

Stress-Strain Behaviour and Ductility of Tie-Confined M40 and M70 Concrete Incorporating Waste Glass and PET Bottle Waste

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Abstract- Concrete is one of the most widely used construction materials and is generally produced using large quantities of natural sand and crushed stone aggregates. Nearly 65–70% of the volume of conventional concrete consists of these natural materials. As a result, the concrete industry places considerable demand on natural resources. With the growing emphasis on sustainable construction, there is a need to reduce the dependence on conventional aggregates by incorporating suitable waste materials into concrete. Materials such as waste glass and discarded polyethylene terephthalate (PET) bottles can potentially serve as alternative aggregates when used at appropriate replacement levels without significantly affecting the required mechanical performance of concrete. The use of glass products has increased considerably in residential and commercial buildings. Glass is commonly used in windows, partitions, interior decoration, furniture, façades and architectural finishes because of its aesthetic and functional advantages. However, its brittle nature results in a substantial quantity of waste during manufacturing, transportation, cutting, handling and installation. A large portion of this waste is often discarded rather than reused, creating disposal and environmental concerns. Similarly, PET, or polyethylene terephthalate, has become one of the most commonly used plastics, particularly for beverage and water bottles. PET bottles are preferred because of their relatively high strength, low density, durability, good appearance and low permeability to gases such as carbon dioxide. The rapid increase in the consumption of PET products has consequently resulted in a significant increase in plastic waste. In many regions, the amount of PET waste generated is considerably higher than the quantity that is recycled. Disposal of such waste in landfills creates long-term environmental problems because plastics degrade very slowly. Therefore, utilizing waste glass and PET materials as partial substitutes for conventional aggregates in concrete can offer a practical method of waste management while also reducing the consumption of natural resources. The present experimental investigation was carried out in different stages to evaluate the possibility of using waste glass and PET bottle waste as aggregate replacements in M40 and M70 grade concrete. In the initial stage, waste glass was introduced separately as a replacement for fine aggregate, coarse aggregate and as a combined replacement for both fine and coarse aggregates. Different replacement percentages were investigated in order to determine the proportion that produced the most suitable compressive strength. A similar procedure was followed for PET bottle waste. Based on the results obtained from these preliminary trials, optimum replacement levels were selected for both M40 and M70 concrete. The confinement index was therefore closely associated with the improvement in the axial response of the concrete specimens. In addition, the stress ratio, strain ratio and ductility factor showed an increasing trend with higher levels of confinement. Overall, the study demonstrates that selected quantities of waste glass and PET bottle waste can be incorporated into M40 and M70 concrete as partial replacements for natural aggregates. When combined with suitable lateral confinement, the resulting concrete can exhibit improved strength and deformation characteristics. This approach provides a useful means of recycling non-biodegradable waste, reducing the consumption of natural aggregates and promoting more sustainable concrete construction.

Keywords: Confinement index; PET waste; Glass waste; Tie-confined concrete; Compressive strength; Stress-strain behaviour; Ductility; High-strength concrete.

I. INTRODUCTION

In recent years, high-strength concrete has gained widespread use in the construction of buildings, bridges, and other major structural systems. Its higher compressive strength allows structural members, particularly columns, to be designed with smaller cross-sectional dimensions while still providing the required load-carrying capacity. This reduction in member size can also decrease the overall self-weight of the structure and the loads transferred to the foundation. However, high-strength concrete generally exhibits relatively brittle behaviour when subjected to compression. Once its ultimate capacity is reached, failure may occur suddenly, resulting in a rapid reduction in load-carrying ability.

The confinement reinforcement is used to restrain the concrete from expansion and thus extends the failure. It is generally accepted that the strength and ductility of reinforced concrete column can be improved by confining it in steel binders, as ties in compression members and stirrups in beams. This improvement ensures seismic stability of the structure during a strong earthquake. Therefore, column confinement is an important component of earthquake resistant reinforced concrete buildings. It is uneconomical to design a structure to respond in the elastic range to the greatest likely earthquake induced inertia forces because the maximum response acceleration may be several times the maximum ground acceleration, depending on the stiffness of the structure. The response of a structure under dynamic loading is influenced by several factors, including its structural configuration and the level of damping available. For satisfactory performance, structures should be capable of dissipating energy through controlled inelastic deformation after the elastic limit has been exceeded. This makes it necessary for certain structural members to possess adequate ductility in addition to sufficient strength. Ductility refers to the ability of a structural member or system to undergo significant deformation in the inelastic range without experiencing sudden failure or a major loss of load-carrying capacity. The ductile behaviour of a structural element largely depends on the

characteristics of the materials from which it is made. Concrete, however, is naturally brittle and has a limited capacity for deformation after reaching its peak strength. Therefore, additional measures are required to improve its deformation capacity and overall structural performance. One effective method is the confinement of concrete, which is commonly achieved by providing properly arranged transverse reinforcement. This reinforcement restricts the lateral expansion of concrete and helps enhance its strength, ductility, and post-peak behaviour.

Confined Concrete

When concrete is subjected to a uni-axial load (Columns for example) while having transverse reinforcement like square/rectangular ties, circular hoops or a helical spring that is what is called Confined Concrete. When the load is acting perpendicular to the direction of the reinforcement that makes the concrete confined.

Confined concrete has stress-strain characteristics that are distinctly different than those of plain concrete. The stress of the confinement keeps on increasing with strain, and thus a monotonically increasing confining pressure is produced. The maximum confining pressure is obtained when the ultimate strength of the confinement is reached. When further load is applied, failure of the confined concrete often occurs as a result of fracture of the confinement reinforcement. The stirrup reinforcement, which is provided, has to take care of shear at the section and simultaneously provide confinement.

The strength of laterally confined concrete columns depends on concrete axial stress at each location on the member's critical cross-section. For a circular section, local stresses over a section are uniformly distributed due to axial symmetry, but for a square section, the local stresses are non-uniform. Good detailed and closely spaced transverse reinforcement in the RC columns can ensure ductile behavior in the event of earthquakes. The non-dimensional parameter called confinement index (C_i) was given by Reddy, S.R., et al (ref no.6) and it

involves all the parameters that influence the behavior of concrete.

The confinement index calculated from formulae

$$C_i = (P_b - \bar{P}_b) (f_v / f_c') \sqrt{b/s}$$

P_b - is the ratio of the volume of ties to the volume of concrete,

$\bar{P}_b$ is the ratio of the volume of ties to the volume of concrete corresponding limiting pitch (1.7 times the least lateral dimension).

b is the breadth of the prism and s is the spacing of ties.

The stress in the steel bars is given by $f_v = \epsilon_v \cdot E_s$ and is always limited to maximum yield strength. ϵ_v is the strain in steel and E_s is the modulus of elasticity of the steel. In the present work 6mm & 8mm steel bars were used for tie confinement.

Objectives of the Study

To evaluate the stress-strain response of confined concrete subjected to uniaxial compressive loading. To examine how different levels of confinement affect the ductility of concrete.

To assess the influence of confinement on the compressive strength and overall load-carrying capacity of concrete.

To investigate the effect of confinement on the strain characteristics and strain ratios of concrete specimens.

To study the mechanical performance, particularly compressive strength, of M40 standard-grade concrete and M70 high-strength concrete in which natural fine and coarse aggregates are partially replaced with waste glass and PET materials at selected proportions.

Scope of the study

The combined effect of confinement and the use of waste glass and PET waste as partial replacements for both fine and coarse aggregates has received limited attention, particularly with respect to the stress-strain behaviour of ordinary and high-strength concrete. To address this gap, the present experimental investigation was designed to evaluate

the influence of these parameters under controlled conditions.

The study focuses on confined M40 standard-grade concrete and M70 high-strength concrete containing selected proportions of waste glass and PET waste as substitutes for natural fine and coarse aggregates. Confinement is provided using 6 mm mild-steel bars and 8 mm TMT bars as lateral reinforcement. The major variables considered in the investigation include the grade of concrete, diameter of transverse reinforcement, number of lateral ties, and type of aggregate replacement material.

The experimental programme is intended to examine how these variables affect the stress-strain response, strength characteristics, deformation capacity, and overall behaviour of confined concrete. The findings are expected to provide additional experimental information on the performance of concrete containing recycled glass and PET waste under different levels of lateral confinement.

Optimal Compressive strength of concrete using of waste glass and PET bottle waste as coarse aggregate & fine aggregate

Engineering properties of concrete using waste glass and PET bottle waste as coarse aggregate & fine aggregate can best be described by studying the following property.

Compressive strength

It is the most common test conducted on hardened concrete, partly because it is an easy test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength. This test is performed as per IS: 516-1959.

II. LITERATURE REVIEW AND RESEARCH GAP

Earlier works on confined concrete & stress-strain behavior of concrete

Mander et al. (1988), carried out investigations on confinement of concrete with nearly full-size reinforced concrete columns, of circular, square, or rectangular wall cross section, and containing

various arrangements of reinforcement, were loaded concentrically with axial compressive strain rates of up to 0.0167/s. The circular sections contained longitudinal and spiral reinforcement, the square sections contained longitudinal reinforcement and square and octagonal transverse hoops, and the rectangular wall sections contained longitudinal reinforcement and rectangular hoops with or without supplementary cross ties. The longitudinal stress-strain behavior of the confined concrete was measured and compared with that predicted by a previously derived stress-strain model with allows for the effects of various configurations of transverse confining reinforcement, cyclic loading, and strain rate. The measured longitudinal concrete compressive strain when the transverse steel first fractured was also compared with that predicted by equating the strain energy capacity of the transverse reinforcement to the strain energy stored in the concrete as a result of the confinement.

Seshu et al. (1997), investigated the behaviour of ferrocement confined reinforced concrete (FCRC) under axial compression, by varying the specific surface factor (S_f) which controls the behavior of ferrocement. Prisms of size 150 x 150 x 300 mm were tested. The results indicated that additional confinement in the form of ferrocement shell improved the ultimate strength; strain at ultimate strength and ductility of concrete. The improvement is in proportion to the S_f of the ferrocement shell for a given confinement index (C_i) of the lateral reinforcement.

Razvi S et al (1999) developed a mathematical model to express the stress-strain relationship of high-strength concrete confined by transverse reinforcement. The model is applicable to both normal-strength and high-strength concretes, covering a strength range between 30 and 130MPa. It incorporates all the relevant parameters of confinement that have been observed to play important roles in column tests. These parameters include the type, volumetric ratio, spacing, yield strength, and arrangement of transverse reinforcement as well as concrete strength and section geometry. Therefore, it can be used for concrete confined by spirals, rectilinear hoops,

cross-ties, welded wire fabric, and combinations of these reinforcements. It has been verified extensively against data obtained from column tests under concentric and eccentric loads, as well as slow and fast strain rates.

Hisataka SATO et al. (2000), Investigated the possibility of improving of square reinforced concrete with lateral reinforcement. Axial loading tests on four units of reinforced concrete columns with square core cross section (272x272x632 mm), and on one unit of plain concrete column with same cross section were carried out. The specimens were made of ordinary-strength concrete with compressive strength of 35 N/mm² the confined specimen were confined with ultra-high strength steel reinforcement with yield strength of 1430 N/mm² as lateral reinforcement and with ordinary strength steel reinforcement with yield strength of 404 N/mm² as longitudinal reinforcement. The configurations of lateral reinforcement were two types. One was assembled by a multi-spiral (a one-way test parameters included arrangement, spacing, and volumetric ratio of confinement reinforcement. Stress-strain, relationships of core concrete were extracted from the obtained load-deformation curves by using a stress-strain idealization of longitudinal reinforcement. The longitudinal stress-strain behavior was studied with respect to the effect of the intermediate lateral ties, the spacing of lateral reinforcement, and the buckling of longitudinal reinforcement and concluded that Buckling of longitudinal reinforcement was a cause of the reduction in stiffness and strength of confined column. Stiffness and ductility of confined column are effectively improved by increasing the number of inner tie bars.

Ramesh k et al (2002), reported that using Steel fiber addition to tie CFRC specimens has the advantage over the confinement by lateral ties in improving the material properties, such as integrity, dimensional stability and performance under large deformations. Steel fiber addition to the tie confined reinforced concrete specimens provides indirect additional confinement of concrete in axial compression.

Motoyuki et al. (2004), presented a concentric loading test of square reinforced concrete columns confined by rectangular ties. Test variables include concrete compressive strength (45 to 130MPa), tie yield strength (320 to 1300MPa), and tie volumetric ratio (0.32 to 1.92%). It was confirmed that transverse reinforcement does not yield in columns using high-strength concrete or tie. A method to compute the stress in the transverse reinforcement at maximum concrete strength and a new stress-strain model for confined concrete are proposed. Over a wide range of confinement parameters, the model shows good correlation with stress-strain relationships established experimentally and confirmed that: i) increasing the tie yield strength does not significantly improve the confinement effect; ii) even if columns have approximately the same $p_s f_{sy}$ product, those with higher volumetric ratios of lower-grade steel performed better than those with lower volumetric ratios of higher-grade steel; and iii) this is because, when higher strength ties are used, the stress in the transverse reinforcement at peak concrete strength is less than 50% of the tie yield strength.

Metin Husem et al. (2006) Investigated about the effects of confinement reinforcement on the behavior of high strength concrete columns are investigated for which prismatic experimental specimens were prepared. In the experiment specimens, four longitude reinforcement and confinement reinforcement were used. For each experiment, stress-strain relationship of concrete was obtained and compared with models proposed earlier. The results show that confinement reinforcement improved the ductility of high strength concrete. The ascending branch of stress-strain curves depended on the ratio of confinement reinforcement was similar to the modified Kent-Park model and the descending branch similar to the Nagashima model and also observed that in the high strength concrete which is more brittle than ordinary concrete, using confinement reinforcement, ductility is increased to a great extent. When confinement reinforcement spacing is decreased to half, ductility improved twice. As a result, by decreasing confinement reinforcement spacing, the earthquake behavior of high strength concrete can be improved.

Decreasing confinement reinforcement spacing has increased the compressive strength of confined concrete to a maximum of 19%.

Visweswara Rao et al. (2014), investigated into the behavior of M30 grade concrete with and without confinement for different percentages of replacement of silica fume is studied under axial compression as per IS mix design. The 150mm x 300mm cylindrical specimens were cast with and without confinement and investigating the mechanical properties like axial compressive strength and stress strain behavior. It was observed that the confinement of concrete has increased the 28 days strength for different percentages of confinement and that the peak stress and corresponding strain at peak stress increased with increase in percentages of confinement and also observed that an increase in volume of confinement improves the ductility factor of confined concrete.

Prasad et al. (2015), used the experimental program which was defined to evaluate the influence of the glass fibers (F_i) content and variation of tie confinement (C_i) on the behavior of SCC. Two grades of concrete M20 and M40, five levels of confinement, five dosages of fibers content were taken as parameters. Specimens of size 150 x 150 x 300 mm were cast and tested at the end of 28 days and reported that Confinement of SCC using lateral ties and fiber addition increases the peak stress, strain at peak stress and strain at 85% of peak stress. With the addition of glass fiber, the ascending portion of the load-deflection changes very slightly, while the descending portion becomes less steep, resulting in higher ductility and toughness.

Jonathan West et al. (2016), presented a stress-strain model for the prediction of the confined compressive strength of high-strength concrete subjected to axial stress. The stress-strain model is based on confining concrete using cross-spirals. The main parameters were the spiral spacing, and the confinement technique either conventional or cross spirals. The model is based on the results of twenty-one high-strength reduced scale concrete columns that were tested under concentric compressive axial load. The proposed model was compared with two

existing models where showed good agreement with the experimental results. The model could be used to predict the confined concrete compressive strength confined with cross-spirals with an average percentage error of 3.28 for high-strength concrete. Ratna Giri et al (2017), Investigated, the stress-strain behavior of tie-confined self-compacting SCC is analyzed and a comparison is made with SCC prepared without self-curing agents. The methodology included studying the stress-strain behavior of two grades of self-compacting SCCs and comparing the results with normal SCC subjected to water curing and no curing. To determine the stress-strain behavior, prism specimens of 100mm x100mm x200mm were tested under axial compression. Lateral ties and longitudinal bars were used in the prisms and two grades of concrete of compressive strength were used. The results obtained will be useful for design engineers working on concrete with curing agents. confinement index calculated from Reddy SR formulae.

Agustiar et al. (2017), Focused on the analysis of various strengths of concrete columns 30MPa and 60MPa reinforced and confined with high-strength reinforcing steel bars 550MPa (Grade 80) with variety cross section of columns. From the study, it can be concluded that the confinement index decreases significantly with the increase of concrete strength. The use of higher-strength transverse steel increases the confinement index. The greater strength of concrete used, the confinement ratio will be smaller at the same spacing.

Wang et al. (2017), presented the results of an experimental program investigating the behavior of confined high strength concrete. Eighteen high strength concrete circular columns confined by spiral reinforcement were tested under axial compression. The test variables included concrete compressive strength, the spacing of the spiral reinforcement and specimen height. The influence of the size of the effect on the behavior of the confined concrete was investigated. Four confined concrete models which are defined in the literature were used to predict peak stress and strain of the core concrete (Mander et al., 1988; Fafitis& Shah, 1985; Razvi&Saatchioglou, 1999; Legeron&Paultre, 2003). A comparative study

of the stress-strain model with the test results indicated that the models used in this study all produced a conservative prediction for the ductility of confined high strength concrete. The model proposed by Fafitis& Shah 1985 can make a more accurate prediction with standard deviation 3.92% and 21.88% in peak stress and strain, respectively, compared to predictions made by other models.

Rajasekhar et al. (2017), investigated into the behavior of circular, confined, reinforced concrete columns was undertaken. Thirty 150 mm diameter, 300 mm high units were cast with varying amounts of longitudinal and lateral steel. These were subjected to concentric or eccentric axial loads to failure at slow or dynamic loading rates. Confinement requirements of reinforced concrete columns are discussed and the results and analyses of experimental work presented. Results include an assessment of the significance of loading rate, eccentricity, amount and distribution of longitudinal steel, and the amount of confining steel. A general stress-strain curve for circular concrete sections loaded at seismic rates is proposed and compared with existing curves based on previous static loading tests.

Baduge et al. (2018), Carried out an experimental program to evaluate the stress-strain behavior and investigate the failure mechanisms of confined very-high strength concrete (VHSC) with compressive strengths of up to 160MPa and lower confinement pressures in the range of 0.6–2.7MPa. Even though post-peak behavior of concrete is explained and modelled using the confinement effects, the study proposes that it can be explained by superposition of the shear strength behavior at the failure plane of concrete, confinement effect, and dowelling action of steel. The stress- strain behavior is further explained through a theoretical approach and it has good agreement with the experimental results.

Appraisal of literature

After a comprehensive literature review, it was found that some researchers investigated the stress-strain properties of confined concrete in which mild steel and TMT steel reinforcement has been used for confinement. The concrete of different grades were

confined with different material such as FRP, FRCC jackets and different types of confinements such as cross-spirals, circular hoops etc were used. Tests were conducted to determine the stress-strain characteristics. In this work, it is proposed to study the stress-strain behaviour of M40 & M70 grade concrete in which sustainable material such as Glass waste and PET bottle waste are used as replacement to both coarse aggregate and fine aggregate in the earlier determined proportions that yield optimum mechanical properties.

Based on the literature review, the mild steel of 6mm diameter and TMT bars of 8mm diameter have been used for confinement of glass concrete and PET waste concrete. A comprehensive review of past work in the area of confinement, stress-strain characteristics and replacing cement, fine aggregate, coarse aggregate by Glass waste & PET bottle waste has been reviewed and an appraisal of review is presented

III. MATERIALS AND METHODS

This study focuses on producing concrete of acceptable strength and ductility under confinement with Glass waste as coarse and fine aggregate and also PET waste as coarse and fine aggregate. This study focuses on determining the stress-strain relation of confined concrete.

Materials used

The different materials used in this work are grade ordinary Portland cement

G.I wire

Steel

Coarse aggregate

Fine aggregate

Potable Water

Glass Waste

Waste PET(Polyethylene teraphthalate)

Super plasticizer (SP430)

Silica fume

Cement:

53 Grade Ordinary Portland cement (fly ash based) conforming to IS: 1489 (part-1) was used in this study. The cement was obtained from a single consignment and of the same grade and same

source. After producing, the cement was stored properly. The specific gravity of the cement is 3.15 G.I rod/wire

3.62mm diameter G.I. wire is used as longitudinal reinforcement. In each specimen four bars are used at corners. The length of one G.I. wire in each specimen is 190 mm.

Steel

Lateral ties used were of mild steel and thermo mechanically treated bars. The bars were bent into square shape with hooks. The yield strengths were 270 Mpa and 550Mpa for mild steel and TMT bars.

Coarse aggregate:

The crushed granite aggregate ratio of 20 mm - 12.5mm aggregates to 10mm-4.75mm aggregates in terms of percentages 60% (20mm-12.5mm): 40% (10mm-4.75mm) ,used as coarse aggregate. The bulk density, specific gravity

and fineness modulus of the coarse aggregate have been 1.46g/cc, 2.78 and 7.2respectively.

Aggregate size

Coarse aggregate of normal size of 20mm -12.5mm & 10mm-4.75mm is used in this study.

Specific gravity

The specific gravity of fine and coarse aggregates 2.68 & 2.78 respectively.

Water absorption

Water absorption is an important property to be considered as it affects the water cement ratio to a great extent. The water absorption of aggregate is determined by measuring the increase in weight of an oven dry sample when immersed in water for 24 hours. In this study, conventional coarse aggregate has a water absorption of 0.47%.

Bulk density & void ratio

Bulk density is the weight of material in a given volume and percentage voids is the ratio of the volume of voids to the total volume. To determine the bulk density, the aggregates are filled in the container and then they are compacted in a standard manner. The weight of the aggregate gives the bulk density.

Fine aggregate

The fine aggregates conforming to zone-2 according to IS: 383-1970 is used. The fine aggregate used was obtained from a nearby river source. The bulk density, specific gravity and fineness modulus of the sand used are 1.3g/cc, 2.68 and 2.64 respectively.

Potable Water

Potable water was used in the experimental work for both mixing and curing as per IS456-2000.

Glass Waste

Glass is a transparent material produced by melting a mixture of materials such as silica, soda ash, and CaCO_3 at high temperature followed by cooling during which solidification occurs without crystallization. In this work waste glass obtained from toughened glass has been used as a replacement to granite coarse aggregate and fine aggregate in making glass concrete. The waste glass was collected from N.N safety glass industries, Hyderabad, Telangana, India.

PET Waste

In this work, PET (Polyethylene Terephthalate) waste has been used as a replacement to both coarse and fine aggregate. PET waste was collected from Srinivasa plastics and co, Hyderabad, Telangana, India.

Super Plasticizer

High range water reducing admixtures called "super plasticizers" are used for improving the flow or workability for decreased water-cement ratio without sacrifice in the compressive strength. The super plasticizer used in this experiment is SP-430 from FOSROC. SP-430 has been primarily developed for applications in high performance concrete for highest durability and performance and its properties are as follows.

Specific gravity = 1.18g/cc

Appearance = brown coloured liquid

Chloride content = Nil. (As per IS: 9103-1999 and BS:5075)

Alkali content = Approx. 1% additional air over control

Volumetric mass at 2 = 1.05 kg/lit

Silica fume:

Silica fume is a very fine pozzolanic material composed of amorphous silica produced by electrical furnaces as a byproduct of the production of elemental silica or Ferro-silicon alloys. High purity quartz is heated to 2000 degree Celsius with coal, coke or wood chips as fuel and electric arc introduced to separate out the material. Silica fume is an ultra-fine powder having the following properties.

Powder with grey colour normally but can vary based on the source.

Minimum specific surface of 15,000 m^2/Kg .

At least 85% SiO_2 content.

Spherical particle shape.

Mean particle size in the range of 0.1 to 0.2 microns.

3.2.10.1 Role of Silica fume in concrete:

Because of the extreme fineness and high silica content, silica fume is a very effective pozzolanic material. Silica fume when added to Portland cement concrete improves its properties particularly the compressive strength, bond strength and abrasion resistance by filling the void spaces. The improvements stem from both mechanical improvements resulting from addition of a very fine powder to the cement paste mix as well as from the pozzolanic reactions between the silica fume and free calcium hydroxide in the paste. Addition of silica fume also reduces the permeability of concrete to chloride ions, which protects the reinforcing steel of concrete from corrosion, especially in chloride-rich environments such as coastal regions. When it is used in concrete, it acts as a filler and as a cementations material. The small silica fume particles fill spaces between cement particles and between the cement paste matrix and aggregate particles. The silica fume also combines with calcium hydroxide to form additional calcium hydrate through the pozzolanic reaction. Both of these actions result in a denser, stronger and less permeable material. Various percentages of silica fume have been tried as an addition in concrete in this work to arrive at the one that provides optimum strengths.

Evaluation of Mix proportions

The final mix proportions were arrived at on the trial and error method by trying various proportions of silica fume & super plasticizer in the designed M40 & M70 concretes to achieve improvement in compressive strength.

Mix proportions

Throughout the experimental programme, the control concrete mixes were designed in accordance with the ACI mix design method. For M40 grade concrete, the mix proportion by weight was adopted as 1 : 1.40 : 1.77 with a water–cement ratio of 0.48, representing cement, fine aggregate, coarse aggregate, and water–cement ratio, respectively. For M70 grade concrete, the corresponding mix proportion was 1 : 0.78 : 1.50 with a water–cement ratio of 0.30.

Tables 3.1 and 3.2 present the quantities of individual constituents required per cubic metre of concrete for both M40 and M70 mixes. These tables include the conventional control mixes, designated as S-0 and H-0, as well as the optimum mixes containing glass waste and PET waste. The glass waste mixes are represented by GS-5 and GH-4, while the PET waste mixes are identified as PS-3 and PH-2. The quantities shown correspond to the selected optimum replacement levels used in the experimental investigation.

Table 3.1 Ingredient content of concrete mixes (kg/m³)-M40 grade concrete

Table 3.2 ingredient content of concrete mixes (kg/m³)-M70 grade concrete

Preparation of Specimen.

The 6mm and 8mm ties were tied to the longitudinal G.I bars at the required pitch in such a manner that the hooks were distributed evenly on all four corners. Fig shows the reinforcement details of the specimen. Mixing and casting of concrete

Concrete mixing was carried out using a standard pan mixer with a capacity of 50 litres. At the beginning of each batch, the dry ingredients consisting of coarse aggregate, fine aggregate, cement, silica fume, and waste glass were placed in

the mixer and blended for approximately two minutes to obtain a uniform dry mixture. The required dosage of superplasticizer was first mixed thoroughly with the measured quantity of water. This liquid mixture was then gradually added to the dry constituents, and mixing was continued for nearly three minutes. During the mixing process, particular care was taken to ensure proper distribution of all ingredients and to prevent any material from adhering to the sides of the mixer.

Before casting, the prepared reinforcement cages were carefully positioned inside cast-iron moulds having dimensions of 100 mm × 100 mm × 200 mm. Freshly mixed concrete was then placed into the moulds in three approximately equal layers. After placing the first layer, corresponding to nearly one-third of the mould depth, compaction was carried out using a needle vibrator. The same procedure was followed for the remaining layers to ensure uniform compaction and minimise the formation of internal voids.

After casting, the exposed surface of each prism specimen was properly finished and the specimens were allowed to remain in the moulds for approximately 24 hours. They were then demoulded and transferred to a water-curing tank for a period of 28 days. After completion of the curing period, the specimens were tested to evaluate their compressive strength and stress–strain behaviour. The investigation included confined concrete mixes in which waste glass and PET waste were incorporated as partial replacements for both natural coarse and fine aggregates.

Test program

The experimental program was designed to study the behavior of confined steel reinforced concrete under axial compression by testing prisms of size 100 mm × 100 mm × 200 mm. the variable in the study is confinement index (C_i) of lateral steel reinforcement.

The experimental program consisted in casting and testing 162 prisms, which are cast in two groups. The first group of prisms casted with standard grade of concrete (M40) and the second one with high

strength concrete (M70). Each group further divided into three sub groups. Each sub-group was caste in three batches. Except the first batch in each sub-group the prisms in the remaining batches were divided into four sets. In each set three identical specimens were cast and tested and the average behaviour was taken to represent the behavior for that set of three specimens.

Out of four sets in each batch, the first set consisted of two lateral ties second set consisted of three lateral ties, third set consisted of four lateral ties and

fourth set consisted of five lateral ties. The details of specimen cast are shown in table.

Fresh properties of concrete

A fresh property of concrete, such as slump flow was measured for all concrete mixes.

Workability

Slump test was conducted, as per IS: 1199-1959 on all concrete mixes to assess the workability. Table 3.6 & 3.7 show the slump values for different mixes of M40 and M70 grade concretes.

Table 1. Ingredient content of M40 concrete mixes.

Table No	Description of the table	Page No
3.1 3.2 3.3 3.4 3.5 3.6 3.7 3.8 3.9 3.10 3.11 3.12 3.13 3.14 3.15 3.16 3.17 3.18 3.19 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 4.10 4.11 4.12	Ingredient content of concrete mixes (kg/m3) – M40 grade concrete Ingredient content of concrete mixes (kg/m3) – M70 grade concrete Details of specimens cast-M40 grade concrete Details of specimens cast-M70 grade concrete Details of prisms Slump values of fresh M40 grade concrete Slump values of fresh M70 grade concrete Glass waste as replacement to fine aggregate in M40grade of concrete Glass waste as replacement to Coarse aggregate in M40 grade of concrete Glass waste as replacement to both coarse and fine aggregate in M40 grade concrete PET waste as replacement to fine aggregate in M40 grade of concrete PET waste as replacement to Coarse aggregate in M40 grade of concrete PET waste as replacement to both fine and Coarse aggregate in M40grade of concrete Glass waste as replacement to fine aggregate in M70 grade of concrete Glass waste as replacement to Coarse aggregate in M70 grade of concrete Glass waste as replacement to both coarse and fine aggregate in M70 grade PET waste as replacement to fine aggregate in M70 grade concrete PET waste as replacement to coarse aggregate in M70 grade concrete PET waste as replacement to both fine and coarse aggregate in M70 grade of concrete Physical properties of ordinary Portland cement(OPC-53) Physical properties of CA, FA & glass Waste and PET waste Material quantities and dosage of admixture for 1m3 of Glass waste-M40 grade concrete Material quantities and dosage of admixture for 1m3 of waste PET-M40 grade concrete Material quantities and dosage of admixture for 1m3 of Glass waste -M70 grade concrete Material quantities and dosage of admixture for 1m3 of PET Waste -M70 grade concrete Compressive strength of concrete-M40 grade Compressive strength of concrete-M70 grade Rebound number of concrete-M40 grade Rebound number of concrete-M70 grade Uni-axial compressive test results for prism specimens Confinement Index, peak stress, peak strain and ductility factor	17 17 20 21 22 24 24 26 26 26 26 27 27 28 28 29 29 30 30 31 32 34 35 35 35 36 36 37 37 37 48

Table 2. Ingredient content of M70 concrete mixes.

Fig No	Description of the figure	Page No
4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 4.10 4.11 4.12 4.13 4.14 4.15 4.16 4.17 4.18 4.19 4.20 4.21 4.22 4.23 4.24 4.25 4.26 4.27 4.28 4.29 4.30 4.31 4.32 4.33 4.34 4.35 4.36	Stress-strain behavior of unconfined M40 grade concrete Stress-strain behavior of unconfined Glass waste M40 grade concrete Stress-strain behavior of unconfined M40 grade concrete with Glass waste Stress-strain behavior of tie confined M40 grade concrete with 8mm diameter ties Stress-strain behavior of tie confined M40 grade concrete with 6mm dia ties Stress-strain behavior of tie confined M40 grade glass waste concrete with 8mm dia ties stress-strain behavior of tie confined M40 grade glass waste concrete with 6mm dia ties Stress-strain behavior of tie confined M40 grade PET waste concrete with 8mm dia ties Stress-strain behavior of tie confined M40 grade PET waste concrete with 6mm dia ties Stress-strain behavior of unconfined M70 grade concrete Stress-strain behavior of unconfined M70 grade concrete with glass waste Stress-strain behavior of unconfined M70 grade concrete with waste PET Stress-strain behavior of tie confined M70 grade concrete with 8mm dia ties Stress-strain behavior of tie confined M70 grade concrete with 6mm dia ties Stress-strain behavior of tie confined M70 grade Glass waste concrete with 8mm dia ties Stress-strain behavior of tie confined M70 grade Glass waste concrete with 6mm dia ties Stress-strain behavior of tie confined M70 grade Waste PET concrete with 8mm dia ties Stress-strain behavior of tie confined M70 grade Waste PET concrete with 6mm dia ties Axial stress ratio (a) and axial strain ratio (b) versus confinement index for M40 grade conventional concrete with square ties of 6mm dia. Axial stress ratio (c) and axial strain ratio (d) versus confinement index for M40 grade conventional concrete with square ties of 8mm dia. Axial stress ratio (a) and axial strain ratio (b) versus confinement index for M40 grade Glass concrete with square ties of 6mm dia. Axial stress ratio (c) and axial strain ratio (d) versus confinement index for M40 grade Glass concrete with square ties of 8mm dia. Axial stress ratio (a) and axial strain ratio (b) versus confinement index for M40 grade PET concrete with square ties of 6mm dia. Axial stress ratio (c) and axial strain ratio (d) versus confinement index for M40 grade PET waste concrete with square ties of 8mm dia. Axial stress ratio (a) and axial strain ratio (b) versus confinement index for M70 grade conventional concrete with square ties of 6mm dia. Axial stress ratio (c) and axial strain ratio (d) versus confinement index for M70 grade conventional concrete with square ties of 8mm dia. Axial stress ratio (a) and axial strain ratio (b) versus confinement index for M70 grade Glass concrete with square ties of 6mm dia. Axial stress ratio (c) and axial strain ratio (d) versus confinement index for M70 grade Glass concrete with square ties of 8mm dia.	41 42 42 42 43 43 44 44 44 45 45 45 46 46 47 47 48 48 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71

	Axial stress ratio (a) and axial strain ratio (b) versus confinement index for M70 grade PET concrete with square ties of 6mm dia. Axial stress ratio (c) and axial strain ratio (d) versus confinement index for M70 grade PET concrete with square ties of 8mm dia. Ductility factor v/s confinement index for M40 grade conventional concrete with square ties of 6mm dia (a) and square ties of 6mm dia (b) Ductility factor v/s confinement index for M40 grade conventional concrete with square ties of 8mm dia (a) and square ties of 8mm dia (b) Ductility factor v/s confinement index for M40 grade Glass concrete with square ties of 6mm dia (a) and square ties of 6mm dia (b) Ductility factor v/s confinement index for M70 conventional concrete with square ties of 6mm dia (a) and square ties of 8mm dia (b) Ductility factor v/s confinement index for M70 grade Glass waste concrete with square ties of 6mm dia (a) and square ties of 8mm dia (b) Ductility factor v/s confinement index for M70 grade PET waste concrete with square ties of 6mm dia (a) and square ties of 8mm dia (b)	
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Optimum mix results for Glass waste and PET waste as Partial replacement to aggregates in M40 and M70 grades of concrete

Preparation of mixes:

In this work, 100mm x 100mm x 100mm size 3 cube specimens were cast and tested for optimal compressive strength. for each trial mixes with different percentages of Glass waste and PET bottle waste as partial replacement to fine aggregate, coarse aggregate and both coarse and fine aggregate for optimum percentage of PET waste and Glass waste in M40 and M70 grade of concrete.

Optimum compressive strength Results

Glass waste Percentage replacement Results for M40 Grade Concrete

4) Optimum PET waste Percentage Replacement Results for M70 Grade Concrete

Curing:

After the completion of casting, all the specimens of three mixes were kept to maintain the ambient conditions viz. temperature of $27 \pm 2^\circ\text{C}$ and 90% relative humidity for 24 hours. The specimens were removed from the moulds and submerged in clean fresh water until just prior to testing. The temperature of water in which cubes were

submerged was maintained at $27 \pm 2^\circ\text{C}$ the specimens were water cured for 28 days.

Tests on Hardened Concrete

The test program consisted of casting 162 prisms of size 100mm x 100 mm x 200 mm. the standard cast iron moulds were fitted such that there are no gaps between the plates of the mould and the small gaps, if any were filled with plaster of Paris to provide a smooth loading surface, to avoid any stress concentration during the application of load. The specimens were tested on a digital compression testing machine of 3000 KN capacity under axial compression after 28 days of water curing. The specimens were tested under strain rate control, 0.1 mm/min. from the previous studies it was observed that the cover of concrete started spalling off about 90% of the ultimate load. Along the concrete, the resistance strain gauges and demec points fixed to the surface usually came off.

The compressometer used for testing was consisted of two square frames, a top frame and a bottom frame made of 12mm mild steel L angle sections. Each frame was attached to the specimen symmetrically at the required gauge length, i.e. 100 mm apart two pairs of diametrical opposite dial gauges with a least count of 0.002 mm were attached to vertical hanger bars fixed to the top frame. The

movable spindles of dial gauges rested on the plane circular heads of the adjustable screws, which were positioned in mild steel plates projecting frame was attached to the concrete specimen by two diametrically opposite pairs of screws at four points. The frames were attached to the specimen by means of screws, which would fit snugly to the concrete. Fig shows the details of compressometer attached to the specimen. Fig shows the photograph of the same arrangement. The capped specimens with the compressometer attached were placed on the movable cross head of the testing machine and tested under strain rate control. The deformations were noted and strains were calculated. The test was continued until the load dropped about 70-80% of the ultimate load in the post ultimate region for both confined and unconfined concrete specimens.

Compressive strength test

The 100 × 100 × 100 mm cube specimens of glass concrete and PET Waste concrete were tested, as per to IS: 516- 1969, on a digital compression testing machine of 3000 KN capacity after 28 days of conventional water curing. The bearing surface of the machine was wiped off clean and any loose sand or other material was removed from the surface of the specimen. The specimen was placed in the machine in such a manner that the load was applied to opposite sides of the cubes as cast that is, not top and bottom. The axis of the specimen was carefully aligned at the center of the loading frame. The load applied was increased continuously at a constant rate until the resistance of the specimen to the increasing load breaks down and could no longer sustain. The maximum load applied on the specimens was recorded and the compressive strength was calculated by using formulae

Compressive strength = Load/Area

Non-destructive testing

a) Rebound hammer test

IV. RESULTS AND DISCUSSION

The results of experimental investigations including compressive strength, stress-strain curves for M40 and M70 grades of concrete mixes are presented & discussed below.

Stress-strain behaviour of concrete

For each test specimen, the longitudinal deformation was determined by taking the average of the readings obtained from the two dial gauges attached to the compressometer. Since no significant spalling was observed until the applied load had reduced by approximately 20–25% from the peak value, the specimens were considered to remain dimensionally stable during this stage of loading. Therefore, the gross cross-sectional area of the specimens was used for the calculation of compressive stress.

For every test series, stress–strain curves were obtained from three companion specimens tested under identical conditions. These individual curves were plotted from a common origin, and an average curve was used to represent the behaviour of the corresponding specimen set. The representative stress–strain responses are presented in Figs. 4.1–4.3, while Figs. 4.10–4.12 illustrate the behaviour of unconfined M40 and M70 grade concretes.

The stress–strain characteristics were evaluated for both M40 standard-grade concrete and M70 high-strength concrete. The investigation included control mixes as well as mixes in which natural coarse and fine aggregates were partially replaced with waste glass and PET waste. Different levels of confinement were provided by using 0, 2, 3, 4, and 5 lateral ties, corresponding to tie spacings of 0, 190 mm, 95 mm, 63.3 mm, and 47.5 mm, respectively. The influence of these variables on the stress–strain response is illustrated in Figs. 4.4–4.9 and Figs. 4.12–4.18.

The experimental results showed that the stress–strain response of both M40 and M70 concrete was nonlinear over most of the loading range, although an approximately linear relationship was observed at relatively small strain levels. As the degree of lateral confinement increased, the deformation capacity and ductility of the concrete specimens also improved. Previous research by Shah and Rangan (1970) indicated that when the vertical spacing of stirrups is equal to or greater than one-half of the specimen dimension, the restraining effect provided by the transverse reinforcement becomes relatively small.

Table 3. Physical properties of ordinary Portland cement.

SNo.	Mix Designation	Compressive Strength(MPa) 28days
1 2 3 4	B5 B10 B15 B20	66 64 69.8 65.2

Table 4. Physical properties of aggregates and waste materials.

SNo.	Mix Designation	Compressive Strength(MPa) 28days
1 2 3 4	B3 B4 B5 B6	69.9 71.4 68.7 66.2

Table 5. Compressive strength of M40 concrete.

S.No	Property	Conventional coarse aggregate	Fine aggregate	glass waste	PET Waste
1 2 3 4	Specific Gravity Bulk density Fineness Modulus Water Absorption	2.79 1.47g/cc 7.195 0.48%	2.67 1.298g/c 2.65 1%	2.56 1.41g/cc 7.42 0.24%	1.3 0.42g/cc 6.98 0.36%

Table 6. Compressive strength of M70 concrete.

Mix code	cement	Silica fume	Fine aggregate	Fine Glass waste	Coarse aggregate	Coarse Glass waste	water
S-0	526.3	0	739.53	0	930.56	0	200
GS-5	505.2	21.05	702.55	36.97	884.03	46.53	248

Table 7. Uniaxial compression test results of prism specimens.

S.No	Designation of the mix	Compressive strength (N/mm2) 28days
1 2 3	S PS GS	53.4 48.2 54.5

Table 8. Confinement index, peak stress, peak strain and ductility factor.

S.No	Designation of the mix	Compressive strength (N/mm2) 28days
1 2 3	H PH GH	72.32 71.85 73.11

The experimental results showed that the stress–strain response of both M40 and M70 concrete was nonlinear over most of the loading range, although an approximately linear relationship was observed at relatively small strain levels. As the degree of lateral confinement increased, the deformation capacity and ductility of the concrete specimens also improved. Previous research by Shah and Rangan (1970) indicated that when the vertical spacing of stirrups is equal to or greater than one-half of the specimen dimension, the restraining effect provided by the transverse reinforcement becomes relatively small.

A comparison of specimens having the same concrete grade and the same number of lateral ties showed generally similar stress–strain behaviour, regardless of the type of replacement material used.

The load-carrying capacity increased progressively with an increase in the level of confinement. However, PET-waste concrete exhibited slightly lower confined performance when compared with conventional concrete and glass-waste concrete. Specimens containing only two lateral ties showed little improvement in load-carrying capacity and behaved almost similarly to the corresponding unconfined specimens.

Among the different confinement arrangements investigated, specimens reinforced with five 8 mm diameter lateral ties exhibited the most pronounced ductile response. These specimens were capable of sustaining comparatively larger deformations before failure. Failure was mainly characterised by the development and gradual extension of vertical cracks, while considerable deformation was

observed at the final stage of loading. These observations confirm that closer lateral reinforcement improves confinement efficiency and enhances the post-peak deformation capacity of concrete.

Influence of confinement index upon the ultimate strength & strains

The influence of confinement upon the ultimate strength is studied by plotting the ratio f_{cu}/f_c' (where f_{cu} is the ultimate strength of a specimen with confinement and f_c' is the ultimate strength of an otherwise identical specimen without confinement) against the confinement index. The influence of confinement upon strains at the ultimate stress has been studied by plotting ϵ_{cu}/ϵ' against the confinement index, where ϵ' is the strain at the ultimate of a plain concrete specimen, ϵ_{cu} is the strain at ultimate of a confined concrete specimen. From the values in table 4.14, the relationships between the confinement index and axial stress ratio (f_{cu}/f_c') and axial strain ratio (ϵ_{cu}/ϵ') were plotted.

Figures 4.19- 4.24 shows the results for M40 grade concrete and figures 4.25 – 4.30 shows the results for M70 grade concrete. The stress ratio and strain ratio were determined with respect to the corresponding strength and strain of specimens.

In all cases, there was an increase with an increase in the confinement index. For specimens with 8mm dia tie reinforcement the stress ratios & strain ratios were high as compared with the specimens of 6mm dia tie reinforcement. The compressive strength i.e. The load carrying capacity increased with the increase in confinement index.

In case of M40 and M70 grade conventional concretes, the specimens with 2,3,4,5 ties of 6mm dia tie reinforcement registered compressive strength (load carrying capacity) values that are 6%, 13%, 17.8% & 39.2% and 1.97%, 4.5%, 8.59% & 11.54% more than the unconfined conventional concrete. Similarly, the corresponding values for 8mm dia. TMT tie reinforcement be 8.7%, 15.6%, 26.08% & 43.47% and 3.80%, 6.47%, 9.85% & 13.23% respectively.

In case of M40 and M70 grade concretes containing glass waste as partial replacement to both coarse and fine aggregates, the specimens with 2,3,4,5 ties of 6mm dia. tie reinforcement registered compressive strength (load carrying capacity) values that are 5.62%, 14.25%, 17.92% & 35.2% and 0.14%, 3.53%, 8.87% & 13.23% more than the unconfined conventional concrete. Similarly, the corresponding values for 8mm dia TMT tie reinforcement be 9.28%, 16.63%, 23.54% & 41.9% and 2.53%, 5.63%, 10.7% & 13.23% respectively.

In case of M40 and M70 grade concretes containing PET waste as partial replacements to both coarse and fine aggregate, the specimens with 2,3,4,5 ties of 6mm dia tie reinforcement registered compressive strength (load carrying capacity) values that are 2.58%, 16.15%, 24.35% & 38.64% and 3.3%, 6.47%, 11.5% & 13.67% more than the unconfined conventional concrete. Similarly, the corresponding values for 8mm dia TMT tie reinforcement be 7.73%, 20.14%, 28.8% & 45.19% and 2.01%, 5.75%, 10.5% & 12.23% respectively.

In case of M40 grade concrete of conventional concrete, the specimens with 5 lateral ties of 6mm dia tie reinforcement registered peak strain value that is 23% more than the concrete containing glass waste as a partial replacement to both coarse and fine aggregate and 18.92% more than the concrete containing waste PET as partial replacements to both coarse and fine aggregates with 5 lateral ties of 6mm dia tie reinforcement.

In case of M40 grade concrete of conventional concrete, the specimens with 5 lateral ties of 8mm dia tie reinforcement registered peak strain value that is 15.38% more than the concrete containing glass waste as a partial replacement to both coarse and fine aggregate and 17.5% more than the concrete containing waste PET as partial replacements to both coarse and fine aggregate with 5 lateral ties of 8mm dia tie reinforcement.

In case of M70 grade concretes with 6mm dia and 8mm dia tie reinforcement the peak strain values are almost similar in all three concretes i.e. the conventional concrete, the concrete containing Glass

waste and concrete containing waste PET as partial replacement to both coarse and fine aggregates. In case of M40 and M70 grade concrete with 6mm dia and 8mm dia reinforcements the peak strains are high for prism specimens with 5 lateral ties.

From the above analysis it was observed that the compressive strength of concrete has been increased with the increase in the level of confinement in both M40 and M70 grades of concrete irrespective of material replaced.

Influence of confinement upon Ductility factor

For the reason that ductility can directly reflect the plastic deformation capacity of the specimens, in this study, the ductility factor was introduced. The ductility factor (DF) is defined as the ratio of strain at 85% of the peak compressive strength in the descending portion to that of the ascending portion. The ductility factors for the concrete specimens with different tie spacing's are shown in table 4.14. figures 4.31 – 4.36 shows the results for M40 and M70 concretes.

Ductility factors obtained from stress-strain ratios of test specimens (prisms) which have 47.5 mm tie spacing were higher than ductility ratios of prism specimens having 190mm, 95mm, and 63.3mm spacing. Thus, both the standard grade concrete and high strength concretes gained ductility to a great extent on decreasing the tie spacing.

The power regression analysis was done by considering confinement index (Ci) values as dependent variables and stress ratios, strain ratios and ductility factors as independent variables. The equations are obtained with R2 values in the range of 0.86-0.98 indicating that the relationships are represented by good-fit curves.

Complete Graphical Results

The following graphs are retained from the experimental programme to preserve the complete graphical presentation of stress-strain response, confinement effects, stress and strain ratios, and ductility relationships for M40 and M70 conventional, glass-waste and PET-waste concretes.

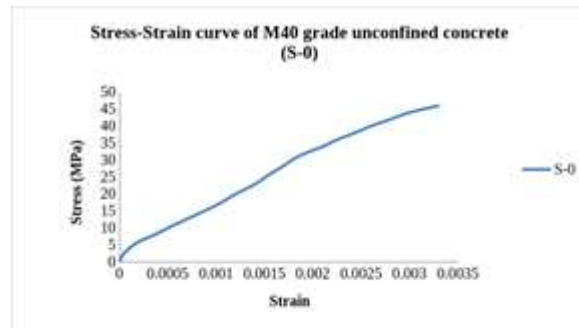


Fig 4.1 Stress-strain behavior of unconfined M40 grade concrete

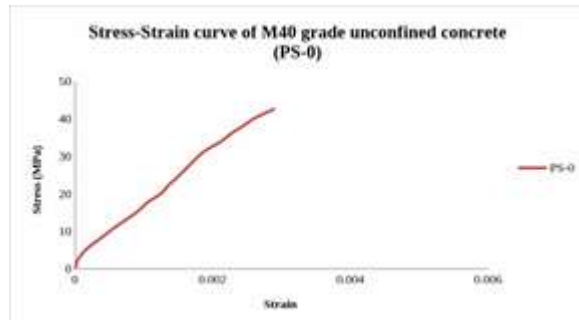


Fig 4.2 Stress-strain behaviour of unconfined PET waste M40 grade concrete

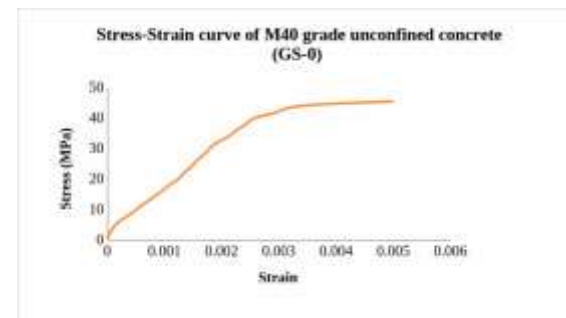


Fig 4.3 Stress-strain behavior of unconfined M40 grade Glass concrete

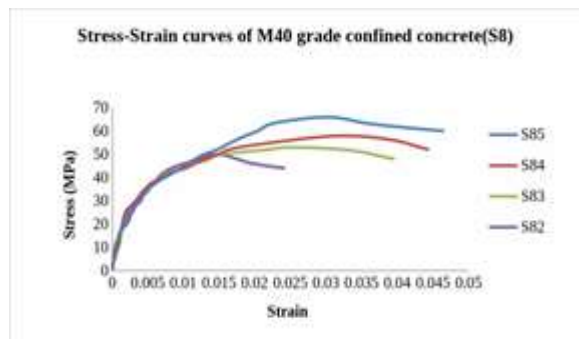


Fig 4.4 Stress-strain of tie confined M40 grade concrete with square ties of 8mm dia reinforcement

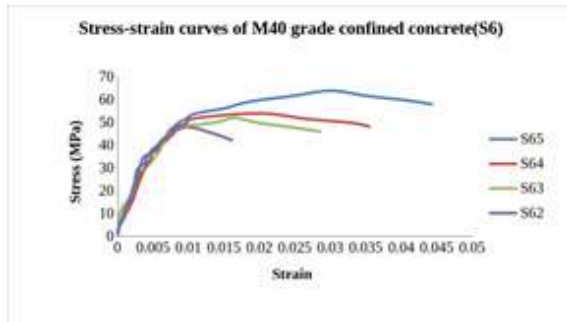


Fig 4.5 Stress-strain behaviour of tie confined M40 grade concrete with square ties of 6mm diameter reinforcement

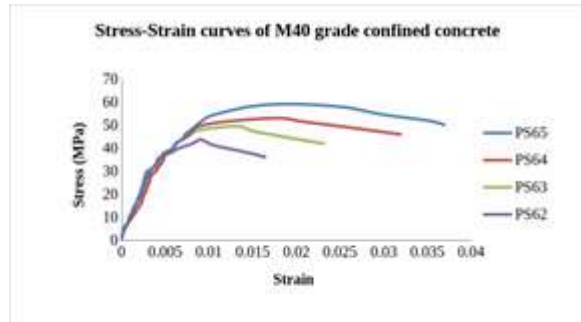


Fig 4.9 Stress-strain of tie confined M40 grade PET waste concrete with square ties of 6mm dia.

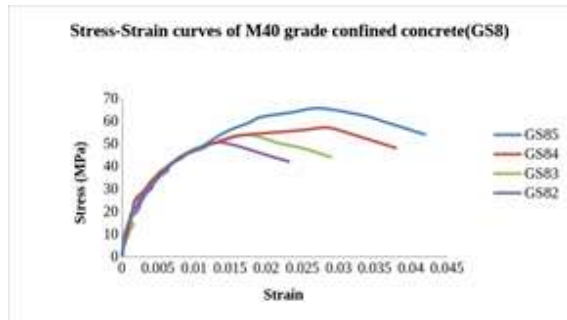


Fig 4.6 Stress-strain of tie confined M40 grade Glass waste concrete with square ties of 8mm dia reinforcement

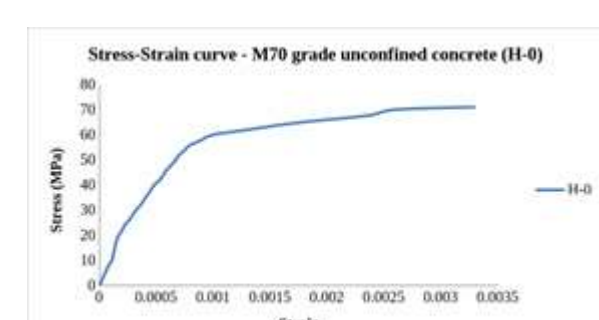


Fig 4.10 Stress-strain behaviour of unconfined M70 grade concrete

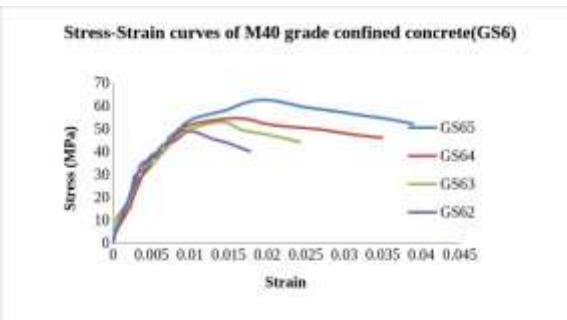


Fig 4.7 Stress-strain behavior of tie confined M40 grade glass waste concrete with square ties of 6mm dia reinforcement

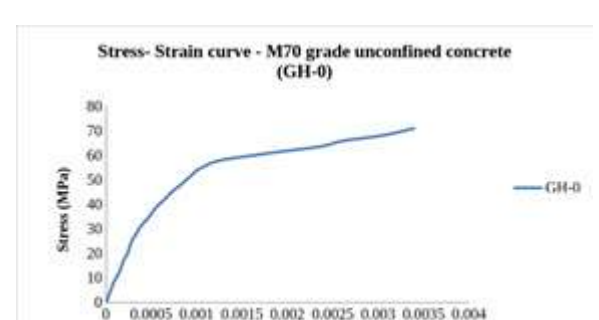


Fig 4.11 Stress-strain behaviour of unconfined M70 grade glass waste concrete

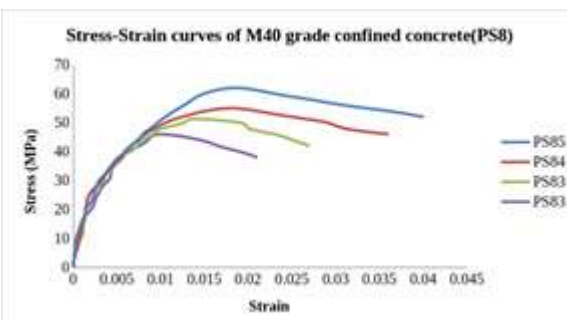


Fig 4.8 Stress-strain of tie confined M40 grade PET waste concrete with square ties of 8mm dia reinforcement

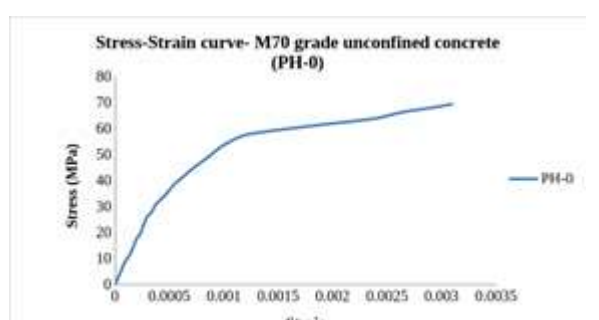


Fig 4.12 Stress-strain behaviour of unconfined M70 grade PET concrete

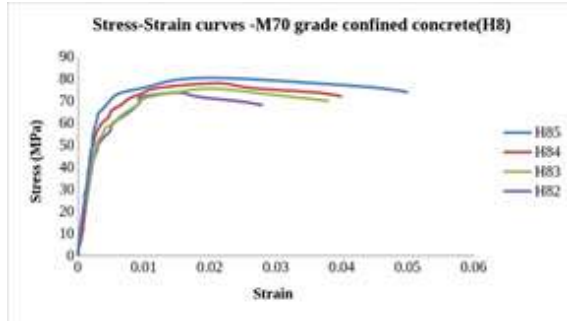


Fig 4.13 Stress-Strain behaviour of tie confined M70 grade concrete with square ties of 8mm dia.

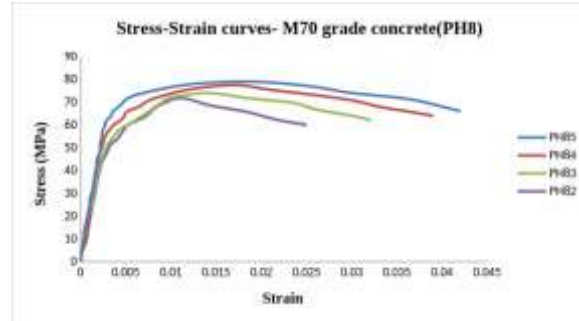


Fig 4.17 Stress-strain behaviour of tie confined M70 grade Waste PET concrete with 8mm dia ties

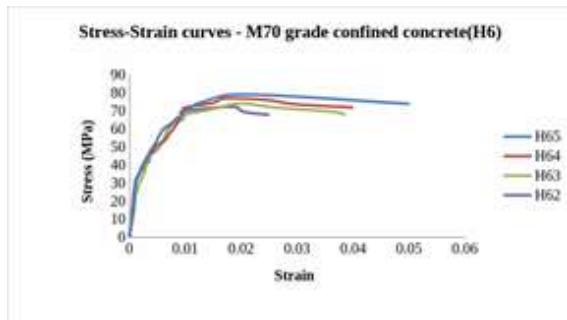


Fig 4.14 Stress-Strain behaviour of tie confined M70 grade concrete with square ties of 6mm diameter

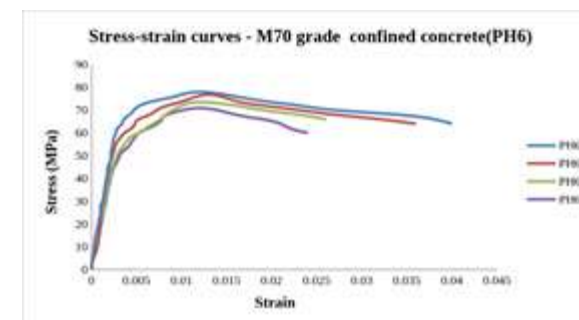


Fig 4.18 Stress-strain behaviour of tie confined M70 grade Waste PET concrete with 6mm dia ties

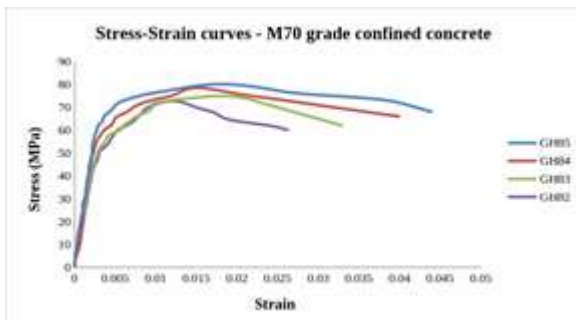


Fig 4.15 Stress-strain behaviour of tie confined M70 grade glass waste concrete with square ties of 8mm dia reinforcement

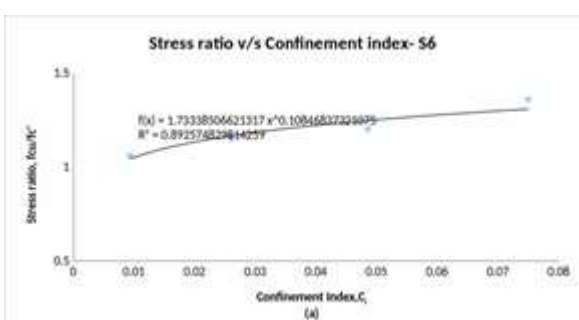


Fig 4.19 Variation of axial stress ratio (a) and axial strain ratio (b) with confinement index for M40 grade conventional concrete with square ties of 6mm dia.

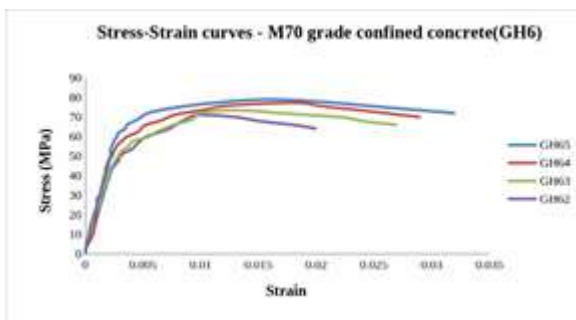


Fig 4.16 Stress-strain behaviour of tie confined M70 grade glass waste concrete with square ties of 6mm dia reinforcement

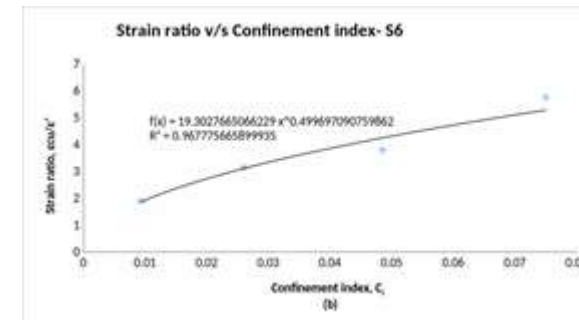


Fig 4.20 Variation of axial stress ratio (c) and axial strain ratio (d) with confinement index for M40 grade conventional concrete with square ties of 8mm dia.

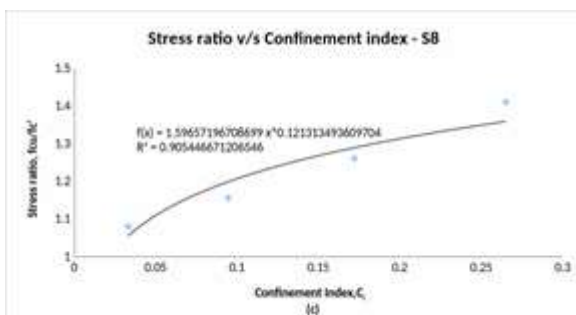


Fig 4.21 Variation of axial stress ratio (a) and axial strain ratio (b) with confinement index for M40 grade Glass concrete with square ties of 6mm dia.

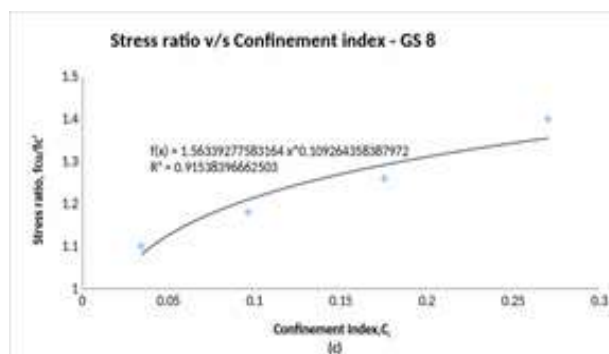


Fig 4.25 Variation of axial stress ratio (a) and axial strain ratio (b) with confinement index for M70 grade conventional concrete with square ties of 6mm dia.

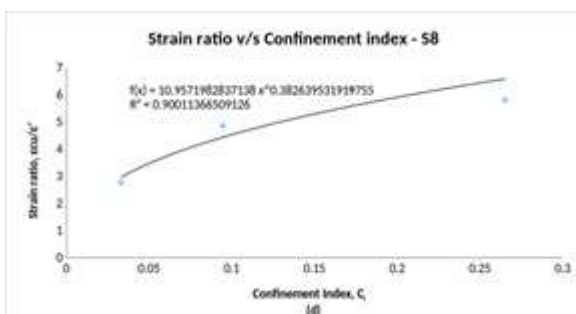


Fig 4.22 Variation of axial stress ratio (c) and axial strain ratio (d) with confinement index for M40 grade Glass concrete with square ties of 8mm dia.

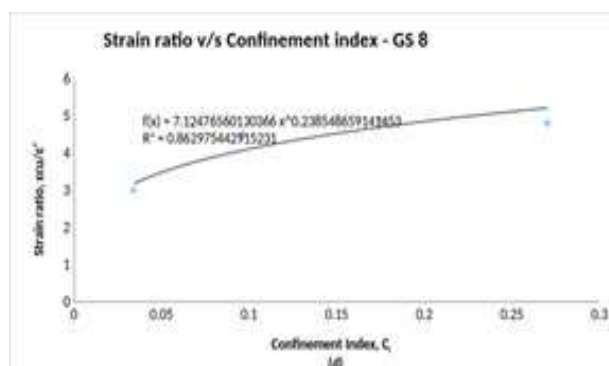


Fig 4.26 Variation of axial stress ratio (c) and axial strain ratio (d) with confinement index for M70 grade conventional concrete with square ties of 8mm dia.

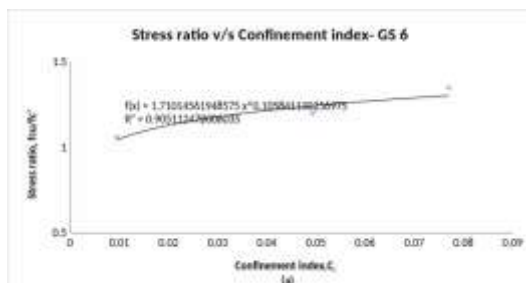


Fig 4.23 Variation of axial stress ratio (a) and axial strain ratio (b) with confinement index for M40 grade PET concrete with square ties of 6mm dia.

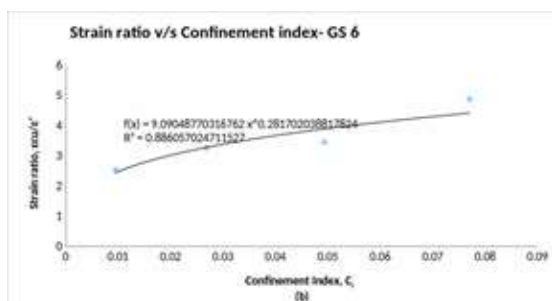


Fig 4.24 Variation of axial stress ratio (c) and axial strain ratio (d) with confinement index for M40 grade PET waste concrete with square ties of 8mm dia.

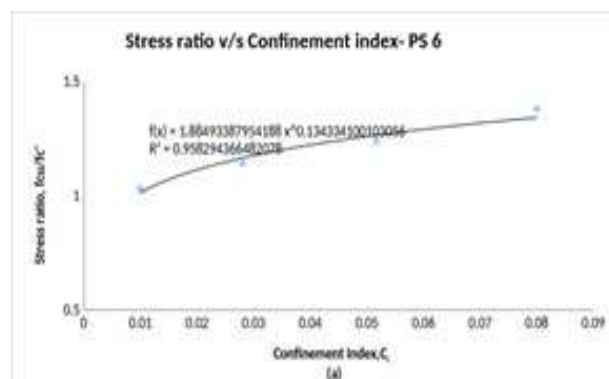


Fig 4.27 Variation of axial stress ratio (a) and axial strain ratio (b) with confinement index for M70 grade Glass waste concrete with square ties of 6mm dia.

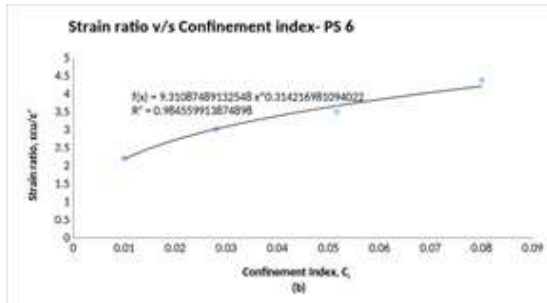


Fig 4.28 Variation of axial stress ratio (c) and axial strain ratio (d) with confinement index for M70 grade Glass waste concrete with square ties of 8mm dia.

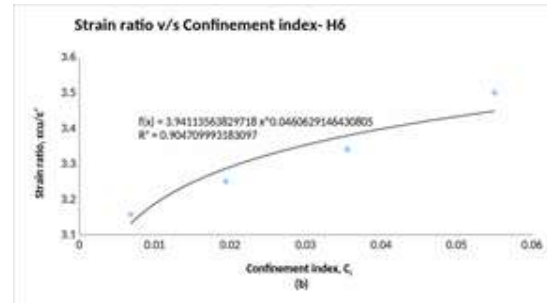


Fig 4.32 Variation of axial stress ratio (c) and axial strain ratio (d) with confinement index for M40 grade conventional concrete with square ties of 8mm dia.

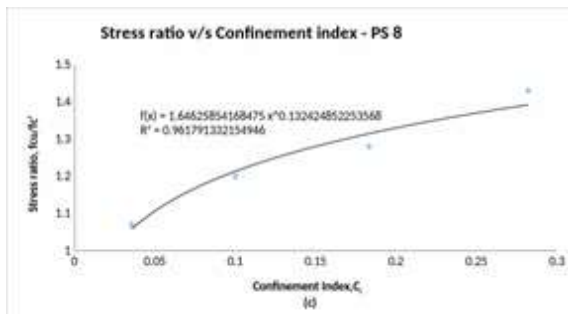


Fig 4.29 Variation of axial stress ratio (a) and axial strain ratio (b) with confinement index for M70 grade PET waste concrete with square ties of 6mm dia.

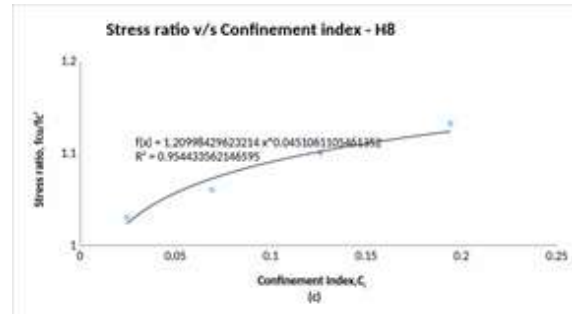


Fig 4.33 Variation of axial stress ratio (a) and axial strain ratio (b) with confinement index for M40 grade Glass waste concrete with square ties of 6mm dia.

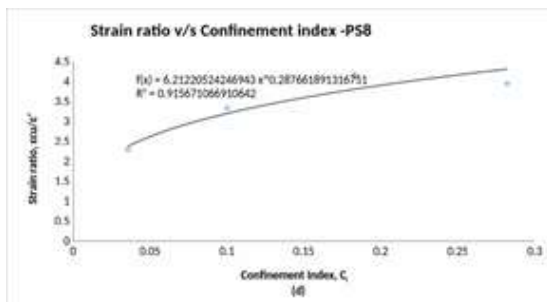


Fig 4.30 Variation of axial stress ratio (c) and axial strain ratio (d) with confinement index for M70 grade PET waste concrete with square ties of 8mm dia.

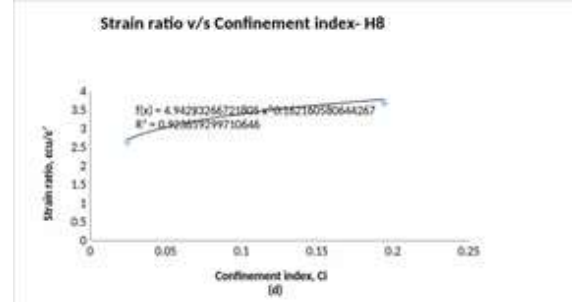


Fig 4.34 Variation of axial stress ratio (c) and axial strain ratio (d) with confinement index for M40 grade Glass waste concrete with square ties of 8mm dia.

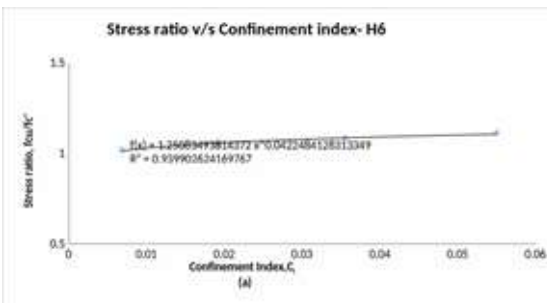


Fig 4.31 Variation of axial stress ratio (a) and axial strain ratio (b) with confinement index for M40 grade conventional concrete with square ties of 6mm dia.

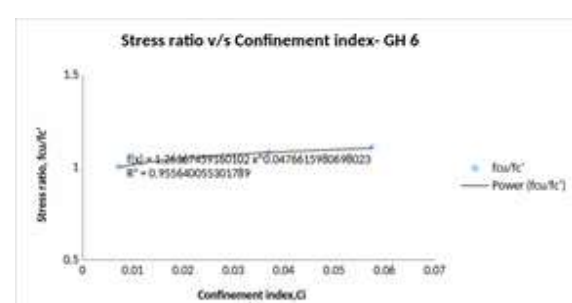


Fig 4.35 Variation of axial stress ratio (a) and axial strain ratio (b) with confinement index for M40 grade PET waste concrete with square ties of 6mm dia.

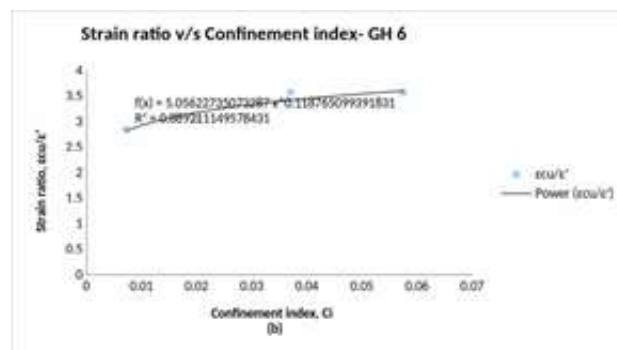
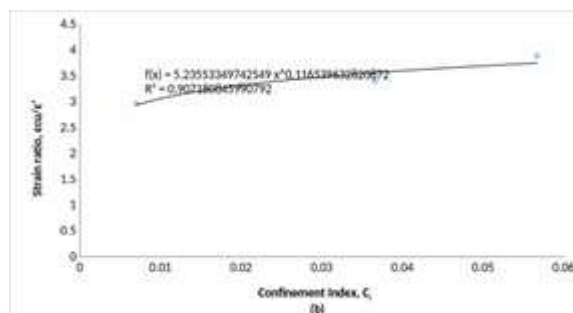
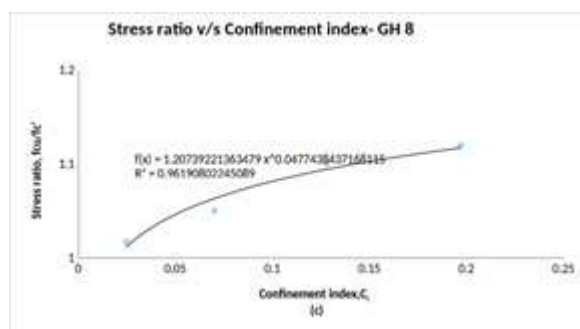


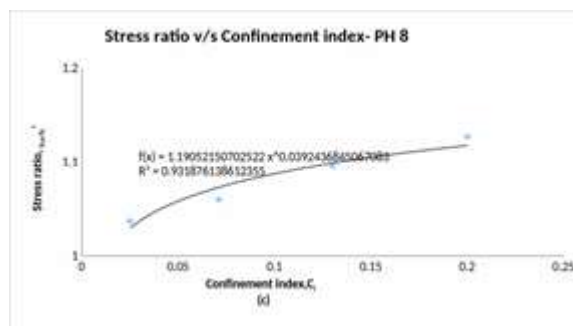
Fig 4.36 Variation of axial stress ratio (c) and axial strain ratio (d) with confinement index for M40 grade PET waste concrete with square ties of 8mm dia.



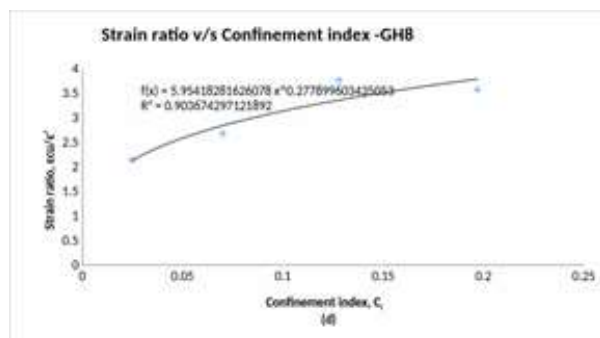
Variation of axial strain ratio with confinement index - M70 grade PET waste concrete with square ties of 6mm dia.



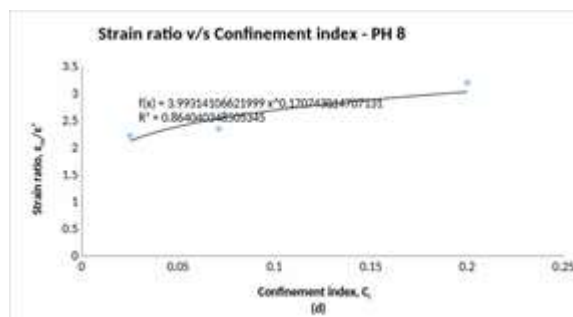
Variation of axial stress ratio with confinement index - M70 grade Glass waste concrete with square ties of 8mm dia.



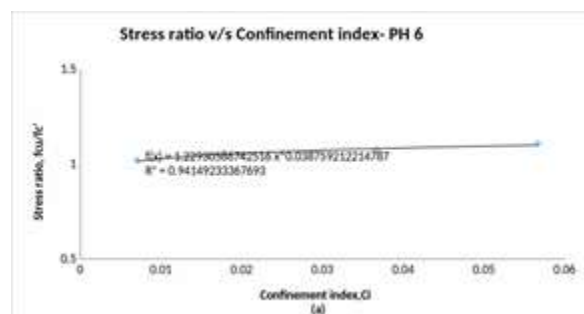
Variation of axial stress ratio with confinement index - M70 grade PET waste concrete with square ties of 8mm dia.



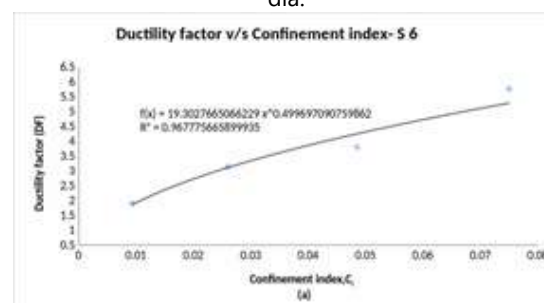
Variation of axial strain ratio with confinement index - M70 grade Glass waste concrete with square ties of 8mm dia.



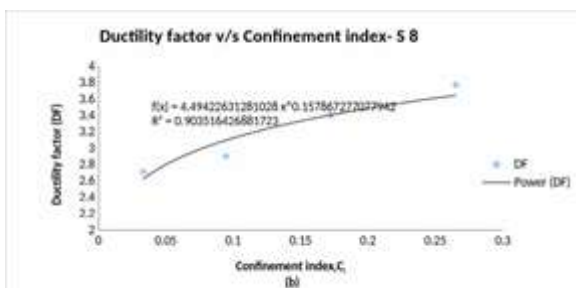
Variation of axial strain ratio with confinement index - M70 grade PET waste concrete with square ties of 8mm dia.



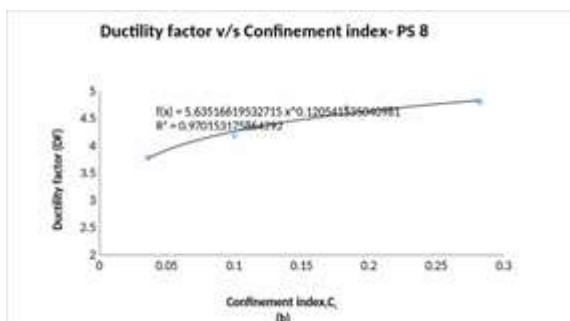
Variation of axial stress ratio with confinement index - M70 grade PET waste concrete with square ties of 6mm dia.



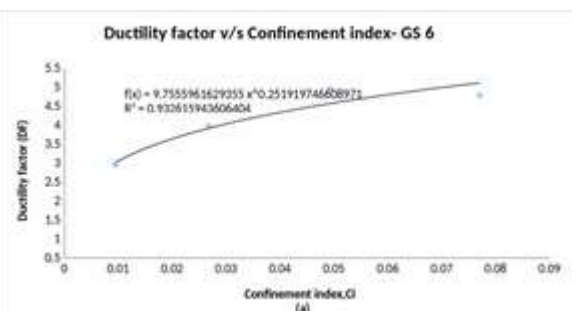
Variation of Ductility factor with confinement index for M40 grade conventional concrete with square ties of 6mm dia.



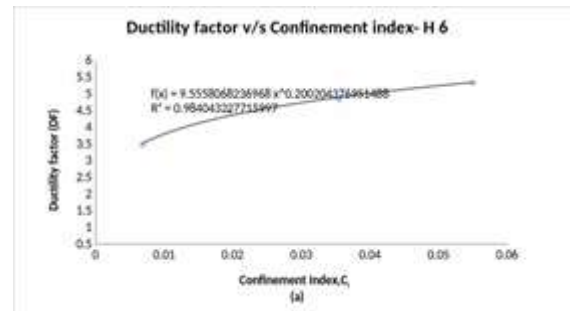
Variation of Ductility factor with confinement index for M40 grade conventional concrete with square ties of 8mm dia.



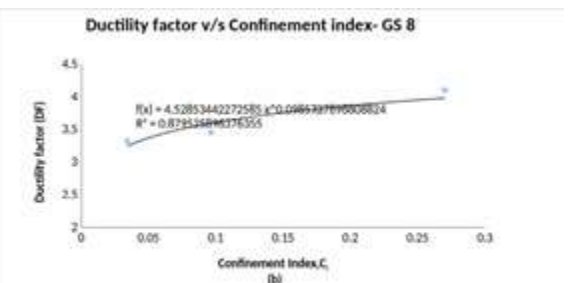
Variation of Ductility factor with confinement index for M40 grade PET waste concrete with square ties of 8mm dia.



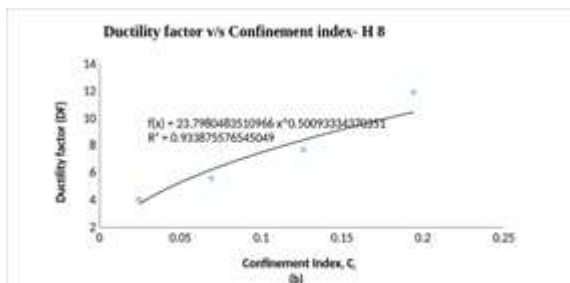
Variation of Ductility factor with confinement index for M40 grade Glass waste concrete with square ties of 6mm dia.



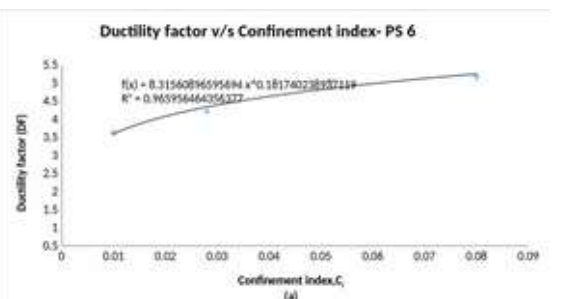
Variation of Ductility factor with confinement index for M70 grade conventional concrete with square ties of 6mm dia.



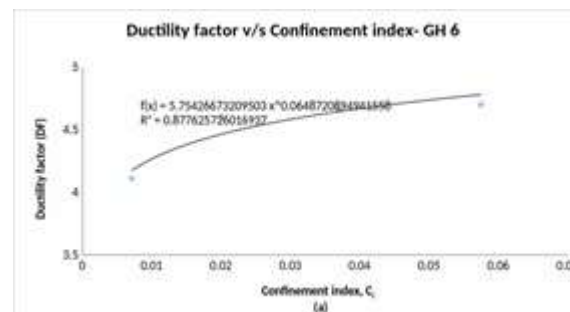
Variation of Ductility factor with confinement index for M40 grade Glass waste concrete with square ties of 8mm dia.



Variation of Ductility factor with confinement index for M70 grade conventional concrete with square ties of 8mm dia.



Variation of Ductility factor with confinement index for M40 grade PET waste concrete with square ties of 6mm dia.



Variation of Ductility factor with Confinement Index for M70 grade glass waste concrete with square ties of 6mm dia.

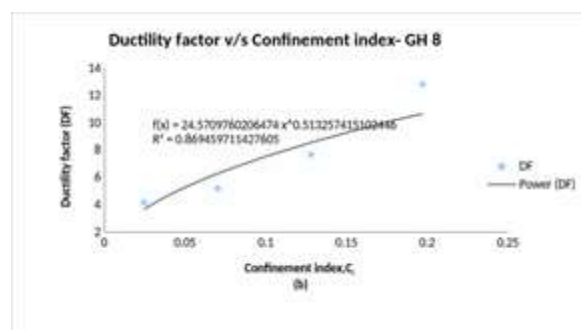
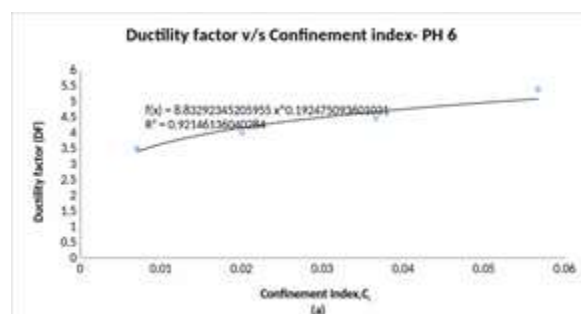


Fig 4.35 Variation of Ductility factor with Confinement Index for M70 grade glass waste concrete with square ties of 8mm dia.



Variation of Ductility factor with confinement index for M70 grade PET waste concrete with square ties of 6mm dia.

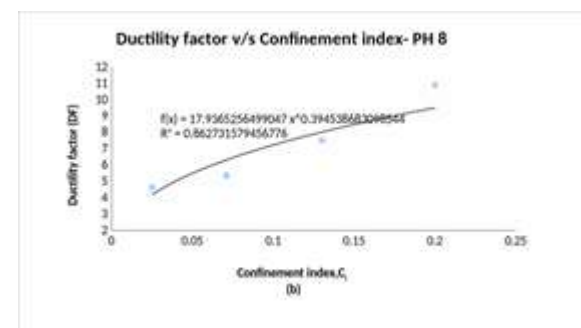


Fig 4.36 Variation of Ductility factor with confinement index for M70 grade PET waste concrete with square ties of 8mm diameter.

V. CONCLUSIONS

Based on a study conducted on confined concrete in which coarse and fine aggregates were replaced with Glass waste in proportion of 5% in M40 grade and 4% in M70 grade concrete and also PET, bottle waste in proportion of 3% in M40 and 2% in M70 grade concrete with 6mm mild steel and 8mm TMT bars, the following conclusions are drawn.

Conclusions

Providing lateral ties significantly improved the behaviour of confined concrete by increasing the peak load, peak stress, and corresponding peak strain.

For specimens having the same concrete grade, tie spacing, and transverse reinforcement diameter, the peak stress, peak strain, ultimate strain, and ductility values of conventional concrete, glass-waste concrete, and PET-waste concrete were found to be broadly comparable.

Confinement produced only a minor change in the ascending branch of the stress-strain curve. However, the descending branch became more gradual, indicating an improvement in post-peak behaviour and ductility.

The ductility factor increased as the number of lateral ties increased. A reduction in tie spacing provided a higher degree of confinement and consequently resulted in a greater confinement index for specimens having the same cross-sectional dimensions.

The effectiveness of confinement was influenced by the strength and quality of the concrete. For a given tie spacing, higher-strength concrete exhibited a comparatively lower confinement index, indicating that the confinement requirement depends on the characteristics of the concrete.

The load-carrying capacity of the specimens improved progressively with an increase in the degree of confinement. Therefore, a higher confinement index (C_i) was associated with greater axial load resistance.

The experimental results showed that the stress ratio, strain ratio, and ductility factor increased as the confinement index increased, demonstrating the beneficial effect of transverse reinforcement on the overall response of concrete.

The companion cube specimens tested after 28 days of conventional water curing exhibited satisfactory compressive strength. Both M40 and M70 grade

concretes, including the control mixes and mixes containing glass or PET waste as partial aggregate replacements, developed good compressive strength at the end of the curing period.

Scope for further investigation

1. Further studies may be conducted using specimens of different dimensions and varying levels of confinement to better understand their influence on concrete behaviour.
2. Future research can focus on determining suitable stress-block parameters and establishing moment–curvature relationships for confined concrete.
3. Additional experimental work may also investigate the combined use of recycled aggregates, waste glass, and PET bottle waste in concrete to evaluate their collective effect on structural and mechanical performance.

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