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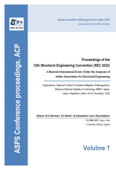

Effect of plastic strips on elastic properties of concrete under cyclic loading

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Abstract

Heterogeneous characteristics of concrete with variation in strength of matrix, aggregate and interface causes non-uniform distribution in stress. Reinforcing concrete alters this distribution and can be designed to reduce non-uniformity. Present study investigates applicability of plastic strips as reinforcement to improve performance of concrete. Since plastic strips are strong in tension, they are oriented to control tensile stress generated in concrete. The approach adopted contributed to increment in compressive strength of fibre reinforced concrete. In comparison with conventional concrete, fibre reinforced concrete has higher but delayed compressive strength, lower initial stiffness and higher energy absorption capacity. In order to assess impact of plastic strips on fundamental properties like Young's modulus and poisons ratio, cylindrical samples with radially oriented plastic strips are subjected to cyclic loading. Poisson's ratio is computed by measuring axial and lateral deformation in the sample. To compute Young's modulus, axial deformation is measured along the gauge length. Response of conventional and fibre reinforced concrete is measured for both loading and unloading cycles considered. In comparison with conventional concrete, fibre reinforced concrete reflects higher axial deformation but the lateral deformation is restrained. This contributes to lower Poisson's ratio for fibre reinforced concrete. Reduction in lateral deformation of fibre reinforced concrete is an effect of confinement generated by plastic strips. The presence of confinement effect reduces net stress acting at a material point thus increasing compression capacity of concrete. Further, Young's modulus of fibre reinforced concrete decreases in comparison with conventional concrete. This is due to softening effect of plastic strips in axial direction. However, progressive increment in loading causes substantial degradation in young's modulus of conventional concrete whereas for fibre reinforced concrete it remains largely stable. Similar stability in also response is reported for poisons ratio. The present study thus establishes role of plastic strips in developing confinement effect contributing to improved performance and predictability in response of strength and material parameters namely Young's modulus and poisons ratio.

Keywords: PET Concrete, cyclic loading, poisons ratio, elastic modulus, confinement effect

1. Introduction

Concrete is inherently heterogeneous on account of its material composition. This heterogeneity in its behaviour is also reflected in terms of response namely peak strength and stress strain behaviour. The large scatter in strength or stress strain response, which is accepted as characteristic feature of concrete behaviour compels usage of high safety factor. This reduces the efficiency in usage of materials and contributes to increased exploitation of natural resources. Attempts at improving this behaviour and extend applicability of concrete has led to development of reinforced cement concrete, fibre reinforced concrete or confined concrete. The development of reinforced concrete was targeted at imparting tension capacity to the resulting concrete. Fibre reinforced concrete or confined concrete on the other hand was aimed at improving the compression behaviour. Application of discrete fibre reinforced concrete contributed by arresting microcracks whereas confined concrete resisted lateral expansion and in process developed confinement stress that partly negated the effect of heterogeneity and improved peak strength and also the stress strain capacity. This improvement in behaviour is quantified in terms of its effect on fundamental elastic properties like elastic modulus and poisons ratio.

Lofgren (2005) investigated crack development for discrete fibre reinforced concrete (FRC) and correlated development and progression of cracks with the evolution of stress strain curve [1]. The study identified that the multiscale progression of cracks can be arrested by providing fibres homogeneously dispersed in the sample. Since crack progression is identified as multiscale phenomenon, it was recommended that provision of wide geometry of fibres will be beneficial. Dopko (2018) has reported fibre geometry in terms of aspect ratio thus classifying high aspect ratio fibres as microfibers, and low

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aspect ratio fibres as macrofibres [2]. Fibres with aspect ratio of 180 or less classified as macro fibres was observed to bridge cracks and contribute to stress transfer. Application of discrete fibres in foamed and light weight concrete has also reportedly contributed to improvement in mechanical performance [3- 7]

Passive confinement development due to embedded reinforcement that generates reaction to restrict lateral expansion thereby contributing to development of confinement [8]. They referred this form of confinement due to reaction of reinforcement as passive. Mirmiran and Shahawy (1997) have observed that restraining lateral deformation by active or passive confinement improves strength and ductility of concrete [9]. Further, restraining element (reinforcement) is ineffective till strain is induced in the element. Confining pressure is generated and increased with increase in strain of restraining element. Naaman (2003) has reported that for effective contact between fibre and the surrounding matrix, poisons ratio and the coefficient of thermal expansion of fibre must be comparable with that of cement matrix [10]. Also, fibre reinforced concrete exhibit better bond slip behaviour than plain concrete with fibres contributing to reduced crack width. However, presence of micro-cracks increases with increasing proportion of fibres [11].

Gao et al. (1997) has reported that for steel fibre reinforced light weight concrete poisons ratio decreases with increase in proportion of fibres [12]. The decrement in poisons ratio in comparison to unconfined concrete is attributed to confinement effect that decreases lateral deformation of concrete. The study also highlighted that a lower value of Poisson's ratio for fibre reinforced concrete as compared to unreinforced concrete, is an indication of confinement induced by fibers within concrete, which reduces the lateral deformations of concrete specimen. Scott et al. demonstrated that continuous reinforcing of concrete with steel hoops exhibit delayed but higher peak strength and post-peak ductile behaviour in comparison with its unconfined counterpart. Bjerkeli et al. (1990) through their studies on continuously reinforced axial columns inferred that the stress strain response for confined concrete column is influenced by reinforced ratio, compressive strength of concrete and the geometry of the member [13]. Michaluk et al. (1998) demonstrated that the performance of steel reinforced, glass fibre reinforced polymer (GFRP) concrete and carbon fibre reinforced polymer (CFRP) concrete slab observed that performance of fibre reinforced polymer (FRP) concrete is comparable with steel reinforced concrete and is sufficiently ductile as they provide adequate warning (deep and wide cracks) prior to failure [14]. Studies on the influence of PET strips macro-reinforced concrete demonstrated effectiveness of PET strips in controlling heterogeneity in stress strain response. Further, the confinement provided by PET strips contributed to increment in compressive strength of resulting concrete [15].

The behaviour of confined and unconfined concrete under cyclic loading is also investigated by many researchers with a view to understand hysteretic behaviour and damage tolerance capacity of confined concrete. Swamy (1976) based on his extensive experimentation suggested unconfined concrete undergoes permanent residual strain at lower stress levels [16]. He also confirmed that energy lost during loading phase is lower than that of unloading phase. The increment of energy lost during unloading is attributed to frictional damping between damaged surfaces. The energy lot during each cycle or hysteretic loss was observed to increase with increase in stress and is influenced by rate of straining, stress strain capacity at peak stress. Imran et al. (1997) studied unconfined concrete behaviour under cyclic loading conditions and identified rapid degradation of elastic stiffness under cyclic loading conditions [17]. The degradation in material behaviour was observed to be function of path whereas peak strength was independent of it. Fadadu et al. (2020), investigated damage tolerance capacity of PET macro reinforced concrete with plain concrete and reported substantial increase in damage tolerance capacity

The synthesis of research above suggests capacity of confinement to influence capacities in tension, compression and flexure. Further, the material properties namely elastic modulus and poisons ratio are also influenced by confinement. However, the extent of confinement developed depends on the method of confinement, reinforcement ratio, grade of concrete and material geometry. Similar studies on cyclic loading suggested improved behaviour of confined concrete. However, studies on cyclic behaviour of confined concrete is limited. Given the improved response of PET concrete under monotonic loading, it is apparent to analyse its behaviour under cyclic loading conditions. Thus, the present study investigates impact of cyclic loading of conventional and PET concrete on material degradation measured in terms of elastic modulus and poisons ratio. For the present study, PET strips are oriented perpendicular to direction of loading.

2. Methodology of Experiment and Analysis Procedure

2.1 Experimental Investigations

Experimental work for the present study considers M40 grade concrete designed as per recommendation of Indian Standard code (IS 10262). A comparative PET macro-reinforced concrete is equivalent of conventional concrete (CC) except for the presence of PET strips that are oriented perpendicular to the loading direction. The mix proportioning of ingredients namely cement sand and coarse aggregates is respectively in the ratio of 1:1.35:2.4. The water cement ratio adopted for the mix is 0.4. The properties of ingredients chosen have been determined in accordance with the recommendations of Bureau of Indian standards (BIS) and ASTM code [IS 383-1970 (1997); IS 8112 (2013); ASTM C33 (2003); ASTM C150 (2007)] and the results are presented in Table 1. The fine aggregates used correspond to zone-III whereas the maximum nominal aggregate size used is 20 mm as per recommendations of BIS and American Concrete Institute (ACI) code [IS 2386-Part 1 (1963); ACI 318 (2014)]. For PET concrete, plastic strips used as macro-reinforcements are derived from used PET bottles. Before stripping, the bottles have been cleaned free of dirt and dust and the truncated part of the bottle has been discarded. The shredding of bottles in the longitudinal direction is done to obtain strips that are approximately 150 mm long, 6 mm wide. The thickness of strips is same as bottle thickness i.e., about 0.2 mm. For cube specimens, the arrangement of PET strips is done with a spacing of 2.5 cm c/c in horizontal direction and for vertical direction, spacing of 2 cm is maintained. In case of cylindrical specimen, the PET strips are arranged in radial pattern with strip length of 7 cm (45^0 apart). Figure 1 depicts the arrangement of PET strips in cube and cylindrical specimen. For representation, the conventional concrete is designated as CC and PET strips modified concrete as PET concrete. In order to prevent agglomeration of PET strips or formation of lumps near its ends, the PET strips have been added after mixing, prior to vibration stage. The specimen demoulding is done after 24 hours of casting. Curing for all samples is done at room temperature in a water curing tank for 28 days. Testing of all samples is done at the end of 28days curing period.

For cube specimens 150mm in dimension, monotonic loading is applied whereas for cylindrical specimen 150mm diameter and 300 mm long, cyclic loading is applied. The stress strain behavior for cube specimens of CC and PET concrete is obtained by performing displacement controlled loading tests. For cylindrical samples, cyclic loading is performed in stages. Each stage of cyclic loading is decided based on pre-peak portion of the stress strain curve. The obtained results are evaluated for variation in Poisson's ratio, relaxation in stress-strain modulus during loading and unloading.

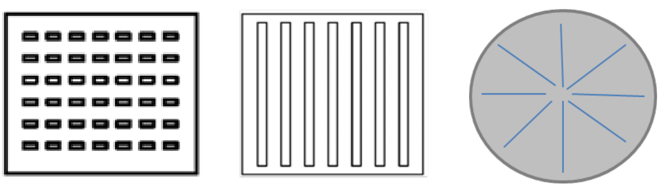
Note: P=80% of the average load of respective cube specimens, P=990 kN for CC and P=1116 kN for PET concrete

2.2 *Procedure for determination of elastic modulus and poisons ratio*

To study behaviour under cyclic loading and associated degradation in material properties, the pre-peak response of stress strain curve obtained for cube specimens is partitioned

Table.1: Specification of material constituents

Property	Value
Portland Pozzolana Cement	
Soundness	1mm
Consistency	37%
Aggregates	
Specific gravity of coarse aggregates	2.98
Specific gravity of fine aggregates	2.54
Grading of fine aggregate	Zone III as per IS 383 (1970)

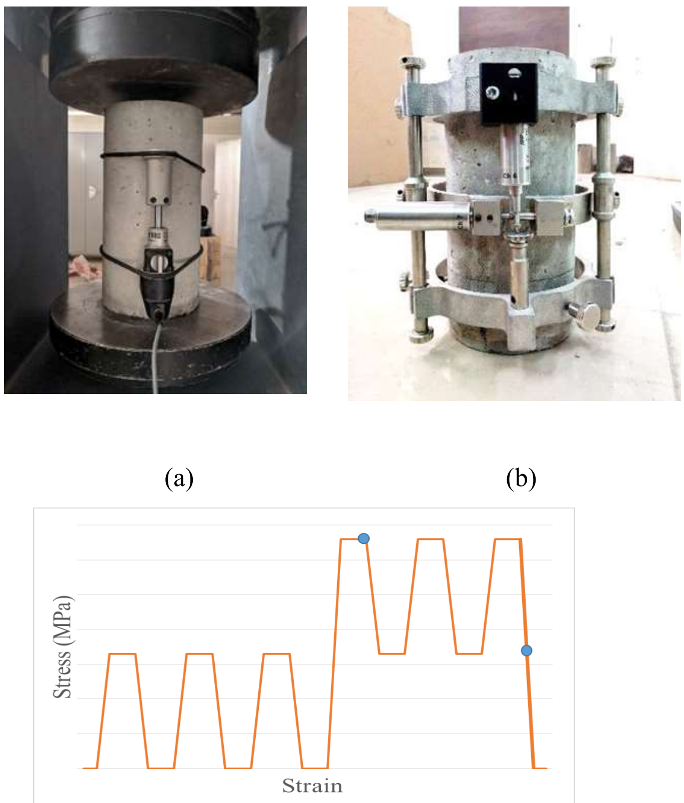


(a) Front view (b) Plan view (c) Plan view

Fig. 1. Geometric layout of PET strips for cube and cylindrical specimens

into four parts. The average of stress-strain response over six samples each of CC and PET concrete have been considered representative. Equivalent cylindrical strength is adopted as 80% of cube strength. The cyclic loading is then applied in four stages as detailed in Table 2. The elastic modulus during loading and unloading phase (Elm and Eulm, respectively) and Poison's ratio at each loading stage is determined by employing procedure outlined in ASTM C469 / C469M – 14 (2014). Figure 2(a) shows the assembly for determination of elastic modulus whereas Figure 2(b) indicates assembly for determination of poisons ratio. Provision of displacement transducer along axial and radial direction allows simultaneous mapping of axial and lateral deformation. Figure 2(c) represents pre-loading and loading cycles followed for each loading stage. The slope from beginning of first unloading curve (indicated with blue tick) and the last point of three unloading curve (indicated with blue tick) is used to evaluate elastic modulus for that stage.

For cyclic loading in stage-I, specimen is first subjected to three pre-loading cycles followed by three loading cycles. The pre-loading cycles have lower limit '0' and upper limit $\frac{P}{6}$. Three loading cycles preceding pre-loading cycles are applied with load range from $\frac{P}{6}$ to $\frac{P}{3}$. At peak load, the load is held for 10s before initiating unloading. Subsequently, similar procedure is for cyclic loading with load range $\frac{P}{4}$ to $\frac{P}{2}$ corresponding to stage-II, stage-III and stage-IV or failure whichever is earlier. The upper and lower bounds of load for each stage of loading is shown in Table.2



(a) (b)

(c)

Fig.2: Setup for determination of (a) elastic modulus (b) poisons ration and (c) typical load history for cyclic loading

Table.2: Cyclic loading stages for determination of elastic modulus and Poisson's ratio

Loading stage	Stage-I	Stage-II	Stage-III	Stage-IV
Lower load limit	P/6	P/4	3.5P/10	4.5P/10
Upper Load Limit	P/3	P/2	7P/10	9P/10

3. Results and Discussion

3.1 Stress strain response for CC and PET concrete

To account for heterogeneity and capture representative response, six specimens each of CC and PET concrete have been tested under uniaxial compression loading. The mean and standard deviation values of peak strength obtained for CC and PET concrete workout to be (56 MPa, 3.84 MPa) and (62.5 MPa, 2.2 MPa) respectively. The representative stress strain response obtained as average of response over six samples is shown in Figure.3.

Comparing CC and PET concrete response at lower stress exhibits stiffer response for CC than PET concrete. However, CC concrete for increasing stress values indicate non-linear softening behaviour whereas PET concrete has more linear behaviour. For higher stress values this results into more stiffened response for PET concrete than CC. Also, continued softening exhibited by CC causes early arrival of peak stress and thus its capacity is lower than that of PET concrete. Also, the point of arrival of peak load for PET concrete is slightly delayed than CC concrete. The post-peak response for CC and PET concrete are qualitatively similar but higher failure stress contributes to higher strain energy of PET concrete. In pre-peak portion difference in continued softening behaviour of CC and linear response of PET concrete indicates role played by PET strips in bridging cracks and effective stress transfer between cracked surfaces.

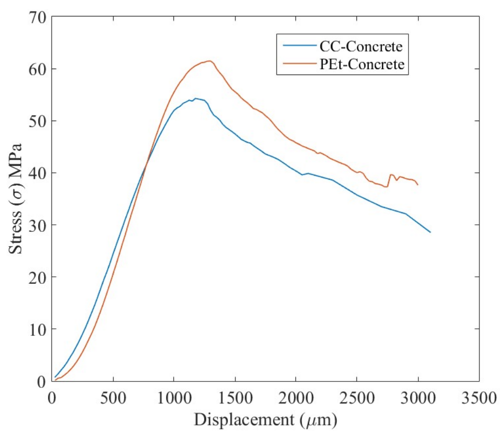
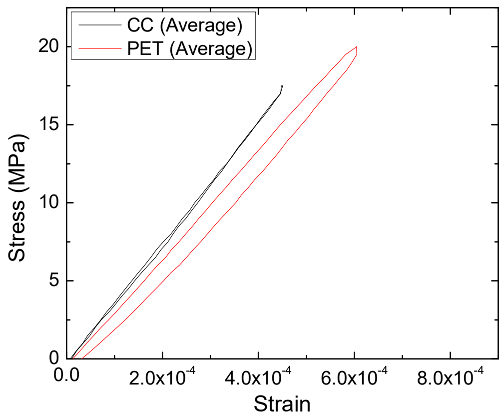


Fig.3: Average stress strain response of CC and PET concrete

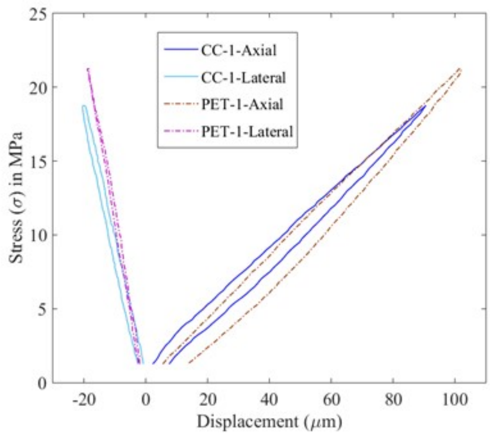
3.2 *Hysteretic Stress-strain response of CC and PET concrete under cyclic loading (Cylindrical specimens)*

The cylindrical specimens of CC and PET concrete subjected to cyclic loading as applied in four stages discussed earlier is analysed to evaluate the evolution of elastic modulus and poisons ratio. Since setup for determination of elastic modulus and poisons ratio is different, first the load history is applied on the sample mounted with elastic modulus setup. Then, the elastic modulus setup is replaced with Poisson's ratio setup and the loading history is repeated. The average response obtained for elastic modulus and poisons ratio setup for stage-I loading is shown in Figure 4(a) and Figure 4(b). The average response for CC is computed over four samples and for PET concrete it is computed over five samples. One sample of CC failed during loading stage and hence its response is not included in the figure.

It can be observed that for stage-I loading, elastic modulus setup exhibits stiffer response for CC than PET concrete. Further, loading-unloading response for CC is identical indicating no accumulated damage in the material. In comparison, PET concrete has softer response with distinct loading and unloading curve implying damage accumulation from stage-I loading itself.



(a)



(b)

Fig.4: Average response of CC and PET concrete at stage-I loading for (a) Elastic modulus and (b) Poisson's ratio

For stage-I loading with Poisson ratio setup, response of CC is still stiffer than PET concrete. However, the loading and unloading paths of CC are no longer identical implying accumulated damage in the material. In case of PET concrete, progression in loading has only marginal effect on loading unloading response. The comparison of axial response shows softening in CC whereas for PET concrete the response is axial and for higher loads the response matches with that of CC concrete. In terms of lateral response, PET concrete exhibits stiffer response than its CC counterpart. Thus, presence of PET strips can be attributed to softening of response in axial direction and hardening in lateral direction. Further, the continued linearity of response for PET concrete in axial direction as compared to softening response of CC can be seen as an effect of crack bridging mechanism of PET strips. The hardening of response for PET concrete in lateral direction can be seen as an effect due to confining behavior of PET strips.

Similar to response for stage-I loading with elastic modulus and poisons ratio setup, subsequent loading stages are executed and their response is evaluated for determination of elastic modulus and poisons ratio.

3.3 *Elastic modulus and Poisson ratio for CC and PET concrete*

The response of CC and PET concrete to cyclic loading as described earlier is evaluated and the elastic modulus and poisons ratio values evaluated at each stage for loading and unloading response is as tabulated in Table.3

From Table.3, it can be observed that the elastic modulus and poisons ratio values of CC and PET concrete is comparable. The lower value of poisons ratio for PET concrete can be attributed partly to lateral stiffening and partly to axial softening. However, the effect of PET strips gets evident only in stage-II loading. In stage-II loading, elastic modulus for CC concrete in loading stage exhibits significant degradation whereas for PET concrete, the values are only marginally lower than those in stage-I. Further, reduction in poisons ratio for CC concrete can be attributed more to axial softening and less to lateral response. In comparison, Poisson ratio values for PET concrete increases in stage-II than in stage-I. In stage-III that corresponds to failure of CC samples, significant degradation in elastic modulus and Poisson ratio values can be observed. For PET concrete, both elastic modulus and Poisson ratio has values similar to stage-II. This degradation in values of CC and PET concrete indicates role of PET strips in offering confinement effect. It also restricts progression of damage thereby permitting stress transfer across damaged phases restricting degradation in material properties.

Table.3: Elastic modulus and poisons ratio for CC and PET concrete

Sr. No	Loading stage	Property	CC	PET
1	Stage-I	E-modulus(L)	29694.57	31321.78
2		E-modulus(U)	31664.66	33928.98
3		Poisson ratio (L)	0.21	0.18
4		Poisson ratio (U)	0.21	0.18
5	Stage-II	E-modulus(L)	26638.89	30949.8
6		E-modulus(U)	28447.67	32368.76
7		Poisson ratio (L)	0.18	0.20
8		Poisson ratio (U)	0.20	0.21
9	Stage-III	E-modulus(L)	17995	30239.1
10		E-modulus(U)	--	32266.13
11		Poisson ratio (L)	0.77	0.21
12		Poisson ratio (U)	--	0.21

4. Conclusions

The present study underlines the role of PET strips in controlling the response of PET macro reinforced concrete. The comparative stress strain response clearly demonstrate the ability of PET strips to restrict damage thereby permitting higher capacity in terms of failure strength and the strain energy density. The response of CC and PET concrete to cyclic loading and subsequent determination of material parameters namely elastic modulus and poisons ratio demonstrate the ability of PET strips in controlling degradation of material properties namely elastic modulus and poisons ratio. The presence of PET strips as confining members is observed to be more effective for controlling degradation in elastic modulus than in Poisson's ratio.

Disclosures

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