International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 03, March-2019

COMPARATIVE STUDY OF FIBRE REINFORCED POLYMERS USED IN RETROFITTING OF REINFORCED CONCRETE BEAMS

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Abstract-This paper presents an experimental study which details the difference in performance of Carbon fibre reinforced polymer (CFRP),Glass fibre reinforced polymer (GFRP),Steel fibre reinforced polymer (SFRP),Coir fibre (CF) and polypropylene sheets (PS) as retrofitting materials used in reinforced concrete beams.To study behaviour of each material,8 beams were cast and then retrofitted externally with that material, then 4 beams were tested for flexural strength and stiffness while as remaining 4 beams were tested for shear strength. Furthermore cost benefit analysis was done to arrive at the most economical material for retrofitting.

Keywords— retrofitting,fibre reinforced polymer sheets,flexural strength,shear strength,stiffness,externally laminated sheets.

I. INTRODUCTION

Every time a reinforced concrete structure is designed and constructed,it is done so keeping in mind the particular function and a particular performance level that structure has to perform.However, deterioration of the structure with time, change in service loads,change in usage of structure,change in codal requirements call for the need to retrofit the structure so as to maintain or even enhance the performance level and functionality of the already constructed structure.Retrofitting of a structure instead of its complete replacement is the cost effective solution most of the times.So repair and rehabilitation of a structure is to be preferred over building anew .

While there exist many techniques for retrofitting a structure,external retrofitting of structural elements with fibre reinforced polymer (FRP) sheets is considered most simple and effective.Here,FRP sheets are laminated on to the external surface of the structural elements, be it beams or columns,these FRP sheets act as external reinforcement and provide confinement and hence increase the load carrying capacity of the member while at the same time inhibiting the crack propogation in the member.Other properties of FRP sheets which make them desirable as retrofitting material are high strength,low weight,high stiffness and ease of installation.Also, the non-corrosive and non-magnetic nature of the materials along with its resistance to chemicals makes FRP an excellent option for external reinforcement.

Some of the most common materials used as FRP materials include carbon fibre , glass fibre ,steel fibre,coir fibre and polypropylene.Many studies have been carried out to study the effect of using these materials as retrofitting materials which unanimously suggest an increase in strength is achieved on using them,however very few studies comment upon the best material for retrofitting taking into account the increase in flexural strength ,shear strength and stiffness along with economy.

II. OBJECTIVES

The following are the objectives of this experimental study:

- To find the most suitable material for flexural strength enhancement by testing all the beams for flexure and then measuring ultimate loads resisted by each one of them.
- To find the most suitable fibre material for providing flexibility in the retrofitted beams by measuring deflections suffered by beams during loading and checking for maximum deflections.
- To study stiffness behaviour of each beam and check for loss of stiffness due to debonding and cracking.
- To find the behaviour of retrofitted beams in shear and compare that behaviour with that of flexure.
- To provide for cost benefit analysis of each beam and thereby arriving at the most economical material that can be used for retrofitting.
- It may be noted here that beams for shear tests were so designed as to fail in shear before compression. This was ensured by making beams over reinforced in flexural reinforcement and deficient in shear reinforcement. Hence, guidelines as provided by IS 456 were not followed.

Experimental program

In this experiment, two types of RCC beams were cas, one type was used for flexural tests while as the other type was to be used for shear tests. For flexural tests,22 beams were designed and cast as per IS 456 such that they satisfied shear strength criteria for two point loading arrangement test but failed the flexural strength criteria for the same two point load test. For shear strength tests,22 beams were designed and cast as per IS 456 such that they satisfied the flexural strength criteria for one point load test but failed the shear strength .The beam dimensions of 150mm x 150mm x 1000mm were same in all the cases.

III. TESTS FOR FLEXURE

The control beams and the retrofitted beams were tested for the flexural strength. The testing procedure for the all the specimens was same. The beams were cured for a period of 28 days. The surface of control beams is cleaned and washed for clear visibility of cracks. The surface of the retrofitted beams is cleaned with cotton. The two-point loading arrangement is used for testing of beams. This has the advantage of a substantial region of nearly uniform moment coupled with very small shears, enabling the bending capacity of the central portion to be assessed .The load is transmitted through a load cell. The test beam was supported on roller bearings acting as supports. The specimen was placed over the two steel rollers bearing leaving 50 mm from the ends of the beam. The remaining 900 mm was divided into three equal parts of 300 mm.Loading was done by hydraulic jack. Dial gauge was used for recording the deflection of the beams. The deflections of the beams were noted till the appearance of the first crack using dial gauge. The dial gauge was removed after the appearance of the crack and the load was further applied till fracture load. The ultimate load or fracture load was taken as the load at which the needle of load dial on the UTM returned back. The average of the all trials was taken and the load –deflection graph was plotted.

It is found that all the beams were failed in flexure. It is observed that the control beam had less load carrying capacity and high deflection values compared to that of the externally strengthened beams using FRP sheets.

IV. TESTS FOR SHEAR

The same procedure as that used in flexure test was used. However, loading mechanism applied here was that of a single point heavy load with roller supports. The load was placed at the center of the beams which were originally designed to fail in shear. Loading was carried on until shear cracks developed and dial guage turned back. The strengths obtained were noted and results are shown in the form of chart. Although there were improvements in strength in all cases however they were marginal as compared to those in flexure. Here all beams were tested using single point loading to derive values of shear strength. It may be noted here that beams for shear tests were so designed as to fail in shear before flexural faiure. This was ensured by making beams over reinforced in flexural reinforcement and deficient in shear reinforcement. Hence, guidelines as provided by IS 456 were not followed.

V. RESULTS

A. STIFFNESS AND DEFLECTION

The deflection of each beam for two point static loading is analyzed. The deflections of each type of retrofitted beams are compared with the control beam. Also the load deflection behaviour is compared between beams retrofitted with different FRP sheets having the same reinforcement. It is noted that the behaviour of the beams when bonded with FRP sheets are better than the control beams. The deflections are lower for higher loads when bonded externally with FRP sheets. The use of FRP sheet had effect in delaying the growth of crack formation. When all the retrofitted beams are considered it is found that the beams with CFRP sheet wrapping had a better load deflection behaviour compared to the other strengthened beams. It is found to be more effective in improving the flexural strength of the beam. At the load of 89 KN the first crack appeared on the beam. The external strengthening of beams using GFRP also reduced the deflections of the beams to an extent. But it had a less load deflection performance when compared with that of CFRP strengthened beams. The strengthening of beams using steel, coir and polypropylene fibre sheets also enhanced the resistance to deflection under applied load. SFRP retrofitted beams had a better load deflection behaviour than the coir fibre and PFRP retrofitted beams.

Since the full wrapping technique on the three sides is used for retrofitting, initial cracks are not visible. Further with increase in loading, propagation of the cracks took place but it had poor visibility of cracks due to the covering of the FRP sheets. The beams retrofitted with PFRP had the maximum deflections and lower ultimate load carrying capacity. From the graph it is clear that all the FRP retrofitted beams have better load deflection characteristics than the control specimen.

If stiffness is defined as ratio of load carried to deflection suffered under that load then stiffness values of all the retrofitted beams are presented by two values. One value represents stiffness up to 2mm deflection and second value represents stiffness value up to 4 mm deflection. The values for stiffness are calculated for various retrofitted beams and also that of control specimen and then presented in tabular and as well as in graphical form as follows

LOAD DEFLECTION CURVE FOR ALL BEAMS

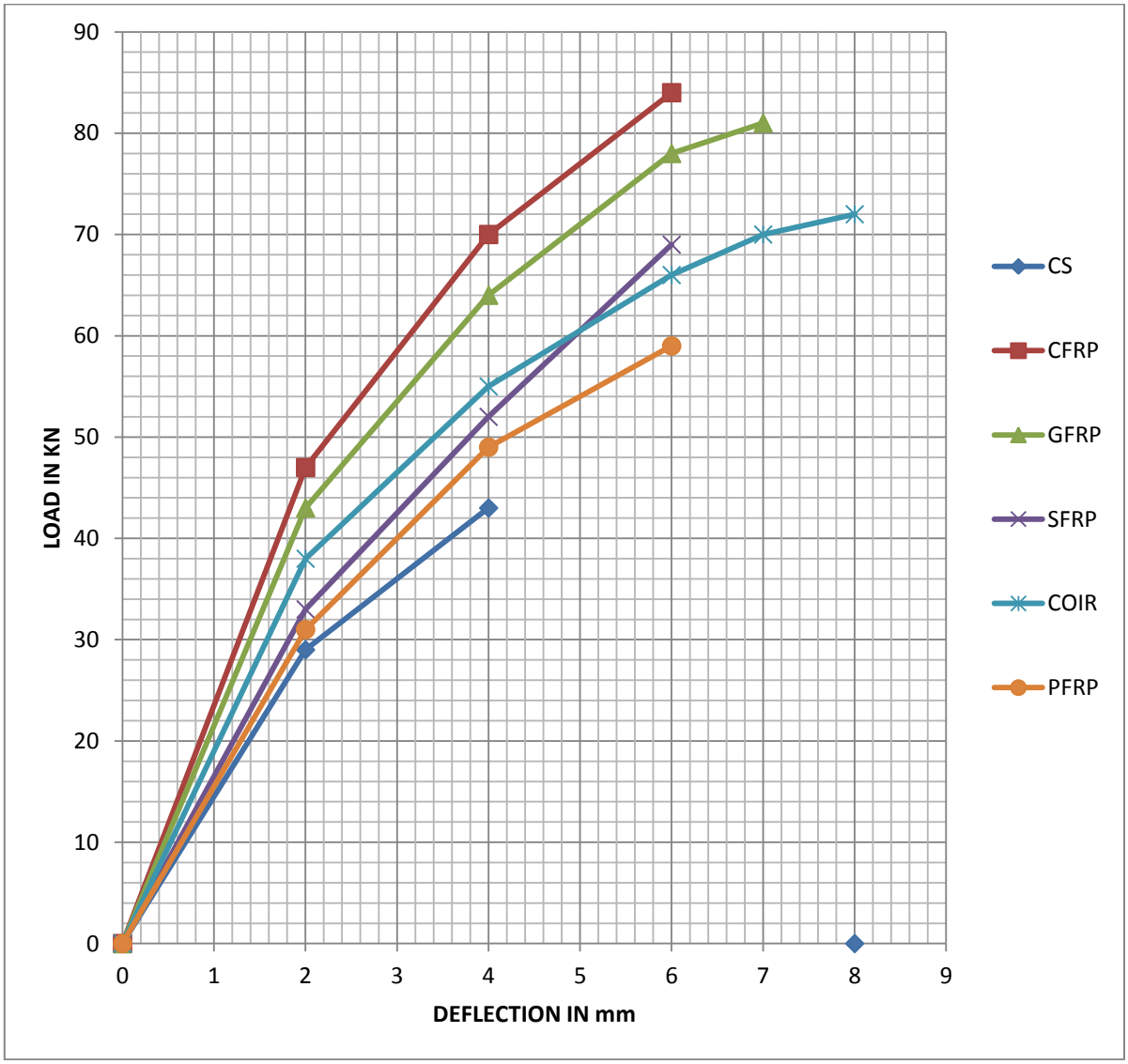
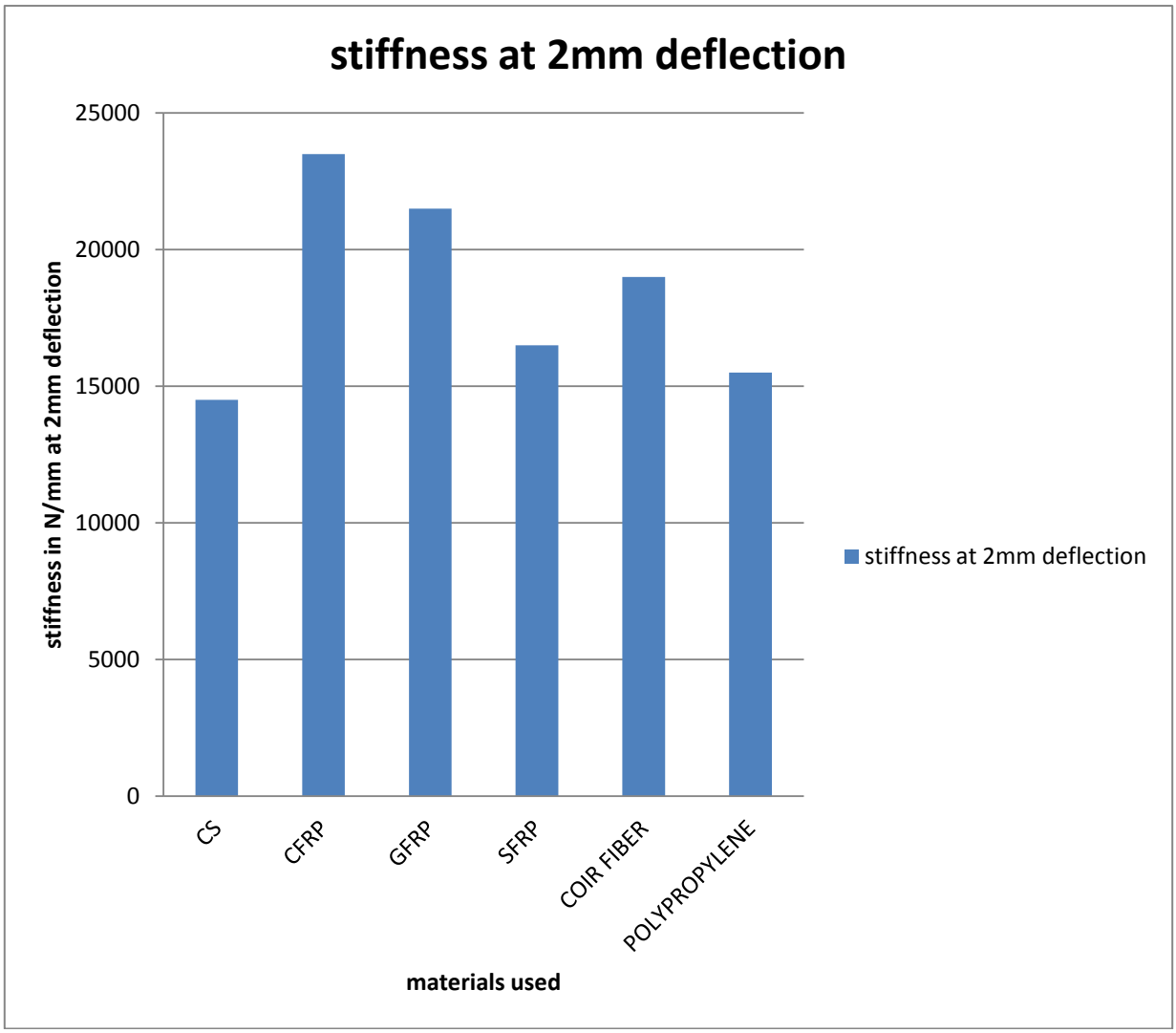


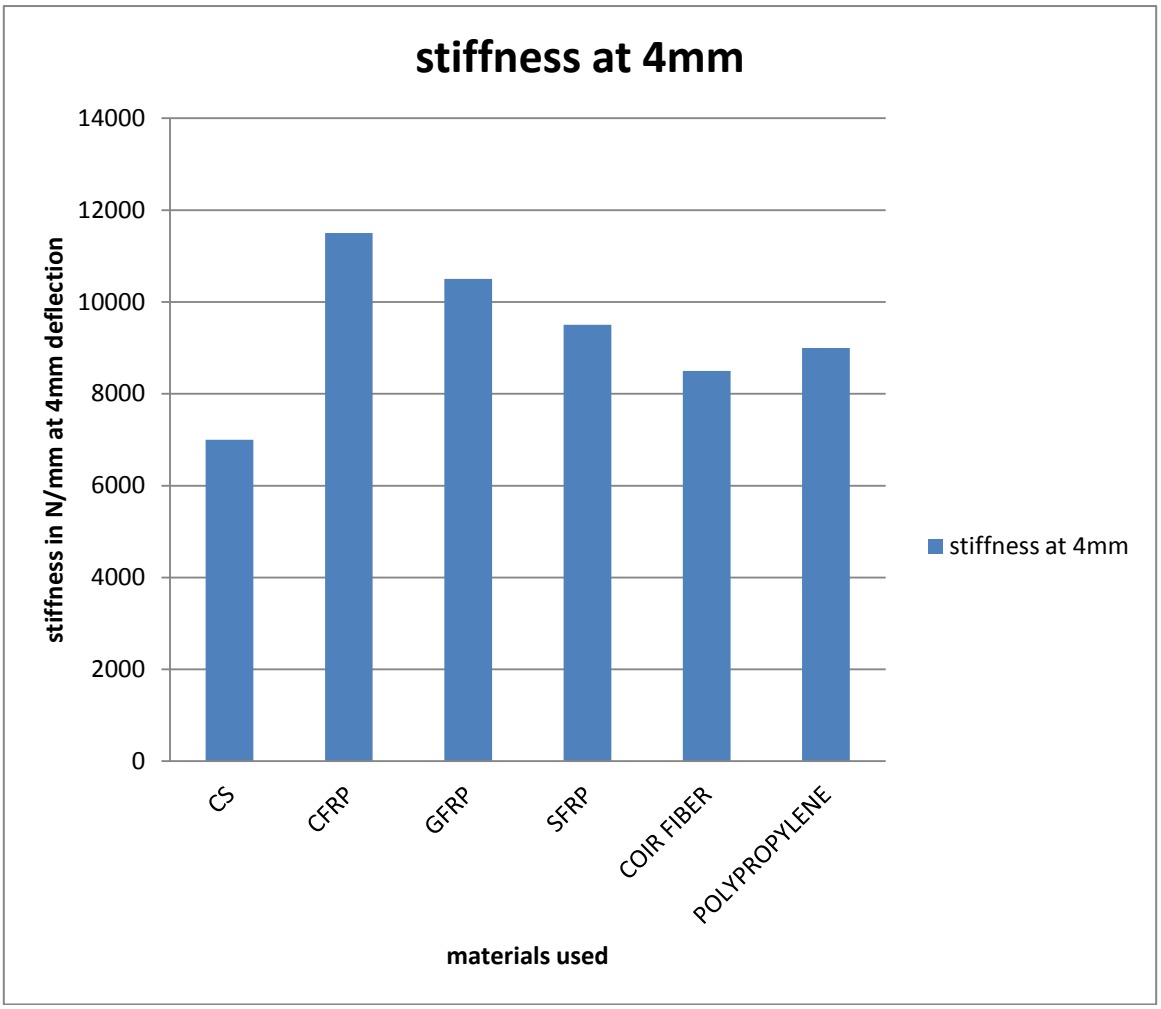
TABLE I
Stiffness values of beams

FIBRE MATERIAL	Stiffness up to 2mm deflection (N/mm)	Stiffness up to 4mm deflection(N/mm)
Control specimen	14500	7000
CFRP	23500	11500
GFRP	21500	10500
SFRP	16500	9500
COIR FIBRE SHEET	19000	8500
POLYPROPYLENE	15500	9000

It can clearly be seen here that all materials are strain softening and this process accelerates once cracks start to appear. Even more curious is the case of coir fibers which loses more than 50% of its stiffness after initial deflection of 2mm. For better understanding of comparison of stiffness of various materials, following graphical representation is helpful.

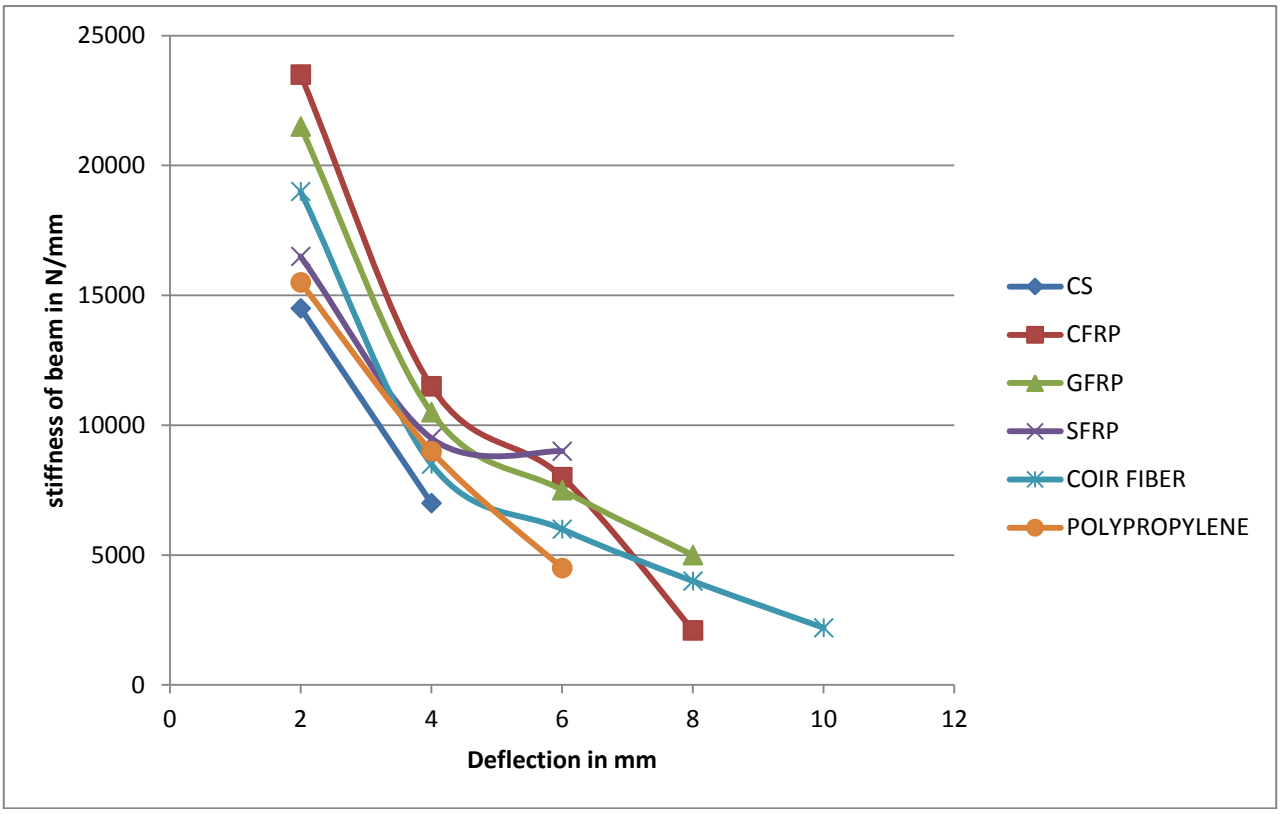


Stiffness values at 2mm in N/mm for various beams



Stiffness values in N/mm at 4mm deflection

Now, a comparison of loss of stiffness will be shown to fully understand deflection behaviour and load resistance mechanism of retrofitted beams.

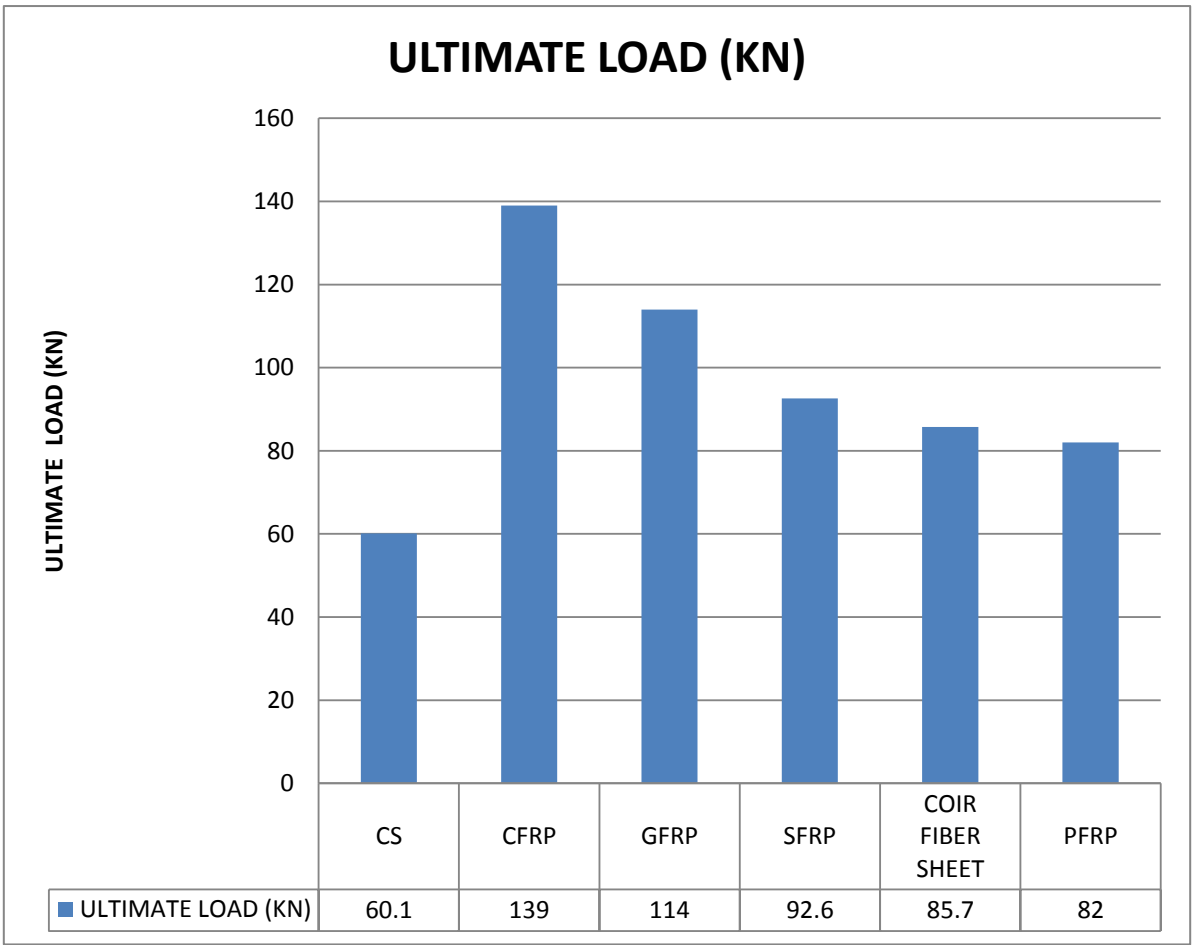


loss of stiffness comparison

As can be seen clearly in this graph that losses in magnitude of stiffness are similar in all cases initially, however coir fibers suffer maximum amount of deflection before problems of debonding and rupture set in. Hence it can be safely said that among all materials tested coir fibers provided the greatest amount of flexibility. Thus coir fibre as a material for retrofitting is best suited to ensure ductile failure in the beam although highest attainable strengths may not be attained.

B. **ULTIMATE LOAD IN FLEXURE**

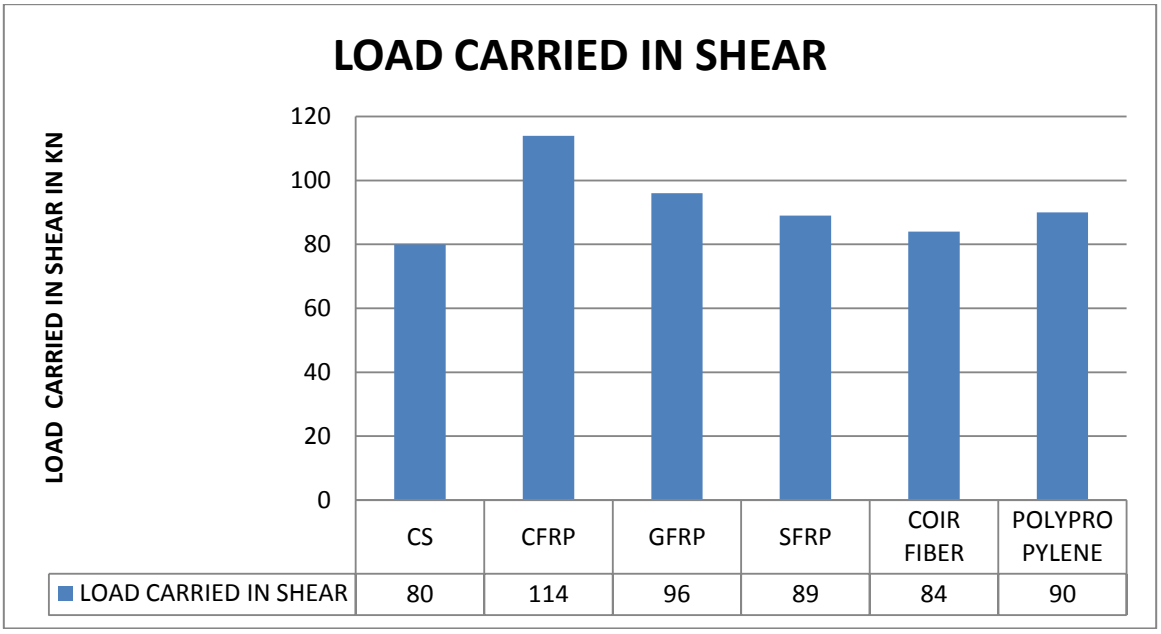
Retrofitting of beams increases the ultimate load capacity of the beams. The control specimen had an ultimate load of 60.1 KN, whereas all the retrofitted beams had an ultimate load greater than 82 KN. The ultimate load capacity of the CFRP retrofitted beams increased by 125% than the control specimen and had the highest ultimate load capacity than all other retrofitted beams. GFRP retrofitted beams had an ultimate load of 114 KN, which 89.6% greater than that of control specimen. Among the five sets of retrofitted beams, the beams retrofitted with PFRP had the least ultimate load carrying capacity and the value is 82 KN, which is 36.4% greater than the ultimate load capacity of control specimen.



Ultimate loads carried in flexure by retrofitted beams

C. LOADS CARRIED IN SHEAR

The maximum shear load was carried by beam retrofitted with CFRP and it was 114 KN .However more important to note here is the amount of shear strength enhancement obtained due to retrofitting .compared to flexural strength the shear strength enhancement was lesser of the value as low as 10% in many of the cases. Hence, it can be fairly said that shear strength enhancement due to retrofitting may not be the best option.



shear strength of beams

VI. EFFICIENCY OF FIBRE POLYMERS

A.EFFICIENCY FACTOR

To arrive at a more representative and practical result we may use the concept of efficiency. To determine efficiency, a formula is being suggested here that may enable a fair comparison in between different materials.

$$\text{Efficiency factor} = \frac{ultimate\ load\ carried\ by\ the\ beam}{Cost\ of\ construction\ of\ beam} \times 100$$

This efficiency factor has been derived taking into consideration the factors of strength enhancement in flexure and additional cost meted out for retrofitting of the beam.
The reason for selecting ultimate load as one of the factors in determining efficiency is the contrast which it brings in with itself that clearly helps in making visible the improvements different materials bring with themselves. Such a distinct contrast and hence a clearly demarcated efficiency factor is not possible if we use shear strength or stiffness as factors instead of ultimate load in flexure.

B. COST EVALUATION

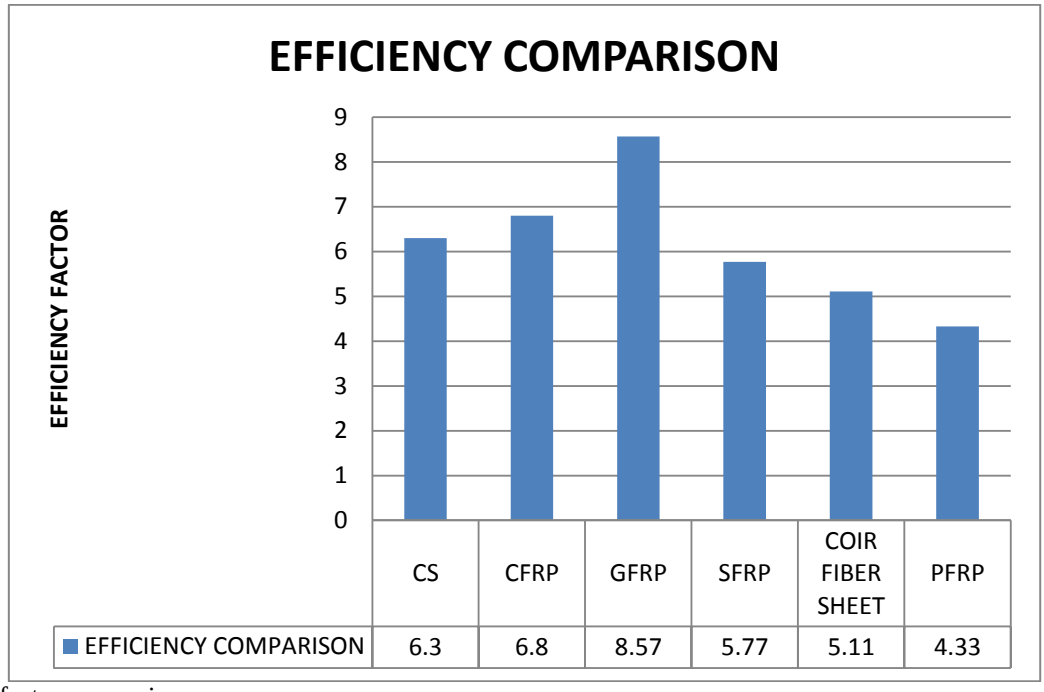
Cost evaluation is carried out as follows:
Cost of CFRP used in casting of one beam = Rupees 1800 @ 2200 per meter square.
Cost of GFRP used in casting of one beam= Rupees 400 @ 400 per meter square.
Cost of SFRP used in casting of one beam = Rupees 600 @ 150 Rupees per kg as 4 kg were used in one beam.
Cost of coir fibre sheets used in casting of one beam = Rupees 700 @ 800 rupees per meter.
Cost of polypropylene reinforced fibre sheets used in casting of one beam = Rupees 1000 @ 1000 rupees per meter.

C. EFFICIENCY COMPARISON

As such using the formula made earlier for efficiency factor, the following values for different materials is as:

TABLE 2
Efficiency factor of beams

MATERIAL	EFFICIENCY FACTOR
CONTROL SPECIMEN	6.32
CFRP	6.80
GFRP	8.57
SFRP	5.77
COIR FIBRE SHEETS	5.11
POLYPROPYLENE SHEETS	4.33



Efficiency factor comparison

Clearly it can be seen here that GFRP is the most economical material when it comes to increase in strength per unit increase in cost. Also it can be seen here that PFRP is least efficient and its strength per unit cost is even lesser than the control specimen. So is the case with SFRP and coir fibre as well.

VII. CONCLUSION

In this experimental investigation the flexural and shear behaviour of reinforced concrete beams externally strengthened by carbon, glass, steel, coir and polypropylene sheets are studied and compared. From the test results and calculated strength values for shear and flexure, the following conclusions are drawn:

- The flexural strength and the cracking moment of the beams improved due to external strengthening of beams with FRP.
- The shear strength of the beams also increased as compared to control specimen , however the gain in strength was very less as compared to that of flexure.
- The deflections of the beams are minimized due to wrapping applied around three sides of the beam.
- Retrofitting of beams made them more stiff and hence more susceptible to brittle failure.
- Among all materials used, coir fibers provided to be most flexible allowing for maximum deflections and hence least susceptible to brittle failure.
- The initial cracks in the strengthened beams appear at a higher load compared to the un-strengthened control beam.
- The strengthening of beams using carbon fibre sheets is found to be more effective in improving the flexural strength and ultimate load capacity of beams.
- The ultimate load capacity of the beams strengthened using carbon fibre sheets is increased by 116% when compared to that of control beam.
- The ultimate load capacity of GFRP, SFRP and coir fibre sheet strengthened beams increased by 89.6%, 54.07% and 42.5% respectively.
- The increase in ultimate load capacity is least for the beams retrofitted with Polypropylene fibre sheets and is increased by only 36.4%.
- Even though the beams retrofitted with CFRP sheets have the maximum ultimate load capacity, the cost of the material is high.
- Retrofitting using GFRP sheets proved to be most economical since its cost is only Rs. 300/m2 and showed 89.6% increase in ultimate load capacity.
- Retrofitting using PFRP sheets is least recommended since its cost is high and increase in ultimate load capacity is less.
- The bonding between the FRP sheet and the concrete is intact up to the failure of the beam which clearly indicates the composite action due to FRP sheets.
- The shear strength increment followed the pattern shown by flexure, that is, shear cracks developed at higher loads and deflections set in at higher loads as well.
- The gain in shear strength was maximum for carbon fibre reinforced polymer beams as was the case with flexure.
- The least gain in shear strength was observed in beams retrofitted with coir fiber , unlike that of flexure where minimal gain was observed in polypropylene retrofitted beams.
- Although the highest gain in shear strength was observed in CFRP retrofitted beams ,however on cost benefit analysis GFRP was found to be most economical material that should be used for shear strength enhancement.
- As can be clearly seen from the tables and charts presented here, that clearly glass fibre reinforced polymer is the most economical material which should be used for retrofitting to prevent both flexural and shear failure.
- Although improvements were seen in both flexural and shear strength because of retrofitting however improvements in shear were very small as compared to those in flexure for all the materials. Hence, retrofitting to enhance shear strength may not prove too effective by using fibre reinforced polymers.
- The loss in stiffness was of similar magnitude in almost all cases, however coir fibers showed greater loss of stiffness as compared to all.

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