Use of polypropylene ropes in concrete to minimize steel reinforcement

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ABSTRACT

Progress in construction and buildings industry depends on so many parameters especially materials used. Concrete materials are cheap but still need minimization in their costs. Steel is one of the materials used in concrete structural members to support the concrete as reinforcement. In this study a polypropylene rope (PP ropes) were used to support the task of steel reinforcement especially in tension zones and to decrease the total cost of the concrete section. To know how this matter achieved seven concrete beams were casted one of them was without polypropylene ropes as control beam where as others were reinforced only with polypropylene ropes. The dimensions of the concrete beams were (200cm ×30cm ×20cm). Whole concrete tests were done to find out the most effective properties of concrete like compression, rupture modulus and tensile strength. Seven beams were exposed to monotonic load to find out the load at failure and corresponding deflection at mid span. Results show that if four ropes were used in tension zone of the concrete section the strength increased by about 9%. This ratio seems to be low but the cheap cost of these ropes encourages designers to use a greater number of ropes in concrete section. This idea needs more future work.

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1.   Introduction

Concrete is considered to be a favorable material used in construction of building structural members. Since this material is composed of locally cheap constituents and has good strength properties to some extent. Efforts had been made to improve its properties. Tenths of materials were tested through using them as an admixture such as chemical materials, fibers and other additives. Improving of concrete characteristics started so many years ago by controlling the quality of its constituents to get high compressive and tensile strengths. Steel reinforcement was considered the best material that increases the efficiency of concrete sections in tension and compression. Steel is expensive so there is a need to find a cheap alternative to replace steel fully or partially. Polypropylene (PP) Ropes are the material which might help to achieve this task. They can be used as fibers or as bars. They are produced globally by so many companies and each one has its private specifications. Polypropylene (PP) is a thermoplastic "addition polymer" prepared from the grouping of propylene monomers [1]. the first two scientists who were working on Polypropylene were Paul Hogan and Robert Banks in Phillips petroleum scientist's organization in 1951. They were followed by an Italian and German scientists Natta and Rehn [1]. The commercial production of this material was started after three years of the polymerization done

by Professor Giulio Natta (Italian chemist) in 1954. The polypropylene was widespread as a commercial production by 1957 across Europe [1]. Now this material is commonly produced all over the world [1].

2. Characteristics of the polypropylene material

1.No reaction with diluted acids or bases.

2.Tough material [3].

3.It retains to its original shape after releasing the effect of torsion, bending or flexing so it has good fatigue resistance [4].

4. An insulated material.

5. Cheap due to its availability.

6.Has high thermal expansion coefficient.

7.Flammable.

8. Has poor bonding.

Some of Polypropylene (PP) properties can be seen in Table 1.

Table 1. Properties of Polypropylene [2]

Property	Value
Technical Name	**Polypropylene (PP)**
Melt Temperature	**130°C (266°F)**
Typical Injection Mold Temperature	**32 - 66 °C (90 - 150 °F)**
Heat Deflection Temperature (HDT)	**100 °C (212 °F) at 0.46 MPa (66 PSI)**
Tensile Strength	**32 MPa (4700 PSI)**
Flexural Strength	**41 MPa (6000 PSI)**
Specific Gravity	**0.91**
Shrink Rate	**1.5 - 2.0 % (.015 - .02 in/in)**

The ropes produced by Thrace Plastic Company. S.A.) [2] are designed with two Z twisted strands and have 2.0 GPa elastic modulus and 20.36% tensile elongation at failure. Polypropylene has poor cyclic loading characteristics. Lastly, prolonged exposure to the sun's ultra violet rays can cause Polypropylene fibers to disintegrate due to degradation. Polypropylene is lighter than water and can be used for floating messenger lines. Samson company which produces these ropes had a variety of such products. This American company made a manual of the mechanical, physical and chemical properties of these ropes [2]. Some of these properties can be seen in Table 2.

Table 2. Properties of PP ropes produced by Samson [3]

PP Rope Size	Coil weight of 220 meters	Breaking Strength of Rope
4 mm	1.63 kg	214 kgf
6 mm	3.67 kg	602 kgf
8 mm	6.60 kg	1060 kgf
10 mm	10.00 kg	1560 kgf
12 mm	14.50 kg	2210 kgf
14 mm	20.00 kg	3050 kgf
16 mm	25.50 kg	3770 kgf
18 mm	32.50 kg	4810

3. Experimental work

The experimental work comprises the following:
1. Materials used and tests achieved to conform standard specifications.
2. Tests on polypropylene ropes.
3. Steel molds.
4. Concrete tests.
5. Beam tests.

3.1 Materials used
3.1.1 Cement
An ordinary Portland cement named AL-Kar (Type I) produced in Najaf Province - Middle region of Iraq was used during this investigate. It was stored in suitable state to avoid any strange risky situations. The results of the chemical and physical indicate that the cement conformed to specification (No.5/1984) [4]. They are shown in Tables 3 and 4 respectively.

Table 3. Chemical composition of cement

Oxides Composition	Content %	Limits of Iraqi Specification No.5/1984[4]
CaO	56	------
SiO$_2$	19	------
Al$_2$O$_3$	3.98	------
Fe$_2$O$_3$	3.76	------
MgO	2.79	<5.00
SO$_3$	2.32	<2.80
L.O.I	3.04	<4.00
I.R	1.01	<1.5
L.S.F	0.962	0.66-1.02
C$_3$A	4.187	------
C$_3$S	57.04	------
C$_2$S	14.83	------
C$_4$AF	10.95	------

Table 4. Physical properties of cement

Physical Properties	Test Results	Limits of Iraqi Specification No.5/1984[4]
Specific Surface Area (Blaine Method), m^2/kg	483	≥ 230
Setting Time (Vicat Apparatus), Initial Setting, hr.: min	2:50	$\geq 00:45$
Final Setting, hr. : min	4:30	$\leq 10:00$
Compressive Strength, MPa 3 days	31.60	≥ 15.00
7 days	38.70	≥ 23.00
Soundness (Autoclave Method),%	0.25	≤ 0.8

3.1.2 Aggregates
Natural sand from Bahr AL-Najaf was utilized for production a concrete mixes of this investigate. A river coarse aggregate was brought from east of Iraq called Bedra position. The aggregates was washed carefully and tested. The consequences of the grading of fine and coarse aggregates are conformed to Iraqi Specifications No.45 - 1984 [5] and the consequences of grading tests can be shown in Tables 5 and 6 respectively.

Table 5. Grading of fine aggregate

Sieve Size (mm)	Cumulative Passing %	Cumulative Passing % Limits of Iraqi Specifications No.45 - 1984 Fine Aggregate-zone (4)
4.75	100	95-100
2.36	100	95-100
1.18	100	90-100
0.60	100	80-100
0.30	50	15-50
0.15	10	0-15

Table 6. Grading of gravel compared with Iraqi Specification No. 45-1984[5]

Sieve size	Allowable Percentage ratio passing through sieves Nominal size of aggregate is(5-20) mm	Current Agg. sample
37.5mm	100	100
20mm	95-100	98
14mm	-	92
10mm	30-60	70
5mm	0-10	8
2.36mm	-	-

3.1.3 Polypropylene ropes

The selected samples of polypropylene ropes were taken from ten independent coils. They are 10m in length each sample. They were tested to see the average weight of them and they were exposed to breaking strength test to know if it is capable of carrying applied loads and their conformation to a standard specification. The average weight for whole selected samples was 1155gm/10m rope length and the average breaking strength of ropes was 3500kg. These results were conformed with the specifications of Samson Ropes Company [2].

3.2 Steel molds and concrete mixes

A (200cm×30cm×20cm) steel molds were fabricated to be used in beams to cast concrete beams of the work. A mix design was done to reach concrete compression strength of about 25MPa. The materials ratio used was 400kg cement: 792kg fine aggregate: 961kg coarse aggregates mixed with 202kg of water. Seven molds were casted giving symbol S starting with S_1 which represents control beam (beam without polypropylene ropes). Other six beams were casted to see the effect of using polypropylene ropes and what can this cheap material supports and helps concrete in compression and tension besides the minimization of steel bars quantity. Four polypropylene ropes were used in the lower layer of concrete in the mold and two ropes in the upper layer. No stirrups were used to study purely the flexural strength of beams as shown in plate 1. The study of shear was not taken into consideration in this paper.

Plate 1. Steel mold used and concrete casting process

3.4 Concrete tests

A samples of concrete were taken to cast (100mm×200 mm) cylindrical shape specimens to be utilized in finding compressive strength of concrete according to ASTM C39-86 [6]. These samples and according to ASTM C496-86 specification [7] were used to find the Strength under Splitting Tension. Beam prisms (100mm×100mm×400mm) were ready according to ASTM C192-88[5] and were tested according to the ASTM C78-84specification [6] to find flexural strength of concrete.

3.4.1 Beam tests

The beams were tested utilizing the calibrated electro hydraulic universal testing machine with maximum range capability of 2000KN. A two points loading mechanism was used to test all beams. The dial gage was fixed in its marked location to touch the center of bottom beam, in order to be certain that the dial plungers had touched the center of beam surface. Loading was ongoing by applying single point load into a platform which was equally separated into two point loads transferred to the concrete beam see Fig.1 and plate 2. The load magnitude for each load step was kept constant in the increments. At each load step, concrete surface strains and the dial gage readings were noted. This procedure was continued till the cracks appeared.

The cracks were noticeable on the beam surface and the load magnitude at these cracks was registered. The flexure cracking load was described as the load at the time when the critical flexure crack crossed the mid -depth of the beam as shown in plate 3. The failure load was recorded when an increase in deformation was noticed with consequent drop in load.
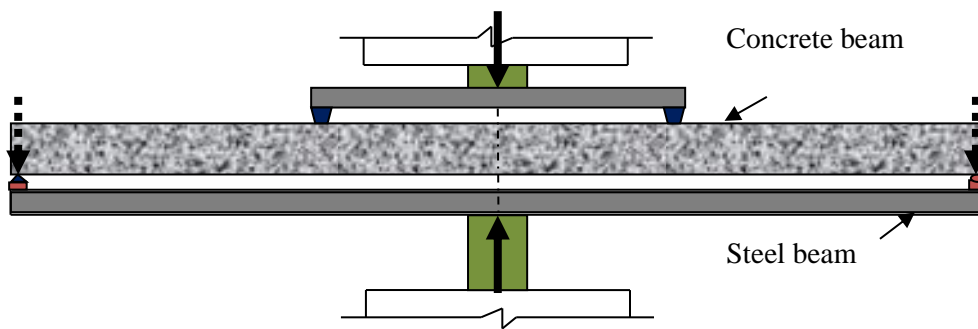

Figure 1. Schematic elevation of Beam Testing

Plate 2. Beam testing   Plate 3. Beam flexural cracks

3.4.2 Analysis of the concrete section
3.4.2.1. When only PP ropes were used in tension zone

Fig.2 shows a rectangular concrete section and reinforced by PP ropes in the lower middle half of a certain simply supported beam. By simple mathematical operations, the following formula can be governed:

$$x = \cfrac{1}{1 + (\cfrac{\sigma_{pp}}{\sigma_c . m})} . d \quad = k.d$$

(1)

x is the upper fiber distance of the section from the neutral axis, σ_{pp} -allowable stress in *pp* ropes area. σ_c – allowable stress in concrete. m –modular ratio = E_{PP} / E_c. d-effective depth of the section, K –neutral axis

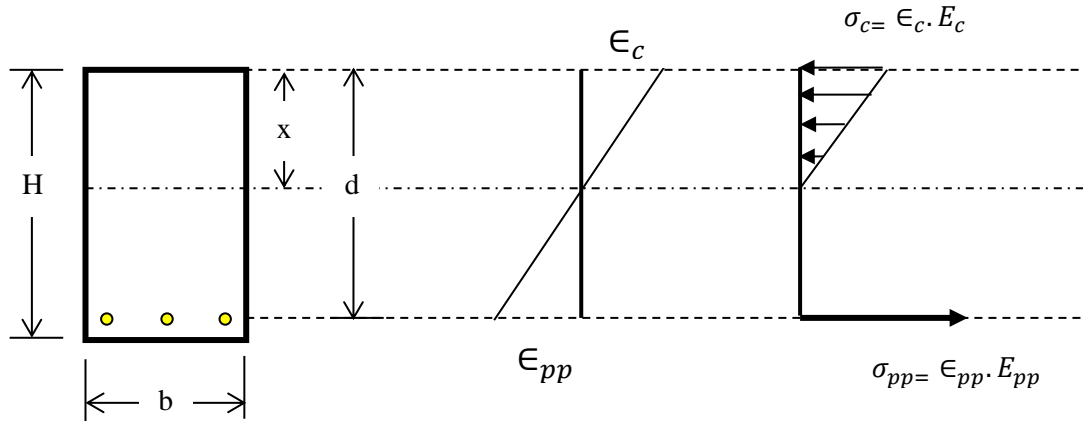constant $= \cfrac{1}{1 + (\frac{\sigma_{pp}}{\sigma_c . m})}$

Figure 2. Stresses and strains induced in rectangular concrete section

ϵ_{pp} is the strain in pp ropes. E_{pp} is modulus of elasticity of *pp* ropes. $\mathcal{E}_c$ is strain in concrete and E_c is concrete the modulus of elasticity.

The developed maximum moment induced in the section is resisted by the compression in concrete whereas tension is resisted by polypropylene ropes and concrete is assumed to resist only compression (tension is ignored). The neutral axis passes through the centre of gravity of the composite section which includes concrete and polypropylene ropes. The formula mentioned is for the position of neutral axis determination when the stresses induced in the section are given. When the geometric shape of the section and area of reinforcement are given, the position of neutral axis is y:

$$x = \frac{-m.A_{pp} \pm \sqrt{(m.A_{pp})^2 + 2m.A_{pp}.b.d}}{b}$$

Where A_{PP} is the area of pp ropes and b is the breadth of the concrete section. The moment of resistance MR of a balanced section can be calculated from the couple of forces shown in Fig. 3.
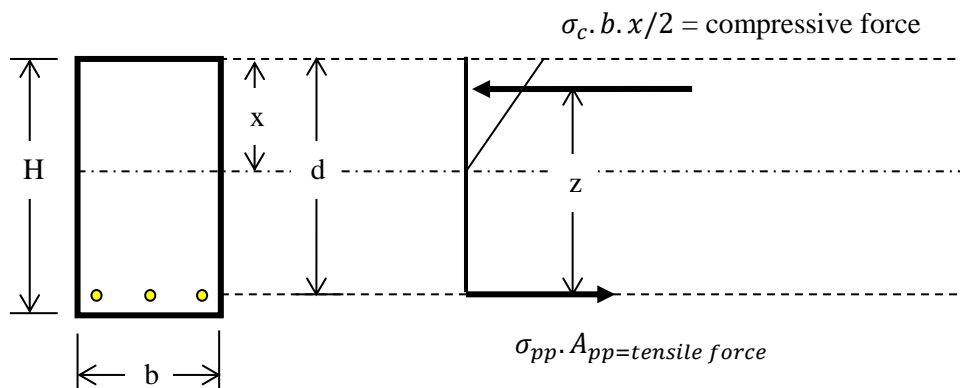

Figure 3. Couple forces induced in rectangular concrete section.

Z = d-(x/3) = d-(kd/3)   = (1-k/3) d = jd

$MR = \sigma_c.b.\frac{x}{2} * z \quad = \quad \sigma_c.b.\frac{x}{2} * jd \quad = \quad \frac{1}{2}k\,j\,\sigma_c.bd^2 \quad = Q\,bd^2$

Q is called moment of resistance constant $= \frac{1}{2}k\,j\,\sigma_c$

The moment of resistance alternatively can be evaluated from tension zone as follows:

$\sigma_{pp}.A_{pp}.j.d = Q.bd^2$

From which

$$A_{pp.} = \frac{\sigma_c.bd}{2\sigma_{pp}}.k \tag{3}$$

The above equation can be used to find out the area of pp ropes reinforcement and by the same way it can be evaluated for under and over reinforced sections. A hint must be mentioned here that the assumptions of the ACI code to compute nominal flexural strength are based on satisfying the applicable conditions of equilibrium and compatibility stress. In addition to that strains in the reinforcement and in the concrete shall be expected directly relative to the distance from the neutral axis. The maximum usable strain at the extreme concrete compression fiber shall be assumed equal to 0.003. A study must be done to know that if these requirements are applicable in using only PP ropes, otherwise new recommendations should be drawn in studying the use of PP ropes only.

3.4.2.2. When in addition of PP ropes a steel reinforcement were used in tension zone

The rectangular section shown in Fig. 4 is reinforced by two types of reinforcement pp ropes and steel. Moment of resistance is also given by for the compression zone:
$MR = Q\,bd^2$
But moment of resistance from tension zone is different now and it will be given by:
$MR = [\sigma_{pp}.A_{pp} + \sigma_s.A_s]jd = Q\,bd^2$
From which $\qquad \sigma_{pp}.A_{pp} + \sigma_s.A_s = \dfrac{MR}{\left(1-\frac{k}{3}\right).d} \tag{4}$

K is calculated from an equation given before and it depends on the stresses induced in pp ropes and concrete because pp ropes has not the ability to withstand strains compared to steel reinforcement and it will fail before it.

$$\sigma_c.b.\frac{x}{2} = compressive\ force$$

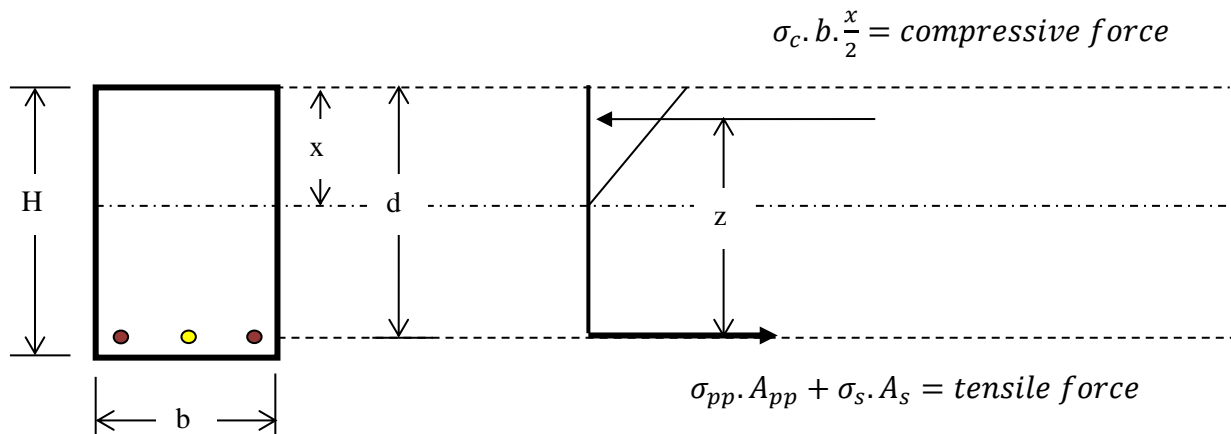$$\sigma_{pp}.A_{pp} + \sigma_s.A_s = tensile\ force$$

Figure 4. Couple forces induced in rectangular concrete section reinforced by pp ropes and steel

The area of pp ropes needed to help and support steel reinforcement to carry tension stresses can be calculated from Eq. (3) when area of steel is given and pp ropes engineering properties are known.

4. Results and discussion
The consequences of tests conducted on the control specimen and other beams are summarized in Table 3 and Table 4.

4.1 Strength in compression
According to ASTM C39-86 [6] the samples were tested in compression. A cylindrical specimen (100mm×200mm) in 28 days' age were used to find out compressive strength of Concrete using compression testing machine.

4.2 Strength under splitting tensile
(100mm×200 mm) cylinders' specimen were prepared according to the ASTM C496-86 specification [7]. strength under splitting tensile values were considered with following expression:

$$\text{fspf} = \frac{2p}{\Pi dl} \qquad (5)$$

fspf= Strength under splitting tensile (MPa), P = Maximum applied load (N), d = Specimen diameter in mm and L = Specimen length in mm.

4.3 Rupture modulus
A concrete prism of (100×mm×100mm×400mm) in dimensions were prepared in accordance with ASTM C192-88 specification [8]. The rupture modulus of concrete is specified by a use of 600 KN capability machine. Prisms were tested by using the two points load with a 300 mm clear span to fulfill the ASTM specification [9]. According to the formula (6) the modulus of rupture can be calculated.

$$\text{frf} = \frac{PL}{bh2} \qquad (6)$$

frf = rupture modulus in (MPa), P = applied load (N), b = specimen width (mm) and   h= specimen depth (mm).

4.4 Modulus of elasticity (static)
ASTM, C469- 87a [10] states that 40% of ultimate compressive strength is applied on the concrete cylinders to achieve Static modulus of elasticity of concrete utilizing the   following expression : -

$$E = [(S2 - S1) / (e2 - 0.00005)] \times 10^{-3} \qquad (7)$$

E= static modulus of elasticity in GPa

S1= stress corresponding to a longitudinal strain (0.00005) in MPa .

S2 = stress corresponding to 40% of ultimate load in MPa .

e2 = longitudinal strain produced by stress S2.

Table 3. Properties of hardened concrete

Sample No.	Compressive Strength f'c (MPa)	Strength under splitting tensile Fsp (MPa)	Modulus Of Rupture Fr (MPa)
S$_1$ (Control batch)	29.4	4.6	3.2
S$_2$	28.9	4.2	4.2
S$_3$	27.8	3.9	4.6
S$_4$	29.0	4.4	3.9
S$_5$	26.8	5.1	4.1
S$_6$	27.9	4.9	4.4

Sample No.	Compressive Strength f'c (MPa)	Strength under splitting tensile Fsp (MPa)	Modulus Of Rupture Fr (MPa)
S₇	28.7	4.8	3.8

Table 4. Loads applied with deflection at mid span

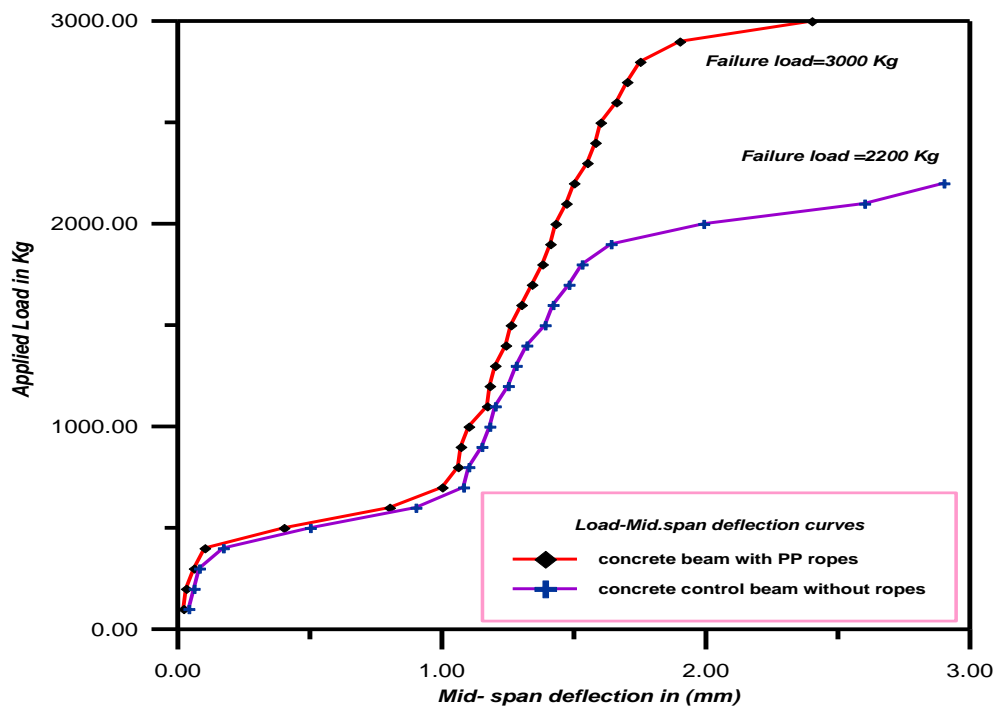| Load applied in (kg)	Deflection in mm for beams with polypropylene ropes	Deflection in mm for beams without polypropylene ropes	Load applied in (kg)	Deflection in mm for beams with polypropylene ropes	Deflection in mm for beams without polypropylene ropes
100	0.02	0.04	1600	1.3	1.42
200	0.03	0.06	1700	1.34	1.48
300	0.06	0.08	1800	1.38	1.53
400	0.1	0.17	1900	1.41	1.64
500	0.4	0.5	2000	1.43	1.99
600	0.8	0.9	2100	1.47	2.6
700	1	1.08	2200	1.5	2.9
800	1.06	1.1	2300	1.55	
900	1.07	1.15	2400	1.58	
1000	1.1	1.18	2500	1.6	
1100	1.17	1.2	2600	1.66	
1200	1.18	1.25	2700	1.7	
1300	1.2	1.28	2800	1.75	
1400	1.24	1.32	2900	1.90	
1500	1.26	1.39	3000	2.40	

Figure 5. Results of the tested beams (with and without polypropylene ropes)

Figure 5 shows the results of the applied loads and corresponding deflections. It is visibly appeared from this figure that the usage of PP ropes improved the capacity of the concrete section to 3000kg compared to 2200kg for section without ropes. In addition, the deflection is minimized to 2.4mm compared to 2.9mm. If the number of ropes increased the capacity is also increased with the help of steel reinforcement.

During the process of PP ropes tests it was noticed that the ropes extended quickly and rapidly till the breaking. That means the material is highly elastic and the concrete under loads extends without capturing extension by this reinforcement. This phenomenon appears clearly when testing beams. The shape of beam failure was flexural fracture accompanied with a growth of vertical cracks in concrete, start from down fibers to the upper face of the beam. Concrete failed before ropes and this means that this material cannot be used alone without steel reinforcement. It can help steel reinforcement to some extent. The use of four PP ropes in the present study raised the capacity of concrete section in tension zone by about 9%. If the number of ropes increased the capacity of the section is expected to be more and that needs more study.

5. Conclusions and recommendations

The following decisions and recommendations can be recorded in this study as:

1. Bond between ropes and concrete is weak, so this property needs study through testing many beams by push-off and pull-out tests.
2. Studying the phenomena of bond experimentally and theoretically leads to an accurate design steps of this new use of ropes in concrete.
3. An effort must be achieved in studying concrete beams of PP ropes in different ages extended to one or two years.
4. Using PP ropes alone in concrete is prohibited because failure starts in concrete before ropes, so sudden failure may occur.
5. The compatibility between concrete and ropes must be studied carefully in so many parameters especially coefficient of thermal expansion.
6. The degradation in ropes strength due to exposure to UV rays is not found in concrete members because ropes are buried in the concrete.
7. According to my opinion PP ropes are not used with concrete by this way ago elsewhere (depending upon the so many producers of this material who are using their manufacturing products properties). There will not be an international or national code used as a standard guide. This means that an independent code must be prepared throughout concentrated efforts and studies.

Acknowledgment

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