Construction and Building Materials 123 (2016) 174–183

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Mechanical and durability properties of concrete using recycled granulated steel

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HIGHLIGHTS

- Performance of concrete containing RGS as a partial replacement of NFA is studied.
- The effect of RGS on the mechanical properties of concrete is investigated.
- Effect of sulphate exposure on RGS concrete is investigated.
- Microscopic analyses are conducted through SEM images.
- Optimum RGS content is found to be 30–50% by weight.

ARTICLE INFO

Article history:
Received 24 January 2016
Received in revised form 13 June 2016
Accepted 28 June 2016

Keywords:
Recycled granulated steel
Structural properties
Strength
Toughness
Scanning electron micrograph
Sulphate resistance

ABSTRACT

Recycled granulated steel (RGS) is a by-product produced in steel re-rolling mills which generate a significant volume of granulated steel each year. This paper describes the influence of RGS on the fresh, hardened, and durability properties of concrete, and compares these properties with those of control concrete specimens containing natural aggregates. RGS is introduced as a replacement of fine aggregates up to 60% by weight. All the tests are conducted in compliance with ASTM standards in compression and flexure under quasi-static loading condition. The results of the mechanical properties are presented in terms of compressive strength, splitting tensile strength, flexural strength and flexural toughness. The compressive and splitting tensile strength of various concrete mixes are determined after 28 and 56 days of curing where as flexural strength is determined after 28 days of curing. The study shows that both the fresh and hardened properties of RGS concrete are quite similar to those of the control concrete. However, with the increase of RGS the slump value increases compared to that of the control concrete. 28 days compressive strength, flexural strength, and flexural toughness increase up to 11%, 31%, and 38%, respectively, with the increase of RGS in the concrete mixtures compared to the control concrete. However, RGS concrete has a lower 28 days tensile strength compare to the control concrete. Furthermore, sulphate resistance of the RGS concrete is investigated extensively. Using scanning electron microscope (SEM) images, a comparison is performed with the unexposed specimens in terms of mechanical strength, physical impact (i.e., linear and volumetric shrinkage), and micro-structural transformation of concrete specimens. Finally, this paper addresses the possible use of RGS (a by-product) in concrete as a replacement of fine aggregate to produce sustainable concrete.

1. Introduction

Concrete is a conventional structural material consisting of chemically inert aggregates bonded together with Portland cement in the presence of water through hydration and hydrolysis reaction. The growing demand for concrete infrastructure today leads to a higher rate of consumption of high quality natural aggregates, thereby depleting this valuable resource to a concerning extent [1–3]. This accelerating depletion of natural aggregate associated with uncontrolled extraction has led to a search for feasible alternatives.

The world is generating billions of tons of industrial waste per year. Studies show that a systematic consumption of recycled

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http://dx.doi.org/10.1016/j.conbuildmat.2016.06.139
0950-0618/

products can help solve the problem of waste disposal [3]. In this regard, the use of recycled fine and coarse aggregates in construction has grown interest among researchers and concrete industries. A review of existing literature on the subject reveals that numerous recent studies have aimed at improving the production of economical and environmentally-friendly concrete using various recycled fine and coarse aggregates such as aggregates derived from demolished structural units [4–7], waste latex paint [8], crushed tile [9], ceramic waste[10], FRP scrap [11], and ground glass waste [12]. Most of these studies involved specific experiments to investigate the regular parameters of concrete, such as compressive strength, tensile strength, flexural strength, durability, and modulus of elasticity. These parameters are correlated with the properties of aggregate used in concrete. However, given the fact that recycled aggregates are obtained from different sources, they possess markedly different characteristics than natural aggregates. This includes differences in gradation, shape, texture, and specific gravity. Moreover, the containment of impurities due to the variation in sources is another major concern [2]. These properties significantly influence the mechanical and durability characteristics of concrete, an effect which cannot be accurately predicted without testing [2,13–17].

Many researchers are currently conducting research on the partial or full replacement of natural aggregates with recycled aggregates. Studies have shown that recycled concrete strength properties strongly depend on the level of replacement. Ulloa et al. [18] showed the influence of recycled aggregate replacement ratio and effective water-binder ratio (w/c ratio) on the compressive strength of recycled concrete. Some researchers have restricted the level up to 30% replacement for maintenance of standard requirements for 5% absorption capacity of aggregates [17]. It was revealed by Etxeberria et al. [17] and Ulloa et al. [18] that concrete produced with 100% recycled coarse aggregate replacement significantly reduce the compressive strength and necessitates a large amount of cement in order to lower the water/cement ratio as well as to improve the compressive strength, a requirement which may compromise the economic viability of a project. Again, full replacement was also not suggested by Thomas et al. [19], Topcu and Canbaz [9], and Evangelista and de Brito [20] in their research studies.

Studies on coarse aggregate replacement have been carried out by numerous researchers, whereas the subject of fine particle replacement has garnered only a few studies [12,20]. With some exceptions, both of these replacements show light variations in compressive strength with respect to conventional concrete. However, a large fluctuation in modulus of elasticity and tensile strength was observed due to the lack of compactness of recycled aggregate indicated by the big stiffness loss of concrete [20,21]. Another study has demonstrated the successful application of ceramic waste as a replacement of coarse aggregate due to its lower tensile to compressive strength ratio compared to conventional concrete [10].

To investigate the proper utilization of recycled material, durability of concrete is another vital criterion as the performance of concrete significantly depends on the durability properties. Topcu and Canbaz [9] showed that the application of crushed tile in concrete not only adversely affect its compressive strength, but also poses an adverse effect on abrasion and freeze-thaw durability. This issue has also arisen with the incorporation of coarse recycled concrete and ceramic aggregates, which results in a higher chloride intrusion than with conventional concrete [21]. Similar results have been found by Thomas et al. [19]. Again Evangelista and de Brito [20] have observed a linear increase in water absorption with increased replacement ratio due to the porosity of fine recycled aggregate. From the research of Huda [22] it was also observed that, durability properties of concrete with recycled aggregates can be further analysed by sulphate test. However, when the issue of durability can be neglected for some structures depending on the nature of the project, the partial replacement of natural aggregate with recycled aggregate may be viable.

The present study addresses a gap in the literature in its investigation of the application of granulated steel as an alternative partial replacement of fine aggregates in concrete. A large number of steel rolling mills are currently running all over the world in order to serve the growing demand for reinforced steel. Granulated steels are the by-product left in the steel rolling mills after the production of reinforcing bars. An effective utilization of this recycled material can be beneficial for resource conservation as well as enhancement of properties of concrete. Though RGS has a resale value, but it is negligible compare to the NFA. Given the growing concern today about environmental issues and the need to mitigate carbon footprint, the use of RGS in concrete will have a positive environmental impact as it conserves natural resources and saves the environment from significant amount of carbon emissions associated with remoulding the RGS in a steel plant as an alternative use of the by-product. To date, no literature has been found that has studied the possible utilization of this unused industrial waste (i.e., granulated steel) in concrete mixtures. Hence, the use of RGS in concrete is a new avenue of research and has been found promising in this current study. First, a study is conducted to investigate the fresh and hardened properties of concrete that uses RGS. Further investigation targets a detailed micro-structural characterization and also examines durability in harsh environmental conditions. The outcome of this study will pave the way for effective utilization of this industrial waste for producing commercially viable structural concrete. This research will help develop new green building materials for sustainable construction. The current practice in the construction industry of Bangladesh is to achieve concrete compressive strength of 25 MPa in 28 days for structural applications. Keeping this in mind, this research aims to investigate the influence of RGS on the fresh, hardened, and durability properties of concrete, and compares these properties with those of control concrete specimens containing natural aggregates. Here RGS is proposed as a replacement to fine aggregate up to 60% by weight. The post-peak energy dissipation of different RGS concrete mixes is evaluated through flexural toughness factors. Finally, micro-structure of concrete specimens is investigated using scanning electron microscopy (SEM) images.

2. Experimental program

2.1. Material

The following are the details of the ingredients used to prepare the concrete specimens.

2.1.1. Cement

In this research, Portland Composite Cement (PCC) is used as the binding material following the specifications of ASTM C595 [23]. The cement used is fresh, without any lumps and it has a fineness of more than 3600 cm^2/gm as per Blaines air permeability method. PCC is commonly available in the local market, and it is the most widely used cement as per industrial practice in Bangladesh. According to BS EN 197-1 [33], PCC is in the class of CEM II/B-M. The chemical composition and properties of PCC are presented in Tables 1 and 2, respectively.

2.1.2. Natural fine aggregate (NFA)

Locally available well graded Sylhet sand of a nominal maximum grain size of 4.75 mm is used. According to the ASTM C136 [24] test method, the fineness modulus and specific gravity are