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FLEXURAL BEHAVIOUR OF CONCRETE BEAMS REINFORCED WITH GLASS FIBRE REINFORCED POLYMER BARS

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Abstract: Corrosion of steel reinforcement is one of the main problems facing the construction industries throughout the world. Many methods have been used to minimize the problem but without success. Thus, more durable reinforcements are highly needed to replace conventional steel. Glass Fibre Reinforced Polymer (GFRP) bars provide a good alternative reinforcement due to its non-corrodible characteristic. This paper presents the flexural behaviour of concrete beams, each measuring 150 x 255 x 2400 mm and reinforced with GFRP and stainless steel bars. The performance of the beams was analysed in terms of their load carrying capacity, load-deflection, load-concrete strain, load-reinforcement strain, cracking and mode of failure. The experimental results show that beams reinforced with GFRP bars experienced lower ultimate load, lower stiffness, and larger deflection at the same load level compared with control beam. However, the performance of the GFRP reinforced concrete beams improved slightly when stainless steel mesh was used as shear reinforcement.

Keywords: *GFRP, Stainless Steel, Concrete Beams, Flexural Behaviour*

Abstrak: Pengaratan tetulang merupakan salah satu masalah utama yang dihadapi dalam industri pembinaan di seluruh dunia. Banyak kaedah telah digunakan untuk meminimakan masalah tersebut namun tidak berjaya. Oleh itu tetulang yang lebih lasak adalah diperlukan untuk menggantikan tetulang konvensional. Bar Polimer Bertetulang Gentian Kaca (PBGK) memberikan satu tetulang alternatif berdasarkan sifatnya yang tidak karat. Kertas kerja ini membentangkan kajian ke atas kelakunan lenturan rasuk konkrit, setiap satu berukuran 150 x 255 x 2400 mm dan ditetulangkan menggunakan bar PBGK dan keluli tahan karat. Prestasi rasuk dianalisis melalui kapasiti tanggung beban, beban-pesongan, beban-terikan konkrit, beban-terikan tetulang, keretakan, dan mod kegagalan. Keputusan ujian menunjukkan rasuk konkrit bertetulang PBGK mempunyai beban maksimum yang rendah, kekukuhan yang rendah, dan pesongan yang besar pada beban yang sama berbanding dengan rasuk kawalan. Walau bagaimanapun, apabila jejaring tetulang tahan karat digunakan sebagai tetulang ricih, prestasi rasuk bertetulang PBGK telah bertambah baik.

Katakunci: *PBGK, Keluli Tahan Karat, Rasuk Konkrit, Kelakunan Lenturan*

1. Introduction

The alarming problem of steel corrosion in reinforced concrete structures leads to the requirement for more durable concrete and corrosion resistant reinforcement to be used for structures where the risk of corrosion is high. One of the methods to enhance the durability of concrete is by the incorporation of pozzolanic materials such as slag, silica fume, and fly ash (Osborne, 1998) in the concrete mix. As for durable reinforcement, stainless steel is one of the options. However, the cost of stainless steel is very expensive compared to carbon steel. Thus, the search for less expensive and more durable reinforcement continues.

In the last two decades, researchers explore the possibility of using Fibre Reinforced Polymer (FRP) materials to be used as concrete reinforcements (Taerwe and Matthys, 1999). The FRP is made of continuous fibre filaments embedded in resin matrix to form various types of shapes such as bars, structural sections, plates, and fabric. Three types of FRP materials commonly available in the market are Carbon Fibre Reinforced Polymer (CFRP), Aramid Fibre Reinforced Polymer (AFRP), and Glass Fibre Reinforced Polymer (GFRP). Many studies have been conducted on the use of CFRP plate and fabric as strengthening material for reinforced concrete beams and columns (Fanning and Kelly, 2001; Mohd.Sam et al., 2002).

Nowadays, the GFRP bar available in the market is manufactured in the same form and diameter as normal carbon steel. Compared with conventional steel the GFRP bars offer more benefits such as high tensile strength to weight ratio, corrosion free, lightweight, non-magnetic, and non-conductive (Saadatmanesh, 1994). However, despite those benefits, the GFRP bars have low elastic modulus and behave elastically up to near failure (Clark, 1994). These two characteristics may affect the behaviour of concrete beams reinforced with such reinforcement, i.e. the stiffness and mode of failure. As from the structural point of view the stiffness is an important aspect to be considered since it affects the load carrying capacity of the member and the deflection at service load.

This paper presents the suitability of GFRP bars to replace the conventional steel as the main tensile reinforcement. The short-term flexural behaviour of concrete beam reinforced with GFRP bars was investigated. The behaviour of the GFRP reinforced concrete beam was compared with concrete beam reinforced with stainless steel bars. The effect of stainless steel mesh as shear reinforcement on the flexural performance of the GFRP reinforced concrete beam was also studied.

2. Methodology

Three reinforced concrete beams were cast and tested to failure. The overall dimensions of the reinforced concrete beam tested were 150 x 255 x 2400 mm. The control beam, B1SSL, was reinforced with 3@16 mm diameter deformed austenitic stainless steel bars whilst the other two concrete beams, B2GL and B3GM, were reinforced with 3@16 mm diameter E-glass GFRP bars. The shear reinforcement for beams B1SSL and B2GL was provided using a 6 mm diameter plain stainless steel bar. Stainless steel mesh type 304 with a diameter of 3 mm and 50 mm square opening was used as shear reinforcement for beam B3GM. All of the beams tested were designed to fail in flexure.

High-strength and high-performance concrete with an average strength of 60 MPa at 28 days was used throughout the study. The compositions of the concrete consisted of ordinary Portland cement, ground granulated blastfurnace slag, silica fume, coarse aggregate, and natural river sand. The coarse aggregate used in concrete mix was a combination of crushed and uncrushed gravel with the nominal diameter of 10 mm. The water-cementitious ratio used was 0.45. Superplasticizer at a dosage rate of 1.0% of the total cementitious materials was used producing the slump of fresh concrete in the range of 150 to 180 mm. The concrete mix proportions used in the investigation are shown in Table 1.

Table 1: Concrete mix proportions

Cementitious materials (kg m^{-3})			Aggregates (kg m^{-3})	
OPC	Slag	Silica Fume	Fine	Coarse
250	80	20	590	1250

All of the beams were cast in steel moulds and manufactured in the laboratory. An electrical strain gauge was bonded onto the middle of the tensile reinforcement to measure the tensile strain during loading. The simply supported beam with the effective span of 2100 mm was tested under four-point loads at the age of 28 days up to failure. The two-point loads were applied in the middle of the beam at a distance of 300 mm apart. The schematic diagram of the beam test set-up is shown in Figure 1. The flexural performance of the beams was studied through the load-deflection, steel and concrete deformation, ultimate load, cracking, and mode of failure of the beams.

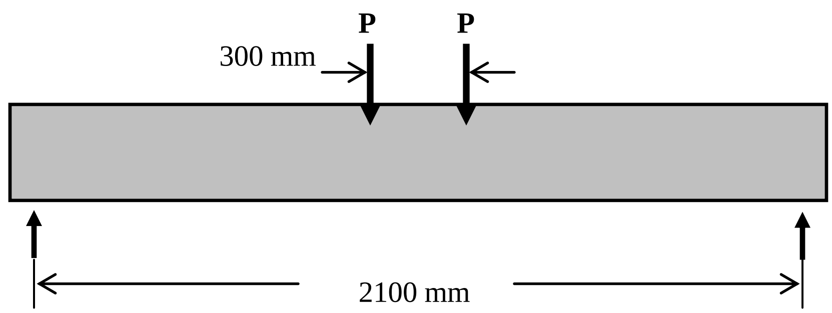

Figure 1: Schematic diagram of the test set-up

3. Results and discussion

3.1 Load-Deflection Behaviour

The short-term load-deflection behaviour of all the beams tested is shown in Figure 2. Initially all beams show relatively linear elastic behaviour up to the cracking load when the concrete cracked at the tension face. Thereafter, the stiffness of the beams, particularly for the GFRP reinforced concrete beams, was reduced at a faster rate, resulting in a larger deflection. This may be due to the effect of low elastic modulus of the GFRP bar compared to stainless steel.

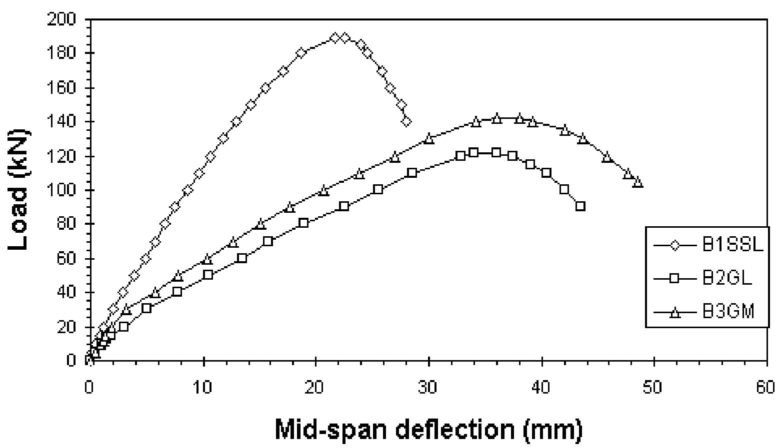

Figure 2: Load-deflection of all beams tested

Comparing the deflection between beams B2GL and B1SSL the former had, for a given load, larger deflection in the order of 2.5 to 3.0 times the deflection of the control beam (B1SSL). The measured deflections at near failure for beams B1SSL and B2GL were 21.7 mm and 35.1 mm, respectively (Mohd.Sam, 1999).

This indicates that direct replacement of steel with GFRP bars, on the basis of the same area replacement, will not produce the same performance as beam reinforced with steel. Thus, some modification in the design has to be considered when GFRP bar is to be used as reinforcement.

The use of stainless steel mesh as shear reinforcement, beam B3GM, resulted in some improvement on the stiffness of the beam. The deflection ratios, at the same load level, between beams B3GM and B1SSL were in the range of 2.0 to 2.7 which show slight improvement as compared with the same beam having links as shear reinforcement. The deflection of the beam near to failure was 34.5 mm. This indicates that the use of stainless steel mesh as shear reinforcement not only provides reinforcement to resist shear load but also increase, to some extent, the stiffness of the beam.

3.2 Ultimate Load at Failure

The ultimate failure loads of all the beams tested are presented in Table 2. The control beam, beam B1SSL, had higher load carrying capacity compared to the GFRP reinforced concrete beam, B2GL, by about 55%. This shows that the low elastic modulus of the GFRP bar had an effect on the load carrying capacity of the beam. As for beam B3GM, the use of stainless steel mesh as shear reinforcement has improved, to some extent, the ultimate failure load of the GFRP reinforced concrete beam by about 16% compared to beam B2GL. This was partly due to the confinement effect of the concrete in the compression zone by the mesh and indicates the effectiveness of stainless steel mesh as shear reinforcement.

Table 2: Ultimate load of all the beams tested

Beam Identification	Ultimate Load (kN)
B1SSL	189
B2GL	122
B3GM	142

3.3 Load-Concrete and Reinforcement Strains

The load-concrete strain at the extreme compression fibre of the beams with respect to the applied load for all the beams tested is shown in Figure 3. Prior to failure the recorded concrete strains for all beams were in excess of 3900 microstrains. In all of the beams tested, the concrete strains follow relatively the same pattern as the deflection. At the same load level, the concrete strain for beam

B3GM was lower than beam B2GL. However, at near failure the concrete strain for beam B3GM reached almost 5000 microstrains. This shows the confinement effect provided by the stainless steel mesh resulting on the increased of the concrete strain capacity.

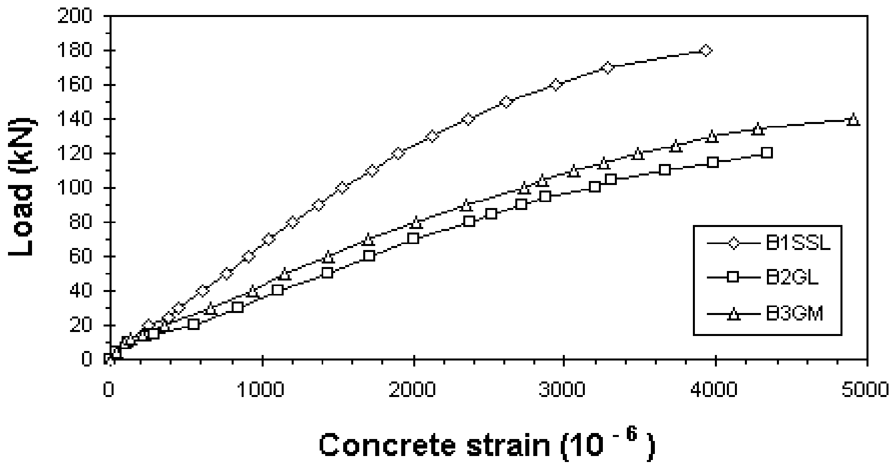

Figure 3: Load-concrete strain for all the beams tested

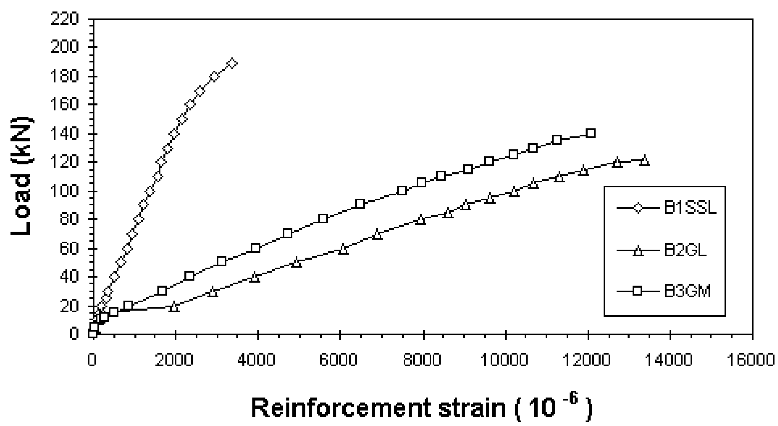

Figure 4: Load-reinforcement strain for all beams tested

Figure 4 shows the load-reinforcement strain relationship for all the beams tested. The recorded tensile reinforcement strains for the GFRP reinforced concrete beams at near failure were in the range of 12000 to 14000 microstrains. These strains correspond to about 66% to 78% of the estimated ultimate strain of the GFRP bar obtained from the tensile test, i.e. 18000 microstrains. This indicates that the GFRP bar did not rupture when the beam failed, and thus eliminating catastrophic failure. On the other hand, for the control beam, the recorded steel strain was about 4000 microstrains. The load-reinforcement strain under load exhibits similar patterns with the load-deflection and load-concrete strain curves.

3.4 Cracking and mode of failure

All of the beams tested failed in flexure with crushing of concrete in the compression zone at the failure stage after the development of flexural cracks. The failure mode and crack pattern of the beams tested are presented in Figure 5.

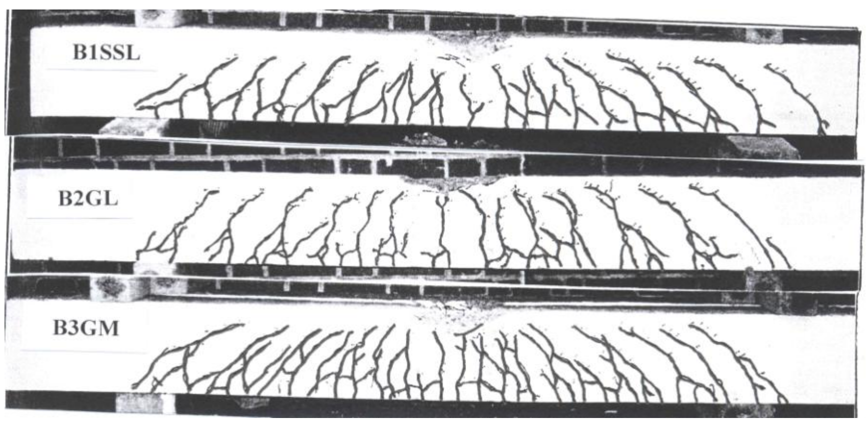

Figure 5: Mode of failure and crack pattern of all the beams tested

Table 3 shows detail of cracks for all beams tested. All of the beams cracked in tension under a relatively small load of about 8% to 11% of their ultimate load. The first visible crack formed between the locations of the two point loads in the region of maximum bending moment. Thereafter, as the load was increased more cracks started to form over the shear span on both sides of the beam. Beam B2GL recorded about 25% less number of cracks and larger crack spacing by about 26.6% compared with the control beam, B1SSL. This may indicate that the stiffness of the GFRP bar had an effect on the cracking behaviour of the beam. In contrast to the control beam and beam B2GL, beam B3GM with stainless steel mesh as shear reinforcement experienced greater number of cracks with smaller crack spacing. The average crack spacing for beam B3GM was about 28% less than the control beam. Thus, it shows that stainless steel mesh can be used to reduce the cracking of the GFRP reinforced concrete beam.

Table 3: Details of cracks for all beams

Beam Identification	Ultimate Load (kN)	First Crack Load (kN)	Total Number of Cracks	Average Crack Spacing (mm)
B1SSL	189	15	20	79
B2GL	122	13	15	100
B3GM	142	12	24	57

4. Conclusions

The main conclusions that can be drawn from this study are as follows:

i) Beam reinforced with GFRP bars showed different flexural behaviour than that of beam reinforced with stainless steel bars due to the low elastic modulus of the bar.

ii) At the same load level, the deflection of the GFRP reinforced concrete beam was about 3 times more than the control beam resulting from the low elastic modulus of the bar. Thus, the deflection, instead of strength will govern the design for concrete beam reinforced with GFRP bars.

iii) The use of stainless steel mesh as shear reinforcement proved to be beneficial in enhancing the stiffness, ultimate load, and cracking performance of the GFRP reinforced concrete beam.

iv) Considerations on the elastic modulus and proper design method are important when GFRP bars are to be used as tensile reinforcement for concrete beam.

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