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A comprehensive review on the Strength, Durability and Sustainability Performance of Concrete Flexure Member with reduced Cement usage

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Abstract—In the modern era, it is imperative that construction materials, particularly concrete and cement, adopt a sustainable strategy. Because cement produces a similar amount of carbon dioxide by weight, which has disastrous impacts on the environment in terms of the greenhouse effect, there is an urgent need to reduce cement use. There have been numerous attempts made in earlier studies to achieve sustainability by using less cement or concrete in constructions without sacrificing their strength and long-term viability. Concrete replacement, concrete consumption reduction, and the use of additional cementitious materials are a few notable ways that have been tested and investigated for their effectiveness in achieving the necessary qualities of the concrete members. This paper presents review on partial replacement of concrete in the with different kind of lightweight materials such as aerated blocks, PVC, Glass fibre, polypropylene plastic sheet and supplementary cementitious materials etc., for the sustainability approach. Strength, durability and sustainability characteristics of structural members with reduced cement usage are discussed in this study. The overall finding of this review study projects that there is a remarkable reduction in the cement usage and thus reducing the environmental hazardous impacts of the same.

Keywords—**Aerated blocks, sustainability, Supplementary Cementitious materials, below neutral axis**

I. Introduction

There is huge demand of cement due to the tremendous infrastructure growth in developing countries. Producing 1 ton of cement can liberate equal amount of carbon dioxide and cause a great impact to the environment, during the calcination process in cement manufacture, when limestone is transformed into lime, and during the burning of fossil fuels to supply thermal energy for calcination to occur, a huge quantity of carbon dioxide is produced, contributing to global warming (David Biello on August 7, 2008: Scientific American) . There is a necessity to reduce the carbon footprint by reducing the utilization of cement content during construction. Continuously growing environmental expenses have compelled scientific research and industrial firms to invest in cement alternatives that are both energy efficient and ecologically sustainable. These alternatives can be achieved by implementing the most essential environmentally responsible behaviour which is to reduce and replace the cement with alternative methods or materials.

In a structural element like a beam the tension zone is below the neutral axis and steel reinforcements are provided in the tension zone of the beam because concrete is weak in taking up tension. (Mr Robert : CivilEngineerx) The concrete below the neutral axis acts as a medium for transferring stress from the compression zone to the tension zone and the concrete placed in this tension zone is called as sacrificial concrete. Adopting an alternate method by providing a substitution in this zone below the neutral axis with any light weight substances as an equivalent will minimize the cement content and does not affect and create a greater impact on the strength of the structural elements. Similarly, replacing conventional concrete with lightweight concrete can be made by using light weight aggregates, entraining air, or completely removing fine aggregates. Light Weight concrete can be produced with materials like pumice, aerated concrete, expanded polystyrene, incinerator bottom ash, Styrofoam and foamed concrete. Due to the highly porous microstructure of light weight aggregate, it has a low density and provides better insulation, resulting in lower thermal conductivity in light weight concrete than in normal weight concrete and it results in minimal usage of concrete thus lesser cement content is consumed.

In the production of concrete, the aim to use environmentally friendly materials derived from industrial by-products in high-strength mortar and concrete motivates the incorporation of a variety of less energy-intensive component ingredients. Industrial solid waste by products like fly ash, GGBS, silica fume as supplementary cementitious materials can be replaced with cement ranging from 10%-70%. (AmiraliEbrahimi et al 2017) Cement can be replaced with materials which are called as supplementary cementitious materials like natural pozzolana obtained from natural siliceous and aluminous deposits like metakaolin and volcanic ash. Nanoparticles and fibres added as an additive has proved to enhance the performance of the concrete and aids with higher percentage of replacement of cement. An extensive study has been conducted and this paper gives an overview of the performance of structural element with reduced cement utilization.

II. Previous research work on Aerocon block cubes, Aluminium oxide and Hollow structural steel section in tension zone of concrete.

A. Replacement of materials at below the neutral axis

Gorde Ajay Jagannath et al, (2017) Investigated the flexural capacity of the Beam by replacing lightweight materials such as Burnt Red Bricks, AAC (Autoclaved Aerated Concrete) Blocks, MurrumInfilled Plastic Bottles at below the neutral axis. This paper says that the flexural capacity of AAC blocks was higher than the conventional beam. But other lightweight materials such as burnt brick, and Murrum Infilled Plastic Bottles were having low flexural capacity than the conventional concrete. The result of this paper indicates that the 30% volume were reduced after replacing the lightweight materials. And also, AAC blocks shown in fig.2 were preferred to use as a replaceable material at below the neutral axis which is having higher flexural capacity. This paper explained a stepwise procedure to install the light material in the beam's proper location shown in the fig 1, Before pouring concrete,

a) Using the formula, get the depth of the neutral axis (Xu) from the top.

$Xu^1 = (0.87fy*Ast) / (0.36fck*B)$

b) From the total depth of the beam, subtract the depth of the neutral axis (Xu).

$(D+d')$ i.e. $D - (Xu+d')$

c) This will be the depth at which the light material will be positioned beneath the neutral axis.

d) Put the item where it is indicated in fig. 1.

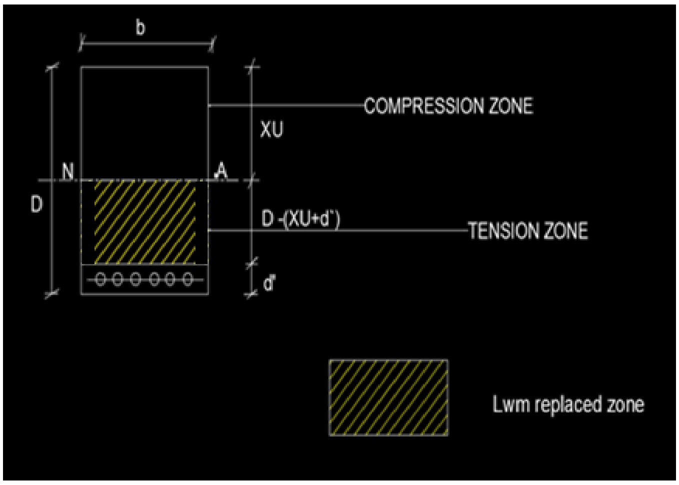

Fig.1. LWM Position in a Beam

Fig 2. AAC blocks

TABLE I. SPECIFICATIONS OF AAC BLOCKS

Parameters	AAC Blocks	Concrete
Block Density (kg/m^{3})	600	2400
Compressive Strength (kg/cm^{2})	40	Differs
Thermal conductivity (W/m.k)	0.132 – 0.151	0.5
Water Absorption (%)	45%	Differs
Drying Shrinkage (mm/m)	0.011 – 0.058	Differs

P. S. Aravind Raj et al, (2019) experimented the research on concrete by using Aerocon blocks and also steel fibres below the neutral axis. This paper concluded that the strength of the Aerocon blocks added specimen was same as controlled one but the self-weight of the specimen was reduced. Ultimate flexural strength, flexural toughness and ductility were increased in the steel fibre added specimen, and also given good performance in deflection and crack while compare to the conventional specimen

Yasser et al, (2015) investigated on Styrofoam used as waste material in the concrete as a filler where the concrete is ignored in the design. This paper says that the ductility displacement is better, slower crack propagation, and also expanded material has higher elongation in the area of tension polistyerene styrocon than the normal concrete. It was concluded that the performance of Styrofoam Filled Concrete in tension zone of the concrete beams showed good agreement than the normal reinforced concrete beams. Fig.3. Shows the Model of stress-strain

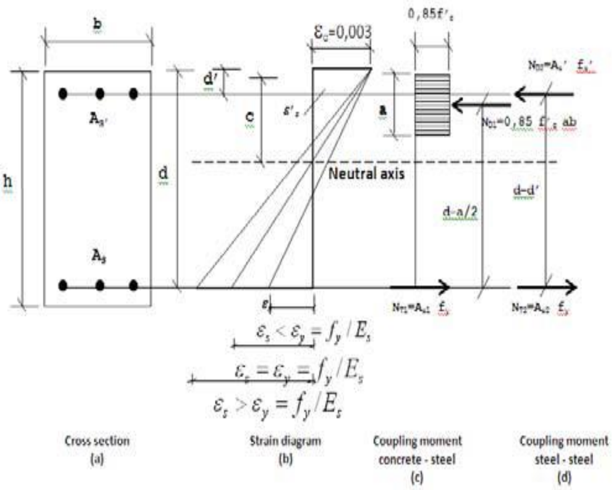

Fig.3. Model of stress-strain

Soji Soman et al, (2016) experimented to create the air voids by using different percentage of polyethylene balls and PVC pipes on below the neutral axis on concrete. This paper concluded that the formation of air voids in below the neutral axis of the concrete can reduce the volume of the concrete which leads to the less labours, and cost reduction. And also, can utilize the tension zone without losing strength while compare to the normal concrete.
Sariman S et al, (2020) analysed the flexural capacity of RC beam by filling a different layer of plastic bottles in the hollow core at below the neutral axis. This study indicates the flexural capacity of the bottle filles RC beam is same as the normal beam. And the stiffness was affected by the hight of the core in the reinforced concrete beam.

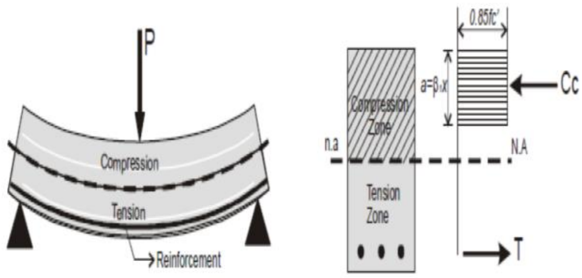

Fig.4. Flexural action of reinforced concrete beam

Win Godwin Jesudhason et al, (2014) Experimentally investigated by partial replacement of Expanded polystyrene sheet (EPS) below the neutral axis of the concrete. This study indicated the replacement provided high ability to withstand bending and shear. And which has lesser weight when compared to the conventional concrete.
Aswathy S Kumar et al, (2015) Investigated by partially replacement of polythene Balls in the concrete below the neutral axis shown in fig 5. It is found that the flexural behaviour of reinforced concrete has similar as conventional concrete and also which is very economical and volume of concrete reduced so that this concrete can be very sustainable to the society by the reduction of corban di oxide emission. [21]

Total tension, $T = f_{st}A_{st}$ ------------------------(1)
Total compression, $C = 0.36f_{ck}\,b(x_u)$----------(2)
Where fst= actual tension in steel corresponding to the strain in steel.
Equating the two expression, we obtain
$f_{st}A_{st} = 0.36f_{ck}\,b(x_u)$

$$\text{i.e. } X_u = \frac{fstAst}{0.36fck\ b} \text{--------------(3)}$$

For under-reinforced beams, steel first reaches yield stress of 0.87fy. Substituting its value and dividing both sides by the effective depth d (IS 456 Annexure G), we get

$$\frac{X_u}{d} = \frac{0.87fyAst}{0.36fck\,b} \text{----------(4)}$$

$$X_u = \frac{0.87x415x1232}{0.36x30x200x280} = 73.5mm$$

Fig. 5. Calculation of Xu

B S Karthik et al, (2014) Investigated on concrete by using different grade of concrete in the tension zone and also at the compression zone. M20 and M25 grade of concrete placed as a layer in bottom and top of the concrete and the results were compared to the conventional concrete. The results indicated that the flexural behaviour, crack patter and the failure mode of the partial beam as similar as Normal RCC beam and also which was very economical.
Basil tom jose et al, (2018) experimentally compared the study by Using Seeding Trays and Polythene Balls as a partial replacement in concrete below the neutral axis with four point load testing shown in Fig 6. This paper says that the flexural strength and ductility index slightly decreased in replaced concrete than the normal concrete. but it was economical due to the percentage of replacement in the concrete.

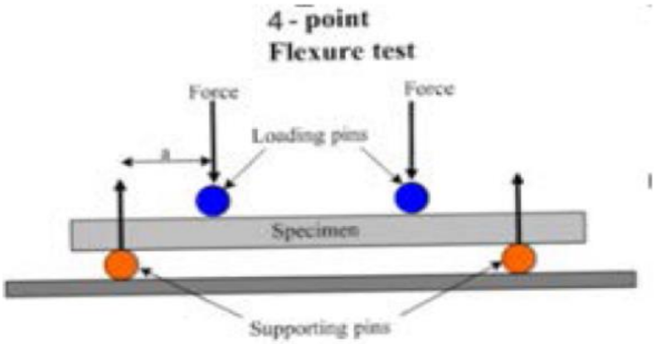

Fig.6 Four point load set up

Jain Joy et al, (2014) studied on concrete beam to find the effect of reinforced concrete by providing PVC hollow pipe below the neutral axis. This paper concluded that the orchestrated PVC hollow pipe at below the neutral axis reduced the volume of the concrete which leads to the less labours, and cost reduction. And also, can utilize the tension zone without losing its strength compare to the normal concrete.
L. F. A. Bernardo et al, (2004) done investigation on Neutral Axis Depth versus Flexural Ductility in High-Strength Concrete Beams. This paper says that the crack formation and strength of high strength concrete seems to be similar as normal concrete. This paper concluded that there is no much difference in between the high strength concrete and the normal concrete.

Dhinesh.N.P et al, (2017) investigated the research on RC beams by replacing the PVC pipes below the neutral axis. This paper says that the replacement was economical, reduction of time and labour. And also, very sustainable and eco-friendly by saving the materials as reduction of carbon emission to the environment.

B. Partial Replacement of concrete using lightweight materials

Prashant Gautam (2013) carried out a comparison study on Red Bricks with Autoclaved Aerated Concrete Blocks to approach sustainability. Using AAC blocks in the construction than the red bricks Achieved cost reduction, dead weight of the structure reduced, no smock exhalation during the manufacturing which was more eco- friendly, lesser joints thus provided more safety during the earthquake. But the compressive strength of the AAC blocks were lesser than the red bricks.

Haejin Kim et al, (2015) explored the research by using crushed returned concrete aggregate to predict shrinkage behaviour of sustainable concrete. The result of the hyperbolic shrinkage model analysed in this study and alternate model was proposed based on the experimental results. This paper indicates The Ultimate shrinkage value was more reliable to the volume of CCA concrete mixtures in the proposed model.

According to ACI 209 (ACI 2008), a hyperbolic time function can be used to connect drying shrinkage, ε_{sh}, to the final shrinkage value
.

$$\varepsilon_{sh} = \frac{t}{35 + t}\varepsilon_{ult}$$

where t = time (days); ε_{ult} = ultimate shrinkage value
($780\gamma_{sh} \times 10^{-6}$ m=m); and γ_{sh} = correction factor

Prakash T M et al (2013) carried out research to predict physical and elastic properties of aerated concrete blocks. The results shows that the Aerated concrete blocks were having low water absorption capacity shown in table 2, lesser self-weight which leads to cost reduction of the structure, low compressive strength, satisfactory level of flexural capacity. Modulus of elasticity were higher even the structure has lower compressive strength. This study concluded that the solid and hollow concrete are much better than the Aerated concrete blocks. Fig 7. Shows the stress strain plot of aerated concrete blocks.

TABLE II. WATER ABSORPTION OF ACB

Specimen No.	Water Absorption (%)	Average Water Absorption (%)	C O V
1	36.97	36.08	0.03
2	35.68		
3	37.26		
4	34.93		
5	35.37		
6	36.32		

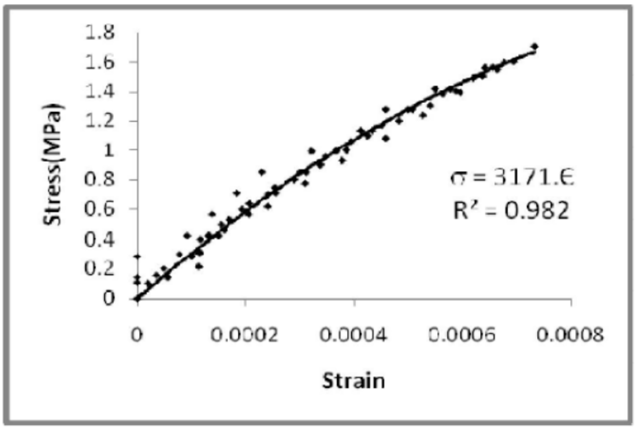

Fig. 7 Stress-Strain plot of ACB

Yuanming Song et al,(2016) carried out investigation on aerated concrete by using Incinerator bottom ash to produce light weight concrete. In this study aluminium powder used as a controlled specimen and 3 various particle sizes of IBA used to predict the potential and gas generation of IBA. When IBA used as a aeration agent achieved Finer particle, alkali morality, temperature reaction was higher, higher gas generation and aeration capacity around 1% that of pure aluminium powder by mass. This Study concluded that the IBA was acting as a better aeration material to replace aluminium powder. Fig 8 shows the SEM images of aerated light weight mortar.

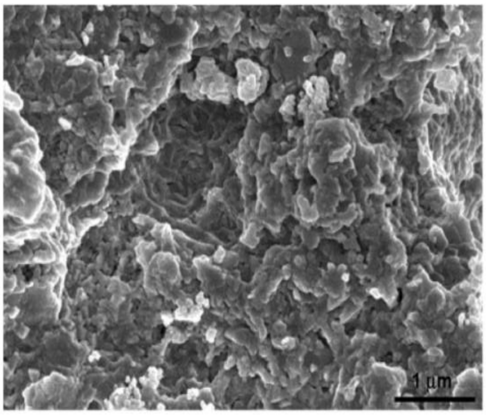

Fig.8. SEM images of IBA aerated lightweight mortar

Narendra Kumar Tiwary et al, (2018) done the experiment on aeriated mortar by using colloidal gas aphrons. Various kind of properties were analysed such as compressive strength, porosity and dry density. When the CGA added more, Compressive strength was decreased, simultaneously dry weight decreased and also porosity increased. Required water usage is minimal. Over all CGA was very economical, lighter in weight which can be used as other industrial wastes like a fly ash.

Nibin Varghese et al, (2015) done the research on RC beam with hollow core at various depth. This study says that the flexural behaviour of the hollow core specimen same as the controlled specimen. Strength increased about 21%, economical, extra labour or time reduction were the advantages of using PVC pipe instead of concrete. And this paper indicated that the optimum depth of hollow core from the top which is 160mm. Fig 9. Shows the stress strain diagram for singly reinforced beam.

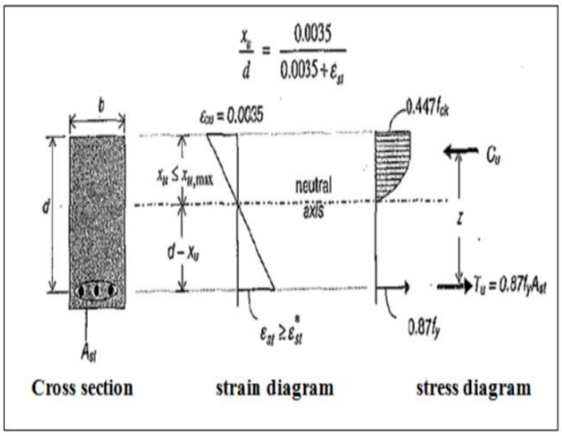

Fig. 9. Stress-Strain Diagram for singly reinforced beam

Anju Varghese et al, (2016) studied the research on RC Hollow core sandwich beams by the replacement of Polyurethane and Expanded polystyrene which shows similar result as conventional specimen in flexural strength and the deflection. Damping property of Polyurethane shows more effective replacement in concrete.

Yasser et al, (2013) Investigated on concrete by Using Styrofoam for analysing Flexural Characteristics of Reinforced Concrete Beams. In this study Styrofoam was acting as filler in the concrete which reduced weight of the concrete. This paper concluded that the specimen has ability to withstand ductility displacement, higher elongation and flexibility. Crack propagation was also slower than the normal concrete.

A.Suba lakshmi1 et al, (2017) Experimentally investigated on light weight concrete by using pumice stone in various proportion. This study says that the pumice stones absorb more water than the normal concrete and reduced weight of the concrete. Increasing more than 50% of replacement shown negative impact on the concrete. This paper concluded that the 50% of replacement given good results in the behaviour of flexural and compressive strength.

Arivalagan, S et al, (2010) Experimentally investigated to obtain the ultimate moment capacity by using lightweight concrete and foamed concrete (polyurethane.) in the hollow and concrete filled steel tubes. This paper concluded that the concrete filling increased energy absorption, residual load carrying capacity to resist cyclic loading shown in fig 10.

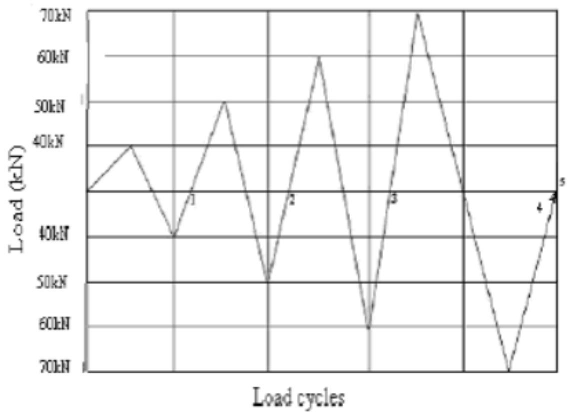

Fig.10. Cyclic loading Diagram

Matthew J et al, (2018) carried out the research on simulated response of steel reinforced ECC Members. in finite element to reduce the fracture energy. bond-slip were helpful to find reinforcement fracture. Various parameters were observed like tensile strength and tensile fracture. This paper concluded that without proper cyclic fracture energy degradation, capturing hysteretic response and deformation capacity will be very difficult for simulations.

Craig Polley et al, (1998) carried out the investigation on concrete by using waste glass as aggregate. Various laboratory testes had been conducted and alkali-silica reactions were examined. Initially compressive strength was lower, finally achieved satisfactory level of compressive strength. Good in Durability. This paper concluded that the 20% of glass replacement was suitable to use as fine aggregate. Size of glass particle higher than 1.5mm was not recommended to use as aggregate due to the poor shape and shape. More water required to maintain the workability of concrete.

A. Peled et al, (2007) done the experiment on concrete by using fabrics on cement such as woven polyvinylalcohol, woven polyethylene, bonded glass mesh and warp knitted weft insertion polypropylene which had been Pultruded and Casted in this study Microstructural analysis was conducted to obtain the tensile behaviour. This paper concluded that the Pultruded process was very effective to resist pullout which is also able to fill the spaces between the fibres.

Jianwei Huang et al, (2010) done the investigation on glass fiber reinforced polymer bars to reduce environmental reduction factors on concrete. New equations were found for design strength of GFRP bar. Research was done on alkali attack and the connection between the concrete pore water and reduction factors. This paper concluded that the GFRP bars have better durability for a longer period and performance to reduce the RF and temperature shown better results.

Sean Monkman et al, (2010) carried out the investigation on carbonation of slag cement concrete to improve the performance and binding of CO2. Four ratios of binders were used. This paper concluded that the GGBS slag reduced the cement usage, which leads to reduce CO2 emission. PH level was decreased in the carbonated concrete, also comparable strength was attained after 28 days, reduced shrinkage, and deicing salt resistance.

Khandaker M. Anwar Hossain et al, (2011) carried out experiment on light weight concrete by using pumice aggregate, volcanic ash-based cement. Various properties were analysed such as mechanical & microstructural characteristics, workability and durability. This paper concluded that the, mixture of VPA &VPAC shown comparable result with other light weight concrete in strength and durability.

Hamdy M. Mohamed et al, (2011) done the research on reinforced concrete- filled fiber-reinforced polymer (FRP) tubes (RCFFTs) beams to analyse the flexural behaviour and to predict deflection. This paper concluded that the RCFFT improves the flexural behaviour and the tension stiffness than the normal specimen. Predicted deflections from the literatures were overestimated, so, in this study, new deflection equations were developed to find the deflection accurately. Fig 11. Shows the load set up for RCFFT beams

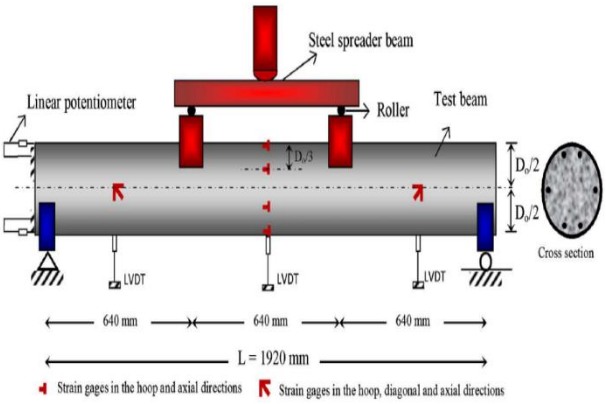

Fig. 11. Test setup for RCFFT beam

Fatih Altun et al, (2001) done the investigation on composite reinforced concrete to predict the flexural behaviour. Composite reinforced concrete developed with two layers which was, at bottom Normal concrete and at top light weight concrete made with pumice stone as aggregate. In this study, Composite reinforced concrete achieved greater reduction in dead weight, vertical displacement was at the acceptable limit and there was a small drop in load carrying capacity compared to the normal concrete. Over all, behaviour of CRC was similar to the normal reinforced concrete.

Husain Al-Khaiat et al, (1999) carried out research on light weight concrete from industrial by product and normal weight concrete to Analyse the performance of strength and durability under hot dry and hot humid coastal exposure conditions. Water penetrability was much higher in LWC50 than the NWC50. Depth of carbonation was moreover similar in both kind of concrete. simultaneously sulfate, and chloride penetration was higher in LWC50 than the NWC50.

Vasser M. Hunaiti, (1997) conducted an investigation on formed concrete and light weight concrete filled in a hollow circular tube to analyse the squash load and ultimate moment capacity under bending and axial compression. Results were compared with unfilled steel sections and the Analytical predicted values. The specimen which is filled with formed concrete was not similar to the predicted values but the light weight concrete filled specimen enhanced the strength of steel. And also, both formed and light weight concrete increased the flexural strength of the specimen.

A. Samer Ezeldin et al,(1992) carried out an investigation on high-strength fiber-reinforced Concrete with and without silica fume to analyse the stress strain behaviour of concrete. In three ratios fibres were added with the concrete. addition of fibres increased the toughness of the concrete with or without silica fume and silica fume makes the fibre reinforced concrete more brittle than the non-silica fume concrete. over all in this study, stress- strain curve of non-silica fume fibre reinforced concrete shown good similarity between experimental and predicted values.

Kirubajiny Pasupathy et al, (2018) done the investigation on fly ash-based geo polymer concrete to analyse the durability performance under exposed condition around 8 years. This study says that the fly ash GPC specimen acts well in carbonation resistance and corrosion resistance. Sportively characteristics also increased and which was confirmed with MIP results. But at the exposed condition, durability of fly ash -GPC was lower than the OPC Concrete.

Yasin Esmaeili et al, (2020) done the research on glass fiber-reinforced polymer concrete beams to analyse the flexural behaviour of concrete beams by applying high level sustained loads up to 40% of the ultimate tensile capacity of their GFRP bars and exposed to aggressive weathering condition around 10 years. All the GFRP specimens were coated with the sand. Only 16% of the strength deteriorated under high sustain load with aggressive weathering. infrared spectra, glass-transition temperature, and interlaminar shear strength remained unchanged.

Mohamed Elchalakani et al, (2016) done investigation to build future sustainable cities by using high volume slag and fly ash in 13 different concrete mixes to reduce CO2 foot print. High volume GGBFS used as replacement for OPC in the percentage of 60,70,80,90. The result shows that the mixture of slag and fly ash can be a better replacement to reduce the CO2 footprint. And Replacement of 90% of GGBFS and 10% of OPC mix was recommended for the future sustainable construction.

Amardeep Singh et al, (2019) investigated on self-compacting concrete by partial/ fully replacement of silica fume, Ultrafine recycled powder and recycled aggregate to analyse the workability of concrete at various intervals. Comparatively up to 10% of recycled powder recommended to use as a partial replacement to satisfy fresh and mechanical properties.

Ramesh Chandra Gupta et al, (2016) done the research on sustainable and durable concrete by partial replacement of copper tailing as natural fine aggregate in the range of 0-80%. Replacement of 80% copper tailing shown better Compressive strength, Flexural strength, shrinkage resistance as similar to the controlled specimen. Highly abrasive resistance up to the replacement of 70% copper tailing.

U. N. Kumbhar et al, (2018) examined on reinforced concrete hollow beam to predict the flexural behaviour by using polypropylene plastic sheet as infilled. Hollow core replacement varied from 25%, 35%and 45%. 12 beams were casted and tested by applying two-point loading after 28 days of curing. Predicted results shows that the increment of replacement, decreased the flexural behaviour as well as deflection shown in fig 12.

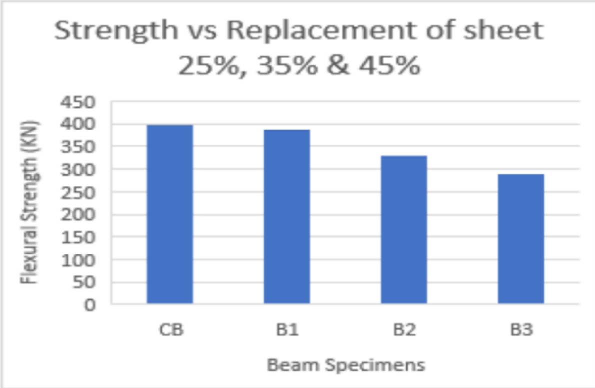

Fig.12. Replaced Specimen vs Flexural Strength

Sangeetha.r (2018) done the investigation on light weight concrete blocks using polypropylene balls in two variety of dimension such as 55mm and 65mm diameter. This paper says that the flexural strength, compressive strength and split tensile strength was higher in 55mm ball diameter specimen than the 65mm ball specimen.

Usha C.M et al (2014) studied experimentally on column by using Unplasticized poly vinyl chloride (UPVC) tubes as infilled concrete. The failure of the column observed as local buckling. This paper concluded that the compressive strength of the UPVC CFT columns were higher around 1.6% while compared to the theoretical values.

C. Replacement of Supplementary Cementous materials in concrete

1. Effect of Sustainability

Alan Maries et al, (2020) conducted an experiment on sustainable concrete by using Low-Carbon concrete. In this study self-pulverization and carbonation process were done to make a precast concrete and while production its achieved significant reduction of both process energy and CO2 emission and combined production of cement and precast concrete which leads to sustainability.

John Zachar et al, (2011) studied using fly ash as cement replacement in precast and prestressed concrete to achieve sustainable and economical products. Comparative studies conducted between the buildings which is constructed with fly ash and without fly ash precast prestressed products. This study indicates the replacement of fly ash increased early age strength, which is more economical and also reduction of cement usage can reduce the environmental impacts.

Keun-Hyeok Yang et al, (2020) conducted research on sustainable lightweight concrete to analyse the shrinkage behaviour by using air form and bottom ash concrete, binder consist of 30% fly ash, 50% ground-granulated blast-furnace slag and 30% ordinary Portland cement. Air form volume varies between 0 to 40% and W/B ratios are 25 % and 30%. Less than 25% of air form and bottom ash aggregates developed no cracks on the specimen under plastic condition. The proposed models forecasted exactly for the shrinkage behaviour of LCW- BF. Details of shrinkage measurements: (a) unrestrained shrinkage; (b) restrained shrinkage; and (c) plastic shrinkage shown in fig. 15

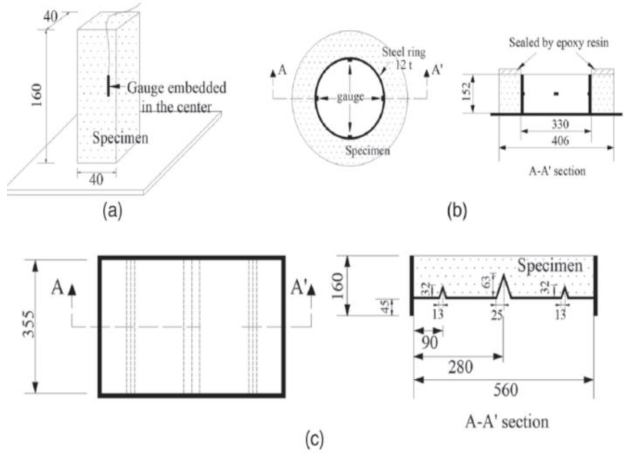

Fig.13. Details of shrinkage measurements

Ashok Admute et al, (2017) Experimentally studied on green concrete, developed by waste materials from the industrial and agricultural use. This paper says that the Addition of micro silica can leads to sustainable concrete by reducing the air pollution, increased consistency as well. Also, Replacement of silica in the amount of 5% and 15% increased the strength of concrete, replacement of 20% shown decrement of strength. Replacement of demolished brick Waste along with fine aggregate was reduced 20% overall cost and strength was similar as controlled specimen.

Sumaiya Afroz et al, (2021) done the research on concrete by using two types of starch which was laboratory starch and arrowroot as a cementitious material. Various tests had been conducted and the result says that the flow of cement mortar increased and the water absorption reduced for a long term. And this paper concluded that the starch was very efficient material which can be used as an admixture instead of using other chemical compounds which leads to produce green concrete.

D. O. McPolin et al, (2007) carried out new test method to find ph profiles of concrete by replacing different Supplementary Cementous materials such as 50% ground granulated blast-furnace slag, 30% pulverized fuel ash, 10% microsilica and 10% metakaolin. Specimens were exposed in carbonation for 6 weeks. After exposure, the performance of controlled specimen shows better result in both depth of carbonation and rate of carbonation than the replaced concrete. Composition of cementitious materials shown in table 3

TABLE III. COMPOSITION OF CEMENTITIOUS MATERIALS

	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	SO_3
OPC	64	21	6	2	3	3
GGBS	41	35	13	8	1	0.1
PFA	2	59	23	1	9	0.3
MK	0.02	55	41	0.3	0.6	0.0
MS	1	93	0.1	0.2	0.3	0.1

Prannoy Suraneni et al, (2018) carried out the investigation on concrete for pavement by the addition of fly ash and slag as supplementary cementitious materials. The increment of SCM replacement decreases the amount of calcium hydroxide and calcium oxychloride. This paper concluded that the SCM’s response and dilution in the pozzolanic tests rapid indication of ability to reduce calcium hydroxide and calcium oxychloride.

Yazan Alrefaei et al, (2018) investigated on hybrid fiber–engineered cementitious composites to analyse the shear behaviour of the beam. steel (ST) fibers and polyethylene (PE) were used in different combinations as cementitious paste or cementitious mortar. shear strength increased 8 times than the non-fibres matrix, also shear strain, ductility, cracking behaviour were improved by cementitious paste and shear strength increased 3 times by cementitious mortar. PE fibres effective as ST fibres to increase the shear behaviour.

J. I. Arimanwa et al, (2012) experimented the research on Aluminium waste cement concrete by using Scheffe's Theory. Both initial and final setting time decreases by the addition of aluminium waste and also reduces the workability. This result of this paper was aluminium was an efficient material to use for cold weather concreting due to the faster hydration process.

Mei-Ni Su et al, (2016) explored this Study by using new deformation-based approach which is continuous strength method to predict moment redistribution and strain hardening of aluminium alloy structural elements were used. Approximately 900 numerical and experimental results found and CSM analysed against to those various results such as simply supported beams, continuous beams, aluminium alloy stub columns, and also cross section based I-sections, angles, channels, square and rectangular hollow sections, both with and without internal cross stiffeners. It was given more accurate results to that both indeterminate and determinate aluminium alloy structural elements.

Sushant Upadhyaya et al, (2015) investigated by using High-Volume Fly Ash to predict Maturity-Based Field Strength of the sustainable concrete. This study indicated that both field curing and standard curing were conducted on concrete beams, cylinders, and slabs. Curing was conducted in the lime saturated water bath for various temperatures and ages. This paper concluded that the result of field curing and laboratory curing were comparatively varying and the concrete which one cured at higher temperature gained early- age strength.

Sarbjeet Singh et at, (2017) experimentally investigated by using granite industry by product on sustainable concrete. The tests were conducted by using various analyses including scanning electron microscopy (SEM) and X-ray powder diffraction (XRD). The results shows that the compressive strength and flexural strength were increased with the proportion up to 25% of GIB in the concrete. And also, Replacement of sand produced more durability to the concrete.

2. Effect of Compressive Strength

Ahmed Ibrahim et al, (2013) done the research on high performance high strength flowable concrete by replacing 70% of Supplementary Cementous materials such as silica fume, class F fly-ash and granulated blast furnace slag instead of Portland cement in three different water cement ratios such as 0.3, 0.33.0.37. Various properties like deformability, filling capacity, flowability, air content, resistance to segregation, permeability, and compressive strength was investigated. Such properties were given superior result with low W/C ratio while compared to the controlled specimen which had 100% Portland cement.

Prabhat Vashistha et al, (2021) carried out research Metakaolinite-Based Cementitious Binder which was calcinated lime sludge from paper industry. 10% and 30% substitution were applied in the cement which shows similar result compared to the controlled specimen. This paper concluded that the lime sludge-based binder was a suitable binder in cement and also reducing environmental impacts.

Clarke Snell et al, (2017) done the investigation on specific heat and thermal capacity of concrete by comparing the geopolymer cement mix and Portland cement mix in the concrete. The results shown that the thermal capacity and specific heat was low in geopolymer and compressive strength was higher while compare to the Portland cement mix. Especially specific heat of geopolymer mix was similar to the mix of granite sand and silica. This paper concluded that the thermal conductivity of geopolymer mix can be act as greater in concrete.

Liu Ninget al, (2015) investigated on concrete by using fly ash, magnesium phosphate cement (MPC), and rape stalk. In different sizes and different combinations, materials were used. Observations were taken by multi-scale morphology. This study says that the MPC was a suitable cementitious material and also has lower thermal conductivity. RS was acting as a good alternative material for a plant concrete. This research concluded that MPC - RS concrete act as a lighter in weight, very unique, better energy absorption under compressive strength than the normal concrete or other light weight concrete.

George Mathew et al, (2014) investigated on laterized concrete by using laterite aggregate and also addition of mineral admixtures such as Fly ash and GGBFS after the exposure of concrete at ambient temperature. This study says that the Replacement of cement either with 20% of fly ash or 25% of GGBFS can produce economical laterized concrete. compressive strength was increased by the combined application of laterite concrete and mineral admixtures at more than 400◦ C temperature, highly thermal crack resistance upto 800◦C. Also laterized concrete was resisted thermal cracks upto 600◦C.

Dr. Kookutla Ramesh (2014) has done his investigation by adding aluminium oxide to free chlorine in concrete. This study says that the Chlorine content considerably reduced by the addition of Aluminium oxide about the range of 10 to 15 % by the weight of cement even the compressive strength of the cement also increased.

Athbi Alazemi et al, (2018) investigated by adding 0.5, 1, 1.5, 2%, of nano aluminium oxide in the concrete. This study explained that the Nano aluminium oxide act as a bridge between silica fume and cement particles. It improved the flexural strength, and compressive strength. And also, when the proportion of aluminium oxide increased the compressive strength was decreased. And Aluminium Nano particles are filled out all the spaces of the concrete which leads to the reduction of porosity in the concrete.

H. Heidarzad et al, (2021) investigated on Durability and Mechanical Properties of Self-compacting Concretes. With the Combined Use of Aluminium Oxide Nanoparticles and Glass Fibre were increased the tensile strength and it increased compressive strength because of high cracking resistance. Aluminium nano particles filled out all the spaces of the concrete which leads to the less water absorption. This study concluded that the combined use of these two materials can improve the durability and mechanical properties of the concrete.

Mohd Warid Hussin et al, (2010) investigated the research by adding sand in various sizes, superplasticizers, Aluminium power in the POFA cement on Palm oil fuel ash (POFA) cement-based aerated concrete. when the amount of aluminium increased, air bubbles entrapped in the concrete which was expanded, reduced density and compressive strength of the concrete also decreased. When the sand size increased, porosity of the concrete also increased. This study indicated that the POFA developed higher strength in the concrete where the standard portion of aluminium powder and superplasticizers applied.

Mathialagan Sumesh et al, (2019) carried out investigation on mortar by using supplementary cementitious materials such as palm oil fuel ash (POFA), treated palm oil fuel ash (TPOFA), and bottom ash at 0,10,20, and 30 percentage of replacement. Microstructures were analysed. The performance of TPOFA given best result than the other specimen and also Compressive strength was very closer to the conventional specimen at 90days. TPOFA and BA has higher strength and also shown good pozzolanic activity. This paper concluded that the 10 % of replacement will be suitable for high strength mortar.

Dalia Ahmed Mohammed Osman et al, (2020) carried out the investigation by Addition of Zinc oxide nano particles in the raw cement. The percentage of nano particles was 1% to 3%. This study concluded that the 1% of zinc oxide mix shown better performance which improves burnability and reduced required level of temperature up to 1,300°C while production of clinker, reduced energy consumption and greenhouse gases and also achieved design compressive strength.

3. Effect of Tensile Strength

Eshmaiel Ganjian et al, (2015) carried out an experiment on paving blocks to reduce the cement content by addition of run-of-station ash (ROSA), basic oxygen slag (BOS), plasterboard gypsum (PG), ground granulated blast-furnace slag (GGBS), and cement bypass dust (BPD). Various parameters were investigated including skid/slip, Tensile strength, and freeze/thaw resistance. This paper concluded that the addition of OPC/GGBS/BPD can reduce 30% of cement content in the concrete while compare to the other wastes.

P Jaishankar et al, (2005) done the research by adding Aluminium nano particles in the cement concrete. SEM pictures shows that the Aluminium particles acted as filler which uniformly distributed throughout the concrete surface. Therefore, the voids of concrete were very lesser than the conventional specimen. It is also found that the compressive strength and split tensile strength is increased significantly.

4. Effect of Flexural Strength

Solomon Debbarma et al, (2020) investigated on reclaimed asphalt pavement to increase the performance by the addition of supplementary Cementitious materials like fly ash (FA), silica fume (SF), and bagasse ash (BA) instead of cement along with 50 % of reclaimed asphalt pavement. This paper says that the SCM given higher flexural strength

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than the controlled specimen. Silica fume and bagasse ash were good at durability properties like abrasion resistance, sulfate and chloride ions resistance which is very suitable for where the vehicles are moving vey faster.

Antroula V. Georgiou et al, (2018) carried out the research on fiber-reinforced strain-hardening cementitious composites. In this study, Polyvinyl alcohol fibers were used as cementitious material to obtain the deformation capacity which leads to the flexural capacity. Test results explained that the fibres in the tension zone load transferred through bridging thecracks. In the compression zone, lateral expansion was resisted by the fibres, and the result was ductile compressiveresponse. Analytical expressions also derived for strain-hardening cementitious composites and compared with the experimental results. Fig.13 shows definition of specimen rotation θ in shear span & Fig 14 shows stress-strain law under compression and equivalent stress block

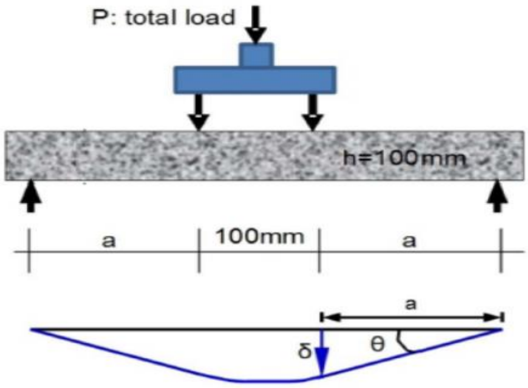

Fig.14. Reference to rotation capacity

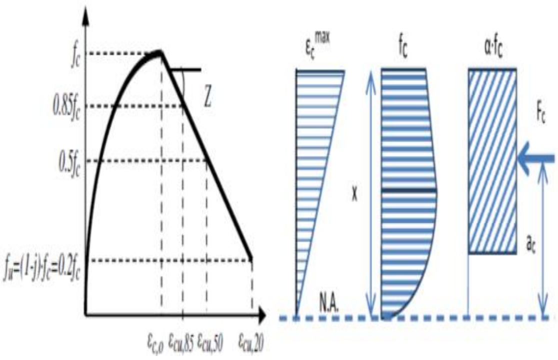

Fig.15. Stress-strain law under compression and equivalent stress block

TABLE 4. RELATION BETWEEN WATER/CEMENTITIOUS MATERIAL RATIO AND AVERAGE COMPRESSIVESTRENGTH OF CONCRETE

Average compressive strength at 28 days, MPa (psi)	Effective water/cementitious material ratio, by mass	
	Non-air entrained concrete	Air entrained concrete
41.4 (6000)	0.41	-
34.5 (5000)	0.48	0.40
27.6 (4000)	0.57	0.48
20.7 (3000)	0.68	0.59
13.8 (2000)	0.82	0.74

Shaikh Faiz Uddin Ahmed (2011) explored his research on mortar by using modified polymer and cementitious materials like polymer, silica fume and slag in mortar. Two parts of mixes were used. Combined silica fume polymer and slag polymer shown good results than the polymer modified mortar alone. Performance of water absorption were good in combined polymer with 40% slag than the combined polymer with 10% silica fume. Compressive strength, flexural strength was higher and lower chloride resistance were predicted in combined polymer with 10% silica fume than the combined polymer with 40% slag. [35]

Rui Liu et al (2012) carried out an investigation on sustainable concrete by using fly ash as cementitious material. Fly ash range was 15 to 60% to satisfy the durability and strength aspect of Colorado Department of Transportation (CDOT) Class D structural concrete. This paper concluded that the 40% range of fly ash satisfied CDOT's required durability and strength. And also, this mixture can reduce the emission of greenhouse gases and embodied energy.

III. Summary of Sustainable Light Weight Structure by Replacing Various Materials below the Neutral Axis

SI .No	Structure Type	Material Replaced	Key Parameter	Key Findings	Authors
1	Concrete Beam	Red Bricks, AAC Blocks, Murrum filled plastic bottles	Flexural strength of an AAC block is 101.36 percent greater than that of a normally cast concrete beam (8.16N/mm2).	30% Volume Reduced by Replacing the Lightweight Materials	Gorde Ajay Jagannath, More Nitin Rajendra, RaundaleVivek Hemant, Sharma Shubham Sunil, Shewale Ganesh Sanjay
2	RC Beam	Aerocon Blocks & Steel Fibres	Steel fibre reinforcement is used in concrete below the neutral axis to boost both, the material's strength and flexural toughness.	The strength of concrete has not significantly decreased. Self-weight of the concrete reduced by Aerocon block. The quantity of steel fibres increased ductility and ultimate flexural strength.	P. S. Aravind Raj, F. S. Frieda, S. P. Sangeetha, R. Divahar
3	RC Beam	Styrofoam	SFC used in this study had a volume proportion of 30% Styrofoam.	Better Ductility Displacement, Slower Crack Propagation, Higher Material	Yasser, Herman Parung, Muhammad W. Tjaronge, and Rudy Djamaluddin

				Elongation	
4	Concrete Beam	Polyethylene balls, PVC pipes,	PVC pipes and polyethylene balls were used to create air spaces.	Reduction of Cost & Volume of concrete	Soji Soman, Anima P
5	RC Beam	plastic bottle	To make the construction lighter, use less concrete and cement, and reduce environmental pollution, the cross-section is filled with plastic bottles.	The height of the hollow core had an impact on the reinforced concrete beam's rigidity. Flexural Capacity same as Conventional beam	S Sariman, R Djamaludin, R Irmawaty, H. Parung
6	RC Beam	Expanded polystyrene sheet	When the sample was submerged in water for 24 hours, EPS sheets absorbed more than 80% of the water, however they quickly regained their properties after drying.	Good flexural capacity, shear cracks only while loading, weightless compared to conventional beam	W.Godwin Jesudhason Dr. G. Hemalatha
7	Concrete Beam	polythene balls	polythene balls used to generate voids at below the neutral Axis	Reduction of Cost & Volume of concrete, Sustainable to society by reduction of CO2	Aswathy S Kumar Anup Joy
8	Concrete Beam	Different Grades of Concrete	M20 grade of Concrete used at tension zone & M25 grade of concrete used at Compression zone	Flexural Behaviour, Crack pattern, Failure mode of partial beam same as normal RCC & economical	B S Karthik, Dr.H.Eramma& Madhukaran
9	Concrete Beam	Seeding Trays& Polythene balls	Comparative Study done between the replacement of seeding trays & Polytene balls	With more replacement, the ductility index decreases. Seeding tray replaced specimens are low cost & good aesthetic appearance than the polythene balls	Basil tom jose, and Divya Sasi
10	RC Beam	PVC Hollow pipe	Analytical validation of the experimental results is performed using the software ANSYS 12.1.	Reduction of Cost & Volume of concrete, can utilize the tension zone without losing its strength	Jain Joy, Rajesh Rajeev

IV. CONCLUSION

The current paper comprises of study on the effect of replacing and reducing the cement in concrete structural elements. Replaced reinforced concrete beams can be used for environmentally friendly and sustainable construction because they conserve concrete, which reduces carbon dioxide emissions during cement manufacture. According to the findings, foamed and lightweight aggregate concrete may be employed in composite construction to enhance the flexural capacity of hollow steel sections. From studies it is evident that cement can be replaced with either 20% fly ash or 25% GGBFS to generate cost-effective laterized concrete. The use of laterite aggregate and mineral admixtures in concrete greatly enhances residual compressive strength at temperatures above 400°C when compared to ordinary concrete.

When polypropylene plastic Sheets were used to replace up to 45% of the reinforced concrete hollow beam below the neutral axis and the results proved to decrease the self-weight of the beam by 21% and increases the deflection of the beam. Silica fume is finer than cement and more reactive to concrete materials, it improves cement consistency and produces more strength in less time than conventional concrete. This contributes towards reduction of cement content in concrete up to 20%. The presence of hollow PVC pipes instead of concrete inthe low stress zone did not cause a significant reduction in the strength of the reinforced concrete beams. The cost and weight reduction of the beams depend on the percentage of concrete replacement. As the length and depth of the beam increases, the concrete consumption is reduced more which leads to saving of cement content utilized. Using lightweight blocks below the neutral axis have not influenced any reduction of strength in concrete, adding additives like fibres have proved to enhance the properties of the concrete and have resulted in less utilization of cement.

It could be concluded that extensive research has been done in replacing with various supplementary cement alternatives and lightweight materials. Replacing the concrete below neutral axis is recommended for the need of wide research which will aid in reducing the concrete in structural elements and reduce the self-weight resulting in huge amount of reduction in cement consumption which will lead to novel potential applications in the field of construction providing an eco-friendly solution to reduce environmental impacts due to high consumption of cement.

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