THE POTENTIALITIES OF GLASS FIBRE REINFORCED CONCRETE FOR STRUCTURAL USES

Dr. A.H.A.Abdel-Reheem
Civil Eng. Dept.,
El-Mansoura Univ.
El-Mansoura, Egypt

Dr. M.M.Kamal
Building Research Centre, Cairo,
Egypt.

Dr. A.M.El-Hadidy
Textile Eng. Dept.,
El-Mansoura Univ.
El-Mansoura, Egypt.

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خلاصه – يشمل هذا البحث على دراسة سلوك الكمرات الخرسانية المسلحة بتسليح تقليدى مع تسليح اضافى من الالياف الزجاجية التى تم وضعها على هيئة طبقات على مسافات مختلفة مقاسة من اسفل منطقة الشد بالكمراته تم قياس الترخيم والانفعالات الطولية والشروخ الحادثة فى مراحل التحميل المختلفة واقصى تحمل للكمراته وقورنت النتائج بتلك التى سجلت للكمرات الخرسانية المسلحة بتسليح تقليدى وبدون اضافة ألياف زجاجية ، ولقد وجدان اضافة الالياف الزجاجية قد ساهم فى زيادة جساءة الكمرات وبالتالى تقليل التشوهات تحت الاحمال مع تأخير ظهور الشروخ كما ان التحمل الاقصى للكمرات قد زاد.

ABSTRACT - The behaviour of steel reinforced concrete beams having glass fibre layers as additional reinforcement at different heights of the beam tension side was investigated. Deflections, longitudinal strains, initial cracking loads as well as cracking pattern and ultimate failure loads for each beam are presented and discussed. Steel reinforced concrete beams without glass fibres were also cast and tested for comparison. Preliminary tests were carried out on plain concrete beams reinforced with glass fibre layers. The contribution of glass fibre reinforcement lies mainly in increasing the beam flexural rigidity and hence less deformations and higher initial cracking loads and ultimate strength.

1. INTRODUCTION

Fibre addition to reinforce cement and concrete has been the subject of many research during the last three decades (1-9). Fibres investigated included steel, glass, asbestos, carbon fibres, kevlar, nylon polypropylene, polyethylene, polyester and cellulose. However, steel (carbon and stainless), glass (alkali-resistant) and polypropylene fibres have shown higher efficiency and adquate resistance to the alkaline cement environment in comparison with the other types of fibres investigated. Research work on glass fibres reinforced concrete is that limited. Glass fibres are widly used in the Egyptian market in many applications. However, this research was planned to study the behaviour of glass fibre reinforced concrete beams to determine the poteniality of such fibres in concrete structural applications.

2. EXPERIMENTAL ARRANGEMENT AND TECHNIQUE

Because of the unsufficient knowledge available on the proper technique of incorporating glass fibres in concrete structural elements, glass fibres were added at the first begining to the concrete mix during mixing in the mixture with different amounts. In all cases, conglomeration of the glass fibres was occured and it was very diffecult to be uniformaly distributed in the concrete mix. However, new technique was followed by casting the fresh concrete with different heights in the forms and the glass fibres were arranged in layers at choosen positions as longitudinal reinforcement and then concrete casting was continued. Compaction was carried out using both a steel rod and mechanical vibration. Trials were carried out to determine the optimum amount of glass fibres to be used in one layer of a beam without causing separation between the surrounding concrete layers.

The concrete mix used was made from Ordinary Portland cement, sand and gravel. The nominal maximum size of coarse aggregate was 19 mm. The mix proportions by weight were 1 cement : 2 sand : 4 gravel and the water / cement ratio was 0.5 by weight. Four percentages of glass fibres of 0,0.15 %, 0.30 % and 0.45 % by volume of concrete were used with the four sets of plain concrete beams S_1,S_2,S_3 and S_4 and the four reinforced concrete beams B_1,B_2,B_3 and B_4, successively. Alkali-resistante glass fibres commercially available were used in this investigation. The glass fibres used are shown in figure (1) and their properties are shown in Table (1). Properties of the concrete mix used in this research are shown in table (2).

2.1. Preliminary Study

In the early stages of the research, preliminary tests were carried out on plain concrete beams reinforced with glass fibre layers. The tests aimed to find out the difficulties or defects which might occur during casting, compacting or after hardening of concrete and during testing of the beams. The preliminary tests were carried out on twelve concrete beams each of 100 x 100 x 500 mm dimensions representing four sets each of three beams. The beams were reinforced with different amounts of glass fibres in layers at different heights of the beam cross section as shown in Table (3). The first set of beams (S_1) was cast with plain concrete for the whole depth as a reference or control set. The second set of beams (S_2) was cast with glass fibre layer at a height of 25 mms measured from the bottom of the beam. The third set of beams (S_3) was cast with two layers of glass fibres at heights of 25 mm and 50 mms, successevely measured from the bottom of the beam. The forth set of beams (S_4) was cast with three layers of glass fibres at heights of 25, 50 and 75 mms respectively measured from the bottom of the beam. The concrete beams were cured in air in the laboratory atmosphere for 28 days after casting as shown in Figure (2). The beams were testing under three point bending test. The deflection at a mid span point of the beam was recorded under loading up till failure as shown in Figure (3). Compressive strength test was carried on the half beams obtained from the flexure test as shown in Figure (4).

2.2. The glass fibres in reinforced concrete beams

The test results of concrete beams reinforced with glass fibres as main reinforcement were very promissing. However, the research work was extended to study the potentialities of using glass fibres as additional reinforcement for steel reinforced concrete beams.

Four reinforced concrete beams, each of a cross section 120 x 200 mms, a total length of 1800 mms and an effective span of 1600 mms were investigated in this work as shown in Table (4) and Figure (5).

Beam (B_1) is a reference or control beam casted of conventional concrete and reinfoced with traditional reinforcement consists of 2 Ø13 mm mild steel longitudinal bars, stirrups Ø 6 mm with spacing 80 mm and 2 Ø 10 mm stirrup hangers.

Beams (B_2,B_3, and B_4) were typically reinforced with steel bars as beam (B_1) and glass fibre layers were provided to them as additional reinforcement. Beam (B_2) provided with one glass fibre layer at 50 mm from the beam tension side, while beam (B_3) was provided with two glass fibre layers at depths of 50 and 100 mm from the beam tension side successvely. Beam (B_4) was provided with three glass fibre layers at depths of 50, 100 and 150 mm. respectively.

Reinforced concrete beams were cast in concrete forms in which the reinforcement was firstly placed in position. Concrete was casted into layers with certain depth then glass fibres were layerd along the beam length and then casting was continued and compaction was carried out using both compaction steel rod and mechanical vibration.

Beams were tested after 28 days from casting. Two day before testing, the steel Demec points used for measuring beam deformations during carrying out the flexure test were fixed in position. Figure (6) shows locations of Demce points for measuring strains and dial gauges for deflections recording. Beams were tested by the four point loading method with two equal concentrated loads at quarter points and spaced at 800 mm apart.

Loads were applied on successive increments. After each load increment longitudinal strains and deflections were recorded and up till beam failure. Initial cracking load and cracking pattern were recorded with load increment.

3. RESULTS AND DISCUSSION

3.1 Plain Concrete Beams

Tests carried out on the beams reinforced with a layer of glass fibres indicated a distinct enhancement in their behaviour under loading in comparison with plain concrete beams. Flexure rigidity, cracking initiation, carrying capacity and mode of failure were improved .Theenhancement increased with the increase of the number of layers of glass fibres at the different heights of the beam cross-section. Compressive strength of concrete was less affected by the incorporation of glass as shown in Table (5).

Value of maximum deflections recorded at the mid span of the various investigated beams at the different stages of loading are represented in Figure (7). Less deflection was recorded for beams casted with glass fibre layer in the beam tension side than those casted with plain concrete for the whole depth. Lower deflections were recorded at the same load for beams having higher number of glass fibre layers. Cracks appeared in beams reinforced with glass fibre layers at loads higher than that of the plain concrete beams. Deflections of beams of sets S_1, S_2 and S_3 were 64 %, 50 % and 45 % respectively of that recorded for the reference set S_1 and its cracking initiation load. Cracking of glass fibre reinforced concrete set of beams S_2, S_3 and S_4 started at loads 120 %, 125 % and 130 % successively of the initial cracking load of the set of reference beams (S_1). The ultimate carrying capacity of the set of beams S_2. S_3 and S_4 are 124 %, 129 % and 131 % of that of the reference set of beams S_1, respectively.

No sings of longitudinal separation between the glass fibre layers and the surrounding concrete was observed during testing and up till failure. Cracks in the direction of loading started at the tension side of the beams and increased in width and length with the increase of the applied load. At failure no complete separation was observed with beams reinforced with three glass fibre layers which were broken into two parts linked together with oriented longitudinal fibres in the compression zone as shown in Figure (8). Plain concrete beams failed without warrning with complete separation.

The compression test reults indicated a negligible increase in the glass fibre reinforced concrete compressive strength in comparison with plain concrete as shown in Table (5).

3.2. Reinforced Concrete Beams

3.2.1. Deflections

The flexure rigidity of steel reinforced concrete beams was greatly increased with the addition of glass fibre layers at different hieghts of the beam tension side. Measured deflections and corresponding deflection lines at the different stages of loading and up till failure are plotted in Figure (9). For all beams, the deflection curves recorded before cracking are smooth and symetrical about the beams centre. Values of maximum deflection recorded at the critical section of the various investigated beams at the different stages of loading are represented in Figure (9). For the same load, and up-till reference beams B_1 failure, the central deflection of beams provided with glass fibre layers is less than the corresponding value of deflection for the reference beam B_1. The decrease in deflection value increase of glass fibre layers. A summary in terms of a comparison between deflections at three definite stages of loading is as shown in Table (6).

The increase in the beams stiffness with the addition of glass fibres beside the considerable increase in the value of beam initial cracking load stimulate the tangible increase in beam resiliance measured by the area under load-deflection diagram up-till beam initial cracking load Figure (10).

3.2.2. Longitudinal Strains

The comparsions of tensile and compressive strains results showed the potentialities of glass fibres in increasing resistance of concrete to tensile and compressive strains. Longitudinal strains distribution over beams central sections at different stages of loading are represented in Figure (11). The strain distribution for all investigated beams across their central section was nearly linear. Some deviations from linearity were to be expected because of in accuraties in strain measurement, and moreover such deviations appeared to be inconsistent but within the limits of the experimental error.

In general, beams having glass fibre layers (B_2, B_3 and B_4) recorded considerably less longitudinal strains than the reference beam B_1. Comparison between extrem fibre tensile strains for various test beams and also for extreme fibre compression strains at different stages of loading are shown in Figure (12) and Figure (13) respectively. For the initial stages of loading the maximum tensile strain values recorded for beams B_2, B_3 and B_4 are about 77 %, 58 % and 35 % successivelly the value recorded for the reference beam B_1 just before its cracking initiation. However, at the same load, the maximum compressive strain values recorded for beams B_2, B_3 and B_4 are about 75 %, 45 % and 35 % respectively the value recorded for the reference beam B_1. The maximum tensile strain values recorded for beams B_2, B_3 and B_4 are about 75 %, 62 % and 44 % successively the value recorded at the ultimate load of the reference beam B_1. However, the maximum compressive strain values recorded for beams B_2, B_3 and B_4 are about 70 %, 51 % and 42 % respectively the value recorded at the ultimate load of beam B_1.

3.2.3. Cracking and Strength

Crack initiation is tangibly retarted by the presence of glass fibre layers in the tension side of the beam. Crack retardation increased with the increase of the number of glass fibre layers in the reinforced concrete beams as shown in figure (14). Initial crack loads recorded for beams B_2, B_3 and B_4 are 160 %, 180 % and 188 % respectively of the initial crack load recorded for the reference beam B_1. However, it is clear that the improvement in beams behaviour is sligtly affected by the addition of glass fibres layers in the compression zone.

Figure (15) represents the crack pattern recorded at the ultimate load of each of the reinforced concrete beams investigated in this work. In general, cracks were consentrated in the mid span area under the Constant bending moment zone. Crack appeared in glass fibre reinforced concrete beams in finer widths than those appeared in the reference beam B_1. Failure was occured in all beams in the mid span area. However failure of beam B_3 occured at the support because of some defects appeared in this area after casting. However, beams cracking pattern is generally modified as a result of the use of glass fibre as additional reinforcement for concrete beams.

4. CONCLUSIONS

1. To avoid conglomeration, glass fibres were arranged in layers during concrete casting in the forms insted of adding to the concrete mix during mixing.
2. Good bond was occured between concrete and glass fibre layers and no separation was observed after casting or during testing up till beams failure.
3. Introducing of glass fibres as longitudinal layers in concrete beams tension zone during casting increase their flexure rigidity, initial cracking load and ultimate strength. The enhancement increases slightly with the increase of number of layers.
4. The gain in beam crack load is more pronounced than its gain in ultimate strength due to the incorporation of glass fibre layers as additional reinforcement for concrete beams.
5. The improvement in beams behaviour is mainly affected by casting the glass fibres layers in the beam tension side. However the effect of the additions glass fibre layers in the beam compression zone has a slight effect on its behaviour.
6. Glass fibres as non corroded material could find wide applications in concrete structural and semi-structural elements exposed to hostile environments.

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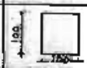
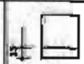
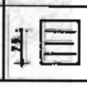
Table (1) : Structure and Properties of Glass Fibre

Filament length (cm.)	23.9
Specific gravity (g/cm³)	2.54
Breaking elongation (%)	4.8
Elastic recovery (%)	100
Average toughness	0.37
Effect of moisture	None
Effect of sunlight	None
Cross-section	Circular
Surface roughness	Smooth
Effect of acids and alkalis:	Resist most acids and alkalis.

Table (2) : Concrete Properties

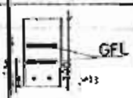
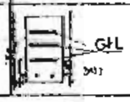
Mix Proportions C : S : G	Cement Content Kg/m³	Cube Compressive Strength (N/mm²) 28 days age	Flexural Strength (N/mm²) 28 days age	Modulus of Elasticity (KN/mm²) 28 days age
1 : 2 : 4 W/C = 0.5	350	32	6.2	25

Table (3) : Test program for the investigated plain concrete beams

Set No.	Number of specimens	Type of concrete	Dimensions of specimens	Tested property	Beam cross-section
1	3	Plain concrete		- Deflection	
2	3	Glass fibre	100 x 100 x 500 mm	- Flexure strength	
3	3	reinforced concrete		- compressive strength	
4	3				

—— GFL

Table (4) Test Program for the Investigated Steel Reinforced Concrete Concrete Beams

Beam No.	Breadth mm.	Depth mm.	Steel Rft. A_s	% A_s/bd	Stirrups Diam. Ø mm.	Stirrups Spacing	Cross Section Configuration	% Glass fibres/bd by vol.
1	120	200	2 Ø 13 (265.3) mm	1.3	6	80		0.0
2	120	200	2 Ø 13 (265.3) mm	1.3	6	80		0.15
3	120	200	2 Ø 13 (265.3) mm	1.3	6	80		0.3
4	120	200	2 Ø 13 (265.3) mm	1.3	6	80		0.45

- Steel bars
- Glass fibres layer (GFL)
- Total span of the beam = 1800 mm
- Effective span = 1600 mm

Table (5) : Flexure and compression test results of the investigated glass fibre reinforced concrete beams

Set No.	Flexure Test: Cracking moment KN.mm.	Flexure Test: Ultimate moment KN.mm	Compressive Strength N/mm²
S_1	-	105	32
S_2	120	130	32
S_3	125	135	34
S_4	130	138	35

Table (6) : Comparison Between Beam Deflection at Different Stages of Loading

Stage of Loading	Central defl. for beam/central defl. for B_1 %		
	B_2	B_3	B_4
Cracking load of beam B_1	67	61	57
Cacking load of each beam	86	78	66
At load just before failure	92	80	67

Figure (1) : Glass fibres used

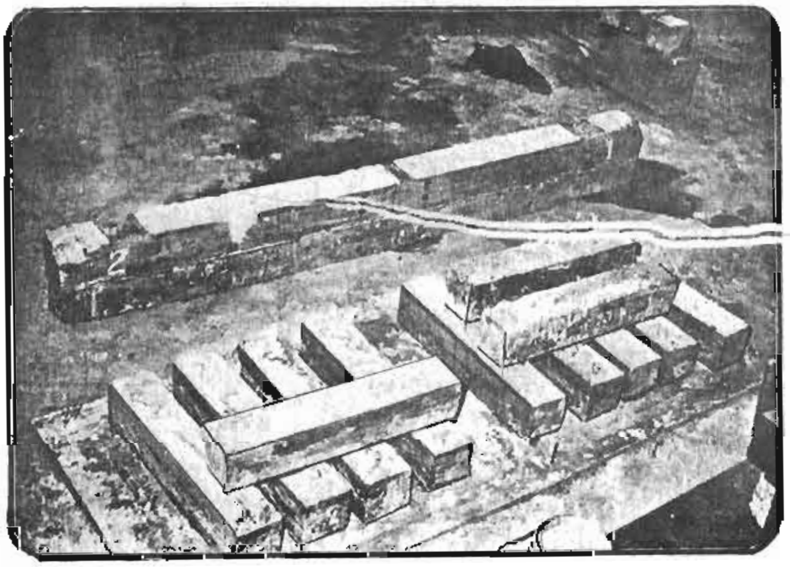
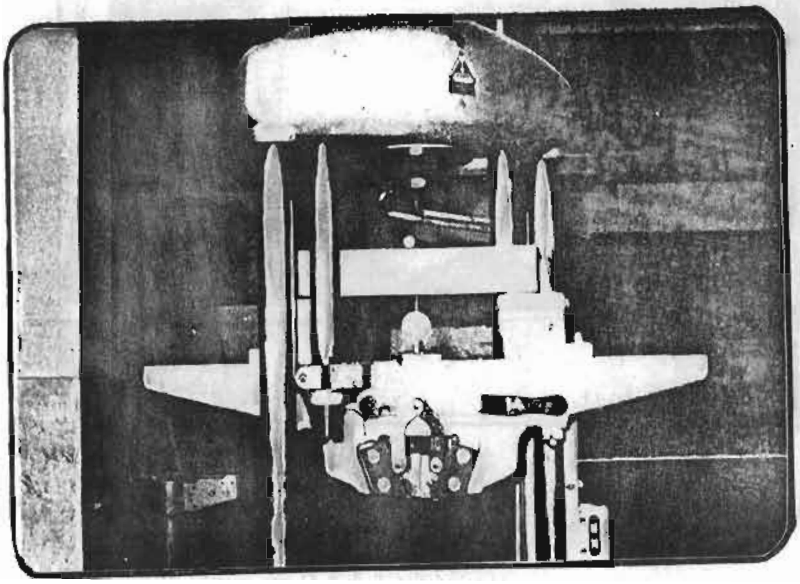


Figure (2) : Curing of beams in laboratory atmosphere.



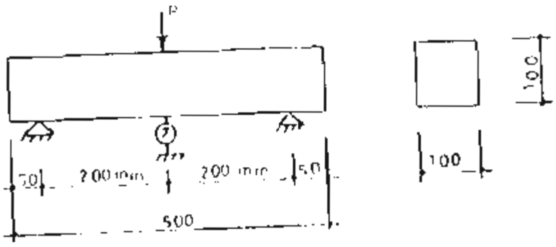


Figure (3) Three point bending test

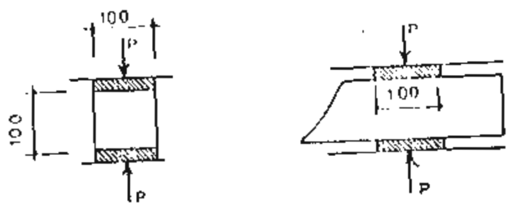


Figure (4) Compression test

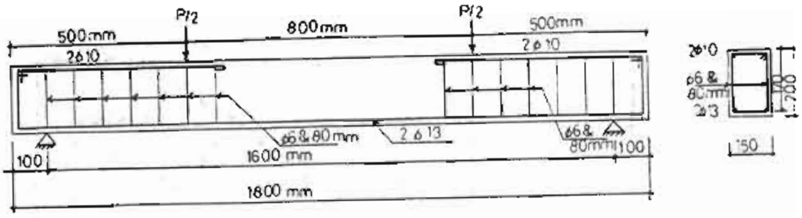
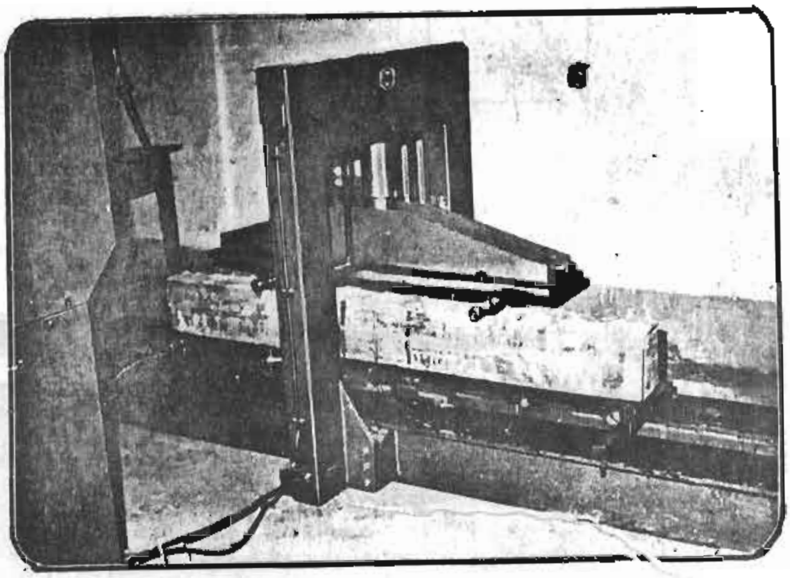


Figure (5) Typical Reinforcement for Investigated Reinforced Concrete Beams.



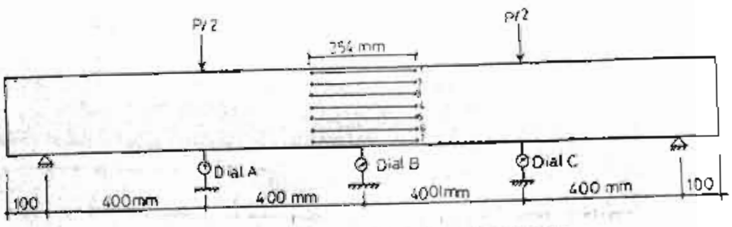


Figure (6) Points of deflection and strain measurements on beams

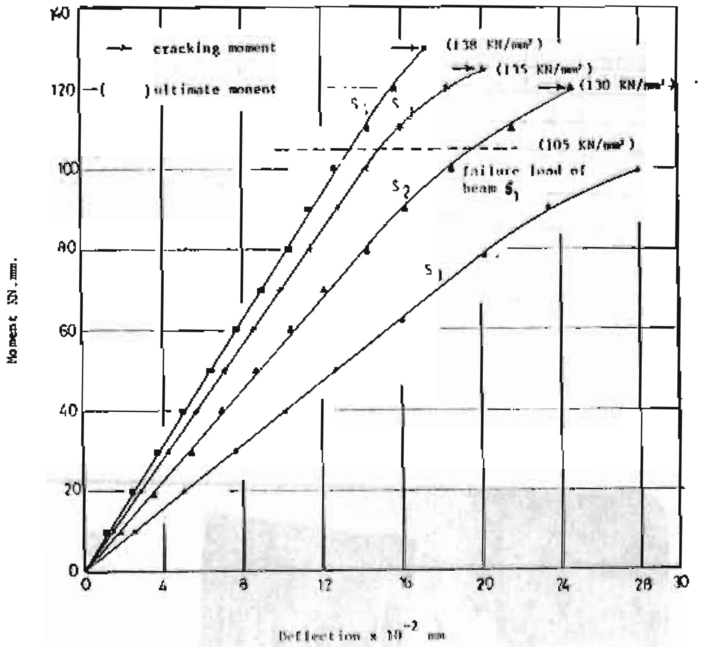


Figure (7) Comparison between maximum deflection values at different stages of loading of glass fibre reinforced concrete beams

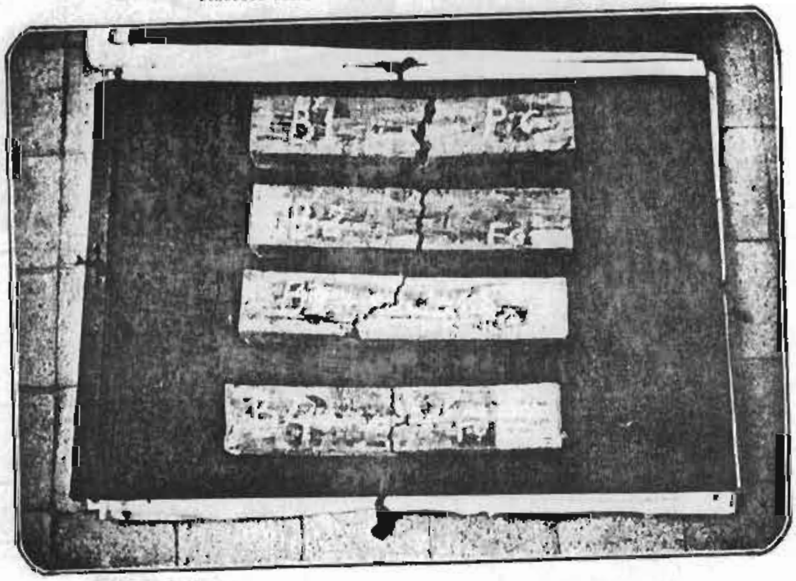


Figure (8) : The tested glass fibre reinforced concrete beams

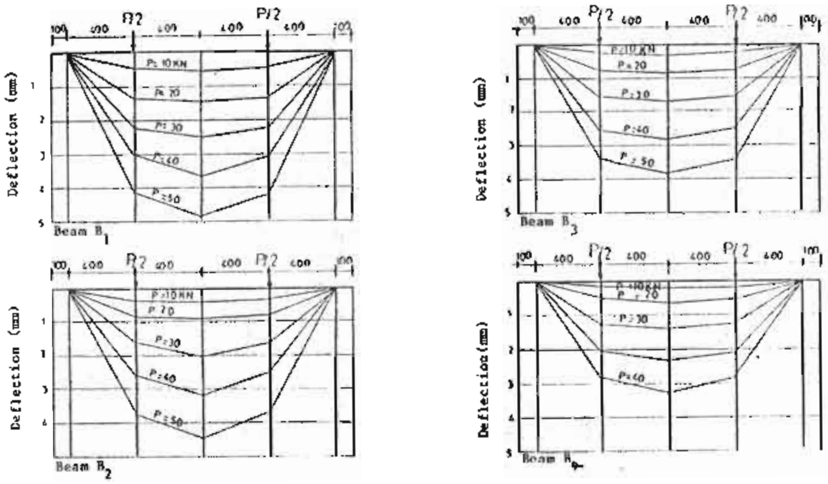


Figure (9) Deflection Line Curves

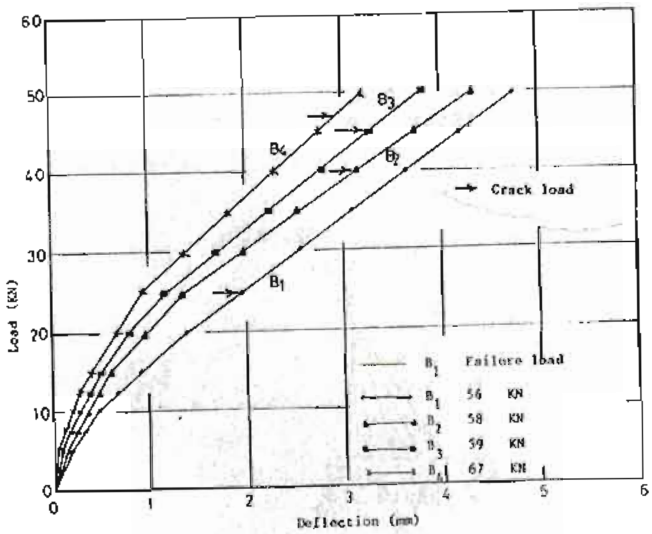


Figure (10) Comparison between maximum deflection values at different stages of loading of steel reinforced concrete beams

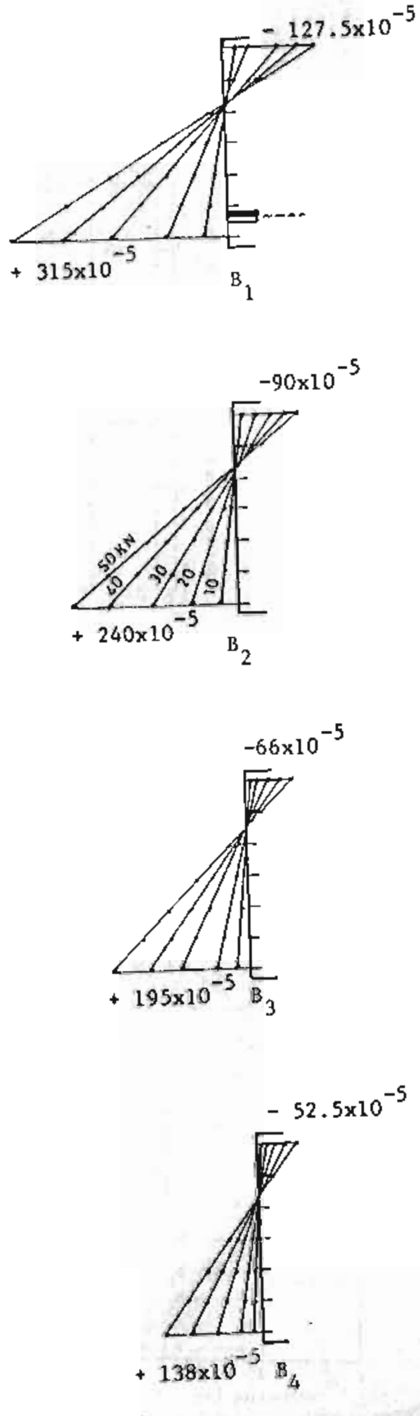


Figure (11) Strain distribution on the central section of reinforced concrete beams.

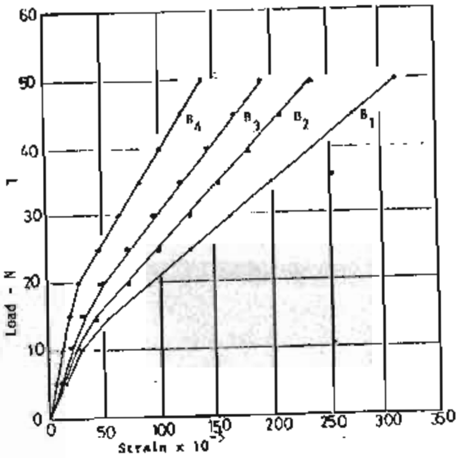


Figure (12) Extreme fibre tensile strain for tested beams

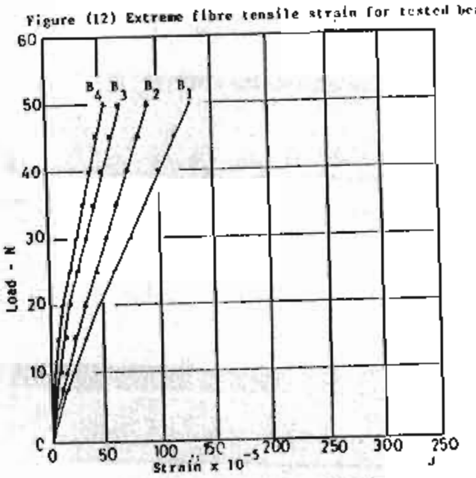


Figure (13) Maximum compressive strain in concrete on the central section of tested beams

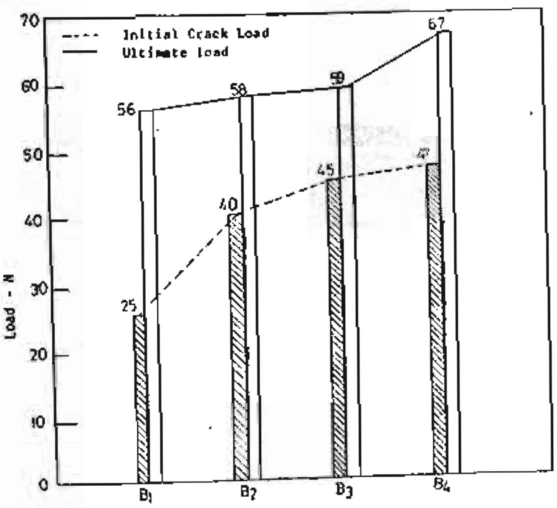


Figure (14) Effect of glass fibre on beam initial crack and ultimate loads.

(B_1)

(B_2)

(B_3)

(B_4)

Figure (15): Crack pattern of steel fibre rinforced concrete beams with glass fibre layers as additional Reinforcement.