Imperial Journal of Interdisciplinary Research (IJIR)
Vol-2, Issue-7, 2016
ISSN: 2454-1362, http://www.onlinejournal.in

Effect of Textile Fabrics on Flexural Strength of RCC Beam

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Abstract: *The textile fabrics are a very beneficial technique in repair and strengthening of reinforced concrete beam. This method is used in a number of applications to improve the flexural strength of structural beams. However, the fabrics used are a bit costly. The aim of this investigation is to observe the change in flexural strength on an Under-Reinforced designed beam by applying woven polypropylene fabric and non-woven polyester fabric that is glued to the Under-reinforced RC Concrete beams with an epoxy bonding agent. Each beam is applied with single, double or triple layers of fabric in U-shape under virgin condition and tested until failure.*

Introduction

India is a land which has a large number of structures standing since decades or maybe centuries. Concrete beams are important elements in structural engineering. They are vulnerable in situations where there is an increase in structural capacity. The rehabilitation and upgrading of structural members, is one of the most crucial problems in civil engineering. Also, a large number of structures having older design methods in different parts of the world are structurally not safe as per the new design methods. Strengthening has become the best suitable way of improving the load carrying capacity and extending the service lives of these structures since replacement of these defective elements requires a large amount of time and money. Premature deterioration of buildings and structures causing infrastructure decay led to the identification of several processes for strengthening or repair purposes. One of the challenges in strengthening of concrete structures is choice of a strengthening method that will enhance the serviceability and strength of the structure along with addressing limitations such as building operations, budget and constructability.

The majority of structural strengthening process involves improving the ability of the structural elements to safely resist the following internal forces caused by loading: flexure, shear, axial, and torsion. Strengthening is gained by either reducing the magnitude of these forces or by enhancing the member's resistance to them. One of the method of repair or strengthening and rehabilitation of RC beam is external bonded reinforcement. External bonded reinforcement can be done using non-woven fabrics or woven fabrics or steel plates.

The repair work of such structures, carried out using retrofitting by steel is the best suited one as of now but is time consuming and may be difficult to retain the aesthetic view of these structures. So our aim was to find something that can be used as an alternative to retrofitting by steel without damaging the aesthetic view of such important buildings such as using technical textile fabrics of woven and non-woven type externally on the beam. The comparison of change of flexural strength w.r.t. reference beam with change in layer as well as fabric is observed.

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Experimental investigation

In the experimental investigation, fabrics used were woven polypropylene and non-woven polyester, both of 180 GSM(gram per sq.m) easily available at around ₹110/kg and ₹130/kg. So, retrofitting of around 5 m^2 can be done using a one kg raw material. The Fabric testing was carried out at **MANTRA Laboratory** and results were obtained for elongation, load, extension, modulus of elasticity as well along with the tensile strength of fabric. The strength of 180 GSM polypropylene was 211.2 N and that of polyester is 2790 N.

Furthermore, Reinforced concrete beams were designed as Under- reinforced section using M20 grade concrete and Fe 500 grade steel. The beams in the calculation were considered as single – reinforced beams. Stirrups were made with 6mm diameter steel bars. The dimensions of the beam were 700mm x 150mm x 150mm. The reinforcement details are given in fig. 1. The beams were cured in a water tank for 28 days. After curing, two beams were tested as reference beams to confirm and remaining beams were strengthened with single, double and triple layer of both the fabrics with two for each type for taking average for accurate readings.

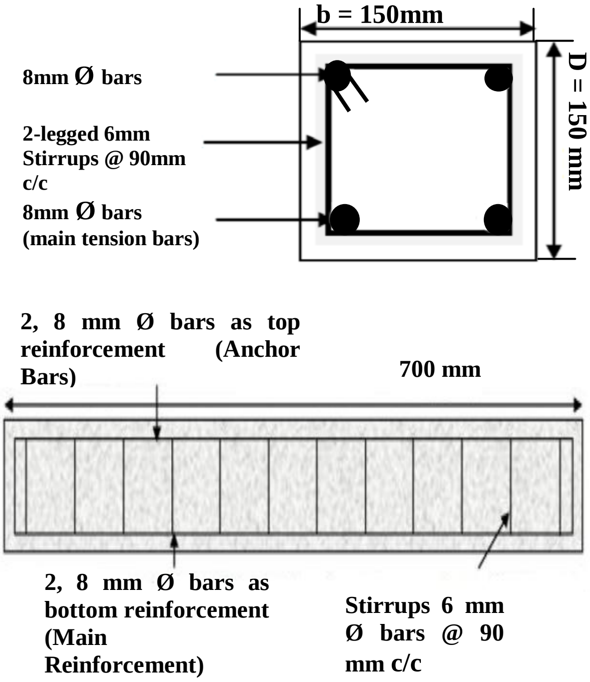


Figure 1. Reinforcement details of beam

Bonding Method

The beam after curing for 28 days were applied with fabric using epoxy based adhesive after cleaning the surface of beam of all dirt. Epoxy Resin which comes in two parts Part A: Epoxy and Part B: Hardener was mixed in 40:60 proportions. The mixing of the resin was done using two spatula and care was taken to ensure uniform mixing. The adhesive was uniformly applied on the concrete surface and then fabric was applied over it in U-shape for single layer. For double and triple layer of fabric, another layer of adhesive was spread on which subsequent layers were prepared. These beams were cured for 7 days at room temperature to allow the adhesive to get its maximum bonding strength

2.2. Arrangement of test set-up

Universal Testing Machine (UTM) having a capacity of 600 kN was used for testing all the specimens. A view of the experimental set-up and the arrangement of the deflection measurement devices are shown in fig. 2. Two-point loading system was used. The load is applied at the equal distance of 200 mm from the center of beam. The span length of the beam is 600mm, same for all specimens.

Figure 2. Beam testing set-up

2.3. Beam Designation

Table 1. Beam Designation

Beam type	**Beam Designation**	**Number of beams**
Reference Beam	O1 and O2/ O	2
Polypropylene Strengthened beam (Single layer)	S1-U1-L1 and S1-U2-L1	2
Polypropylene Strengthened beam (Double layer)	S1-U1-L2 and S1-U2-L2	2
Polypropylene Strengthened beam (Triple layer)	S1-U1-L3 and S1-U2-L3	2
Polyester Strengthened beam (Single layer)	S2-U1-L1 and S2-U2-L1	2
Polyester Strengthened beam (Double layer)	S2-U1-L2 and S2-U2-L2	2
Polyester Strengthened beam (Triple layer)	S2-U1-L3 and S2-U2-L3	2

3. Beam Testing and results

The beams were tested to the ultimate failure. First of all, two reference beam were tested and then the remaining twelve beams, two of each kind were tested and the ultimate load as well as the maximum deflection and mode of failure was noted.

The reference beam failed in flexure near the point of application of load with the ultimate load being 76 kN and the deflection was 7.82 mm.

Figure 3. Flexural failure of reference beam

The polypropylene strengthened beam showed an increase in load carrying capacity and a decrease in deflection when compared with the deflection at the ultimate load carrying capacity of reference beam. The failure in case of single and double layer of both the fabrics involved flexural failure + crushing of concrete on applying extra load. However, there was no debonding of fabric-fabric interface or fabric-concrete interface and no fabric rupture. In case of beam with triple layer of fabric, possibly due to increase in stiffness, the failure of beam in addition to the above failure involved debonding of fabric resulting in reduced load carrying capacity compared to double layer and almost similar to the beam with single layer of fabric and the deflection was more or less same to the double layer of fabric strengthened beam.

Figure 4. Crushing of concrete in compression and debonding of polypropylene fabric of triple layer

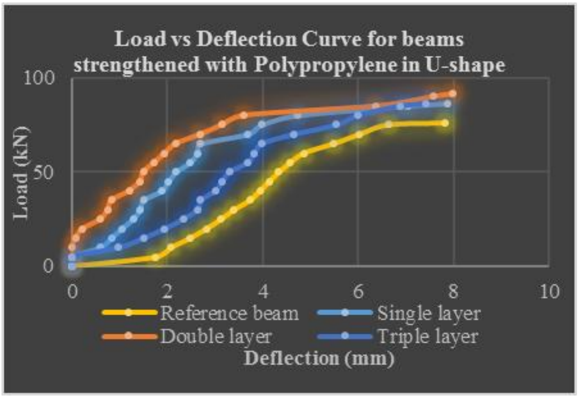
Figure 5. Flexural failure of beam strengthened with single layer of polypropylene fabric

Figure 6. Crushing and debonding of triple layer of polyester fabric from concrete

The crushing of beam with triple layer of polypropylene as well as polyester fabric is shown in figure. The crushing of concrete due to breaking of bond between fabric and concrete at upper surface resulted in reduction in load carrying capacity. The table showing the load carrying capacity of the beams and the load vs deflection curve for both the type of fabric strengthened beam is as shown below.

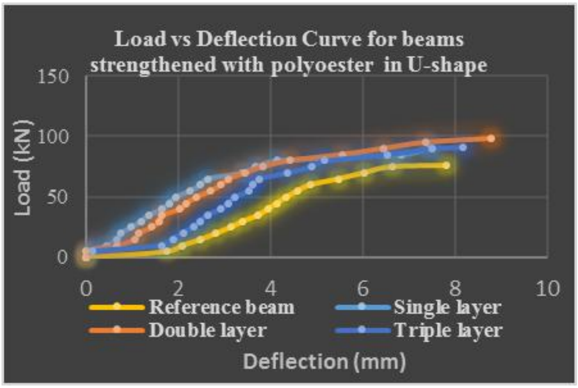
Table 2. Load, deflection and mode of failure of beams

Beam type	Load (kN)	Deflec tion (mm)	Mode of failure
Reference Beam	76	7.82	Flexural Failure
Polypropylene Strengthened beam (Single layer)	86.4	7.87	Flexural Failure without debonding or fabric rupture
Polypropylene Strengthened beam (Double layer)	91.45	7.98	Flexural Failure without debonding or fabric rupture
Polypropylene Strengthened beam (Triple layer)	86.25	7.43	Flexural failure with debonding of fabric from concrete and crushing of concrete
Polyester Strengthened beam (Single layer)	96.6	8.6	Flexural Failure without debonding or fabric rupture
Polyester Strengthened beam (Double layer)	98.1	8.78	Flexural Failure without debonding or fabric rupture
Polyester Strengthened beam (Triple layer)	91.35	8.18	Flexural failure with debonding of fabric from concrete and crushing of concrete



Graph 1. Load vs Deflection curve for beams strengthened with polypropylene fabric

The reference beam failed at 76 kN showing a maximum deflection of 7.82 mm. The single layer of polypropylene fabric strengthened beam showed a maximum deflection of 7.87 mm at 86.4 kN, however the deflection at ultimate load = 76 kN was about 4 mm which is 48.8% less than reference beam deflection. The beam strengthened with double layer of polypropylene showed a deflection of about 3.2 mm at 76 kN which is 59.08% less than reference beam. The beam strengthened with triple layer of polypropylene showed a deflection of 5.7 mm at 76 kN which is 27% less than reference beam. However, it is more than beam with single and double layer of fabric possibly due to debonding of fabric.



Graph 2. Load vs Deflection curve for beams strengthened with polyester fabric

The single layer of polyester fabric strengthened beam showed a maximum deflection of 8.6mm mm at 96.6 kN, however the deflection at ultimate load = 76 kN was about 3.7mm which is 52.68% less than reference beam deflection. The beam strengthened with double layer of polyester showed a deflection of about 3.9 mm at 76 kN which is 50.12% less than reference beam. The beam strengthened with triple layer of polypropylene showed a deflection of 4.9 mm at 76 kN which is 37.34% less than reference beam.

3.2. Experimental Flexural Strength Calculations

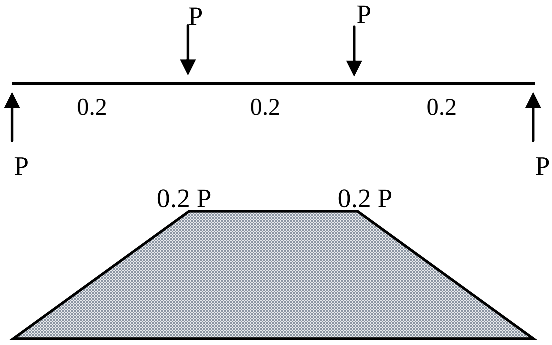


Figure 7. Diagrammatic view of test set-up

The above figure gives a diagrammatic view of the test set-up. The span length of 600 mm = 0.6 m is divided into 3 spans each of 0.2 m with the moment diagram given below it.
For reference beam,
Total load obtained by test is 76 kN. Since it is a two-point loading system, the load at each point P = 76/2 = 38 kN
Hence M_u = Px0.2 = 38x0.2 = 7.6 kN.m
The similar moment values are obtained for the beams wrapped in fabric, the values of which are tabulated below.

Table 3. Experimental flexural strength

Beam type	M_u (kN.m)
Reference Beam	7.6
Polypropylene Strengthened beam (Single layer)	8.64
Polypropylene Strengthened beam (Double layer)	9.145
Polypropylene Strengthened beam (Triple layer)	8.625
Polyester Strengthened beam (Single layer)	9.66
Polyester Strengthened beam (Double layer)	9.81
Polyester Strengthened beam (Triple layer)	9.14

Analytical flexural strength calculation

The flexural strength of beam is obtained from the following data:
f_y = tensile strength of steel = 500 N/mm^2
f_{ck} = grade of concrete = 20 N/mm^2
A_{st} = area of steel = 100.53 mm^2
b = width of beam = 150 mm
Effective cover = cover block + ½ diameter of steel
= 20 + 8/2 = 24 mm

d = effective depth of beam = 150 – 24 = 126 mm
f_{fp} = tensile strength of polypropylene = 8.45 N/mm^2
f_{fe} = tensile strength of polyester = 111.6 N/mm^2
LA_s, LA_{f1}, LA_{f2} = lever arm of steel in tension, fabric in bottom and fabric on sides of beam respectively
For reference beam
As per IS:456-2000, for limit state method

$$Mu = 0.87 \times f_y \times A_{st} \times d \left(1 - \frac{f_y \cdot A_{st}}{d \cdot f_{ck} \cdot b}\right)$$

$$= 0.87 x 500 x 100.53 x 126 \left(1 - \frac{100.53 \times 500}{126 \times 20 \times 150}\right)$$

= **4.78 kN.m**

For beam strengthening using a layer of fabric, additional tensile strength of fabric is required to be added for computation. Thus, the compressive force of concrete (C) is equal to the tensile force of steel (Ts) in the bottom plus the tensile force of fabric in the bottom (Tf1) plus the tensile force of fabric on the sides of beam(Tf2). The fabric in the compression part of the beam is ignored for simplicity in calculations.

Thus,

$C = T_{f1} + T_s + T_{f2} = A_{f1} x\ f_f + A_s x f_s + A_{f2} x\ f_f$
Where,
f_f = tensile strength of either polypropylene or polyester fabric
A_s = Area of steel in tension
A_{f1}=Area of fabric in bottom
A_{f2}=Area of fabric on sides of the beam
For beam with single layer of polypropylene fabric,
As per IS:456-2000, for Fe 500 grade steel
$(x_u)_{max} = 0.46d = 0.46x126 = 57.96$ mm
Thus, C = T
⇨ $0.36 f_{ck} \cdot x_u \cdot b = 0.87 f_y \cdot A_{st} + f_f (A_{f1} + A_{f2})$
∴0.36 X 20 X x_uX 150 = 0.87 (500) (100.53) + 8.45 {(150 X 0.5) + [(150 – 57.96) 2 X 0.5]}
∴x_u= 41.80 mm
$M_u = T_s \times LA_s + T_{f1} \times LA_{f1} + T_{f2} \times LA_{f2}$
= 0.87 X 500 X 100.53 [126 – 0.42 (41.80)] + 150 X 0.5 X 8.45 [150 – 0.42 (41.80)] + 2 X 0.5 X 8.45 [150 – 41.80] X $[(\frac{150-41.80}{2})$+ 41.80 – 0.42 (41.80)]
= **5.39 kN.m**

The analytical value of moment carrying capacity i.e. flexural strength for all other cases is found similarly which is tabulated below. For cases, where $x_u > (x_u)_{max}$,as the section becomes over-reinforced, for moment calculation $x_u = (x_u)_{max}$. The beams on application of polyester fabric analytically became over-reinforced section.

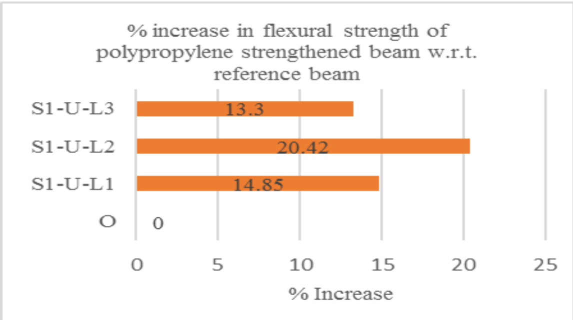
Table 4. Analytical flexural strength

Beam type	M_u (kN.m)
Reference Beam	4.78
Polypropylene Strengthened beam (Single layer)	5.39
Polypropylene Strengthened beam (Double layer)	5.63
Polypropylene Strengthened beam (Triple layer)	6.06
Polyester Strengthened beam (Single layer)	5.72
Polyester Strengthened beam (Double layer)	6.99
Polyester Strengthened beam (Triple layer)	8.28

The analytical values obtained are lesser than the experimental value. One reason may be due to the use of nominal mix design and higher grade of materials for low grade of concrete. Also, the properties of bond between fabric-fabric as well as fabric-concrete has not been touched which may possibly the reason for high experimental values.

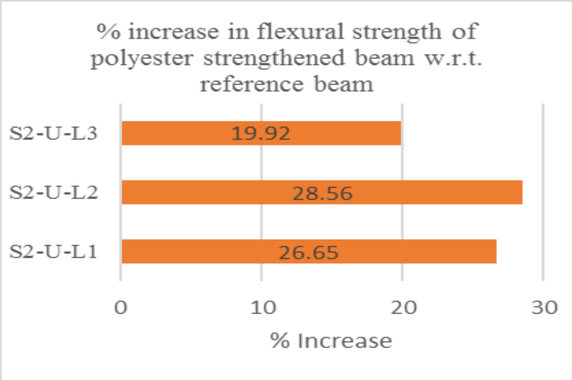
4. Result Discussions:

The %Rise in the moment carrying capacity is shown below. The beam with triple layer of fabric didn't show the expected rise in flexural strength. In fact, it was less than the single and double layer of fabric. The U-shape application of single layer of polypropylene showed an increase of flexural strength by about 14.85%, double layer of polypropylene showed an increase of 20.42% and the triple layer of polypropylene showed an increase of 13.30% with respect to the moment carrying capacity of reference beam. However, there was decrease in flexural strength by 1.55% and 7.12% respectively when compared with beam with single and double layer of externally applied fabric respectively.



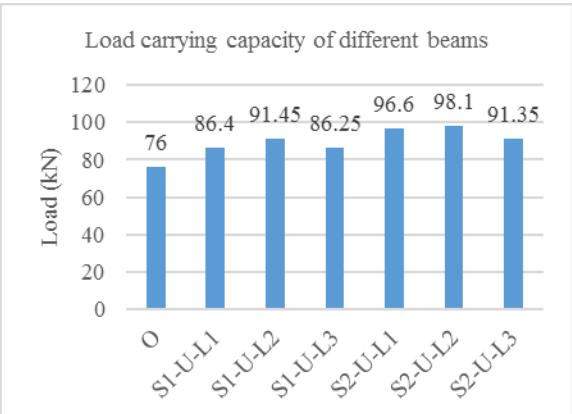
Graph 3. Comparison of %change in flexural strength of polypropylene strengthened beam w.r.t reference beam

The beam with single layer of polyester fabric showed an increase of flexural strength by 26.65%, double layer of polyester fabric showed an increase of flexural strength by 28.56% while the beam with triple layer of fabric showed an increase of flexural strength by 19.92% w.r.t reference beam, it however showed decrease of flexural strength by 6.73% and 8.64% compared to the beam with single and double layer of polyester respectively.



Graph 4. Comparison of change in flexural strength of beams strengthened with polyester compared with reference beam

The ultimate load carrying capacity of these beams as obtained experimentally is given below. The maximum load carrying capacity was obtained with beam strengthened with double layer of polyester. The polyester fabric had in general achieved higher load carrying capacity when compared with polypropylene fabric. The load carrying capacity of single as well as triple layer of polypropylene applied on beam was the same. Hence, the triple layer of fabric is not needed for strengthening. The best option is to use double layer of fabric for the strengthening purpose for either of the fabric.



Graph 4. Load carrying capacity of different beams

5. Conclusion

1. The experimental value of moment carrying capacity and load carrying capacity of reference beam was found to be greater than the analytical value of moment carrying capacity and load carrying capacity of the beam. This may be due to the use of the concrete having higher compressive strength than the selected grade of concrete due to the nominal mix design.
2. The beams with single and double layer of both fabrics showed improved performance in flexure suggesting it can be a good and economical alternative to retrofitting by steel for strengthening of beam.
3. In case of polypropylene fabric, the triple layer of U-shape fabric showed an improvement in strength by about 13.3%. Whereas the beam with triple layer of U-shape polyester fabric showed an improvement in strength by about 19.92%. However, the %increase in flexural strength was less when compared with the double layer of same fabric applied in U-shape. The beam with triple layer of polypropylene and polyester fabric in U-shape showed a decrease of about 7% and 8.64% with respect to the flexural strength of U-shaped double layer of polypropylene fabric and polyester fabric respectively.
4. The results of load carrying capacity and moment carrying capacity was higher experimentally compared to the analytical results. This may be because of the fact that the characteristic compressive strength of concrete was 25.11 N/mm^2 experimentally instead of 20 N/mm^2 used than that meant to be. But the increase in flexural strength is found to be higher analytically compared to the experimental value. For this, a detailed study is required on the behavior of fabric in presence of adhesive and the strength of bonding between the fabric and the concrete surface. This effect might be one of the reasons why the strength of fabric bonded beams was lower than the theoretical.
5. The exact analytical value can be obtained experimentally after thoroughly analyzing the properties of the adhesive bond and using the desired materials adopting the mix design.
6. The deflection at reference beam's ultimate load is less for all the fabrics strengthened beam indicating its ability to withstand the onset of initial crack.

6. References

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