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Mechanical behavior of three generations of 100% repeated recycled coarse aggregate concrete

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HIGHLIGHTS

- Investigate different properties of repeated recycled coarse aggregates.
- Investigate the mechanical properties of three generations of 100% recycled concrete.
- Compare performances of natural aggregate concrete and repeated recycled concrete of different generations.
- Stress–strain behavior of repeated recycled concrete.

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ABSTRACT

Demolished concrete generates significant volume of construction and demolition (C&D) waste worldwide that has huge potentials for concrete coarse aggregate. This study discusses the use of recycled coarse aggregate in concrete in a repeated fashion, and investigates the fresh and hardened properties of this green concrete type. Three different generations (1st, 2nd and 3rd) of repeated recycled concrete were produced using 100% recycled coarse aggregate (RCA) as a replacement of natural coarse aggregate where RCA was recycled 3 times over its life span. i.e. the 3rd generation recycled concrete was made with RCA, which was produced after 3 repeated casting of recycled concrete with 100% RCA and then demolishing the hardened concrete. The results show that the repeated recycled concrete experienced slightly lower compressive strength than the control concrete; however, all mixes successfully achieved their target strength at 56th day expect the 3rd generation concrete. Another interesting finding of this study shows that even the 3rd generation concrete could surpass the target strength by at least 25% while considering long term strength gain. The stress–strain curves of repeated recycled concrete are also presented and discussed.

1. Introduction

The consumption of natural aggregate is significantly increasing with the increased production and utilization of concrete in the construction sector. Construction industry is one of the largest consumers of natural aggregate. Every year 15 billion tonnes of concrete are produced throughout the world which means 2 tonnes of concrete per inhabitant per year [1]. In order to fulfill this huge demand, the sources of good quality natural aggregates are considerably declining all over the world. Each year ten to eleven billion tonnes of aggregate are being used all over the world [2]. Approximately two billion tonnes of aggregates are being produced and used in European Union countries per year [3]. Rapid and increased use of natural aggregate raise a huge concern regarding the possible unavailability of natural aggregate in the near future.

On the other hand, a significant portion of infrastructures are now reaching or getting close to the end of their service life [4]. A recent study [5] showed that about 30% of the municipal infrastructures in Canada are more than 85 years old and around 80% of the infrastructures have passed their expected design life. An economic study revealed that a huge amount of investment is required for the repair and maintenance of the existing civil infrastructure in Canada which would cost almost $130 billion where most of those structures are aging and nearing the end of their life span [6].

New public infrastructure projects of $12-billion were announced by the federal government to replace the old and deficient infrastructure by new construction [7]. This replacement will increase the amount of construction and demolition (C&D) waste already found in landfill. If this replacement process is constantly

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going on, soon there will be a scarcity of available land spaces to dump waste materials. Currently concrete waste makes up about 12% of the construction and demolition waste found in Ottawa [8]. The replacement process of structure is not only raising a dumping issue but also becoming a threat to the environment. Many countries throughout the world have been suffering from lack of proper dumping place. Initiatives have been taken to minimize the use of natural aggregate and land filling, for instance heavy taxes have been introduced to discourage the disposal of C&D waste. Recycling or reusing of demolished concrete is a viable option which can significantly decrease the burden of landfill. Large scale recycling can deplete the consumption of limited resources like natural aggregate as well as play a vital role in solving the waste disposal problem [4]. Researchers cannot only think about the current condition, they also need to envisage the future situation from their curious/intuitive perceptions because the wide application of RCA can result in new challenges. One has to think about the next generation of this recycled concrete, i.e. what happens when this recycled concrete structures need to be demolished and what about its disposal issue. Similar steps can be taken i.e. the idea of "repeated recycled coarse aggregate" to be used in concrete production can be a viable solution to the growing problem regarding the C&D waste disposal and limited source of natural coarse aggregate. In this study, the fresh and hardened properties of sustainable recycled concrete made with repeated recycled coarse aggregates are investigated. Although previous research has been conducted for the use of RCA in concrete, the use of repeated recycled coarse aggregate is a new research area and has been found, in this study, to have exciting potential. The properties of recycled concrete are significantly affected by the gradation, shape, and texture of the recycled aggregate used. Since recycled aggregates can be obtained from different sources, their shape and textures are likely to vary over a wide range. Katz [9] found that the gradation and attached mortar content of recycled aggregates are not influenced by the crushing strength and the age of parent concrete. Natural aggregate has a specific gravity of around 2.7. On the other hand recycled aggregate's specific gravity is less than natural aggregate it can significantly affect the strength of recycled concrete. Padmini et al. [10] investigated the influence of parent concrete on the properties of recycled aggregate. They concluded that the absorption capacity of recycled concrete increases with the increased strength of parent concrete. Matias et al. [11] investigated the effect of superplasticizer on the mechanical properties of recycled concrete. They found that superplasticizers can increase the compressive and splitting tensile strength of recycled concrete but in a less effective manner as compared to natural concrete. Salem et al. [12] and Katz [9] explained that the presence of attached mortar on the surface of recycled aggregate is responsible for this reduced specific gravity of recycled aggregate. A lower absorption capacity is observed by natural coarse aggregate which is around 0.3%. RCA has a higher absorption capacity than natural coarse aggregate due to the attached mortar. Due to the higher absorption capacity of recycled aggregate, the concrete mixes become stiffer and less workable compared to natural aggregate concrete [12].

Tavakoli and Soroushian [13] showed that several factors are correlated with the strength of recycled concrete. Original/parent concrete strength has a significant impact on the strength of recycled concrete. Recycled concrete strength properties are also affected by coarse aggregate replacement level. They found that the values of flexural, compressive and splitting tensile strength of recycled concrete differed from conventional concrete and it decreases with the increasing recycled aggregate replacement levels.

In case of recycled concrete it is very difficult to get clear and appropriate idea about its quality because the origin of the recycled aggregate is often unknown. Due to the variation in sources, recycled concrete aggregate may possess impurities along with the adhered mortar content. This significantly influences the properties of recycled concrete and make it difficult to predict the properties of new concrete [2]. Therefore, proper investigation about this new generation repeated recycled concrete is very necessary to understand the behavior of its mechanical and durability properties. Moreover, this will pave the way for future research opportunities and new challenges to the researchers. Most importantly, repeated recycled coarse aggregate will reduce the load on the landfill and decrease the use of natural aggregate thus, offsetting related extraction, processing, transportation, and environmental loads. Different types of aggregate properties and mechanical behavior of recycled concrete made with three different generations of repeated recycled coarse aggregates are covered in this study.

2. Sources of aggregates

This study considers the use of 100% RCA to be used repeatedly in first, second and third generation (i.e. RCA was recycled 3 times over its life span) of concrete production and compares the mechanical behavior of produced concrete among them. The target was to produce 32 MPa concrete with different generations of repeated RCA and compare it with natural aggregate concrete. Natural sand was used as fine aggregate for the production of both natural and repeated recycled aggregate concrete. Recycled fine aggregate was not considered in this study. Natural coarse aggregate, RCA, and sand were collected from OK Builders. Although recycled aggregate was collected from OK Builders' Winfield pit, due to winter and other circumstances lots of unwanted materials were mixed with recycled coarse aggregate. Several screening, sieving, and washing were done to remove these impurities. Recycled coarse aggregate was sieved to discard particle size smaller than 5 mm.

3. Production of repeated recycled coarse aggregate

This study evaluates the performance of first, second and third generation of recycled concrete made with 100% RCA and compares them with that of natural aggregate concrete. 1st generation recycled aggregate concrete (RC1) was produced using 100% RCA which were collected from OK Builders Winfield pit. After curing for 56 days, this concrete was crushed and went through several screening and crushing process to produce 2nd generation repeated recycled aggregate. The 2nd generation recycled aggregates were sieved and washed to eliminate the smaller sized particles (less than 5 mm) from the stockpile. This 2nd generation repeated recycled coarse aggregate (RCA2) was used to produce recycled concrete which is described as 2nd generation repeated recycled concrete (RC2) in this study. Then RC2 was cured for another 56 days, and then further crushed and recycled to produce the 3rd generation recycled concrete aggregate. The 3rd generation recycled coarse aggregate (RCA3) was then sieved to remove smaller particles (less than 5 mm) and washed thoroughly with water to remove other impurities. The RCA3 was used to produce the 3rd generation repeated recycled concrete (RC3). The flow diagram of production process of different generations recycled concrete is depicted in Fig. 1.

Since different generations of repeated recycled concrete were produced using sequential crushing of different generations of concrete, it was very difficult to estimate the amount of recycled coarse aggregate for producing the 1st generation recycled concrete (RC1). Almost 1 m^3 of concrete (more than 480 cylinders and 29 beams) was cast using the 1st generation recycled coarse