EXPERIMENTAL STUDY AND FEA MODELLING OF USING WOVEN FABRIC KENAF COMPOSITE SHEETS TO IMPROVE FLEXURAL RESISTANCE ON FOAMED CONCRETE BEAMS

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DEDICATIONS

I would like to dedicate this thesis to my parents, who gave the little they had to ensure i would have the opportunity of an education. Their efforts and struggles have allowed me to have a key to unlock the mysteries of our world and beyond.

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ABSTRACT

Foamed concrete has gained much attention among engineers as an alternative construction material due to excellent specific strength. However, presence of pore structure within foamed concrete matrix may reduce its flexural resistance. Commercial fiber-reinforced polymer (FRP) composites were employed as flexural strengthening material. In order to allow wider applicability of FRPs in Malaysia, natural fibers such as kenaf fiber composites is potential as beam strengthening material due to its excellent tensile modulus and elongation at break. The objectives of this project is to conduct experimental work on foamed concrete beams strengthened with woven fabric kenaf fiber reinforced polymer (KFRP) composite tested under four-points bending following ASTM-C78-02. Later strength predictions were performed within 2-D Extended Finite Element Method (XFEM) modelling framework and agreement with experimental datasets was discussed. Testing series includes variation of KFRP sheet length, woven KFRP architecture, normalized notched height and KFRP thickness. Twelve models were developed for strength prediction by incorporating constitutive law of traction-separation relationship to require un-notched strength, σ_o and fracture energy value, G_F. Fracture energy (G_F) value was independently taken from measured experimental datasets. Here, fracture energy value from Hillerborg was adopted (measured G_F is 0.015 N/mm) of foamed concrete, good agreement with available literatures. Experimental results exhibited all series demonstrates improvement on flexural strength, despite of shear failure and FRP fracture modes exhibited. The longest KFRP length specimen failed in FRP rupture gives the optimum ultimate load at failure. Validation works showed good agreements with an average discrepancy of 10%. However, less good prediction was found with FRP fracture (only one model), although consistence fracture behavior was demonstrated. Testing series with presence on notch is giving the best predictions as constitutive model incorporated are associated with stress concentration. This study promotes an early feasibility study of KFRP sheet as strengthening material in foamed concrete beam and (XFEM) development used as prediction tools.

ABSTRAK

Konkrit busa mula mendapat perhatian di kalangan jurutera sebagai bahan binaan alternatif kerana kekuatan spesifik yang sangat baik. Walaubagaimanapun, kehadiran rongga dalam matriks konkrit busa mengurangkan rintangan lenturan dalam struktur. Serat bertulang polimer (FRP) sintetik telah digunakan sebagai bahan penguat lenturan. Bagi memperkasakan penggunaan FRP di Malaysia, serat asli seperti serat kenaf berupaya digunakan sebagai penguat rasuk kerana modulus tegangan dan pemanjangan putus yang baik. Objektif penyelidikan ini merangkumi ujikaji rasuk konkrit busa yang diperkukuh dengan komposit gentian kenaf tetulang polimer (KFRP), diuji di bawah lenturan empat titik mengikut ASTM-C78-02. Kemudian, prediksi kekuatan kemudiannya dilakukan dalam kerangka kerja 2-D XFEM model dan akan dibandingkan dengan data eksperimen yang duji sebelumnya. Siri uji kaji termasuk variasi panjang KFRP, seni bina tenunan KFRP, nisbah ketinggian takuk dan tebal KFRP. Prediksi kekuatan dijalankan dengan menggunakan hubungan tarik-pemisah yang memerlukan kekuatan maksimum, σ_o, dan nilai tenaga putus, G_F. Nilai tenaga putus (G_F) diukur daripada pengukuran eksperimen. Model Hillerborg diguna pakai sebagai model putus (G_F diukur adalah 0.015 N/mm) konkrit busa, nilai ini bersesuaian dengan nilai literatur sedia ada. Keputusan eksperimen mendapati ujikaji semua rasuk yang diperkuat KFRP menunjukkan penambahbaikan pada kekuatan lenturan, sama ada mod kegagalan ricih atau kegagalan FRP. Konsisten pasca-pemprosesan daripada model XFEM dengan pemerhatian eksperimen diperolehi. Spesimen KFRP terpanjang memberikan beban kegagalan yang optimum. Hasil pengesahan menunjukkan persetujuan yang baik dengan selisih purata 10%. Prediksi yang kurang tepat diperolehi dengan mod kegagalan FRP (hanya ada satu model), meskipun mod kegagalan yang konsisten telah ditunjukkan. Siri ujian dengan kehadiran pada takuk memberikan prediksi terbaik kerana model konstitutif yang digunakan berkaitan langsung dengan pengumpulan tegasan. Kajian ini berupaya melihat keupayaan KFRP sebagai bahan pengukuhan asuk konkrit busa dan pembangunan XFEM sebagai alat prediksi kekuatan lenturan rasuk.

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LIST OF SYMBOLS AND ABBREVIATIONS

AAS	-	Alkali activated slag
ACI	-	American Concrete Institute
AFRP	-	Aramid fiber reinforced polymer
ASTM	-	American Society for Testing Materials
BCA	-	British Cement Association
BK	-	Benzeggagh-Kenane failure criterion
CBD	-	Cracked Brazilian disk
CBT	-	Corrected beam theory
CBBM	-	Compliance based beam method
CCM	-	Compliance calibration method
CFRP	-	Carbon fiber reinforced polymer
CST	-	Compression shear test
DBT	-	Direct beam theory
DCB	-	Double cantilever beam
EB	-	Externally bonded
ECM	-	Experimental compliance method
EGM	-	Extended global mesh
ENF	-	End notch flexure
ELSJ	-	End loaded shear joint
FA	-	Fly ash
FEA	-	Finite element analysis
FKAAB	-	Faculty of Civil Engineering and Built Environment
FKMP	-	Faculty of Mechanical and Manufacturing Engineering
FRP	-	Fiber reinforced polymer
FS	-	Foam stabilizer
GFRP	-	Glass fiber reinforced polymer
IWP	-	Impact wedge peel
KFRP	-	Kenaf fiber reinforced polymer
LEFM	-	Linear elastic fracture mechanic
LOI	-	Loss of ignition
LWA	-	Lightweight aggregate
MMB	-	Mixed mode bending
NSM	-	Near surface mounted
OPS	-	Oil palm shell
PC	-	Portland Cement

PvC	-	Pulverized ceramic
POFA	-	Palm oil fuel ash
SF	-	Silica fume
SVNBD	-	Sharp V notched Brazilian disk
TDCB	-	Tapered double cantilever beam
WDCB	-	Wedge double cantilever beam
XFEM	-	Extended finite element method
2-D	-	Two-dimensional
4ENF	-	Four point bend end notched flexure
a	-	Longitudinal distance crack length
δ	-	Displacement
δ_{max}	-	Displacement at maximum
E	-	Elastic modulus
E_x	-	Longitudinal elastic modulus
E_y	-	Transversal elastic modulus
$\varepsilon_{n,max}$	-	Maximum nominal strain normal only mode
$\varepsilon_{s,max}$	-	Maximum nominal strain shear only mode first direction
$\varepsilon_{t,max}$	-	Maximum nominal strain shear only mode second direction
f'_c	-	Compressive strength
f_t	-	Tensile strength
G_F	-	Fracture energy
G_{IC}	-	Critical fracture energy first mode
G_{IIC}	-	Critical fracture energy second mode
$H(x)$	-	Discontinuous jump shape function
H	-	Beam depth
h_a	-	Adhesive thickness
K	-	Stress intensity
L	-	Beam length
L_a	-	Span beam length
L_e	-	Effective length
L_f	-	FRP length
mm	-	millimeter
P	-	Point load
ρ	-	Density
w/c	-	Water cement ratio
c/s	-	Cement sand ratio
v	-	Poisson's ratio
σ_o	-	Unnotched strength
$T_{n,max}$	-	Maximum nominal stress normal-only mode
$T_{s,max}$	-	Maximum nominal stress shear-only mode first direction
$T_{t,max}$	-	Maximum nominal stress shear only mode second direction
W	-	Beam width
θ	-	Angle of bearing plane

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CHAPTER 1

INTRODUCTION

1.1 Research Background

A foamed concrete, also known as a cellular concrete is a mortar that has been artificially enchased within air gaps which was started to use in low or medium load-bearing applications such as partitions, filling grades, road embankment infills and structures construction particularly on weak foundations. The advantages of foamed concrete are low-weight, great flow-ability, minimal aggregate used and excellent thermal insulations. However, it possesses few drawbacks that limit its application, such as low structural strength. More recently, extensive research was carried out globally to produce foamed concrete in structural applications. Few attempts were reported such as incorporating of high siliceous pozzolanic materials to improve its mechanical properties. Incorporation of industrial by-product such as fly ash, rice husk ash (RHA) and silica fumes (SF) able to improve its mechanical properties substantially. A study conducted by Gökçe, H. S., Hatungimana, D., & Ramyar, K, (2019) found that incorporation 10% of fly ash as cement replacement produced a foamed concrete with a density of 1556 kg/m^3, and a compressive strength of 28.4 MPa. Additionally, a study by Lee *et al.*, (2018) that incorporated silica fume as 10% cement replacement could produce a density 1700 kg/m^3 and impressive compressive strength of 27.12 MPa while Gencel *et al.*, (2022) exhibited 35 MPa with 15% of silica fume. Additionally, Ahmad *et al.*, (2019) yields 1300 kg/m^3 of strength 24.3 MPa with incorporation of 20% of expanded clay aggregate. While Yao *et al.*, (2022) use steam curing to improve compressive strength in early age.

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