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The use of steel slag aggregate to enhance the mechanical properties of recycled aggregate concrete and retain the environment

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HIGHLIGHTS

- The properties of waste materials (RCA and SSA) are studied and compared to normal aggregate.
- The use of RCA adversely affects the properties of concrete, but the use of SSA enhances the properties of concrete.
- Concrete containing both RCA and SSA is studied. The mechanical properties of RAC are enhanced.
- Environmental problems can be reduced.

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ABSTRACT

Waste materials, such as demolished concrete rubbles and steel slag, are dumped in landfills. Such action destroys the environment. Recycling these materials and using them as coarse aggregate in new concrete mixes would eliminate the problem. The paper summarizes a two-stage research conducted to evaluate the use of the two environmentally harmful materials in concrete.

Stage 1 studies the effect of using recycled concrete aggregate (RCA) or steel slag aggregate (SSA) on the properties of normal concrete. First, RCA and SSA properties have been determined and compared with those of normal aggregates. Later, RCA and SSA were introduced in concrete mixes. In these mixes, natural coarse aggregate is partly or totally replaced by RCA or SSA. Results show that the use of RCA or SSA has an adverse effect on the workability and air content of fresh concrete. While RCA resulted in reduction in the mechanical properties of concrete, SSA enhanced these properties.

In order to enhance the properties of RAC so that it can be used safely in structural concrete, the RCA has been partially replaced by SSA in stage 2 of the research. Results show that this is possible.

1. Introduction

1.1. Recycled concrete aggregates (RCA)

The average world production of concrete in our rapid developing industrialized world is about 6 billion tons per year [1]. Since earth is the source of the aggregates (either natural or crushed), then obtaining these amounts would have an adverse effect on the environment. Furthermore, demolishing concrete structures and dumping the concrete rubbles would aggravate the problem. Therefore, recycling construction material plays an important role to preserve the natural resources and helps to promote sustainable development in the protection of natural resources; thus reduces the disposal of demolition waste from old concrete [2]. For example, the amounts of demolished buildings in Europe amount to around 180 million tons per year [3].

Old concrete and masonry that have "reached the end of the road" can be recycled and used not only as aggregate for new concrete, but also for a number of other applications in construction [4]. For example, since 1982 the ASTM definition of coarse aggregate has included crushed hydraulic cement concrete, and the definition of manufactured sand includes crushed concrete fines [4]. Similarly, the U.S. Army Corps of Engineers and the Federal Highway Administration encourage the use of recycled concrete as aggregate in their specifications and guides [5]. Several Refs. [3–12] have presented literature survey and research results in the field of the use of RCA, concrete and masonry and their effect on maintaining the environment. Based on these references, the advantages of using RCA in concrete can be summarized as follows:

1.1.1. Environmental considerations

Ref. [12] provided brief environmental considerations regarding the use of concrete, quoted in their own words: "In this time of increasing attention to the environmental impact of construction and sustainable development, Portland cement concrete has much

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to offer: (1) it is resource efficient-minimizing depletion of our natural resources; (2) it is inert, making it an ideal medium in which to recycle waste or industrial byproducts; (3) it is energy efficient, it is superior to wood and steel; (4) it is durable, continuing to gain strength with time; and finally (5) it is recyclable, fresh concrete is used on an as-needed basis (whatever is left over can be reused or reclaimed as aggregate), and old hardened concrete can be recycled and used as aggregate in new concrete or as fill and pavement base material". Parekh et al. [13] considered the use of RCA in concrete as an appropriate and "green" solution to the anticipated increased world – wide construction activity.

1.1.2. Economic factors

Recycling concrete is an attractive option for governmental agencies and contractors alike because most municipalities impose tight environmental controls over opening of new aggregate sources or new dumping areas [12]. By time, the increase of the cost of starting new quarries is increased and will be farther away. Hence, the cost and transport distances of conventional aggregates could continue to increase as sources becomes scarcer. Since landfill space is limited and can be far away, especially in urban areas, the disposal of demolished rubbles becomes costly and dumping fees will most likely rise as construction debris increases and the number of accessible landfills decreases.

1.1.3. Solving the problem of lack of materials

According to Kawakami et al. [14], utilization of concrete that uses RCA as a construction material is expected to contribute to solving the issue of lack of raw materials, and thus would allow the construction of infrastructures using a circulatory system for resources. Such situation was faced in Hong Kong and recycling aggregate was an attractive solution [15].

1.1.4. Other uses

While unprocessed RCA is useful to be applied as many types of general bulk fill, bank protection, sub-basement, road construction and embankments, processed RCA can be applied to new concrete including lean and structural grade concrete, soil–cement pavement bases and bituminous concrete [9]. Moreover, it has been used to produce high strength concrete [10].

The use of RCA for the production of concrete involves breaking demolished concrete into materials with specified size and quality. These materials can then be combined to produce aggregate of a pre-determined grading and hence can be used in concrete. Moreover, the steel reinforcement can also be recycled and then can be used in structural concrete reducing the effect on natural resources.

1.2. Steel slag

Steel slag, the by-product of steel and iron producing processes, was used in civil engineering tenths of years ago. Waste materials from the steel industry are produced in high amounts and shapes ranging from large boulders to dust. Since large quantities of these wastes are generated daily, they are considered problematic and hazardous for both the factories and the environment. The disposal of these materials will have a negative impact on the environment. The use of the local steel slag, as fine or coarse aggregate, resulted in enhancement of the performance of the structures [16–22].

Steel slag has been used as coarse aggregate in concrete structures. Several studies proved that the use of steel slag in concrete as coarse aggregate improves the mechanical properties of hardened concrete [22–29].

Qasrawi [22] showed that the use of relatively high Fe_2O_3 steel slag as coarse aggregate enhances the compressive and flexural strength of concrete. He also showed that the strength development of steel slag concrete performed much better than normal concrete resulting in concrete of higher strength at later ages.

Alizadeh et al. [23] carried out a research to evaluate the effect of steel slag on hardened concrete. Experimental results indicated that steel slag aggregate concretes achieved higher values of compressive, flexural and flexural strength and modulus of elasticity, compared to natural aggregate concretes.

Kamal et al. [24] presented a study on using blast furnace steel slag, which was crushed and screened to the required sizes, as coarse aggregate in concrete. The results show that the properties of hardened concrete, such as compressive, flexural and bond strength are higher for concrete containing steel slag when compared with those containing natural aggregate. Also the use of steel slag enhanced the elastic properties: There was an increase in the modulus of elasticity and a decrease in Poisson's ratio.

Shekarchi et al. [25,26] conducted a comprehensive research on the utilization of steel slag as aggregate in concrete. They concluded that the use of air-cooled steel slag with low amorphous silica content and high amount of ferric oxides is unsuitable to be employed in blended cement. On the other hand, utilization of steel slag as aggregate is advantageous when compared with normal aggregate concrete mixes.

Maslehuddin et al. [27] presented a comparative study of steel slag aggregate and crushed limestone concretes; where, only part of the coarse aggregates is replaced by slag aggregates. The study concluded that the compressive strength of steel slag aggregate concrete is marginally better than that of crushed limestone aggregate concrete. Moreover, the improvement in the flexural strength steel slag concrete is not significant.

Manso et al. [28,29] presented a study in which electric arc furnace slag has been used to obtain concrete of better quality. The study shows that steel slag can be used to enhance concrete properties.

1.3. Aims of the research

In stage 1 of this research the author investigates the use the RCA and SSA in normal concrete mixes and studies the possible effects on some of the fresh and hardened concrete properties. The research is a continuation of the previously conducted researches on the use of RCA and steel slag in concrete [22,30].

Because of the lower quality concrete obtained when RCA is produced, and the higher quality obtained when steel slag is used, in stage 2, the RCA is partially replaced by steel slag aggregate in order to enhance, as possible, the mechanical properties of both RCA and RAC. By such use, both RCA and steel slag aggregate can be safely dumped in concrete maintaining the mechanical properties of structural normal aggregate concrete.

2. Materials

The cement used in all mixes is ordinary Portland cement conforming to ASTM C150 Type I specifications. Natural coarse aggregate is crushed limestone from local sources. Gradation of the normal aggregates was obtained using ASTM C136. Natural coarse aggregate used in the mixes was obtained by combining various aggregates of different single-sized aggregates in order to arrive at a grading accepted by ASTM C33 and BS 882 for grading requirements for coarse aggregate of nominal maximum size 20–5 mm. The procedure described by Montegomry et al. [32] has been followed in the preparation of RCA as follows: First, RCA was obtained by crushing the previously tested samples in the lab into manageable lumps and then crushing these lumps in a Los Angeles abrasion machine. These particles were then washed, dried and sieved using the standard sieves for coarse aggregates. Any material passing sieve 5 mm was discarded. Later, the sieved particles were combined in order to obtain a gradation similar to that of the natural aggregates. By this, the possible effect of the change of gradation on the properties of concrete is minimized. The graduation of both natural and RCA aggregates are within ASTM C33 and BS 882 for grading requirements for coarse aggregate of nominal maximum size 20–5 mm. Natural sand, known locally as desert sand, is used in all mixes. The fineness modulus of sand is 1.76. The sand is not within the ASTM C 33-92 standard