INVESTIGATING THE PHYSICO-MECHANICAL PROPERTIES OF BAMBOO FIBER REINFORCED COMPOSITE (BFRC) PLATES AND ITS EFFECTS ON STRENGTHENING OF RC BEAMS EXTERNALLY

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Sintetik bertetulang gentian polimer komposit (FRP) adalah kaedah yang berkesan untuk pengukuhan bertetulang anggota konkrit (RC) luaran. Walau bagaimanapun, kos yang tinggi, kesan alam sekitar, dan kesan buruk terhadap kesihatan manusia adalah sekatan yang terutama kepada komposite FRP. Oleh itu, serat semula jadi bertetulang polimer komposit (NFRPC) untuk pengukuhan struktur RC adalah satu kecenderungan yang berminat dalam industri pembinaan. Kajian ini membentangkan penyiasatan eksperimen ke atas tingkah laku struktur rasuk RC dengan bukaan terletak di kawasan ricih dan lengkungan yang diperkukuhkan dengan buluh serat plat komposit (BFRC) luaran. Tujuan kerja ini adalah untuk mencirikan sifat-sifat fiziko-mekanik *Gigantochloa Scortechinii Gamble* (*G. scortechinii*) serat dan plat BFRC satu arah. Pesongan beban, corak keretakan, dan mod kegagalan rasuk RC yang diperkuatkan oleh plat BFRC juga dikaji. Buluh tempatan telah dirawat dengan natrium hidroksida (NaOH) yang berbeza konsentrasi (0, 5, 10, dan 15 %) dan tempoh merendam (0, 24, 48, dan 72 jam) sebelum tertakluk kepada proses penggilingan. Pencirian fiziko-mekanikal telah dijalankan untuk menilai parameter rawatan optimum untuk kesesuaian serat sebagai tetulang dalam komposit polimer. Plat BFRC telah dihasil dengan menggunakan kaedah susunan tangan yang terbuka dengan berbeza jenis termoset damar (epoxy, poliester, dan resin vinylester) dan pelbagai beban serat (0, 10, 20, 30, dan 40 %). Sifat-sifat fiziko-mekanik plat BFRC telah diperiksa untuk menentukan nisbah campuran yang optimum. Sebanyak 12 rasuk konkrit bertetulang telah diuji pada Fasa 1 (penguatan ricih) dan Fasa 2 (penguatan lengkungan), dan di bawah empat titik lentur sehingga kegagalan. Setiap fasa terdiri daripada dua rasuk kawalan, dan selebihnya diuji dengan atau tanpa pengukuhan plat BFRC. Untuk lengkungan pengukuhan, plat BFRC telah diikatkan pada rasuk tampang bawah sepanjang rentang tengah, manakala plat BFRC telah terikat pada kedua-dua bahagian atas dan bawah perentas bukaan untuk ricih pengukuhan. Dari keputusan yang diperolehi, permukaan morfologi, hablur indeks, kestabilan haba, dan sifat tegangan serat menunjukkan peningkatan yang beransur-ansur dengan peningkatan kepekatan NaOH dan tempoh merendam disebabkan oleh penyingkiran konstituen bukan selulosa. Serat buluh dirawat dengan kepekatan 10 % dan 48 jam mempertunjukkan sifat-sifat fiziko-mekanikal yang paling ketara di antara semua parameter rawatan. Sifat-sifat fiziko-mekanikal plat BFRC telah dipertingkatkan dengan peningkatan kandungan isi padu serat tanpa mengira jenis matriks. Pada 40 % beban serat, Serat buluh yang diperkukuhkan dengan epoxy damar (BFREC) telah didapati sebagai nisbah optimum sebab mempamerkan sifat-sifat fiziko-mekanikal yang tertinggi. Rasuk yang mengandungi bukaan pekeliling yang besar di zon ricih telah menyebabkan beban muktamad sebanyak 53.5 %. Di antara perbandingan dengan rasuk yang mengandungi bukaan yang tidak diperkuatkan, kapasiti rasuk pemulihan oleh pengukuhan ricih adalah 52.14 %. Kapasiti muatan beban muktamad bagi rasuk yang diperkukuh di lengkungan telah meningkatkan beban kegagalan sebanyak 7 %. Rasuk yang diperkukuhkan juga menunjukkan beban retak pertama yang lebih tinggi. Kedua-dua lengkungan dan pengukuhan ricih berkesan mengurangkan penyebaran keretakan serta meningkatkan kemuluran rasuk yang diperkukuhkan. Penemuan yang diperolehi menunjukkan bahawa plat BFREC satu arah boleh digunakan sebagai bahan pengukuhan luaran untuk pengukuhan struktur.

ABSTRACT

The synthetic fiber reinforced polymer (FRP) composite is an effective method for strengthening the reinforced concrete (RC) member externally. However, high cost, environmental impact, and adverse effects on human health are the major limitation of FRP composite. Thus, the natural fiber reinforced polymer composite (NFRPC) for the strengthening of RC structure is the trending interests in the construction industry. This study presented an experimental investigation on the structural behaviour of RC beams with openings in shear and flexure strengthened using bamboo fiber reinforced composite (BFRC) plates. The purposes of this work are to characterize the physico-mechanical properties of *Gigantocholoa scortechinii Gamble* (*G. scortechinii*) fiber and unidirectional BFRC plate. The load-deflection, cracking patterns, and failure mode of BFRC plates strengthened RC beams were also studied. The bamboo culms were treated with different sodium hydroxide (NaOH) concentrations (0, 5, 10, and 15 %) and soaking durations (0, 24, 48, and 72 hours) before subjected to the mill rolling process. The physico-mechanical characterizations were performed to evaluate the optimum treatment parameters for the suitability of fiber as reinforcement in the polymer composite. The BFRC plates were fabricated using an open mould hand lay-up method with different types of thermoset matrix (epoxy, polyester, and vinylester resin) and various fiber loadings (0, 10, 20, 30, and 40 %). The physico-mechanical properties of BFRC plates were examined to determine the optimal mix ratio. A total of 12 beams were tested in Phase 1 (shear strengthening) and Phase 2 (flexural strengthening) under four-point bending until failure. Each phase consists of two control beams, two beams of which was tested with or without the strengthening of BFRC plates. For flexural strengthening, the BFRC plates were bonded at the bottom soffit along the middle span, whereas the BFRC plates were bonded at both top and bottom chords of the openings for shear strengthening. From the obtained results, the surface morphology, crystallinity index, thermal stability, and tensile properties of fiber showed a gradual improvement with increasing NaOH concentrations and soaking durations due to the removal of non-cellulosic constituents. The bamboo fiber treated at 10 % concentrations and 48 hours presented the most outstanding physico-mechanical properties among all the treatment conditions. The physico-mechanical properties of the BFRC plates were enhanced with the increase of fiber content regardless the type of matrix. At 40 % of fiber loading, the bamboo fiber reinforced with the epoxy matrix (BFREC) was confirmed as the optimum ratio by exhibiting the highest physico-mechanical properties. The inclusion of large circular openings in the shear zones led to a reduction in ultimate load by 53.5 %. As compared to the beam with unstrengthened openings, the regained beam capacity by shear strengthening was 52.14 %. The ultimate load-carrying capacity of the flexural strengthened beams had improved the failure load by 7 %. The strengthened beams also exhibited higher first crack load. Both flexural and shear strengthening effectively mitigated the cracks propagation and improved the beam ductility. The obtained findings indicate that the unidirectional BFREC plate could be utilized as external strengthening material for structural strengthening.

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%	Percentage
N/mm^2	Newton per millimetre square
GPa	Giga Pascal
Kg	Kilogram
Kg/m^3	Kilogram per meter cube
N	Newton
°C	Degree Celsius
Mm	Millimetre
MPa	Mega Pascal
Sec	Seconds

LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
ATR	Attenuated total reflection
BFRC	Bamboo fiber reinforced composite
BFREC	Bamboo fiber reinforced epoxy composite
BFRPC	Bamboo fiber reinforced polyester composite
BFRVC	Bamboo fiber reinforced vinylester composite
BS	British standard
CFRP	Carbon fiber reinforced polymer
FDPM	Forestry Department Peninsular Malaysia
FKASA	Faculty Civil Engineering & Earth Resources
FRIM	Forest Research Institute Malaysia
FRP	Fiber reinforced polymer
FTIR	Fourier transform infrared spectroscopy
GFRP	Glass fiber reinforced polymer
LVDT	Linear variable displacement transducer
MEKP	Methyl Ethyl Ketone Peroxide
NFRPC	Natural fiber reinforced polymer composite
PMC	Polymer matrix composite
RC	Reinforced concrete
SEM	Scanning electron microscope
TGA	Thermogravimetric analysis
UMP	University Malaysia Pahang
WPC	Wood-plastics composite
XRD	X-ray powder diffraction

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