

Self-Compacting Concrete (SCC) Advances in Mix Design and Field Applications

Rahul Kumar

M.Tech Student, Civil Engineering Department, Sandip University, Sijoul

Abstract - In recent years, research on Self-Compacting Concrete (SCC) has increasingly focused on the development of high-strength variants. High-strength SCC has been widely adopted in applications such as precast bridge components and high-rise building construction. The use of manufactured sand (M-sand) as a fine aggregate provides an effective solution to the depletion of natural sand resources. This study aims to optimize the mix design of high-strength self-compacting concrete incorporating manufactured sand (MSH-SCC). The effects of fine aggregate replacement ratio, sand ratio, and maximum nominal size of coarse aggregate on the performance of MSH-SCC were systematically investigated. The results indicate that the optimized mix proportions for different strength grades satisfy the required performance criteria. It was observed that the fine aggregate replacement ratio and maximum aggregate size significantly influence the workability of SCC, whereas the sand ratio has a comparatively minor effect. Furthermore, the yield stress of MSH-SCC showed a positive correlation with both the fine aggregate replacement ratio and the maximum aggregate size, while plastic viscosity reached peak values under specific conditions. The variation in mix design parameters had only a limited influence on the mechanical strength of the concrete. Overall, this study provides a scientific basis for the mix design of high-strength SCC using manufactured sand and supports its application in sustainable and low-carbon construction practices. In addition, there is an increasing demand for advanced concrete materials that offer high strength, durability, improved serviceability, and cost-effectiveness over an extended service life. Ultra-High Performance Concrete (UHPC), also known as Reactive Powder Concrete (RPC), fulfills these requirements. UHPC is characterized by a very low water-binder ratio (typically less than 0.25) and optimized particle packing, resulting in compressive strengths exceeding 120 MPa and a dense microstructure that significantly reduces permeability. This study also evaluates the compressive strength and durability characteristics of UHPC mixtures incorporating supplementary cementitious materials such as silica fume, nano-silica, and ground granulated blast furnace slag (GGBS) or Alcofine as partial replacements of cement. Steel fibers were included at varying dosages of 0.5%, 1.0%, and 1.5% by volume, with a constant water-binder ratio of 0.18. A comprehensive literature review was conducted to understand global advancements in UHPC. The findings indicate that optimized UHPC mixes with supplementary cementitious materials exhibit excellent performance, particularly in terms of resistance to sulphate attack and chloride ion penetration. The Rapid Chloride Penetration Test (RCPT) results classified all mixes within the "Very Low" to "Negligible" permeability range, as per ASTM C1202 standards.

Keywords: Ultra high-performance concrete (UHPC), Durability properties, Mechanical characteristics, Resistance to chemical attacks, Sustainable infrastructure.

INTRODUCTION

Self-compacting concrete (SCC) can completely fill molds under its own weight, effectively reducing the difficulty of vibrating concrete in building structures with a large amount of reinforcement. It has been widely used in engineering.

The design methods for SCC mix proportions can be mainly categorized into the following types: (a) Design methods for SCC mix proportions based on the fixed aggregate content. This design approach was proposed by Okamura, which involves limiting the aggregate content, using a lower water-to-cement ratio, and employing high-performance water-reducing agents in trial mixes until the desired workability is achieved. (b) Design methods for SCC mix proportions based on the aggregate packing density factors. The basic principle of this method is to treat the cementitious materials and the aggregate

Concrete stands as the cornerstone of construction materials, being widely utilized in the creation of load-bearing structures across the globe. Researchers have long sought materials that offer enhanced performance, enabling the construction of taller, longer, and more robust structures. The usage of cementitious materials traces back thousands of years to civilizations such as those in Italy, ancient Egypt, Greece, and the Middle East. The journey towards modern Portland cement began in 1756 when John Smeaton, in an experiment for lighthouse construction, combined limestone, sand, and additives including pozzolans. The modern production of Portland cement commenced in 1824, pioneered by Joseph Aspdin, an Englishman, and further refined by Isaac C. Johnson in the 1840s. These advancements led to increased demand and costs associated with concrete production, resulting in the creation of stronger and more durable materials.

By the 1950s, concrete with a compressive strength of 34 MPa was considered high strength. Subsequent advancements in concrete development during the 1960s pushed the boundaries further, achieving compressive strengths ranging from 41 to 52 MPa, which became commercially viable and termed as high-strength concrete. By the mid-1960s, concrete with compressive

strengths ranging from 40 to 80 MPa was classified as High-Performance Concrete (HPC), signifying a new era of concrete technology characterized by exceptional strength and durability.

PERFORMANCE CONCRETE

system separately, viewing the mix design as a process of filling the voids between loosely packed aggregates with the cementitious paste. The aggregate packing density factor (PF) is selected based on the target workability of the SCC, and the amounts of coarse and fine aggregates are determined [10,11]. Based on the design strength of the SCC, the amounts of cement, water-to-cement ratio, mineral admixtures, and high-performance water-reducing agents are calculated sequentially [12]. (c) Design methods for SCC mix proportions based on empirical parameters. Based on empirical data, the unit aggregate quantity, cementitious material quantity, and water-to-cement ratio are determined through experience formulae summarized in engineering practice [13,14]. Currently, the Chinese technical specification for the application of SCC, as well as Japanese standards and European guidelines, also follow the basic idea of the empirical trial mix method for designing SCC mix proportions.

(d) Design methods for SCC mix proportions based on statistical factors. Represented by Khayat

and Sonebi, statistical factors are used for the experimental design of SCC mix proportions and the prediction of the related performance. Raw material component parameters are treated as independent variable factors, while the test results are treated as dependent variables. A functional relationship between the SCC mix proportion component parameters and test results is established to calculate the mix proportions.

In general, there are differences in the design methods and standards for SCC mix proportions, and a lack of unified standards and specifications among different mix design methods. More importantly, mix design methods are mainly aimed at low-strength SCC, and there is a relative lack of research on the mix design for high-strength self-compacting concrete (HS-SCC). The engineering application of HS-SCC lacks references. In the past few decades, particularly in countries with a high construction demand like China and India, the design methods and cases for SCC mix proportions have primarily been focused on medium- and low-strength SCC with strength grades below C60. There are relatively few cases of using manufactured sand to prepare SCC with strength grades reaching to C60 or even C80. With the continuous development of infrastructure construction, the demand for high-strength self-compacting concrete in structures such as precast bridge components, high-rise buildings, and hydraulic facilities has been steadily increasing. Existing mix design methods are no longer able to meet the requirements of practical production.

Additionally, SCC is typically made with river sand. However, as high-quality, non-renewable river sand (RS) resources are gradually depleting, there is an increasing call for manufactured sand (MS) to replace natural sand as a fine aggregate in concrete, presenting a good opportunity for the concrete industry to move towards green and low-carbon development. However, SCC has relatively strict requirements for fine aggregates. Although the production of manufactured sand has largely achieved standardization and scalability, the manufactured sand produced from parent rock through processes such as crushing and dust removal still cannot meet the quality standards of high-quality medium sand in terms of the grading, particle shape, angularity, stone powder content, and MB value. On the one hand, the stone powder of MS can improve the cohesiveness and water retention of the mixture, improve the interface performance of the concrete [28], optimize the particle size distribution of the concrete, and improve the compactness. The rough surface of manufactured sand increases the friction between the aggregates [29], facilitating the formation of an interlocking structure, thus enhancing the mechanical properties of the MS-SCC. These characteristics of manufactured sand, however, can significantly reduce the rheology and workability of the SCC, regardless of the rise in the paste matrix, which is beneficial for lowering the flow resistance related to aggregate contacts and frictions. High-strength concrete, with its low water-binder ratio and large dosage of water-reducing admixtures, struggles to maintain good workability. The rough surface of manufactured sand often significantly exacerbates the deterioration of its filling ability. Zhang showed that MS greatly decreased the stability of SCC, and the static stability index increased from 10.3% to 29.13% when the amount of MS exceeded 20%, thus increasing risk of segregation. D. Suriya prepared C50 MS-SCC and also reached the conclusion that the fluidity of the concrete deteriorates with the increase in manufactured sand. Therefore, how to decrease the adverse impacts of manufactured sand on the workability of SCC is one of the key issues in the application of high-strength self-compacting concrete with manufactured sand (MSH-SCC) [34].

Given the lack of a systematic mix design method and performance studies for MSH-SCC, this study replaced part of the river sand with manufactured sand and optimized the SCC mix designs for C40, C60, and C80 concretes, leading to a versatile method for producing high-strength concrete. At the same time, conventional concrete performance tests were conducted to verify the

applicability of the optimized mix proportions. And key mix design parameters were also adjusted, for instance, the replacement rate of the manufactured sand (20, 40, and 60%), the sand ratio (47, 49, and 51% for C40 concrete; 45, 47, and 49% for C60 concrete; 39, 41, and 43% for C80 concrete), and the maximum nominal aggregate size (13, 20, and 25 mm), so to explore the variations in the workability and mechanical strength of MSH-SCC.

2. Materials and Methods

2.1. Raw Materials

Portland cement P·I 52.5 was provided by Ningguo Cement Plant (Xuancheng, China). S95 mineral powder was purchased from Ningbo Henglong Building Materials Technology Co., Ltd. (Ningbo, China). Class I fly ash was provided by Taizhou Power Plant (Taizhou, China). SF-92 silicon fume was purchased from Qinghai Lantian Environmental Protection Co., Ltd. (Xining, China). The chemical compositions of these materials are listed in Table 1.

Table 1. Chemical composition of the used cementitious materials.

Constituents	Fe ₂ O ₃	SiO ₂	Al ₂ O ₃	CaO	MgO	SO ₃	TiO ₂	Loss on Ignition
					(%)			
Cement	3.80	22.15	5.63	66.04	0.96	3.05	1.19	2.21
Fly ash	3.24	58.06	31.28	1.90	0.60	0.85	1.30	1.95
Silica fume	0.20	95.26	0.18	1.43	0.20	0.53	—	2.20
Mineral powder	7.00	50.88	19.41	11.19	1.35	0.69	0.69	2.17

The coarse aggregate used in the experiments was limestone, primarily divided into the following two sizes: 5–10 mm and 10–25 mm. The fine aggregates used consisted of the following two types: river sand and manufactured sand from tuff. Tables 2 and 3, respectively, present the technical specifications for the fine and coarse aggregates, and Figure 1 illustrates the grading curve for the fine and coarse aggregates.

Table 2. Technical characteristics of the coarse aggregate.

Apparent Density	Volume Density	Bulk Density	Porosity	Moisture Content	
	(g/cm ³)	(g/cm ³)	(s)	(%)	(%)
5–10 mm	2.870	2.820	1.70	39.88	0.83
10–25 mm	2.840	2.815	1.71	40.05	0.70

Table 3. Technical characteristics of the fine aggregates.

Apparent Density	Angularity	Crushing Value	Methylene Blue Value	Sand Equivalent	Moisture Content	
	(g/cm ³)	(s)	(%)	(g/kg)	(%)	(%)
MS	2.650	25.16	6.2	1.1	69	2.00
RS	2.610	21.33	11.4	0.2	75	1.42

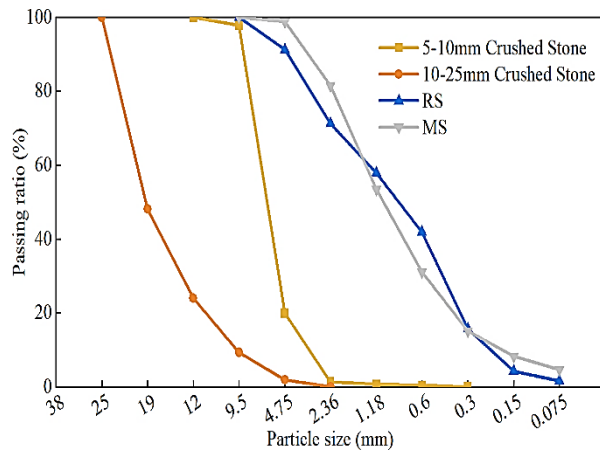


Figure 1. Particle size distribution of the aggregates.

In addition, polycarboxylate superplasticizer (SP) was provided by Jiangsu Sobute New Material Co., Ltd. (Nanjing, China). The dosage of SP was determined based on the optimized mix proportions for the concrete at different strength levels.

2.2. Preparation of MSH-SCC

The cementitious material and dry sand aggregates were mixed for 150 s, and the SP was dissolved in water and then added into the mixture. After mixing for 120 s, the fresh MSH-SCC was obtained and used to test the workability and to fabricate the specimens.

The mixing was carried out under 20 ± 2 °C.

2.3. Workability Test

The workability of the SCC was carried out according to the Chinese standard for SCC [35]. The test used the slump flow, T500, and J-ring flow. Generally, a larger slump flow and shorter slump flow time indicate a better concrete filling performance. The difference between the values obtained from the J-ring flow test and the flow spread was referred to as the PA value; a smaller PA value indicates a better passing ability. The slump flow of the SCC should be the average of two diameters perpendicular to each other on the spread surface after the slump of the concrete mixture stops, measured with a precision of up to 1 mm, and with the results rounded to the nearest 5 mm. A stopwatch was used to measure the time that the concrete took for the slump flow to reach 500 mm, recorded as T500, with a precision of up to 0.1 s. The J-ring should be the average of two diameters perpendicular to each other on the spread surface after the slump of the concrete mixture stops, measured with a precision of up to 1 mm, and with the results rounded to the nearest 5 mm.

Rheological Test

The rheological properties of the concrete were measured using the ICAR coaxial cylinder rheometer, produced in Copenhagen, Denmark. This equipment consists of a computer, a testing bucket, a rheometer, and blades, as shown in Figure 2. Firstly, a stress growth test was conducted on the mixture at a low rotational speed. The mixture showed linear elastic behavior until reaching the yield torque, after which the internal structure was disrupted, causing a gradual decrease in torque. The peak torque value was then used to calculate the static yield stress. After the pre-shear, a flow curve test was performed, and the torque results from the descending segment were used to calculate the dynamic yield stress and plastic viscosity [36].

also referred to as performance-enhanced concrete, belongs to a specialized category of concrete formulations designed to offer advantages beyond those achieved by conventional ingredients, curing methods, and standard mixing practices. Tailored to meet the demands of specific environments and unique applications, UHPC ensures the ability to withstand design loads and deliver exceptional performance within the intended structure. Essentially, UHPC embodies a superior-quality concrete characterized by enhanced strength, improved durability, and long-term stability compared to conventional concrete. Additionally, it may include concrete formulations that significantly reduce construction time while maintaining long-term serviceability.

The current study serves as a continuation of previous research, aiming to explore the durability characteristics of Ultra High-Performance Concrete (UHPC) through three distinct trial mixes. Each mix involves variations in the inclusion of alccofine as a replacement for binder material, with percentages set at 10%, 15%, and 20%. Additionally, consistent amounts of 2% nano silica and 8% silica fume are incorporated into each mix. Furthermore, crimped steel fibers are introduced in three varying percentages: 0.5%, 1%, and 1.5% relative to the weight of cement in each mix. Following the attainment of the desired strength, durability tests are conducted on these three mixes to evaluate their performance over time.

PROPERTIES OF UHPC

- Renowned for its combination of strength, durability, and ductility, UHPC offers a versatile solution for various construction needs.
- UHPC demonstrates enhanced resistance to erosion, corrosion, and abrasion, making it ideal for use in harsh environmental conditions.
- Despite its impressive properties, UHPC is inherently brittle in nature, necessitating careful consideration in design and construction practices.

The literature review on Ultra encompasses various studies conducted by researchers to explore its strength and durability properties, as well as investigate the incorporation of supplementary cementitious materials to enhance its performance.

Yang et al. (2009) examined the feasibility of replacing costly silica fume in UHPC production with alternative materials like natural sands and recycled glass cullet. Their study also investigated the influence of curing temperatures on UHPC's ductility and mechanical properties.

Tuan et al. (2011) explored Rice Husk Ash (RHA) as a potential substitute for silica fume in UHPC formulation, aiming to address cost and availability challenges associated with silica fume.

Al-Azzawl et al. (2011) investigated the performance of UHPC incorporating steel fibers, evaluating the effect of different types of admixtures and steel fiber ratios on its mechanical properties.

Wang et al. (2012) studied the impact of using Ground Granulated Blast Furnace Slag (GGBS) as a partial cement replacement on the compressive strength and fluidity of UHPC.

Tayeh et al. (2012) assessed UHPFRC as a repair material for aging structures, comparing its permeability characteristics with normal concrete.

Xu et al. (2014) focused on HPC's resistance to sulphate attack under various conditions of water-cement ratio, stress ratio, and sulphate concentration.

Ghafari et al. (2014) investigated the effects of incorporating nano silica on UHPC properties, highlighting improvements in durability, pore connectivity reduction, and interfacial bonding enhancement.

Abbas et al. (2016) examined the mechanical and durability characteristics of UHPC with varying lengths and dosages of steel fibers, aiming to optimize its performance.

Li et al. (2020) conducted a comprehensive review of UHPC's durability properties, covering aspects like water and chloride permeability, corrosion, freeze-thaw resistance, and fire resistance.

Alobaidi et al. (2020) proposed a Durability Assessment-based Design approach for structures using Ultra-High-Durability Concrete, developed within the ReSHEALience project, to ensure long-lasting performance in harsh environments.

Borg et al. (2021) contributed to the Horizon 2020 ReSHEALience Project by formulating and validating Ultra High Durability Concrete for structures subjected to extreme conditions.

Gowda et al. (2023) investigated the production of High Early Strength-High Performance Concrete using Ultra-fine Slag and Ultra-fine Silica, examining mechanical properties, durability, and microstructural characteristics.

These studies collectively contribute to advancing the understanding and application of UHPC, addressing key challenges and exploring innovative approaches to enhance its performance and durability.

In the present study, a range of materials including cement, water, aggregates, GGBS, nano-silica, silica fume, and steel fibers were utilized. This chapter outlines the various properties of these materials and the testing procedures employed. The overarching goal was to formulate Ultra High Performance Concrete (UHPC) with a targeted strength exceeding 120 MPa. The primary objective focused on achieving an optimal mix design by determining the appropriate quantities of these materials to attain the desired properties. The experimental setup was designed to assess both the compressive strength and durability characteristics of the UHPC concrete specimens.

In this study, four distinct mixes (M1, M2, M3, and M4) were prepared, with varying percentages of Alccofine replacing 0%, 10%, 15%, and 20% of the weight of cement, respectively. Each mix maintained a low water-binder ratio of 0.18 to facilitate the development of Ultra High Performance Concrete (UHPC). Additionally, four different percentages (0%, 0.5%, 1.0%, and 1.5%) of steel fibers were incorporated into each mix to investigate the compressive strength and durability properties of the UHPC.

For compressive strength evaluation, six cubes were cast for each mix and percentage of steel fibers, tested at both 7 and 28 days. Furthermore, three cubes were cast for each mix and steel fiber percentage to assess sulphate attack on the UHPC. To examine chloride ion penetration, three cylindrical specimens were cast.

RESULTS AND DISCUSSION

The results and discussions on the compressive strength and durability tests conducted on the Ultra High Performance Concrete (UHPC) mixes are outlined below. To enhance the properties, varying percentages of alccofine, nano silica, and silica fume were incorporated into the mix along with cement (OPC 53 Grade) and different sizes of aggregates. The investigation into the properties of UHPC specimens was carried out after 28 days of curing. The experimental program included the following steps:

- Testing the different physical and chemical properties of the materials to develop UHPC.
- Creating various trial design mixes for UHPC to determine the optimal superplasticizer dosage for the desired workability.
- Casting and curing the concrete specimens for 28 days.
- Casting 150 mm x 150 mm x 150 mm cubical specimens to assess compressive strength and sulphate resistance of the concrete.
- Casting cylindrical specimens measuring 100 mm x 50 mm for evaluating chloride ion penetration using the Rapid Chloride Permeability Test (RCPT).

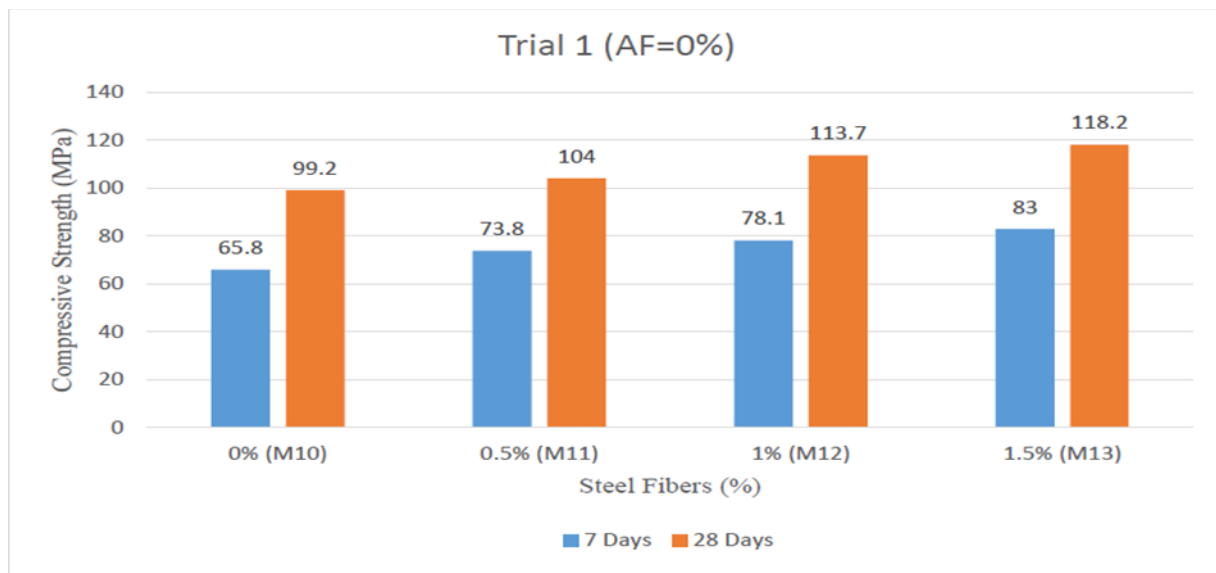


Figure 2: Variation of compressive strength for Trial 1 with AF=0%

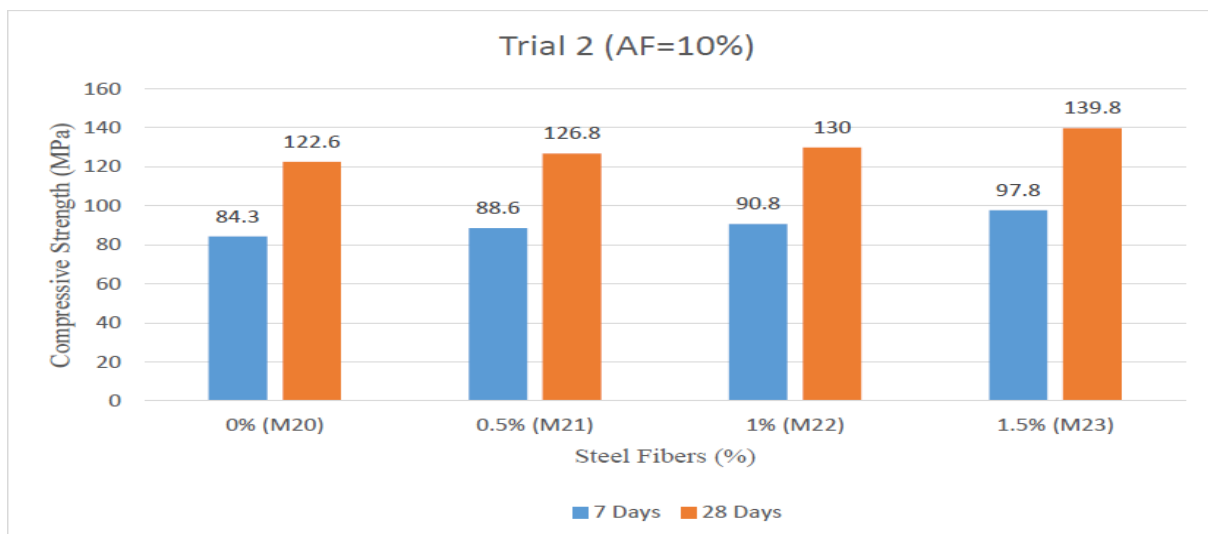


Figure 3: Variation of compressive strength for Trial 2 with AF=10%

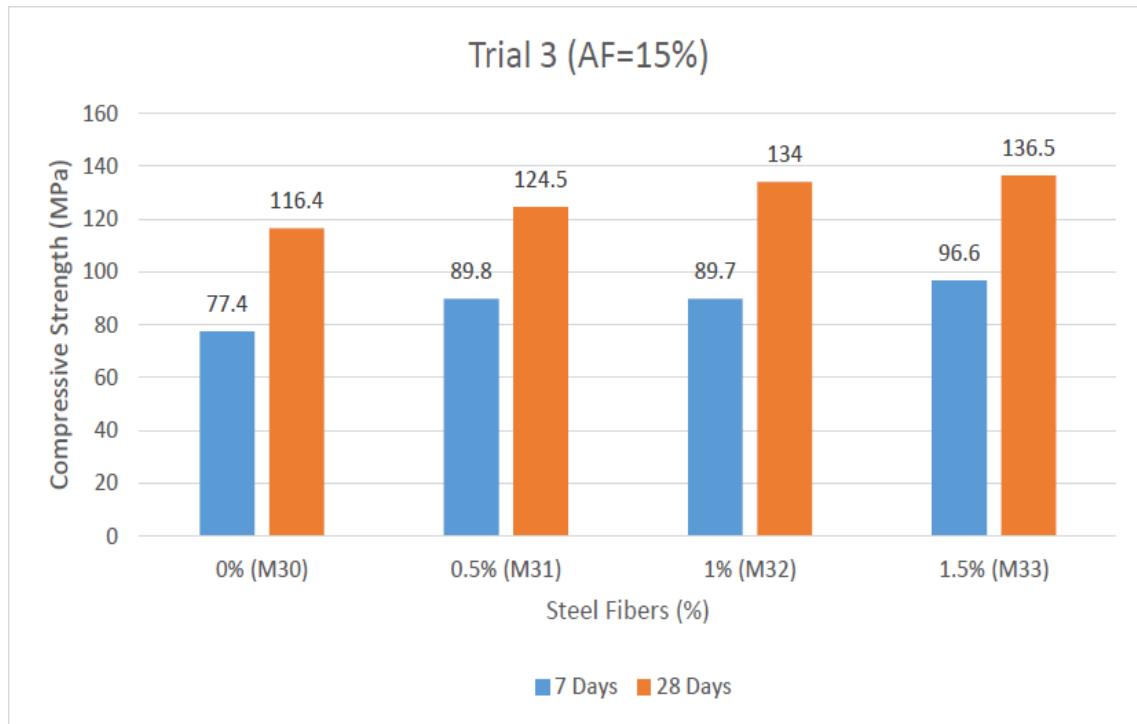


Figure 4: Variation of compressive strength for Trial 3 with AF=15%

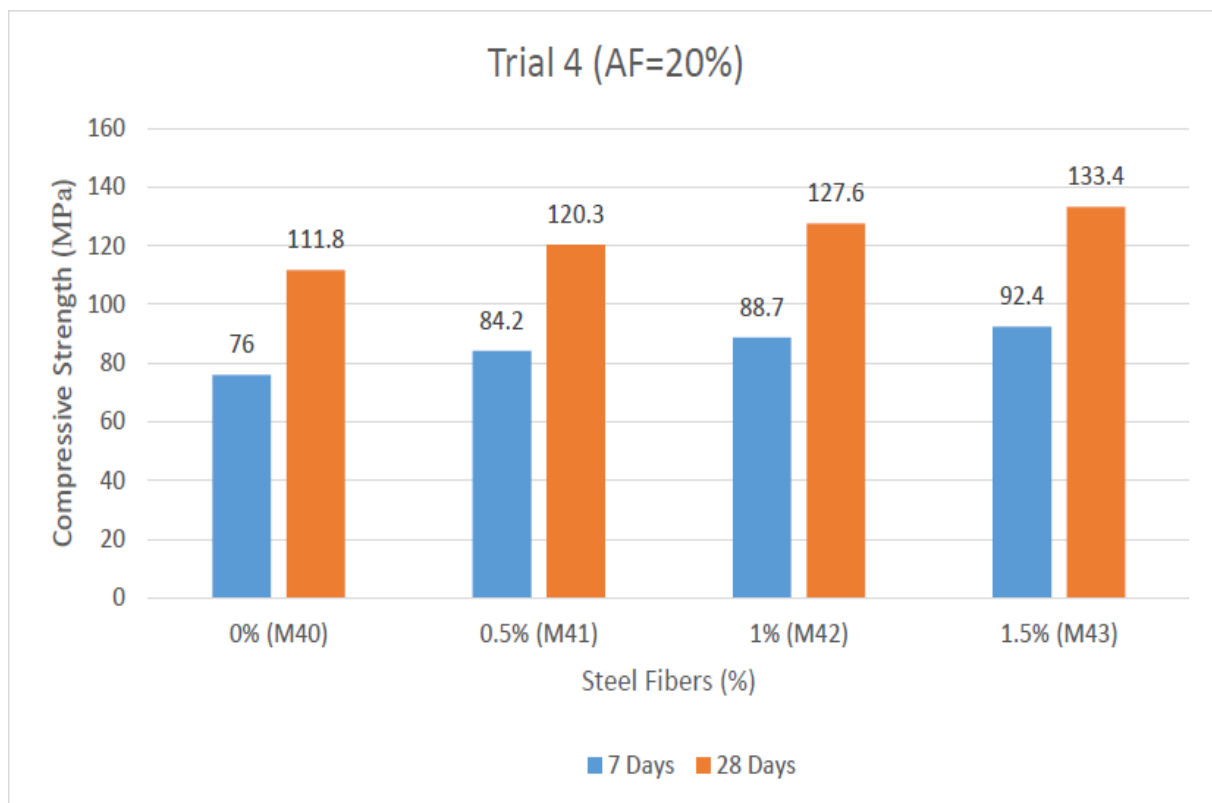


Figure 5: Variation of compressive strength for Trial 4 with AF=20%.

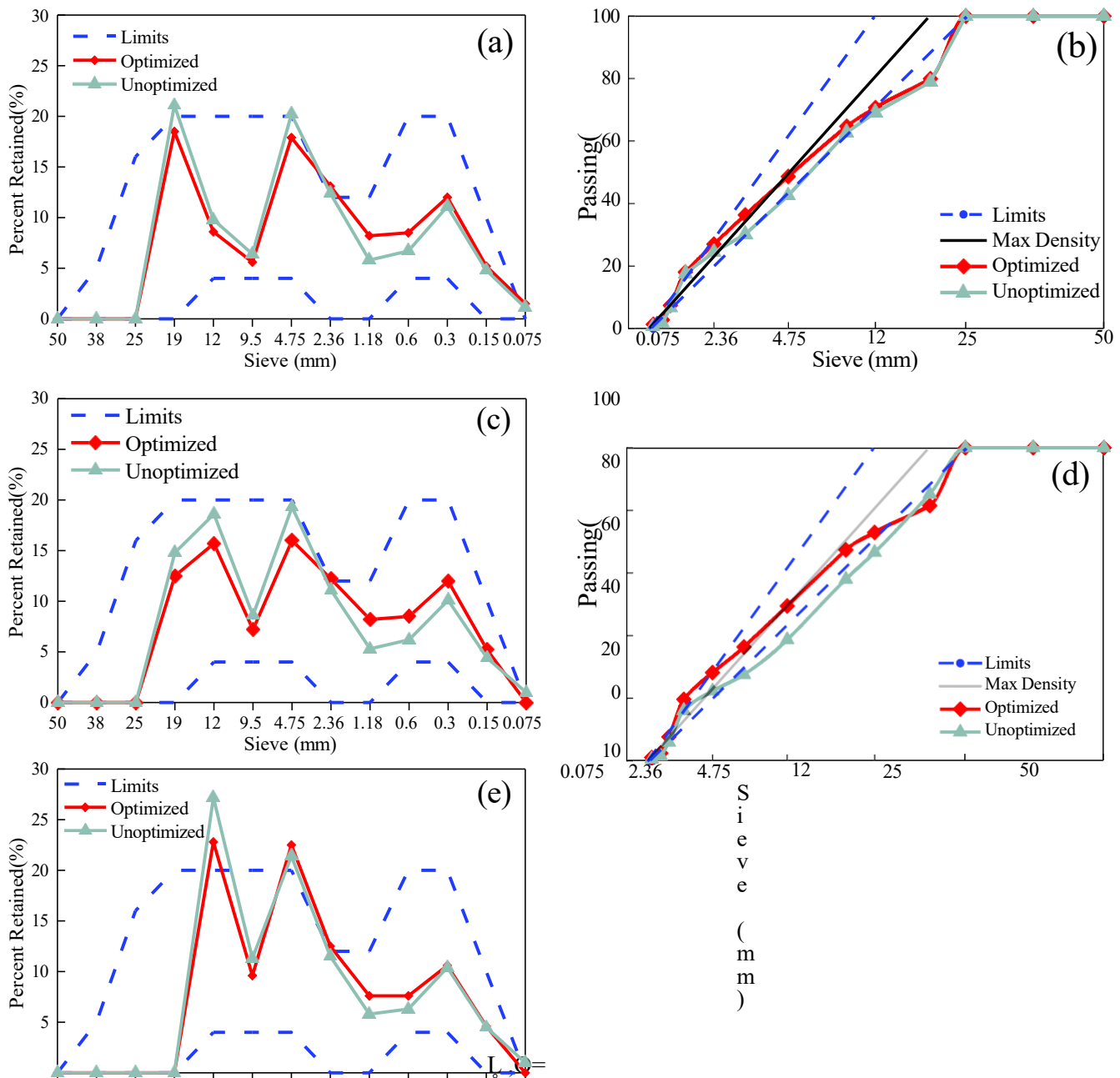


Figure:6 Tarantula Curve for C40 concrete; (b) Power 45 chart for C40 concrete; (c) Tarantula Curve for C60 concrete; (d) Power 45 chart for C60 concrete;

CONCLUSION

The key conclusions regarding the strength and durability characteristics of Ultra High-Performance Concrete (UHPC) are summarized below:

- Compressive Strength:
 - Supplementary cementitious materials like Alccofine (GGBS), silica fume, and nano silica significantly contribute to the development of strength and durability in concrete mixes. Their small particle size aids in filling voids in the concrete matrix, reducing porosity, and increasing density. Additionally, their high pozzolanic nature promotes the production of C-S-H gel, leading to stronger bonds among concrete constituents.
 - The addition of steel fibers can increase compressive strength by up to 16%. Higher steel fiber content correlates with increased compressive strength in concrete mixes.
 - Concrete mixes containing 10% Alccofine exhibit optimal results in compression tests and resistance to sulphate attack, while mixes with 20% Alccofine demonstrate the least chloride ion penetration.
 - UHPC mixes can achieve compressive strength exceeding 120 MPa with a water-binder ratio of 0.18, 8% silica fume, 2% nano silica, and 10%, 15%, or 20% Alccofine replacement for cement.
 - Compressive strength exceeding 130 MPa can be attained in UHPC mixes with the same water-binder ratio, 8% silica fume, 2% nano silica, and 10%, 15%, or 20% Alccofine, along with 1% or 1.5% steel fiber addition.
- Sulphate Attack:
 - Increasing the percentage of steel fibers enhances compressive strength and resistance to sulphate attack in concrete mixes with a constant water-binder ratio. Steel fibers improve bonding between concrete ingredients and reduce porosity, contributing to greater strength and durability.
 - UHPC mixes exhibit resistance to sulphate attack due to the presence of supplementary cementitious materials, which increase impermeability. The best resistance against sulphate attack is observed in mixes containing 10% Alccofine.
- Rapid Chloride Penetration Test (RCPT):
 - Resistance to chloride ion penetration is excellent, with all UHPC mixes classified as 'Very Low' or 'Negligible' according to ASTM C 1202. Increasing the percentage of Alccofine decreases chloride ion permeability.
 - However, higher steel fiber content increases permeability due to their high conductivity, facilitating charge passage through concrete and increasing chloride ion content. The UHPC mix containing 8% silica fume, 2% nano silica, and 20% Alccofine without steel fibers demonstrates the maximum resistance to chloride penetration.

REFERENCES

- [1] Yang, S. L., Millard, S. G., Soutsos, M. N., Barnett, S. J., & Le, T. T. (2009). Influence of aggregate and curing regime on the mechanical properties of ultra-high performance fibre reinforced concrete (UHPFRC). *Construction and Building Materials*, 23(6), 2291-2298.
- [2] Van Tuan, N., Ye, G., Van Breugel, K., Fraaij, A. L., & Dai Bui, D. (2011). The study of using rice husk ash to produce ultra high performance concrete. *Construction and Building Materials*, 25(4), 2030-2035.
- [3] Al-Azzawi, A. A., Ali, A. S., & Risan, H. K. (2011). Behavior of ultra high performance concrete structures. *ARPN Journal of Engineering and Applied Sciences*, 6(5), 95-109.
- [4] Wang, C., Yang, C., Liu, F., Wan, C., & Pu, X. (2012). Preparation of ultra-high performance concrete with common technology and materials. *Cement and concrete composites*, 34(4), 538-544.
- [5] Xu, S. L., Shen, L. H., Wang, J. Y., & Fu, Y. (2014). High temperature mechanical performance and micro interfacial adhesive failure of textile reinforced concrete thin-plate. *Journal of Zhejiang University SCIENCE A*, 15(1), 31-38.
- [6] Abbas, S., Nehdi, M. L., & Saleem, M. A. (2016). Ultra-high performance concrete: Mechanical performance, durability, sustainability and implementation challenges. *International Journal of Concrete Structures and Materials*, 10(3), 271-295.
- [7] Li, Junquan & Wu, Zemei & Shi, Caijun & Yuan, Qiang & Zhang, Zuhua. (2020). Durability of ultra-high performance concrete – A review. *Construction and Building Materials*. 255. 119296. 10.1016/j.conbuildmat.2020.119296.
- [8] Alobaidi, Salam & Bamonte, Patrick & Luchini, Massimo & Mazzantini, Iacopo & Ferrara, Liberato. (2020). Durability-Based Design of Structures Made with Ultra-High- Performance/Ultra-High-Durability Concrete in Extremely Aggressive Scenarios: Application to a Geothermal Water Basin Case Study. *Infrastructures*. 261. 102. 10.3390/infrastructures5110102.
- [9] Borg, Ruben & Cuenca, Estefanía & Garofalo, Roberto & Schillani, Fabrizio & Nasner, Milena & Ferrara, Liberato. (2021). Performance Assessment of Ultra-High Durability Concrete Produced From Recycled Ultra-High Durability Concrete. *Frontiers in Built Environment*. 7. 10.3389/fbuil.2021.648220.
- [10] Gowda, Shanthan & Ranganath, R.V.. (2023). High early strength-high performance concrete produced with combination of ultra-fine slag and ultra-fine silica: Influence on fresh, mechanical, shrinkage and durability properties with microstructural investigation. *Construction and Building Materials*. 10.1016/j.conbuildmat.2023.131462.
- [11] IS 1999 – 1959 (Reaffirmed 1999): Methods of sampling and analysis of concrete, Bureau of Indian Standard, New Delhi.
- [12] IS 383 – 1970: Specification for coarse and fine aggregates from natural sources for concrete, Bureau of Indian Standard, New Delhi.
- [13] IS: 10262 – 1982 (Reaffirmed 2004): Recommended Guidelines for Concrete mix design, Bureau of Indian Standard, New Delhi.
- [14] IS: 10262 – 2009: Recommended Guidelines for Concrete mix Proportion, Bureau of Indian Standard, New Delhi.
- [15] IS: 12269 – 2013: Specification for 53 Grade Ordinary Portland Cement, Bureau of Indian Standard, New Delhi.
- [16] IS: 2386 (Part I, III), 1963: Methods of Test for aggregates for Concrete, Bureau of Indian Standard, New Delhi.
- [17] IS: 4031 (Part 4, 5 and 6) – 1988: Methods of Physical Tests for Hydraulic Cement, Bureau of Indian Standard, New Delhi.
- [18] IS: 456 – 2000: Code of practice – Plain and Reinforced Concrete, Bureau of Indian Standard, New Delhi.