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Combined influence of glass powder and granular steel slag on fresh and mechanical properties of self-compacting concrete

Shahir Rehman [a], Shahid Iqbal [a,*], Ahsan Ali [b]

[a] Department of Civil Engineering, CECOS University of IT and Emerging Sciences, Peshawar, Pakistan
[b] Department of Civil Engineering, Quaid-e-Awam University College of Engineering, Science and Technology, Larkana, Pakistan

HIGHLIGHTS

- SCC is developed using GP and GSS as cement and fine aggregate replacements.
- Effects on fresh and mechanical properties are studied.
- Workability improves with increasing GP content.
- Mechanical properties improve with increasing GSS content.
- Mechanical properties decline with increasing GP content.

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ABSTRACT

Industrialization has enhanced the utilization of natural resources and add-up in air and land pollution. Now, it's high time to explore alternative materials to deal with depletion of natural resources especially for construction purposes and to prevent environmental degradation from industrial wastes. This research work is aimed at investigating the combined effect of two industrial wastes i.e. glass powder (GP) and granular steel slag (GSS) as cement and fine aggregate replacement materials on mechanical properties of self-compacting concrete (SCC). Fresh concrete properties studied include workability, density and air content while the hardened concrete properties include compressive strength, splitting tensile strength, flexural strength and modulus of elasticity. Results indicate increase in workability with increasing glass powder content while there is decreasing trend in workability with increasing steel slag content. Compressive strength, splitting tensile strength, flexural strength and modulus of elasticity improved with increasing granular steel slag content at constant level of glass powder with maximum increase of 11%, 13.2%, 19.3% and 20% respectively, compared to the control mix. Thus, use of industrial wastes as cement and aggregate replacement can play vital role in reducing utilization of natural resources, besides decreasing land and air pollution, without compromising on mechanical properties of concrete.

1. Introduction

Concrete is the most widely used construction material. Conventional concrete is combination of cement, fine aggregates, coarse aggregates and water. To achieve certain desired mix properties, some chemical admixtures are also added. Cement is the most important component in concrete which binds the aggregates together, but its production is very energy consuming and contributes to about 7% of greenhouse gases, globally, to the atmosphere [1]. Aggregate, the principal components in concrete, makes up to 70% of the concrete volume [2,3].

Modern development and industrialization has created a lot of facilities for the mankind. On the other hand, this industrialization, due to the emission of hazardous gases and production of solid wastes, has created a lot of environmental issues like pollution, depletion of natural resources and problems in waste management [4,5]. To overcome these problems, researchers have tried to used waste materials from different industries to replace some portion of aggregates and to investigate their effect on properties of concrete. Using recycled coarse aggregates and blast furnace slag as partial replacement of coarse aggregate and cement up to 50%, reduce compressive strength, splitting tensile strength and flexural

* Corresponding author.
E-mail address: shahid.iqbalmce@gmail.com (S. Iqbal).

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strength by up to 20%, 10% and 10% respectively [6]. There is increase in compressive strength of concrete up to 14% when up to 100% natural aggregates are replaced by stainless steel oxidized slag [7]. The compressive strength of electric arc furnace slag is 35% higher compared to reference concrete [8]. Using recycled fine aggregates from demolition work along fly ash and steel slag reduces the compressive strength of concrete by 27–32% [9]. There is 40–50% decrease in 28-day compressive strength, splitting tensile strength and flexural strength of concrete when natural coarse and fine aggregates are replaced by steel slag aggregates in different proportions [10]. Replacing 10–30% fine aggregates by iron slag increases the compressive strength of concrete by 50–110% [11]. Researchers have reported decrease in compressive strength of concrete above 30% utilization of furnace steel slag [12,13]. Utilizing air cooled slag as partial replacement of course aggregate and water cooled slag as partial substitution of fine aggregate, study reported improvements in strength of concrete [14]. 33%, 9.8% and 22% improvements are reported in compressive strength, flexural strength and modulus of elasticity at concrete age of 28 days when basalt aggregates were replaced by steel slag aggregates, however there was reduction in workability of concrete [15]. With addition of blast furnace slag in concrete as partial sand replacement up to 30%, there is improvement in compressive and tensile strength of resulting concrete [16]. Workability reduces when iron slag is used as partial replacement of fine aggregate in SCC production due to its granular texture while there is improvement of 20%, 21% and 14% in hardened concrete properties at 28 day i.e. compressive strength, splitting tensile strength and flexural strength up to the replacement level of 40% [17]. Thus steel slag, which is the byproduct in steel production industry, can effectively be utilized as natural aggregate replacement in concrete.

"Self-compacting concrete (SCC) is a highly flowable, non-segregating concrete that can spread into place, fill the formwork, and encapsulate reinforcements without any mechanical consolidation" [18]. Similar to the conventional concrete, SCC mixtures are composed of cement, course aggregate, fine aggregate, water and admixtures. However, for better rheological properties, quantity of coarse aggregate is reduced while quantity of fine aggregate is increased [19]. Unlike normal vibrated concrete, SCC contains high composition of powder as fillers to improve the flow properties of concrete. In addition to being uneconomical, utilizing high amount of cement as the only powder content has undesirable environmental impacts. This has led the researchers to replace some of the cement proportion by different powder materials like fly ash, silica fumes and blast furnace slag etc. which reduces the cost of concrete and also improves its performance [20,21]. Thus, supplementary cementitious materials are used, replacing some part of Portland cement as many of them increases the durability of concrete without compromising on its strength [22,23]. Another research reported that, SCC contain powder filler like fly ash, glass powder, lime stone powder etc. for improved workability [24]. Iqbal et al. added different amounts of fly ash to investigate the properties of SCC and reported improvements in fresh and hardened concrete properties [25]. Steel slag when used as partial substitution of fine aggregates has negative impact on workability of concrete when used in replacement levels over 50%. However best results for compressive strength were reported between the substitution levels of 15–30% [26]. By using marble powder and limestone powder as fillers in SCC, there is improvement in the mechanical and transport properties of concrete [27].

Glass powder is a useful industrial waste. It exhibits pozzolanic behaviour when the particle size is less than 38 μm [28,29]. The pozzolanic properties may be attributed to the high amount of silica. The particles of glass powder are very fine, filling voids between cement grains which results in more durable concrete. There is around 6% increase in compressive strength of concrete when 20% cement is replaced by glass powder, however, compressive strength reduces for higher substitution level [30]. The highest compressive strength and lowest porosity is achieved for concretes containing up to 30% glass powder content as cement replacement. Beyond this replacement level, there is reduction in strength of concrete [31]. Another study reported decrease in compressive strength of 33 MPa reference concrete when more than 5% cement was replaced by glass powder, while increase in strength of 45 MPa reference concrete up to replacement level of 10% [32]. Thus glass powder may be utilized as partial replacement of cement in concrete because of its pozzolanic behaviour when particle size is lower than 38 μm. The demand of glass is increasing day by day. To the author‘s knowledge, there is no literature available on the combined use of granulated steel slag and glass powder in SCC production as fine aggregate and cement replacement. Therefore, this study is conducted to investigate the effect of steel slag and glass powder in SCC on the fresh and hardened concrete properties, when they are used in different proportions.

2. Objectives

In modern world of civil engineering, cement is the most commonly used construction material, but unfortunately production of cement is a highly energy-consuming process and large amount of carbon dioxide is emitted to the environment [1]. SCC needs high amount of powder content for better rheological characteristics. To achieve this, high amount of cement is required but the cost of such concrete will be very high [21]. Therefore, additional fillers are used to fulfill this requirement. Likewise, aggregates occupy large volume in concrete but due to high cost of natural materials, construction industry needs to find alternative materials to overcome such problems [33].

Large amounts of industrial wastes are produces which end up in land-fills requiring additional resources. Utilizing these wastes in the production of concrete can help reduce environmental pollution and preservation of natural resources. As, these wastes are available in large quantities, free of cost, this may also help in reduction of concrete cost. Industrial wastes like glass powder and steel slag have been used by researchers as cement and aggregate replacements in concrete, but to the author's knowledge, they have not been used in combination for production of SCC.

Therefore, this study is aimed at investigating the fresh and hardened concrete properties of SCC when granular steel slag and glass powder are used in combination as fine aggregate and cement replacement. Objectives of this study are:

1. To investigate the combined effect of glass powder and steel slag on fresh properties of SCC i.e. workability, air content and fresh concrete density.
2. To study the combined influence of glass powder and slag on hardened properties of SCC i.e. compressive strength, splitting tensile strength, flexural strength and modulus of elasticity.

Mix-design of powder type SCC is finalized using trial mixes used as reference mix. The targets set were a minimum slump flow of 600 mm and a minimum 28-day compressive strength of 20 MPa. A combination of nine other mixes containing 20%, 30% and 40% glass powder as cement replacement and 40%, 60%, and 80% granular steel slag as fine aggregate replacement were prepared. Fresh and hardened concrete properties were then investigated for all of the concrete mixes.

3. Materials

The normal weight fine and coarse aggregates were collected from the local building construction material supplier with maximum aggregate size of 16 mm. Steel slag was obtained from the local steel manufacturing industry in the form