

CHARACTERISTICS OF FERROCEMENT SANDWICH AERATED
CONCRETE WALL ELEMENTS INCORPORATING
POZZOLANIC WASTE MATERIALS

TAHA MEHMAN NAVAZ

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To My Lovely Parents

Dr. Hossin Ali Mehman navaz and Zahra Abooata

And

My Wife and Daughter

Fereshteh Moayed and Parimah Mehman navaz

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ABSTRACT

Sandwich construction is defined as a structure that is constructed using ferrocement and aerated concrete. In contrast to the conventional concrete system, it is usually made of thin face sheets or encasement of high performance material and a thick, lightweight and low strength material as core element. Partial substitution of cement with pozzolanic materials and replacement of fine aggregate with bottom ash in this sandwich system could, be a viable strategy for reducing cement and fine aggregate consumption without impairing the performance of the system. However, the main problem of a sandwich construction is the delamination of the face sheets leading to their premature failure which is believed can be avoided by providing encasement over the core. This research focuses on the development and the characteristics of ferrocement sandwich aerated concrete wall elements by partial substitution of cement with palm oil fuel ash (POFA), pulverized fuel ash (PFA) and fine aggregate with bottom ash (BA) at varying proportions. The tests conducted involved the optimization of POFA, PFA and BA in binary and ternary cement blends in producing self-compacting and aerated concrete of desired properties for ferrocement encasement and core. In addition, the development of ferrocement encased lightweight aerated concrete sandwich wall elements as well as the investigation of strength characteristics and the durability properties were also conducted. The performance of the mixes was studied in terms of the workability, density and compressive strength. The partial replacement of cement with pozzolanic materials was done by weight in the range of 0 to 50% of the cement. Other aspects of the study included, failure mode, flexural behaviour, load-deflection behaviour, load-deformation behaviour and load-strain behaviour. From the study, it was observed that the workability of the mixes containing POFA and PFA were significantly improved by 116%, as well as the compressive strength (93%) and unit weight by 45%. The performance of one layer wire mesh (WM) and plastic mesh (PM) showed satisfactory results in ductility and deformation. An increase of 166% (WM) and 66% (PM) for compressive were observed. At the same time, for flexure strength an increase of 39% (WM) and 95% (PM) were achieved. No delamination were found for both WM and PM wall element. In addition, the durability test on the wall elements in terms of permeability, acid attack and elevated temperature demonstrated high potentials of the specimens to be used under aggressive environment. Furthermore, the deformations of wall elements were validated with Finite element model using ANSYS software and the values predicted from the ANSYS software models were 85% - 90% accuracy compared to the experimental results. Finally, the sandwich incorporating one layer of plastic mesh can be used as a wall unit with minimum risk of delamination.

ABSTRAK

Pembinaan elemen teralit ditakrifkan sebagai satu struktur yang terbina daripada simen ferro dan konkrit berudara. Ianya berbeza dengan sistem konkrit konvensional di mana kepingan kebiasaannya diperbuat daripada permukaan yang nipis atau salutan bahan berprestasi tinggi dan penggunaan bahan yang tebal, bahan ringan dan kekuatan rendah sebagai teras. Penggantian separa simen dengan bahan-bahan pozolana dan penggantian batu halus dengan abu bawah dalam sistem panel apitan boleh menjadi strategi yang berdaya maju untuk mengurangkan simen dan penggunaan batu halus tanpa mengganggu prestasi sistem. Selain itu, masalah utama bagi pembinaan panel teralit ialah penyahikatan bagi lembaran muka yang membawa kepada kegagalan pramatang yang dipercayai boleh dielakkan dengan menyediakan lebih lapisan pada teras. Oleh itu, kajian ini memberi tumpuan kepada pembangunan ciri-ciri elemen dinding konkrit berudara teralit simen ferro yang mengabungkan abu bahan api kelapa sawit (POFA) dan abu bahan api terhancur (PFA) sebagai bahan-bahan buangan pozolana dan abu bawah (BA) sebagai gantian batu halus. Ujian yang dijalankan melibatkan pengoptimuman POFA, PFA dan BA dalam campuran simen binari dan ternari untuk menghasilkan konkrit padat sendiri dan berliang yang masing-masing bertujuan untuk membungkus simen ferro dan teras. Lain-lain termasuk pembangunan dan pemeriksaan ciri-ciri kekuatan simen ferro bersalut elemen berudara dinding teralit konkrit ringan dan ujian ketahananlasakan juga dijalankan. Prestasi campuran telah diuji dari segi keboleherjaan, ketumpatan dan kekuatan mampatan. Penggantian separa simen dengan bahan-bahan pozolana mengikut berat dalam lingkungan 0 hingga 50% daripada simen. Aspek lain yang dikaji ialah lenturan, mod kegagalan, kelakuan beban-pesongan, kelakuan beban-ubah bentuk dan tingkah laku beban-keterikan. Dari kajian ini diperhatikan bahawa keboleherjaan campuran yang mengandungi POFA dan PFA telah bertambah baik dengan ketara sehingga 116% dan begitu juga 45% unit berat dan kekuatan mampatan 93%. Prestasi satu lapisan jejaring wayar (WM) dan jejaring geogrid (PM) menunjukkan keputusan memuaskan dari segi kemuluran dan tingkah laku ubah bentuk. peningkatkan sebanyak 166% (WM) dan 66% (PM) untuk kekuatan mampatan telah dicapai. pada masa yang sama, kekuatan patah meningkat sebanyak 39% (WM) dan 95% (PM). Tidak ada penyahikatan berlaku terhadap kedua-dua elemen dinding WM dan PM. Selain itu, ujian ketahananlasakan pada elemen apitan dari segi kebolehtelapan, serangan asid dan suhu tinggi menunjukkan potensi yang tinggi penggunaan spesimen ini dalam persekitaran yang agresif. Tambahan pula, keputusan ubah bentuk elemen dinding telah disahkan dengan model unsur terhingga menggunakan perisian ANSYS dan nilai-nilai yang diramalkan daripada model perisian ANSYS adalah 85% - 90% tepat berbanding dengan keputusan ujikaji. Akhir sekali, penggunaan satu lapisan jejaring plastik dalam elemen apitan boleh digunakan sebagai unit dinding dengan risiko penyahikatan yang minimum.

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LIST OF ABBREVIATION

AAC	-	Autoclaved Aerated Concrete
AC	-	Aerated Concrete
ACI	-	American Concrete Institute
ASTM	-	American Standards for Testing of materials
BA	-	Bottom Ash
BS	-	British Standards
C-S-H	-	Calcium Silicate Hydrate
FC	-	Ferrocement
FFB	-	Fresh fruit bunches
FRP	-	Fibre Reinforced Polymer
IBS	-	Industrialized building systems
IFS	-	International Ferrocement Society
ISAT	-	Initial Surface Absorption Test
LVDT	-	Linear Variable Differential Transformer
MOE	-	Modulus of Elasticity
MOR	-	Modulus of Rupture
NAAC	-	Non-Autoclaved Aerated Concrete
OER	-	Oil Extraction Ratio
OPC	-	Ordinary Portland Cement
PCI	-	Precast/Prestressed Concrete Institute
PCSP	-	Precast Concrete Sandwich Panels
PFA	-	Pulverized Fuel Ash
PM	-	Plastic mesh
POFA	-	Palm Oil Fuel Ash
RC	-	Reinforced Concrete
RHA	-	Rice Husk Ash

RILEM	-	International Union of Testing and Research Laboratories for Materials and Structures
RM	-	Ringgit Malaysia
SCC	-	Self-compacting concrete
SCM	-	Supplementary cementing material
SD	-	Standard deviation
WM	-	Wire mesh
SP	-	Superplasticizer
UPV	-	Ultrasonic Pulse Velocity
USA	-	United States of America
UTM	-	University Technology Malaysia
W/b	-	Water-Binder Ratio
w.r.t	-	With respect to
GUI	-	Graphical User Interface
FEA	-	Finite Element Analyses
FE	-	Finite Element

LIST OF SYMBOLS

a	-	Average distance between line of fracture and the nearest support measured in the tension surface of the beam
A_{ci}	-	Cross-sectional area perpendicular to loading direction (mm ²)
b	-	Average width of specimen
d	-	Average depth of specimen
E_c	-	Modulus of elasticity of the concrete
EX	-	Modulus of elasticity of the concrete (E_c) in ANSYS
f	-	Stress at any strain(ϵ), psi
f_{ci}	-	Compressive strength (MPa)
F_i	-	Ultimate load in compression (N)
f_y	-	Yield stress
f_0	-	Initial strength of concrete at 27 °C
f_T	-	Residual strength after heating at T °C
H	-	Height
H/L	-	Aspect ratio
H/t	-	Slenderness ratio
L	-	Span length
L	-	Length
P	-	Maximum applied load
P_r	-	Porosity
PRXY	-	Poisson's ratio (μ) in ANSYS
R	-	Modulus of rupture
T	-	Effective transit time (s)
t	-	Thickness

V	-	Pulse velocity ($\frac{m}{s}$)
V	-	Total volume
V_c	-	Core volume
V_e	-	Encasement volume
V_T	-	Pulse velocity after heating at T °C
V_{27}	-	initial pulse velocity of concrete at 27 °C
W_a	-	Percentage of water absorption
W_{od}	-	Weight of oven dry specimen
W_{ssd}	-	Weight of saturated surface dry specimen
W_s	-	Weight of submerged specimen
μ	-	Poisson's ratio
ε	-	Strain at stress f,
ε_0	-	Strain at the ultimate compressive strength, f'_c
σ	-	Stress

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Malaysia is undoubtedly one of the fast developing countries in the world (Razak, 2010). The pace of construction activity which is commensurable to the development has been in exponential pattern over the last three decades (Sumadi and Ramli, 2008). This necessitates the exploration of sustainable construction techniques/systems that meet the demand for environmental friendly, safe, fast, cost-effective, and quality housing and infrastructures for the well-being of the society (Sambasivan and Soon, 2007). Despite the rate of development, the provision of housings is still in deficit form (Thanoon *et al.*, 2004). The high cost of construction materials and the labour intensity nature of the conventional building system contribute immensely on the deficit in housing (Cabeza *et al.*, 2013). Exploration of other sources of construction materials become imperative in other to meet the housing and development needs of the country. Agro and industrial waste have been seen to play an important role in this regards, among which are palm oil fuel ash and pulverised fuel ash. Application of these wastes in building production system such as industrialized building system (IBS) could provide a viable approach for adequate housing provision.

The IBS denotes the concept of the prefabrication and industrialization of building components (Kamar *et al.*, 2011). In this system, the elements are installed with a minimum time period and labour at the site as compare to the conventional

system of cement or concrete blocks which are heavier in weight. Application of light-weight elements such as aerated concrete reinforced with ferrocement for walling system would not only reduce the dead load of the structure, but also improves its performance and reduces the cost of construction (Sakthivel and Jagannathan, 2013). The use of agro and industrial wastes to partially substitute ordinary Portland cement (OPC) in aerated concrete and self-compacting mortar to produce ferrocement sandwich wall system would improve the performance of the concrete. Furthermore, the environmental threat sequel to disposal of these wastes to landfills will be curtailed (Raut *et al.*, 2011).

According to Sumathi *et al.* (2008), some of the tropical climate countries in the world have palm oil plants but Malaysia is ranked as the world's largest producer of palm oil, give a report for 52% of the total world oils and the industry is the main agricultural industry in the country. The country strives to maintain this leading role in the next decades. This development leads to increase in palm oil plantation in 1920 with 400 hectares to year 2002 which accounted for about 3.6 million hectares and with a targeted expansion in the year 2020 to be around 5.2 million hectares (Basiron *et al.*, 2005). In the year 2006, the country recorded production worth over 15 million tons of crude palm oil (MPOB, 2006). Therefore, it is expected that higher quantities of waste will be discharged to the environment from the industry in the near future (Shehu and Abdul Awal, 2012). It is interesting to note that palm oil industry giant effort to restrain the excess of solid waste (Palm shell, bunch and fibre) generated is its used as a fuel in the electricity generation, making the industry self-sustained in term of energy generation and utilization. Though, further by-product emerges in the form of ash known as palm oil fuel ash (POFA) which is believed to be about 5% of the total solid waste fed into boiler mills (Borhan *et al.*, 2010). Innovation of new product through integration of this freely available waste would be one of the solutions to sustainably use this environmentally degrading by-product into beneficial material so as to meet up the housing needs and housing demands of the people at a very minimal cost of construction.

The basic concept of sandwich structures consists of two thin skins (faces) and a lightweight thicker core. This practice is found common in construction industry owing to its lightness and versatility and is adopted as a new innovation in building construction (La Rosa *et al.*, 2014). The product also has the capability of dead load reduction thereby resulting in more economically and friendly structural design (Narayanan and Ramamurthy, 2000a). The incorporation of palm oil fuel ash (POFA) and pulverized fuel ash (PFA) as partial cement replacement material in the lightweight and ferrocement composite as construction materials concrete mix would decrease the amount of cement used as compared to ordinary aerated and ferrocement concrete hence reduce the high dependency on cement. This approach for industrial or agricultural waste replacement cement has been reported in the previous researches (Abdul Awal, 1998; Khairunisa, 2009; Sumadi and Hussin, 1993). Therefore, the creation of a new material is not only expected to offer an extra incoming profit for industry of POFA and PFA and reducing ash ending at landfill as well as bringing improvement to Malaysian construction technology.

1.2 Problem Statement

The rapid development of lightweight, low cost, durable, industrialized and sustainable housing system as per IBS is ever demanding problem (Mydin *et al.*, 2014; Yunus and Yang, 2011). Developing low cost and environmental friendly construction materials is a challenging issue at present. The presence of IBS usually focuses on the use of cement or concrete blocks for the infill or to certain extent, serves as non-load bearing walls which are heavier in weight. The development of ferrocement, aerated concrete and self-compacting mortar as encasement of ferrocement with the aid of pozzolanic materials as partial cement replacement is relatively new. Ferrocement structural elements are high performance composite material and its advantageous lightweight makes it a replaceable conventional material for building construction. Interestingly, ferrocement structural elements have not gained much popularity because of their thin section causing transferable

heat, noise and also perceived corrosion problem particularly in the tropical environments.

Considering the demand for shelter globally there is the need to improve the quality of the ferrocement structurally. Therefore the challenge of looking inward to the use of environmental friendly materials could be a possible solution in overcoming the disadvantages associated with the use of OPC in the production of ferrocement component.

However, evaluation of aerated concrete as a core and self-compacting mortar as encasing of ferrocement using POFA and PFA as cement replacement materials may lead to higher quality product that require adequate investigations. Thus, sandwich composite construction system with newly developed composites made of ternary materials (cement, POFA and PFA) presents one of the potential solutions in which the ferrocement is applied as face sheets/encasement and lightweight aerated concrete as core.

1.3 Aim and Objectives of the Research

The aim of the research is to investigate ferrocement characteristics of sandwich aerated concrete wall elements incorporating pozzolanic waste materials (POFA & PFA).

The following objectives are set out to achieve the targeted aim.

1. To evaluate the physical, chemical and microstructural characteristics of POFA and PFA.
2. To determine the optimum mix proportion for mortar incorporating POFA and PFA for aerated concrete sandwich wall elements.

3. To investigate the suitability of the blend of POFA and PFA for thin ferrocement encasement by evaluating the flow-ability of the formulated self-compacting cement mortar.
4. To investigate the effect of mesh type, number of mesh layer and orientation on the failure behaviour associated with sandwich aerated concrete material including compression, flexural and delamination.
5. To assess the durability performance of the aerated concrete and sandwich specimens, including water absorption, ISAT tests, resistance to acid attack and elevated temperature.
6. To investigate the failure behaviour (compression and flexural) of large size ferrocement encased lightweight aerated concrete wall elements based on the optimum mesh content.
7. To validate the experimental study of sandwich wall element with finite element software in terms of compression and flexural strength obtain the maximum deformation.

1.4 Scope of the Research

This experimental project consists of two phases. The first phase focused on the development of optimum mix for aerated concrete and self-compacting mortar containing POFA and PFA. Self-compacting mortar allowed for casting the thin ferrocement skin boxes over aerated concrete in single operation. The compressive strength and unit weight of the mortar were used as parameters for optimization. The effect of POFA and PFA as the replacement of cement in mortar for making affordable product is also a part of focused objectives.

The second phase of the experimental study included; the behaviour of sandwich specimens, cubes, blocks prism beams and wall elements of relatively large

size. These were investigated under compression as major parameter and bending as an additional effect. Two types of mesh namely square wire mesh, and square plastic (geogrid) mesh were incorporated in ferrocement box by varying the number of layers; 0, 1, 2 and 3. Furthermore, the performance of the sandwich specimens was examined based on unit weight, load-axial deformation, load-lateral deformation under compression, ultimate compressive strength and flexural strength. In addition, load-deflection and load-strain relationship in the presence of bending was also investigated. The failure mode and composite action of sandwich elements with respect to loading conditions were studied. Consequently, efforts were made to achieve affordable ferrocement lightweight aerated concrete with POFA and PFA. Investigation into the material uniformity of sandwich wall elements applying UPV test was also carried out. Finally, finite element analysis was carried out to validate the experimental study.

1.5 Significance of the Research

Palm oil fuel ash and pulverized fuel ash are the common wastes generated from palm oil mills and power generation plant in Malaysia. At present these wastes are disposed as land fill material without any economic benefit, and large amount of money is expended in disposal operation. POFA and PFA can be used considerably to enrich the properties of concrete and other related construction materials which will reduce the pressure on the domestic and industrial consumption of OPC and also promote the sustainability of natural environment.

Furthermore, the outcome of the study would also provide more information on the performance of POFA and PFA cement based aerated concrete and self-compacting mortar for producing ferrocement sandwich wall elements in term of engineering properties.

The research finding is expected to encourage the use of the new approach for producing lightweight composite wall elements for construction industry. This in

turn, will be useful for promoting better quality of construction and innovative systems in the construction industry. The present study is surely a step forward to achieve quality products which will be affordable and durable in environment friendly way.

1.6 Structure of the Thesis

The thesis will be organized in different chapters as follows:

Chapter One: The general appraisal and overview of the study with regards to the introduction, study background, aim & objective were also established. It further significance of the study and briefly layout of the thesis are also described in this chapter.

Chapter Two: Examines the bodies of literature relevant to this research based on the theoretical applicability and presents the findings logically. Hence, it focused on the previous work done on the past research work on the use of pozzolanic materials, aerated concrete, self-compacting concrete and ferrocement, its properties and in the field of civil engineering profession. Finally this chapter is concluded with comprehensive but precise concluding remarks which summarize the review and established justification for the study.

Chapter Three: discusses the methodological choices made in the study to achieve the research objectives bearing it in mind the primary aim of the study. It describes the materials and experimental approach adopted in two phase. The approaches were illustrated and discussed step-by-step. The remaining parts of the chapter focus on description of subjects, the description of instrument and materials, study procedures and laboratory experiments in accordance to the procedures outlined by various standards like ASTM and BS.

Chapter Four: Discusses the results obtained from the first phase of the experimental programme. The results comprise of the development and optimum of the best percentage of POFA and PFA for use in aerated concrete as core and flow-ability of self-compacting mortar as encasing. This would be suitable for casting the thin ferrocement making with POFA and PFA for skin boxes over aerated concrete is discussed.

Chapter Five: Present the results of the second phase of the experimental studies based on the behaviour of sandwich specimens, cubes, blocks prism beams and wall elements in term of compressive strength, flexural strength, acid attack, elevated temperature, UPV test and type and layer of meshes.

Chapter Six: Validate of the experimental study of sandwich wall element with finite element software in term of maximum deformation in compression and flexural.

Chapter Seven: Concludes the results of the study and discussions are made on the achievement and finding of the objectives of the study and the contribution of the research to the existing knowledge. This also outlines the recommendations made for future research.

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