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Analysis of the Flexural Behaviour of Glass Fiber-Reinforced Plastic

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ABSTRACT: Glass fibre reinforced polymer (GFRP) profiles are finding increasing applications in civil engineering structures, owing to the several advantages they offer over traditional materials. However, due to the combustible nature of their polymer matrix, there are well-founded concerns about their behaviour at elevated temperature and under exposure to fire. These concerns are hindering the widespread acceptance of GFRP profiles, particularly in buildings, which need to comply with relatively strict requirements in terms of fire reaction and fire resistance behaviour. Even though the GFRP structural shapes are available, the designers of such component are facing problem in the design since reliable design criteria is lacking. Thus there is an urgent need to understand the behaviour of the GFRP structures and their components under various types of loading and support conditions. This thesis reports an experimental and analytical study by using finite element software ANSYS on the flexural behaviour of I-section beams made of GFRP profiles. Tests were first carried out on coupon specimens, in order to determine the material properties of the GFRP specimens used in experimental investigation. Full scale tests were then conducted on simply supported beams with span 800 mm subjected to transverse load at the top flange mid-point. The first part of the paper is aimed at investigating the flexural behavior under service and failure conditions experimentally, the objective of the second part is to study the analytical behavior of the flexural members by simulating the finite element model of the beams using SHELL element in ANSYS. The results obtained confirm that, due to the low Young's modulus and high strength, the beam structural integrity is often governed by excessive deformation criteria or local and global buckling criteria.

KEYWORDS: GFRP profiles; High-temperature properties; Fire resistance; Modelling; Design.

I. INTRODUCTION

Technology is improving day-by-day in utilization of the versatile materials in the engineering structures, which are subjected to the conventional materials and complex loading histories combining cyclic thermal/humidity and mechanical loading. With the limits of the technology pushed, the materials failed to answer the requirements of the designers or manufactures. Researchers in materials technology are constantly looking for solutions to provide stronger, durable materials which will answer the needs of their fellow engineers. GFRP materials are one of the most favoured solutions to this issue in the field. By mixing the stronger properties of traditional materials and eliminating the disadvantages they bear, GFRP materials is providing compromising solutions and alternatives to many engineering fields.

Fibre Glass is generally thermoset with a type of plastic or epoxy resin. When cured, the end product will hold its shape because of the resin, while the fiber glass will provide strength and stiffness. Just as important, the resin has additional corrosion- and heat-resistant properties not found in any type of metal products. This technology has led to increased durability and strength in hostile and corrosive environments such as chemical processing plants, food processing, waste water treatment and sewage centers, etc.,

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Fabric of glass fibres are impregnated with a resin and shaped into the required form. The surface treatment can be different for each supplier. It can be for example a roughening of the surface, forming a continuous thread on the whole surface or also sand coating the specimen. After the surface treatment the resin is cured and the specimen is cut to length. A final step in the production can be a surface coating for giving the fibers, besides the capsuling in resin, an additional protection against alkaline degradation.

Use of Fibre reinforced polymer (FRP) composites for construction of new structures and rehabilitation of existing structures has increased significantly over past decades. FRP composites are lightweight, non-corrosive, exhibit high specific strength, and specific stiffness, are easily constructed, and can be tailored to satisfy performance requirements.

For structural applications, FRP composites are typically fabricated using a polymer matrix, such as epoxy, vinyl ester, or polyester, and reinforced with various grades of carbon, glass, and/or aramid fibers. Due to its advantageous characteristics, FRP composites have been included in new construction and rehabilitation of structures through its use as reinforcement in concrete, bridge decks, modular structures, formwork, and external reinforcement for strengthening and seismic upgrade. While the mechanical advantages of using FRP composites are widely reported in literature, questions remain in regards to the feasibility of FRP composites within the framework of a sustainable environment.

GFRP material is one of the most favoured solutions to this problem in the field. Glass Fibre Reinforced Polymer (GFRP) is one such alternate material, having high strength to weight ratio. GFRP materials are very light weight in comparison with steel, having specific gravity one third of steel. This is a corrosion resistant material and saves the galvanizing cost which is mandatory in case of steel tower or poles.

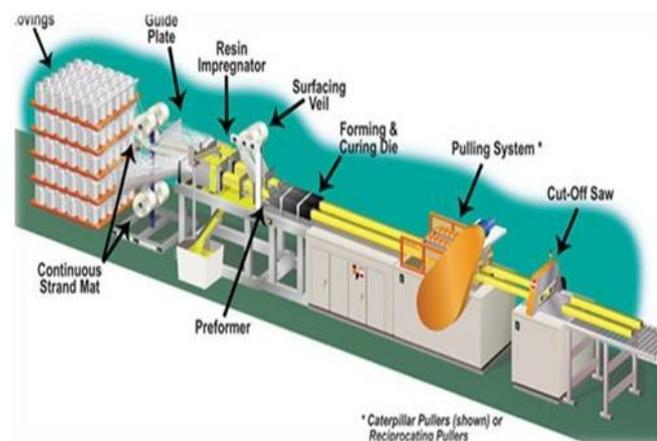


Figure 1: Process Of GFRP Structural Sections.

The manufacturer uses caterpillar style 'pullers' to pull the finished part to the cutoff saw where it will be cut to the desired length. The end result is a high-strength profile ready for use when it leaves the machine. products provide designers and engineers with the benefits of high strength - to weight ratio, corrosion resistance, excellent dielectric properties, and dimensional stability. GFRP sections are produced or manufactured by a process called as shown in the figure 1.

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Vol. 6, Issue 10, October 2017

II. LITERATURE REVIEW

Mottram J.T. (1992) have been compared the short-term critical loading for linear elastic lateral-torsional buckling of a I-beam with theoretical predictions. In the buckling experiment, an E-glass reinforced polymer I-beam was simply supported about the major axis, and supported at both ends such that lateral deflection, warping and twist were restrained. It was subjected to a central point load applied to the top compression flange. The experimental evidence for critical loading was shown to compare favourably with the predictions using a finite difference method. The finite difference approach is used to solve the governing differential equation derived using thin-walled theory. Through the finite difference and other analytical models, he has shown that the classical one-dimensional isotropic theories can be adapted, by suitable substitution for the moduli parameters, to predict the buckling load for composite beams made from orthotropic panels.

Charles N. Rosner et al (1995) have conducted studies on the behavior of bolted connections GFRP in plates. A total of 102 single-bolt connections were tested. It was observed that in the use of specimens with in small edge distances, the failure changed from net-tension to cleavage failure as width of plate to diameter of the bolt (w/d) ratio was increased. In specimen with large edge distances, the failure changed from net-tension to bearing failure by increasing the (w/d) ratio.

Nahla K. Hassan et al (1996) have conducted 3D FE analysis on single and multi-bolted connections to determine the failure process. The strains and load displacement relationship of the specimens were studied with the fibre orientation of 0°, 45° and 90° with respect to the load. Analytical results shows that the magnitudes of the net tensile stresses are very high near the hole boundary and decreases rapidly away from the bolt hole at a distance equal to the hole diameter.

Turvey G.J. (1996) have done a series of lateral buckling tests on a GRP I-section cantilever beam. The cantilever, which had spans ranging from 0.5 to 1.5 m, was subjected to point loads applied above, at and below the centroid of the free end cross-section. Vertical and horizontal deflections and the rotation of the free end cross-section were recorded as the beam was loaded and unloaded. Lateral buckling loads computed from modified simple closed form formulae and finite element eigen value analysis were compared with the maximum test loads. The tests showed that significant vertical free end deflections develop before the cantilever buckles laterally and it is concluded that the effects of pre buckling deformations and geometric nonlinearity in addition to a more accurate evaluation of the in-plane shear modulus may have to be taken into account in order to achieve a closer correlation between the numerical analysis and the test results.

Davalos J.F. et al (1997) have combined analytical and experimental study of flexural-torsional buckling of fiber-reinforced plastic (FRP) composite cantilever I-beams. An energy method based on nonlinear plate theory is developed for instability of FRP I-beam, and the formulation includes shear effect and bending-twisting coupling. Four different geometries of FRP I-beams with cantilever beam configurations and with varying span lengths are experimentally tested under tip loads to evaluate their flexural-torsional buckling response. The loads are applied at the centroid of the tip cross-sections, and the critical buckling loads are obtained by gradually adding weight onto a loading platform. The effects of vertical load position through the cross-section, fiber orientation and fiber volume fraction on buckling behavior are also studied. The proposed analytical solutions can be used to predict the flexural-torsional buckling loads of FRP cantilever beams and to formulate simplified design equations.

Davalos J.F. et al (1997) have studied combined analytical and experimental evaluation of flexural-torsional and lateral-distorsional buckling of fiber-reinforced plastic (FRP) composite wide-flange (WF) beams. For the analysis of lateral-distorsional buckling, a fifth-order polynomial shape function is adopted to model the deformed shape of web panels. The models are validated by testing two geometrically identical FRP WF beams but with distinct material architectures produced by the process. The beams are tested under mid span concentrated loads to evaluate their flexural-torsional and lateral-distorsional buckling responses. A good agreement between the proposed analytical

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Vol. 6, Issue 10, October 2017

approach and experimental and finite-element analyses results is obtained, and simplified engineering equations for flexural-torsional and lateral-distorsional buckling loads for other FRP shapes and to formulate simplified design equations.

III. DESIGN METHODOLOGY

Experimental Programme Of GFRP Beams Subjected To Mid Point Transverse Load

The objective of the tests performed on the GFRP I beams with cross section dimensions of 150 x 75 x 5 mm and 200 x 100 x 10 mm was to assess their serviceability behavior, to obtain information about their ultimate behavior, identifying the important failure modes and determining the corresponding collapse loads.

This experimental programme comprised testing of four simply supported beams of two different cross section dimensions subjected to mid span transverse load through different spreading plates at the top flange. All the beams were laterally unrestrained.

Table 1 : Details of GFRP I beams subjected to experimental programme

Specimen	Width of the flange (mm)	Depth of the section (mm)	Thickness of flange and web (mm)	Length of the beam (mm)	Simply supported span (mm)	Loading system
A1	72	150	5	1000	800	Square steel spreading plate
A2	75	150	5	1000	800	Cylindrical steel wedge
B1	100	200	10	1000	800	Square steel spreading plate
B2	100	200	10	1000	800	Cylindrical steel wedge

Table 2: Results Of Experimental Investigation On GFRP I beams

Specimen No	Cross Sectional area (mm ²)	Length (mm)	Maximum deflection at mid span (mm)	Ultimate load (KN)	Ultimate stress (N/mm ²)
A1	1450	1000	5.4	23.50	16.2
A2	1450	1000	6.2	33.00	22.75
B1	3800	1000	4.5	34.50	9.07
B2	3800	1000	5.2	41.25	10.85

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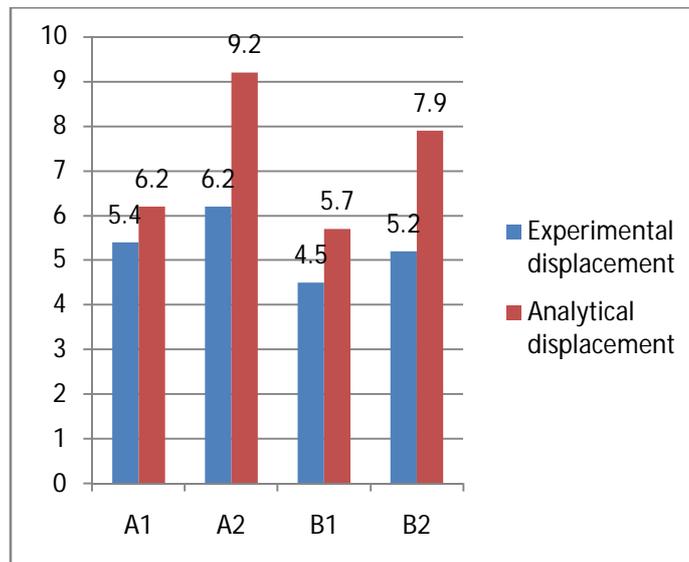
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Vol. 6, Issue 10, October 2017

Table 3: Results From Linear Static Analysis On GFRP I Beams

FE model	Input load (KN)	Maximum deflection (mm)	Maximum stress (MPa)	FE model	Input load (KN)
A1	23.50	6.2	19.20	A1	23.50
A2	33.00	9.2	27.83	A2	33.00
B1	34.50	5.7	13.20	B1	34.50
B2	41.25	7.9	14.23	B2	41.25

Graph 1 Comparison of Experimental and Analytical Displacement



The results obtained from both the experimental programme and analytical studies are in good agreement. The modes of failure is also same in both experimental and analytical studies. The Graphs 1 and 2 shows the comparison of analytical and experimental displacement and stress values.

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Vol. 6, Issue 10, October 2017

Graph 2 Comparison of Experimental and Analytical Stress

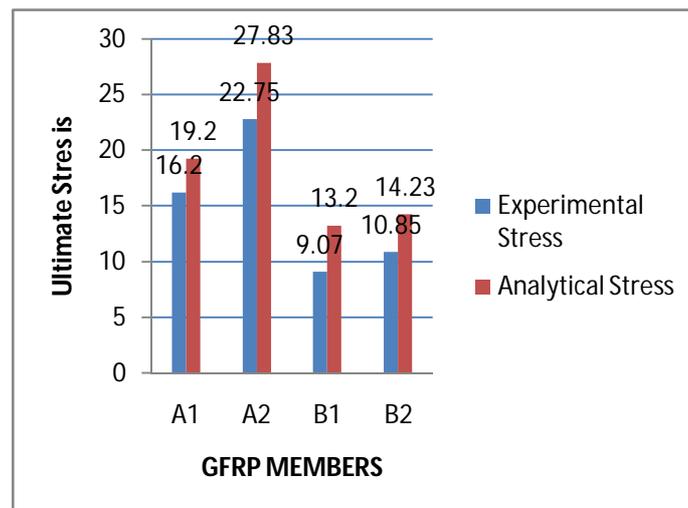


Table 4 : Results Of Experimental Investigation On MILD STEEL I beams

Specimen No	Cross sectional area (mm ²)	Length (mm)	Maximum deflection at mid span (mm)	Ultimate load (KN)	Ultimate stress (N/mm ²)
A1	1450	1000	5.2	24	16.55
A2	1450	1000	6.0	33.5	23.10
B1	3800	1000	4.35	35	9.2
B2	3800	1000	5.10	41.56	10.93

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Vol. 6, Issue 10, October 2017

Graph 3 Comparison of ultimate stress values of GFRP SECTION and MILD STEEL in Midpoint transverse load test.

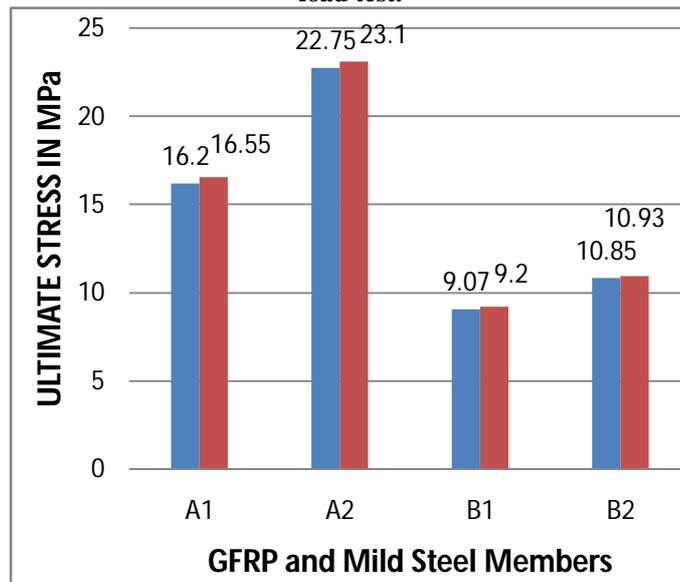


Table 5 : Coupon Tensile Test Results Of GFRP Plate Section

Initial Length (mm)	Area (mm ²)	Final Length (mm)	Failure load (KN)	Ultimate stress (MPa)	Ultimate strain	Modulus of elasticity (GPa)
200	150	202.6	63.6	424	0.013	32.6
200	150	202.8	64.3	429	0.014	30.64
200	150	202.8	64.5	430	0.014	30.7

Table 6 : Coupon Tensile Test Results Of Mild Steel Plate Section

Initial Length (mm)	Area (mm ²)	Final Length (mm)	Failure load (KN)	Ultimate stress (MPa)	Ultimate strain	Modulus of elasticity (GPa)
200	150	202.6	63.9	426	0.013	32.76
200	150	202.7	64.6	430.6	0.0135	31.9
200	150	202.7	64.8	432	0.0135	32

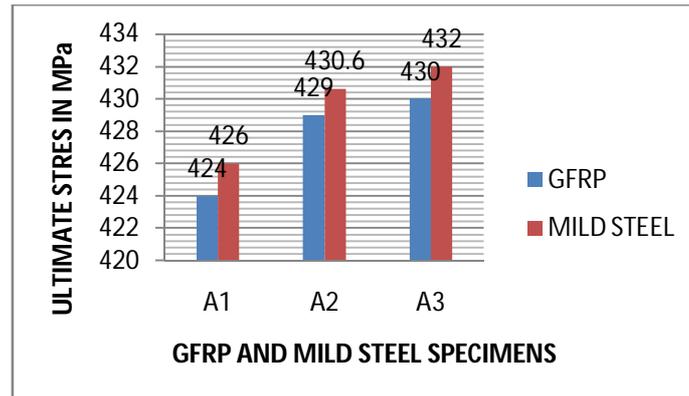
Graph 3 Comparison of ultimate stress values of GFRP SECTION and MILD STEEL in coupon tensile test

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Vol. 6, Issue 10, October 2017



IV. CONCLUSION

The study presented an experimental and analytical study on the flexural behavior of GFRP I sections. Initially, material characterization tests were carried out, in order to determine the most relevant GFRP mechanical properties namely the elastic constants and material strength. Further an experimental program for full scale tests was conducted on GFRP flexural members. Based on the observed and measured flexural behavior by varying the loading approaches in two different cross sectional dimensions, the following conclusions are drawn,

- It has proved that Strength of the mild steel sections and strength of the GFRP sections are almost similar.
- The results of numerical investigation based on the simulation of beam finite element models are in good agreement with the experimental results.
- From the analytical and experimental results, the behavior of GFRP flexural members were studied, it is observed that the failure mode is governed by local and global buckling.
- Load displacement behavior of GFRP beams is linear upto failure regardless of the modes of failure, this substantially differs from the behavior of steel and concrete beams, whose failure is almost always governed by yielding and cracking.
- Low young's modulus of the used GFRP members implies that the design of GFRP members is practically always governed by either local buckling or global buckling criteria, or deformation criteria.
- In the first loading approach, the beam A1 and B1 were failed at the maximum load of 23.5 KN and 34.5 KN respectively due to web crushing at the mid span.
- In the second loading approach, the beams A2 and B2 were failed at the maximum load of 33 KN and 41.25 KN respectively due to local buckling of flange.
- Simply supported beams provided experimental evidence of failure mechanisms triggered by the occurrence of local and global buckling.

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Vol. 6, Issue 10, October 2017

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