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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.

Full length article **Corresponding Author*, e-mail: *vkvijyendra@gmail.com;* doi# 10.71111/Science today/4-24-1-1-st-4

1. Introduction

1.1 General

In recent years, 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 tons of glass waste annually, of which only 45% is recovered, with the rest often ending up in landfills or being down cycled 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 CO_2 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 CO_2 emissions associated with cement manufacturing [1-4].

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. 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 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 [5-6].

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 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. 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 potential to reduce costs compared to the use of expensive admixtures for achieving high concrete strength, as current market admixtures often cost and can inflate construction expenses [7-8].

1.2 Glass Recycling (GR)

Glass recycling is a 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 melting 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. Main types used include clear, green, and brown/amber glass [9].

1.3 Why Glass Recycling?

i) Saves Limited Natural Resources: There is a finite number 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 [10].
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 [11].

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 [12].

1.5 How is Glass 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 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 the crash to suppress dust.
iv) Screening: 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 [13].
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 [14].

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 compressive, flexural and tensile strength of concrete.

2. Materials and Methods

2.1.1 Cement

Cement is a 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 formation of submicroscopic crystals or a gel-like material, giving concrete its strength [15]. Table (1a-o) shows properties and characteristics of materials.

2.1.2 Fine Aggregate (Sand)

Fine aggregate, typically sand, used in concrete to fill voids b/w coarse aggregates & cement particles. Smaller in size than gravel and larger than silt, usually less than 4.75

mm in diameter. Sand is essential for mechanical properties of concrete and primarily composed of silica (SiO_2) [16].

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 [17].

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 [18-20].

2.1.5. Water

In this study, tap water was utilized for concrete mixtures. It is essential that water used in concrete construction meets stringent quality standards to ensure optimal performance and longevity of concrete structures. Water should be devoid of any contaminants that could potentially compromise integrity or aesthetics of the concrete. MgO, SO_3, K_2O & Cl do not present in waste glass powder. 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. Concrete mix design carried out using a systematic analysis in accordance with IS: 10262-2009, and proportions of ingredients used in concrete mix chosen to generate an economical concrete with necessary strength after cube hardened [21-23].

- 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 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 [24-26].

- ***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 requirements specified in the Indian Standard, ensuring they contribute effectively to the mechanical properties of the concrete [27].

- ***Cement (Ordinary Portland Cement - OPC)***

Ordinary Portland Cement, specifically Birla A1 Premium, utilized in this investigation. Cement is finely ground material known for its adhesive and cohesive properties, providing binding medium in concrete mixtures. The cement used in this study adhered to standards set by IS: 8112 – 2013 for Ordinary Portland Cement 43 grade [28-30].

- ***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 [31-34].

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 mold 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 [35-38].

- ***Initial Setting Time***

The initial setting time of concrete is the duration from the moment water is added to the cement until cement paste reaches a particular consistency. Specifically, it is time elapsed until a 1 mm square section needle, under specified conditions, fails to penetrate cement paste placed in Vicat's mould at a depth of 5 mm to 7 mm from bottom of 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 [39-41].

- ***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 behaviour during the setting phase, ensuring proper handling and application during construction [42-44].

- ***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 same volume [45-48].

Formula :-

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

- ***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 [49-51].

- ***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:
$Percent\ of\ cement\ retained\ on\ sieve = (W2/W1) \times 100$ 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.

Experimental results show that every parameter are on specified range as given in Indian Standard [52-54].

2.2.2.2 Sand

The locally available sand conforming to Zone –II conforming to IS code 383-1970 is used [55-57].

- ***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 [58-60].

- ***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), specific gravity is typically around 2.64. It is calculated using formula:

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

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:

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

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

Various tests were 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. [61-63].

2.2.2.3 Coarse Aggregate

In the experimental studies, the coarse aggregate used 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 volume of aggregate

2.2.2.4 Glass 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 waste glass powder obtained: Several tests conducted on Waste glass powder.

2.2.3 Experimental Setup and Mix Design

- ***Material Replacement and Test Specimens***

In this study, Ordinary Portland Cement (OPC) partially replaced with waste glass powder at varying percentages (10%, 15%, 20%, 25%, and 30%) for both M30 and M40 grade concrete [64-67]. 72 concrete specimens 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***

Mix proportions for M30 and M40 grade concrete determined according to Indian standards IS: 456:2000 and IS 10262:2019 [68-69]. The following six mix designs used in 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 [70]:
  - 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 direction of applied load.

- ***Comparative Analysis***

Results of compressive strength, flexural strength, and split tensile strength for glass powder-modified concrete mixes were compared with those of the control mix (plain concrete). This comparison will provide insights into effectiveness of waste glass powder as a cement replacement in terms of enhancing or maintaining mechanical properties of concrete [71].

- ***Quantity of materials For M30 grade concrete***

Mix proportions for various replacements of cement with glass powder are given in table (1a-o) for M30 grade concrete [72].

- ***Quantity of materials For M40 grade concrete***

Mix proportions for various replacements of cement with glass powder are given in table (1a-o) for M40 grade concrete [73].

2.2.4 Casting 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 allowed to cure for 24 hrs. before de molding.
  - After de molding, 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 effects of WGP replacement on compressive, flexural, and split tensile strengths of concrete can be accurately assessed, providing valuable insights into potential of using waste glass powder in concrete production [74].

- ***Test Specimen details***

After calculating required sample quantities, 72 cubes, beams, and cylinders of specific sizes and shapes prepared. Cubes cast to test compressive strength after 7 and 28 days of curing, while cylinders made to evaluate split tensile strength at same intervals [75].

2.2.5 Curing

The cubes were maintained at a controlled temperature of 27°C and a relative humidity of 90% for first 24 hours after water addition. After this initial curing period, specimens marked, de molded, and immediately submerged in clean water for continued curing until just before testing [76]. Proper curing is critical for achieving desired properties of hardened concrete, such as:
  - Durability
  - Strength
  - Water-tightness
  - Abrasion resistance
  - Dimensional stability

Curing marks the final stage in 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 long-term strength of concrete.

2.2.6 Testing on Concrete
2.2.6.1 Compressive Strength Test as per IS: 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. Load applied gradually at a rate of 140 kg/cm² per minute until the specimens failed [77]. Compressive strength then calculated using following formula:

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

- 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.

2.2.6.2 Split Tensile Strength test as 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. Cylindrical specimen is positioned horizontally between loading surfaces of CTM, and load is applied along vertical diameter of the cylinder until it fails [78]. Test specimen and crack pattern in cylinder are shown in 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:

$$fb = pl/\{bd2\}$$

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 [79]. Figures 1a-k shows various materials and parameters involved in the present study.

3. Results and discussion

Tables 2a to 2f shows results of the present study.

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 illustrates the gain in Split Tensile Strength for various percentages of glass powder tested at both the 7th and 28th days (Figure 2a-l). These results provide insight into how the incorporation of glass powder affects the tensile properties of the concrete over time. 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

Results indicate that replacing 25% of cement with waste glass powder increases split tensile strength of concrete compared to control mix, both at 7 and 28 days of curing [80].

3.1.2 Flexural Strength Test

The Flexural Strength test conducted at 7 and 28 days using a flexural strength testing machine. The results, indicate 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 flexural strength of concrete over time. Data from these tests provide insights into structural performance and potential benefits of incorporating waste glass powder into concrete mixtures. Results of flexural strength test shows 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 flexural strength of concrete compared to control mix, at both 7 days and 28 days of curing. Bar diagrams were created to display flexural strength test results for various M30 grade concrete mixes at both 7 and 28 days. Mix 4 showed highest flexural strength among tested mixes at both intervals. Nevertheless, increasing amount of waste glass powder beyond this mix led to a reduction in flexural strength [81].

3.1.3 Compressive Strength Test

The compressive strength tests were conducted using a Compression Testing Machine at both the 7th and 28th days. 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. The bar diagram illustrates 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 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 [82].

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 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. 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. Above Bar diagram drawn between various mixes and Split Tensile strength test result at 7 days and 28 days for M40 grade concrete. Mix 5 shows better result (higher Split Tensile Strength) at 7 days and 28 days. After adding more waste glass powder it decreases its strength [83].

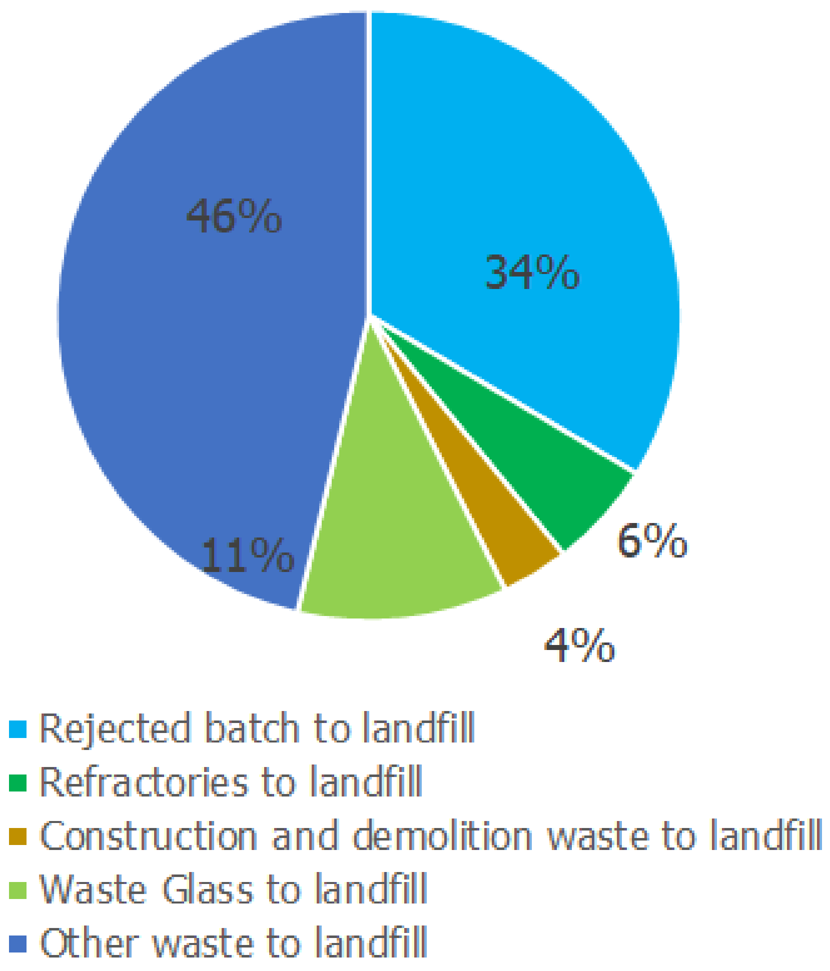

Figure 1a. Wastes to landfill (Source: Waste and Circular economy)

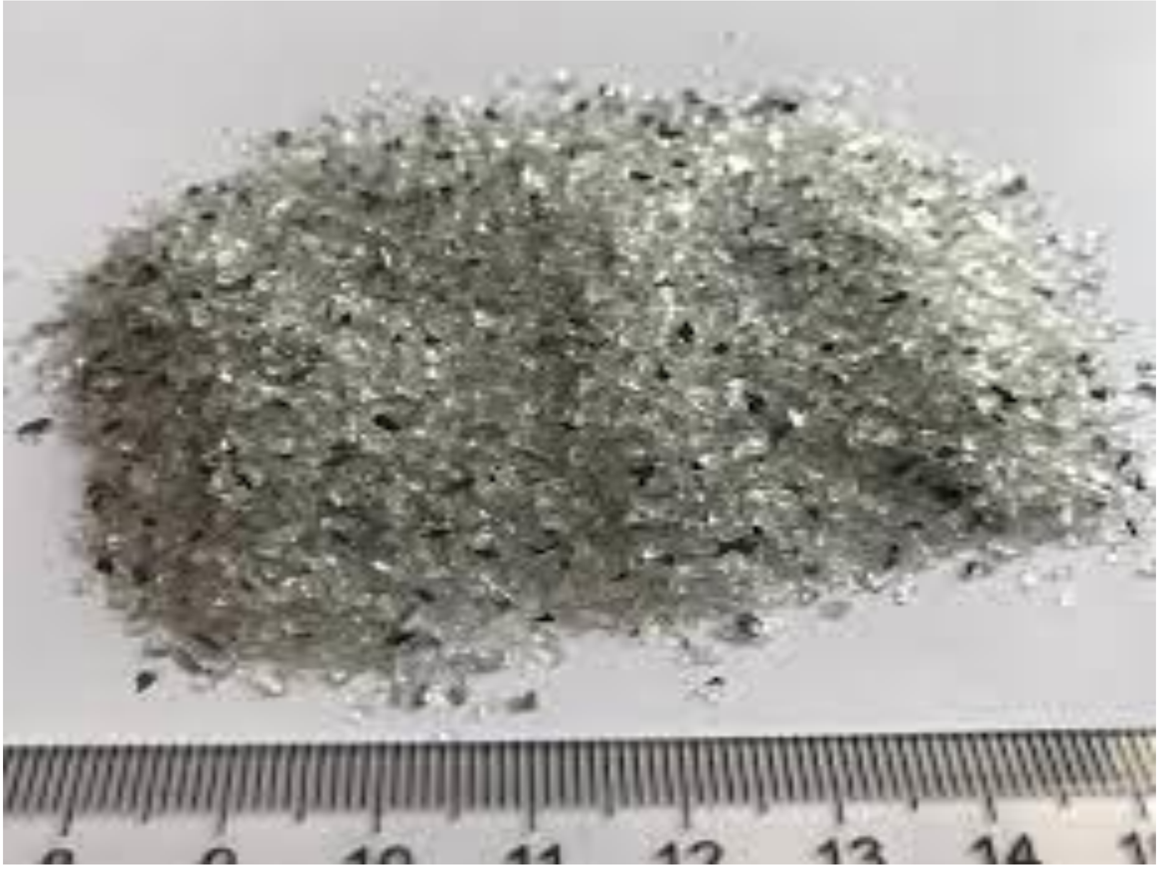

Figure 1b. Cullet's of Waste White Glass

Figure 1c: White Glass Powder

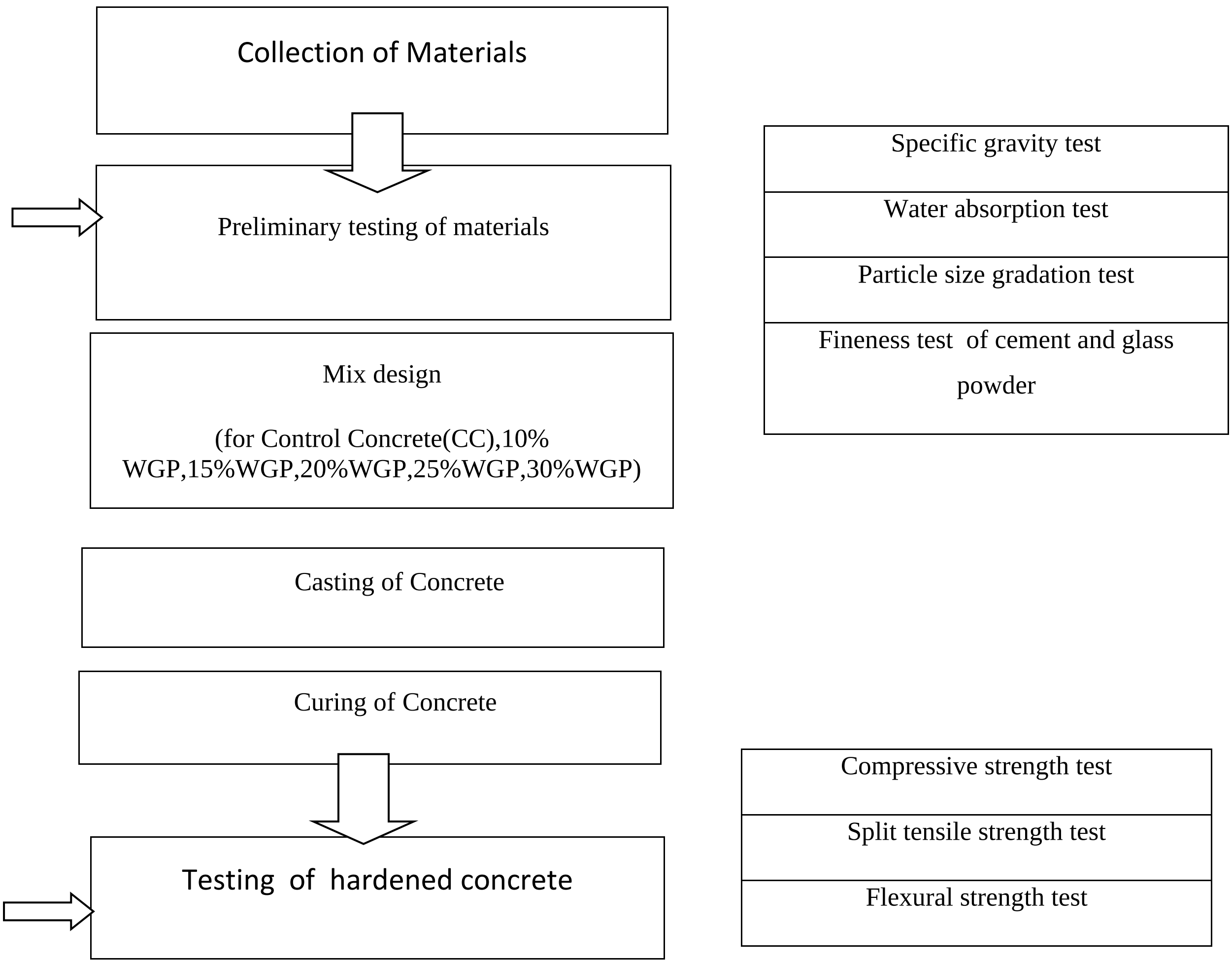

Figure 1d. Flow chart of method adopted

Figure 1e. Vicat Apparatus for Consistency, Initial setting time & Final setting time test of cement

Figure 1f. Specific gravity test of sand

Figure 1g. Sieve analysis of sand

Figure 1h. Specific Gravity & Water absorption test machine of coarse aggregate

Figure 1i. Casting of cubes

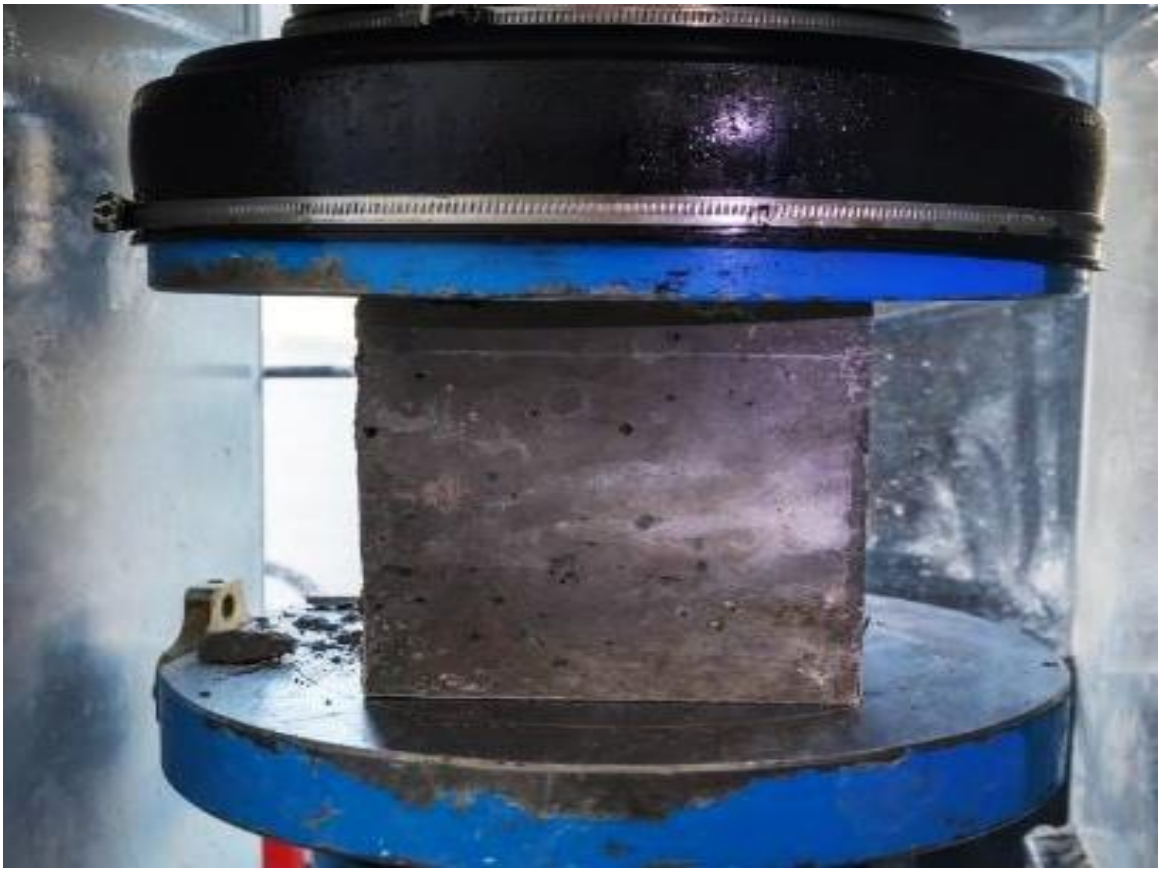

Figure 1j. Compressive strength test of concrete cube by CTM machine

Figure 1k. Split Tensile Strength test of Concrete Cylinder by CTM machine

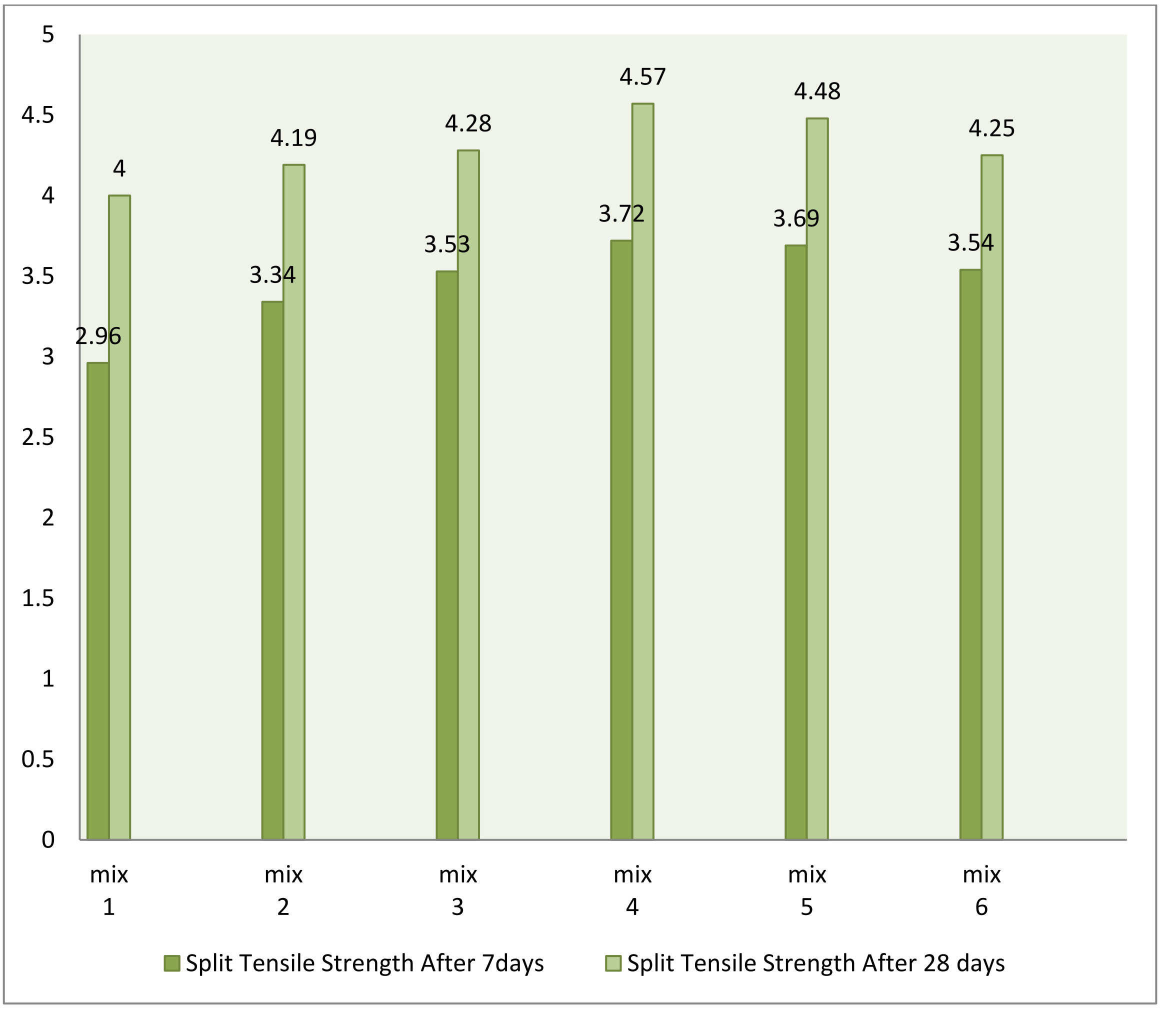

Figure 2a. Result of Split tensile strength test for M30 Grade concrete.

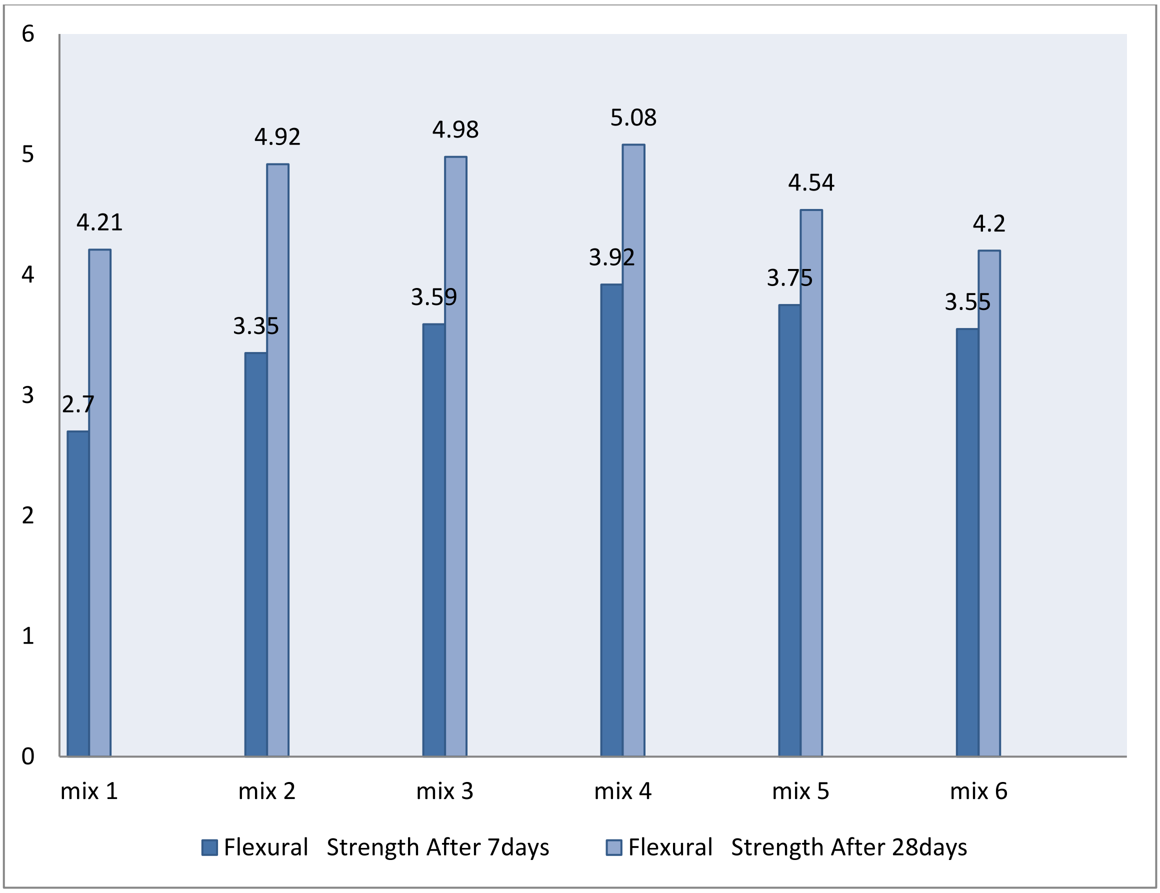

Figure 2b. Result of Flexural strength test for M30 Grade concrete

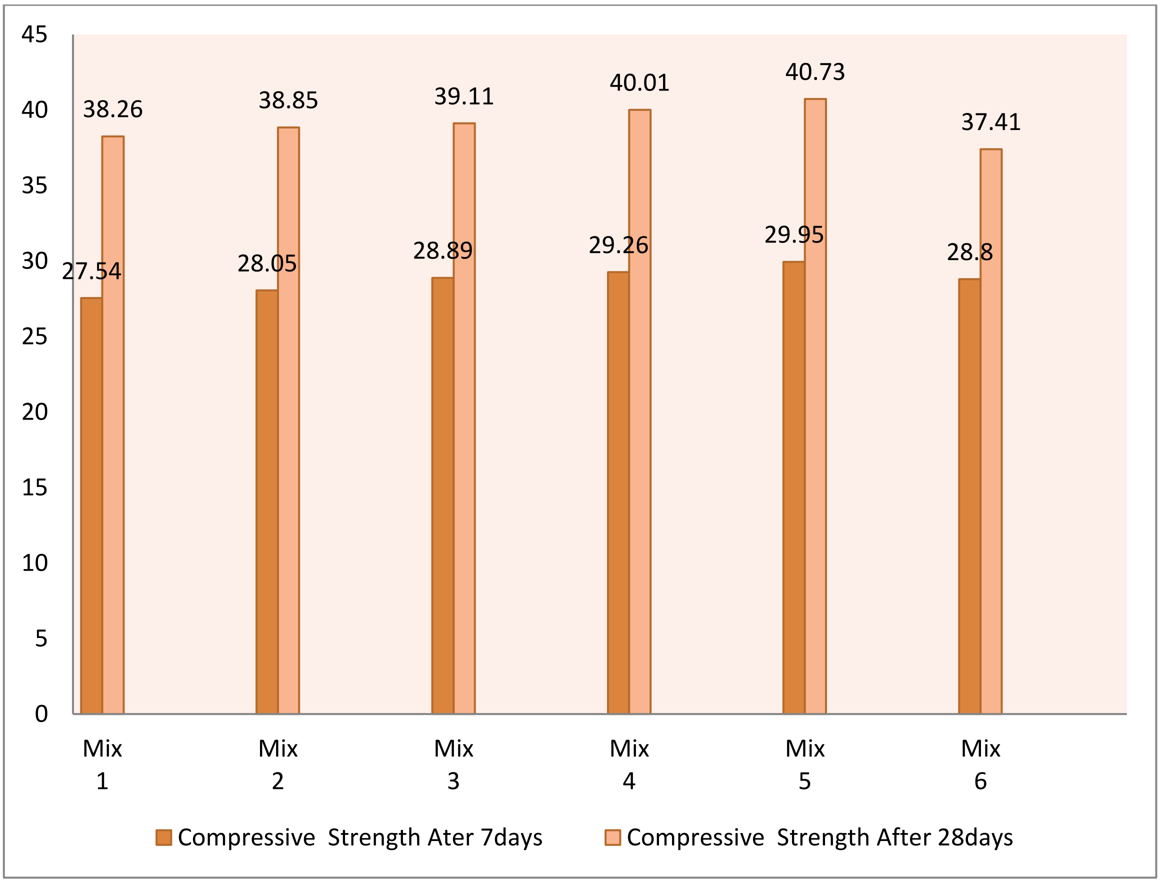

Figure 2c. Result of Compressive Strength Test of M30 Grade concrete

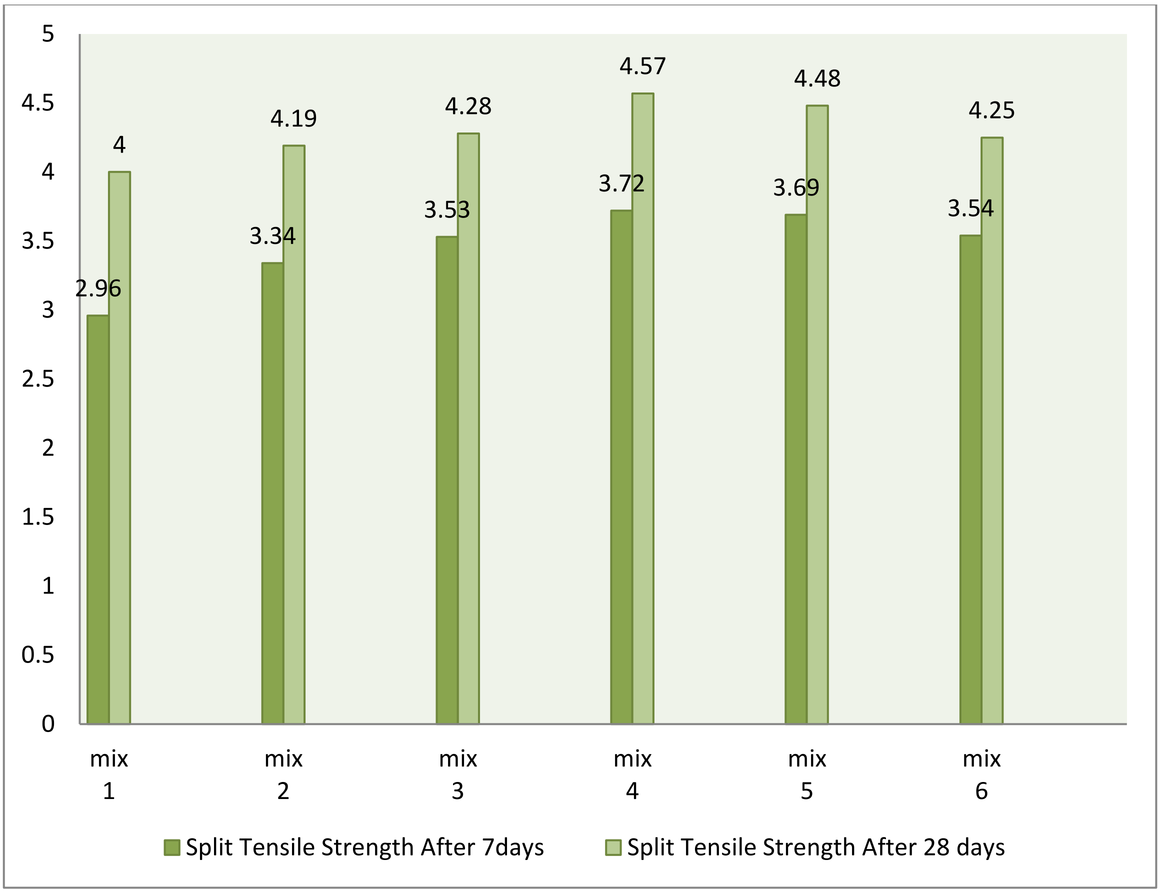

Figure 2d. Result of Split Tensile Strength Test of M40 Grade concrete

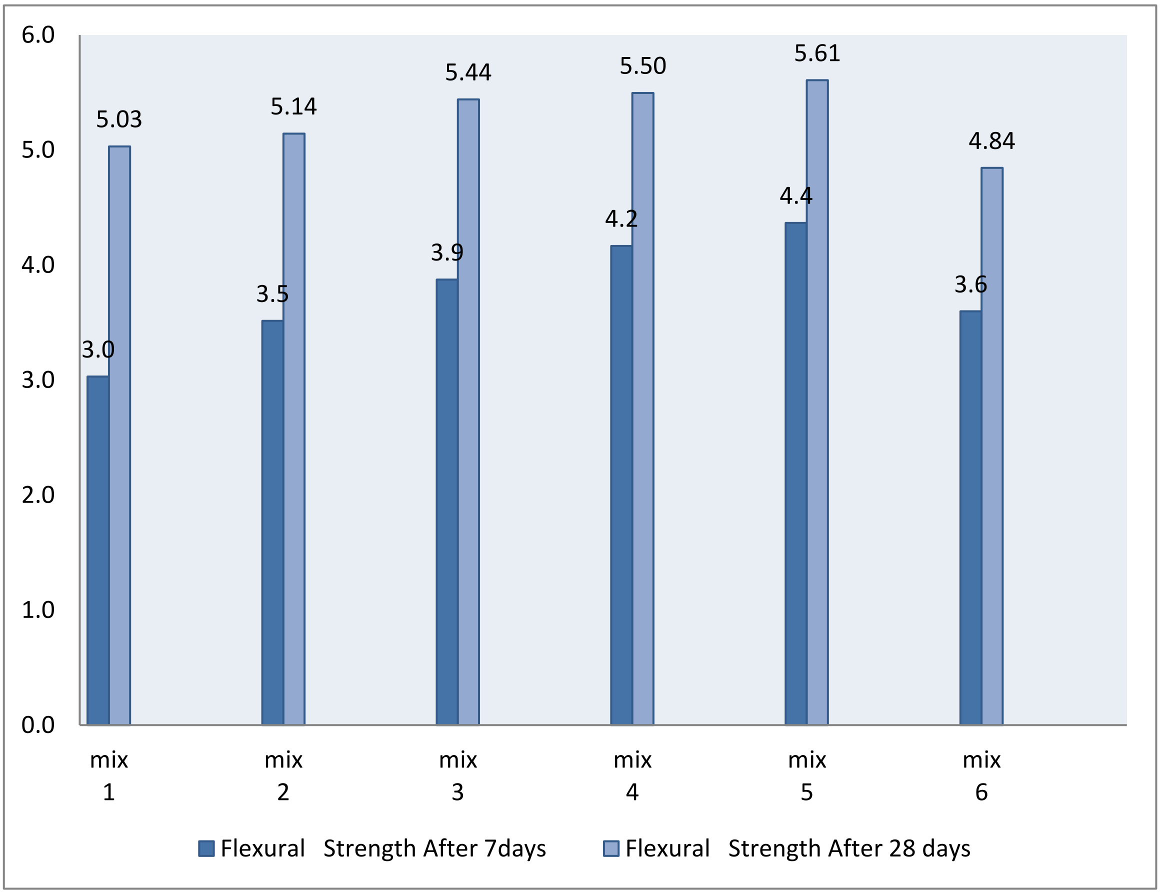

Figure 2e. Result of Flexural Strength Test of M40 Grade concrete

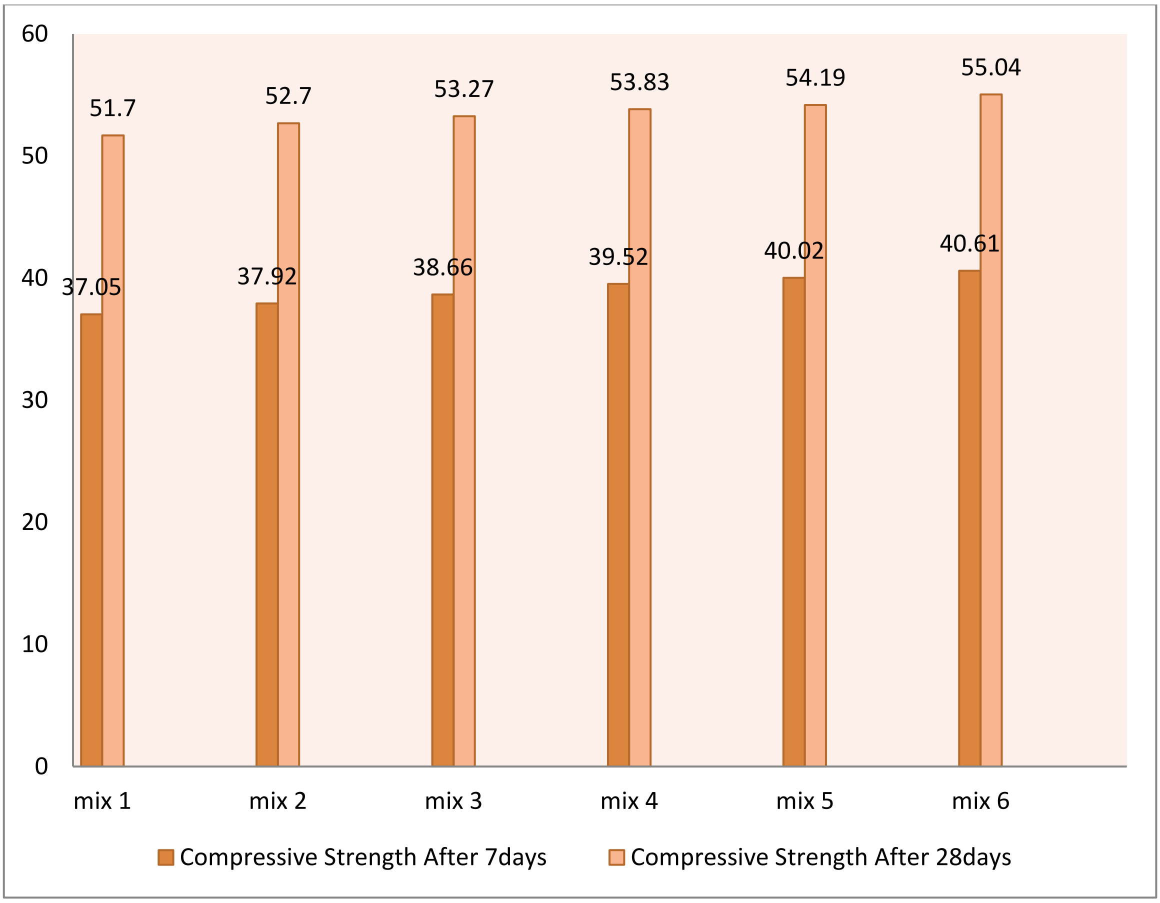

Figure 2f. Result of Compressive strength test of M40 Grade concrete

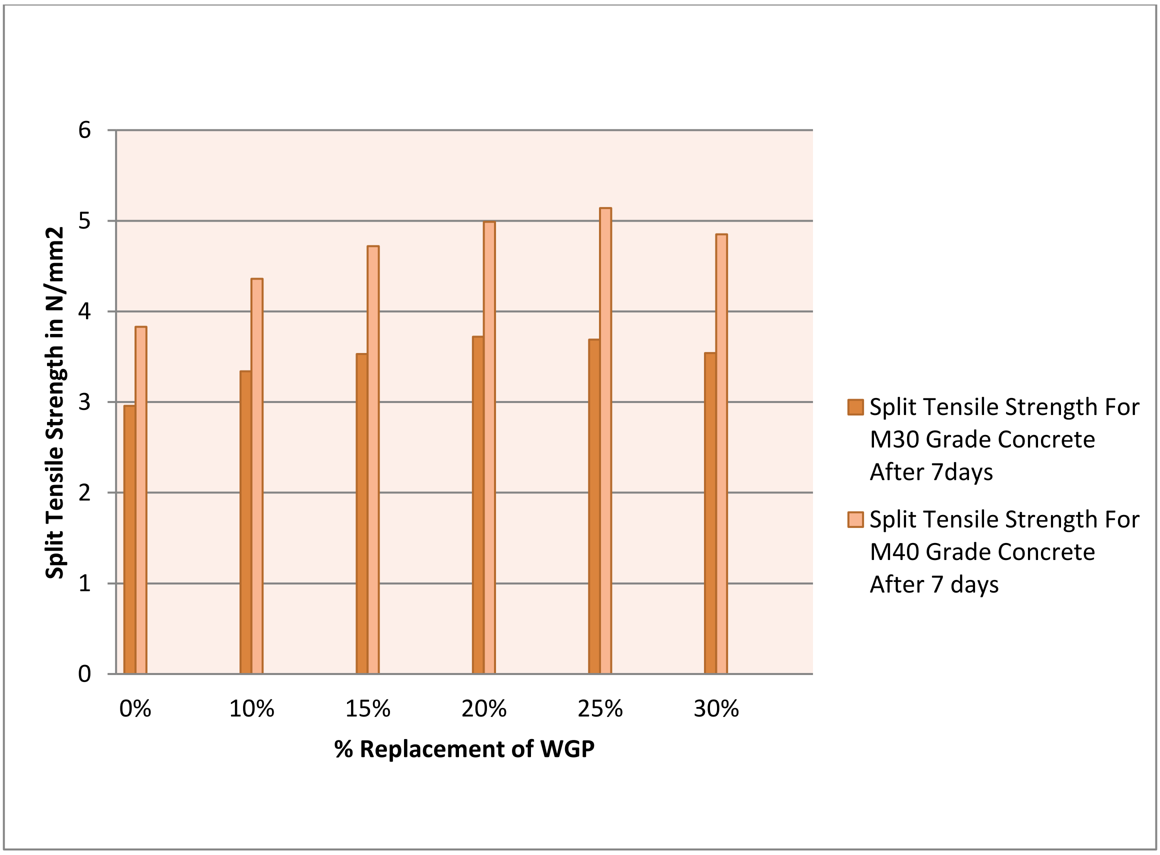

Figure 2g. Split tensile strength at 7days for various % waste glass powder for M30 & M40 grade concrete

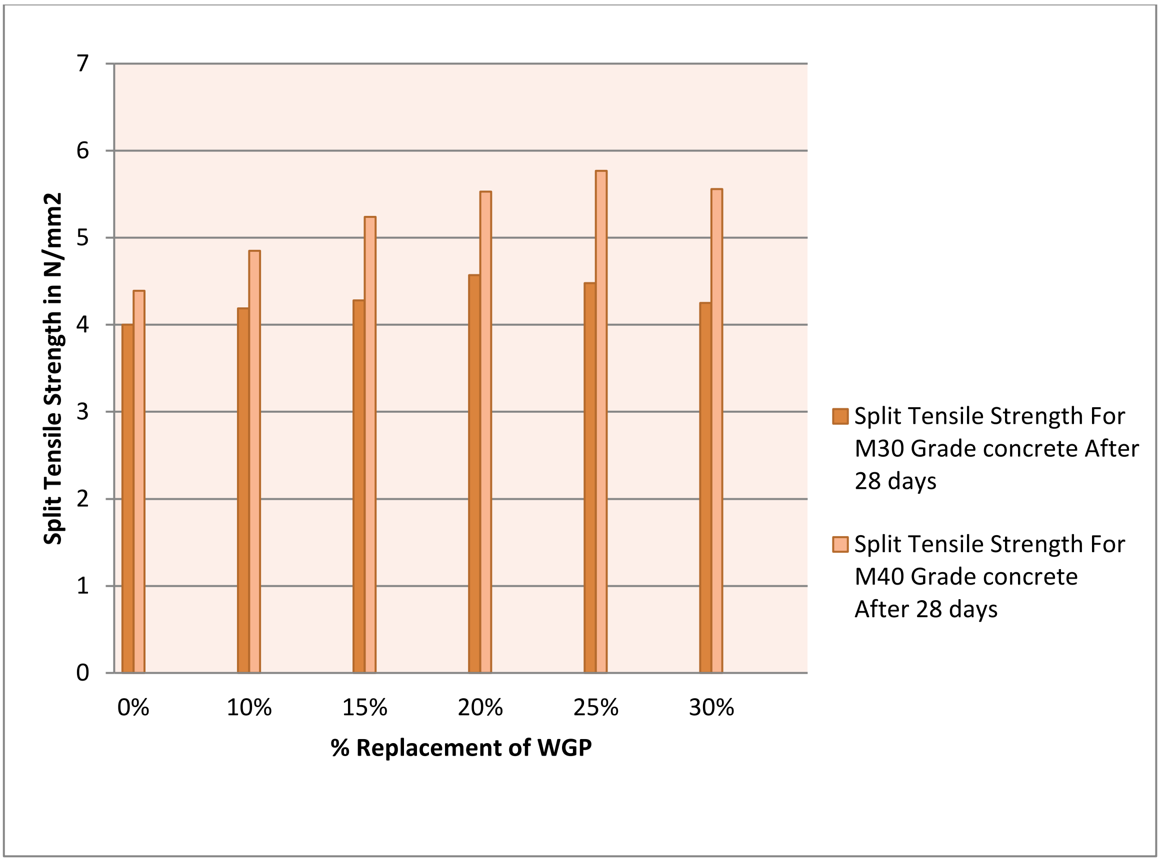

Figure 2h. Split tensile strength at 28days for various % waste glass powder for M30 & M40 grade concrete

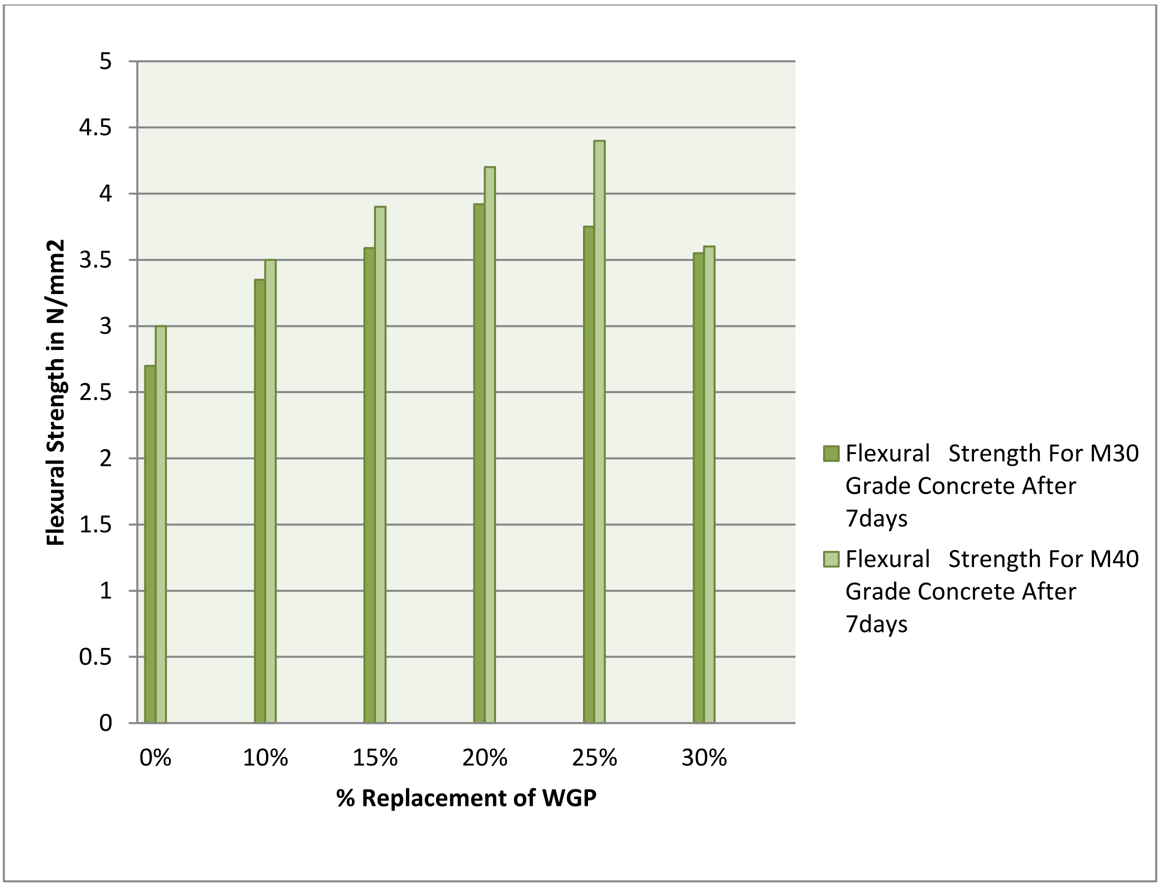

Figure 2i. Flexural strength at 7days for various % waste glass powder for M30 & M40 grade concrete

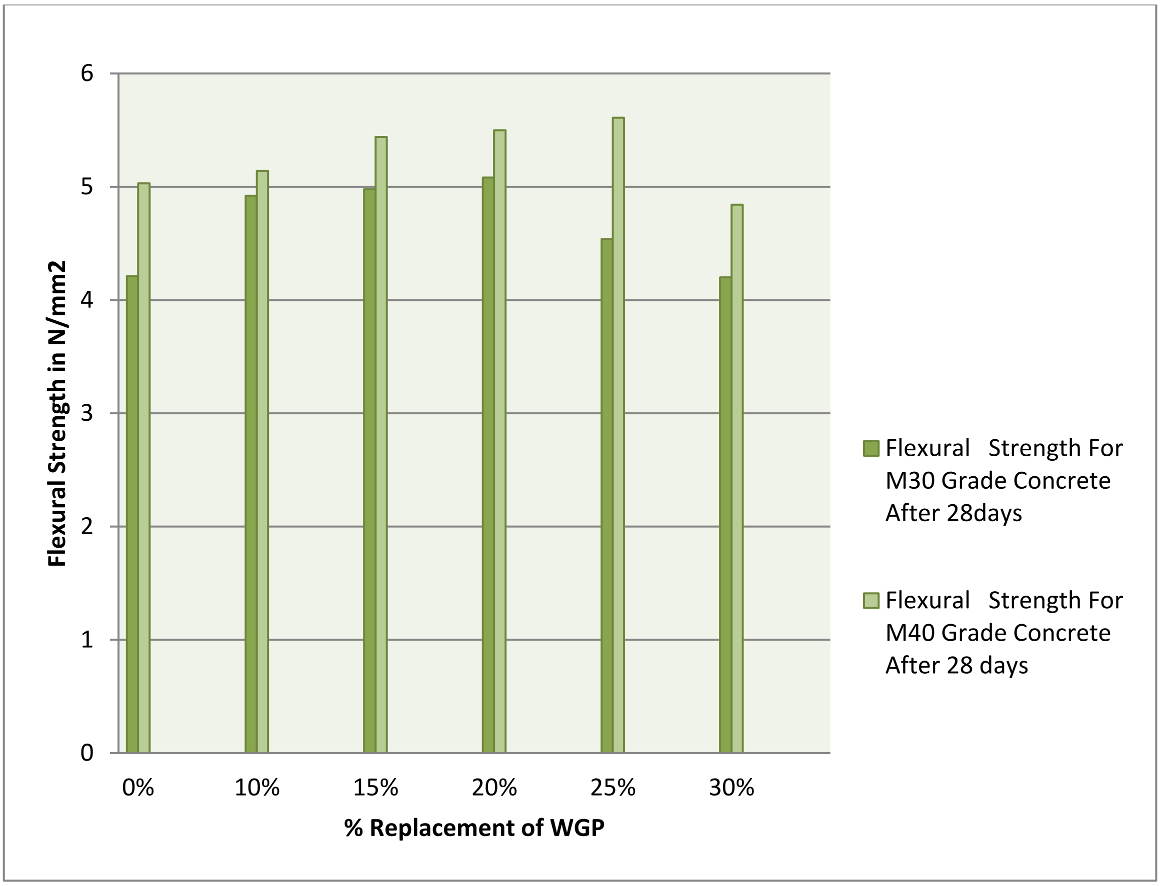

Figure 2j. Flexural strength at 28days for various % waste glass powder for M30 & M40 grade concrete

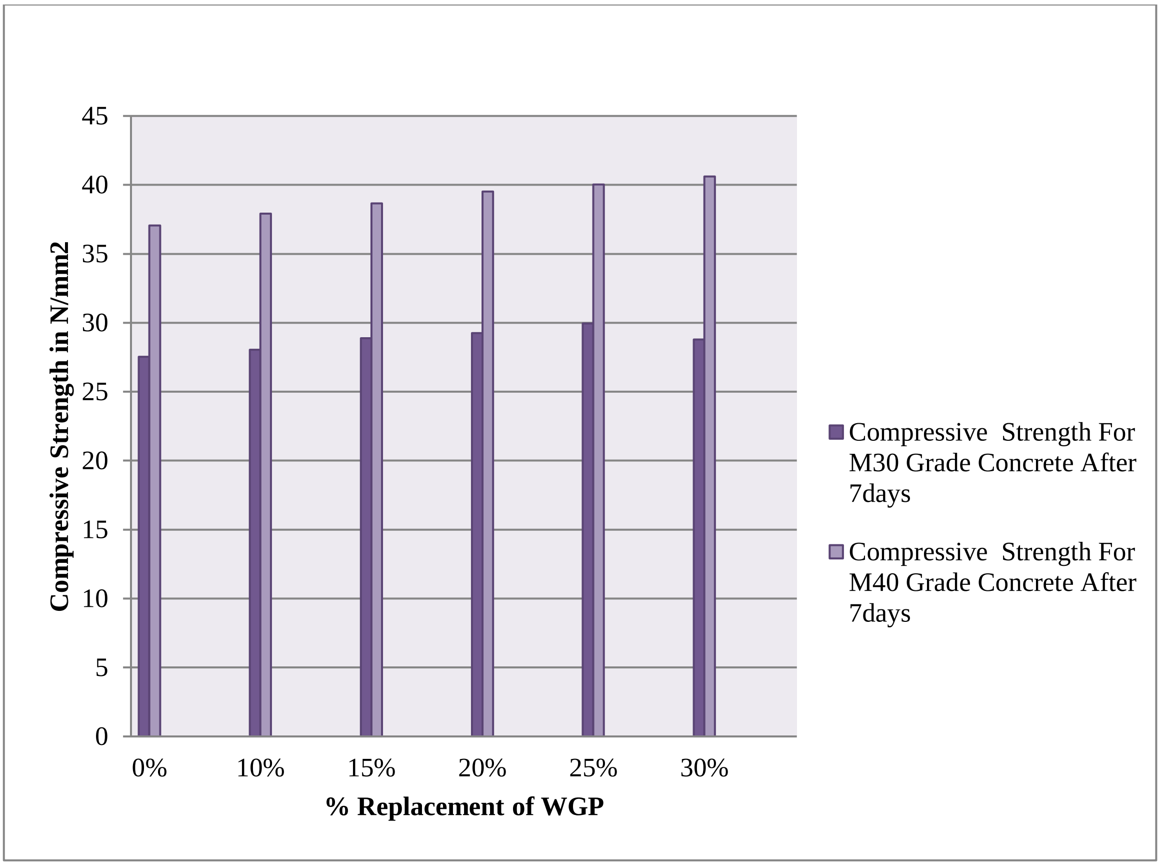

Figure 2k. Compressive strength at 7days for various % waste glass powder for M30 & M40 grade concrete

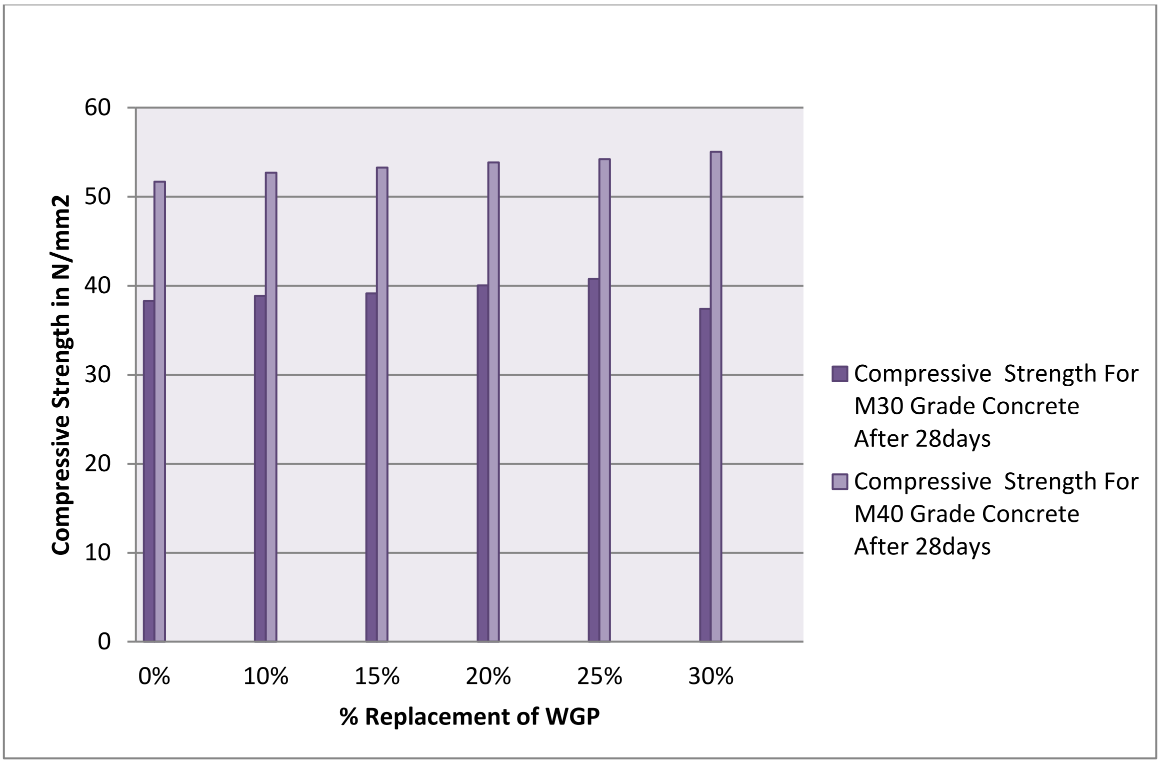

Figure 2l. Compressive strength at 28days for various % waste glass powder for M30 & M40 grade concrete

Table 1a. Comparison between Chemical properties of Cement & glass powder

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 1b. Physical properties of cement

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 1c. Physical properties of sand

Property	Experimental Results	Specification referred to	Method of test reference to
Specific Gravity	2.64	IS code 383-2016	IS :2386 PART 3(1963)
Water Absorption	0.864	IS code 383-2016	IS :2386 PART 3(1963)
Surface Moisture content	Nil	IS code 383-2016	IS :2386 PART 3(1963)
Grading zone	II	IS code 383-2016	IS :2386 PART 1(1963)

Table 1d. Sieve Analysis of sand

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 1e. Physical properties of 20mm 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)

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

Table 1f. Physical properties of 10mm coarse aggregate

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)

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

Table 1g. Physical properties of combine coarse aggregate

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)

Sieve Analysis Test (Grading of Coarse Aggregate)

Table 1h. Grading of 20mm coarse aggregate

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 1i. Grading of 10mm 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 1j. Grading of combine 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 1k. Physical properties of Glass powder

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

Table 1l. Mix proportions for 1m^3 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 1m. Mix proportions for 1m^3 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 1n. Specimen Geometry

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 1o. Numbers of specimen details for M30 & M40 Grade

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 2a. Result Split tensile strength test for M30 Grade concrete

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 2b. Result of Flexural strength test for M30 Grade concrete

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 2c. Result of Compressive Strength Test of M30 Grade Concrete

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 2d. Result of Split Tensile Strength Test of M40 Grade Concrete

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 2e. Result of Flexural Strength Test of M40 Grade Concrete

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 2f. Result of Compressive Strength Test of M40 Grade Concrete

Concrete mix	Compressive Strength in N/mm^2			
	After 7day	Average 7days 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	

3.2.2 Flexural Strength Test

Flexural Strength test conducted at 7 and 28 days using a flexural strength testing machine. Results obtained show flexural strength gain for various percentages of glass powder replacement at 7th and 28th days of testing [84].
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. 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 Flexural strength) 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 on the 7th and 28th days using Compression testing machine. From the result analysis, the Compressive strength, 37.05 N/mm^2 & 51.7 N/mm^2 for control concrete and 40.61 N/mm^2 & 55.04 N/mm^2 for 25% replacement of cement with waste glass powder at the end of 7 days & 28 days respectively. 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 Compressive strength) at 7 days and 28 days. After which adding more waste glass powder it decreases its strength.

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

- Split tensile strength test
- Flexural Strength Test
- Compressive Strength Test

4. Conclusion

1. Experimental Study Summary

The mix design for concrete was prepared for two grades: M30 and M40. An extensive experimental study was conducted to evaluate the compressive strength, split tensile strength, and flexural strength of these concrete grades with varying percentages (0%, 10%, 15%, 20%, 25%, and 30%) of waste glass powder as a partial replacement for cement.

2. M30 Grade Concrete

- Compressive Strength**:** Increased up to 25% replacement of waste glass powder, then decreased.

- Flexural Strength and Split Tensile Strength**:** Increased gradually up to 20% replacement, then decreased at 25% and 30% replacements.

3. M40 Grade Concrete

- Compressive Strength**:** Increased up to 30% replacement of waste glass powder.
- Flexural Strength and Split Tensile Strength: Increased gradually up to 25% replacement, then decreased at 30% replacement.

4. Using waste glass powder as a partial replacement for cement significantly improves the strength of concrete. The optimum dosage of waste glass powder has been identified for design purposes.

Conflict of interest

The authors declare that there is no conflict of interests.

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