferred that RCCF could find potential use in light-weight concrete construction.

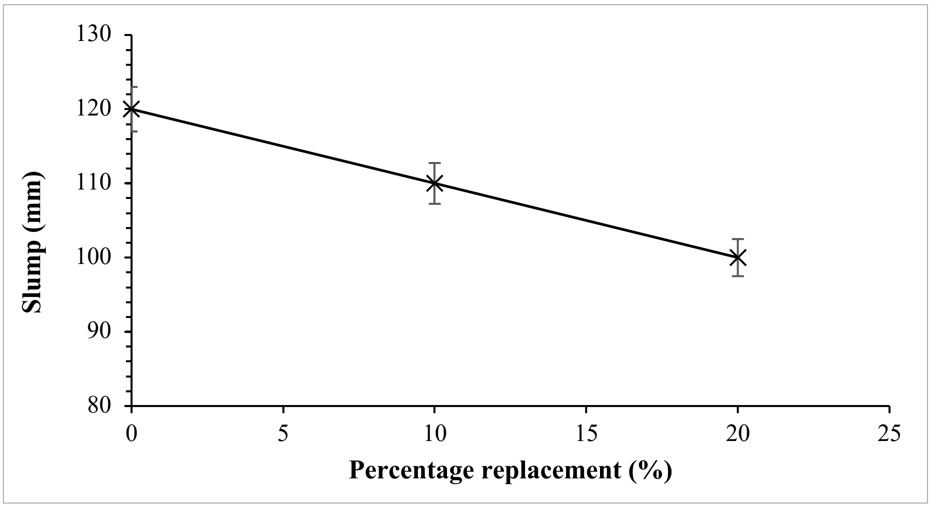

Figure 1: Trial cement mix with subsequent slump

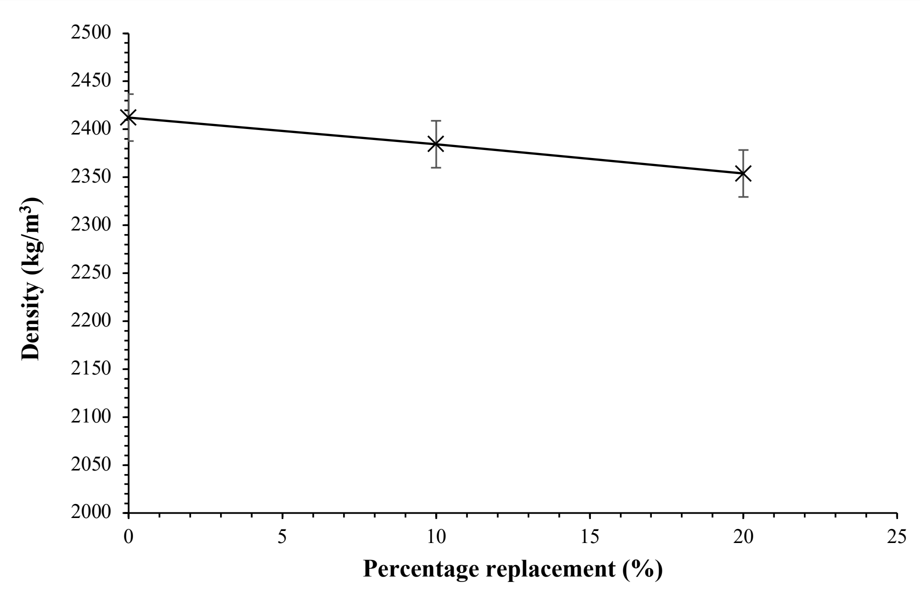

Figure 2: Density of concrete at various RCCF replacement levels

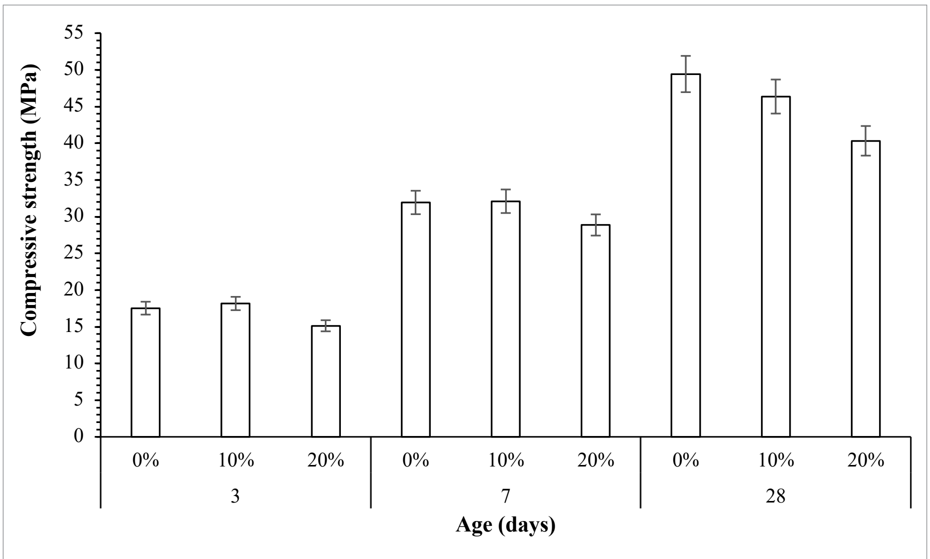

Figure 3: Compressive strength of concrete at various RCCF replacement levels

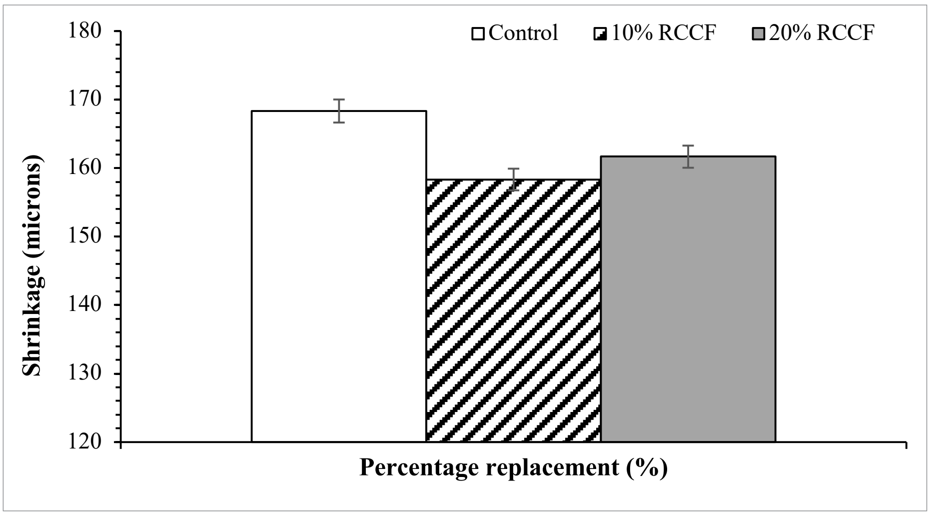

Figure 4: Accelerated drying shrinkage of concrete at varying RCCF content

3.3 Compressive strength

The compressive strength test results are presented in Figure 3.

It can be observed that the replacement of cement with RCCF resulted in a reduction in compressive strength at all ages. Similar trends and observations have also been reported by other researchers [1, 3, 7, 11–13]. While studies by Prošek et al [7] and Oksri-Nelfia et al [3] report that the replacement of cement with 20-30% RCCF by mass of cement would not result in a significant change in properties; the test results from this study do not support their observations entirely. The results from this study, however, are consistent with the findings of Ma and Wang [1]. The replacement of cement with 20% RCCF reduced compressive strength significantly at all ages. However, the difference between the compressive strength of the control mix and the 10% RCCF mix at all ages was not statistically significant.

The observed reduction in strength due to the replacement of cement with RCCF could be attributed to the increased porosity of RCCF mixes [2, 6, 13], the low quantity of anhydrous cement in RCCF and the overall reduction in cement content in RCCF concrete mixes. A reduction in cement content results in a corresponding reduction in the volume of C-S-H formed during hydration [2]. A reduction in the volume of C-S-H, the main strength bearing component of concrete, results in a corresponding reduction in compressive strength. The reduction in strength, with all factors held constant, would be proportional to the reduction in cement content. Oksri-Nelfia et al [3] further report that the low anhydrous cement content in RCCF reduces the likelihood of hydraulic actions (and the formation of C-S-H) with would manifest as a reduction in strength.

3.4 Accelerated drying shrinkage

The test results for accelerated drying shrinkage are presented in Figure 4.

From Figure 4, it can be observed that the incorporation of RCCF in concrete reduced accelerated drying shrinkage significantly in relation to the control mix. The reduction in shrinkage could be attributed to the reduction in the volume of cement paste which is usually responsible for shrinkage in concrete. Also, anhydrous and hydrated cement and crushed aggregate particles in RCCF could have provided internal restraint to the shrinkage of the paste. The recycled sand and hydrated cement particles within RCCF also act as microfillers which would reduce the porosity of interfacial transition zones [6,7]. These microfillers would also result in a pore-blocking effect which reduces interconnectivity in the pores; and a consequent reduction in the rate of loss of moisture (i.e., shrinkage) from the concrete.

4. CONCLUSIONS

The following conclusions have been arrived at based on the test results from this study:

i. The replacement of cement with RCCF resulted in a significant reduction in slump. The reduction in slump increases with an increase in RCCF content.
ii. The replacement of cement with RCCF results in a reduction in density. This reduction, however, is not significant.
iii. The replacement of cement with 20% RCCF results in a significant reduction in compressive strength at all ages. The replacement of cement with 10% RCCF, however, does not result in a significant reduction in compressive strength at all ages.
iv. The replacement of cement with RCCF results in a significant reduction in accelerated drying shrinkage. **CB**

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holds a BSc. in Civil Engineering from the University of Nairobi (UoN) and MSc. and PhD degrees in Civil Engineering from the University of Cape Town (UCT). He is a Senior Lecturer at the Department of Civil and Mining Engineering at the University of Namibia (UNAM). His research interests are in cement and concrete materials, particularly relating to concrete durability, repair, condition assessment, deterioration modelling, the use of recycled waste products, admixtures and novel materials in concrete production.

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