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EXPERIMENTAL STUDY ON STRENGTH OF THE CONCRETE BY PARTIAL REPLACEMENT OF FINE AGGREGATE BY USING WASTE GLASS POWDER

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ABSTRACT

Concrete is a fundamental construction material composed of cement, fine aggregate, coarse aggregate, and water. The high demand for concrete has led to the rapid depletion of natural resources, particularly fine aggregates like sand, resulting in significant environmental concerns and sustainability issues. The extraction of natural sand has adverse ecological impacts, including riverbed degradation, habitat destruction, and increased carbon footprint from transportation and processing. Consequently, there is a growing need to find alternative materials that can partially or fully replace natural fine aggregates and cement to mitigate these problems.

This study investigates the use of waste glass powder (WGP) as a partial replacement for cement in concrete. Various concrete mixes, including a control mix and five experimental mixes with different proportions of WGP, were evaluated for their mechanical properties and durability. Compressive strength, split tensile strength, flexural strength, water absorption, and pulse velocity tests were conducted at various curing days to determine the optimal proportion of WGP. The results indicate that incorporating WGP enhances the mechanical properties and durability of concrete up to an optimal replacement level. Mix 2, with the specific proportion of WGP, exhibited the highest strengths and improved durability, demonstrating the potential of WGP as a sustainable alternative in concrete production. The study concludes that while WGP can significantly enhance concrete properties, the replacement proportion must be carefully controlled to achieve optimal performance and sustainability.

***KEYWORDS**: Concrete, Fine Aggregate, Depletion, Waste Glass Powder (WGP), Partial Replacement, Compressive Strength, Split Tensile Strength, Flexural Strength, Water Absorption, Pulse Velocity, Sustainable Construction, Environmental Impact, Cement Replacement, Mechanical Properties, Durability*

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INTRODUCTION

1.1 General

The construction industry is a significant consumer of natural resources, which has led to the exploration of sustainable alternatives to traditional construction materials. Among these alternatives, the partial replacement of fine aggregate in concrete with waste materials has gained considerable attention due to its potential to reduce environmental impact and enhance material properties. One such promising waste material is waste glass powder (WGP), a by-product of the glass recycling process.

Waste glass, which is often disposed of in landfills, poses a significant environmental challenge due to its non-biodegradable nature. However, glass possesses several advantageous properties, such as high silica content and durability, making it a suitable candidate for reuse in concrete production. The use of WGP not only helps in reducing the burden on landfills but also contributes to the conservation of natural resources by replacing a portion of the fine aggregate in concrete.

This experimental study investigates the effects of partially replacing fine aggregate with WGP on the strength properties of concrete. The primary objective is to evaluate the feasibility and performance of concrete mixes incorporating varying proportions of WGP. The study aims to determine the optimal replacement level that maximizes the mechanical properties ofconcrete while ensuring environmental sustainability.

Concrete, being the most widely used construction material, relies heavily on fine and coarse aggregates for its structural integrity. Fine aggregates, typically composed of natural sand, are essential for achieving the desired workability and strength. However, the extraction of natural sand has led to environmental degradation and depletion of natural resources. Incorporating WGP as a partial replacement for fine aggregate offers a dual benefit: it provides a sustainable solution to waste glass disposal and mitigates the environmental impact associated with natural sand extraction.

This research encompasses a comprehensive experimental program that includes the preparation of concrete mixes with different percentages of WGP. The mechanical properties of these mixes, such as compressive strength,tensile strength, and flexural strength, are evaluated and compared with those of conventional concrete. The findings of this study are expected to provide valuable insights into the potential of WGP as a viable alternative to naturalfine aggregates, promoting sustainable construction practices and contributing to the development of eco-friendly concrete.

In summary, this study explores the innovative use of waste glass powder in concrete, aiming to enhance the material properties while addressingenvironmental concerns. The results will contribute to the growing body of knowledge on sustainable construction materials and pave the way for future research and practical applications in the construction industry.

1.2 Waste Glass Powder (Wgp) and Its EnvironmentalImpact

Globally, millions of tons of waste glass are produced annually. For instance, the United States alone generated approximately 10.5 million tons of glass waste in 2018, with only 33% being recycled, leaving a substantial amount disposed of in landfills (U.S. Environmental Protection Agency, 2018).This poses significant environmental challenges due to glass's non- biodegradable nature and the slow degradation process that can take thousands of years (Crocker, 2010).

1.2.1 Benefits of Using WGP in Concrete

Glass possesses several advantageous properties, such as high silica content and durability, making it a suitable candidate for reuse in concrete production. The use of WGP not only helps in reducing the burden on landfills but also contributes to the conservation of natural resources by replacing a portion of the fine aggregate in concrete. Studies have shown that incorporatingWGP into concrete can enhance its mechanical properties, including compressive strength and durability, due to the pozzolanic reaction between theglass powder and cement hydration products (Ganjian et al., 2009; Ganesan et al., 2013).

1.3 OBJECTIVE OF THIS WORK

The primary objective of this experimental study is to investigate theeffects of partially replacing fine aggregate with waste glass powder (WGP) on the strength properties of concrete. Specifically, the study aims to:

i. To perform the various fresh concrete properties with inclusion of WGP

ii. To evaluate the compressive, tensile, and flexural strength of concrete mixes incorporating various proportions of WGP.

iii. To determine the optimal percentage of WGP that can be used as a partial replacement for fine aggregate to achieve maximum mechanical properties.

iv. To assess the durability characteristics of concrete containing WGP.

v. To conduct the UPV test on concrete samples to know the influence of WGP in concrete.

1.4 SCOPE OF THIS WORK

This study focuses on exploring the use of waste glass powder (WGP) as a partial replacement for fine aggregate in concrete. It involves reviewing existing research, sourcing and preparing materials, and designing concrete mixes with different amounts of WGP. The study will test these mixes for compressive, tensile, and flexural strength, as well as workability and durability. By analyzing the results, the study aims to determine the optimal percentage of WGP for concrete and assess its environmental benefits, ultimately providing practical recommendations for sustainable construction practices.

1.5 ARRANGEMENT OF THE PROJECT WORK

The thesis is structured as follows:

- **Chapter 1: Introduction** – Provides the background, problem statement, objectives, scope, significance, and structure of the study.
- **Chapter 2: Literature Review** – Reviews the existing research on the use of waste materials in concrete, particularly waste glass powder.
- **Chapter 3: Materials and Methodology** – Describes the materials used, mix design, experimental procedures, and testing methods.
- **Chapter 4: Experimental studies, Results and Discussion** – Presents the results of the experimental program and discusses the findings.
- **Chapter 5: Conclusions and Recommendations** – Summarizes the key findings, draws conclusions, and provides recommendations for future research.

CHAPTER 2 REVIEW OF LITERATURE

2.1 GENERAL

The increasing demand for construction materials, coupled with environmental concerns, has spurred interest in sustainable alternatives in concrete production. One such alternative is the use of waste materials, particularly waste glass powder (WGP), as a partial replacement for fine aggregates. This review explores the research and findings related to the use of WGP in concrete, focusing on its effects on concrete properties, environmental benefits, and practical implications. The review will discuss various studies that investigate the mechanical properties of concrete containing WGP, its impact on sustainability, and the challenges associated with its use.

2.2 Properties of Waste Glass Powder

2.2.1 Chemical and Physical Properties

Waste glass powder (WGP) is produced by grinding used glass into a fine powder. Glass primarily consists of silica (SiO_2) along with other oxides like sodium oxide (Na_2O) and calcium oxide (CaO) (Siddique & Naik, 2004). The high silica content of glass contributes to its pozzolanic properties, which can positively influence concrete performance. Siddique (2010) highlights that the fineness of the glass powder is crucial as it affect reactivity and effectiveness as a pozzolan. Finer powders have larger surface areas, enhancingtheir pozzolanic activity and improving concrete properties.

2.2.2 Pozzolanic Properties

WGP exhibits pozzolanic behavior, which means it can react with calcium hydroxide ($Ca(OH)_2$) released during cement hydration to form additional calcium silicate hydrate (C-S-H) gel, enhancing concrete's strength and durability (Hwang & Lee, 2010). This reaction is beneficial as it contributes to a denser microstructure with fewer voids, thus improving the mechanical properties of concrete (Ganjian et al., 2009). Recent studies, suchas those by Manso et al. (2020), reaffirm these findings and indicate that the use of WGP can significantly enhance the microstructural properties of concrete.

2.3 Mechanical Properties of Concrete with WGP

2.3.1 Compressive Strength

The impact of WGP on the compressive strength of concrete has been widely studied. Research by Cordeiro et al. (2009) found that concrete containing up to 20% WGP as a fine aggregate replacement showed comparable or superior compressive strength compared to conventional concrete. More recent studies by Ganesan et al. (2018) have confirmed these results, showing that up to 10% WGP can improve compressive strength by enhancing the bonding between cement and aggregates. However, excessive replacement can lead to reduced compressive strength due to lower density and increased water absorption of glass powder (Cordeiro et al., 2009).

2.3.2 Tensile and Flexural Strength

Tensile and flexural strengths are crucial for assessing concrete's load-bearing capacity and flexibility. Choi et al. (2005) demonstrated that concrete with 10% to 15% WGP exhibited improved tensile strength due to better bonding properties. Recent work by Kumar et al. (2022) also found that concrete mixes with up to 15% WGP had enhanced flexural strength, benefiting from the filler effect and improved microstructure. These findingsare supported by Soudki et al. (2006), who reported similar improvements in flexural strength with moderate WGP content.

2.3.3 Workability

The workability of concrete mixes containing WGP can beinfluenced by the fine glass powder's surface area, which often increases water demand (Siddique & Tabsh, 2005). However, with appropriate adjustments in water content, WGP can improve workability by enhancing cohesiveness and reducing segregation. Recent studies, such as those by Hossain & Jeyaraj(2016), show that concrete incorporating WGP maintains good workability andimproved consistency compared to traditional mixes.

2.4 Durability and Sustainability Aspects

2.4 1 Durability

Concrete durability is critical for long-term performance, particularly its resistance to environmental factors such as moisture, temperature, and chemical attacks. Recent research by Hwang & Lee (2020) indicates that WGP can enhance concrete durability by improving its resistance to sulfate and chloride attacks. The pozzolanic reaction with WGP contributes to a denser microstructure, reducing permeability and enhancing resistance to aggressive agents. Similarly, Zeyad (2019) found that concrete with WGPshowed better resistance to water absorption and aggressive chemicals.

2.4.2 Environmental Benefits

The use of WGP in concrete provides substantial environmentalbenefits. It reduces the volume of waste glass that would otherwise be landfilled and mitigates the environmental impact of natural sand extraction (Siddique & Naik, 2004). Recent studies by Kumar & Kumar (2023) highlight that utilizing WGP in concrete can significantly lower the carbon footprint and promote resource conservation by recycling glass waste and reducing reliance on natural aggregates.

2.5 Challenges and Limitations

2.5.1 Variability in Glass Quality

A challenge in using WGP is the variability in glass quality, which can affect the consistency and performance of the concrete. Differences in glasstypes and contamination levels can lead to inconsistent results (Kumar & Kumar, 2017). Standardizing the quality of WGP is essential to ensure reliable and reproducible results in concrete applications. Recent work by Ganesan et al. (2023) emphasizes the need for rigorous quality control and standardization to address these challenges.

2.5.2 Long-Term Performance

While short-term studies have shown promising results, there islimited research on the long-term performance of concrete containing WGP. Future research is needed to assess the long-term durability and structuralperformance of WGP concrete under varying environmental conditions (Zeyad, 2019). This includes studying the long-term effects on structural integrity, performance under extreme conditions, and potential issues such as shrinkage and cracking.

The incorporation of waste glass powder as a partial replacement for fineaggregate in concrete offers a promising approach to sustainable construction. Research indicates that WGP can enhance mechanical properties, durability, and environmental sustainability of concrete. However, challenges related to variability in glass quality and long-term performance must be addressed through further research and standardization. Overall, the use of WGP aligns with the growing emphasis on eco-friendly construction practices and resource conservation.

2.6 SUMMARY FROM LITERATURE

The incorporation of waste glass powder (WGP) into concrete has been extensively studied due to its promising benefits and sustainability aspects. Research reveals that WGP, composed mainly of silica (SiO_2) along with other oxides such as sodium and calcium oxides, possesses significant pozzolanic properties. This enhances the mechanical properties of concrete, improving compressive, tensile, and flexural strengths when used as a partial replacement for fine aggregates. Studies by Cordeiro et al. (2009) and Kumar et al. (2022) confirm that up to 20% WGP can result in concrete with comparable or superior strength compared to conventional mixes. Additionally, WGP has been shown to positively affect workability, though it may increase water demand, which can be managed with appropriate adjustments. The durability of concrete containing WGP is also notable, with enhanced resistance to sulphate and chloride attacks reported (Hwang & Lee, 2010; Zeyad, 2019). The use of WGP not only offers environmental benefits by reducing landfill waste and lessening reliance on natural aggregates but also aligns with sustainable construction practices.

2.7 NEED FOR PRESENT STUDY

Despite these advantages, several areas require further investigation. There is a need for more research on the long-term performance of concrete with WGP, particularly under varying environmental conditions, to ensure its reliability and structural integrity over time. Quality control issues related to the variability in glass quality also need to be addressed to standardize the performance of WGP in concrete applications. Furthermore, a detailed environmental impact assessment is necessary to quantify the benefits of WGP fully. Optimizing mix proportions to balance performance and workability is another area that requires further exploration. Practical implementation strategies, including economic feasibility and compatibility with existing construction methods, should also be examined. This study aims to fill these gaps by investigating the effects of WGP on concrete properties, optimizing its use, and evaluating its long-term performance, contributing to the advancementof sustainable construction practices.

CHAPTER 3 PROPERTIES OF MATERAILS

3.1 GENERAL

This chapter provides a detailed description of the materials used in this study and their respective properties, which are critical for understanding the behavior and performance of the concrete mixes. The materials examined include Ordinary Portland Cement (OPC) 53 Grade, natural river sand as fine aggregate, crushed granite as coarse aggregate, waste glass powder (WGP), andwater.

3.2.MATERIALS UTILISED IN THIS STUDY

3.2.1 Cement

Lot of factors impact on the strength of concrete, but strength of cement is the most important and direct factor. Ordinary Portland Cement (OPC) 53 grade is used corresponding to IS-8112(1989). Throughout the investigation, a single batch of ultra-tech cement (OPC) is utilized. According to Indian standard code, various properties of cement are evaluated. The physical properties of cement is tabulated in Table 3.1

Table 3.1: Properties of Cement

S.No	Physical Properties	Results
1	Fineness	8%
2	Normal Consistency	30%
3	Initial setting time	78 minutes
4	Final setting time	210 minutes
5	Specific gravity	3.15
6	Compressive strength at 7-days	20.65MPa
7	Compressive strength at 28-days	51.3 MPa

3.2.2 Fine Aggregate

Locally available river sand is used in this investigation. Properties of fine aggregate and sieve analysis are presented in Table 3.2 and 3.3 respectively.

Table 3.2: Properties of Fine Aggregate

S.No	Name of the test	Value
1	Specific Gravity	2.57
2	Water absorption	0.65%
3	Bulk density	1750 kg/m^3
4	Fineness modulus	2.70
5	Moisture Content (%)	0.50

Table 3.3: Sieve Analysis test of Fine Aggregate

I.S. SieveSize	Weight retained (gm)	Cumulative weight retained (gm)	Cumulative percentageweight retained	Cumulative percentageweight passing
10 mm	3	3	0.6	99.4
4.75 mm	8	11	2.2	97.8
2.36 mm	17	28	5.6	94.4
1.18 mm	75	103	20.6	79.4
600 microns	232	335	67.0	33.0
300 microns	120	455	91.0	9.0
150 microns	42	497	99.4	0.6
< 150 microns	3	500	100.0	0.0

3.2.3 Coarse Aggregate

The coarse aggregate is the strongest and least porous component of concrete. The coarse aggregate occupies more than 85% of the volume of concrete. The maximum size of the coarse aggregate was limited to 20 mm. The properties and sieve analysis of coarse aggregates are listed in Tables 3.4 and 3.5.

Table 3.4 Properties of Coarse Aggregate

S.No	Name of the test	Value
1	Specific Gravity	2.70
2	Water absorption (%)	0.5
3	Bulk density (kg/m^3)	1620

Table 3.5: Sieve Analysis of Coarse Aggregate

I.S. SieveSize	Weight retained (gm)	Cumulative weight retained (gm)	Cumulative percentage weight retained	Cumulative percentage weight passing
40 mm	0	0	0	100
20 mm	140	140	7.0	93.0
10 mm	1820	1960	98.0	2.0
4.75 mm	40	2000	100	0

3.2.4 Waste Glass Powder (WGP)

Waste glass powder (WGP) used in this study was obtained by crushing and grinding waste glass bottles to a fineness of 300 µm. The specific gravity of the WGP was 2.50, and its chemical composition predominantly consisted of silica (SiO_2), with minor components of sodium oxide (Na_2O) and calcium oxide (CaO). The pozzolanic activity of the WGP was evaluated by conducting a standard lime reactivity test, which showed a satisfactory reactivity index. The particle size distribution was optimized to ensure adequate pozzolanic reactions with the cement paste, enhancing the overall performance of the concrete. The chemical composition of WGP includes the following major components

Table 3.6: Properties of Waste Glass Powder (WGP)

Property	Value	Standard/Specification
Specific Gravity	2.50	ASTM C618
Fineness (Passing 300 µm sieve)	100%	ASTM C618

Table 3.7: Chemical composition of WGP

Component	Percentage (% by weight)
Silica (SiO_2)	72.0
Sodium Oxide (Na_2O)	14.0
Calcium Oxide (CaO)	10.0
Aluminum Oxide (Al_2O_3)	1.5
Magnesium Oxide (MgO)	0.5
Potassium Oxide (K_2O)	0.3
Iron Oxide (Fe_2O_3)	0.2

Figure 3.1: Waste Glass Powder (WGP).

Specific Gravity

The specific gravity of WGP is 2.50, which is lower than that of conventional fine aggregates. This property indicates that WGP is lighter,which can influence the overall density of the concrete mix.

Fineness

WGP used in this study passes through a 300 µm sieve entirely, ensuring a fine particle size. The fineness of WGP is crucial as it affects the material's pozzolanic activity. Finer particles provide a larger surface area for the chemical reactions that occur during the hydration process, potentiallyenhancing the strength and durability of the concrete.

Chemical Composition

The chemical composition of WGP predominantly consists of silica (SiO_2), which is beneficial for its pozzolanic properties. The presence of sodium oxide (Na_2O) and calcium oxide (CaO) also plays a role in the chemical reactions that occur within the concrete matrix, contributing to the overall performance of the concrete. Table 3.6 and 3.7 shows the properties ofWGP. Figure 3.1 depicts the sample of WGP.

3.2.5 Water

Potable water free from impurities and conforming to IS: 456-2000 standards was used for both mixing and curing the concrete. The pH value of the water was 7, ensuring that it was neutral and would not adversely affect the hydration process or the durability of the concrete.

3.3 Concrete Mix Design

The mix design process for M30 grade concrete involves selecting appropriate proportions of cement, fine aggregate, coarse aggregate, and water to achieve the desired strength and durability. In this study, Waste Glass Powder (WGP) is used as a partial replacement for fine aggregate. The replacement levels of WGP range from 10% to 30% in increments of 5%.

3.4 Mix Proportions by Weight

The mix proportions by weight for M30 grade concrete, based on the above calculations, are as follows: Table 3.8 depicts the mix proportions of all mixes and Table 3.9 lists the mix identification of each mixes.

Table 3.8: Mix Proportions

Mix Combination	Cement(kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Water (kg/m³)	WGP (kg/m³)
Control mix	379.60	674.54	1108.43	186	0
Mix 1	379.60	607.09	1108.43	186	67.45
Mix 2	379.60	573.36	1108.43	186	101.18
Mix 3	379.60	539.63	1108.43	186	134.91
Mix 4	379.60	505.91	1108.43	186	168.64
Mix 5	379.60	472.18	1108.43	186	202.36

Table 3.9: Mix Identification

Mix	Replacement Level
Control mix	0% WGP
Mix 1	10% WGP
Mix 2	15% WGP
Mix 3	20% WGP
Mix 4	25% WGP
Mix 5	30% WGP

CHAPTER 4 EXPERIMENTAL PROGRAMME

4.1 INTRODUCTION

In the pursuit of enhancing concrete properties, an experimental programme was designed to investigate the effects of Waste Glass Powder (WGP) as a partial replacement for fine aggregate. This programme includes a series of tests to evaluate the workability, mechanical strength, durability, and other key characteristics of the concrete mixes. The tests performed are as follows: workability tests (Slump test, Compaction factor test), mechanical strength tests (Compressive strength, Split tensile strength, Flexural strength), durability tests (Water absorption, Sulphate attack), and Ultrasonic Pulse Velocity (UPV) test.

4.1.1 Batching, Mixing and Curing Process

Batching is the initial process where the precise quantities of each component are measured. There are two primary methods of batching: weigh batching and volume batching. In weigh batching, the components are measured by weight using calibrated scales, ensuring high accuracy and consistency. This method is preferred for large-scale construction projects where precision is crucial. In contrast, volume batching uses containers of fixed volume to measure the materials, which is simpler but less accurate.

Mixing follows batching and involves combining the measured materials to achieve a homogeneous mixture. The mixing process can be performed using different methods. Hand mixing is a traditional technique where the components are manually mixed on a clean surface, usually suitable for small quantities. However, it is labor-intensive and less consistent. For larger volumes, mechanical mixing is employed, using concrete mixers to ensure a uniform mixture. Mechanical mixers are more efficient and provide a consistent mix, crucial for achieving the desired strength and workability of theconcrete.

After mixing, curing is the final crucial step that involves maintaining adequate moisture and temperature conditions to allow the concrete to set and gain strength. Proper curing helps in preventing the premature drying of the surface and ensures that the concrete reaches its maximum strength. Curing methods include covering the concrete with wet burlap, applying curing compounds that retain moisture, or using water spraying techniques. The curing process typically lasts for a minimum of 7 days, although some projects may require longer to achieve optimal results.

7 Days Curing: At this stage, concrete typically gains a significant portion of its compressive strength. Curing during this period is essential to prevent the surface from drying out prematurely, which can lead to surface cracking and reduced durability. The primary goal of curing at 7 days is to ensure that the initial hydration of cement continues effectively. The concrete should be kept moist through methods such as wet curing with water, covering with wet burlap, or applying curing compounds that retain moisture.

14 Days Curing: By 14 days, concrete continues to strengthen and approach its intended strength more closely. The hydration process is still ongoing, and proper curing remains critical to achieving the desired strength and durability. At this point, the concrete should still be protected from drying and temperature extremes. Extended curing methods, like keeping the surface covered and periodically moist, help prevent premature drying and support further strength development.

28 Days Curing: The 28-day mark is a standard reference point for assessing concrete's full strength potential. By this time, concrete typically reaches about 70-90% of its ultimate compressive strength. Proper curing up to this stage ensures that the concrete achieves its design strength and durability characteristics. Although most of the strength gain occurs within the first 28 days, continued curing beyond this period may further enhance the concrete's properties, especially in critical applications.

Each step in the concrete production process is essential for ensuringthe durability, strength, and overall quality of the final product. Proper batching, mixing, and curing practices contribute significantly to the performance and longevity of concrete structures.

4.2 WORKABILITY TESTS

4.2.1 Slump Test

The slump test is conducted to determine the consistency of fresh concrete and its workability. The procedure involves cleaning the slump cone and dampening it with water, placing the cone on a flat, non-absorbent surface, and filling it with concrete in three layers, each approximately one-third of the cone’s height. Each layer is compacted with 25 strokes of a tamping rod. After leveling the top surface, the cone is carefully lifted vertically upwards. The slump is measured by determining the difference in height between the top of the cone and the highest point of the slumped concrete. A high slump indicates high workability, while a low slump indicates low workability. The slump test setup is depicted in Figure 4.1.

Figure 4.1: Slump Test.

4.2.2 Compaction Factor Test

The compaction factor test assesses the workability of concrete with low and medium workability. The procedure begins with filling the upperhopper with fresh concrete and leveling it. The trap door is then opened toallow the concrete to fall into the lower hopper, followed by opening thesecond trap door to let the concrete fall into the cylinder. The excess concrete is struck off to level the top of the cylinder, and the filled cylinder is weighed to record its mass (M1). The cylinder is then emptied and refilled with the same concrete in layers, compacting each layer thoroughly, and weighed again to record the mass of fully compacted concrete (M2). The compaction factor is calculated by dividing the mass of partially compacted concrete (M1) by the mass of fully compacted concrete (M2). The compaction factor test setup is illustrated in Figure 4.2.

Figure 4.2: Compaction Factor Test

Table 4.1: Test findings on Workability Tests.

S.No	Mix Combination	Slump in mm	Compaction Factor
1	Control mix	82	0.91
2	Mix 1	80	0.90
3	Mix 2	77	0.89
4	Mix 3	74	0.87
5	Mix 4	70	0.85
6	Mix 5	68	0.82

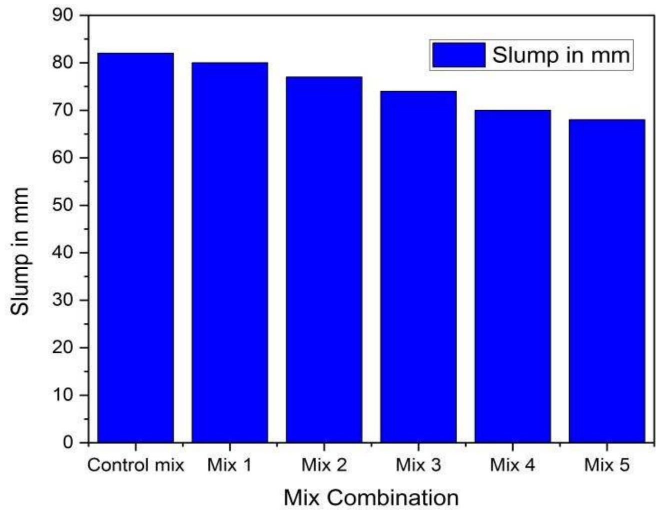

Figure 4.3: Test Findings on Slump Test.

Figure 4.1 and 4.2 exhibits the slump and compaction factor test. The slump test results show a decreasing trend in workability with an increase in WGP replacement percentage. The control mix without WGP exhibited the highest slump value, indicating higher workability. As the WGP content increased, the slump values decreased, which suggests that the addition of WGP reduces the workability of the concrete mix. This can be attributed to the angular and irregular shape of the glass particles, which may hinder the free flow of the concrete mix.

The compaction factor test results are consistent with the slump test findings. The compaction factor values decrease with increasing WGP content, indicating a reduction in workability. The control mix achieved the highest compaction factor, while Mix 5 with 30% WGP replacement recorded the lowest value. The decline in compaction factor with higher WGP percentages further confirms that incorporating WGP into the concrete mix affects its flowability and ease of compaction.

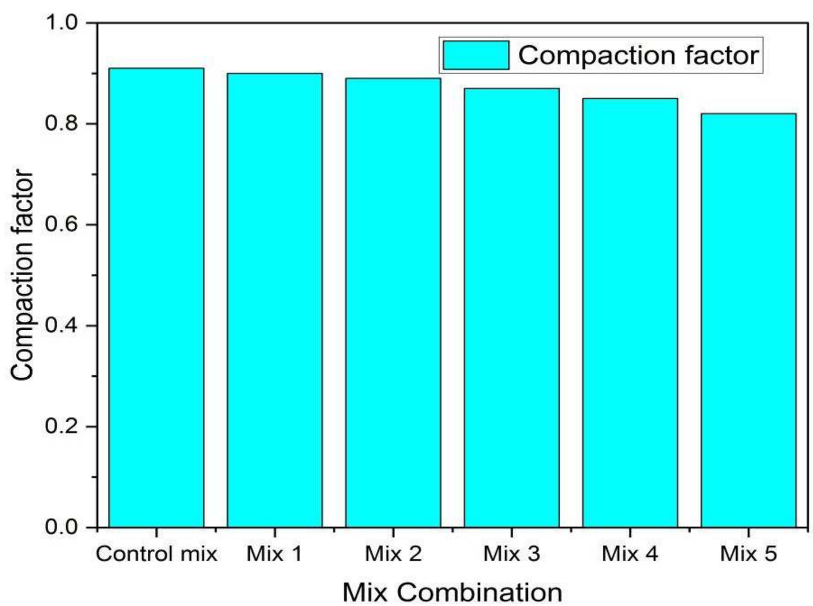

Figure 4.4: Test findings on Compaction Factor Test.

4.3 Mechanical Strength Tests

4.3.1 Compressive Strength Test

The compressive strength test determines the compressive strengthof hardened concrete. Concrete cubes of size 150mm x 150mm x 150mm are prepared and cured for the specified period (usually 7, 14, or 28 days). After curing, the cubes are removed from the curing tank and allowed to surface dry. Each cube is then placed in a compression testing machine, and the load is gradually applied at a rate of 140 kg/cm² per minute until the cube fails. The maximum load applied to the cube before failure is recorded, and the compressive strength is calculated by dividing the maximum load by the cross-sectional area. The casting of cube specimens are depicted in Figure 4.5. thetest results are summarized in Table 4.2.

Figure 4.5: Casting of Cubes.

Table 4.2: Test Results on Compressive Strength Test

S.No	Mix Combination	Compressive strength (N/mm²)		
		7 days	14 days	28 days
1	Control mix	19.85	25.20	33.02
2	Mix 1	20.65	27.12	33.98
3	Mix 2	21.78	28.07	34.52
4	Mix 3	20.58	27.80	32.02
5	Mix 4	20.16	26.54	31.66
6	Mix 5	19.75	24.23	31.05

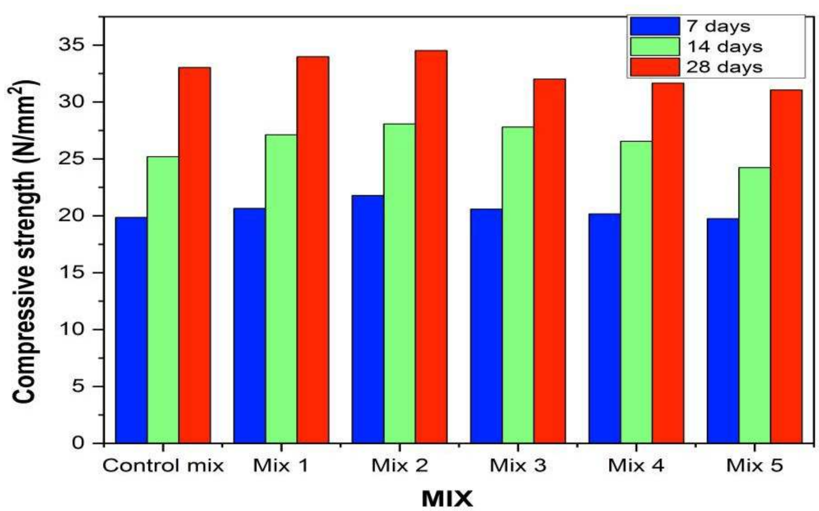

Figure 4.6: Development of Compressive Strength

Figure 4.6 shows the development of compressive strength at various curing days. The study investigates the compressive strength of various concrete mixes, including a control mix and five experimental mixes with varying proportions of waste glass powder (WGP) as a partial replacement for cement. Compressive strength tests conducted at 7, 14, and 28 days revealed that Mix 2, with a certain proportion of WGP, achieved the highest compressive strengths of 21.78 N/mm², 28.07 N/mm², and 34.52 N/mm², respectively, indicating the optimal replacement level for maximizing strength. While Mix 1 and Mix 3 also showed improved strengths compared to the control mix, further increases in WGP content in Mixes 4 and 5 led to a reduction in strength. The control mix recorded strengths of 19.85 N/mm², 25.20 N/mm², and 33.02 N/mm², serving as a baseline. The results suggest that while WGP can enhance compressive strength up to an optimal point, excessive replacement may diminish these benefits, highlighting the importance of balancing WGP content for optimal concrete performance.

4.3.2 Split Tensile Strength Test

The split tensile strength test indirectly determines the tensile strength of concrete. Concrete cylinders of size 150mm diameter and 300mm height are prepared and cured for the specified period. After curing, the cylinders are removed from the curing tank and allowed to surface dry. Each cylinder is placed horizontally between the loading surfaces of the compression testing machine, and the load is gradually applied until the cylinder splits along the vertical diameter. The maximum load applied before failure is recorded, and the split tensile strength is calculated using the formula:

$$\text{Split Tensile Strength} = \frac{2P}{\pi LD}$$

Where, P is the compressive load on the cylinder; L is the length of cylinder and D is the diameter of the cylinder. Cylinders of 150mm diameter and 300mm length were cast, cured and 3 numbers were tested sequentially at a time on the 7th, 14th and 28th day of casting and the average values obtained were compared with that of the control specimen. Figure 4.7 shows the schematic diagram of split tensile test.

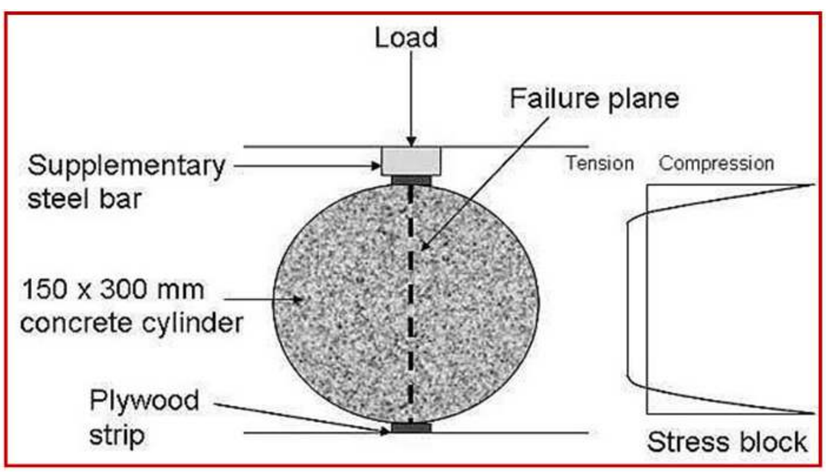

Figure 4.7: Schematic Diagram of Spilt Tensile Strength.

Figure 4.8: Experimental Setup for Split Tensile Strength.

Table 4.3 Test Results on Split Tensile Strength.

S.No	Mix Combination	Split tensile strength (N/mm²)		
		7 days	14 days	28 days
1	Control mix	3.02	3.45	4.68
2	Mix 1	3.28	3.65	4.72
3	Mix 2	3.47	3.73	4.78
4	Mix 3	3.45	3.70	4.70
5	Mix 4	3.42	3.65	4.65
6	Mix 5	3.34	3.57	4.52

Figure 4.8 illustrated the test setup for split tensile test. Table 4.3 lists the test results on split tensile strength test. The study evaluates the split tensile strength of various concrete mixes, including a control mix and five experimental mixes with different proportions of waste glass powder (WGP) as a partial cement replacement. The split tensile strength was measured at 7, 14, and 28 days. Mix 2 exhibited the highest strengths of 3.47 N/mm², 3.73 N/mm²,and 4.78 N/mm², respectively, at these intervals, suggesting it as the optimal mix. Mixes 1 and 3 also showed improved strengths compared to the control mix, which recorded values of 3.02 N/mm², 3.45 N/mm², and 4.68 N/mm², respectively. However, further increasing WGP content in Mixes 4 and 5 led to a decrease in split tensile strength, with Mix 5 having the lowest values of 3.34 N/mm², 3.57 N/mm², and 4.52 N/mm². These results indicate that while WGP can enhance split tensile strength up to an optimal level, excessive WGPreplacement may reduce these benefits, emphasizing the need to balance WGP content for optimal performance. Figure 4.9 indicated the variation in split tensile strength.

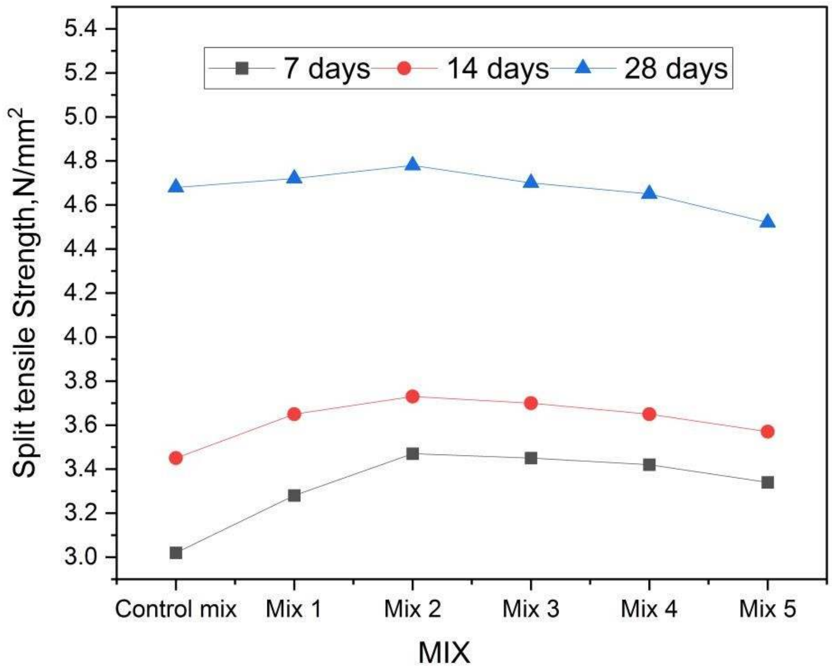

Figure 4.9: Development of Split Tensile Strength.

4.3.3 Flexural Strength Test

The flexural strength test determines the flexural strength of concrete. Concrete prisms of size 100mm x 100mm x 500mm are prepared and cured for the specified period. After curing, the prisms are removed from the curing tank and allowed to surface dry. Each prism is placed in a flexuraltesting machine with the loading points at one-third spans of the prism length. The load is gradually applied until the prism fails, and the maximum load applied before failure is recorded. The flexural strength is calculated using the formula:

Flexural Strength = $\frac{PL}{bd^2}$

where P is the maximum load,

L is the span length, b is the width,and d is the depth of the prism.

Figure 4.10: Experimental Setup for Flexural Strength.

Table 4.4: Test Results on Flexural Test

S.No	Mix Combination	Flexural strength (N/mm^2)		
		7 days	14 days	28 days
1	Control mix	2.98	4.12	6.85
2	Mix 1	3.02	4.20	6.93
3	Mix 2	3.18	4.25	7.06
4	Mix 3	3.10	4.18	7.00
5	Mix 4	3.04	4.02	6.93
6	Mix 5	2.98	3.95	6.89

Figure 4.11 depicts the variation in flexural strength at various curing days. The study assesses the flexural strength of various concrete mixes,including a control mix and five experimental mixes with different proportions of waste glass powder (WGP) as a partial cement replacement. Flexural strength was measured at 7, 14, and 28 days. Mix 2 demonstrated the highest flexural strengths at all intervals, with values of 3.18 N/mm², 4.25 N/mm², and 7.06 N/mm², indicating it as the optimal mix. Mixes 1 and 3 also showed improved flexural strengths compared to the control mix, which recorded values of 2.98 N/mm², 4.12 N/mm², and 6.85 N/mm², respectively. However, increasing the WGP content further in Mixes 4 and 5 resulted in reduced flexural strengths, with Mix 5 exhibiting the lowest values of 2.98 N/mm², 3.95N/mm², and 6.89 N/mm². These results suggest that while WGP can enhance flexural strength up to an optimal point, excessive replacement may decrease these benefits, highlighting the importance of balancing WGP content for concrete performance optimal

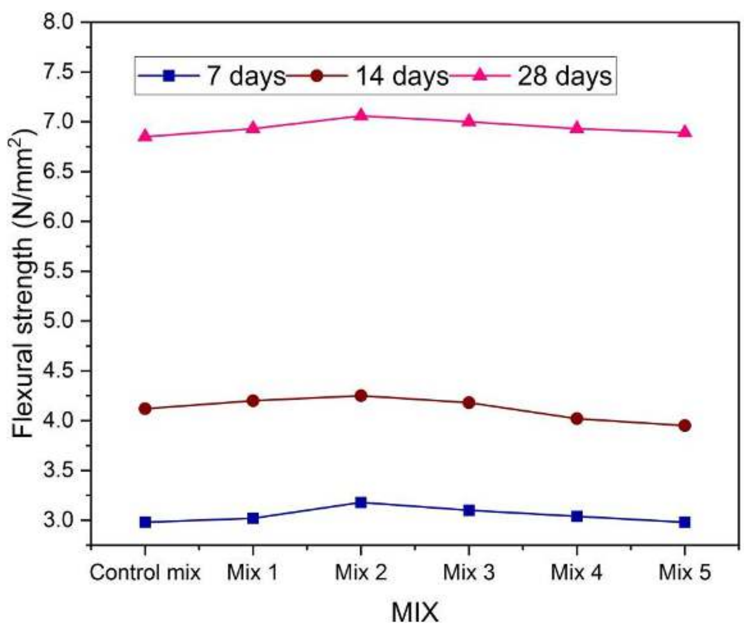

Figure 4.11: Development of Flexural Strength Test.

4.4 DURABILITY TESTS

A concrete is said to be durable if it withstands the conditions for which it has been designed over a period of years without any deterioration. Hence the production of concrete involves appropriate selection and proportioning of the constituents to produce a composite mainly characterised by its low porosity and pore structure. The durability tests are presented in this chapter. The following durability test were performed on the WGP addedconcrete specimen.

4.4.1 Water Absorption Test

The water absorption test measures the water absorption capacity of hardened concrete, indicating its porosity and permeability. Concrete cubes of size 150mm x 150mm x 150mm are prepared and cured for the specified period. After curing, the cubes are dried in an oven at 105°C until a constant weight is achieved, and the dry weight (W1) is recorded. The cubes are then immersed in water for 24 hours. After immersion, the cubes are removed, wiped off excess water, and weighed to obtain the wet weight (W2). The water absorption is calculated using the formula:

Percentage of saturated water absorption = $\frac{W2-W1}{W1}$ X 100

Where, W1= Weight of specimen after drying at oven temperature of 105° CW2= Weight of specimen at saturated condition (saturated weight)

Table 4.5 Water Absorption Test

MIX ID	Water Absorption (%)
Control mix	3.19
Mix 1	2.97
Mix 2	2.96
Mix 3	2.84
Mix 4	2.81
Mix 5	2.75

Table 4.5 presents the water absorption test on various WGP mixedconcrete specimens. The study measures the water absorption of various concrete mixes, including a control mix and five experimental mixes with different proportions of waste glass powder (WGP) as a partial cement replacement. The results show that the control mix has the highest water absorption at 3.19%, while the experimental mixes demonstrate reduced water absorption. Mix 5 exhibits the lowest water absorption at 2.75%, followed by Mix 4 at 2.81%, Mix 3 at 2.84%, Mix 2 at 2.96%, and Mix 1 at 2.97%. This indicates that incorporating WGP reduces water absorption in concrete, with the lowest absorption observed in mixes with higher WGP content.

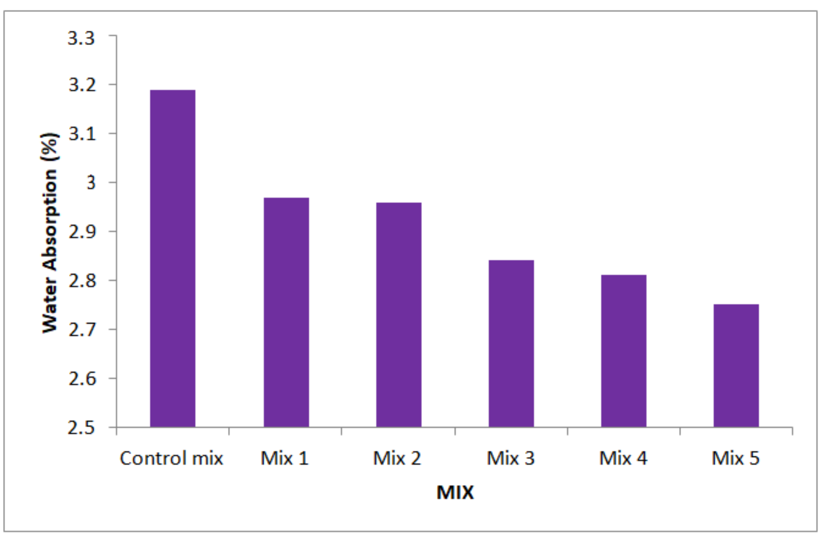

Figure 4.12: Test Results on Water Absorption Test.

4.4.2 Sulphate Attack Test

The sulphate attack test assesses the resistance of concrete to sulphate attack, which can cause expansion and deterioration over time. Concrete cubes of size 150mm x 150mm x 150mm are prepared and cured for the specified period. After curing, the cubes are immersed in a 3% sodium sulphate (Na_2SO_4) solution for a specified duration (30 days). The cubes are periodically removed, cleaned, and any changes in weight, length, or appearance are measured. The properties of the exposed cubes are compared with those of control cubes stored in water. Visual inspection for cracks, spalling, and other signs of deterioration is also performed. Figure 4.13 depicts the weight loss and strength loss after sulphate attack of specimens.

Table 4.6: Weight and Strength Loss after Sulphate Attack

Mix ID	Weight loss (%)	Strength loss (%)
Control mix	4.56	5.25
Mix 1	3.94	5.11
Mix 2	3.90	4.97
Mix 3	3.88	4.93
Mix 4	3.85	4.89
Mix 5	3.81	4.85

Figure 4.13 depicts the test results on sulphate attack test. The Control mix exhibited a weight loss of 4.56% and a strength loss of 5.25%. In comparison, Mix 1 demonstrated a slight improvement with a weight loss of 3.94% and a strength loss of 5.11%. Mix 2 further reduced both weight and strength loss to 3.90% and 4.97%, respectively. Mix 3 showed marginally lower values with weight loss at 3.88% and strength loss at 4.93%. Mix 4 and Mix 5 recorded the lowest weight loss and strength loss, at 3.85% and 4.89%, and 3.81% and 4.85%, respectively. These results indicate that Mix 5 had the best performance in minimizing both weight and strength loss, suggestingimproved material efficiency and durability.

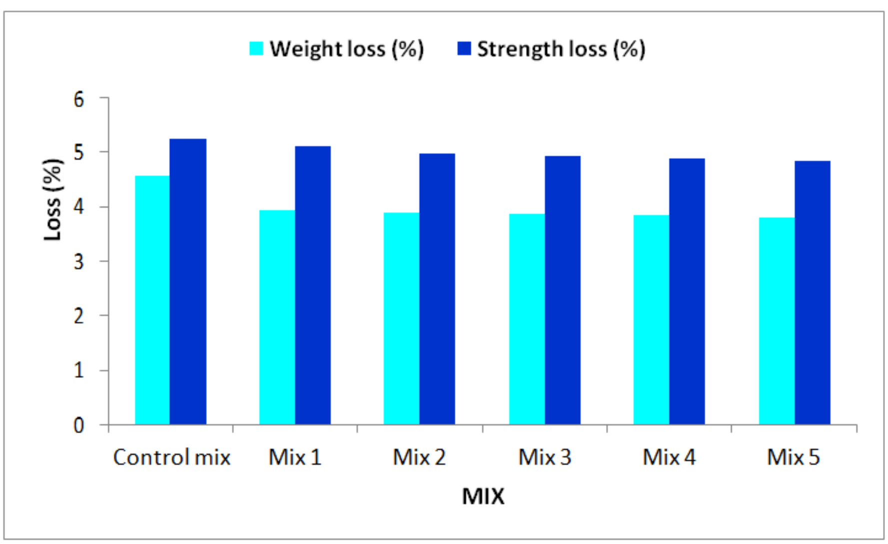

Figure 4.13: Weight and Strength Loss After Sulphate Attack.

4.5 ULTRASONIC PULSE VELOCITY (UPV) TEST

The Ultrasonic Pulse Velocity (UPV) test evaluates the quality and uniformity of concrete using ultrasonic pulse velocity. The procedure involves cleaning the surfaces of the concrete specimen to ensure good contact and applying a coupling agent (grease) to the transducers. The transducers areplaced on opposite faces of the concrete specimen, and the travel time of the ultrasonic pulse from the transmitting to the receiving transducer is measured. The pulse velocity is recorded using the UPV testing apparatus. High pulse velocity indicates good quality and uniformity of concrete, while low pulse velocity indicates possible defects or lower quality concrete.

According to IS 13311 (Part 1): 1992, the quality of concrete can be assessed based on the ultrasonic pulse velocity as follows:

Table 4.7 UPV Test Range

Pulse Velocity (km/s)	Concrete Quality
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Satisfactory/Medium
Below 3.0	Poor

These ranges help in interpreting the results of the UPV test, providing an indication of the concrete's integrity and uniformity.

Table 4.8 UPV Test Results

Mix ID	Pulse Velocity (km/s)	ConcreteQuality (IS 13311 (Part 1): 1992)
Control mix	3.70	Good
Mix 1	3.72	Good
Mix 2	3.75	Good
Mix 3	3.63	Good
Mix 4	3.58	Good
Mix 5	3.52	Good

The study evaluates the pulse velocity and concrete quality of various concrete mixes, including a control mix and five experimental mixes with different proportions of waste glass powder (WGP) as a partial cement replacement. According to IS 13311 (Part 1): 1992, all mixes are classified as having "Good" quality concrete. The pulse velocity for the control mix is 3.70 km/s. The experimental mixes show slight variations, with Mix 2 having the highest pulse velocity at 3.75 km/s, followed by Mix 1 at 3.72 km/s, Mix 3 at 3.63 km/s, Mix 4 at 3.58 km/s, and Mix 5 at 3.52 km/s. These results suggest that incorporating WGP maintains good concrete quality while slightly affecting pulse velocity.

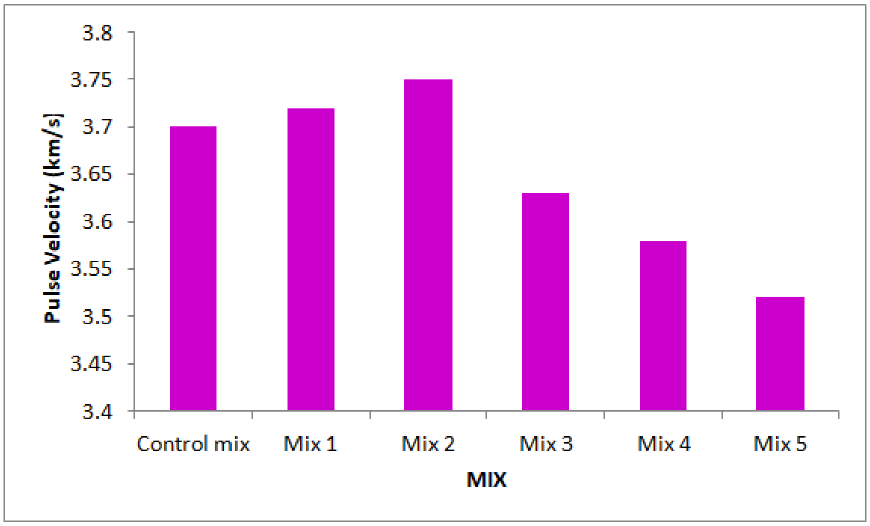

Figure 4.14 UPV Test Results.

4.6 SUMMARY

This chapter outlined the comprehensive experimental programme designed to evaluate the impact of Waste Glass Powder (WGP) as a partial replacement for fine aggregate in concrete. The programme includes various tests to assess the workability, mechanical strength, durability, and quality of the concrete mixes. The workability tests conducted were the Slump test and Compaction factor test, which provided insights into the consistency and ease of handling of the fresh concrete. Mechanical strength was evaluated through Compressive strength, Split tensile strength, and Flexural strength tests, offering critical data on the concrete's load-bearing capacities. Durability tests, including Water absorption and Sulphate attack tests, assessed the concrete's resistance to environmental factors and potential deterioration. Additionally,the Ultrasonic Pulse Velocity (UPV) test was employed to evaluate the quality and uniformity of the concrete, with results interpreted based on the IS 13311 (Part 1): 1992 standards. Together, these tests provide a thorough understanding of the performance and suitability of concrete with WGP for structural applications.

CHAPTER 5 SUMMARY AND CONCLUSIONS

5.1 GENERAL

This study investigates the influence of waste glass powder (WGP) as a partial replacement for cement in concrete. Various concrete mixes, including a control mix and five experimental mixes with increasing proportions of WGP, were evaluated for their compressive strength, split tensile strength, flexural strength, water absorption, and pulse velocity. The primary aim was to determine the optimal proportion of WGP that enhances the mechanical properties and durability of concrete.

5.1.1 Compressive Strength

The compressive strength tests were conducted at 7, 14, and 28 days. The control mix exhibited compressive strengths of 19.85 N/mm², 25.20 N/mm², and 33.02 N/mm², respectively. Mix 2, with an optimal proportion of WGP, achieved the highest compressive strengths of 21.78 N/mm², 28.07 N/mm², and 34.52 N/mm², respectively. Mixes 1 and 3 also showed improvements compared to the control mix, while Mixes 4 and 5, with higher WGP content, demonstrated a decline in strength. These findings suggest that an optimal amount of WGP can enhance compressive strength, but excessive replacement can be detrimental.

5.1.2 Split Tensile Strength

The split tensile strength was measured at 7, 14, and 28 days. The control mix recorded split tensile strengths of 3.02 N/mm², 3.45 N/mm², and 4.68 N/mm², respectively. Mix 2 again exhibited the highest strengths at 3.47 N/mm², 3.73 N/mm², and 4.78 N/mm², indicating that WGP improves tensile properties up to an optimal level. Similar to the compressive strength results, Mixes 4 and 5 showed reduced tensile strength, emphasizing the need to balance WGP content.

5.1.3 Flexural Strength

Flexural strength tests at 7, 14, and 28 days revealed that the control mix had strengths of 2.98 N/mm², 4.12 N/mm², and 6.85 N/mm², respectively. Mix 2 recorded the highest flexural strengths of 3.18 N/mm², 4.25 N/mm², and

7.06 N/mm². Mixes 1 and 3 also demonstrated improvements, whereas Mixes 4and 5 showed reduced flexural strengths, reinforcing the trend observed in compressive and tensile strengths.

5.1.4 Water Absorption

The water absorption test indicated that the control mix had the highest absorption rate at 3.19%. Incorporating WGP reduced water absorption in the experimental mixes, with Mix 5 having the lowest rate at 2.75%, followed by Mix 4 at 2.81%, Mix 3 at 2.84%, Mix 2 at 2.96%, and Mix 1 at 2.97%. This suggests that WGP enhances the durability of concrete by reducing its permeability.

5.1.5 Pulse Velocity

Pulse velocity tests, conducted in accordance with IS 13311 (Part 1):1992, showed that all mixes were classified as having "Good" quality concrete. The control mix had a pulse velocity of 3.70 km/s. Mix 2 achieved the highest pulse velocity at 3.75 km/s, followed by Mix 1 at 3.72 km/s. Mixes 3, 4, and 5 showed slightly lower velocities at 3.63 km/s, 3.58 km/s, and 3.52 km/s, respectively. These results indicate that WGP maintains good concrete quality while slightly varying the pulse velocity.

5.2 CONCLUSIONS

Optimal WGP Replacement: The study identifies Mix 2, with a specific proportion of WGP, as the optimal mix that enhances compressive, split tensile, and flexural strengths. This mix demonstrated superior mechanical properties and durability compared to the control mix and other experimental mixes.

Balance in WGP Content: While WGP can improve concrete properties, there is a threshold beyond which additional WGP reduces strength and performance. Mixes 4 and 5, with higher WGP content, exhibited decreased strengths, emphasizing the need for careful balance in the replacement proportion.

Enhanced Durability: The reduction in water absorption rates with increasing WGP content indicates improved durability of the concrete. Lower permeability can enhance the lifespan and resilience of concrete structures.

Consistent Quality: All mixes, including those with WGP, maintained good quality concrete as per pulse velocity measurements, demonstrating that WGP does not compromise the overall quality of concrete.

In summary, incorporating waste glass powder as a partial replacement for cement in concrete can significantly improve its mechanical properties and durability up to an optimal level. This study highlights the potential of WGP in producing sustainable and high-performance concrete, provided the replacement proportion is carefully controlled. Further research and real-world applications are encouraged to validate these findings and explore the practical implications of using WGP in concrete construction.

5.3 FUTURE SCOPE

The following points outline the potential future scope;

- Further research can be conducted to fine-tune the proportions of waste glass powder (WGP) and other supplementary cementitious materials to achieve optimal mechanical properties and durability.
- Studies can investigate the combined effects of WGP with other waste materials like fly ash, slag, or silica fume toenhance concrete performance.
- Extended investigations on the long-term durability ofconcrete with WGP, including resistance to freeze-thaw cycles, sulfate attack, and chloride penetration, can provide more comprehensive insights into its performance in various environmental conditions.
- The structural behaviour of reinforced concrete elements incorporating WGP under various loading conditions, including seismic performance, can be explored.

APPENDIX 1

1. Grade designation	M30
2. Type of cement	OPC 53 grade
3. Maximum Nominal Size of aggregates	20 mm
4. Maximum water cement ratio	0.49
5. Workability	75 mm slump
6. Exposure condition	Mild
7. Method of concrete Placing	Manual mixing
8. Degree of supervision	Good
9. Type of aggregate	Crushed angular
10. Maximum cement content	450kg/m^3
11. Chemical admixtures	None

Test Data for Materials

Cement used - 53 grade

Specific gravity of cement - 3.15Chemical Admixtures - Nil Specific gravity of:

i. **Coarse Aggregate - 2.70**

ii. **Fine aggregate - 2.57**

Target Strength for Mix Proportioning

F'ck = Fck + 1.65 × S

= 30 + 1.65 × 5

= 38.25 N/mm2

Selection of water cement ratioFor 20 mm aggregate

From Table 5 (IS456:2000) =186 ltr

Estimated water content =186 ltr

1. **Calculation of cement content:** Water Cement Ratio - 0.49 Cement Content - 186/0.49

= 379.60 Kg/m^3

From Table 5, IS 456: 2000, minimum cement content for "MILD" exposure conditions =300 Kg/m^3 (379.60 Kg/m3 > 300 Kg/m^3)

Hence ok.

2. Calculation of Aggregate Content

From table 3: Volume of coarse aggregate corresponding to 20 mmaggregate and fine aggregate (zone II) and w/c ratio 0.62

Volume of coarse aggregate = 0.62 – 0.01 = 0.61Volume of fine aggregate = 1 – 0.61 = 0.39

3. Mix Calculation

The mix calculations per unit volume of concrete shall be as follows:Volume of concrete =1 m^3 (a)

$$Volume\ of\ Cement = \frac{\text{Mass of Cement}}{Specific\ Gravity} X \frac{1}{1000}$$

$$Volume\ of\ Cement = \frac{379.60}{3.15} X \frac{1}{1000}$$

$$Volume\ of\ Cement = 0.1205 Cum \qquad (b)$$

$$Volume\ of\ Water = \frac{\text{Mass of Water}}{Specific\ Gravity} X \frac{1}{1000}$$

$$\text{Volume of water} = \frac{186}{1} X \frac{1}{1000}$$

Volume of water = 0.186 m^3 (c)

Volume of all in aggregate = (a-(b+c))Volume of all in aggregate = 0.693 m^3

1. **Mass of Coarse Aggregate = 0.673 x 0.61 x 2.70 x 1000**

= 1108.43 kg/m^3

2. **Mass of Fine Aggregate = 0.673 x 0.39 x 2.57 x 1000**

= 674.54 kg/m^3

Table A-1 Mix proportion of M30 grade of Concrete

Cement(kg/m^3)	Water litres/m^3	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)
379.60	186	674.54	1108.43
1	0.49	1.77	2.91

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