

Research Paper

SUSTAINABLE PRODUCTION OF SELF-COMPACTING CONCRETE USING FLY ASH AND GRANITE WASTE

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Abstract: This study explores the impact of ground granite waste (GW) as a incomplete additional for fine aggregates in self-compacting concrete (SCC) mixed with fly ash (FA). The study assessed various properties of SCC, including water permeability, water absorption, sorptivity, resistance to chloride attack, drying shrinkage, and carbonation. Water permeability and absorption decreased with up to 30% GW replacement, attributed to the filler effect and better particle packing. However, beyond 30% replacement, permeability and absorption increased due to poor particle gradation and micro-crack formation. Sorptivity and chloride attack resistance improved with up to 30% GW substitution, while mixtures containing 35-50% GW showed superior resistance compared to the control mix. Drying shrinkage decreased with lower GW levels, but higher GW content led to increased shrinkage. Carbonation depth was reduced in mixtures with up to 50% GW replacement, benefiting from refined pore structure. Overall, SCC mixtures with fly ash and up to 30% GW replacement demonstrated enhanced durability, highlighting GW's potential as a sustainable alternative in concrete production.

Keywords: Self-compacting concrete (SCC), ground granite waste (GW), fly ash, water permeability, water absorption, sorptivity, chloride attack, drying shrinkage, carbonation, durability, sustainable concrete.

1. INTRODUCTION

The quick growth of infrastructure in countries like India and China has headed to a significant rise in the request for cement-based products, containing mortar, normal compacted concrete (NCC), and self-compacting concrete (SCC). Among these, SCC has converted particularly common due to its excellent flowability, passing ability, and stability, making it a preferred option in construction. However, the withdrawal of raw materials like cement, sand, and aggregates for these products has resulted in severe environmental challenges, such as greenhouse gas emissions, depletion of groundwater, and erosion of riverbanks. This has prompted the search for sustainable alternatives to natural aggregates. Additionally, industrial growth has generated large amounts of waste, which, if not correctly achieved, can lead to serious ecological and health risks. The use of industrial waste materials, including ceramic waste, fly ash, granite powder, rubber tire waste, plastic waste, and stone industry waste, in construction presents a sustainable solution by minimizing environmental harm and conserving natural resources.

SCC, which was developed in the late 1980s, has transformed the construction industry with its ability to flow through densely reinforced sections without the need for external vibration. This has resulted in reduced labor and energy consumption, faster construction times, and improved design flexibility, homogeneity, and mechanical performance. However, the high cost of SCC, primarily due to the use of a higher cement content (300–600 kg/m³) and chemical admixtures, remains a challenge. To address this, mineral admixtures such as fly ash and ground granulated blast furnace slag (GGBS) are used as incomplete replacements for cement, enhancing both the fresh and hardened possessions of SCC while decreasing its ecological effect by lowering the cement content.

The granite industry, which plays a major role in India's economy, generates significant waste during the cutting and polishing processes, with over 30% of granite being discarded as waste. Improper disposal of granite waste (GW) – either as slurry or dry dust – causes damage to ecosystems and human health, resulting in air and water pollution, reduced soil fertility, blocked sewer systems, and respiratory issues due to the crystalline silica content. Despite these challenges, GW has considerable potential in construction. It can be utilized for soil stabilization, ceramic production, brick and tile manufacturing, paving, cladding, road embankments, asphalt, and in cement-based products like mortar, NCC, and SCC. The use of GW in construction offers various benefits, including cost reduction, improved material strength, enhanced resistance to environmental factors, reduced greenhouse gas emissions, and conservation of natural resources. Moreover, it helps address waste disposal issues, reduces landfill use, and opens up opportunities for recycling and sustainable development.

The purpose of this study is to assess the effects of ground granite waste (GW) as a partial auxiliary for fine aggregates in self-compacting concrete (SCC). The research will focus on examining the impact of GW replacement on key durability parameters. Additionally, the study will investigate the resistance of SCC mixtures to chloride attack, drying shrinkage, and carbonation when blended with fly ash and varying levels of GW. The objective is to identify the optimal level of GW replacement that improves the durability properties of fly ash-blended SCC mixtures, providing insights into sustainable alternatives for enhancing concrete performance.

2. REVIEW OF LITERATURE

In a 2019 study, Cheah et al. studied the water absorption possessions of mortar blends containing up to 100% ground granite waste (GW) as a replacement for fine aggregates. They establish that substituting fine aggregates with up to 60% GW improved water absorption resistance equated to the control mortar. Moreover, the same study reported enhanced shrinkage resistance in blended mortar composites with GW as a fine aggregate substitute.

Similarly, Gupta and Vyas (2018) observed improved water absorption properties when GW was used to replace sand in the mortar mix. Aarthi and Arunachalam (2018) examined the drying shrinkage of self-compacting concrete (SCC) with up to 20% GW as a cement substitute, finding that granite-modified SCC showed better shrinkage resistance.

Gupta and Vyas (2018) also studied the drying shrinkage behavior of mortar composites modified with GW and concluded that replacing fine aggregates with GW decreased the material's resistance to shrinkage deformation. Aarthi and Arunachalam (2018) also investigated the chloride penetration properties of SCC with up to 20% GW as a cement substitute, finding that granite-modified SCC exhibited superior resistance to chloride infiltration.

Singh et al. (2017) assessed the consequence of GW on the water penetrability of normal concrete and found that replacing up to 50% of fine aggregate with GW improved the concrete's resistance to water penetration. They also evaluated the drying shrinkage of normal material with up to 70% GW as a fine aggregate additional and found that up to 40% GW exhibited shrinkage resistance similar to or better than the control mix.

3. MATERIALS & METHODS

3.1 Materials

3.1.1 Cement: The study utilized Ultratech brand 43-grade Ordinary Portland Cement (OPC), which obeys with BIS: 8112 (1989). The cement had a consistency of 27.2%, a specific gravity of 3.18, and a specific surface area of 295 m²/kg. Its chemical composition, analysed via XRF, revealed important quantities of calcium oxide (CaO), silicon dioxide (SiO₂), and other oxides.

3.1.2 Fly Ash: Class F fly ash was sourced locally, compatible to ASTM C618 (2017). The chemical composition, determined by XRF, showed a high presence of silicates and aluminates. Fly ash had a specific gravity of 2.30 and a specific surface area of 350 m²/kg, making it suitable for use in cement-based materials.

3.1.3 Aggregates and Granite Waste: River sand, classified as Zone-II according to BIS: 383 (2016), was used as the fine aggregate with a extreme particle size of 4.75 mm. It had a specific gravity of 2.65 and a water absorption rate of 1.05%. Crushed basalt stone, used as coarse aggregate, had a extreme size of 10 mm, a specific gravity of 2.72, and a water absorption of 0.38%. Additionally, granite waste was sourced in a moist state from a granite cutting facility, dried, and then used as a fine aggregate replacement. This granite waste had a specific gravity of 2.58, a water absorption rate of 4.60%, and a finer particle gradation compared to natural sand.

3.1.4 Water and Chemical Admixture: Tap water was used for the manufacture and preserving of all samples. A poly-carboxylate ether-based superplasticizer, Glenium Sky 8777 (BASF), was used to enhance the workability of the concrete mixtures, adhering to BIS: 9103 (1999).

4. RESULTS AND DISCUSSION

4.1 Water Permeability

Water permeability evaluates the movement of water through an unsaturated sample under applied pressure. The water penetration depth in the SCC mixtures ranged from 12.5 mm to 35.0 mm. Initially, as the fine aggregate was replaced with up to 30% GW, the water penetration depth decreased, but it increased when the replacement level surpassed this threshold. Mixtures containing 35–50% GW showed lower penetration depths than the control mix, which can be recognized to the uneven, angular shape of the GW. This texture helps form interconnected capillaries that block the continuous flow of water. Additionally, the smaller particle size of GW contributed to improved impermeability by filling voids and reducing inter-particle gaps, which strengthened the concrete matrix and decreased porosity. However, when the replacement level exceeded 30%, the permeability increased due to poor particle gradation, which led to micro-cracks and weaker attachment among the cement paste and aggregates. The mixtures with up to 50% GW, excluding the one with 60% replacement, had lower permeability than the control blend, which is attributed to the improved filler effect of the fly ash. The mix with 30% GW replacement showed the least water penetration, likely due to optimal packing, as supported by bulk density and void percentage results. In contrast, the 60% GW mixture exhibited the highest permeability because excess water trapped during the hardening process formed capillaries and voids, creating a continuous pore network.

4.2 Water Absorption

Water absorption processes the extent to which water penetrates unsaturated concrete samples submerged in water. The water absorption values for the SCC mixtures ranged from 3.01% to 3.81%. The control mixture containing fly ash (F30G0) had lower water absorption than the OPC-based control (F0G0), likely due to the finer particle size of fly ash. This aligns with other studies, although some have found higher absorption in fly ash-based SCC due to the larger particle size of fly ash. Replacing fine aggregates with up to 30% GW reduced water absorption, but the absorption increased beyond this level. The reduced absorption in mixtures with GW can be accredited to the improved filler effect of GW, which created a denser, more compact matrix, limiting water ingress. However, after a certain level of GW replacement, the filler effect diminished due to insufficient binder content to compensate for the high surface area of GW. The mixture with 60% GW exhibited the highest absorption, as trapped excess water led to void formation during hardening. Despite this, all fly ash-blended mixtures maintained initial water absorption below 3%, indicating good concrete quality.

4.3 Sorptivity

The sorptivity test measures the water absorption through capillary action, with results displayed as capillary rise over the square root of time. The sorptivity coefficient, which specifies the rate of capillary water rise, revealed that replacing 30% of cement with fly ash reduced the sorptivity coefficient compared to the OPC-based control mix. This reduction is due to fly ash filling microvoids, which hinders water movement. The addition of GW further lowered the sorptivity coefficient, particularly at replacement levels up to 35%.

However, beyond this level, the sorptivity coefficient increased due to an insufficient amount of binder to counterbalance GW's high surface area. The mixture with 60% GW exhibited the highest sorptivity coefficient, likely due to the excess fines in GW that raised binder demand, resulting in a binder shortage. This, in turn, weakened the interfacial changeover zone (ITZ) among the binder and aggregates. Additionally, internal bleeding at higher GW levels contributed to the increased sorptivity by creating capillaries and voids.

5. CONCLUSION

The addition of ground granite waste (GW) to self-compacting concrete (SCC) blended with fly ash significantly improved the concrete's durability up to a 30% replacement level. Mixtures containing up to 30% GW displayed decreased water permeability, absorption, and sorptivity, as well as enhanced resistance to chloride and lower carbonation depths. However, when the GW replacement exceeded 30%, these properties began to worsen, with increased permeability, absorption, sorptivity, and drying shrinkage, likely due to poor particle gradation and inadequate binder content. Fly ash further contributed to the durability improvements by refining the matrix and providing a filler effect. Thus, SCC blends with up to 30% GW are recommended for applications requiring superior durability, offering an eco-friendly solution that reduces waste while improving concrete performance.

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