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Flexural Properties of Polyethylene Terephthalate Fibre Reinforced Concrete

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Abstract : Since the rapid swift of modern industrialization taking place globally, the issues developed in the tremendous shortages in the building construction materials and in the same mean time generation of indecomposable wastes are also increasing. The fabrication and usage of plastics, packed PET beverages bottles and the rate at which solid plastic waste are generated have increased considerably[1]. Plastics composition 12.3% of total waste formed, in that most of which is from redundant PET water bottles.
The concrete of M_{20} grades were selected for the study. The PET fibers were obtained from used beverage bottles, by melting the PET bottles at extract into a standard fiber. The fibers were added in the volume fraction of 0.5 %, 1.0 %. 1.5 % and 2.0%. The aspect ratio adapted was 15, 30 and 45.The concrete specimens were casted and tested after 28 days of curing. Based on the mechanical properties, optimum mix was selected and same was used to find out the flexural behavior of Reinforced concrete beam and results were discussed in the end.

1.0 Introduction

1.1 General

Nowadays Plastics are commonly used substances which play a major role in nearly every aspect of human lives. The widespread generations of plastics waste needs proper recycling, reuse management. The highest amount usage of plastics was found in containers and packaging of goods, since they are durables and disposal goods.

The major directions of disposal were done by following ways as mentioned below:

- using of plastic waste as alternative fuel in cement kilns and power plants
- Material recycling of waste polymers

Plastics are one of the important innovative materials in the present century and it is also an ubiquitous material. A sizeable growth development in the consumption of Plastics in all aspects is observed all over the world in recent years, which also accelerate the production of plastic based materials[2,3]. The usage of plastic material is based on low density property, easy processing, and excellent thermal and electrical insulating properties and also a very good mechanical properties and chemical resistance, low cost in comparison to other materials.

PET is a thermoplastic nature material. It is well also known as “polyester,” which often causes confusion, because of polyester resins contains thermosetting properties. PET is a transparent polymer, with a decent mechanical properties and excellent dimensional stability under variable load. PET has high-quality gas barrier properties and also having better chemical resistance. Above said properties of PET caused its wide range of application in the form of bottles, thermally stabilized and electrical components[4,5,6].

1.2 Sources of PET wastes

In general, Waste PET was categorized in to following three major streams:

a) Beverage Bottles: In this category there was a small problem with recycling of materials, it related with different types additives mixed with PET bottle during manufacturing process and molecular weight of PET. Which are affecting on repeatability of obtained products. Figure 1 shows the waste PET Bottles to be recycled.

Figure. 1 Waste PET Bottle

b) Foils: In this type, problems related with additives used during production molecular weight of PET, etc., which are affecting on repeatability of obtained products.

c) Cord from tires: This category having anenormous problem with recycling of material. Currently, this fraction of waste PET is used as an alternative fuel[7,8]. The major problems during material recycling of waste tire cord are contaminations of ground tire rubber and metals.

1.3 Properties of PET

The properties of Polyethylene terephathalate (PET) are as under:

PET is melted under 250°C, In melting stage of plastic is converted in to the 1mm diameter and converted in to a role. Then the PET fibre is cut in to required sizes. Figure 2 and Table 1 shows the PET fibre and properties of PET respectively.

Figure. 2 PET fibre

Table. 1 Properties of PET fibre

PET fibre Properties	Values
Young's modulus (E)	2800-3100
Tensile strength(σt)	55-75 Mpa
Elastic limit	50-150%
Notch test	3.6 KJ/m²
Glass transition temperature(Tg)	67-81°C
Vicat B	82°C
Linear expansion coefficient (α)	0.00007 per K
Water absorption (ASTM)	0.16
Meting point	>250°C
Boiling point	>350°C (decomposes)
Density	1.38 g/cm³
Solubility in water Practically	Insoluble

1.4 Utilization of PET in Concrete

Concrete is the most frequently used construction material worldwide. However, it is weak in tensile strength, low ductility, heavy weights, and low energy absorption. These points have prompted civil engineers to make use of conventional reinforcement to better the tensile strength and ductility of concrete[8,9,10]. The addition of fibers to concrete would act as crack inhibitors and substantially improve the cracking resistance, tensile strength, wear and tear, impact strength, fatigue resistance and ductility of the modified concrete. The concept of using fibers in concrete as reinforcement is not new one. In last few decades lot of research work was carried out in Fiber Reinforced Concrete (FRC), but very minimum in the area of FRC with PET fibre[11,12].The objectives of this experimental study described within this paper were (i) studying the mechanical properties of PET fibre (ii) studying the flexural properties of PET fibre.

2.0 Experimental Programme

To attain the main aim of the current study, an experimental program, including the test of concrete cubes - 36 Nos (150mm x 150mm x 150mm), cylinder - 36 Nos (150mm dia and 300 mm height), prism -30 Nos (500 mm x 100 mm x 100 mm) were cast and tested. The specimens are with 0.5%, 1.0%, 1.5% and 2.0% of volume fraction with the Aspect ratio of 15, 30 & 45 mm are used.

2.1 Materials

The following materials are used in order to make good concrete.

Cement of OPC with 43 grade has been used and conforming to IS 8112-1989. Table.2 shows the physical properties of cement.

Table. 2 Physical properties of Cement

Physical properties	Values	Permissible Limit
Specific gravity	3.1	3.10 - 3.15
Normal consistency	31	30 – 35
Initial setting time(min)	37	30 minimum
Final setting time(min)	570	600 maximum

Fine aggregate of natural river sand classified under zone III has been used[13,14]. The following properties of sand were determined by conducting tests as per IS: 2386 (Part- I). Table.3 shows the physical properties of fine aggregate.

Table. 3 Physical properties of Fine Aggregate

Properties	Observed Value
Fineness Modulus	3.24
Specific Gravity	2.63

Coarse aggregate of crushed granite stones obtained from local quarries were used as coarse aggregate. The maximum size of coarse aggregate used was 20 mm. The properties of coarse aggregate were determined by conducting tests as per IS: 2386 (Part – III). Table.4 shows the physical properties of course aggregate.

Table. 4 Physical properties of Coarse Aggregate

Properties	Observed Value
Fineness Modulus	6.78
Specific Gravity	2.68
Impact Value	24.80%
Crushing Value	30.4

Portable water free from salt was used for casting and curing of concrete as per IS: 456 – 2000 recommendations

2.2 Mix design and Mix proportion

Table.5 shows the various mixes and its designation of PET fibre reinforced concrete based on IS 10262.

2.3 Casting and testing procedures:

A laboratory type concrete mixer machine was used to mix the ingredients of concrete. The following procedure was followed in casting. First, aggregates and cement were mixed for one minute, water being added within two minutes. Thenthefibres were manually added and dispersed throughout the mass in slow increment. Now the materials were allowed to mix thoroughly for three more minutes. The fibrous concrete was manually placed in the respective moulds. All the specimens were well compacted using a table vibrator. The specimens were demoulded after 24 hours and allowed to curing

Table.5 Mix design and Mix proportion

Mix	Cement (kg/cum)	Sand (kg/cum)	Course Aggregate (kg/cum)	Water (Ltrs/cum)	Volume Fraction	Aspect Ratio
CC	320	730	1120	160	-	-
PFC1	320	730	1120	160	0.50%	0.15
PFC2	320	730	1120	160		0.3
PFC3	320	730	1120	160		0.45
PFC4	320	730	1120	160	1.00%	0.15
PFC5	320	730	1120	160		0.3
PFC6	320	730	1120	160		0.45
PFC7	320	730	1120	160	1.50%	0.15
PFC8	320	730	1120	160		0.3
PFC9	320	730	1120	160		0.45
PFC10	320	730	1120	160	2.00%	0.15
PFC11	320	730	1120	160		0.3
PFC12	320	730	1120	160		0.45

2.3.1 Compression Strength Test

- One of the important properties of concrete is its strength in compression. The strength in compression has definite relationship with all other properties of concrete.
- The aim of this experimental test is to determine the maximum load carrying capacity of test specimens.
- The compression test on cubes and cylinders were conducted according to Indian Standard specifications (IS: 516 – 1959).
- Figure. 3 shows the average compression strength values of various mix of concrete.

2.3.2 Split Tensile Test

- A direct measurement of ensuring tensile strength of concrete is difficult. One of the indirect tension test methods is split tension test. The split tensile strength test was carried out on the compression testing machine. The casting and testing of the specimens were done as per IS 5816: 1999.
- Figure. 4 shows the average split tensile strength values of various mix of concrete.

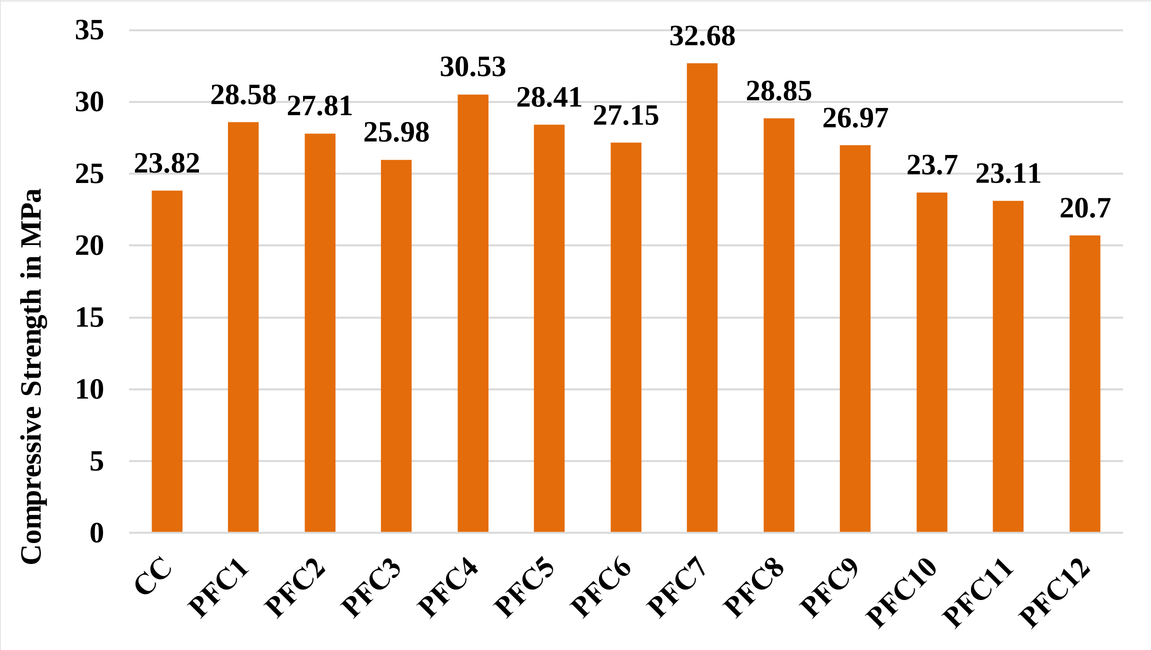

Figure. 3 Compression Strength Test Results

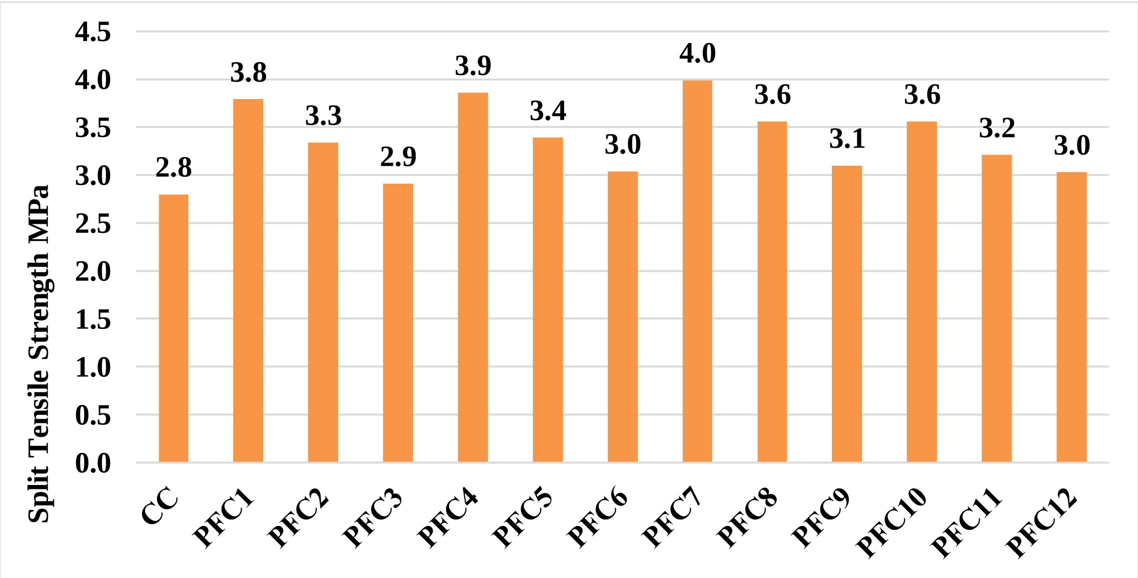

Figure. 4 Split Tensile Strength Test Results

2.3.3 Modulus of Rupture Test

- The extreme fibre stress calculated at the failure of specimen is called Modulus of rupture. It is also an indirect measure of predicting the tensile strength of concrete. Flexural strength test was conducted as per recommendations IS: 516 – 1959. In flexural strength test, beams of size 10 × 10 × 50 cm were cast.
- Figure. 5 shows the modulus of rupture values of various concrete mix.

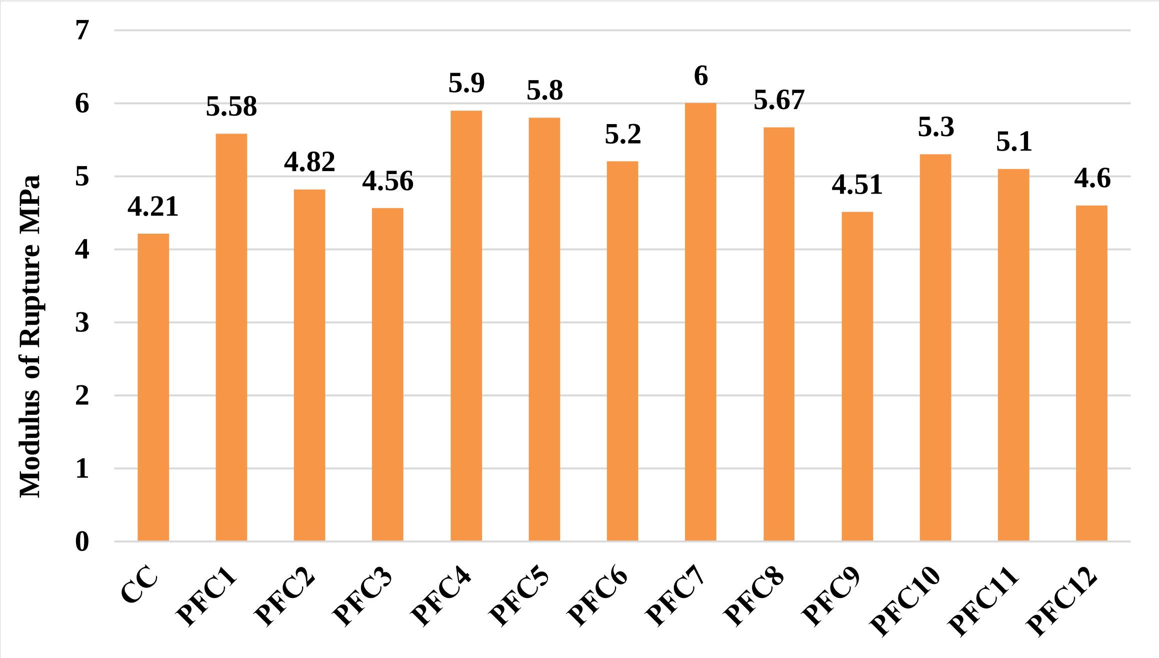

Figure. 5 Modulus of Rupture Test Results

2.3.4 Flexural Behaviour of Beam under static loading

- This experimental programme consists of casting and testing of ten numbers of 2.1 m long reinforced concrete beams. All the beams were tested over a simply supported span of 2.1 m. The beam was designed as under reinforced section to sustain a minimum ultimate load of 30 kN. The details of reinforcements present in the beam specimen has displayed in Figure. 6. And Table. 6 shows the typical salient points of load deflection curve of the beam specimen.
- The benefit of addition of recycled PET fibres on the flexural strength of reinforced concrete beams has been investigated in this section. Based on the experimental investigations, load vsmidspan deflection has been drawn. Seismic critical parameters such as ductility, energy absorption capacity at three salient points such as first cracking, first yielding and ultimate points. Figure. 7 shows the typical crack pattern of the beam specimen.

- Displacement Ductility = $\delta u / \delta y$

- Where.

  δu - Ultimate Deflection in mm

  δy - First Yield Deflection in mm

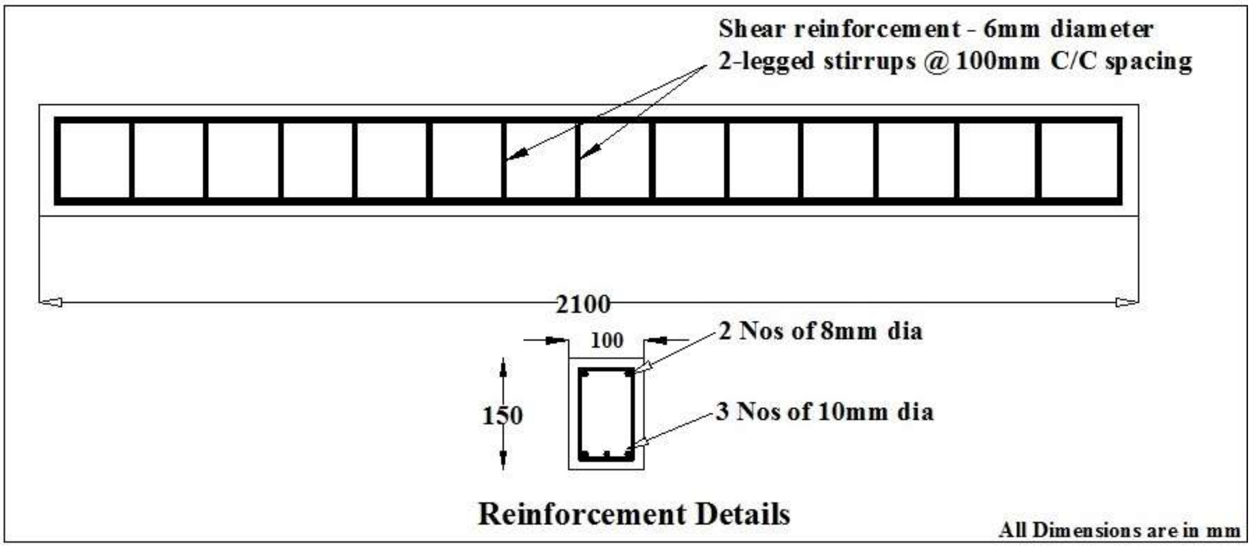

Figure.6 Typical Reinforcement and Specimen Details of Beam

Table.6 Value of Load and Deflection at First Crack, Yield and Ultimate points

Flexural Behaviour of Beam - Static Load Test							
S.No	**Mixes**	**P_{cr} (kN)**	**δ_{cr} (mm)**	**P_y (kN)**	**δ_y (mm)**	**P_u (kN)**	**δ_u (mm)**
1	CC	7.5	6.4	30.3	24.3	35.8	30.1
2	PFC1	9.4	6.3	37.6	21.3	43.2	28.4
3	PFC4	11.1	3.1	42	23.5	48.3	27.1
4	PFC7	12.8	3.6	46.4	20.6	53.4	24.3

Figure.7 Typical crack pattern of Beam

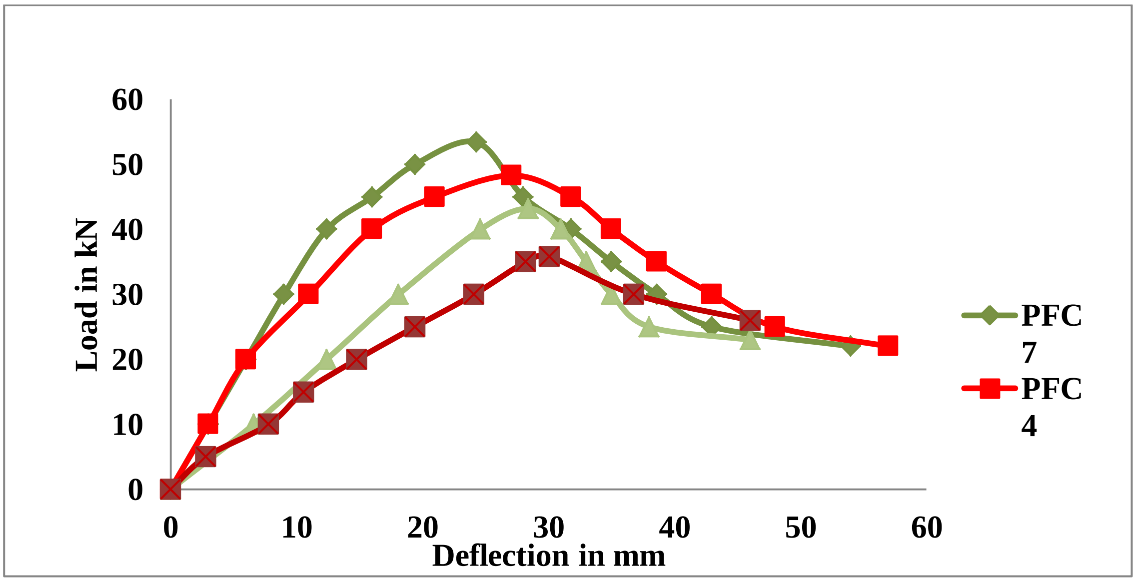

Figure. 8 Load-Deflection curve of beam specimen

Table. 7 Values of Displacement Ductility and Energy Absorption

Mixes	Displacement Ductility	Energy Absorption in kN-mm
CC	1.24	1510.3
PFC1	1.33	1848.6
PFC4	1.15	2679.6
PFC7	1.18	2764.0

3.0 Results and Discussion

- Concrete with the aspect ratio of 15 provides higher strength when compared with other aspect ratio. So, the concrete with 1.5% volume fraction have the higher compression strength value of 32.68 MPa. This value is 37.2% more than the CC, 58% more than that concrete with 2.00% volume fraction of fibre, 7% more that concrete with 1.00% volume fraction of fibre and 14.35% more than that concrete with 0.50 % volume fraction of fibre.
- Concrete with the aspect ratio of 15 provides higher strength when compared with other aspect ratio. So, the concrete with 1.5% volume fraction have the higher split tensile strength value of 4.0 MPa. This value is 42.85% more than the CC, 33.33% more than that concrete with 2.00% volume fraction of fibre, 2.56% more that concrete with 1.00% volume fraction of fibre and 5.0% more than that concrete with 0.50 % volume fraction of fibre.
- Concrete with the aspect ratio of 15 provides higher strength when compared with other aspect ratio. So, the concrete with 1.5% volume fraction have the higher modulus of rupture value of 6.0 MPa. This value is 42.51% more than the CC, 13.20% more than that concrete with 2.00% volume fraction of fibre, 1.69% more that concrete with 1.00% volume fraction of fibre and 7.52% more than that concrete with 0.50 % volume fraction of fibre.
- Based on the mechanical test results, the concrete with fibre aspect ratio 15 and volume fraction of 1.5 has good behavior at all aspects. In that, the volume fraction of 2.00% has less value in above tests. Also its values were closely with CC.
- The mechanical properties test results proven that the PET fibres with the aspect ratio of 15 provide better performance. So, this leads to study the flexural behavior of beam under static loading.
- Beam with 1.5% volume fraction and the aspect ratio of 15 behaves well and good under the static loading condition of flexural test.

4.0 Conclusion

- The Mechanical Properties tests, the volume fraction of 0.5%, 1.0% and 1.5% with the aspect ratio of 15 results better performance in the all aspects. For the remaining aspect ratio's the performance of the specimen is somewhat low compared with 15. Also quiet increased value when compared with conventional concrete specimen.
- The 2.0% volume fraction with the three aspect ratio did not shine much when compared with PFC specimen and very closer to CC specimen.
- Beam with 0.5%, 1.0% and 1.5% of volume fraction with 15 aspect ratio beam's have been undergone for this test.
- 1.5% of volume fraction beam has resist the ultimate load of 49% more than the CC beam and the deflection has 19.3% lower than the CC. This results leads, the addition of fibre increases the ductility of the member as well as load carrying capacity of the member.
- The remaining 0.5% and 1.0% volume fraction members are resisting the load of 35% and 21% more than the CC, and the deflection has 10% and 5.6% lower than the CC.

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