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"AN EXPERIMENTAL INVESTIGATION ON INFLUENCE ON STRENGTH OF M30 & M40 GRADE CONCRETE BY PARTIAL REPLACING CEMENT WITH WASTE GLASS POWDER "

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ABSTRACT

In this study, the effect of waste glass powder on the properties of different grade concrete was examined by conducting a series of compressive strength, splitting tensile strength and flexural strength tests. According to this aim, waste glass powder (WGP) was first used as a partial replacement for cement and six different ratios of WGP were utilized in concrete production: 0%, 10%,15%, 20%, 25% & 30%.To examine the combined effect of different ratios of WGP on concrete performance, mixed samples were then prepared by replacing cement. For the hardened concrete, 150 mm X 150 mm X 150 mm cubic specimens and cylindrical specimens with a diameter of 100 mm and a height of 300 mm were tested to identify the compressive strength and splitting tensile strength of the concrete produced with waste glass powder. Next, a three-point bending test was carried out on samples with dimensions of 150 X 150 X 700 mm to obtain the flexure behavior of different mixtures. According to the test results, it is observed that the compressive strength of M30 grade concrete increases up to 25% replacement of waste glass powder after that strength is reduces. Flexural strength and Split tensile strength of M30 grade concrete gradually increases up to 20% replacement of waste glass powder and for 25% and 30% replacements the strength values are reduces .The compressive strength of M40 grade concrete increases up to 30% replacement of waste glass powder .Flexural strength and Split tensile strength of M40 grade concrete gradually increases up to 25% replacement of waste glass powder and for 30% replacements the strength values are reduces.

Keywords : WGP, Beam specimen, Split tensile strength, Flexural strength, Compressive strength, M40 grade concrete, M30 grade concrete, Hardened Concrete.

I. INTRODUCTION

1.1General

In recent years, the significant increase in material usage has led to a rapid rise in waste and emissions both in India and globally. The global ecosystem's capacity to absorb this growing amount of waste is limited. India alone produces three million tonnes of glass waste annually, of which only 45% is recovered, with the rest often ending up in landfills or being downcycled into construction material aggregates.

Effective resource recovery is essential for sustainable living. We have a limited timeframe to transition towards a circular economy and sustainability, and the glass industry plays a crucial role in this transition.

Global annual cement production has reached 2.8 billion tons and is expected to rise to approximately 4 billion tons per year. The cement industry faces challenges such as rising energy costs, requirements to reduce CO2 emissions, and the availability of raw materials. Using waste glass to replace cement can reduce the cost of concrete production, decrease cement consumption, and directly lower CO2 emissions associated with cement manufacturing. Additionally, utilizing waste materials can reduce the overall cost of concrete production.

Several attempts have been made to explore the potential of using glass in concrete applications, both as a replacement for coarse aggregate and as a hydration-enhancing filler. While previous efforts have focused on using glass powder to partially replace cement in concrete, it is increasingly recognized that this approach could yield significant advantages. The pozzolanic properties of glass powder show promise in enhancing various concrete properties.

Glass, derived from a combination of inorganic minerals, can be classified into different types based on its composition, with soda-lime glass being the most prevalent. Typically, glass contains about 70% silica. Though the presence of alkali in glass could lead to alkali-silica reactions and volumetric changes, finely ground glass does not contribute to these issues.

Glass powder, acting as a pozzolan, ensures a more uniform distribution and greater volume of hydration products. When incorporated into a concrete mixture, glass powder alters the cement paste structure, leading to the development of stronger calcium silicate hydrates (C-S-H) and fewer weak and soluble calcium hydroxides ($Ca(OH)_2$) compared to conventional cement pastes. The resulting calcium silicate hydrate serves as the primary binder, enhancing the concrete's strength. In contrast, calcium hydroxide does not function as a binder and can occupy space within the concrete, with the potential to react with carbon dioxide and form a soluble salt that may cause efflorescence. The fine particle size of glass powder effectively fills and plugs capillary pores in concrete, reducing pore size and increasing concrete density.

The principal objective of this study is to promote sustainability by minimizing waste and developing a more efficient concrete mixture that offers greater strength through the use of waste glass. This approach has the potential to reduce costs compared to the use of expensive admixtures for achieving high concrete strength, as current market admixtures are often costly and can inflate construction expenses.

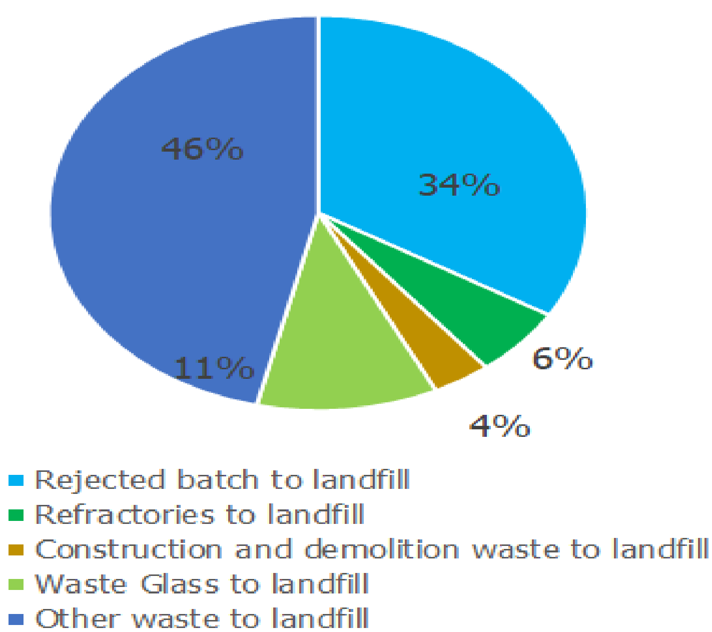

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Figure : 1.1: Wastes to landfill (Source: Waste and Circular economy)[17]

1.2 Glass Recycling(GR)

Glass recycling is the process of transforming waste glass into usable products. Glass constitutes a significant portion of household and industrial waste due to its weight and durability. Common types of glass in the waste stream include bottles, broken tableware, light bulbs, and other items. Crushed glass ready for remelting is known as cullet. Glass waste is typically sorted by chemical composition and sometimes by color, as different colors of glass retain their hues through recycling. The main types used include clear, green, and brown/amber glass.

1.3 Why Glass Recycling?

i) **Saves Limited Natural Resources:** There is a finite amount of natural resources on Earth, and while some are renewable, our demand for them is high. Recycling reduces the need for raw materials used in product manufacturing, preserving precious resources like bauxite, iron ore, and sand. Since recycled glass requires less energy than virgin materials, it also conserves non-renewable resources such as oil and coal.

ii) **Prevents Air and Water Pollution:** Recycling glass reduces air and water pollution, lowers energy consumption, and decreases greenhouse gas emissions linked to global warming.

iii) **Saves Energy:** Glass recycling uses less energy compared to producing glass from raw materials like sand, lime, and soda ash. Energy costs drop by about 2-3% for every 10% increase in recycled glass used in manufacturing.

iv) **Saves Space in Landfills:** Recyclable materials make up a significant portion of household waste globally. By recycling, fewer items end up in rapidly filling landfills. Glass, which takes an incredibly long time to break down naturally (approximately one million years), occupies valuable space in landfills.

1.4 Background on the Use of Recycled Glass

Since the 1960s, various studies have explored using recycled glass as an aggregate in cement concrete products. Recent decades have seen renewed interest due to the high cost of glass disposal and environmental regulations. Recycled glass has been utilized in road construction, glass penstocks, wall panels, bricks, glass fiber, landscaping materials, reflective beads, and tableware.

1.5 How Glass is reclaimed?

i) Collection and Transportation: Glass is collected from both multi-stream and single-stream recycling bins, as well as community drop-off points. Collection methods include curbside pickup for residential and commercial sectors. Glass is then transported to specialized glass recycling centers.

ii) Sorting: At recycling facilities, glass undergoes optical sorting to remove contaminants such as ceramics or plastics. Glass is also sorted by color, a process facilitated by additives like iron for producing brown glass.

iii) Breaking: Sorted glass is crushed into smaller pieces using hammer mills to prevent airborne glass particles. Water may be added during crushing to suppress dust.

iv) Screening: The crushed glass passes through rotary screens to separate particles by size, typically between 3/8" and 3/4". A blower removes paper labels and other non-glass materials.

v) Fluidized Bed Dryer: Glass fragments are passed through a dryer where hot air (approximately 190°F) removes residual sugar, bacteria, and remaining labels. Remaining contaminants are removed by vacuum.

vi) Primary Screening and Pulverization: Glass pieces that pass through the primary screen are pulverized to finer sizes using a grinder. This process continues until the glass is reduced to the desired size.

vii) Secondary Screening: Finely pulverized glass is further classified by size through secondary screening. Different size grades cater to various manufacturing needs.

viii) Cullet: The final product, glass cullet, undergoes a final screening to remove specific sizes or contaminants. Screen sizes are adjusted based on customer requirements, such as mesh sizes for fiberglass manufacturing.

Cullet is collected in bins or containers as the finished product, available in sizes ranging from pebbles to fine powder.

Figure : 1.2 : Cullets of Waste White Glass

1.6 Objectives

The study aims to achieve the following objectives:

1. Investigate the potential of using waste glass powder as a partial replacement for cement in concrete production, reducing the environmental impact of cement production
2. Conduct experimental research to examine the impact of waste glass powder on M30 & M40 grades of concrete.
3. Conduct experimental research to analyze the influence of glass powder on the compressive, flexural and tensile strength of concrete.

II. MATERIALS& METHODOLOGY

2.1 Materials

2.1.1 Cement

Cement is the primary binding material in concrete. It consists of finely ground powders that, when mixed with water, undergo hydration to form a hardened mass. This hydration process involves the formation of submicroscopic crystals or a gel-like material, which gives concrete its strength.

2.1.2 Fine Aggregate (Sand)

Fine aggregate, typically sand, is used in concrete to fill voids between coarse aggregates and cement particles. It is smaller in size than gravel and larger than silt, usually less than 4.75 mm in diameter. Sand is essential for the mechanical properties of concrete and is primarily composed of silica (SiO2).

2.1.3 Coarse Aggregate

Coarse aggregate provides strength and durability to concrete. It consists of materials such as gravel, crushed stone, or recycled concrete with sizes ranging from 3/8 inch to 1.5 inches in diameter. In your study, aggregates of 20mm and 10mm sizes were used.

2.1.4 Glass Powder

Glass powder, derived from waste glass (such as from windows and doors), was collected, crushed, and ground into fine particles. This powder, which passes through a 90µm IS sieve, is used as a partial replacement for cement in your experimental concrete mixes.

Glass powder has potential benefits such as improving the sustainability of concrete by recycling waste materials and potentially enhancing certain properties of concrete when used correctly.

2.1.5. Water

In this study, tap water was utilized for the concrete mixtures. It is essential that water used in concrete construction meets stringent quality standards to ensure optimal performance and longevity of the concrete structures. The water should be devoid of any contaminants that could potentially compromise the integrity or aesthetics of the concrete.

Figure: 2.1: White Glass Powder

The following physical properties of waste glass powder were obtained:

S.No	Properties (%)	Cement	Waste Glass Powder(WGP)
1	Loss on ignition	7.24	0.8
2	SiO_2	23.71	70.22
3	Cao	57.27	11.13
4	MgO	3.85	-
5	Al_2O_3	4.51	1.64
6	Fe_2O_3	4.83	0.52
7	So_3	2.73	-
8	Na_2O	-	15.29
9	K_2O	0.37	-
10	Cl	0.0068	-

Table: 2.1: Comparison between Chemical properties of Cement & glass powder

The above table shows chemical properties of cement and waste glass powder. MgO ,SO3,K2O & Cl not present in waste glass powder.

2.2Methodology

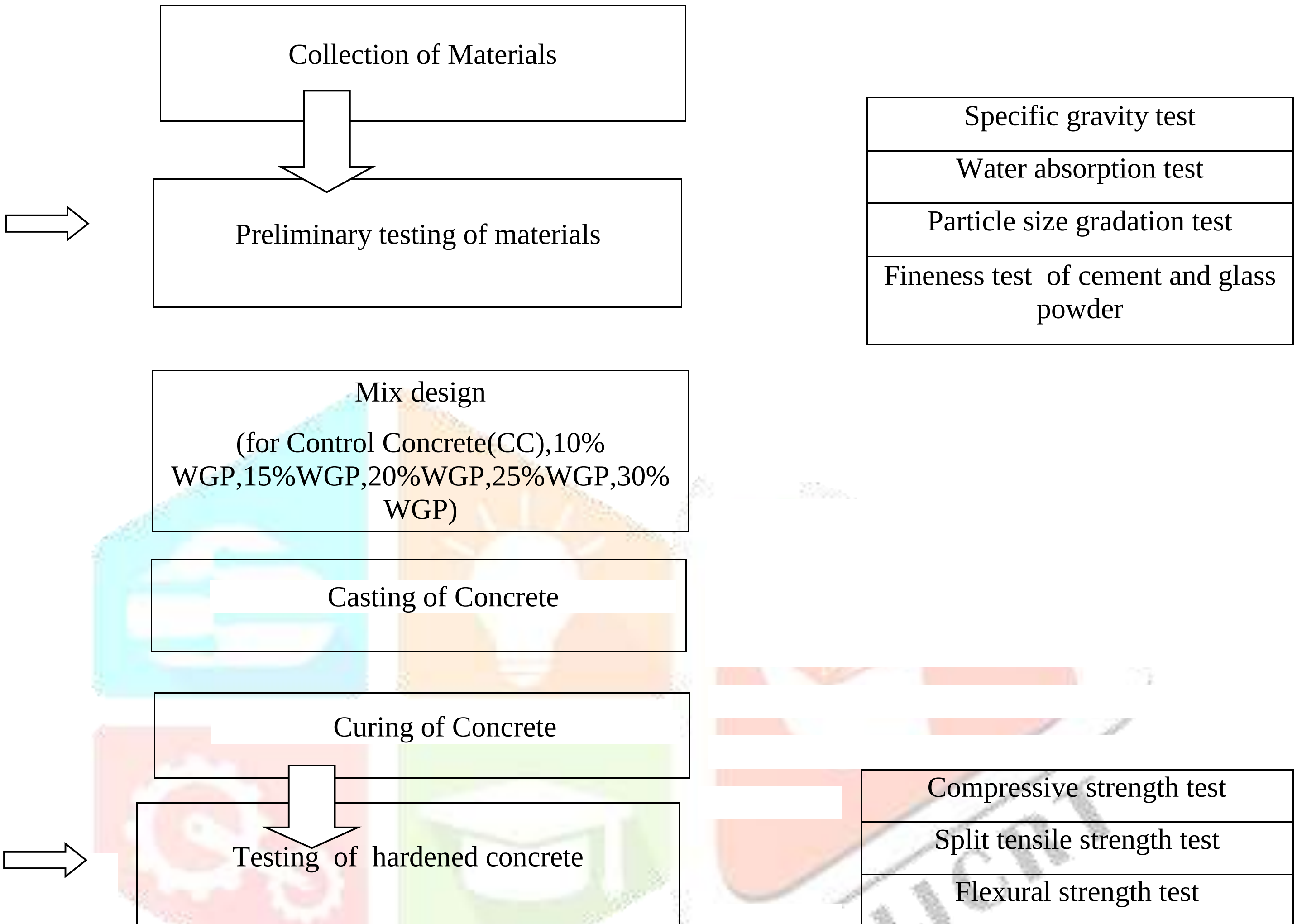

Figure: 2.2: Flow chart of method adopted

The purpose of this study is to investigate the performance of waste glass powder-containing concrete by creating concrete cube samples, cylindrical samples, and pullout samples and testing them for engineering qualities such as compressive strength, split tensile strength, and bond strength. The concrete mix design is carried out using a systematic analysis in accordance with IS: 10262-2009, and the proportions of the ingredients used in the concrete mix are chosen to generate an economical concrete with the necessary strength after the cube is hardened.

- Collecting material
- Testing material
- Proportional and compatible mixing of material
- Casting
- Testing of compressive, Bond and tensile strength

2.2.1 Collecting material

Fine Aggregate (River Sand)

The fine aggregate used in this study was sourced from the Raipur region and consisted of river sand conforming to Zone II as per IS: 383-1970 standards. River sand is essential in concrete for its fine grain size and suitability in achieving desired workability and strength characteristics.

Coarse Aggregate

The coarse aggregate used in the project was angular in nature, with a nominal maximum size of 20 mm and 10 mm. Both sizes of coarse aggregates complied with the requirements specified in the Indian Standard, ensuring they contribute effectively to the mechanical properties of the concrete.

Cement (Ordinary Portland Cement - OPC)

Ordinary Portland Cement, specifically Birla A1 Premium, was utilized in this investigation. Cement is finely ground material known for its adhesive and cohesive properties, providing the binding medium in concrete mixtures. The cement used in this study adhered to the standards set by IS: 8112 – 2013 for Ordinary Portland Cement 43 grade.

Waste Glass (Glass Powder)

White waste glass was employed in the experiments after undergoing a cleaning process to remove foreign bodies by soaking in water. The glass was subsequently ground to a fine powder, ensuring that 100% of the particles passed through a 90-micron sieve and were retained in a 75-micron sieve. The specific gravity of the glass powder was measured to be 2.59, highlighting its potential as a supplementary cementitious material in concrete mixes.

2.2.2 Testing of Materials

2.2.2.1 Cement

The Ordinary Portland Cement used in this study was categorized as 43 grade and conformed to IS: 8112 – 2013 specifications. The cement underwent various tests to verify its suitability for use in concrete mixes, including:

a).Consistency Test: This test determines the standard consistency of cement, which is the point where the Vicat plunger penetrates 5 to 7 mm from the bottom of the Vicat mould under standardized conditions. This consistency is crucial in assessing the initial workability of the cement paste.

b).Initial & Final Setting Time: The setting time of concrete is crucial in determining its workability and eventual strength development. It is defined by two distinct phases:

Initial Setting Time

The initial setting time of concrete is the duration from the moment water is added to the cement until the cement paste reaches a particular consistency. Specifically, it is the time elapsed until a 1 mm square section needle, under specified conditions, fails to penetrate the cement paste placed in the Vicat's mould at a depth of 5 mm to 7 mm from the bottom of the mould.

Final Setting Time

The final setting time of concrete refers to the period from the moment water is added to the cement until a 1 mm needle, again under specified conditions, leaves a slight impression on the paste in the Vicat's mould, but a 5 mm attachment does not leave any impression.

Calculation

The setting times are typically determined by recording the time intervals from the moment water is added (T1) until the specified needle tests indicate the initial (T2) and final (T3) setting times:

- **Initial Setting Time:** T2−T1
- **Final Setting Time:** T3−T1

These calculations help in understanding the concrete's behavior during the setting phase, ensuring proper handling and application during construction.

Figure: 2.3 : Vicat Apparatus for Consistency,Initial setting time & Final setting time test of cement

Specific Gravity

Specific gravity is a measure of how much heavier a substance is compared to an equal volume of water or a standard reference substance. For cement, the specific gravity typically ranges from 3.1 to 3.16. This range indicates that cement is approximately 3.1 to 3.16 times denser than water of the same volume

Formula :-

$$\text{Specific gravity} = \frac{(w_2 - w_1)}{(w_2 - w_1) - (w_3 - w_4)0.79}$$

d).Fineness

The fineness test of cement assesses the particle size distribution of the cement particles, which directly impacts its quality and performance in concrete mixes. A finer particle size generally indicates better quality cement due to improved hydration characteristics and strength development.

Calculation Method

The fineness of cement is determined by measuring the percentage of cement particles retained on a standard sieve. This is calculated using the formula:

Percent of cement retained on sieve=$(W_2/W_1)\times100$

Where:

- W_1 is the initial weight of the cement sample.
- W_2 is the weight of cement particles retained on the sieve after sieving.

Tests results are shown in Table 2.2 below:

S.No.	Physical Properties	Experimental Results	IS: 8112 – 2013 Requirements	Method of test reference to
1	Consistency	32%	26-33%	IS 4031-1988(part-5)
2	Specific gravity	3.15	3.1-3.16	IS 4031-1988(part-11)
3	Initial setting	60min	>30min	IS 4031-1988(part-5)
4	Final setting time	490min	<600min	IS 4031-1988(part-5)
5	Fineness	8.65%	<10%	IS 4031-1996(part-2)

Table: 2.2: Physical properties of cement

The above table shows the physical properties of cement. Experimental results show that every parameter are onspecified range asgiven in Indian Standard.

2.2.2.2Sand

The locally available sand conforming to Zone –II conforming to IS code 383-1970 is used.

Specific Gravity Test& Water Absorption Test (IS :2386 PART 3(1963)):

The specific gravity and water absorption of fine aggregate (sand) are crucial parameters that determine its suitability for use in concrete mixes.

Specific Gravity

Specific gravity is defined as the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. For fine aggregate (sand), the specific gravity is typically around 2.64. It is calculated using the formula:

$$\text{Specific Gravity}=D/A-(B-C)$$

Where:

- A = Weight of the saturated and surface-dry sample
- B= Weight of the dried pycnometer

- C = Weight of the pycnometer filled with distilled water
- D = Weight of the oven-dried sample

Water Absorption

Water absorption of fine aggregate indicates its ability to absorb moisture, affecting the workability and durability of concrete. It is calculated using the formula:

$$\text{Water Absorption (\%)} = 100 \times (A - D)/D$$

Where:

- A = Weight of the saturated and surface-dry sample
- D = Weight of the oven-dried sample

Figure: 2.4: Specific gravity test of sand

Figure: 2.5: Sieve analysis of sand

S.No.	Property	Experimental Results	Specification referred to	Method of test reference to
1	Specific Gravity	2.64	IS code 383-2016	IS :2386 PART 3(1963)
2	Water Absorption	0.864	IS code 383-2016	IS :2386 PART 3(1963)
3.	Surface Moisture content	Nil	IS code 383-2016	IS :2386 PART 3(1963)
4.	Grading zone	II	IS code 383-2016	IS :2386 PART 1(1963)

Table: 2.3: Physical properties of sand

Various tests performed on sand to analyze its physical properties referring IS code 2386 -1963 and IS code 383-2016, we get specific gravity 2.64,water absorption 0.864.

IS: Sieve (mm)	Weight retained (gms)	Cumulative Wt. Retained (gms)	% Retained	% Passing
10.00	0	0	0	100
4.75	19	19	1.90	98.10
2.36	60	79	7.92	92.08
1.18	190	269	26.95	73.05
0.60	313	582	58.32	41.68
0.30	310	892	89.38	10.62
0.150	75	967	96.89	3.11

Table: 2.4: Sieve Analysis of sand

The above Table shows grading of sand, according to results the sand is of zone –II.

2.2.2.3 Coarse Aggregate

In the experimental studies, the coarse aggregate used was crushed angular aggregate conforming to BIS 383-1970, with sizes ranging from 20mm to 10mm mixed in a 1:1 ratio.

Specific Gravity & Water Absorption Test

Calculation:

Specific Gravity of Aggregate = {W4} / {W3 - Ws}

Apparent Specific Gravity = {W4} / {W4 - Ws}

Water Absorption of Aggregate = {(W3 - W4) *100}/W4

Where:

W1 = Weight of saturated aggregate sample suspended in wire basket

W2 = Weight of basket suspended in water

Ws = Weight of saturated aggregate in water = (W1 - W2)

W3 = Weight of surface dry aggregate in air

W4 = Dry weight of aggregate

W3 - Ws = Weight of water equal to the volume of aggregate

Figure: 2.6 : Specific Gravity & Water absorption test machine of coarse aggregate

i) For 20 mm Aggregate

S.No.	Property	Experimental Results	Specification referred to	Method of test reference to
1	Specific Gravity	2.709	IS code 383	IS :2386 PART 3(1963)
2	Water Absorption	0.40	IS code 383	IS :2386 PART 3(1963)
3.	Surface Moisture content	Nil	IS code 383	IS :2386 PART 3(1963)

Table:2.5: Physical properties of 20mm coarse aggregate

Various tests performed on 20mm aggregate, we get specific gravity 2.709,water absorption 0.40.

ii) For 10mm Aggregate

S.No.	Property	Experimental Results	Specification referred to	Method of test reference to
1	Specific Gravity	2.709	IS code 383	IS :2386 PART 3(1963)
2	Water Absorption	0.45	IS code 383	IS :2386 PART 3(1963)
3.	Surface Moisture content	Nil	IS code 383	IS :2386 PART 3(1963)

Table:2.6: Physical properties of 10mm coarse aggregate

Various tests performed on 10mm aggregate, we get specific gravity 2.709,water absorption 0.45.

iii) For 1:1 (20mm:10mm) Coarse Aggregate

S.No.	Property	Experimental Results	Specification referred to	Method of test reference to
1	Specific Gravity	2.709	IS code 383	IS :2386 PART 3(1963)
2	Water Absorption	0.543	IS code 383	IS :2386 PART 3(1963)

3.	Surface Moisture content	Nil	IS code 383	IS :2386 PART 3(1963)

Table: 2.7: Physical properties of combine coarse aggregate

Sieve Analysis Test(Grading of Coarse Aggregate)

The Grading of 20mm & 10mm size aggregate is describe below:

i)Individual Gradation of 20mm

Average % age passing					Average % passing
IS: Sieve (mm)	% Passing (1)	% Passing (2)	% Passing (3)	% Passing (4)	
40.00	100	100	100	100	100
20.00	93.45	91.13	93.25	94.25	93.02
10.00	10.90	11.29	11.65	10.75	11.15
4.75	1.7	1.81	1.65	1.32	1.62

Table: 2.8:Grading of 20mm coarse aggregate

ii) Individual Gradation of 10mm

Average % age passing					Average % passing
IS: Sieve (mm)	%age Passing (1)	%age Passing (2)	%age Passing (3)	%age Passing (3)	
12.50	100	100	100	100	100
10.00	90.66	90.40	89.90	91.02	90.50
4.75	7.04	7.82	6.07	7.70	7.16
2.36	1.09	2.02	2.26	3.12	2.12

Table: 2.9: Grading of 10mm coarse aggregate

iii) Combine 20mm:10mm Gradation

IS Sieve Size in mm	Wt of Sample (g)			Wt of Sample(g)			Combined % of Passing	Ideal	Specified Limits
	20 MM Size			10 MM Size					
	Retained Wt(g)	100%	50%	Retained Wt(g)	100%	50%	100%		
40	Average of 03 samples Values	100	50.0	Average of 03 samples Values	100	50.0	100.0	100.0	100.0
20		95.8	47.9		100	50.0	97.9	97.5	95 - 100
10		2.77	1.4		97.38	48.7	50.1	40.0	25 - 55
4.75		2.73	1.4		4.52	2.3	3.6	5.0	0- 10

Table: 2.10 : Grading of combine coarse aggregate

2.2.2.4Glass Powder

The waste glass used in the experiments was plain clear glass from windows and doors collected from various locations in Raipur, Chhattisgarh. The collected glass was mechanically crushed and ground into a fine powder. This powder was then sieved through an IS sieve of 90µm size in the lab. The following physical properties of the waste glass powder were obtained:

S.No.	Physical Properties	Experimental Results
1	Specific gravity	2.59
2	Fineness passing 90u is sieve	98%
3.	Colour	White

Table: 2.11:Physical properties of Glass powder

Several tests conducted on Waste glass powder.Table 2.11 shows physical properties of Waste glass powder.

2.2.3 Experimental Setup and Mix Design

Material Replacement and Test Specimens

In this study, Ordinary Portland Cement (OPC) was partially replaced with waste glass powder at varying percentages (10%, 15%, 20%, 25%, and 30%) for both M30 and M40 grade concrete. A total of 72 concrete specimens were cast, comprising:

- **Cubes:** 60 specimens of size 150x150x150mm for testing compressive strength.
- **Beams:** 12 specimens of size 150x150x700mm for testing flexural strength.
- **Cylinders:** 12 specimens of size 150x300mm for testing split tensile strength.
- **Control Mix:** 12 specimens each of cubes, beams, and cylinders using conventional concrete without glass powder.

Mix Design

The mix proportions for M30 and M40 grade concrete were determined according to Indian standards IS: 456:2000 and IS 10262:2019. The following six mix designs were used in the study:

1. **Control Mix:** Water-cement ratio of 0.44 without any glass powder.
2. **10% Glass Powder Replacement:** 10% of cement weight replaced with glass powder.
3. **15% Glass Powder Replacement:** 15% of cement weight replaced with glass powder.
4. **20% Glass Powder Replacement:** 20% of cement weight replaced with glass powder.
5. **25% Glass Powder Replacement:** 25% of cement weight replaced with glass powder.
6. **30% Glass Powder Replacement:** 30% of cement weight replaced with glass powder.

Testing Parameters

The concrete specimens were subjected to the following tests to evaluate their mechanical properties:

- **Compressive Strength:** Measured using cubes to assess the load-bearing capacity.
- **Flexural Strength:** Tested on beams to evaluate resistance to bending forces.
- **Split Tensile Strength:** Assessed on cylinders to measure tensile strength perpendicular to the direction of applied load.

Comparative Analysis

The results of compressive strength, flexural strength, and split tensile strength for the glass powder-modified concrete mixes were compared with those of the control mix (plain concrete). This comparison will provide insights into the effectiveness of waste glass powder as a cement replacement in terms of enhancing or maintaining the mechanical properties of concrete.

Estimation of Quantity Of Materials: The mix proportions are given in Table

Figure: 2.7 : Casting of cubes

Quantity of materials For M30 grade concrete

% Replacement	Cement	Glass Powder	Water	Sand	Coarse Aggregate	w/c ratio

Controlled Concrete	436	0	192	641	1130	0.44
10	392.4	43.6	192	641	1130	0.44
15	370.6	65.4	192	641	1130	0.44
20	348.8	87.2	192	641	1130	0.44
25	327	109	192	641	1130	0.44
30	305.2	130.8	192	641	1130	0.44

Table: 2.12 : Mix proportions for 1m^3 concrete

Mix proportions for various replacements of cement with glass powder are given in above table for M30 grade concrete.

Quantity of materials For M40 grade concrete

% Replacement	Cement	Glass Powder	Water	Sand	Coarse Aggregate	w/c ratio
Controlled Concrete	534	0	192	584	1104	0.36
10	480.6	53.4	192	584	1104	0.36
15	453.9	80.1	192	584	1104	0.36
20	427.2	106.8	192	584	1104	0.36
25	400.5	133.5	192	584	1104	0.36
30	373.8	160.2	192	584	1104	0.36

Table: 2.13 : Mix proportions for 1m^3 concrete

Mix proportions for various replacements of cement with glass powder are given in above table for M40 grade concrete.

2.2.4Casting of Test Specimens

In this study, alternatives to standard cubes, cylinders, and beams were used to evaluate the compressive strength, flexural strength, and split tensile strength of concrete. The concrete mixes included varying proportions of waste glass powder (WGP) as a replacement in M30 and M40 grades of concrete. For each proportion of WGP replacement, three specimens were tested at 7 days and three at 28 days.

Methodology

1. **Material Preparation**:
    - Coarse and fine aggregates were measured and laid out in a pan.

- Ordinary Portland Cement (43 Grade) and WGP were added according to the mix design.
- Water was added based on water-binder ratios of 0.44 and 0.36.

2. **Mixing**:
   - The concrete mixtures were thoroughly blended until a homogeneous and consistent texture was achieved.
3. **Casting**:
   - Fresh concrete was poured into molds for cubes, beams, and cylinders.
   - The concrete was compacted using a tamping rod.
4. **Curing**:
   - Specimens were allowed to cure for 24 hours before demolding.
   - After demolding, specimens were cured underwater for 7 and 28 days.
   - Specimens were then air-dried before testing.
5. **Testing**:
   - Compressive, flexural, and split tensile strength tests were conducted according to Indian standards.

This process ensures that the effects of WGP replacement on the compressive, flexural, and split tensile strengths of concrete can be accurately assessed, providing valuable insights into the potential of using waste glass powder in concrete production

Test Specimen details

Sr. No.	Tests Performed	Specimen Shape	Specimen Dimensions
1	Compressive Strength	Cube	150mm X 150mm X 150mm
2	Split Tensile Strength	Cylinder	150mm Dia. X 300mm Height
3	Flexural Strength	Beam	150mm X 150mm X 700mm

Table: 2.14 : Specimen Geometry

The Casting of members for M30 & M40 grade concrete are as follows:

Concrete mix	% Replacement of cement by Waste glass powder(WGP)	Tested ages					
		Cube specimen		Cylindrical specimen		Beam specimen	
		7days	28days	7days	28days	7days	28days
mix 1	0	3	3	3	3	3	3
mix 2	10	3	3	3	3	3	3
mix 3	15	3	3	3	3	3	3
mix 4	20	3	3	3	3	3	3
mix 5	25	3	3	3	3	3	3
mix 6	30	3	3	3	3	3	3

Table:2.15: Numbers of specimen details for M30 & M40 Grade

Tables show that after calculating the required sample quantities, 72 cubes, beams, and cylinders of specific sizes and shapes were prepared. Cubes were cast to test compressive strength after 7 and 28 days of curing, while cylinders were made to evaluate split tensile strength at the same intervals.

2.2.5 Curing

The cubes were maintained at a controlled temperature of 27°C and a relative humidity of 90% for the first 24 hours after water addition. After this initial curing period, the specimens were marked, demolded, and immediately submerged in clean water for continued curing until just before testing. Proper curing is critical for achieving the desired properties of hardened concrete, such as:

- Durability
- Strength
- Water-tightness
- Abrasion resistance
- Dimensional stability

Curing marks the final stage in the concrete-making process. Concrete that is not adequately cured can lose up to 50% of its potential strength compared to moist-cured concrete. While curing at high temperatures can lead to rapid early strength gain, it may negatively impact the long-term strength of the concrete.

2.2.6 Testing on Concrete

2.2.6.1 Compressive Strength Test as perIS: 516-1959

To determine the compressive strength of both M30 and M40 grades of concrete, 72 trial specimens were prepared, including control concrete and concrete with varying percentages of waste glass powder (WGP) replacement. The test cubes used for this purpose measured 15 cm x 15 cm x 15 cm.

After casting, these specimens were subjected to compression testing using a compression testing machine (CTM) after 7 and 28 days of curing. The load was applied gradually at a rate of 140 kg/cm² per minute until the specimens failed. The compressive strength was then calculated using the following formula:

Compressive strength (MPa)=Failure load (P) / Cross-sectional area (A)

Where:

- P is the compressive load on the cube at failure.
- A is the cross-sectional area of the cube.

The compressive strength is given by the load at failure divided by the cross-sectional area of the specimen.

Figure: 2.8 : Compressive strength test of concrete cube by CTM machine

2.2.6.2 Split Tensile Strength testas per IS: 516-1959

The split tensile strength gain test at various percentages of waste glass powder replacement at 7days & 28th day are carried out on cylindrical specimen of 150mmdia and 300mm height using Split Tensile strength testing machine.The cylindrical specimen is positioned horizontally between the loading surfaces of CTM, and the load is applied along the vertical diameter of the cylinder until it fails.

Figure: 2.9 : Split Tensile Strength testof Concrete Cylinder by CTM machine

The test specimen and the crack pattern in the cylinder are shown in the diagram.
The formula for calculating split tensile strength is:
$T=2P/\pi LD$
Where,
P is the compressive load on cylinder
L is the length of cylinder
D is its diameter
T is the split tensile strength of cylinder

2.2.6.3 Flexural Strength Test as per IS: 516-1959

Seventy-two trial specimen beams of size 150mm x 150mm x 700mm were cast, and the flexural strength test was conducted on the 7th and 28th days using a flexural strength testing machine. The flexural strength, or modulus of rupture is calculated using the following formulas:

$$f_b = pl/\{bd^2\}$$

Where:

b = width of the specimen (cm)

d = failure point depth (cm)

l = supported length (cm)

These calculations are essential for determining the beam's flexural strength, which is critical for assessing the tensile strength of concrete.

III. RESULTS AND DISCUSSION

3.1 Test Results of M30 Grade Concrete

3.1.1 Split Tensile Strength Test

The Split Tensile Strength test was conducted on the 7th and 28th days using a Split Tensile Strength testing machine. The results of these tests are summarized in Table No. 3.1, and Figure No. 3.1 illustrates the gain in Split Tensile Strength for various percentages of glass powder tested at both the 7th and 28th days. These results provide insight into how the incorporation of glass powder affects the tensile properties of the concrete over time.

Concrete mix	Split Tensile Strength in N/mm^2			
	After 7days	Average 7days Strength	After 28days	Average 28days Strength
mix 1	2.98	2.96	4	4
	2.81		3.9	
	3.1		4.1	
mix 2	3.49	3.34	4.22	4.19
	3.35		4.15	
	3.18		4.2	

mix 3	3.52	3.53	4.35	4.28
	3.68		4.2	
	3.39		4.3	
mix 4	3.3	3.72	4.5	4.57
	3.75		4.3	
	4.1		4.91	
mix 5	3.45	3.69	4.3	4.48
	3.63		4.33	
	4		4.81	
mix 6	3.34	3.54	4.1	4.25
	3.46		4.18	
	3.81		4.46	

Table: 3.1: Result Split tensile strength test for M30 Grade concrete

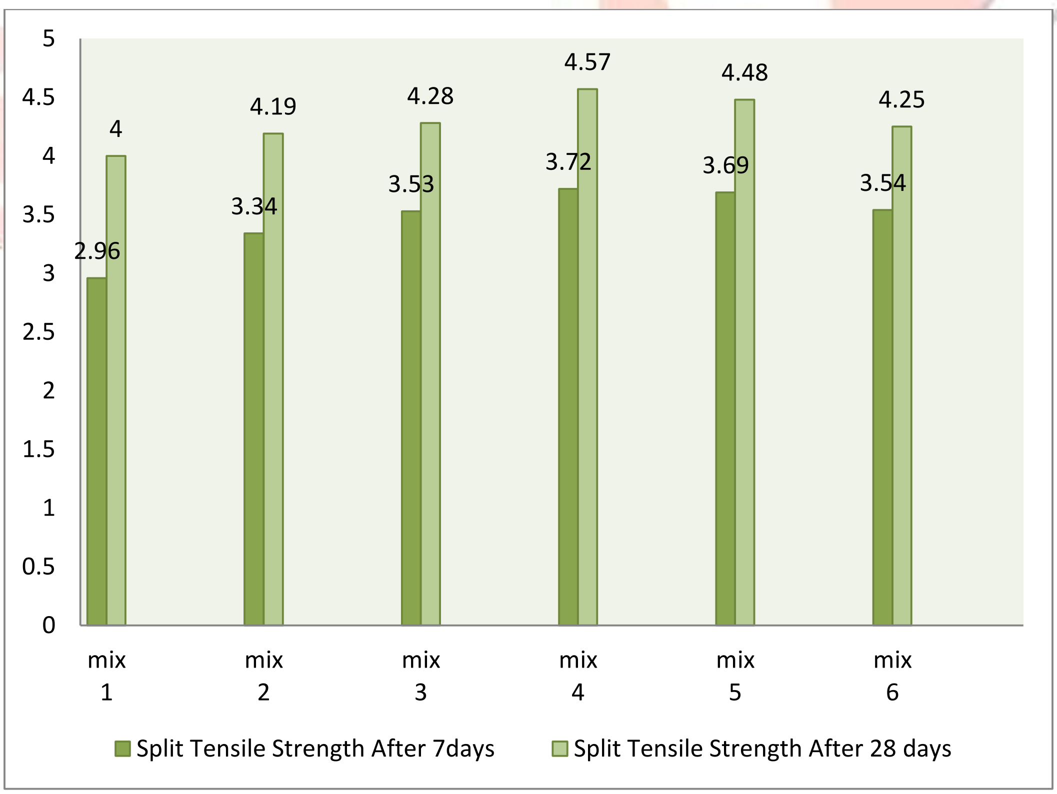

Figure: 3.1: Result of Split tensile strength test for M30 Grade concrete

The result analysis of the split tensile strength tests shows the following values:

For Mix 1 (control concrete):

- At 7 days: 2.96 N/mm²

- At 28 days: 4.00 N/mm²

For Mix 5 (25% replacement of cement with waste glass powder):

- At 7 days: 3.72 N/mm²

- At 28 days: 4.57 N/mm²

These results indicate that replacing 25% of cement with waste glass powder increases the split tensile strength of the concrete compared to the control mix, both at 7 days and 28 days of curing.

3.1.2 Flexural Strength Test

The Flexural Strength test was conducted at 7 and 28 days using a flexural strength testing machine. The results, presented in Table No 3.2 and Figure No 3.2, indicate the flexural strength gained with various percentages of cement replacement by waste glass powder at both testing intervals.These results demonstrate how different replacement percentages of waste glass powder affect the flexural strength of the concrete over time. The data from these tests provide insights into the structural performance and potential benefits of incorporating waste glass powder into concrete mixtures.

Concrete mix	Flexural Strength in N/mm^2			
	After 7days	Average 7days Strength	After 28days	Average 28days Strength
mix 1	2.48	2.7	4.72	4.21
	2.52		3.8	
	3.1		4.12	
mix 2	3.54	3.35	5.23	4.92
	3.69		4.89	
	2.81		4.64	
mix 3	3.57	3.59	5.45	4.98
	3.9		4.8	
	3.3		4.7	
mix 4	4.42	3.92	5.6	5.08
	3.52		5.1	
	3.81		4.54	
mix 5	3.59	3.75	4.81	4.54
	3.76		4.7	
	3.91		4.12	
mix 6	3.29	3.55	4.1	4.2
	3.64		3.9	
	3.71		4.61	

Table: 3.2: Result of Flexural strength test for M30 Grade concrete

The table displaying the results from the flexural strength test shows the following values:

For Mix 1 (control concrete):
- At 7 days: 2.70 N/mm²
- At 28 days: 4.21 N/mm²

For Mix 5 (25% replacement of cement with waste glass powder):
- At 7 days: 3.92 N/mm²
- At 28 days: 5.08 N/mm²

These results indicate that replacing 25% of cement with waste glass powder enhances the flexural strength of the concrete compared to the control mix, at both 7 days and 28 days ofcuring.

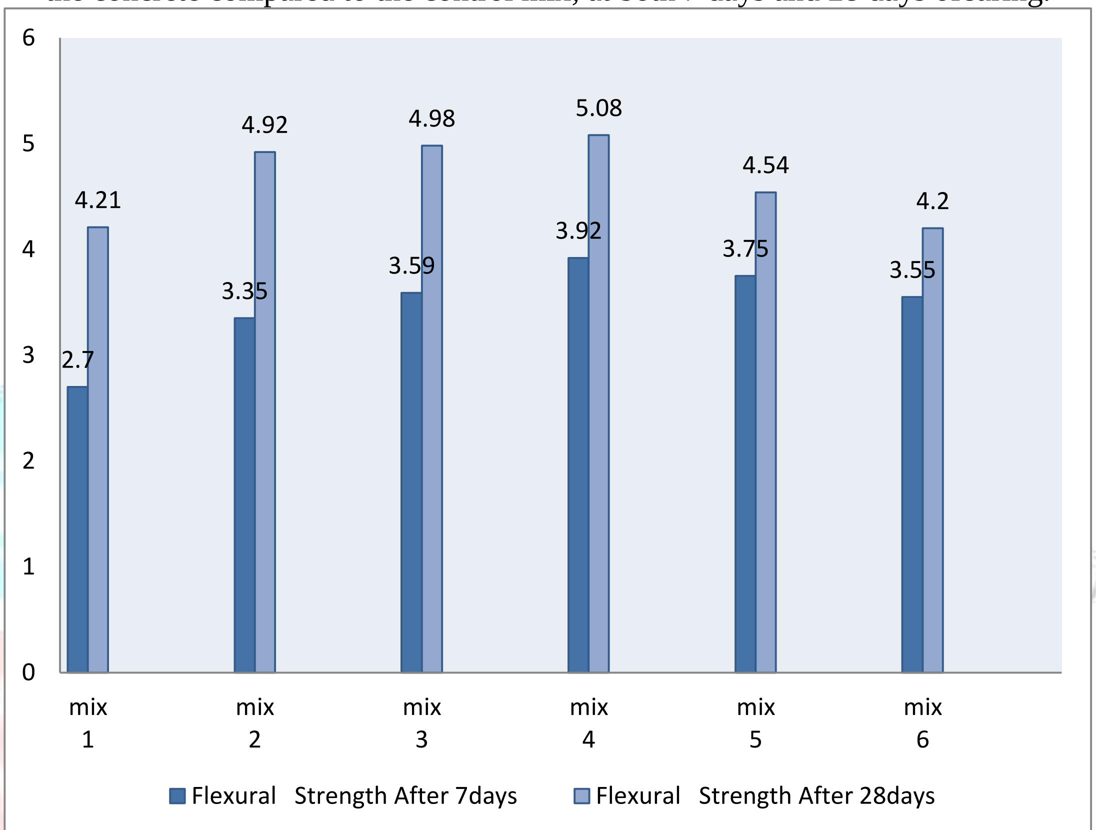

Figure: 3.2 :Result of Flexural strength test for M30 Grade concrete

Bar diagrams were created to display the flexural strength test results for various M30 grade concrete mixes at both 7 and 28 days. Mix 4 showed the highest flexural strength among the tested mixes at both intervals. Nevertheless, increasing the amount of waste glass powder beyond this mix led to a reduction in flexural strength.

3.1.3 Compressive Strength Test

The compressive strength tests were conducted using a Compression Testing Machine at both the 7th and 28th days. The results for various percentages of glass powder are detailed in Table No. 3.3 and depicted in Figure No. 3.3, illustrating the compressive strength development across different percentages of glass powder at the specified test durations.

Concrete Mix	Compressive Strength in N/mm^2			
	After 7days	Average 7days strength	After 28days	Average 28days strength
Mix 1	27.3	27.54	38.75	38.26
	27.45		37.94	
	27.87		38.1	
Mix 2	27.89	28.05	38.8	38.85
	28.32		38.96	
	27.94		38.76	
Mix 3	28.75	28.89	39	39.11
	29		39.43	
	28.93		38.9	
Mix 4	29.1	29.26	39.16	40.01
	29.53		40.29	
	29.16		40.13	
Mix 5	29.86	29.95	40	40.73
	30		41.3	
	29.98		40.89	
Mix 6	28	28.8	37	37.41
	29.75		38.1	
	28.69		37.12	

Table: 3.3 : Result of Compressive Strength Test of M30 Grade Concrete

From the result analysis, the Compressive strength, 27.54 N/mm2 & 38.26 N/mm2 for control concrete and 29.95 N/mm2 & 40.73 N/mm2 for 30% replacement of cement with waste glass powder at the end of 7 days &28 days respectively.

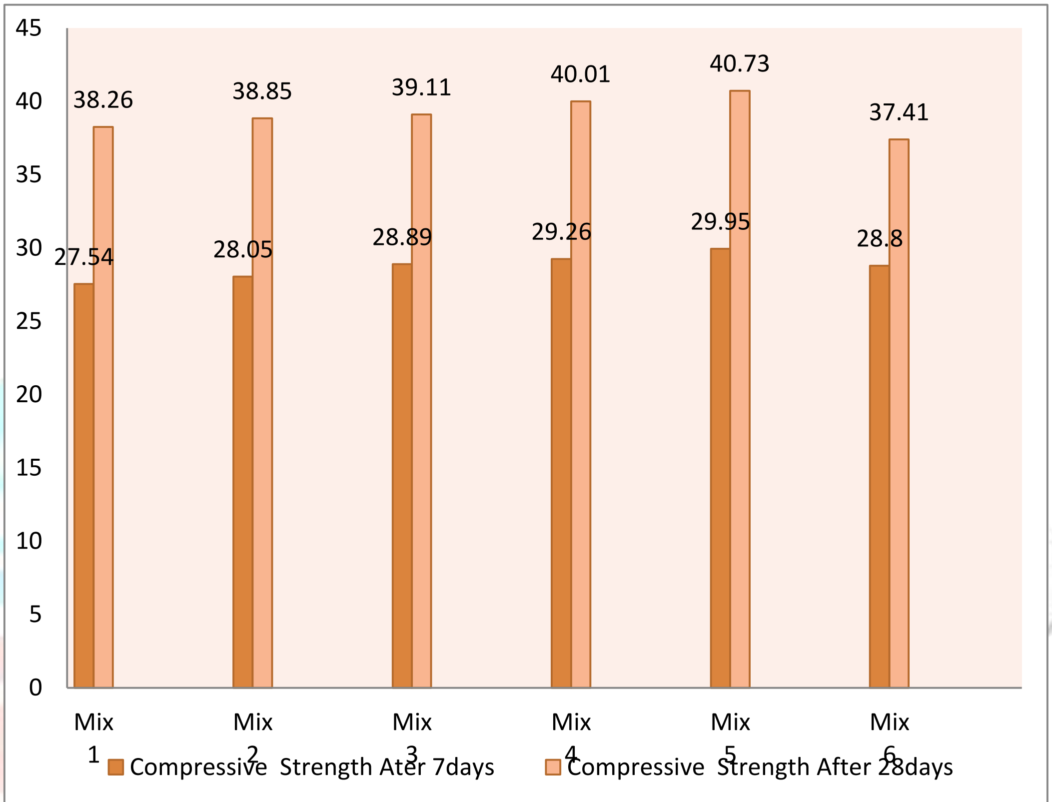

Figure : 3.3 : Result of Compressive Strength Test of M30 Grade concrete

The bar diagram illustrates the relationship between various mixes and their corresponding Compressive Strength test results at 7 and 28 days for M30 grade concrete. Mix 5 demonstrates the highest Compressive Strength at both the 7th and 28th days. However, with the addition of more waste glass powder beyond this mix, a decrease in Compressive Strength is observed. This indicates that while an optimal amount of glass powder enhances concrete strength, excessive amounts can adversely affect its performance.

3.2 Tests Results of M40 grade concrete

3.2.1 Split Tensile Strength Test Report

The Split Tensile Strength test was conducted at 7 and 28 days using a split tensile strength testing machine. The results, which show the effects of varying percentages of glass powder replacement, are presented in Table No 3.4 and illustrated in Graph No 3.4. These results indicate the split tensile strength gained at different percentages of glass powder replacement when tested at both 7 and 28 days.

The data from these tests provide insights into the impact of waste glass powder on the tensile properties of concrete, highlighting how different replacement levels influence the material's performance over time.

Concrete mix	Split Tensile Strength in N/mm^2			
	After 7days	Average 7days strength	After 28days	Average 28days strength
mix 1	3.81	3.83	4.29	4.39
	3.92		4.76	
	3.75		4.12	
mix 2	4.23	4.36	4.85	4.85
	4.76		5	
	4.1		4.69	
mix 3	4.56	4.72	5.12	5.24
	4.9		5.49	
	4.61		5.12	
mix 4	4.98	4.99	5.46	5.53
	4.1		5.68	
	4.89		5.43	
mix 5	5.1	5.14	5.79	5.77
	5.27		5.82	
	5.06		5.7	
mix 6	4.86	4.85	5.63	5.56
	5.1		5.71	
	4.61		5.34	

Table : 3.4 : Result of Split Tensile Strength Test of M40 Grade Concrete

From the result analysis, the Split Tensile Strength values were as follows:

Control Concrete - 3.83 N/mm² at 7 days and 4.39 N/mm² at 28 days.

30% Replacement with Waste Glass Powder - 5.77 N/mm² at 7 days and 5.77 N/mm² at 28 days.

This indicates a significant increase in split tensile strength with 30% waste glass powder replacement at both 7 and 28 days.

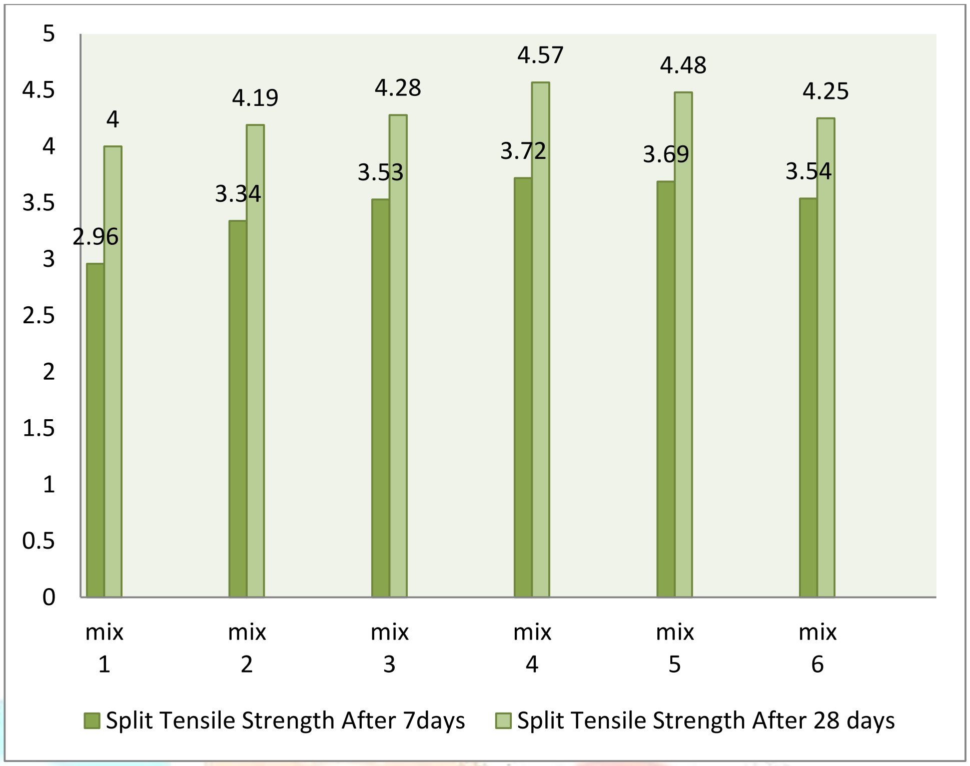

Figure : 3.4 : Result of Split Tensile Strength Test of M40 Grade concrete

The above Bar diagram drawn between various mixes and Split Tensilestrength test result at 7 days and 28 days for M40 grade concrete. Mix 5shows better result (higher Split TensileStrength) at 7 days and 28 days. After which adding more waste glass powder it decreases its strength

3.2.2 Flexural Strength Test

The Flexural Strength test was conducted at 7 and 28 days using a flexural strength testing machine. The results obtained are presented in Table No 3.5 and illustrated in Graph No 3.5, which show the flexural strength gain for

various percentages ofglass powder replacement at the 7th and 28th daysof testing.

Concrete mix	Flexural Strength in N/mm^2			
	After 7days	Average 7days strength	After 28days	Average 28 days strength
mix 1	2.9	3.0	4.81	5.03
	2.96		4.1	
	3.23		4.55	
mix 2	3.65	3.5	5.46	5.14
	3.79		5.06	
	3.1		4.91	
mix 3	3.81	3.9	5.89	5.44
	4.1		5.47	
	3.71		4.96	
mix 4	4.73	4.2	5.96	5.50
	3.81		5.47	
	3.96		5.06	
mix 5	4.89	4.4	6	5.61
	3.98		5.69	
	4.23		5.13	
mix 6	4.1	3.6	5.31	4.84
	3.46		5.1	
	3.23		4.12	

Table:3.5: Result of Flexural Strength Test of M40 Grade Concrete

From the result analysis, the Flexural strength, 3.0 N/mm2 & 5.03 N/mm2 for control concrete and 4.4 N/mm2 & 5.61 N/mm2 for 25% replacement of cement with waste glass powder at the end of 7 days &28 days respectively.

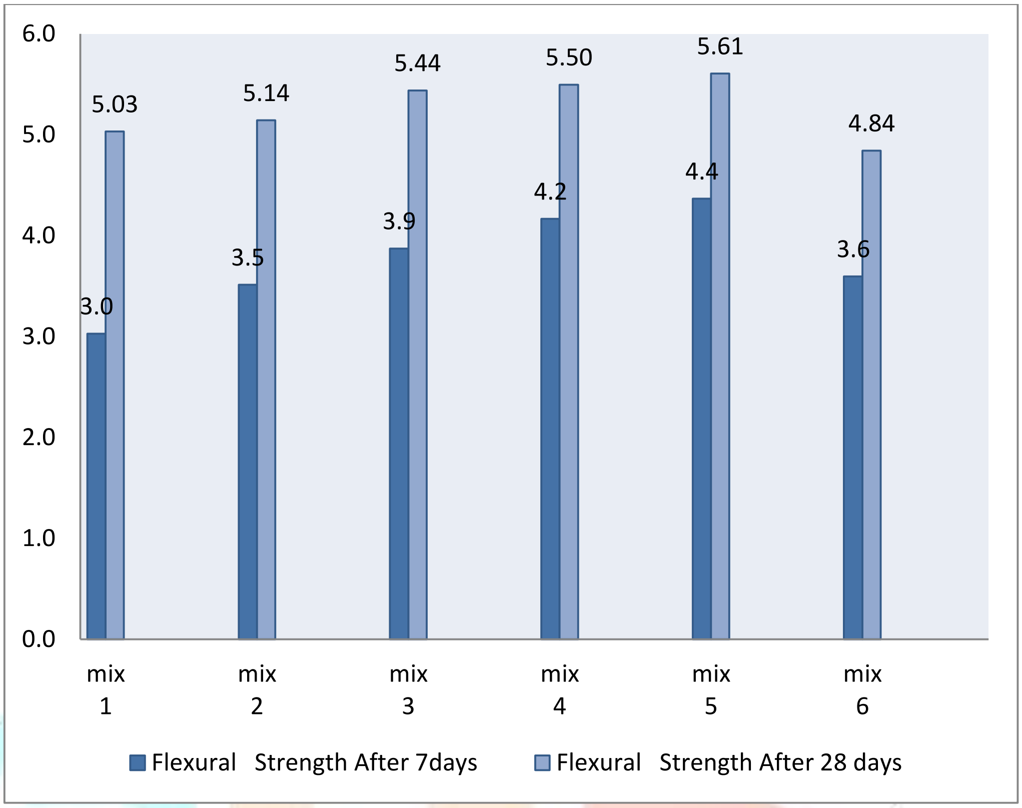

Figure: 3.5 : Result of Flexural Strength Test of M40 Grade concrete

The above Bar diagram drawn between various mixes and Flexural strength test result at 7 days and 28 days for M40 grade concrete. Mix 5 shows better result (higher Flexuralstrength) at 7 days and 28 days. After which adding more waste glass powder it decreases its flexural strength.

3.2.3 Compressive Strength Test

Compressive Strength test was carried out at 7th and 28th days using Compression testing machine. The results obtained on various percentages of glass powder are shown in Table No 3.6 Figure No 3.6.

Concrete mix	Compressive Strength in N/mm^2			
	After 7day	Average7days strength	After 28days	Average 28days strength
mix 1	36.7	37.05	51	51.7
	37.53		52.3	
	36.91		52	
mix 2	37.63	37.92	52.6	52.7
	38.38		52.9	
	37.76		52.7	
mix 3	38.56	38.66	53	53.27
	39		53.5	
	38.43		53.3	

mix 4	39.1	39.52	53.65	53.83
	39.89		53.94	
	39.57		53.89	
mix 5	39.57	40.02	54	54.19
	40.32		54.23	
	40		54.36	
mix 6	40.11	40.61	54.91	55.04
	40.9		55.01	
	40.84		55.21	

Table : 3.6 : Result of Compressive Strength Test of M40 Grade Concrete

From the result analysis, the Compressive strength, 37.05 N/mm2 & 51.7 N/mm2 for control concrete and 40.61 N/mm2 & 55.04 N/mm2 for 25% replacement of cement with waste glass powder at the end of 7 days &28 days respectively.

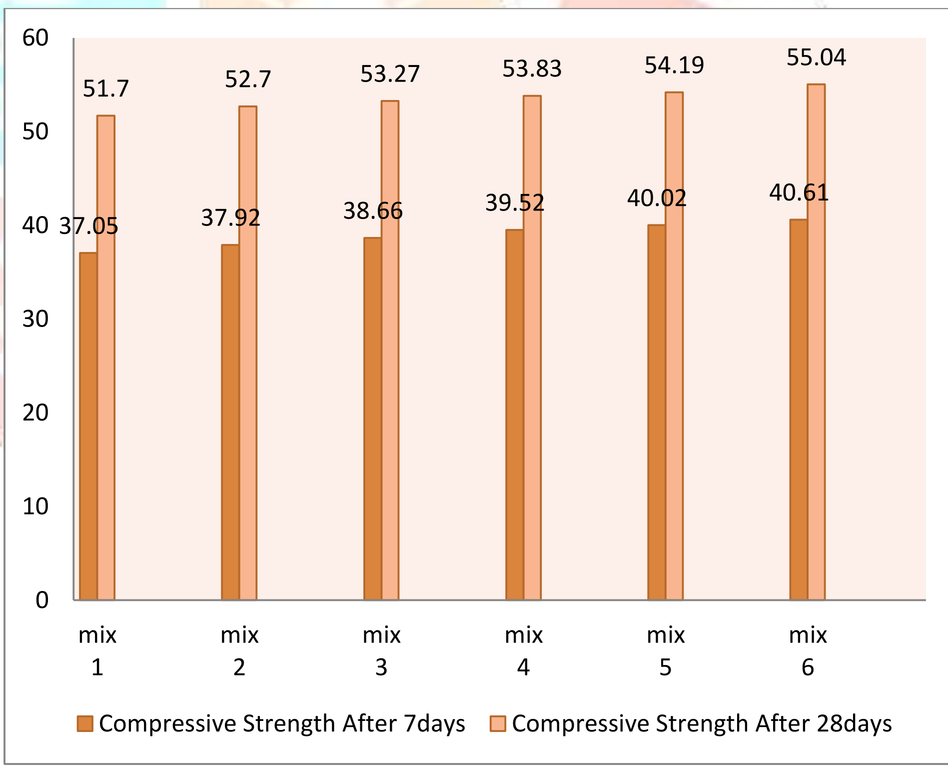

Figure: 3.6 : Result of Compressive strength test of M40 Grade concrete

The above Bar diagram drawn between various mixes and Flexural strength test result at 7 days and 28 days for M40 grade concrete. Mix 6 shows better result (higher Compressivestrength) at 7 days and 28 days. After which adding more waste glass powder it decreases its strength

3.3 Comparison between test result of M30 & M40 Grade Concrete for various % of WGP after 7days & 28 days respectively:

Split tensile strength test

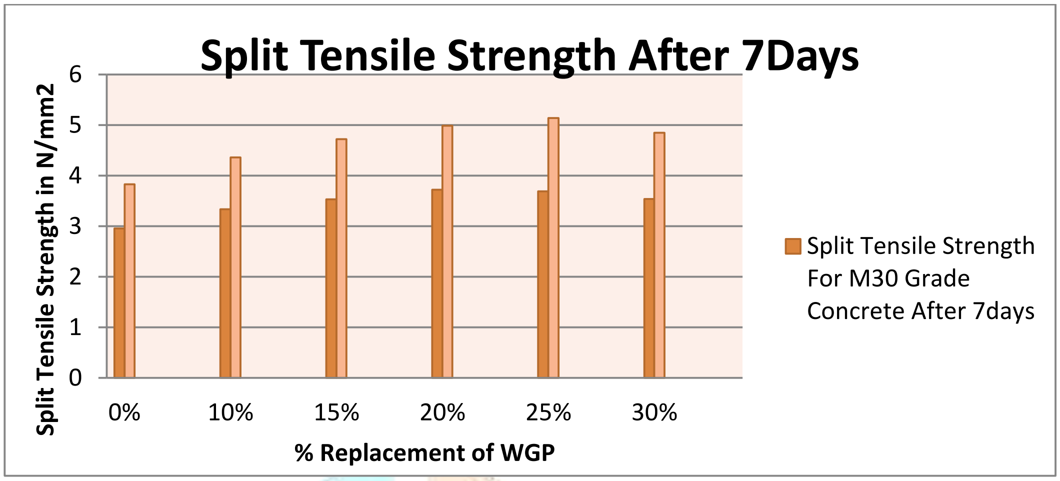

Figure :3.7 : Split tensile strength at 7days for various % waste glass powder for M30 & M40 grade concrete

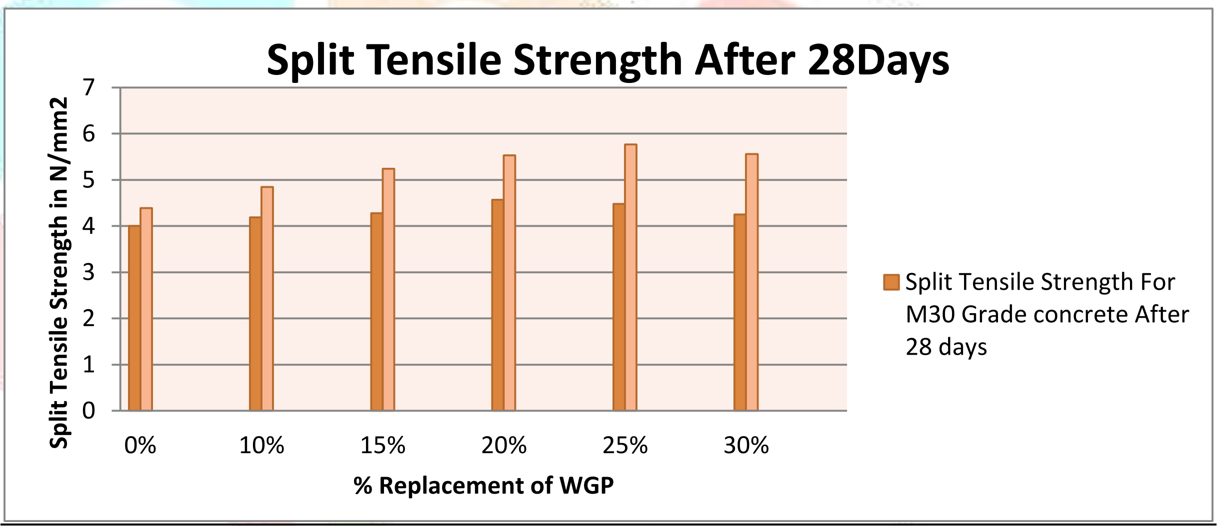

Figure: 3.8 : Split tensile strength at 28days for various % waste glass powder for M30 & M40 grade concrete

Flexural Strength Test

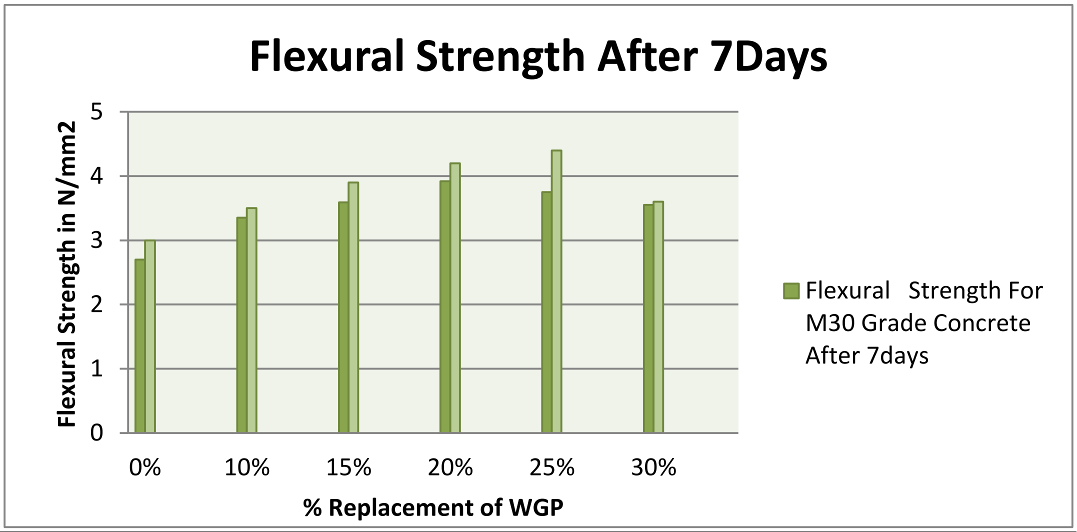

Figure: 3.9 : Flexural strength at 7days for various % waste glass powder for M30 & M40 grade concrete

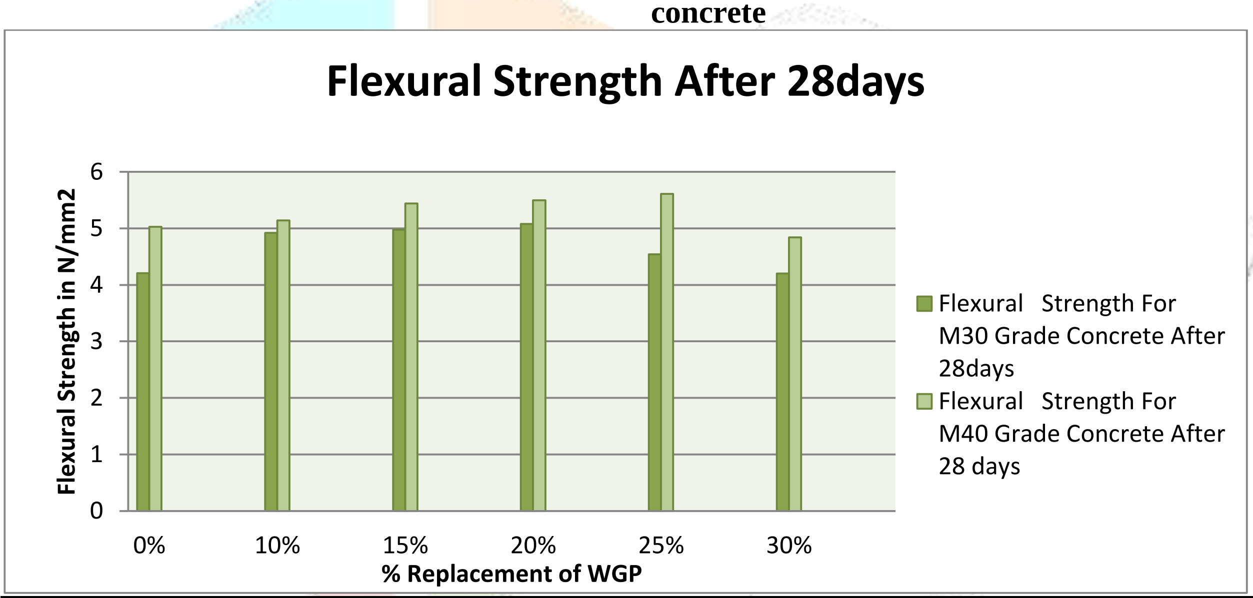

Figure :3.10 : Flexural strength at 28days for various % waste glass powder for M30 & M40 grade concrete

Compressive StrengthTest

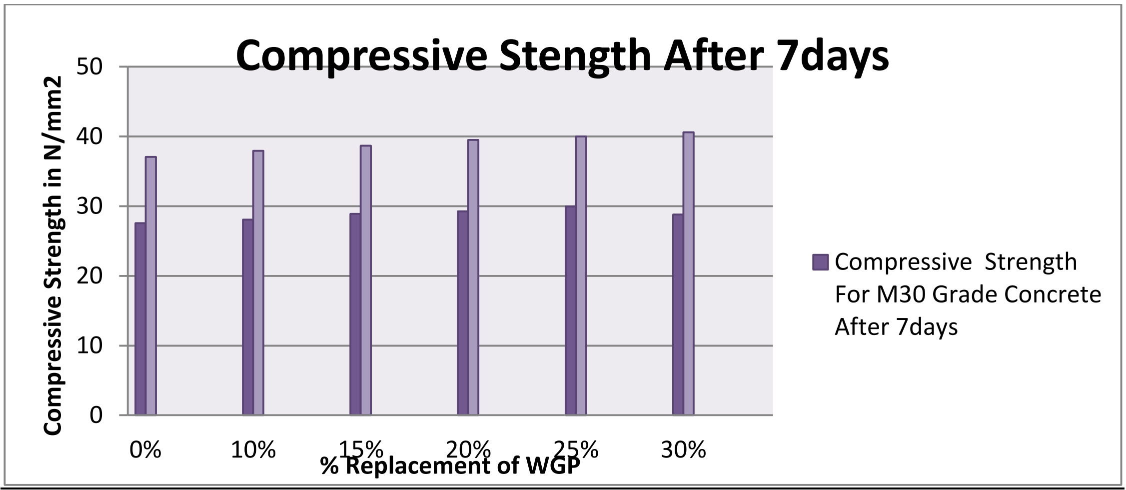

Figure :3.11 : Compressive strength at 7days for various % waste glass powder for M30 & M40 grade concrete

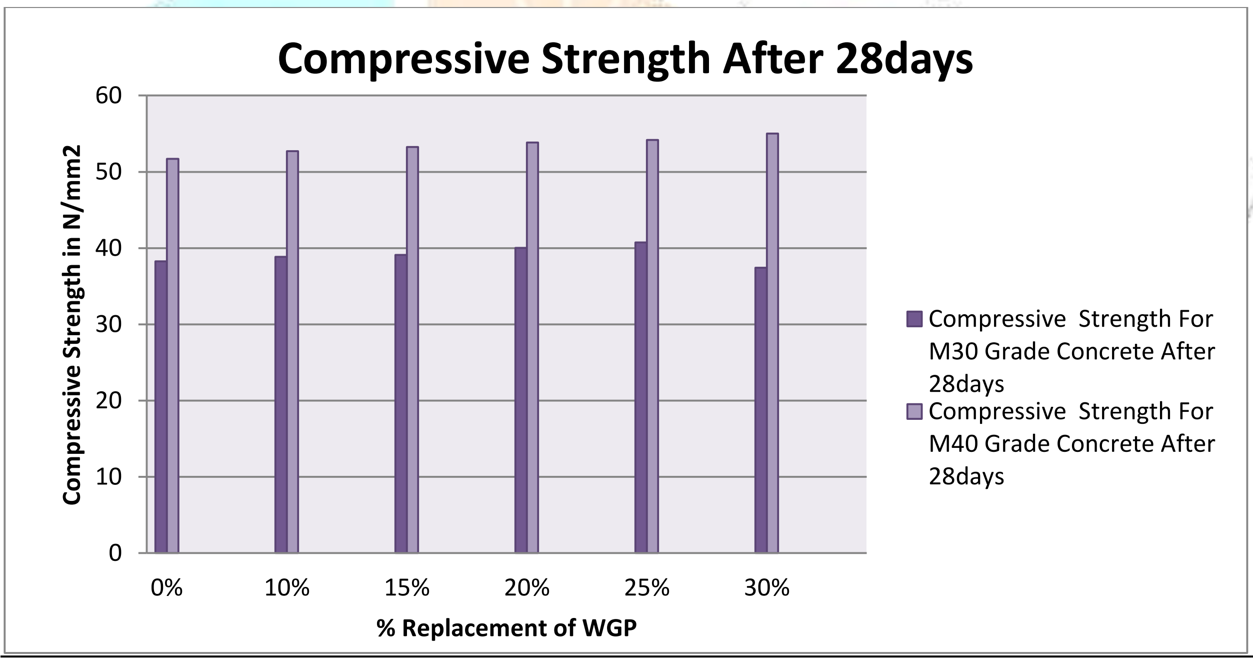

Figure : 3.12 : Compressive strength at 28days for various % waste glass powder for M30 & M40 grade concrete

IV. ACKNOWLEDGEMENT

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