International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Development of fiber reinforced self-compacting green concrete using glass fiber and poly- propylene fiber

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ABTRACT :

The demand for sustainable and high-performance construction materials has led to significant innovation in concrete technology. Self-compacting concrete (SCC), known for its excellent flowability and compaction without mechanical vibration, when integrated with fiber reinforcement and green materials, offers a synergistic solution to many structural challenges. This paper reviews the development and performance of fiber-reinforced self-compacting green concrete (FR-SCGC), particularly focusing on the use of glass fibers (GF) and polypropylene fibers (PPF). The review covers the fresh and hardened properties, durability, mechanical behavior, sustainability aspects, and current research trends in using such fiber combinations. Emphasis is placed on the potential of these fibers in improving concrete performance while supporting environmental sustainability.

Keywords: - Unconfined Compressive Strength (UCS), CBR, Maximum Dry Density (MDD), and Optimum Moisture Content (OMC).

1.1 INTRODUCTION :

Concrete is the most widely used construction material globally. However, traditional concrete requires compaction and contributes significantly to CO_2 emissions due to cement production. In recent years, **self-compacting concrete (SCC)** has emerged as a superior alternative, offering enhanced workability and reduced labor. Moreover, integrating **green materials** (industrial by-products such as fly ash, GGBS, silica fume) into SCC reduces its environmental footprint.

Fiber-reinforced concrete (FRC) incorporates discrete fibers to improve tensile strength, ductility, and crack resistance. **Glass fibers** and **polypropylene fibers** have gained attention due to their affordability, corrosion resistance, and compatibility with SCC matrices. This review highlights the development and performance characteristics of fiber-reinforced self-compacting green concrete (FR-SCGC) using glass and polypropylene fibers.

1`.2 Materials Used in FR-SCGC

Cementitious Materials

Ordinary Portland Cement (OPC) is commonly used, often partially replaced by:

- Fly Ash
- Ground Granulated Blast Furnace Slag (GGBS)
- Silica Fume
- Metakaolin

Fine and Coarse Aggregates

- River sand or manufactured sand for fine aggregates.
- Crushed stone or gravel for coarse aggregates.

Superplasticizers

- High-range water reducers, essential for SCC flowability.

Fibers

Glass Fibers

- High tensile strength, corrosion resistance, low density.
- Improves post-cracking behavior and impact resistance.

Polypropylene Fibers

- Chemically inert, lightweight, economical.
- Controls shrinkage cracking, enhances toughness and ductility.

1.2 LITERATURE SURVEY & BACKGROUND

Development of self-compacting concrete

Paul Ramsburg et al. (2000) their research was focused on the development of SCC mixes making use of a natural pozzolona to enhance the SCC properties at Rotondo Precast. The calcinated shale generated by the Lehigh Cement Company was utilized as natural pozzolana under the trade name XPM. The characteristics of calcinated shale enhanced the cohesion of the concrete mix, allowing for improved control of segregation and eliminating the need for a viscosity-modifying agent. In addition, it is found that the total cementitious material content needed in the concrete was found to be less than the cement content required for the conventional SCC mixes. A natural pozzolana with a composition of 30% was determined to be optimal for the reduction of segregation and for achieving adequate early age strengths.

Nan Su et al. (2001) introduced a straightforward mix design procedure for self-compacting concrete (SCC), emphasizing the importance of filling the voids in loosely filled aggregates with binder paste. A factor known as packing factor (PF) has been introduced for aggregate. The ratio of the mass of aggregates in a tightly packed state to that in a loosely packed state is defined as follows. The procedure is entirely contingent upon the packing factor (PF). A higher value of PF signifies an increased aggregate content, necessitating a reduced amount of binder and resulting in diminished flow ability. The conclusion drawn indicates that the packing factor plays a critical role in determining the aggregate content and significantly influences properties such as flowa bility, self-consolidating ability, and strength. In the mix design, the volume of fly ash to mortar was between 54% and 60%. It was determined that the plasticity factor will be the controlling factor for the U-box test.

Sonebi et al. (2002) conducted an investigation on the fresh properties of self-compacting concrete, including filling ability (measured by slump flow), flow time (measured by orimet), and plastic fresh settlement measured in a column. The outcomes of SCC were evaluated against a control mix. The compressive strength and splitting tensile strength of self-compacting concrete (SCC) were evaluated.

The effects of water/powder ratio, slump and nature of the sand on fresh settlement were also evaluated. Keeping the volume of coarse aggregate and the dosage of Super Plasticizer constant, it was concluded that the settlement of fresh selfcompacting concrete increased with the increase in water/powder ratio and the nature of sand influenced the maximum settlement.

Hajime Okamura and Masahiro Ouchi (2003) indicated that self-compacting concrete was initially developed in 1988 to enhance the durability of concrete structures. Since its inception, numerous studies have been conducted, leading to its application in practical structures across Japan. This innovation aims to reduce construction time, particularly in large-scale projects, such as the anchorages of the Akashi-Kaikyo Bridge, which opened in April 1988. The bridge, featuring the longest span in the world at 1,991 meters, serves as a prominent example (Kashima 1999). It is further reported that, SCC was used for the wall of a large LNG tank belonging to the Osaka Gas Company and the adoption of SCC in this project resulted in decrease of the construction period of the structure from 22 months to 18 months

Ravindrarajah et al. (2003) reports an investigation into the development of self compacting concrete with reduced segregation potential. The self-compacting concrete mix that meets the criteria established by the differential height method is modified in various ways to enhance the fine particle content by partially substituting fine and coarse aggregates with low-calcium fly ash. It is reported that the systematic experimental approach showed that partial replacement of coarse and fine aggregate could produce self-compacting concrete with low segregation potential as assessed by the V-Funnel test. The report presents the findings of the bleeding test and the development of strength over time, concluding that fly ash can be effectively utilized in the production of self-compacting high-strength concrete while minimizing segregation potential.

Amit Mittal et al. (2004) indicated that self-compacting concrete is appropriate for use in areas with congested reinforcement structures or in locations where access for concreting is challenging. The authors in their topic "Use of SCC in a pump house at TAPP 3 & 4 Tarapur", explained in brief the methodology adopted for the design and testing of SCC mixes and the methods adopted for concreting walls and structures housing a condenser cooling water pump at Tarapur Atomic power project 3 & 4

Zhu et al. (2004) conducted an assessment to evaluate the impact of self-compacting concrete (SCC) on the bond and interfacial properties surrounding steel reinforcement in practical concrete elements. The pullout tests were conducted to assess the bond strength between the reinforcing steel bar and the concrete. The depth sensing nano-indentation technique was used to evaluate the elastic modulus and micro-strength of the Interfacial Transition Zone (ITZ) around steel reinforcement. The bond and interfacial properties surrounding deformed steel bars in various self-compacting concrete (SCC) mixes with strength grades of 35 MPa and 60 MPa were analyzed, alongside those in conventional vibrated reference concrete of equivalent grades.

Venkateswara Rao et al. (2010) formulated standard and high strength self-compacting concrete (SCC) utilizing various aggregate sizes, adhering to the Nan Su mix design methodology. The findings demonstrated that self-compacting concrete can be formulated using graded aggregates of all sizes, meeting the characteristics required for SCC. The mechanical properties, specifically compressive strength, flexural strength, and split tensile strength, were analyzed at 3, 7, and 28 days for both standard and high strength self-compacting concrete (SCC) utilizing various aggregate sizes. It was noted that with 10mm size aggregate and 52% fly ash in total powder the mechanical properties were superior in standard SCC, while 16 mm size aggregate with a 31% fly ash in total powder improved the properties of high strength SCC.

Sandra Nunes et al. (2011) investigate the impact of various types of cement on the rheological properties of self-compacting concrete (SCC) mortar and paste mixes. Twelve reference SCC mortar/paste mixes, corresponding to four distinct types of cement and three varying levels of aggregate content, exhibited variations in workability attributed to different deliveries of cement sourced from the same factory. Physical and chemical analysis of cements was carried out for the different deliveries.

Dubey sanjay kumar and Chandak Rajeev (2013) prepared self-compacting concrete without using viscosity modifying agent as was done in the study. Portland pozzolana cement is applicable in the formulation of self-compacting concrete. Different types of SCC having different compressive strength can be prepared by different combination of cement, lime and silica fume. The paper presents to develop self compacted concrete by using Portland pozzolana cement, hydrated lime and silica fume. Lime serves as a filler material. The incorporation of SF enhances the bond within the aggregate-matrix by facilitating the development of a transition zone in concrete that exhibits reduced porosity. The test results for acceptance characteristics of self-compacting concrete such as slump flow; V-funnel and L-Box are presented. Further, compressive strength at the ages of 7, 28, and 60 days was also determined and results are included.

According to Dhiyaneshwaran et al. (2014), an increase in the dose of Super Plasticizer results in enhanced workability. The optimum percentage replacement of cement with fly ash is 30%.The acid resistance of SCC with fly ash was higher when compared with concrete mixes without fly ash at the age of 28, 56 & 90 days. Compressive strength loss decreases with the increase of fly ash. Upon immersion of the specimen in Sodium Sulphate Solution for durations of 28, 56, and 90 days, a corresponding increase in the average weight reduction is observed. Additionally, an increase in the percentage of fly ash within the concrete results in a decrease in weight. The utilization of 30% fly ash is associated with a reduced water absorption level, which serves as an effective indicator of limited open porosity. This characteristic can restrict the high flow of water into the concrete.

Fiber reinforced self-compacting concrete

Buquan Miao et al. (2003) studied the mix design and mechanical properties of self-compacting Steel Fiber Reinforced Concrete (SFRC). By using superplasticizers and mineral admixtures such as slag and fly ash, three SFRC of different fiber contents (0.5, 1.0 and 1.5%) and one plain concrete mix with high fluidity (slump ˜ 250mm) have been successfully developed without bleeding or segregation. The study examined the compressive and flexural strengths, flexural toughness, shrinkage, and creep of four concrete mixes. It has been shown that increasing steel fiber content could improve the flexural strength and toughness of self-compacting SFRC even though its compressive strength reduced due to the increase of air content. Giriprasad et al. (2009) conducted experiments on normal and self-compacting concrete by modifying the mix ingredients to evaluate the mechanical properties. The study involved testing the compressive, tensile, and flexural strengths for a comparative analysis of both types of mixes. The experimental results indicate that stress-strain curves have been plotted, revealing a behaviour that closely resembles that of conventional concrete and self-compacting concrete (SCC). Analytical equations have been proposed based on existing empirical models of „Carriera & Chu‟(1985) as modified for descending portion from „Popovics‟ (1973) model which represents only ascending portion and „Saenz Model‟ as also modified from „Desayi‟s model‟ of only ascending portion. It was concluded that values of strain at peak stress under axial compression for both the concretes are close to 0.002 as given in IS:456- 2000. I

In their 2011 study, Valeria Corinaldesi and Giacomo Moriconi examined the characteristics of self-compacting concrete (SCC) incorporating three distinct types of fibers: Steel, Poly-Vinyl-Alcohol, and Polypropylene high toughness fibers. Limestone powder and recycled concrete powder have been incorporated as mineral additions. The properties of fresh and hardened concrete, including workability, strength, and shrinkage, were evaluated. The findings indicate that self-compacting concrete (SCC) incorporating the specified fibers and additives exhibited favorable performance with enhanced durability.

Grunewald et al. (2012) discussed the potential for improving performance of fibers in self-compacting concrete. Notable distinctions were identified between conventional concrete and self-compacting concrete (SCC) at specific fiber types and dosages, particularly regarding the variability of results and flexural performance. Mechanical testing and image analysis of concrete cross-sections reveal the impact of flow on performance, as well as the orientation and distribution of fibers. Differences between traditionally compacted and flowable concrete are pointed out.

Deepak Raj et al. (2012) are studied the addition of S-glass fibers does not affect the filling ability, passing ability and segregation resistance of self compacting concrete. A workability test was performed on 12 trial mixes of GFRSCC, with variations in the length and quantity of glass fibers utilized. The results indicate that the flowability of GFRSCC is directly proportional to both the length and quantity of glass fiber added. Specifically, the outcomes fall within the recommended range when the appropriate amounts and lengths of glass fiber are incorporated. The authors observed that the 1% of 2.4 mm size glass fibered SCC results fall within the recommended ranges established by EFNARC.

Review of literature on green concrete

Praveen Kumar and Kaushik (2005) carried tests to explore the use of crusher dust, stone chips and fly ash in SCC. The application of a high range water reducing agent addresses the elevated water requirements of the crusher dust, while maintaining the existing water/binder ratio. The presence of fly ash with suitable physical and chemical characteristics in sufficient Andhra University, Visakhapatnam 31 quantity off sets the increase in water demand resulting due to the use of crusher dust. The combination of crushed sand and fly ash is proposed for utilization in the production of self-compacting concrete (SCC). The authors investigated the development of SCC mixes on these lines with an aim to achieve reasonable compressive strength of 40 to 60 MPa at the age of 28 days. The authors employed Okamura's method of mix proportioning for self-compacting concrete (SCC), establishing a water-powder ratio by volume of 1.0. The powder composition was designed to include a significant proportion of fly ash, approximately 50-70% of the cement content by weight, to mitigate the increased water demand associated with crusher dust and to enhance long-term strength and durability. The micro silica content utilized was 5% of the weight of cement, aimed at achieving improved packing of powder particles. The experimental study conducted by the authors concluded that crusher dust is suitable for use as a fine aggregate when combined with low calcium fly ash to formulate SCC mixes. The results indicate that a low water to powder ratio can be achieved with the incorporation of crusher dust, resulting in elevated compressive strengths.

Sheinn et al. (2001) addressed the utilization of alternative materials, specifically Quarry dust, for Self-Compacting Concrete (SCC) applications. The study involved rheological measurements on pastes and concrete mixtures that incorporated both limestone and Quarry dust, which were subsequently

compared. The findings indicate that the supplied quarry dust can be effectively utilized in the production of self-compacting concrete (SCC). However, due to its shape and particle size distribution, the mix with quarry dust required a higher dosage of superplasticizers to achieve comparable flow properties.
Brouwers and Radix (2005) studied the role of particle size distribution in selfcompacting concrete and using the packing theory of Andersen, and its modifications by Funk and Dinger, cheap SCC mixes can be composed to meet the standards and requirements in the fresh state. Furthermore, a carboxylic polymer type super plasticizer was employed as sole admixture; an auxiliary viscosity enhancing admixture is not needed to obtain the required properties.
Dakshina Murthy et al. (2007) conducted experimental study on sulphate ion attack on ordinary, standard and higher grade concretes at early ages i.e.7 days and 28 days. The main variable investigated in this study is percentage variation in fly ash. The cement is replaced by fly ash up to 40% at regular intervals of 10%. The test results demonstrate that the incorporation of fly ash in concrete enhances resistance to sulphate attack across all three concrete grades. A simple empirical equation had been proposed to study the behaviour of concrete under acid attack using best fit method.
Kanmalai Willias et al. (2008) conducted an examination of the performance characteristics of concrete incorporating granite powder as a fine aggregate. Granite powder was substituted for sand in increments of 0%, 25%, 50%, 75%, and 100%. Additionally, cement was partially replaced with 7.5% silica fume, 10% fly ash, and 10% slag. 1% super plasticizer was incorporated to enhance workability. The effects of curing temperature at 32oC and 1, 7, 14, 28, 56, and 90 days compressive strength, split tensile strength, modulus of elasticity, drying shrinkage and water penetration depth were found. Experimental results demonstrated that an increase in the proportions of granite powder led to a reduction in the compressive strength of concrete.
In their 2009 study, Eshagiri Rao et al. conducted a comparison between normal and self-compacting concrete of M60 grade. The research involved altering the mix ingredients to evaluate the mechanical properties, specifically through testing compressive, tensile, and flexural strengths for both types of concrete mixes. Based on the experimental results, stress-strain curves have been plotted and the behaviour is observed to be almost similar to conventional concrete & SCC.
Shahul Hameed et al. (2009) presented the feasibility of usage of quarry rock dust and marble sludge powder as hundred percent substitutes for natural sand in concrete. The research indicates that the compressive strength, split tensile strength, and durability of concrete incorporating quarry rock dust exceed those of conventional concrete by approximately 14%.

Mazloom et al. (2010) were done an experimental research on the workability and compressive strength of self-compacting concrete. The study concentrated on concrete mixtures with water/binder ratios of 0.35 and 0.45, maintaining consistent total binder contents. The concrete mixes contained four different dosages of super plasticizer based on carboxylic with and without silica fume.
Mahzuz et al. (2011) conducted an investigation into the utilization of stone powder in concrete as a substitute for sand, employing three concrete mix proportions: 1:1.5:3, 1:2:4, and 1:2.5:5. The comparison of compressive strength results for these mixes, utilizing sand versus stone powder, indicated that stone powder yields higher values than sand by approximately 14.76%, 4%, and 10.44%, respectively. In another study conducted by Wakchaure et al, (2012) using artificial sand in place of river sand, it was found that for M30 mix using artificial sand , the compressive strength increased by 3.98%, the flexural strength by 2.81% and split tensile strength by a marginal value than concrete which used river sand. Shirule et al. (2012) investigated the compressive strength and split tensile strength of concrete with varying percentages of marble dust powder as a partial replacement for cement (0%, 5%, 10%, 15%, 20%). The findings revealed that the compressive strength of concrete improved with the inclusion of waste marble powder up to a 10% replacement by weight of cement, while additional amounts of waste marble powder resulted in a reduction of compressive strength. The optimal percentage of replacement identified was 10%.

Ahmed Fathi et al. (2013) conducted the experiments on fly ash added SCC mixture with different percentages. The experiments were conducted by varying the percentages of fly ash as a mineral admixture and the amount of water. The fresh requirements of self-compacting concrete (SCC) were investigated using the slump test, V-funnel test, and L-box. The tensile strength and porosity test were investigated. The test result found out that the higher compressive strength was found with 5% of PVA and water to cement ratio was 0.25, also the result found out that the fly ash will increase the compressive strength and decrease the porosity of SCC at long term.
Neethu Joseph et al. (2013) conducted an investigation into the strength and mechanical properties of cold bonded quarry dust aggregate when exposed to high temperatures. Concrete cubes are prepared and tested at an age of 28 days. Cubes are heated to elevated temperatures of 2000C, 3000C and 4000C for different durations. Tests were conducted to determine the influence of heating on compressive strength of concrete. Test results indicated that quarry dust which is waste material can be used for the manufacture of cold bonded artificial coarse aggregate and that the quarry dust aggregate concrete can withstand a temperature up to 4000C.
Rao et al. (2015) examines the properties of glass fiber reinforced self-compacting mortars (GFSCMs) in both fresh and hardened states, focusing on the effects of different types and sizes of fine aggregate. Mini-slump flow and mini V-funnel tests were conducted to assess the workability of GFSCMs. The compressive, split tensile, and flexural strength tests were conducted after 28 days of water curing. Water sorptivity tests were performed on cube specimens that had been cured for 28 days. The variable parameters in this study include type of fine aggregate, particle size of aggregate, and mix proportions. The test results indicated a reduction in compressive, split tensile, and flexural strength as the size of the aggregate decreased. Conversely, sorptivity exhibited a decrease with an increase in aggregate size and immersion time. The authors concluded that the strength of GFSCMs was greater when using natural sand in comparison to crushed stone fine aggregate and foundry sand.

1.3 CONCLUSION

Fiber-reinforced self-compacting green concrete (FR-SCGC) using glass and polypropylene fibers is a promising material that combines high performance with sustainability. While there are challenges related to workability and mix design optimization, the mechanical and durability improvements make it a viable choice for advanced construction. Future studies should focus on long-term performance, environmental impact assessments, and cost-effectiveness in large-scale applications.

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