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RESEARCH ARTICLE

EXPEIMENTAL INVESTIGATION OF REINFORCED RECYCLED AGGREGATE CONCRETE SLAB UNDER STATIC LOADING

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Recycled Concrete aggregate (RCA), Natural coarse aggregate (NCA), Treated Recycled Coarse Aggregate (TRCA), Fine aggregate (FA) ,Yield deflection, cracking moment, toughness index etc.,

ABSTRACT

The main focus of this experimental program is to conserve the natural resource and protection of environmental is the key to sustainable development. The investigation on flexural behavior of reinforced recycled aggregate concrete slabs with natural aggregates (NCA), recycled aggregate (RCA) and treated recycled aggregate (TRCA).Twelve test slab specimens of size 600mm x 600mm x 60mm with fixed end condition and two way slab criteria have been considered with four different concrete matrices of three each for following matrices viz.,(i)S-1:100%NCA (ii) S-2:50%NCA+50%TRCA (iii) S-3:30 % NCA+50%TRCA+20%RCA (iv) S-4:80%NCA+20%RCA .The experimental investigation examines testing of test slab specimen under static loading to determine its first crack load, ultimate load, yield deflection, ultimate deflection, ductility index, toughness index, cracking moment. The investigation indicates encouraging results of RCA and TRCA slab in all respect pointing to recycle aggregate as potential alternative source of aggregates of 21st century. From the experimental results that the test slab specimen S-2 has attained maximum First crack load, ultimate load, ductility Index, Toughness Index, cracking moment and Punching shear strength W.R.T test slab specimen S-3 and S-4.Comparison is made between experimental results and theoretical prediction of the same.

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INTRODUCTION

The deposition of construction garbage which is increasingly accumulated due to various causes such as demolition of old construction is also an environmental concern. In India, the Central Pollution Control Board has assessed that the solid waste generation is about 48 million tones per annum of which 25% are from the construction industry (Zaki I. Mahammud, 2017). This scenario is not so different in the rest of the world. In order to decrease the construction waste, recycling of waste concrete as aggregate is beneficial and effective for preservation of natural resources at the same time minimizing the disposal problems. Under the concept of sustainable construction it is necessary to establish harmonized indicators, standards and methods for assessing the impact of building products and technological processes of the construction industry on the environment. One of the basic commodity that have a significant impact on the environment is construction waste and his recycling options. Concrete aggregate (RCA), which can be made from concrete elements, has a great potential in reducing the volume of landfills and full re-using of concrete rubble.

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The reinforced concrete slabs supported on all its four sides on beams or walls having the ratio of long span less than or equal to 2 are called as two way slabs. The structural action in such slabs is two way. The loads are carried by the slab along short and long span both. The bending moments and deflections in two way slab are considerably less than the one way.

LITERATURE REVIEW

From the critical literature review, various investigators examines Surface treatment, using two slurries containing nanomaterials, was applied to recycled aggregate (RA). It has proved that properties of both RA and RAC on the macroscale were improved by the surface treatment using nanomaterials (Hongru Zhang**,** 2017) recycled aggregates were crushed and soaked in water for 24 hours for water treatment then kept for drying the recycled aggregate soaked with diluted sulphuric, hydrochloric and nitric acids separately and then those aggregates were used for casting of concrete cubes.. The test results showed that the compressive of the recycled aggregate concrete is found to be lower than the natural aggregate. The strength of recycled aggregate concrete can be improved by the water and acid treatments (Goudappa Biradar-2015) the crack width and strains of rectangular one way simply supported steel reinforced concrete slabs by using natural and recycled coarse aggregate under simulated uniform loading. The reinforced concrete (RC) slab specimens of size 1300×600×90mm were cast, M20 grade of concrete with various percentages of steel such as 0.30%, 0.40% and 0.50% were cast. All the twelve slabs were 90mm thick. The investigations indicated encouraging results for RAC slabs in all respects, thus pointing to recycled aggregate as potential alternative source of aggregate of the 21st Century(Dr. B. Madhusudana Reddy,2017).The experimental work was conducted on (6) recycled coarse aggregate concrete (RCAC) slab specimens and (2) natural coarse aggregate concrete (NCAC) slabs. All the slabs were simply supported on four edges and tested under a central patch load. Using 35 MPa grade of concrete were used. Four concrete mix proportions were used with (0%, 30%, 60% and 100%) replacement of natural coarse aggregate with recycled coarse aggregate for each aggregate size.

The test results showed that the first punch crack load, ultimate punch load, stiffness and energy absorption decrease as the replacement of natural coarse aggregate with recycled coarse aggregate increases. Also as the recycled aggregate size increases the cracking and failure load increases (Zaki I Mahammud, 2017).The test slab specimens were tested under displacemet controlled 1000 kN capacity Universal Testing Machine at a loading rate of 6 x 10^{-6} m/sec. They observed from the quasi static loading, exhibited strain hardening to an elongation of 0.15% and a tensile strength of 11 MPa. Multiple crack was observed in the high moment region and final fracture occurred by fibre pull out in one localized bending crack at the centre of the specimen(Katrin Habel et. al.,2006)The experimental campaign has been carried out on 12 specimens. Moreover, three reinforced natural aggregate concrete slabs have been casted and tested as benchmarks. Four replacement percentages (30, 50, 80 and 100%) of coarse recycled aggregates in place of coarse natural aggregates have been considered. The punching shear behavior of simply supported reinforced recycled concrete slabs under a central patch load has been investigated by means of failure patterns, ultimate loads and deflection–load curves. There is no evident reduction in the first crack load with increasing replacement percentage of NCA with RAC. The first crack load of RC slabs for replacement percentages of 30% and 50% is increased by 15% with respect to NC slabs; for an 80% replacement percentage, there is a reduction of 11%, and for higher replacement percentages, the first crack load is very similar to that of NC. The differences between RC and NC slabs in deflection at first crack load reach 10% for replacement percentages until 50% (Lorena Francesconi, 2016). From the detailed literature review it has been concluded that slabs casted using RCA as partial replacement have shown the similar results with that of Controlled specimen slab. Many literature review concentrated on using RCA as a partial replacement and not mentioning about the source of RCA and the surface treatment of RCA in static behaviour of slab and not many of them attempted combination of RCA,TRCA and NCA in the design mix. Hence an attempt has been made in this experimental study to use RCA and TRCA as a partial replacement to that of NCA and with a detailed experimental investigation of reinforced recycled aggregate concrete slab under static loading to determine various parameters such as load deflection curve, ultimate load, cracking moment, crack pattern, ductility index, and toughness index.

EXPERIMENTAL PROGRAM

In the present experimental study, is to utilize recycled concrete as coarse aggregate for the production of concrete as a sustainable development in the construction industry. It is essential to know the optimization % of replacement of RCA to NCA for cement concrete and optimization % of replacement of TRCA to NCA for cement concrete, many trial mixes of M-25 grade of concrete mixes were done to fix the combination of different % replacement of RCA and TRCA with NCA. The following matrices viz., (i)S-1:100%NCA(conventional concrete of grade M-25) (ii) S-2:50%NCA+50%TRCA (M-25 grade concrete made using 50% natural coarse aggregate and 50 % treated recycled concrete aggregate) (iii) S-3:30 % NCA+50% TRCA+20%RCA (M-25 grade concrete made using 30% natural coarse aggregate, 50% treated recycled concrete aggregate and 20% recycled coarse aggregate) (iv) S-4:80%NCA+20%RCA (M-25 grade concrete made 80% natural coarse aggregate and 20% recycled coarse aggregate)has been considered to cast the test slab specimen as shown in table-1. For the above mixes (table-1) thetest slab specimens were casted and tested to study the flexural behavior of slab under static loading to experimentally determine various parameters such as first crack load, ultimate load, yield deflection, ultimate deflection, ductility index, toughness index and cracking moment.

Materials Used: In this experiment, Birla super Portland cement 53grade was used, to ascertain the physical characteristics of the cement, tests were conducted in accordance with the Indian standards confirming to IS-12269:1987. Manufactured sand (M-sand) was used. The tests on the fine aggregate were conducted in accordance with IS 2386 Part 1 to Part 4-1964 (Reaffirmed-2011) to determine Specific gravity, Bulk density and Fineness modulus. Crushed angular natural coarse aggregate (NCA) of 20 mm down size has been used as coarse aggregate. Recycled concrete aggregate (RCA) of angular size 20 mm down size brought from rock crystals (Kerala crushers), Chikkajala, Bengaluru, has been used in this experiment. The sieve ana1ysis of combined aggregates confirms to the specifications of IS 383: 2016 for well graded aggregates. The tests on thecoarse aggregate were conducted in accordance with IS 2386 Part 1 to Part 4-1963 (Reaffirmed- 2011) to determine Specific gravity and Bulk density. Nitoflor Lithurin (basically mixture of Sodium silicate and Lithium silicate) was used to surface treat the recycled concrete aggregate to enhance its properties of RCA to obtain Treated Recycled Concrete aggregate (TRCA). Ordinary potable water was used for mixing and curing purposes.

Table 1. Designation of Test Slab specimens

Design Mix	Designation Test Specimen	Mix Proportion
MIX-1	SLAB-1: S-1	100% NCA
MIX-2	SLAB-2: S-2	50%NCA+50%TRCA
MIX-3	SLAB-3: S-3	30%NCA+50%TRCA+ 20%RCA
MIX-4	SLAB-4: S-4	80%NCA+20%RCA

Mix proportion: A concrete mix grade of M-25 was aimed in the present experimental investigation, the design mix proportion was obtained as per IS10262:2000 Method. Based on the same the target strength for M-25 was achieved for various % of replacement of NCA with RCA and TRCA were arrived. The mix proportion to cast test slab specimen are shown in table no 2.

Table 2. Materials required for respective test Slab specimen

Mix	cement	Fine aggregate	Coarse aggregate	Treated RCA	RCA	w/c	water
Test specimen	kg	kg	kg	kg	kg		kg
S-1	10.78	20.71	32.84	-	-	0.49	191.58
S-2	10.78	20.71	16.87	15.97	-	0.49	191.58
S-3	10.78	20.71	11.19	15.97	5.68	0.49	191.58
S-4	10.78	20.71	27.16	-	5.68	0.49	191.58

Casting of Test Slab Specimens: Individual materials were batched in an electronic weighing balance. The materials were properly mixed in mixer. Firstly, the aggregates and cementitious materials were mixed randomly in the dry state. The whole dry mixture is then mixed for 5 minutes. Steel prefabricated formworks were used for casting the slab specimens. The reinforcement mesh was then placed in the formwork, taking care to provide the required clear cover on the bottom and sides. The slabs were casted with the help of hand trowel and Pick-Mattock. Electrical Needle vibrator of 25 mm diameter was used for proper consolidation of the concrete. Mould was filled with concrete then the mould was fully compacted by tamping. Sufficient care was taken to see that concrete was properly filled in corners and the edges of the mould. As soon as the air bubbles stopped to rise, the top surface of the mould was finished with trowel by applying little pressure till the lattice layer appears. Total twelve test slab specimens are named sequentially as shown in table no. 1, were casted. After 24 hours, test specimens were de-moulded and were cured continuously for 28 days in water tanks. Details of test slab specimens are shown in table no.3

Table 3. Details of Test Slab Specimen

Thickness (mm)	60
Dimension of slab (mm)	600 x 600
Main Steel (dia in mm)	8
Distribution steel (dia in mm)	8
Spacing (mm)	90 mm c/c

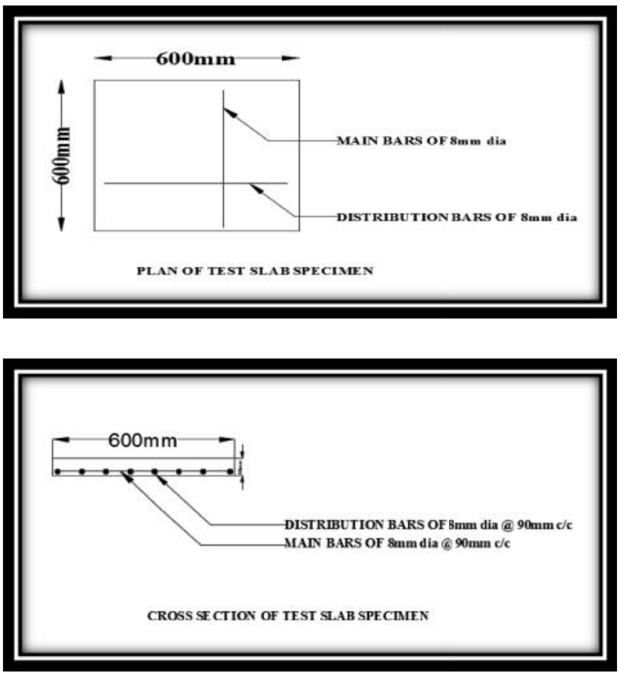


Figure 1. Plan and C/s of Test Slab Specimen

Experimental setup: Static testing machine which is used in the present investigation is fabricated and installed at Department of Civil Engineering Bangalore University, Bengaluru. It is a manual operated hydraulic jack system and was rigidly fixed to a RCC pedestal foundation to a height of 0.3 m above ground level and the pedestal was extended up to 0.7 m giving it total height of 1 m, to which a frame of height 2.5 m fabricated with I-sections of ISMB 250 and is mounted. The loading assembly is supported vertically by a horizontal I-section of ISMB 250. The test slab specimens were rested upon I-sections of square frame of 600 mm x 600 mm which was made up of ISHB 160 that it rests upon the pedestal. For static testing of the test slab specimens fixed edge condition are considered. Two C-clamps on each side of the specimen was fixed to frame to obtain the required end condition. Since the study is mainly aimed at evaluation of static response due to load, as also the cumulative effect of such loading on the concrete slab elements. The detailed view of the static testing machine is shown in Figure 2.

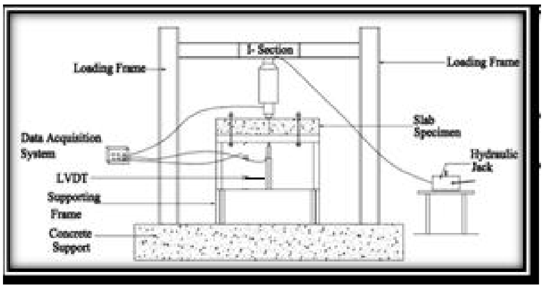


Fig 2. Static Test Setup

RESULT AND DISCUSSION

RESULTS OF TEST SLAB SPECIMENS

The test was conducted at the structural laboratory of UVCE, Civil Engineering Department, Bangalore University, Bengaluru, the results of test slab specimens under monotonic loading until ultimate stage was conducted to investigate:

- Load Deflection Behavior
- First Crack Load
- Ultimate Load
- Variation of slope of linear trend within load – deflection curve
- Deflection variation
- Ductility index
- Energy absorption capacity
- Toughness index
- Cracking moment
- Punching Shear
- Crack pattern

Results of load deflection curve (P- δ curve): Deflection is one of the important serviceability limit states to be satisfied in the design of concrete structures. A significant overall property of a structural member is its response to load which is completely described by load deflection relationship. The combined load deflection behavior of all test slab specimen as shown in Figure 7

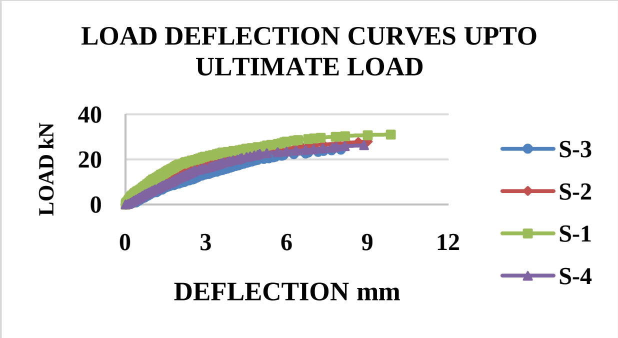
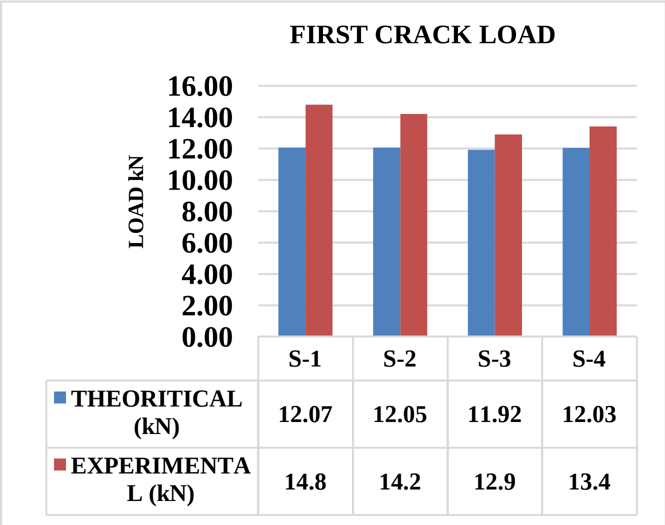


Figure 3. Load Deflection Curve up to Ultimate load

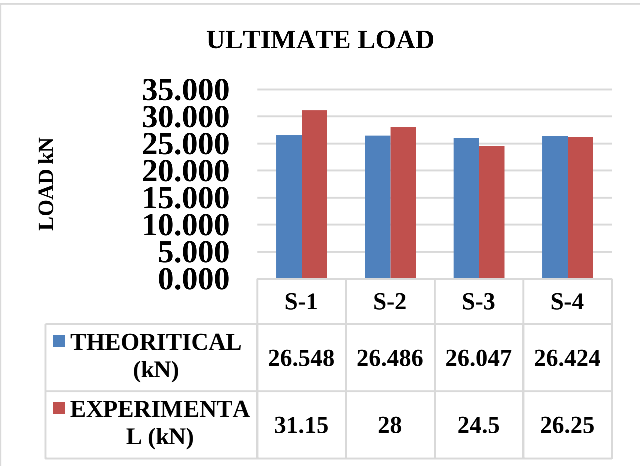
First crack load: The experimentally obtained values of first crack load for S-1 is 14.8 kN whereas for S-2, S-3 and S-4 are 14.2 kN, 12.9 kN and 13.4 kN respectively. It is observed that from experimental results, first crack load for other slabs as achieved up to 95.94%, 87.16%, and 90.54% with respect to control slab S-1.



	S-1	S-2	S-3	S-4
THEORITICAL (kN)	12.07	12.05	11.92	12.03
EXPERIMENTAL (kN)	14.8	14.2	12.9	13.4

Figure 4. Comparison of Experimental and Theoretical values of First Crack Loads

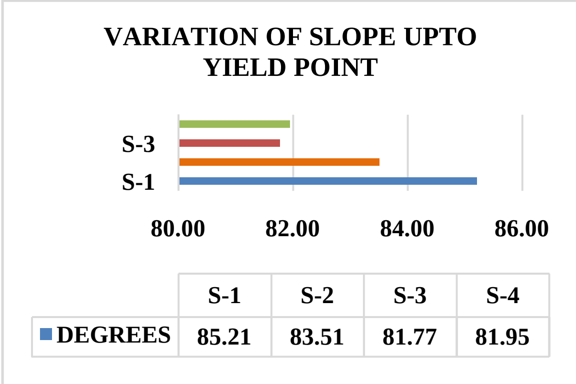
Ultimate Load: The experimentally obtained values of ultimate Load for S-1 is 31.15 kN whereas for S-2, S-3 and S-4 are 28kN, 24.5 kN and 26.25 kN respectively. It is observed that from experimental results, ultimate load for other slabs are achieved up to 89.88%,78.65% and 84.26% with respect to control slab S-1.



	S-1	S-2	S-3	S-4
THEORITICAL (kN)	26.548	26.486	26.047	26.424
EXPERIMENTAL (kN)	31.15	28	24.5	26.25

Figure 5. Comparison of Experimental and Theoretical values of Ultimate Loads

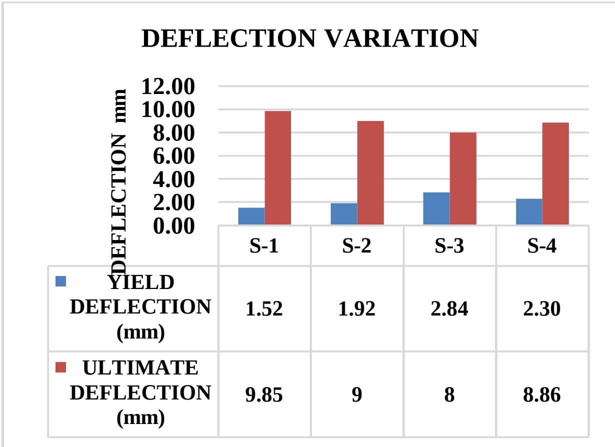
Variation of slope of linear trend within load deflection curve: The experimentally obtained values of Variation of slope of linear trend within load deflection curve for S-1 is 85.21 whereas for S-2, S-3 and S-4 are 83.51, 81.77 and 81.95 respectively.



	S-1	S-2	S-3	S-4
DEGREES	85.21	83.51	81.77	81.95

Figure 6. Variation of slope of linear trend within load deflection curve

Deflection variation: The experimentally obtained values of yield deflection for S-1 S-2, S-3 and S-4 are 1.52, 1.92, 2.84 and 2.30 mm whereas ultimate deflection for S-1, S-2, S-3 and S-4 are 9.85, 9, 8 and 8.86 mm respectively.

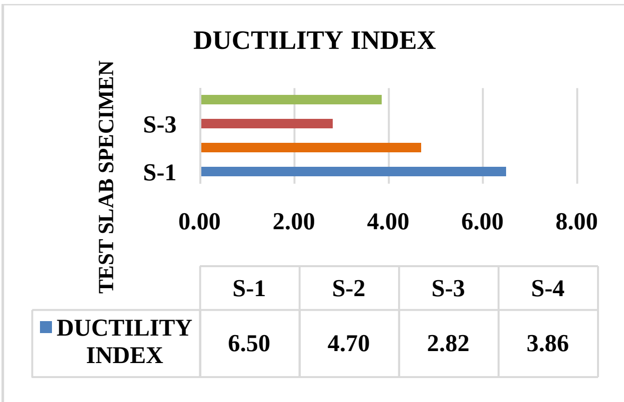


	S-1	S-2	S-3	S-4
YIELD DEFLECTION (mm)	1.52	1.92	2.84	2.30
ULTIMATE DEFLECTION (mm)	9.85	9	8	8.86

Figure 7. Deflection Variation

Ductility Index: To determine the ductility index as obtained from load v/s deflection to evaluate maximum flexural strength and minimum occurrence of cracking, by using equation below.

Ductility factor (μ_d) = $\frac{U \quad D}{D \quad a \; f \quad c}$



	S-1	S-2	S-3	S-4
DUCTILITY INDEX	6.50	4.70	2.82	3.86

Figure 8: Ductility Index

From the results it can be seen that Ductility is achieved w.r.t S-1 by 72.30%, 43.38%, and 59.38 % for S-2, S-3 and S-4 test slab specimens respectively.

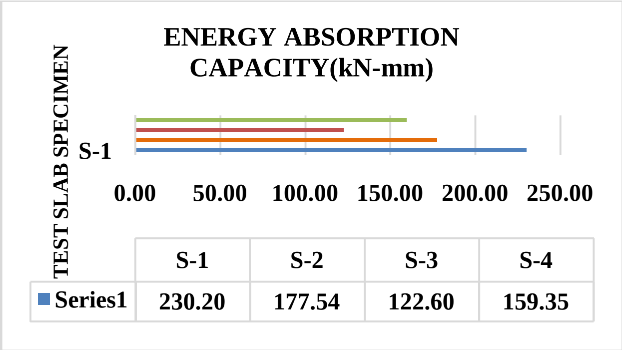


Figure 9. Energy Absorption Capacity

Energy Absorption Capacity: The area under the P-δ curve considered in this study consists of the area under the ascending portion up to the peak load under descending portion up to the load under descending portion up to 0.80 $P_{u.}$ The experimentally obtained values of Energy absorption capacity S-1, S-2, S-3 and S-4 concrete test slab specimens are 230.20 kN-mm, 177.54 kN-mm, 122.60 kN-mm, and 159.35 kN-mm respectively.

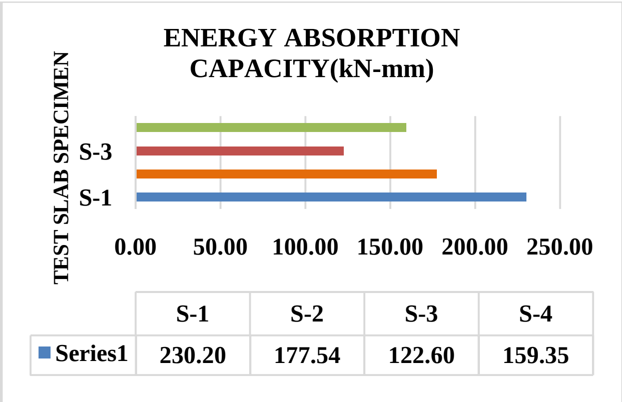


Figure 10. Energy Absorption Capacity

It is observed from that from experimental results, energy absorption capacity for S-2,S-3 and S-4 has been achieved up to 77.12%, 53.25%, 69.22% respectively with respect to S-1.

Toughness Index: The area obtained from the load deflection curve with 80% of post peak load as cut off point was divided by the area computed up to the first crack load, and this is termed as Toughness Index.

$$\text{Toughness Index} = \frac{\text{Area under the post peak load deflection curve up to } 0.8P_u}{\text{Area up to first crack load}}$$

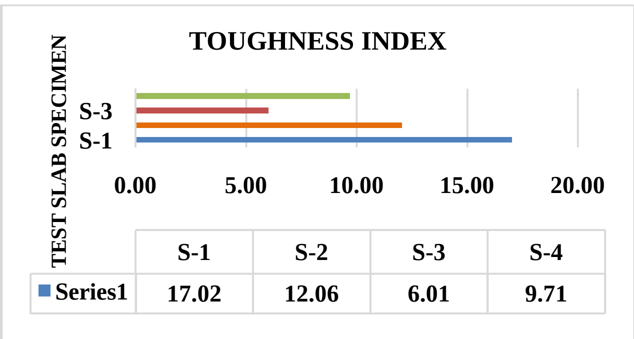


Figure 11. Toughness Index

From the results it can be seen that toughness is achieved w.r.t S-1 by 70.85%, 35.31%, and 57.05% for S-2, S-3 and S-4 test slab specimens respectively.

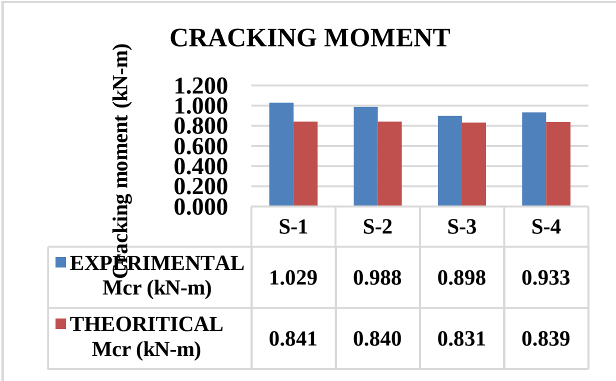


Figure 12. Comparison of Experimental and Theoretical values of cracking moment

Table 4. Comparison of Experimental Punching Shear values with standard codes of Practice

Slab Designation	Ultimate Punching shear loads in P_u kN			Exp. / IS:456 - 2000	Exp/ACI 318 – 2005
	Experimental values	IS:456-2000	ACI 318-2000		
S-1	31.15	26.55	31.53	1.17	0.99
S-2	28.00	26.49	31.46	1.05	0.89
S-3	24.50	26.05	30.94	0.94	0.79
S-4	26.25	26.42	31.39	0.99	0.84

Cracking Moment: The experimentally obtained values of cracking moment for S-1 is 1.029 kN-mm whereas for S-2, S-3 and S-4 are 0.988 kN-mm, 0.898 kN-mm and 0.933 kN-mm respectively. It is observed that from experimental results, cracking moment for other Slab is 96.01%, 87.26% and 90.67% with respect to control slab S-1.

Punching shear strength: Punching shear is a type of failure of reinforced concrete slabs subjected to high localized forces. In slab structures this occurs at column support points. The failure is due to shear. This type of failure is catastrophic because no visible signs are shown prior to failure. The Punching Shear for different concrete matrices are computed using IS 456:2000 and ACI 318-2000 codal provisions. The experimentally obtained values of ultimate punching shear strength are compared with the results of above said codal provisions and are tabulated in table 6-13. The experimental ultimate punching shear load (P_u) and the predicted value of Punching Shear (P_u)using specified codal provisions IS:456-2000 and ACI 318-2000 are tabulated in Table no. 6-13 From this table it can be seen that, the experimentally observed values for S-1,S-2,S-3 and S-4 are achieved up to 117 %, 105%, 94 %, 99% as per IS code procedures and 99%, 89%, 79%, 84% as per ACI code procedure respectively

Crack Pattern: Cracks on the tension surface were concentrated along the diagonals, extending radially from the loading point (centre) towards the edges of the specimen. With the increased loading, newer cracks were developed along the middle axes and cracks were widely spread on tension surface as clearly seen in Figure below.

As expected, specimen failed by punching. The circular load cells punched suddenly through the specimen and slight scabbing and circular wide cracks were observed around the centre on tension surface as a result of the punching. The number of cracks developed for S-1,S-2, S-3 and S-4 are 12,14,18 & 16 respectively.

Conclusion

The experimentally obtained values of the compressive strength at 28 days for Mix 1 concrete is 31.70 N/mm^2 whereas for Mix 2, Mix 3 and Mix 4, the compressive strength is found to be 31.56 N/mm^2, 30.52 N/mm^2 and 31.41 N/mm2 respectively which is more than the target strength calculated as per IS 10262-2009. It is observed that from experimental results, compressive strength for Mix 2, Mix 3 and Mix 4 has achieved 99.56%, 96.27% and 99.08% of Mix 1(control Mix) strength respectively. It is experimentally evident that compressive strength of MIX 2 has been significantly achieved 99.56% of strength in comparison with MIX 1(control Mix) concrete.

It is observed that from experimental results, first crack load for other slabs as achieved up to 95.94%, 87.16%, and 90.54% with respect to control slab S-1.It is experimentally evident that for test slab specimen S-2, first crack load has been significantly achieved up to 95.94 % in comparison with S-1(Control Specimen). It is observed that from experimental results, ultimate load for other slabs are achieved up to 89.88%,78.65% and 84.26% with respect to control slab S-1.It is experimentally evident that for test slab specimen S-2 ultimate load has been significantly achieved up to 89.88% in comparison with S-1(Control Specimen). The ductility index of S-1, S-2, S-3 and S-4 concrete test slab specimens are 6.50, 4.70, 2.82 and 3.86 respectively. Ductility is achieved w.r.t S-1 by 72.30%, 43.38%, and 59.38 % for S-2, S-3 and S-4 test slab specimens respectively. It is observed that the Ductility Index for S-2 is achieved higher value w.r.t S-1(Control Specimen) than all other concrete matrices.

The experimentally obtained values of Energy absorption capacity S-1, S-2, S-3 and S-4 concrete test slab specimens are 230.20 kN-mm, 177.54 kN-mm, 122.60 kN-mm, and 159.35 kN-mm respectively. It is observed from that from experimental results, energy absorption capacity for S-2,S-3 AND S-4 has been achieved up to 77.12%, 53.25%, 69.22% respectively with respect to S-1.It is experimentally evident that for S-2's Energy absorption capacity has been significantly achieved up to 77.12% in comparison with S1(Control Specimen) test slab specimen. The toughness index of S-1, S-2, S-3 and S-4 concrete test slab specimens are 17.02, 12.06, 6.01 and 9.71 respectively. Toughness is achieved w.r.t S-1 by 70.85%, 35.31%, and 57.05% for S-2, S-3 and S-4 test slab specimens respectively. It is observed that the Toughness Index for S-2 is achieved higher value w.r.t S-1 than all other concrete matrices.

The experimentally obtained values of cracking moment for S-1 is 1.029 kN-mm whereas for S-2, S-3 and S-4 are 0.988 kN-mm, 0.898 kN-mm and 0.933 kN-mm respectively. It is observed that from experimental results, cracking moment for other Slab is 96.01%, 87.26% and 90.67% with respect to control slab S-1.It is experimentally evident that for S-2 cracking moment has been significantly achieved up to 96.01% in comparison with S-1(Control Specimen). The experimental ultimate punching shear load (P_u) and the predicted value of Punching Shear (P_u)using specified codal provisions IS:456-2000 and ACI 318-2000 are tabulated in Table no. 6-13 From this table it can be seen that, the experimentally observed values for S-1,S-2,S-3 and S-4 are achieved up to 117 %, 105%, 94 %, 99% as per IS code procedures and 99%, 89%, 79%, 84% as per ACI code procedure respectively.

It is evident from the experimental results that test slab specimen S-2 has attained maximum, First crack load, ultimate load, ductility Index, Toughness Index, cracking moment and Punching shear strength w.r.t test slab specimen S-3 and S-4.

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