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# The role of 0–2 mm fine recycled concrete aggregate on the compressive and splitting tensile strengths of recycled concrete aggregate concrete

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## ABSTRACT

The aim of this study is to investigate the role of 0–2 mm fine aggregate on the compressive and splitting tensile strengths of recycled concrete aggregate (RCA) concrete with normal and high strengths. Normal coarse and fine aggregates were substituted with the same grading of RCAs in two normal and high strength concrete mixtures. In addition, to keep the same slump value for all mixes, additional water or superplasticizer were used in the RCA concretes. The compressive and splitting tensile strengths were measured at 3, 7 and 28 days. Test results show that coarse and fine RCAs, which were achieved from a parent concrete with 30 MPa compressive strength, have about 11.5 and 3.5 times higher water absorption than normal coarse and fine aggregates, respectively. The density of RCAs was about 20% less than normal aggregates, and, hence, the density of RCA concrete was about 8–13.5% less than normal aggregate concrete. The use of RCA instead of normal aggregates reduced the compressive and splitting tensile strengths in both normal and high strength concrete. The reduction in the splitting tensile strength was more pronounced than for the compressive strength. However, both strengths could be improved by incorporating silica fume and/or normal fine aggregates of 0–2 mm size in the RCA concrete mixture. The positive effect of the contribution of normal sand of 0–2 mm in RCA concrete is more pronounced in the compressive strength of a normal strength concrete and in the splitting tensile strength of high strength concrete. In addition, some equation predictions of the splitting tensile strength from compressive strength are recommended for both normal and RCA concretes.

## 1. Introduction

Concrete is the most widely used construction material due to its many advantages, such as low cost, availability of raw constituent materials, workability and its ability to be cast into many shapes, good fire resistance and durability. The many advantages of concrete are weighed against the severe energy consumption and pollution resulting from the manufacture of cement [1]. In addition, a study conducted by Struble and Godfrey [2] revealed that between a reinforced concrete beam and a steel I-beam with the same moment capacity, the concrete beam required much less energy and had a lower net environment impact than the steel beam.

It was reported that about 2.7 billion $m^3$ of concrete was produced in 2002 worldwide, which is more than 0.4 $m^3$ of concrete produced per person annually [3]. It is expected that the demand for concrete will grow to approximately 18 billion tons (about 7.5 billion $m^3$) a year by 2050 [4]. Due to at least three-quarters of the volume of concrete being occupied by aggregate [5], such a huge usage of concrete increases the use of natural aggregates, which creates an ecological imbalance and has a significant effect on the environment. Consuming such enormous quantities of natural resources for making concrete and cement means that the current concrete construction practice is unsustainable [6]. Meyer [7] stated that there are five ways to achieve sustainability of the concrete industry: (1) increase the use of supplementary cementitious materials, (2) increase the use of recycled materials, (3) improve durability, (4) improve mechanical properties, and (5) reuse of wash water. Among these five ways, the use of recycled aggregates saves natural resources, dumping space and supports the environment [8].

Concrete waste constitutes the major proportion of construction waste totalling about fifty per cent of the total waste generated [9]. Researchers have shown that among the many types of solid waste generated from the construction industry recycled

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concrete aggregate (RCA) is a good substitute for aggregate in producing structural concrete [10,11]. Tam et al. [9] reported that a concrete made of recycled aggregates fulfils green requirements. These requirements are: (i) it can recycle and reduce natural resources and energy consumption; (ii) it will not affect the environment; and (iii) it can maintain sustainable development. It has been reported [12] that a concrete containing recycled aggregate has a lower compressive strength compared to that of normal aggregate (NA) concrete. This is due to the lack of bonding between recycled aggregate and cement matrix and also the high water absorption capacity of recycled aggregate [13]. The quality of concrete containing RCA strongly depends on the amount of RCA in the concrete mixture. It has been reported [6] that for manufacturing structural grade concrete by the partial substitution of the natural aggregate with RCA by up to 50% is feasible. In addition, reports [14–16] have shown that RCA can be used in high strength, high performance and durable concretes.

To produce a RCA concrete of good quality, factors such as remaining micro cracks in RCA after the crushing process, high water absorption, smaller specific gravity of RCA as well as a possible reduction in quality and durability need to receive proper consideration in advance [17]. To produce good quality RCA concrete, using coarse and fine RCAs, the use of fine RCA in concrete is not recommended; alternatively, the replacement of natural sand by recycled fines was recommended to be limited to a maximum of 20% [12]. Sima and Park [18] reported that at any age (up to 28 days) of a mortar, the compressive strength reduces as the natural sand is replaced with the fine RCA. They also reported that for making structural concrete members, coarse RCA can be fully used instead of normal coarse aggregate. However, for such a purpose in a concrete containing 100% coarse RCA, the fine RCA can be used for up to 60% of the total fine aggregate. The reports of many researchers have revealed that the compressive strength of RCA concrete decreases as the amount of RCA increases; this is because of the existence of the cement paste residue in the aggregate particles [19]. Fig. 1 shows a schematic of a RCA surrounded with new mortar in RCA concrete [20]. Indeed, the use of RCA in concrete involves an increase in the mortar content in the resulting concrete, which, in turn, potentially increases the shrinkage strain. The drying shrinkage strain of RCA concrete may range from 20% to 70% more than the reference concrete, which, together with the 100% replacement of NA with RCA, might reach up to 263% [21].

Although, much research has been conducted on the use of recycled aggregates in structural concrete, a large amount of these materials are used in non-structural concretes or used as road bases [22]. Due to the wide variation in the properties of concrete containing recycled aggregate, engineers still prefer the use of virgin materials, or the use of recycled material is limited to a low level replacement of coarse aggregate. In 2012, from a review of the use of RCA in concrete [12] it was concluded that more research is required to investigate the effect of RCA on the properties of concrete in terms of the splitting tensile and flexural strengths, the bond between the aggregate and paste, porosity, chloride penetration, as well as the effect of quality of the parent concrete of RCA. In addition, it was recommended that further research is needed to investigate the potential use of RCA in the production of high strength, high performance, lightweight and self-compacting concretes. Therefore, there are still many questions concerning RCAs, RCA concretes and their properties which are still unanswered.

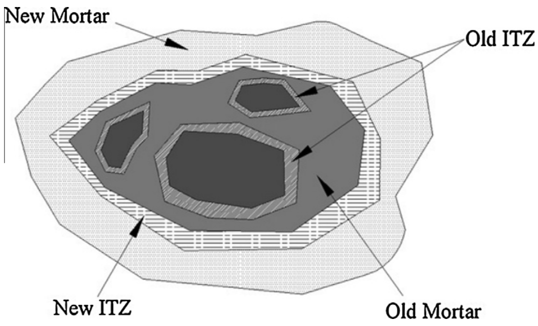

**Fig. 1.** A recycled aggregate surrounded with new mortar in a recycled aggregate concrete [20].

The aim of this study is to investigate the effects of using 0–2 mm fine RCA instead of NA on the compressive and tensile strengths of normal and high strength concretes. In this study, the quality of the parent concrete is known. In addition, to achieve a better and more accurate comparison between normal aggregate and RCA concretes, similar grading was used for normal and recycled concrete aggregates.

## 2. Experimental work

### 2.1. Materials used

#### 2.1.1. Binder

Type II Portland cement and silica fume were used as the binder. The cement used had a specific gravity, Blain surface area, initial and final setting times of 3.15, 3.06 $m^2/g$, 115 min and 195 min, respectively. The cement had 3, 7 and 28 days compressive strength of about 18.5, 30.0 and 40.0 MPa, respectively. The chemical composition of the cement and silica fume is shown in Table 1.

#### 2.1.2. Superplasticizer

A sulphonated naphthalene formaldehyde superplasticizer (SP) was used for mixes containing silica fume. The amount of SP used was to achieve a slump value in the range of 80–100 mm.

#### 2.1.3. Aggregates

The recycled concrete aggregates (RCAs) were produced from crushing tested reinforced concrete beams (RCBs) in the laboratory (Fig. 2), which can be called the parent concrete (PC). The mix proportion of the PC is shown in Table 2. On average, the compressive strength of the PC was about 30 MPa. The concrete rubble obtained from the primary crushing of the RC beams was crushed using a crushing machine to achieve aggregate of different sizes.

Natural coarse and fine aggregates, which were used the manufacture of the PC, were also used in this study. From the different sizes of RCA, coarse and fine RCA with the same grading as the natural aggregates were achieved. Therefore, the grading of sand used in all mixes (normal sand, combined sand and RCA sand) is the same. The grading of sand along with the ASTM: C33 sand grading curves are shown in Fig. 3. The densities of the coarse and fine RCAs were 2.31 and 1.97 $g/cm^3$, respectively, while the density of natural coarse and fine aggregates in the SSD condition were 2.86 and

**Table 1**
The chemical composition of binder.

| Oxide composition | OPC | Silica fume |
|---|---|---|
| $SiO_2$ | 21.9 | 94.6 |
| $Fe_2O_3$ | 3.3 | 0.9 |
| $CaO$ | 63.3 | 0.5 |
| $MgO$ | 1.2 | 1.0 |
| $Al_2O_3$ | 4.9 | 1.3 |
| $SO_3$ | 2.1 | 0.1 |
| $K_2O$ | 0.6 | 1.0 |
| $Na_2O$ | 0.4 | 0.3 |
| LOI | 2.4 | – |