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INFLUENCE OF GLASS POWDER AND STEEL SLAG ON PROPERTIES OF CONCRETE: A REVIEW

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ABSTRACT

To overcome the scarcity of natural resources as construction material and to reduce the hazards from industries, industrial wastes can play a very significant role. In this paper, the influence of glass powder and steel slag is reviewed. It is concluded that glass powder and steel slag can upset some portion of concrete thereby providing significant improvement in mechanical properties of concrete consequently reducing the environmental hazards from industries.

KEYWORDS

Concrete, glass powder, steel slag, mechanical properties

INTRODUCTION

Concrete is a mixture of cement, fine aggregate and coarse aggregate. Some chemical admixtures are also added to gain varied properties. According to a study 11 billion tons of concrete was consumed worldwide [1]. Concrete is the most important construction material but the production of cement is very energy consuming and is a major source of greenhouse gases [2]. The emission of greenhouse gas is approximately 7% from cement industry. Similarly due to rapid industrialization, the concrete industry is facing scarcity of natural resources as construction materials. The use of waste materials is the best possible alternative to overcome these problems. Much attention has been paid toward the use of waste materials in concrete.

Glass is one of the oldest man-made materials. According to a study 130 million tons of waste glass is produced in the world [3]. The use of glass powder in the concrete binds the aggregate together thereby increasing the strength of concrete. The particles of glass powder are very fine and act as a filler, resulting in lower porosity and improving the durability of concrete. Glass is amorphous in nature and contains large amount of silica. When the particle size is less than 75μm then they show pazzolanic properties [4]. The problem with the use of glass powder is its high content of silica, but according to studies, ground glass powder does not influence the alkali-silica reaction [5], [6].

To overcome the exploitation of natural resources and reduce the emission of CO_2, the use of steel slag in concrete can also play a vital role [7]. The production of steel yields 15-20% of steel slag [8]. Approximately 35% of steel slag is disposed as waste material [9]. In 2012, the worldwide production of steel slag was nearly 230 million tons. This disposed slag not only affecting agriculture and environment but also causes shortage of space for landfilling.

Extensive research work has been performed to replace the aggregates by steel slag and the results showed positive influence on concrete properties [10], [11], [12]. Some other researchers have also reported the beneficial role of slag on fire resistance of concrete [13][14]. Steel slag contain cementing properties due to high amount of silica and calcium, but due to low cooling process its hydration process is very low compared to normal cement [15]. Tsakiridis et al. [16] have utilized steel slag for production of Portland cement clinker. They concluded that 10% replacement of steel slag results no negative impact on quality of cement produced. Steel slag in fine form can be utilized as admixture for concrete [17].

EFFECTS OF GLASS POWDER ON PROPERTIES OF CONCRETE

Effect on workability

Raju and Kumar [18] studied the workability of concrete, replacing the cement with glass powder from 5% to 40%. The results indicated that increasing the content of glass powder, the workability decreased. Vandhiyan et al. [19] suggested the possible reasons for reduction in workability. According to their findings, the loss in workability may be due to angular particles and high surface area of glass powder. Topcu and Canbaz [20] studied the behaviour of waste glass in concrete. They concluded that the addition of waste glass marked no significant effect on the workability of concrete. The utilization of waste glass slightly reduced the workability of concrete. Pollery et al. [21] concluded that concrete made with waste glass require more water than ordinary concrete. Schwarz et al. [22] investigated the behaviour of plain and glass powder modified concrete. They reported increase in the workability as the content of glass powder was increased. The increase in the workability may be due to the non-absorbent nature of glass powder which leaves free water in the mixture. Castro and Brito [23] studied the workability of concrete containing glass as fine and coarse aggregate. They reported increase in the workability when glass was used as coarse aggregate but as fine aggregate, there was reduction in the workability.

Effect on compressive strength

Aliabdo et al. [1] studied the performance of concrete containing glass powder. They reported increase in the compressive strength up to 10% replacement of cement with glass powder. Beyond this level, no further improvement was observed in the compressive strength of concrete. Yu et al. [24] investigated the effect of glass powder in addition with steel slag on compressive strength of concrete. They concluded that the compressive strength of concrete increased as the age of concrete increased. They also investigated that the compressive strength become double when the water/cement ratio was decreased from 0.55 to 0.40. Patil and Sangle [25] studied the effect of particle size of glass powder on compressive strength of concrete. They concluded that for particle size less than 90 micron, the concrete compressive strength was higher as compared when particle size ranges between 90 and 150 micron. They proposed 20% replacement of cement with glass powder as the optimum value. Tuan et al. [26] used glass powder with sewage sludge in light weight concrete. They concluded that there was loss in the compressive strength. Terro [27] replaced fine and coarse aggregate with recycled glass and investigated the mechanical properties of concrete. He concluded that the compressive strength decreased up to 20% from its original strength as the temperature increased. Parghi and Alam [28] studied the properties of concrete with recycled glass powder. They concluded that compressive strength increased with age of concrete and percentage of recycled glass powder. The higher strength may be due to high content of silica and alumina dissolution which contribute to pozzolanic reaction. Lee et al. [29] studied the particle size as well as curing effect on concrete block containing fine glass powder. They concluded that compressive strength decreased as the particle size increased. There was almost 8.8% loss in compressive strength for 28 days at 25%

replacement level when particle sizes were greater than 2.38mm. When particle sizes were reduced to less than 600 μm, there was significant increase in compressive strength.

Effect on tensile strength

Madandoust and Ghavidal [32] studied the effect of glass powder with rice husk ash on splitting tensile of concrete for 7, 28, 42 and 90 days of curing. They concluded that the tensile strength increased with the age of concrete. They reported that the ratio of tensile strength of concrete containing glass powder with rice husk to tensile strength of normal concrete was 71% at 7 days and 97% at 90 days of curing condition. They further stated that this ratio could be affected by many factors like testing method, shape and size of coarse aggregate etc. Raghvendra [33] investigated in his research that replacement of cement with 20% glass powder and 40% foundry sand achieved higher tensile strength compared to ordinary concrete. Afshinnia and Rangaraju [31] concluded in their investigation that practice of glass powder as aggregate, increased the splitting tensile strength by 21% but when cement was replaced by glass powder there was 12% reduction in splitting tensile strength of 28 days curing. Aliabdo et al. [1] studied the tensile strength of concrete by replacing cement with glass powder. They reported large increase in the tensile strength which may be due to the enhancement in the properties of transition zone.

Effect on flexural strength

Jitendra and Saiji [34] concluded in their findings that up to 35% replacement of cement with glass powder, improvement was seen in flexural strength but the maximum value was attained at 20% replacement level. Similarly other researchers like Dali and Tande (2012) and Bhagyasri et al. (2016) have also proposed 20% of cement with glass powder as the optimum value for flexural strength of concrete. The study of Park et al. [30] showed that the addition of waste glass reduced the flexural strength of concrete. Raju and Kumar [18] studied the variation in flexural strength by replacing cement with glass powder. The results showed the highest strength of 27%, 20% and 17% compared to control mix at 7, 28 and 90 days at 20% replacement of cement by glass powder. Yu and Tao [24] concluded that the flexural strength increased with the age of concrete. Similarly when w/c ratio was reduced, large improvement was in the flexural strength for the same type of concrete.

Effect on modulus of elasticity

Madandoust and Ghavidel [32] studied the modulus of elasticity concrete containing glass powder. They concluded that modulus of elasticity increased as the concrete become older. The modulus of glass powder added concrete to normal concrete was 88% at 7 days and 97% at 90 days of age. They further stated that concrete containing glass powder and rice husk ash are less compact as compared to normal concrete which results in lower modulus elasticity of concrete, but for long term the modulus of elasticity increased. Yu and Tao [24] investigated the effect of water/cement of concrete containing glass powder in addition with slag. There was significant increase in modulus of elasticity of concrete when water/cement ratio was reduced.

Effect on alkali-silica reaction

Zheng [37] investigated the role of glass powder in controlling alkali-silica reaction in concrete. They concluded that the alkali concentration increased in the pores due to reaction of glass powder, fine glass grains induced alkali-silica reaction (ASR) expansion largely. This mitigation was due to the increase in alumina concentration in pores, which decrease the dissolution of reactive silica, hence controlling the alkali-silica reaction. Schwarz et al. [22] used flame emission spectroscopy and electrical conductivity and measured that small amount of alkalis were released from glass powder into the pore solution. Cota et al. [38] measured the ASR expansion for 28 days, which varied from 0.011 to 0.427. They concluded that the largest expansion was measured for coarse glass particles.

EFFECT OF STEEL SLAG ON PROPERTIES OF CONCRETE

Effect on workability

Roslan et al. [39] studied the effect of steel slag along with steel sludge on workability of concrete at w/c ratio of 0.58. They concluded that as the steel slag content was increased, there was decrease in the workability. This decrease in workability may be due to rough surface of steel slag and steel sludge. Similarly they concluded that no segregation and bleeding were observed in placing and compacting the concrete. Netinger et al. [42] studied the increasing content of steel slag in the mixture and reported reduction in workability.

Effect on air content

Qasrawi [11] concluded from experiments that addition of steel slag increased the air content by 1.5-2 times the expected value for higher replacements of steel slag. These increases in the air content may be attributed to angular particle size of steel slag compared to natural aggregates. Netinger et al. [42] studied that the air content of reference concrete was 0.9% but increased to 2.8% due to addition of steel slag.

Effect on fresh concrete density

Khan et al. [40] investigated that the addition of steel slag increased the fresh density of control mix from 2400 kg/m^3 to 2750 kg/m^3. This is due to higher density of steel slag. Gonzalez-Oretga et al. [7] investigated concrete properties containing steel slag. They concluded that density of concrete steel slag was 25% higher than control mix. Huang et al. [41] studied the effect of steel slag on density of green artificial reef concrete. The density of artificial reef concrete was 2765 kg/m^3, 15% higher than normal concrete density of 2400 kg/m^3. The higher density may be attributed to higher the specific gravity of steel slag (3.39) compared to sand and gravel (2.4-2.9). This higher density may be effective against sea waves.

Effect on compressive strength

Gozalez-Oretga et al. [7] studied the compressive strength of concrete containing steel slag. The results obtained for compressive strength were satisfying the minimum strength for 28 days of 30 MPa. The compressive strengths of concrete containing slag and control mix were ranging 45-50 MPa. There was 15% increase in strength between 28 days and 90 days. Anastasiou et al. [49] investigated the effects of steel slag with fly ash on compressive strength of concrete. The 28 days compressive strength was nearly equal to that of control mix. The highest strength of 58 MPa was obtained for 365 days, which was 17.5% more than control mix. Plankar et al. [46] studied the effects of steel slag as coarse aggregate on compressive strength of concrete. They observed loss in compressive strength when steel slag was added as coarse aggregate compared to control mix. This reduction may be due to coating of calcite on surface of aggregates which affects the bond between aggregates and paste [47]. Pang et al. [48] concluded from their investigation that compressive strength increased up to 20% by the addition of steel slag at 3, 7 and 28 days of curing. They also observed strength loss at curing age of 60 days. Qjang et al. [44] studied the mechanical properties of concrete at w/c ratio of 0.45 and 0.30. They concluded that compressive strength of concrete with 10% slag at 90 days and w/c of 0.45 was 2.4% higher than control mix. They concluded that compressive strength of high strength concrete is not much affected by addition of steel slag. The proposed 20% of cement replacement with steel slag the optimum value. Ghouleh et al. [45] investigated that contribution of steel slag as aggregate to compressive strength of concrete was similar to control mix. Qjang and Peiyu [43] observed that the early strength of reference concrete was higher than concrete having steel slag. After 7 days, the steel slag added concrete gets strength quicker than reference concrete. The 90 and 360 days strength of concrete with steel slag was higher than reference concrete.

Effect on tensile strength

Mengxiao et al. [50] compared the splitting tensile strength of concrete having fly ash and steel slag under temperature match curing condition. They investigated that the early age splitting tensile strength of concrete containing high volume of fly ash was higher than concrete with steel slag. The increase in later age splitting tensile strength of both type of concretes were nearly similar. Qasrawi [11] investigated that the use of steel slag increased the tensile strength of concrete. This enhancement could be attributed to angularity of steel slag which influences the interaction of cement matrix. San-Jose et al. [55] concluded that addition of steel slag obtained similar split tensile strength as that of control mix. They also investigated that there was high cohesion in concrete having steel slag showing good regularity in fracture behaviour than control mix. Sabapathy et al. [54] investigated the effect of steel slag as coarse aggregate on split tensile strength of concrete for 7 days and 28 days of curing. The observed that maximum tensile strength was obtained at 25% replacement of steel slag. Beyond this level, there was loss in split tensile strength which may be due to porosity of concrete due steel slag.

Effect on flexural strength

Roslan et al. [39] investigated in their findings that 20% of steel can be added to concrete without any fear of quality effect on flexural strength. Alizadeh et al. [53] investigated the flexural strength of concrete containing steel slag. The results showed that flexural strength of concrete having steel slag was higher than control mix. Netinger et al. [42] investigated the effect of temperature on flexural strength of concrete having steel slag. They observed that flexural strength of specimen having high amount of steel slag was highly affected by temperature beyond 873 K. The flexural strength decreased to zero beyond this temperature.

Effect on modulus of elasticity

Gonzalez et al. [7] investigated modulus of elasticity of steel slag added concrete for 90 days of curing. They concluded that modulus of elasticity of steel slag added concrete was 10% higher than control mix. This increase may be attributed to hardness of steel slag. Netinger et al. [42] studied the effect of temperature on concrete having steel slag as aggregate. They concluded that modulus of elasticity increased up to 373 K but beyond this there was decrease in modulus of elasticity. Increasing temperature beyond 873K, the modulus of elasticity of control mix was 31% and concrete having slag was 23% of its initial values. Khan et al. [40] concluded in their investigation that addition of steel slag increased the modulus of elasticity of concrete. This could be attributed to high crushing strength of concrete (Airey et al., 2004) and its irregular surfaces which makes the bond stronger (Zhou et al., 1995).

Effect on fire resistance of concrete

Netinger et al. [42] analysed the temperature effects on concrete containing steel slag. They concluded that slag in combination with Portland cement could not provide satisfactory resistance of concrete against fire. As the coefficient of thermal expansion of slag is higher, which causes deterioration of contact between aggregate and cement paste.

CONCLUSION

- Glass powder shows good performance in concrete. The optimum value of glass powder in the concrete is 20%. Beyond this level reduction occurs in the mechanical properties of concrete. The air content improves as the glass powder content increases in the mixture. Similarly increase in the workability occurs with the addition of glass powder.
- Mechanical properties of concrete with steel slag are highly influenced by particle size of steel slag. Fine particles results good or similar mechanical properties compare to normal concrete. The increasing content of steel slag have adverse effects on properties of concrete, higher the content of steel slag lesser will be the results for mechanical properties compared to control mix.

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