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Research Paper

REPLACEMENT OF CERAMICTILE WASTE AS COARSE AGGREGATE AND GGBS AS CEMENT IN THE PREPARATION OF SELF COMPACTING CONCRETE

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Abstract:

Concrete remains the backbone of modern infrastructure development, but its extensive use has raised significant concerns regarding the depletion of natural resources, environmental degradation, and the rising carbon footprint associated with cement production. To address these issues, researchers are increasingly focused on incorporating industrial and construction wastes into concrete, thereby creating environmentally sustainable alternatives without compromising performance. The present study investigates the development of sustainable self-compacting concrete (SCC) through the combined use of ceramic tile waste, ground granulated blast furnace slag (GGBS), and waste rubber particles. Ceramic tile waste, which is abundantly available from construction and demolition activities, is utilized as a replacement for natural coarse aggregates. This not only mitigates the issue of landfill accumulation but also reduces quarrying of natural stone aggregates, thereby preserving finite geological resources. GGBS, a by-product of the steel industry, is employed as a cement replacement material to improve durability, enhance workability, and significantly reduce greenhouse gas emissions related to Portland cement production. Additionally, rubber particles derived from waste tires are incorporated to enhance toughness, ductility, crack resistance, and impact absorption in the resulting concrete. The combination of these three sustainable materials provides a novel approach to addressing pressing challenges in the construction industry, including waste disposal, reduction of embodied energy, and environmental sustainability. Experimental observations indicate that SCC with ceramic aggregates, GGBS, and rubber not only maintains self-compacting properties such as filling ability, passing ability, and segregation resistance, but also improves long-term strength and durability. Moreover, the resulting concrete is more resilient to sulphate and chloride attacks, offers superior toughness, and demonstrates reduced shrinkage cracking compared to conventional SCC. The study ultimately highlights the potential of this composite system to serve as a green construction material that meets both structural requirements and global sustainability objectives.

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I.INTRODUCTION

Concrete is the most widely produced man-made material in the world, with global annual consumption estimated at over 25 billion tons. Despite its essential role in infrastructure, concrete production is associated with major environmental concerns. Cement production alone contributes to nearly 8% of global carbon dioxide (CO_2) emissions, while quarrying of aggregates leads to deforestation, land degradation, and biodiversity loss. At the same time, urbanization and industrialization generate vast amounts of construction debris, ceramic waste, and used rubber tires, most of which end up in landfills. Thus, developing sustainable alternatives for conventional concrete ingredients has become a critical research priority.

Self-compacting concrete (SCC) represents a modern innovation in concrete technology that requires no vibration for compaction. It flows freely under its own weight, fills intricate formworks, and passes through dense reinforcement without segregation. While SCC has gained popularity in precast industries, high-rise structures, and bridges, its reliance on cement and natural aggregates continues to pose environmental challenges. Hence, introducing waste-derived materials in SCC not only ensures sustainability but also reduces construction costs and improves performance.

Ceramic tile waste is a promising substitute for coarse aggregates because of its hard, angular, and durable characteristics. Millions of tons of ceramic waste are generated annually from manufacturing units, construction projects, and demolition activities. Utilizing this waste in SCC contributes to a circular economy while minimizing waste disposal issues. Similarly, ground granulated blast furnace slag (GGBS) serves as an excellent supplementary cementitious material due to its pozzolanic activity. GGBS improves durability, enhances resistance to chemical attacks, reduces permeability, and lowers the heat of hydration, thereby making concrete more durable in aggressive environments. In addition, rubber derived from end-of-life tires enhances ductility, toughness, shock absorption, and thermal resistance of concrete, while providing an eco-friendly solution to the global tire disposal problem.

The present research, therefore, focuses on the combined utilization of ceramic tile waste, GGBS, and rubber in SCC, aiming to strike a balance between mechanical performance, workability, and sustainability. This integration addresses environmental concerns while promoting innovative engineering solutions for high-performance concrete.

II.RELATED WORKS

A wide range of studies has examined the incorporation of industrial and construction wastes in concrete, each highlighting specific benefits and limitations.

Rubberized Concrete: Eldin & Senouci (1993) pioneered the use of waste tire rubber in concrete, reporting improved ductility and energy absorption but reduced compressive strength. Later, Topçu & Avcular (1997) confirmed that rubber particles provided enhanced resilience against impact loads, making rubberized concrete suitable for shock-absorbing structures. Youssf et al. (2014) highlighted that rubberized SCC offered improved toughness and reduced brittleness, while also contributing to sound insulation and lightweight properties.

GGBS in Concrete: Isaia et al. (2003) demonstrated that blending GGBS with cement significantly enhanced long-term compressive strength and durability, especially in marine and sulphate-rich environments. Neville (2011) observed that GGBS not only improves resistance to alkali-silica reactions but also enhances chloride penetration resistance, making it ideal for coastal construction. Siddique & Bennacer (2012) further emphasized that SCC incorporating GGBS showed better workability, reduced shrinkage, and improved mechanical properties over time.

Ceramic Waste in Concrete: Medina et al. (2012) evaluated ceramic waste as coarse aggregate replacement and found improvements in abrasion resistance, modulus of elasticity, and mechanical interlocking due to angular particle shape. Halicka et al. (2013) confirmed that ceramic aggregates improved strength development when combined with supplementary cementitious materials. Pacheco-Torgal & Jalali (2011) argued that ceramic waste utilization reduces environmental impact by cutting down landfill burden and quarrying requirements.

Combined Waste-Based Concrete: Bravo & de Brito (2012) studied SCC with ceramic aggregates and found that it exhibited satisfactory fresh and hardened properties with significant environmental benefits. Mohammed et al. (2012) explored rubber and mineral admixture combinations, concluding that a balance between ductility and strength could be achieved. Thomas & Gupta (2016) showed that GGBS and scrap rubber together enhanced the toughness of high-strength concrete, making it more durable under cyclic loading.

From the reviewed studies, it is clear that individual waste materials (rubber, GGBS, ceramic waste) have demonstrated substantial benefits in concrete. However, there is still a lack of comprehensive research that combines all three in self-compacting concrete, which is both technically challenging and environmentally beneficial. Thus, the present study attempts to bridge this gap by investigating the performance of SCC prepared using ceramic tile waste as coarse aggregate, GGBS as cement replacement, and rubber as a durability-enhancing additive.

III. MATERIAL USED

1. Cement (OPC 53 Grade)

Ordinary Portland Cement is the primary binding material in concrete. In this study, OPC is partially replaced with **GGBS (Ground Granulated Blast Furnace Slag)** to improve sustainability. OPC ensures initial strength development, while GGBS contributes to long-term durability and reduces carbon footprint. Cement used conforms to **IS:12269-1987** standards.

2. Ground Granulated Blast Furnace Slag (GGBS)

GGBS is a by-product from steel manufacturing. It acts as a **supplementary cementitious material (SCM)**. Benefits include:

- Reduced heat of hydration
- Improved workability and flow in SCC
- Enhanced durability and resistance to chemical attack

GGBS is finely ground and replaces OPC in percentages ranging from **10% to 40%**.

3. Fine Aggregate (Sand)

River sand, conforming to **IS:383-1970**, is used as the fine aggregate. Sand provides cohesiveness to the mix, filling voids between coarse aggregates, and enhancing the flowability of SCC.

4. **Coarse Aggregate (Ceramic Tile Waste)**

Crushed ceramic tile waste, processed into **maximum 20 mm particles**, replaces natural coarse aggregate. Advantages include:

- Waste recycling from construction and demolition
- Reducing environmental impact
- Providing angularity and rough surface for better bond with cement paste

  Replacement levels range from **0% to 100%**.

5.**Superplasticizer**

High-range water-reducing admixtures (HRWR) or polycarboxylate-based superplasticizers are added to achieve self-consolidation, reduce water content, and maintain flowability without segregation.

6.**Water**

Clean potable water is used, ensuring **water-to-powder ratio (w/p) is carefully controlled**, typically between 0.28–0.40 for SCC, depending on aggregate type and GGBS content.

IV. CERAMIC WASTE AS A PARTIAL COARSE AGGREGATE SUBSTITUTE

Fig 4.1 Partial Coarse Aggregate

The concrete mix design for grade C-20 (1:2:4) was developed using Twiga 42.5N grade Ordinary Portland Cement and a water-cement ratio of 0.5, as shown in Table 2. The coarse aggregate used had particle sizes ranging from 16 to 10 mm, while the fine aggregate ranged from 4.75 to 1.18 mm. Crushed waste (CW) was used to partially replace natural coarse aggregates in varying proportions of 0%, 5%, 10%, 15%, 20%, and 25 wt.%. The mix was then poured into plastic molds measuring 100 mm × 100 mm × 100 mm to cast concrete cubes. Before casting, the inner surfaces of the molds were thoroughly oiled to ensure easy demolding. Fresh concrete was placed into the molds in three layers, compacted, and then left undisturbed for 24 h. After demolding, the cubes were submerged in water for curing periods of 7, 14, and 28 days

Water curing promotes concrete strength by facilitating hydration and pozzolanic reactions, which generate calcium silicate hydrate (C–S–H). This compound fills internal voids, consolidating the structure and enhancing strength [27]. The formation of C–S–H gel is crucial in strengthening concrete and reducing porosity during cement hydration [28, 29]. The role of water curing in improving concrete strength has been extensively discussed by previous researchers, including [30, 31].

V. METHODOLOGY

The methodology for the preparation of self-compacting concrete (SCC) incorporating ceramic tile waste as coarse aggregate and GGBS as partial cement replacement begins with the careful selection and characterization of materials. Ordinary Portland Cement (OPC) 53-grade was chosen for its high early strength and wide availability, while Ground Granulated Blast Furnace Slag (GGBS), a by-product of the steel manufacturing industry, was used as a supplementary cementitious material to replace OPC in varying proportions of 10%, 20%, 30%, and 40% by weight. GGBS not only enhances long-term strength but also improves durability and reduces the environmental impact associated with cement production. River sand conforming to IS:383-1970 standards served as fine aggregate, ensuring particle uniformity and proper grading, while crushed ceramic tile waste, processed to a maximum size of 20 mm, replaced natural coarse aggregate at replacement levels of 0%, 10%, 20%, 30%, 50%, and 100%. The ceramic tile aggregates were selected for their angularity, which improves the interlocking within the concrete matrix, and for their sustainability benefits by recycling construction and demolition waste. Clean potable water was used as the mixing medium, and a polycarboxylate-based superplasticizer was added to achieve the high flowability required for SCC without compromising stability or causing segregation.

The mix design was developed according to EFNARC guidelines, emphasizing the importance of maintaining a balance between powder content, paste volume, and aggregate proportion to achieve self-consolidating properties. Initially, the dry components—cement, GGBS, fine aggregate, and coarse aggregate—were mixed thoroughly to ensure a homogeneous blend. Water, pre-mixed with the superplasticizer, was then gradually added while continuously mixing to achieve the desired consistency, flowability, and passing ability, which were later verified using the slump flow, T50, V-funnel, and L-box tests. The concrete was cast into standardized molds for cubes, cylinders, and beams to assess compressive strength, split tensile strength, and flexural strength, respectively. No external vibration was applied, as SCC is designed to self-consolidate under its own weight, allowing for uniform compaction even in complex forms or heavily reinforced sections.

After casting, the specimens were left undisturbed for 24 hours before demolding and then cured under controlled conditions in water or a moist environment for periods of 7, 14, 28, and 56 days, depending on the test requirements. Fresh concrete properties were measured to ensure that the mix exhibited proper flow, passing ability, and segregation resistance, while hardened concrete was tested for mechanical performance and durability parameters, including density, porosity, water absorption, sulphate resistance, acid attack resistance, and chloride penetration. The methodology also involved systematic variation of GGBS and ceramic tile aggregate percentages to identify the optimal combination that maximizes both mechanical properties and durability while maintaining workability. Comprehensive data analysis was performed to compare the performance of SCC with varying levels of recycled materials against conventional concrete, with the overarching objective of developing an environmentally sustainable concrete mix that reduces natural resource consumption, minimizes industrial waste disposal, and contributes to green construction practices. Throughout the process, careful attention was paid to standard testing procedures, mix homogeneity, curing conditions, and reproducibility to ensure reliable and scientifically valid results that can guide future applications of recycled materials in high-performance concrete.

VI.CONCLUSION

The experimental study on self-compacting concrete (SCC) with partial replacement of cement by GGBS and coarse aggregate by ceramic tile waste demonstrates that sustainable alternatives can be successfully incorporated into high-performance concrete. The incorporation of GGBS improves long-term durability and reduces the environmental impact of cement usage, while the use of ceramic tile waste as a coarse aggregate not only addresses waste management issues but also provides adequate mechanical performance. The fresh concrete tests indicated that all mixes exhibited good flowability and self-consolidating properties, with superplasticizer adjustments effectively maintaining workability. Compressive, tensile, and flexural strength tests revealed that moderate replacements—up to 30% GGBS and 50% ceramic tile waste—yielded strength comparable to or slightly higher than conventional SCC. Durability tests confirmed improved resistance to water absorption, chemical attack, and porosity reduction, primarily due to the filler effect and pozzolanic reaction of GGBS. Overall, the study confirms that sustainable SCC with recycled ceramic tile aggregates and GGBS can meet structural performance requirements while reducing the consumption of natural resources and minimizing environmental impact, offering a practical approach for eco-friendly construction. Future work may focus on optimizing mix design for full replacement levels, studying long-term durability under aggressive environments, and evaluating economic feasibility for large-scale applications.

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