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GLASS FIBRE REINFORCE POLYMER STRUCTURAL SELECTION AS CONCRETE BEAM REINFORCEMENT

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Abstract: Fibre Reinforced Polymer (FRP) made of a combination of continuous fibre embedded in resin matrix is an advanced composite material that has been identified as a potential new construction material. Some of the advantages of FRP are high tensile strength, lightweight, non-magnetic and durable. Since it is a non-corrodible material it may be used as reinforcement in concrete member. This paper presents the performance of concrete beams reinforced with different types of glass Fibre Reinforced Polymer (GFRP) sections. Two concrete beams, 125x200x2400 mm, reinforced with GFRP I-section and GFRP plate were cast and tested to study their flexural behaviour. Comparison was made with a control beam on the aspect of ultimate load, load-deflection behaviour, load-reinforcement strain behaviour, and mode of failure. The experimental results show that beams reinforced with GFRP sections experienced lower load carrying capacity, lower stiffness, larger deflection and less number of cracks. The failure of the GFRP reinforced concrete beams was either by crushing of concrete at the compression zone or rupture of the GFRP reinforcement.

Keywords: *GFRP; Flexural Behaviour; Concrete Beams; Ultimate Load.*

Abstrak: Polimer Bertetulang Gentian (PBG) diperbuat daripada kombinasi gentian selanjar terbenam dalam matrik resin merupakan bahan termaju yang dikenalpasti berpotensi sebagai bahan binaan yang baru. Di antara kelebihan PBG ialah kekuatan tegangan yang tinggi, ringan, tanpa-magnet dan tahanlasak. Oleh kerana ia merupakan bahan yang tidak karat ia mungkin boleh digunakan sebagai tetulang dalam anggota konkrit. Kertas kerja ini menerangkan prestasi rasuk konkrit bertetulang dengan Polimer Bertetulang Gentian Kaca (PBGK) yang mempunyai keratan berbeza. Dua rasuk konkrit, 125x250x2400 mm, menggunakan keratan-I dan plat PBGK sebagai tetulang telah dibina dan diuji bagi mengkaji kelakunan lenturannya. Perbandingan telah dibuat dengan rasuk kawalan dari segi kekuatan muktamad, kelakunan beban-pesongan, kelakunan beban-terikan tetulang, dan bentuk kegagalan. Keputusan ujikaji menunjukkan rasuk dengan tetulang PBGK mempunyai kapasiti tanggung beban yang rendah, kekukuhan yang rendah, pesongan yang besar dan jumlah retak yang kurang. Kegagalan rasuk konkrit dengan tetulang PBGK adalah sama ada konkrit pecah pada zon mampatan atau tetulang PBGK putus.

Katakunci: *PBGK; Kelakunan Lenturan; Rasuk Konkrit; Beban Muktamad.*

1. Introduction

Nowadays, the construction industries around the world face a major problem due to corrosion of steel reinforcement. The cost of maintenance of any deteriorated reinforced concrete structures is very expensive. Thus, researchers have tried and studied various methods to minimize the problem ranging from developing a more durable concrete to coating the reinforcement with epoxy. Unfortunately, these methods were found to be unable to completely solve the problem. Currently, an Advanced Composite Materials or popularly known as Fibre Reinforced Polymer (FRP) emerge as one of the alternative construction materials and being studied for application in future construction (Saadatmanesh, 1994). These FRP materials, a combination of continuous fibres embedded in resin matrix, have high tensile strength to weight ratio, lightweight, non-magnetic, and non-corrodible (Randall, 1987). Study on the GFRP bars found that the bars have high durability upon exposure to different aggressive environments (Mohd. Sam, 2002). The types of FRP materials generally used in the construction are Carbon Fibre Reinforced Polymer (CFRP), Aramid Fibre Reinforced Polymer (AFRP), and Glass Fibre Reinforced Polymer (GFRP). The FRP materials can be manufactured in various forms such as reinforcement, structural sections, plates and sheets (Bakis et al., 2002). Studies that have been conducted indicate that the CFRP and GFRP plates can be used to strengthen reinforced concrete beams and improving the flexural behaviour of the beams (Mohd. Sam et al., 2002a; Mohd. Sam et al., 2002b; Saadatmanesh et al., 1990). In addition, the CFRP sheet can be optimized to strengthen concrete column where an increase in the ultimate load capacity can be achieved (Mohd. Sam et al., 2002c). This study concentrates on the investigation pertaining to the suitability of GFRP sections as tensile reinforcement for concrete beams as an alternative to the conventional steel.

2. Experimental Design

A total of three reinforced concrete beams were casted and tested to study the effect of replacing steel reinforcement with GFRP sections on the flexural behaviour of the beam. The GFRP sections used were in the form of I-section and rectangular plate made of E-glass fibres having young modulus in the range of 20 to 40 GPa. The overall dimensions of the beams were 125x200x2400 mm with concrete cover of 20 mm. One of the beams, control beam, was reinforced with high tensile steel with a diameter of 12 mm as the main tensile reinforcement; beam B1C. The second beam was reinforced with 2 GFRP I-section, beam B2GI, while the third beam used one 10 mm thick GFRP plate, beam B3GR, as tensile reinforcement. The area of tensile reinforcements for all the beams B1C, B2GI, and B3GR were 453 mm^2, 460 mm^2, and 445 mm^2, respectively. All beams were provided with 6 mm diameter mild steel stirrup and the beams were designed to fail in flexure. Concrete grade 50 was used in the manufacturing of the reinforced concrete beams. Ordinary Portland cement and crushed aggregates with maximum size of 10 mm were used in the concrete mix. All the beams were casted in a steel mould. After compaction the beams were cured in the steel mould for three days before being demoulded. After demoulding, the beams were covered with wet sacks for another four days for curing. All the beams were tested simply supported at the age of 28 days under four-point loading. The schematic diagram of the testing arrangement of the beam is shown in Figure 1. Figure 2 shows the details of beam cross-section and reinforcements used in the study.

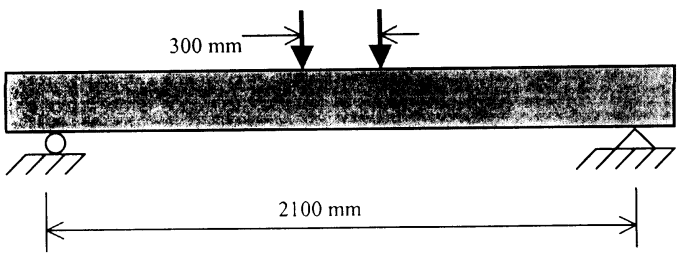

Figure 1: Schematic diagram of testing arrangement

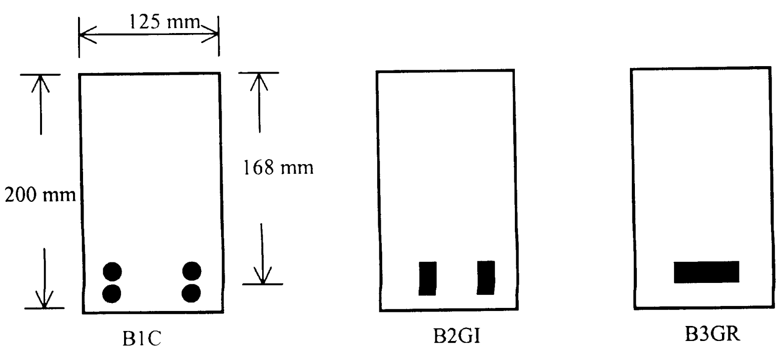

Figure 2: Details of beam cross-section and reinforcements

3. Results and Discussion

3.1 Ultimate load

The recorded experimental ultimate load of the beams B1C, B2GI, and B3GR were 76.6 kN, 46.2 kN, and 29.6 kN, respectively. The results show that beam with GFRP section as main tensile reinforcement produced lower load carrying capacity compared with the control beam. Beam B2GI recorded ultimate load of about 60% of the control beam. On the other hand, for beam B3GR the ultimate load was only 39% of the control beam. This was probably due to the lower elastic modulus of the GFRP section compared with the steel reinforcement. Thus, the elastic modulus of the tensile reinforcement used will have an effect on the stiffness of the beam. Therefore, further study should be conducted to find ways of improving the elastic modulus of the GFRP material. Comparing between beams B2GI and B3GR, the former had higher load carrying capacity by about 56%. This was because of the effect of different arrangement of the GFRP sections used in the beams as shown in Figure 3. The GFRP I-section used in beam B2GI was relatively stiffer than the GFRP plate used in beam B3GR due to its geometrical shape.

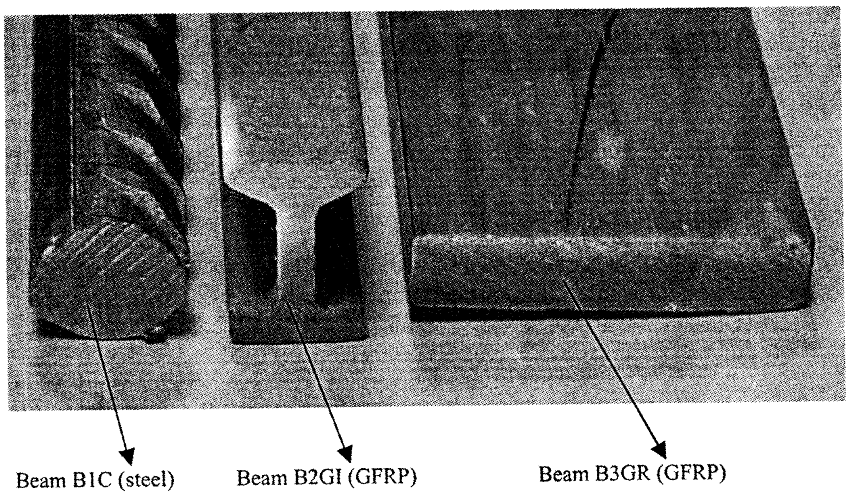

Figure 3: Different type of reinforcements used in the study

3.2 Load-Deflection

The load-deflection behaviour of all the beams tested is shown in Figure 4. Initially all the beams have relatively the same stiffness. However, once the beam cracked, the stiffness of the GFRP reinforced concrete beam decreased at a faster rate compared with the control beam. Thus results in larger deflection of the GFRP reinforced concrete beam. The recorded deflection near failure for all beams B1C, B2GI, and B3GR were about 19 mm, 50 mm, and 32 mm, respectively. It can be seen from the figure that the stiffness of beams B2GI and B3GR was much lower than the control beam. Again, this was due to the lower elastic modulus of the GFRP sections compared with steel reinforcement. At the same load level, the deflection of beams reinforced with GFRP sections was higher by about 4 to 6 times compared with beam B1C. Thus, at service load, the deflection of beam reinforced with GFRP sections will be higher than beam B1C and may not satisfy the design criteria. In addition, larger deflection will also lead to wider crack width of the beam.

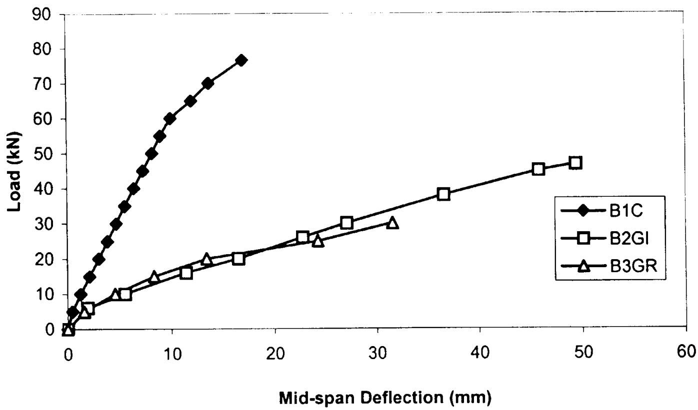

Figure 4: Load-deflection of all the beams tested

3.3 Load-Reinforcement Strain

The tensile strain of the reinforcements was measured and recorded using electrical strain gauges. The load-reinforcement strain behaviour of all the beams tested is shown in Figure 5. It can be seen that the behaviour of the load-reinforcement strain was quite similar to the load-deflection of the beams. An increase in the applied load will increase the tensile strain of the reinforcement. From the figure it can be said that the bond between concrete and GFRP and steel reinforcements was relatively good. This ensures the transfer of tensile load from concrete to the tensile reinforcements. The experimental results also indicated that the strain of the GFRP reinforcement had linear behaviour up to failure. On the other hand, the steel reinforcement had yield point before failure. Thus, in the design process, the aspect of ductile behaviour of the beam needs to be taken into account based on the type of tensile reinforcement used. The recorded tensile strain near failure for beams B2GI and B3GR were about 16,000 and 5,000 micro strains, respectively. On the other hand, the steel reinforcement started to yield at about 3,200 micro strains. Obviously, the behaviour of the steel reinforcement was elastic-plastic while for the GFRP section only experienced elastic behaviour. These different strain characteristics of the reinforcement have to be considered when GFRP section is to be used as concrete reinforcement.

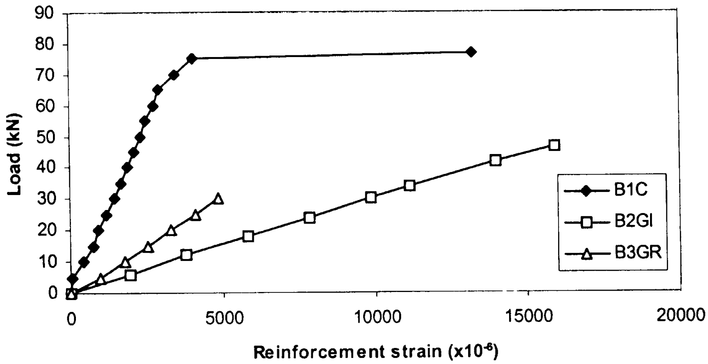

Figure 5: Load-reinforcement strain of all the beams tested

3.4 Mode of Failure

The recorded experimental results show that all the beams failed in flexure. Beam B1C failed as under-reinforced beam with yielding of tensile reinforcement followed by crushing of concrete at the compression zone. As for beam B2GI, the failure was due to the crushing of the concrete at the compression zone. Meanwhile, for beam B3GR, the GFRP rectangular plate was ruptured when the beam failed. This type of failure is not recommended since it will cause catastrophic failure of the structures. The total number of cracks generated for beams B1C, B2GI, and B3GR were 20, 8, and 3, respectively. Hence, beam with lower ultimate load due to lower elastic modulus experienced lower number of cracks compared with beam that has higher load carrying capacity. In addition, the crack spacing for beam B3GR was also larger than beam B2GI and B1C. The measured average crack spacing for beams B1C, B2GI, and B3GR were 90 mm, 170 mm, and 200 mm, respectively. It was also observed that the first crack load of the GFRP reinforced concrete beams, beams B2GI and B3GR, was lower by 50% compared with the control beam. The first crack load for GFRP reinforced concrete beams was 5 kN while for the control beam the value was 10 kN. The schematic diagram of the cracking of all the beams tested in this study is shown in Figure 6.

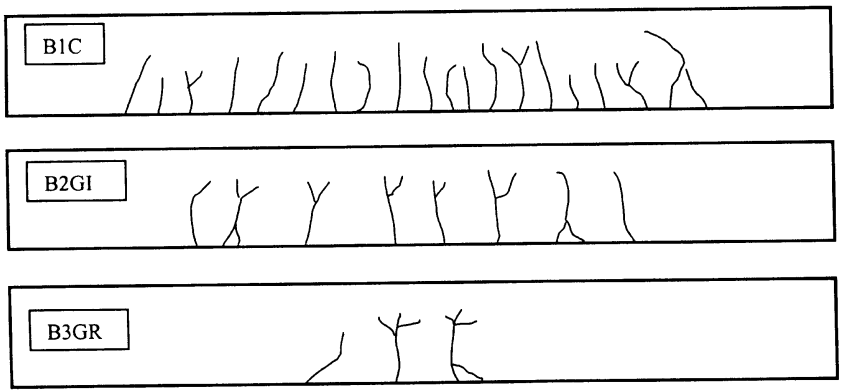

Figure 6: Schematic diagram of the cracking of the beams

4. Conclusion

The main conclusions that can be drawn from this investigation were as follows:

1. Concrete beam reinforced with GFRP sections experienced lower load carrying capacity and stiffness compared with the conventional reinforced concrete beam. This was mainly due to the lower elastic modulus of the GFRP section compared with steel reinforcement.
2. The number of cracks for beam reinforced with GFRP section was lower than the conventional beam. In addition, the average crack spacing of the GFRP reinforced concrete beam was also larger compared with the control beam.
3. The mode of failure for beams reinforced with GFRP sections were slightly different compared with the control beam. The GFRP reinforced concrete beams will fail either by concrete crushing at the compression zone or rupture of the GFRP reinforcement. Failure due to rupture of GFRP reinforcement is not recommended since it may results in catastrophic failure of the structures.

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