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4. Tajuk Projek: Investigation of Durability Performance of Polymer Modified Cement System in

Title of Project

Infrastructure Developments

5. Ringkasan Penilaian/Summary of Assessment:

	Tidak Mencukupi Inadequate		Boleh Diterima Acceptable	Sangat Baik Very Good	
	1	2		3	4
i) Pencapaian objektif projek: Achievement of project objectives	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
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State other benefits such as product development, product commercialisation/patent registration or impact on source and society.

Nil

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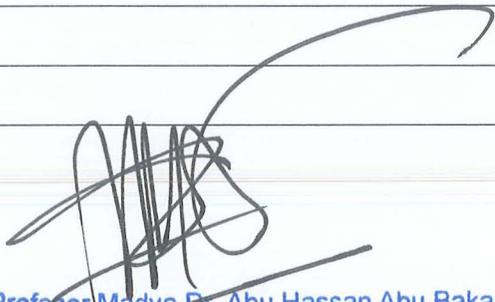
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19/8/2011
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FW: Journal of Engineering, Design and Technology - Decision on Manuscript ID JEDT-Dec-2010-0082

Sent: Monday, June 13, 2011 11:45 AM

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Sent: Thursday, June 09, 2011 11:00 PM

Subject: Journal of Engineering, Design and Technology - Decision on Manuscript ID JEDT-Dec-2010-0082

09-Jun-2011

Dear Mr. Zailan:

Manuscript ID JEDT-Dec-2010-0082 entitled "Structural behaviour of polymer modified ferrocement in concrete structural development." which you submitted to the Journal of Engineering, Design and Technology, has been reviewed. The comments of the reviewer(s) are included at the bottom of this letter.

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Sincerely,
Prof. Theo Haupt
Editor, Journal of Engineering, Design and Technology
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Reviewer(s)' Comments to Author:

Reviewer: 1

Recommendation: Minor Revision

Comments:

Good job, but please note:

1. Revise the name. I think it isn't good enough.
2. There are many grammar/syntax errors which sometimes cause incomprehensibility. Some problems are provided later.
3. Please explain loading situations (p. 3, paragraph 4) by a graph or an image. Also in that graph, please show cross section of the specimens.
4. In the section of "load-Deflection Characteristics", please compare the results in an integrated table. It is not understandable in the current form.
5. Conclusion may be extended and many more items can be concluded, so please provide them.
6. Please provide units for variables of equations 2, 3, and 4. (Similar to equation 1)
7. For equation 2, please explain Beta in better words.
8. Please get an English language expert to improve the text in respect with grammatical rules.
9. Some problems:

On page 2:

Line 17: word "structural" needs revision.

Line 43: change "with" by "by".

Line 46: "moderate" needs revision.

Line 52: "with time when" needs revision.

Line: 56: "high" > "high performance".

On p. 3:

Line 1: "has shows" > "has shown".

On p. 4:

Line 22 is incomprehensible.

The sentence which begins at the 3rd line does not have any verb.

Line 41: "figure" > "figures".

Line 44: "these existence" is incomprehensible.

On p. 5:

Expression of “higher the ratio” is used several times but it is incorrect.

Line 40: there is a grammatical error.

Line 43: “are having” > “have”.

On p. 6:

Line 35: “determining” > “determines”

On p. 7:

Line 20: “of” > “was”.

Line 43: “cement” > “ferrocement”.

There are some grammatical errors in conclusion. Please remove the problems.

Generally be careful when using “the”. It seems you use that more than it is necessary.

Thank you.

Additional Questions:

1. Originality: Does the paper contain new and significant information adequate to justify publication? Will the paper be of interest to an international readership? Will the paper be useful to the respective profession and/or discipline?: Yes. I think it is interesting for global readers, so it is publishable.

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field, the ability to review the literature and cite an appropriate range of literature sources? Is any significant work ignored?: The literature review is little weak. It is suggested to provide with more papers which have focused on interactions between polymers and ferrocement.

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed robust, rigorous and appropriate?: Yes. The methodology is well-designed and the methods are acceptable.

4. Results: Are results presented clearly, correct technically and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper? Do the charts, tables and figures add value and enhance the interpretation of the results?: Yes. Generally, the results are presented clearly. There are several charts, figs, etc. which present the problem and the results very well. Just in one case it seems a table is needed. I have mentioned to this problem in the field of "comment to the authors".

Also conclusion is too brief. I think some more items can be added.

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: Yes. It is applicable, as I think. The paper has provided some practical information and results. Results of such a this paper can be easily used in ferrocement and concrete production.

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: I think some grammatical issues are here that sometimes make the paper incomprehensible. In case of removing them, I think it will be a significant paper.

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Appendix A (Abstract of Research)

ABSTRAK

Masalah utama yang dihadapi di dalam industri pembinaan ialah masalah ketahanan struktur konkrit terhadap keadaan persekitaran dan kakisan tetulang besi oleh ion-ion klorida. Untuk mengatasi permasalahan ini beberapa kaedah telah dipraktikkan. Salah satu kaedah ialah dengan menggunakan bahan yang mempunyai ciri-ciri mekanikal dan nilai estatika yang tinggi, iaitu melalui kaedah pengubahsuaian polimer di dalam rekabentuk mortar dan konkrit. Hasil perkembangan ini beberapa jenis campuran polimer untuk mortar dan konkrit telah dihasilkan. Ini menjadikan mortar dan konkrit terubahsuai polimer adalah bahan pembinaan yang popular kerana wujud keseimbangan yang baik antara kos dan prestasinya. Untuk mencapai ciri-ciri konkrit yang di kehendaki, kajian eksperimen ke atas beberapa jenis campuran polimer adalah diperlukan. Ciri-ciri konkrit yang dihasilkan akan dapat dipertingkatkan melalui penyelidikan dan penemuan kuantiti campuran bahan yang optimum. Perkembangan penggunaan bahan polimer di dalam campuran mortar dan konkrit, mendesak para penyelidik menjalankan kajian penyelidikan yang lebih intensif untuk menghasilkan rekabentuk campuran bahan polimer dengan mortar dan konkrit yang lebih baik ciri-cirinya.

Hasil kajian menunjukkan dengan percampuran bahan polimer iaitu Stirena Butadiena Kopolimer (SBC) dengan kandungan polimer pejal sebanyak 50% dan 46% dan Acrylik Resin (AR) dengan kandungan polimer pejal 50% dan 46% di dalam mortar bukan sahaja telah mempertingkatkan keupayaan kekuatan lentur pada mortar tetapi juga telah mempertingkatkan ciri-ciri ketahanan, iaitu dengan mengurangkan kekenyalan modulus, resapan air, pengecutan dan pengembangan, resapan klorida dan ketelapan udara. Sementara itu kaedah pengawetan selama 28 hari di dalam air pada peringkat awal pengawetan, dapat mengurangkan hidrasi simen serta dapat membantu pembentukan lapisan nipis filem polimer di sekeliling partikel simen yang dapat menutupi liang-liang roma kecil yang wujud di antara partikel simen dan agregat.

ABSTRACT

Deterioration of the concrete may be due to the environmental conditions and corrosion of steel reinforcement as a result of chloride ions has become a major problem in reinforced concrete structures. In an attempt to combat the problem various methods have been used. One of the ways to make a material of high mechanical properties and high aesthetic values is through a polymer modification of mortar and concrete. As a result, various polymer-based admixture have been developed, and polymer modified mortar and concrete using them are currently popular construction material because of their good cost-performance balance. To achieve desired concrete properties, experimental research on certain types of polymer admixture is necessary. Through researching and finding the optimal admixture quantity, concrete properties can be significantly improved. The wide applications of polymer modification for mortar and concrete urges researchers to carry out extensive work in order to establish a good base for this development.

The test result show that the addition of polymer emulsions, namely a Styrene Butadiene copolymer (SBC) with a polymer solids content of 50% and 46% by weight and Acrylic Resins (AR) with a polymer solids content of 50% and 46% by weight to the mixes improve not only the flexural strength of the mortar matrix, but also enhance the durability characteristics of the material by reducing the modulus of elasticity, water absorption, shrinkage and expansion, chloride penetration and oxygen permeability. Initial water curing for 28 days allows the cement hydration to proceed, and enables the polymers particles to coalesce to form a continuous layer of polymer films which partially fills the smaller voids and microspores, surrounds the aggregate and coats the gel resulting in a less porous, and a less permeable mortar matrix.

Appendix B

Comprehensive Technical Report

**Investigation of Durability Performance of Polymer Modified
Cement System in Infrastructure Developments**

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INTRODUCTION

1.1 Background of Study

In the early years of the 20th century, concrete was rapidly becoming the most popular building material. However concrete have some disadvantages such as delayed hardening, low tensile strength, large drying shrinkage and low chemical resistance. Durability of concrete structures is one of the main problem faced by the construction industry . For example deterioration of concrete structures as a result of chemical attack and corrosion of reinforcement is mainly attributed to the ingress of chlorides, sulphates and other aggressive substances into concrete. The use of ordinary Portland cement systems alone in severe environmental conditions may not be effective and cannot provide long term solutions because the problems of deteriorations will exist after a shorter period of time. To reduce these disadvantages, polymers have been utilized as an additive.

Polymer-modified or polymer cement material that is designed to replace part of cement hydrates binder of conventional cement with polymer. The concept of polymer modification for cement mortar and concrete is not nothing new, because a lot of research and development of polymer modification has been done for 70 years or more. As a result, many effective polymer modification systems for mortar and concrete have been developed, and currently is used in various applications in the construction industry.

A polymer-based material mixture, defined as a mixture of compounds consisting of polymer material as the main ingredient effective in modifying or improving the properties such as strength, deformability, adhesion, waterproofness and durability of cement mortar and concrete. One such attempt is polymer-modified mortar or concrete, which is made by the modifying ordinary cement mortar or concrete with polymer additives such as latexes, redispersible polymer powders, water-soluble polymers, liquid

resins and monomers. The cement mortar and concrete which are made by mixing with the polymer-based admixtures are called polymer-modified mortar and concrete, respectively.

Polymer addition is found to increase flexural strength and other engineering properties of mortars by reducing shrinkage and chloride permeability has been reported by Ramli. M. A high resistance to chloride ion penetration has been reported by Mehta from tests on acrylic latex-modified mortar and concrete ponded with 3% sodium chloride for a period of 60 days. These results also indicate a low penetration of water and salt into the polymer-modified cement systems and thus play a significant role in enhancing the durable performance of concrete construction. Based on this data, to achieve the characteristics desired concrete, experimental research on certain types of polymer admixture is required. Through researching and finding the optimal mix of quantity, concrete properties can be significantly improved. Wide applications in polymer modification for mortar and concrete encourage researchers to implement a wide range of research studies to build a good foundation for this development.

The purpose of this research is to investigate the durability performance of various polymer-modified cement system in concrete construction. This includes study of the behaviour of various polymer-modified mixes, the effect of different curing conditions on its mechanical properties, dimensional stability, impermeability characteristics, carbonation and water absorption.

EXPERIMENTAL PROGRAMME AND CHARACTERISTICS OF MATERIALS

2.1 Introduction

The experimental programme with distinctions of the objective, the characteristic of materials used in this project, the preparation of the test specimens and the test procedures. Also, the properties, chemical compositions and mix design process were listed down in this section.

2.2 Objectives

The specific objectives of this research are :-

- a. To developed a mix design procedure methods for a durability of polymer modified cement system.
- b. To study t he effect of polymer modification on the durability and flexibility performance.
- c. To evaluate the structural behaviour of polymer modified cement system in infrastructure.

2.3 Experimental Programme

This experimental programme for this research project consisted of two parts. The first part emphasizes on the effect of polymer modification on cement concrete, which includes its engineering properties, pore structure, permeability and chloride penetration of polymer modified cement mortar. This second part of the experimental programme investigates the structural performance of polymer modified cement mortar when used in structure application. The details of the test programme are presented in Table 2.1.

Table 2.1 : Details of test programme

Objective	Types of Test	Size of Specimen	The Age (days)
Engineering Properties	a. Slump	Every type of mix	
	b. Density	100mm x 100mm x 100mm	30, 60, 90,180
	c. Compressive strength	100mm x 100mm x 100mm	30, 60, 90,180
	d. Pulse velocity	100mm x 100mm x 100mm	30,60,90,180
	e. Flexural strength	100mm x 100mm x 500mm	30,60,90,180
	f. Shrinkage & expansion	100mm x 100mm x 500mm	1,2,3,7,14,28,60,90,180
	g. Dynamic modulus	Calculation	30,60,90,180
Durability Properties	a. Water absorption	75 mm diameter cores	30,60,90,180
	b. Oxygen permeability	50 mm diameter cores	30,60,90,180
	c. Carbonation	100mm x 100mm x 500mm	30,60,90,180
	d. Lost weight	100mm x 100mm x 100mm	30,60,90,180

2.4 Assessment of Test Quality

Testing of concrete structures may be needed when necessary engineering data to enable decisions to be based on the structure. The reason for this may include the initial tests to collect data prior to the renovation of structures, or diagnostic tests to rate the reason of damage or distress, examination of normal structure, or a test to settle the dispute on the quality of concrete. The first stage of any evaluation of the structure must be documented consideration of all available records from the time of construction, especially in the concrete mix proportion, the source material, the test cube, and the temperature and humidity at the time of casting.

It is important that the objectives of a test programme are clearly defined at the outset and agreeable to all parties concerned, particularly when there is a dispute over concrete quality. Furthermore, all parties involved in a dispute should be aware of the variability which can be found in concrete structures as a result of varying concrete supply and differences in compaction and curing regimes. In choosing the test locations and the frequency of testing, engineers should ensure that the test programme will provide sufficient data to allow sensible conclusions to be reached, whilst keeping costs and structural damage to a minimum. It is also important that the test types and procedures are agreed, particularly for test not covered by a National Standard.

Concrete structures can be assessed for strength, comparative quality, local integrity, potential durability and to determine the causes of deterioration. Current British Standards (BS) for testing are :-

a. Slump test

The slump test is a very useful method of detecting the variations in the uniformity of mix. Although slump test does not measure the workability of concrete, the ACI 116R-90 describes it as a measure of consistency. The slump of fresh concretes was determined following the British Standard BS 1881: Part 102:1983.

b. Density

The density of hardened mortar prisms was determined according to the British Standard BS 1881: Part 114: 1983, Method for determination of hardened concrete. For the above density test, a procedure for determination of the volume by water displacement method had been used.

c. Flexural Strength

The flexural strength of polymer modified cement mortar was performed on 100mm x 100mm x 500mm mortar prisms at the 30, 60, 90 and 180 days and carried out in accordance with British Standard BS 1881: 1983, Method of determination of flexural strength. The flexural strength (f) of mortar prisms was obtained from the average strength of three test results determined from the following expression,

$$f = P L / b d^2$$

where

P is the breaking load (N)

L is the distance between the supporting rollers

b and d are the lateral dimensions of the cross-section of specimens (mm)

d. Compressive Strength

The compressive strength of the mortar specimens was determined from parts of the prisms tested for flexural strength based on the equivalent cube strength method specified in BS 1881 : Part 119: 1983. In this test, each half of prism after failure in flexure, was tested by applying the compressive load through square steel plates of the same size as the cross-section of the prism. By equivalent cube strength method, each set of compressive strength data represents the average of six test results.

e. Dynamic Modulus of Elasticity

The dynamic of elasticity of concrete is related to the structural stiffness and deformation process of concrete structure, and is highly sensitive to cracking. The dynamic modulus of elasticity was determined from the fundamental resonance frequency following the method described in the British Standard BS 1881: 209: 1990. The test was conducted by excitation in the longitudinal mode of vibration on the 100 x 100 mm end face of prism with a path length of 500 mm.

The dynamic modulus, E_d (in GPa) of all specimens was calculated based on the following expression:

$$E_d = 4 \eta^2 L^2 \rho 10^{-15}$$

Where

L is the length of the specimen (mm)

η is the fundamental frequency in the longitudinal mode of vibration (Hz)

ρ is the density of the specimen (kg/m^3)

f. Ultrasonic Pulse Velocity

For ultrasonic pulse velocity measurement, a direct method using a portable ultrasonic non-destructive indicating test (PUNDIT) instrument was adopted in accordance with the British Standard BS 1881: part 203: 1986. The time taken by the pulsating wave to travel from one longitudinal end of the prism to the other, was recorded by means of 54 kHz transducers of 50 mm diameter. Since the distance travelled by this pulse is fixed and equals the length of the prism, the velocity of the pulsating wave could be easily determined.

To obtain higher accuracy and consistent results, petroleum jelly was applied to the surfaces in contact with the transducer and receiver prior to measurement. The pulsating time (in microseconds) across 500 mm length of mortar prism was taken when a steady reading was recorded by the PUNDIT. The average value of pulse velocity was determined from the three test prisms cured at three different curing conditions.

g. Shrinkage and Expansion

Concrete prisms of 100 x 100 x 500 mm were used to measure drying shrinkage and wetting expansion of the specimens. Once the specimens were demoulded at approximately 24 hours after casting, demec discs were attached to the four faces of each specimen over a gauge length of 205 mm. Initial strains were taken within one hour after demoulding, and thus, the plotted and tabulated strains are those which occurred since this time.

For each mix, three specimens were prepared and hence, the tabulated and plotted results are the average of twelve readings. For all strain measurements, a demec gauge of 205 mm gauge length was used, with a gauge sensitivity of 6.55×10^{-6} m/m per division. For shrinkage and expansion test, the readings were taken at close intervals at early ages, but the period between readings was gradually increased as the specimens matured.

h. Water Absorption

The water absorption of specimens was tested in accordance with BS 1881: part 122: 1983, using 75 mm diameter core samples extracted from the concrete prisms.

i. Oxygen Permeability

For oxygen permeability, Leeds cell permeameter was used to determine the permeability of concrete samples of size 50 mm diameter with average thickness varying from 36-40 mm.

k. Chloride Penetration

The test for chloride penetration on composite slabs was based on the determination of acid soluble chloride ions following the British Standard BS 1881 : Part 124 : 1992.

l. Load, Deflection and Crack Measurements

These tests were conducted on concrete specimens and subjected to static loading using four point loading.

2.5 Curing Regimes

Curing plays a major role in the cement hydration process, and has a significant effect on the engineering properties of polymer-modified cement system. To investigate the effect different curing conditions on the behaviour of polymer modified cement systems, mortar prisms were subjected to two curing regimes as follows:-

Curing A :

The specimen were kept to ambient air condition (air curing) after demoulding until the time of test

Curing B :

After demoulding, the specimen were kept in a salt water tank (salt water curing) until the time of test

2.6 Mix Design

a. Type of specimens

1. Control mortar (CONTROL)
2. SB- Styrene Butadiene Copolymer mortar @ solid content 45.8% (SBCM I)
3. SB-Styrene Butadiene Copolymer mortar @ solid content 49.9% (SBCM II)
4. AR – Acrylic Resins mortar @ solid content 46 % (ACM I)
5. AR – Acrylic Resins mortar @ solid content 50 % (ACM II)

c. Design of Mixes

The mortar mix proportions used in this study were cement : sand : 1 : 2.5, all by weight with a water-cement (w/c) ratio of 0.45 for the initial mixes. All the mixes were designed for a slump 100 – 150 mm. A superplasticizer (SP), was therefore used as and when necessary. Another aspect being considered when designing the mix proportion is the cement content and the compactness of the matrix to be achieved. Compactness of matrix is an important factor ensuring durability mortar and can be improved by reducing the water content or using low water-binder ratio with an appropriate amount of cement content.

The amount of cement content used in the mortar mix, designed based on the following expression (Paillere, A.M., 1985).

$$C = 700 / \sqrt[5]{D}$$

Where C is the cement proportion in kg/m³

D is the maximum size of aggregate in mm

If the maximum size of fine aggregate in the mix proportion is 5.0 mm, the cement content should be used is about 500 kg/m³. The details of the mixes are shown in Table 2.2

Table : 2.2 : Details of mix design

Type of Mix	Cement (kg/m³)	Polymer (%)	Superplasticiser (%)	Sand (kg/m³)	W/c ratio	Slump (mm)
CONTROL	500	0	1	1250	0.45	100-150
SBCM IA	500	10	1	1250	0.33	100-150
SBCM IB	500	15	1	1250	0.27	100-150
SBCM IIA	500	10	1	1250	0.35	100-150
SBCM IIB	500	15	1	1250	0.30	100-150
ACM IA	500	10	1	1250	0.33	100-150
ACM IB	500	15	1	1250	0.27	100-150
ACM IIA	500	10	1	1250	0.35	100-150
ACM IIB	500	15	1	1250	0.30	100-150

d. Preparation of Mixing

Based on design of mixes are shown in Table 2.2

Procedure :-

- a. Per cube volume @ 0.001 m^3 (100mm x 100mm x 100mm)
- b. Per prisms volume @ 0.005 m^3 (100mm x 100mm x 500mm)

e. Mixing

Calculation :-

5 cubes + 5 prisms + Additional factor of 15% for waste resulting from 5 cubes and 5 prisms.

$$[(5 \times 0.001\text{m}^3) + (5 \times 0.005\text{m}^3) + (0.15 \times 0.03\text{m}^3)] = 0.0345 \text{ m}^3$$

2.7 Characteristic of Materials

2.7.1 Cement

Portland cements are composed of four basic chemical compounds shown with their names, chemical formulas, and abbreviations :

1. Tricalcium silicate : $3\text{CaO} \cdot \text{SiO}_2 = \text{C}_3\text{S}$
2. Dicalcium silicate : $2\text{CaO} \cdot \text{SiO}_2 = \text{C}_2\text{S}$
3. Tricalcium aluminate : $3\text{CaO} \cdot \text{Al}_2\text{O}_3 = \text{C}_3\text{A}$
4. Tetrcalcium aluminoferrite : $4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{FeO}_3 = \text{C}_4\text{AF}$

The relative percentages of these compounds can be determined by chemical analysis. Each of the components exhibits a particular behavior, and it can be shown that by modifying the relative percentages of these compounds, the behavior of the cement can be altered.

Tricalcium silicate hardens rapidly and is largely responsible for initial set and early strength. In general, the early strength of Portland cement concretes will be higher with increased percentages of C_3S . However, if moist curing is continued, the later strength after about 6 months will be greater for cements with higher percentage of C_2S .

Dicalcium silicate hardens slowly, and its effect on strength increases occurs at ages beyond one week.

Tricalcium aluminate contributes to strength development in the first few days because it is the first compound to hydrate. It is, however, the least desirable component because of its high heat generation and its reactivity with soils and water containing moderate to high sulfate concentrations. Cements made with low C₃A contents usually generate less heat, develop higher strengths, and show greater resistance to sulfate attacks.

The *tetracalcium aluminoferrite* compound assists in the manufacture of Portland cement by allowing lower clinkering temperature. C₄AFe contributes very little to the strength of concrete even though it hydrates very rapidly.

The Portland cement used in the test was a typical ASTM Type I (Normal) Portland Cement conforming to the British Standard BS 12:1991. This type is a general concrete construction cement utilized when the special properties of the other types are not required. It is used where the concrete will not be subjected to sulfate attack from soil or water or be exposed to severe weathering conditions. It is generally not used in large masses because of the heat of hydration generated. Its chemical composition and some physical properties are presented in Table 2.3

Table 2.3 : Chemical composition and fineness of ASTM Type I (Normal) ordinary Portland cement (OPC)

Chemical compounds	Chemical Composition %	Chemical compounds	%
SiO ₂	20.5	Free CaO	1.50
Al ₂ O ₃	5.8	CI	0.02
Fe ₂ O ₃	2.3	L.O.I	0.96
CaO	64.9	IR	0.2
MgO	1.1	Blaine fineness	370 m ² /kg
SO ₃	3.11		
Na ₂ O	0.19		
K ₂ O	0.60		

Table 2.4 : Main compound composition of ASTM Type I (Normal) ordinary Portland cement (OPC)

Name of compounds	Composition (Supplier) (%)	Composition (Calculation) (%)
Tricalcium silicate (C ₃ S)	51.19	50.70
Dicalcium silicate (C ₂ S)	21.17	22.50
Tricalcium aluminate (C ₃ A)	11.48	8.60
The tetracalcium aluminoferrite (C ₄ AF)	7.00	9.40

Table 2.5 : Calculation of percentage proportion of main compounds in ordinary Portland cement (OPC)

Name of compounds	Calculation of percentage of main compounds in Ordinary Portland Cement (OPC)
Tricalcium silicate (C ₃ S)	$4.07 (\text{CaO} - \text{free CaO}) - (7.60 \times \text{SiO}_2 + 6.72 \times \text{Al}_2\text{O}_3 + 1.38 \times \text{Fe}_2\text{O}_3 + 2.85 \times \text{SO}_3) = 50.70$
Dicalcium silicate (C ₂ S)	$2.87 \times \text{SiO}_2 - 0.754 \times \text{C}_3\text{S} = 22.50$
Tricalcium aluminate (C ₃ A)	$2.65 \times \text{Al}_2\text{O}_3 - 1.69 \times \text{Fe}_2\text{O}_3 = 8.60$

The tetracalcium aluminoferrite (C ₄ AF)	3.04 x Fe ₂ O ₃ = 9.40
--	--

Table 2.6 : Test for initial and final setting times of ordinary Portland cement (OPC)

Test for setting time	Ordinary Portland Cement (OPC)
The initial setting time	55 minutes
The final setting time	146 minutes

2.7.2 Fine Aggregate

The aggregate component of a mortar mix occupies 60 to 80 percent of the value of mortar, and their characteristics influence the properties of the mortar. The selection of aggregates will determine the mix design proportion and the economy of the resulting mortar. Aggregates selected for use should be clean, hard, strong, and durable particles, free of chemicals, coatings of clay, or other materials that will affect the bond of the cement paste. Aggregates containing shale or other soft and porous organic particles should be avoided because they have poor resistance to weathering. Any aggregates that do not have adequate service records should be tested for compliance with requirements.

River sand was used as fine aggregate for all the mixes. It forms the major ingredient of the polymer-modified mortar mix. To ensure that the batches of fine aggregates used always comply with the grading zone, sieve analysis was carried out in accordance with the British Standard BS 812: Part 103 : 1985. The grading of sand is important in order to improve the workability of mortar, and also to avoid excess of fine particles. The analysis of 500g of sample of sand showed that the material complied with the grading limit of zone 4 and its

fineness modulus was 2.46. The results are presented in Table 2.8 and Fig. 2.1, respectively. It is clear from the table that the majority of the sand particles.

Table 2.8 : Sieve analysis for Fine Aggregate

Sieve Size Range (mm)	Sieve (g)	Fraction % by mass	Nominal Aperture Size (mm)	Cumulative Undersize % by mass
> 5.00	4.9	0.98	5.00	99.02
5.00 - 2.36	130.0	26.04	2.36	72.98
2.36 - 1.18	125.0	25.04	1.18	47.94
1.18 - 0.600	115.3	23.09	0.600	24.85
0.600 - 0.300	82.3	16.48	0.300	8.37
0.300 - 0.150	29.5	5.91	0.150	2.46
< 0.150	12.3	2.46		
Total	499.3	100		
Fineness Modulus (F.M) 2.46				

Table 2.9 : Grading Limits for Mix Design Procedure

BS Sieve Weight Percentage				
BS Sieve Size	Zone 1	Zone 2	Zone 3	Zone 4
10 mm	100	100	100	100
5 mm	90-100	90-100	90-100	95-100
2.36 mm	60-95	75-100	85-100	95-100
1.18 mm	30-70	55-90	75-100	90-100
600 μ mm	15-34	35-59	60-79	80-100
300 μ mm	5-20	8-30	12-40	15-50
150 μ mm	0-10	0-10	0-10	0-15

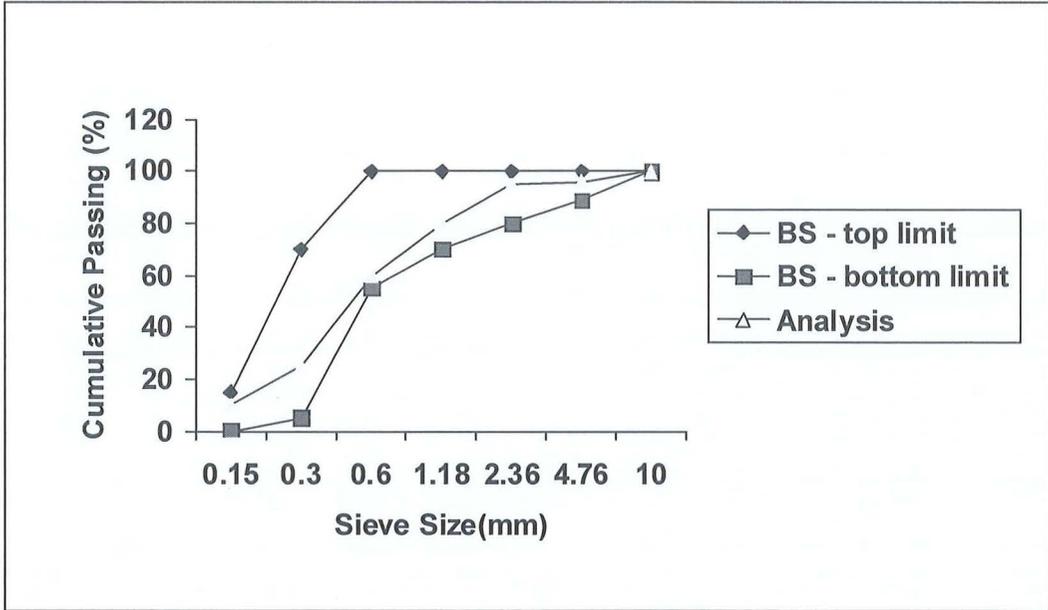


Figure 2.1 : Grading curve of fine aggregate

In getting good quality fine aggregate, physical characteristics such as relative density and water absorption will be carried out, tests are referred to British standard (BS) 812: Part 1: 1975. The result of test calculations for relative density and water absorption for fine aggregates used in this study are shown in Table 2.10.

Table 2.10 : Determination of Relative Density and Water Absorption for Fine**Aggregate**

Test No	A (g)	B (g)	C (g)	D (g)	Relative Density (Oven-Dried Basis)	Relative Density (Saturated Surface Dried)	Water Absorption (% of Dry Mass)
					$\frac{D}{D-(B-C)}$	$\frac{A}{A-(B-C)}$	$\frac{100(A-D)}{D}$
A	500	1724	1385	498.8	3.12	3.10	0.24
B	500	1698	1385	498.9	2.69	2.68	0.22

2.7.3 Mixing Water

Water is the most important and least expensive ingredient of concrete or mortar. A part of mixing is utilized in the hydration of cement to form the binding matrix in which the inert aggregates are held in suspension until the matrix had hardened. The remaining water serves as lubricant between the fine and coarse aggregates and makes concrete workable. Generally, cement requires about three-tenth of its weight of water for hydration. Hence the minimum water cement ratio required is 0.30. But the concrete containing water in this proportion will be very harsh and difficult to place. Additional water is required to lubricate the mix, which makes concrete or mortar workable. This additional water must be kept minimum, since too much water reduces the strength of concrete or mortar.

Portable water can be used for manufacturing concrete or mortar. The water/cement ratio (mass ratio of water to cement) is the key factor that determines the strength of concrete or mortar. A lower w/c ratio will yield a concrete or mortar which is stronger and more durable, while a higher w/c ratio yield a concrete or mortar with a larger slump, so it may be placed more easily. Cement paste is the material formed by combination of water and cementitious materials; that part of the concrete or mortar which not aggregate or reinforcing. The workability or consistency is affected by the water content, the amount of cement paste in the overall mix and the physical characteristics of the aggregates.

The water used for the preparation of the mortar in the test was portable tap water conforming to the British Standard BS 3148 : 1980. Such water which was obtained from public supply, where its chemical composition was acceptable for drinking and was hence considered suitable for use in making the concrete or mortar specimens. BS 3148 gives the standards for the testing of water for its suitability for use in mortar or concrete making. If the water is suitable for drinking it is suitable for mortar or concrete making. Whether, if the water is suspected to be unsuitable, two types of test cubes may be made. First with the suspected water and another with portable water. The strengths and general appearances at 7 and 28 days will provide useful information.

2.7.4 Polymer Materials

Polymer are produced by combining a large number of small molecular units (monomers) by the chemical process known as polymerization to form long-chain molecules. Protein and cellulose are natural polymers, while plastics and rubbers are synthetic organic polymers and silicones are synthetic inorganic polymers. Due to the need for water in a cement mix, polymer solutions based on water are more suitable than those based on other solvents. Methylcellulose is a polymer that is soluble in water. The reduction in resistivity is an indication of an improvement in the degree of fiber dispersion. The presence of Methylcellulose, which is not conductive, presumably at the fiber-matrix

interface, is expected to increase the resistivity of the mortar. In spite of this, the resistivity of the fiber mortar is decreased by the Methylcellulose addition.

Polymers classified into two distinct classes, thermoplastics, and thermosetting materials. Due to the need for water in a cement mix, polymer particle dispersions based on water are more suitable than those based on other liquids are. The polymers used in the dispersions are not soluble in the liquids used. As most polymers are not soluble in water, the choice of polymers for dispersions is wide compared to that of polymer for solutions.

In this research provides a comparative study of four polymer admixtures were used. A Styrene Butadiene copolymer (SB), with the trade name of Latex DL 620, containing 50% by weight of polymer solids, a Styrene Butadiene copolymer (SB), known as Dow Latex 470, containing 46% by weight of polymer solids. A Acrylic Resins (AR), known as Craymul 2423, containing 50% by weight of polymer solids and a Acrylic Resins, with the trade name of Craymul 2741, containing 46% by weight of polymer solids were used together with the ordinary Portland cement mortar. The more important physical and chemical properties of these polymer emulsions are shown in Table 2.11.

Table 2.11 : Physical and chemical properties of polymer latexes

Properties	Styrene Butadiene Copolymer (SBC) Latex DL 620	Styrene Butadiene Copolymer (SBC) Dow Latex 470	Acrylic Resin (AC) Craymul 2423	Acrylic Resin (AC) Craymul 2741
Appearance	Milky white liquid emulsion	Milky white liquid emulsion	White liquid	White liquid
Odour	Slight	Slight	Slight	Slight
pH	5.5-6.5	8.5-11.0	7.5-8.5	8.0-9.0
Boiling point	100°C	-	-	-
Specific gravity	0.98 – 1.040 g/cm ³	-	1.02 g/cm ³	1.06 g/cm ³
Brookfield Viscosity	300 Max mPa.s	-	7000-14000 mPa.s	40-100 mPa.s
Solids content	50%	46%	50%	46%
Particle size	-	160-180 nm	150 nm	200 nm

2.7.5 Super Plasticizer

Super plasticizer, also known as plasticizers, include water-reducing admixtures. Compared to what is commonly referred to as a “water reducer” or “mid-range water reducer”, super plasticizers are “high-range water reduces”. High range water reducers are admixtures that allow large water reduction or greater flow ability (as defined by the manufacturers, suppliers, and industry standards) without substantially slowing set time or increasing air entrainment.

Each type of super plasticizer has defined ranges for the required quantities of mortar or concrete mix ingredients, along with the corresponding effects. They can maintain a specific consistency and workability at a greatly reduced amount of water. Dosages needed vary by the particular mortar or concrete mix and type of super plasticizer used. They can also produce a high strength mortar or concrete. As with most types of admixtures, super plasticizers can affect other concrete properties as well. The specific effects, however should be found from the manufacturer or supplier.

There are two most common types of super plasticizer: sulfonated melamine-formaldehyde condensates; and sulfonated naphthalene-formaldehyde condensates. The type of super plasticizer used in this experimental investigation was a sulphonated naphthalene-formaldehyde condensate known as Admix SP1000. It is a high performance super plasticizer, supplied by Fosroc Expandite Sdn Bhd, which shows a remarkable slump retention properties. The physical and chemical properties of Admix SP1000 super plasticizer is shown in Table 2.12.

Table 2.12 : Physical and chemical properties of Admix SP1000

Appearance	Dark brown liquid
Solubility	Soluble
Specific gravity	1.15 at 20° C
pH	4.5 – 6.5
Air entrainment	Air content will be increased by 1-2 %
Chloride entrainment	Nil based on BS 5075

ENGINEERING PROPERTIES OF POLYMER MODIFIED CEMENT MORTAR

3.1 Introduction

In engineering practice, the strength of cement mortar and concrete is commonly considered to be the most valuable property, although, in many practical cases, other characteristics, such as durability and permeability, may in fact be more important. The problems of low tensile strength, and flexural strength properties, high drying shrinkage, high permeability and water absorption, are some of the typical disadvantages of ordinary cement mortar. Polymer-modified cement mortar, which is made by modification of the cement matrix with polymer additives such as latexes, is known to impart high durability performance, and was designed to reduce these disadvantages.

This chapter emphasizes the engineering properties of polymer modified cement mortars, such as compressive strength, flexural strength, drying shrinkage, dynamic modulus of elasticity, ultrasonic pulse velocity, water absorption and carbonation. The main aim of this part of the investigation is to develop a suitable mix design, which exhibits not only high early strength development, but also a high durability performance of polymer modified cement mortars.

The type of polymer materials, and the effect of different curing conditions on engineering properties of PMM, were also investigated. This chapter focus on the presentation and discussion of test results of engineering properties of polymer modified cement systems.

3.2 Dimensional Stability

3.2.1 Workability

Workability of fresh cement mortar is usually defined in terms of the amount of mechanical work, or energy, required to produce full compaction of the mortar without any segregation. In this study the workability of the the fresh polymer modified cement mortar was measured using the slump test which is not only easy to perform but also commonly used at the constructied site. The slump test which measures the consistecny of fresh polymer modified cement mortar was conducted in accordance with British Standard BS 1881:Part 102:1983.

All mixes used in this investigation are designed an average slump ranging between 100-150 mm. Such slump range can be achieved fairly easily by polymer modified cement mortar, even of sufficiently low water-cement ratio.

To evaluate how the slump decreases over a period of time, analysis on the fresh mixes was carried and the results are presented in Fig. 3.1. The results show that the polymer modified cement mortar in the mix not only decreases the consistency of the mix, but also exhibits a higher rate of slump compared to that of the unmodified mix, CONTROL. This also on advantage for the polymer modified cement system because higher slump loss will help to minimise the problem of segregation of aggregates.

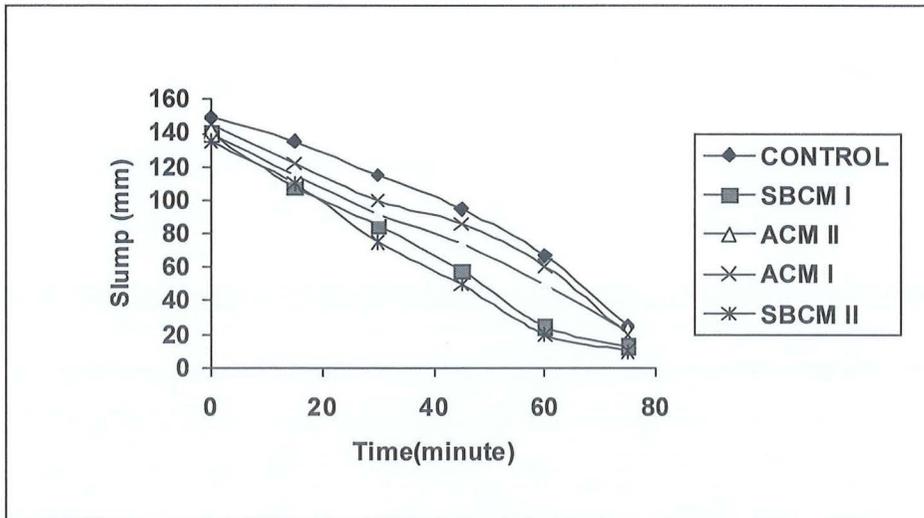


Figure 3.1 : The slump decreases over a period of time

3.2.2 Density

It certainly true that there is often a good correlation between strength and density for a particular mix. The correlation between strength and density arises because air and water are the two lightest ingredients of concrete and cement is normally the heaviest ingredient. The other factor likely to influence density, is the specific gravity of the aggregate. Although a high density concrete is not always of high strength, in most cases the higher density shows superior performance in strength and durability.

The most accurate method of determining density of hardened mortar specimens is by weighing the specimen in air and suspended in water.

The density, ρ is then calculated from the following expression;

$$\rho = \frac{W_a}{W_a - W_w}$$

Where W_a = weight of specimen in air

W_w = weight of specimen in water

The density of polymer modified cement mortar specimens for two different exposure conditions is presented in Figures 3.2 and 3.3. The effect of curing condition on that 28 days in water and followed by salt water curing do not show significant increase. All the polymer modified cement mortar specimens exhibit a much lower density than that of unmodified control specimen. The control specimen CONTROL, show the highest hardened density of about 2448 kg/m³ at the age 365 days. The density of ACM II and SBCM II specimens is about 2476 kg/m³ and 2425 kg/m³ at the age 365 days, followed by SBCM I with density of 2413 kg/m³ at the age 365 days. The ACM I specimen show the lowest density of about 2204 kg/m³ at the age 365 days.

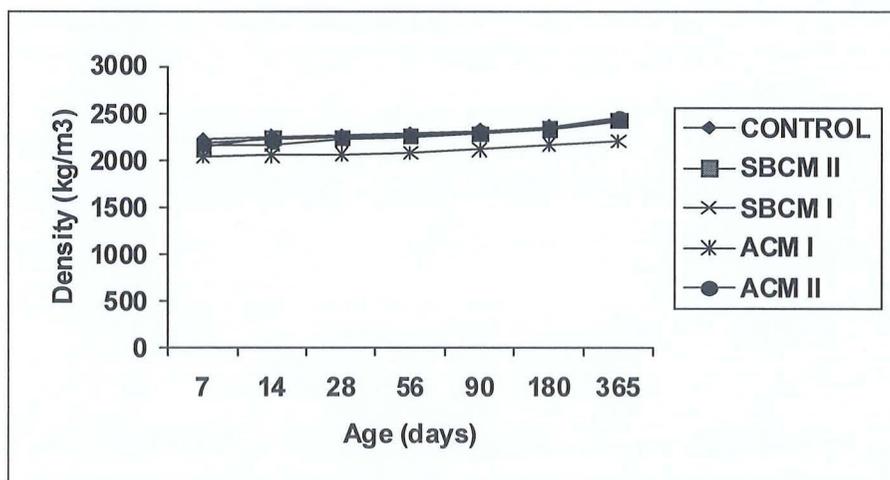


Figure 3.2 : Density of cement mortar – curing 28 days in water and followed by salt water curing (Kg/m³)

In the curing conditions on that 28 days in water and followed by air shows that, all the polymer modified cement mortar specimens also a much lower density compared to unmodified control specimen. The result in Figure 3.3 also show that the density of all specimens increases with the increasing age of curing. The CONTROL specimen show a increase from 2178 kg/m³ at about 7 days to 2383 kg/m³ at the age of 365 days. The SBCM II modified mortar shows the highest density compared to other modified mortar

specimens of about 2089 kg/m³ at the age of 7 days to 2357 kg/m³ at the age of 365 days.

Based on the test results, polymer modification reduces the density of cement mortars by about 5% depending on the type and amount of polymer solids used in Portland cement system.

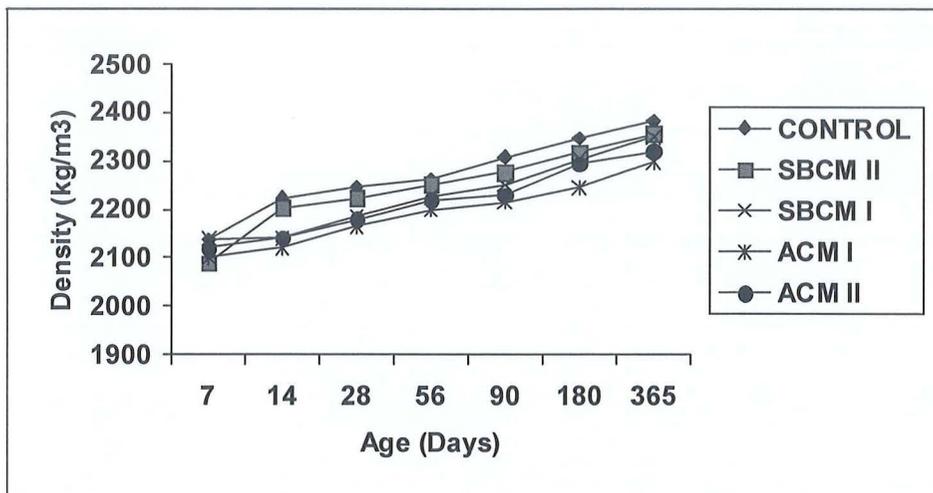


Figure 3.3 : Density of cement mortar – curing 28 days in water and followed by air curing (Kg/m³)

3.2.3 Compressive strength

Concrete is used primarily in a compressive mode, and therefore in engineering practice, compressive strength is important. In this test, the compressive strength of concrete was tested by applying the compressive load through a square steel plate, 100 x 100 mm in size, using a concrete crushing machine.

The compressive strength results of all the mixes tested in this study are shown in Figures 3.4 and 3.5, respectively for the two different curing regimes. The result shown that, all the specimens do not show significant increase in curing 28 days in water and followed by salt water curing and their compressive strengths are almost the same as that of under curing 28 days in water and followed by air curing.

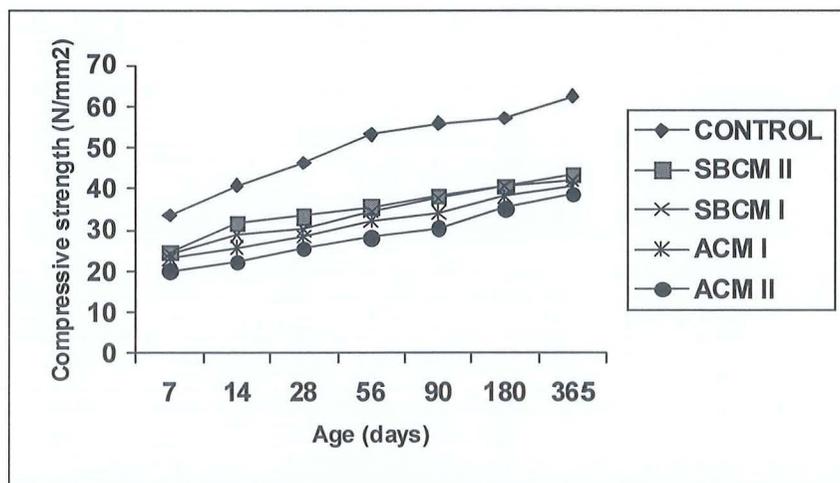


Figure 3.4 : Compressive strength of cement mortar – curing 28 days in water and followed by salt water curing (N/mm²)

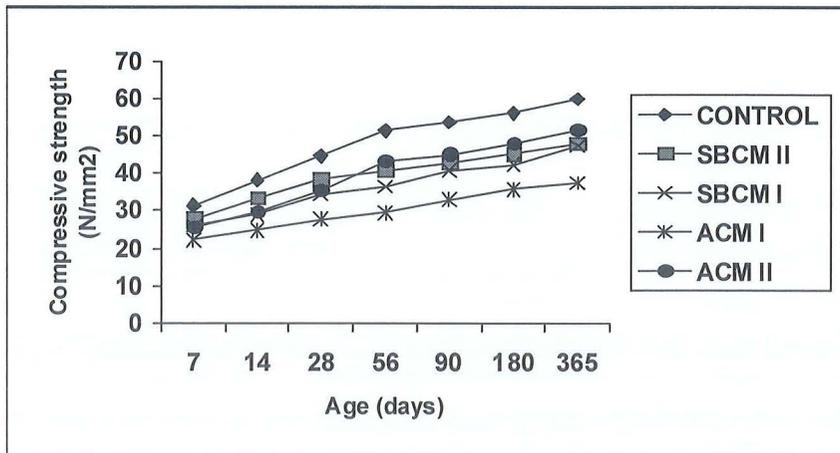


Figure 3.5 : Compressive strength of cement mortar – curing 28 days in water and followed by air curing (N/mm²)

The results of figures 3.4 and 3.5 also reveal that the compressive strength of the polymer modified cement mortar mixes are always lower than that of the unmodified, CONTROL. The SBCM II mix exhibits higher strengths than that of SBCM I, ACM II and ACM I in prolonged salt water curing. Under prolonged air curing, the ACM II shown higher compressive strength than that SBCM II, SBCM I and ACM I.

3.2.4 Pulse velocity

The pulse velocity of a concrete material depends on its density and the elastic properties of the concrete. It is indicative of the quality of the material which relates to the development of its microstructure, denseness, and also the presence of internal microcracking. The pulse velocity in cement mortar also depends on the path length, the lateral dimensions of the specimens tested, the presence of reinforcement as well as the moisture conditions of the test specimens. In general, the velocity is increased with increased moisture content.

The result of the ultrasonic pulse velocity tests are shown in Figures 3.6 and 3.7. The result show that the variation pulse velocity of all mixes increases with the increasing age of specimen.

The result also show conclusively that an initial 28 days in water and followed by salt water curing leads to better pulse velocity development for all the mixes than an initial 28 days in water and followed by air curing. However, the differences in these pulse velocity values between initial salt water and initial air curing, are only marginal. Although the control mix CONTROL was slow develop its microstructure, it showed the highest pulse velocity values, under both curing. Whereas, polymer modified cement mortar specimens have generally lower pulse velocity values.

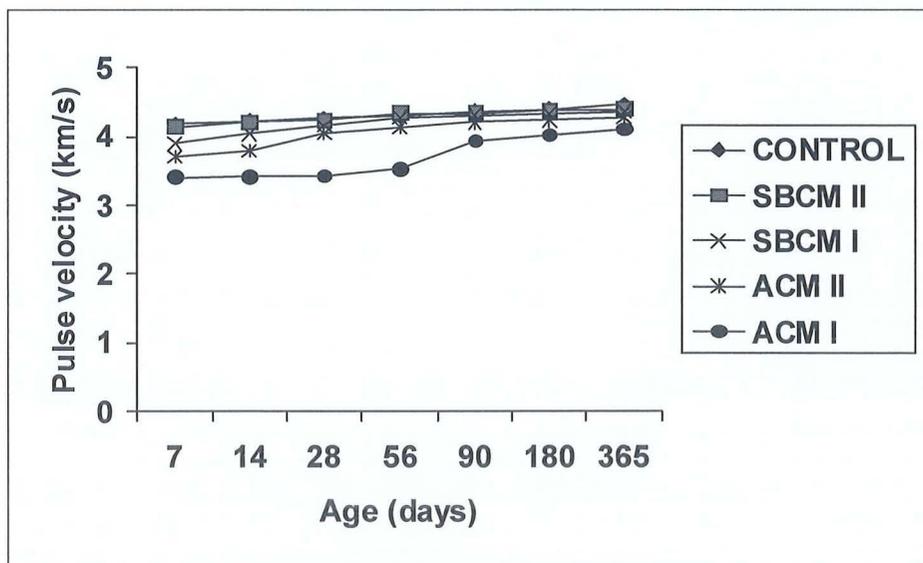


Figure 3.6 : The Pulse Velocity of cement mortar – curing 28 days in water and followed by salt water curing (km/s)

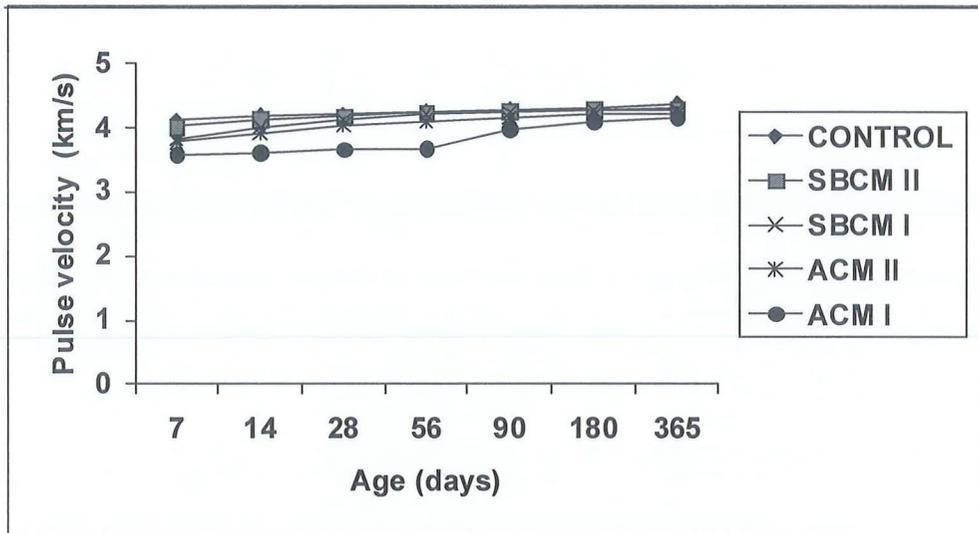


Figure 3.7 : The Pulse Velocity of cement mortar – curing 28 days in water and followed by air curing (km/s)

3.2.5 Flexural strength

The flexural strength results of all the mixes tested in this study under the two different curing conditions are presented in Figures 3.8 and 3.9. Irrespective of the type of initial curing, salt water or air, the polymer modified cement mortar materials show higher flexural strength values compared to the control unmodified mortar mix. The initial salt water curing show in Figure 3.8 gives a higher margin of flexural strength values than when the material is subjected to initial air curing show in Figure 3.9. The SBCM II mix exhibits higher flexural strength values then that of SBCM I, ACM II and ACM I, under both curing regimes.

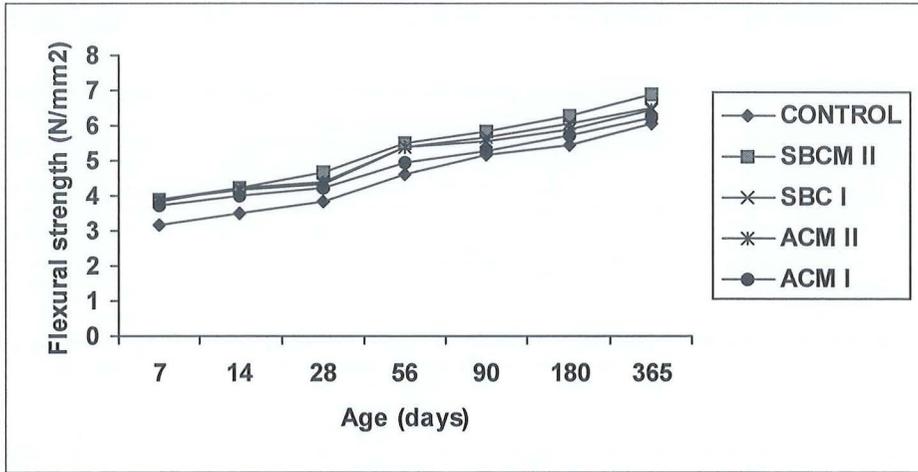


Figure 3.8 : The Flexural Strength of cement mortar – curing 28 days in water and followed by salt water curing (N/mm²)

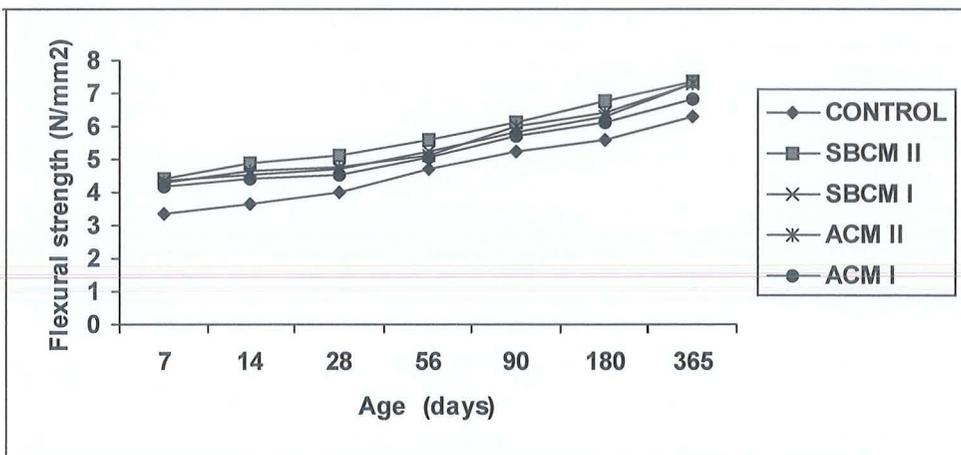


Figure 3.9 : The Flexural Strength of cement mortar – curing 28 days in water and followed by air curing (N/mm²)

3.2.6 Shrinkage and Expansion

Dimensional changes such as shrinkage and expansion due to temperature changes and different environments can cause damage to the structure of cement mortar and concrete. This situation will result in cracks or fractures in the structure of cement mortar or concrete and this facilitates aggressive agents such as acids, chlorides and other reinforced structures attack. Dimensional changes such as shrinkage, occurs when the structure of mortar and concrete exposed to dry environment. This situation causes the water contained in the cement mortar and concrete will seep out of the structure and drying shrinkage. Dimensional changes while development occurs, when the mortar and concrete structures exposed to environmental watering. This exposure causes the water in the outside will seep into the structure of cement mortar and concrete and causing the development of wet. Changes either large or small dry shrinkage and expansion occur in the wet cement mortar and concrete is closely related to aggregate type, aggregate size, water cement ratio, humidity and so forth.

Therefore, laboratory studies on the dimensional changes such as shrinkage and expansion of control unmodified mortar mix (CONTROL) and all the polymer modified cement mortar specimens (SBCM II, SBCM I, ACM II and ACM I) in two different environmental conditions in which preservation salt water and air will be reviewed, according to the test set, - 1, 2, 3, 4, 7, 14, 21, 28, 56, 90, 180 and 365 days.

Effects of changes in dimensions of shrinkage and expansion of polymer modified cement mortars are shown in Figures 3.10 and 3.11. Where two (2) of the polymer latex styrena Butadiena (SBC) and Acrylic Resin (AC) with the mixture of 10% to 15% of the weight of cement used will be compared with ordinary cement mortar mix or control in terms of dimensional changes that occur either large or small throughout the test period has been set. Results from test results that have been carried out for both methods of preservation, showing all the specimens of polymer modified cement mortars SBCM II, SBCM I, ACM II and Acm I change and development dimensions of the smaller shrinkage and expansion compared with the control cement mortar, (CONTROL).

Figure 3.10 shows the test results change over the development dimension specimens which showed the cement mortar preservation in salt water. Test results found that cement mortars control, CONTROL showed the biggest change in dimensions of 864 mikrostrain for preservation period for 365 days compare to polymer modified cement mortar specimens, (SBCM II, SBCM I, ACM I and ACM II). That changes the development dimension of the specimens for each sample is 413 mikrostrain, 426 mikrostrain, 474 mikrostrain and 561 mikrostrain.

Methods for preservation in the air, Figure 3.11, showing contraction for the dimensional changes over time to 365 days is CONTROL -1224 mikrostrain, SBCM II is -364

mikrostrain, SBCM I is -402 mikrostrain, ACM II is -416 mikrostrain and ACM I is -509 mikrostrain. Relationship between the period of time with the preservation and development dimensions of change contraction for both methods of preservation, shows there is increasing expansion and contraction changes dimension with factor term preservation time for all specimens of cement mortar experience in preservation and preservation of salt water in the air.

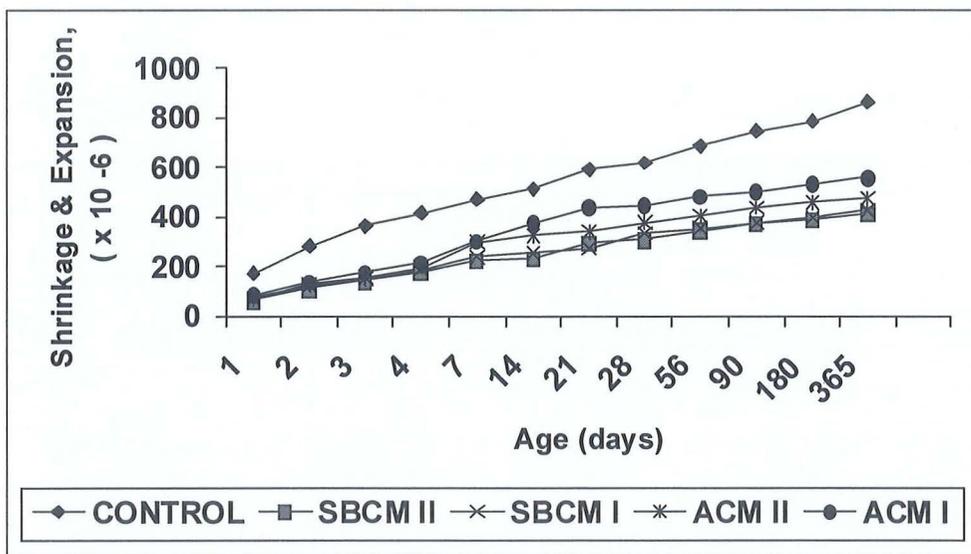


Figure 3.10 : The expansion of cement mortar , curing in salt water (x 10⁻⁶)

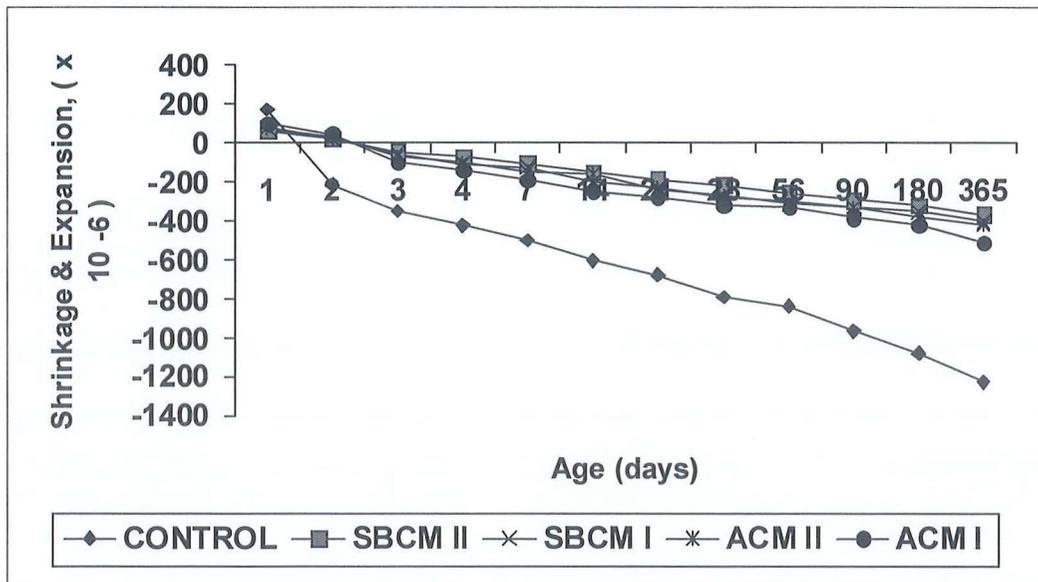


Figure 3.11: The shrinkage of cement mortar , curing in air (x 10⁻⁶)

3.2.7 Modulus of elasticity

The results of modulus of elasticity tests are shown in Figures 3.12 and 3.13. It can be seen that prolonged water curing enhanced the development of dynamic modulus of elasticity compared to that under prolonged air curing. Analysis of test preservation in salt water shows, elasticity modulus polymer modified cement mortar was smaller compared with the control cement mortar. On average modulus of elasticity polymer modified cement mortars, SBCM II is 36.2 N/mm², SBCM I is 34.3 N/mm², ACM II was 35.6 N/mm² and 32.9 N/mm² is ACM I. Cement mortars to control, CONTROL was 40.6 N/mm².

For preservation in the air, the average value of modulus of elasticity shown by CONTROL is 39.6 N/mm², SBCM II is 37.1 N/mm², SBCM I is 35.3 N/mm², ACM II is 36.4 N/mm² and 33.9 N/mm² is ACM I. Factors as density and strength of cement

mortar unmodified control (CONTROL) is higher than the polymer modified cement mortars SBCM II, SBCM I, ACM I and ACM II. Differences preservation methods provide only a small effect on the value of modulus of elasticity for all specimens. Elasticity modulus values, i.e the difference shown in the average about 10%. Analysis, shows there is increasing elasticity modulus of elasticity for all specimens for both methods with the preservation period. Polymer modified cement mortar which SBCM II, SBCM I, ACM I and ACM II value indicates a smaller modulus of elasticity, which average approximately 16.4% and 12.7% , compared with the control cement mortar, CONTROL method for preservation in salt water and air.

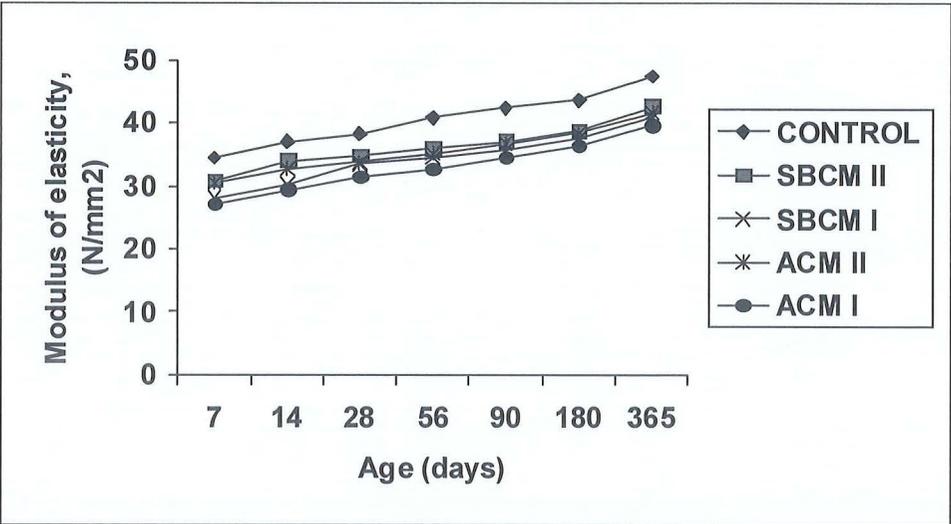


Figure 3.12 : The modulus of elasticity of cement mortar – curing 28 days in water and followed by salt water curing (N/mm²)

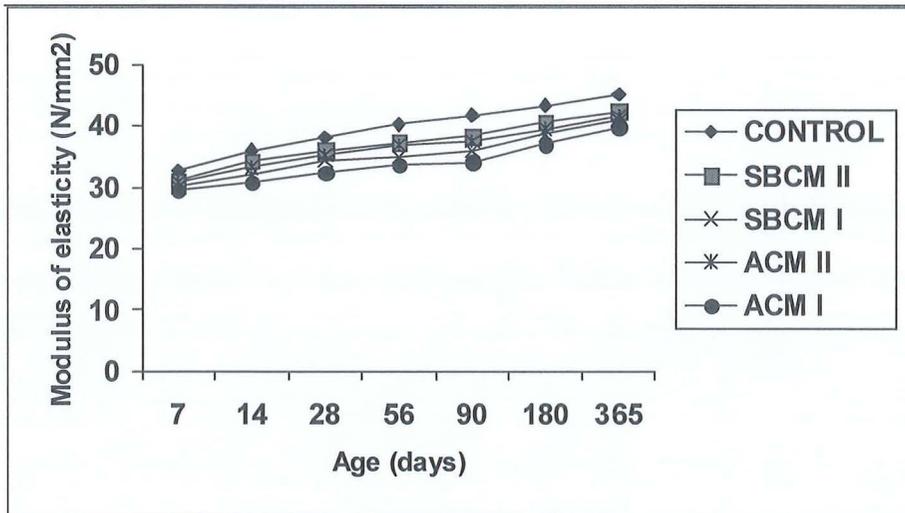


Figure 3.13 : The modulus of elasticity of cement mortar – curing 28 days in water and followed by air curing (N/mm²)

DURABILITY PROPERTIES OF POLYMER MODIFIED CEMENT MORTAR

4.1 Introduction

4.2 Water Absorption

Water absorption test conducted based on BS's British standards 1881: Part 122: 1983. To test this, as much as three (3) samples of cylindrical specimens in diameter 75 mm, for unmodified mortar control (CONTROL) and all polymer modified mortar which SBCM II, SBCM I, ACM II and ACM I were taken from the prism has been broken (from the prism flexure strength testing) use core drill machine having eyes diamond.

Those specimens then put in into drying oven during 72 ± 2 hours in temperature $105 \text{ }^\circ\text{C}$. After sufficient period specimens will be removed from drying oven and cooled in airtight container during 24 ± 2 hours. Before being immersed into water during 30 ± 0.5 minutes, that specimens are weighed and weight recorded as W_i . Once removed from immersion, the wet specimens will be dried and weighed before and recorded as the weight, W_a .

Formula for calculation water absorption was as follows:-

$$w = \left[\frac{(W_a - W_i)}{W_i} \right] \times 100 \% \times \text{correction factor} \quad (4.1)$$

Where :-

$$\text{Correction factor} = \frac{\text{volume (mm}^3\text{)}}{[\text{wide core surface (mm}^2\text{)} \times 12.5]}$$

Where :-

w = water absorption (%)

W_a = weight in water (g)

W_i = weight in air (g)

The water absorption is expressed as the percentage of the weight of water absorbed by the composite by the dry weight of the composite at saturated surface dry condition. Water absorption is a very important property of this composite that needs to be studied. It can measure accurately the volume occupied by the material and water that may seep into the pores in the composite.

Results of tests conducted on unmodified mortar control (CONTROL) and all polymer modified mortar which SBCM II, SBCM I, ACM II and ACM I preserved in two (2) methods of preservation of 28 days in water and salt water until the test period and 28 days curing in water and air until the test period, shown in Figures 4.1 and 4.2.

The results of Figures 4.1 and 4.2 also reveal that, with the use of polymer materials in the cement mortar has successfully reduced the rate of water absorption to two different methods of preservation in the salt water and air. While the rate of water absorption to all polymers modified mortars are different. This factor depends on the type and quantity of polymer used and the method of preservation conducted.

Water absorption average for specimen test experience inside preservation period in salt water, unmodified mortar control, (CONTROL) was 2.35 %, SBCM II was 1.36 %, SBCM I was 1.49 %, ACM II was 1.09 % and ACM I was 1.31 %. Whereas for test specimen experience inside preservation period in the air , the CONTROL was 3.09 %, SBCM II was 1.61 %, SBCM I was 1.89 %, ACM II was 1.32 % and ACM I was 1.52 %.

Refer Figure's analysis 4.1 and 4.2 shows; the use of polymer materials in the cement mortar has successfully reduced the rate of water absorption. These are because cement mortar modified polymer won covered empty apertures pore in ordinary cement mortar with polymer layer. Generally effect of closure this polymer layer increases with the increase of polymer content or polymer ratio cement. These features have successfully reduced water absorption, air permeability and water movement vapour. While in terms of preservation methods that have been conducted on polymer modified cement mortar, showing a high water absorption rate successfully reduced to specimens that experienced a period of preservation in the air compared with specimens that experienced a period of preservation in salt water.

This factor was brought most polymer modified mortar strength easily lost prostration with immersion in water compared after immersion. This is because the optimum strength polymer modified mortars achieved at reasonable temperature for the hydration of cement in wet conditions in early stage and followed by dry conditions in assisting the formation of the polymer layer will cover the particles-polymer particles.

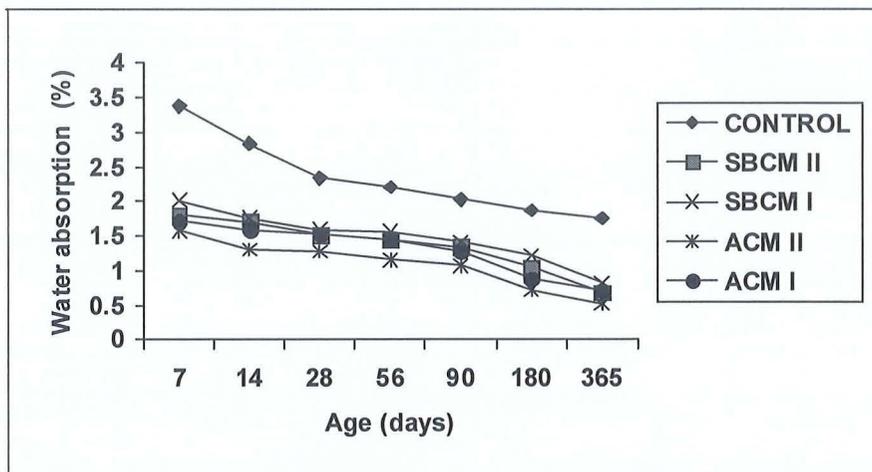


Figure 4.1 : Water absorption of cement mortar – curing 28 days in water and followed by salt water curing (%)

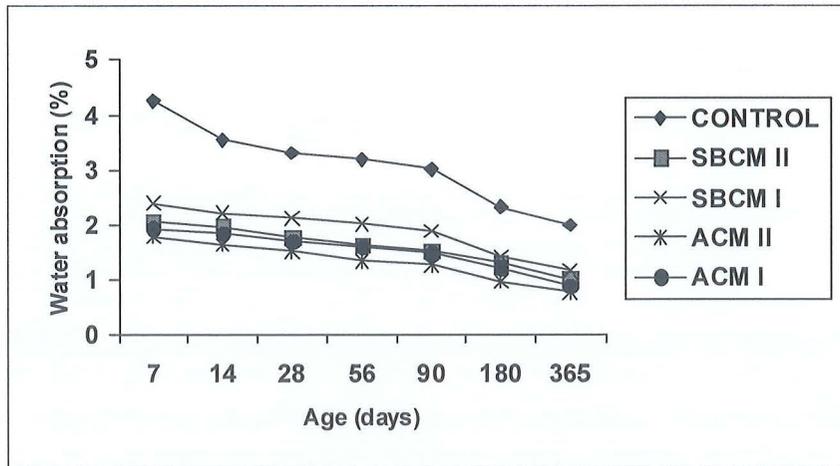


Figure 4.2 : Water absorption of cement mortar – curing 28 days in water and followed by air curing (%)

4.3 Oxygen Permeability

Flow rate in the cement mortar or concrete is normally too slow; the tests showed lamina is better than the flow movement of air or water. Lamina viscous flow of is dependent on fluid characteristics such as thickness and density, as well as the characteristics of the porous medium porous. Principle about permeability for fluids which no pressure (eg. water) can determined according Darcy principle Empirical Law ;

$$v = \frac{k A \Delta P}{\eta \ell} \quad (4.2)$$

Where

v is flow rate

A is cross-sectional area of specimen

ℓ is length of specimen

ΔP is fluid pressure head across specimen

η is viscosity of fluid

k is intrinsic permeability

When pressure fluid such as oxygen is used, the viscosity is $2.02 \times 10^{-5} \text{ Ns/m}^2$ at temperature 20°C , Eq (4.2) must be made using the modification form expressions that have been introduced by Grube and Lawrence.

Calculation of the total fluid pressure on the average in the specimens (Cabrera and Lynsdale, 1988), Eq. (4.2) as modifications are made which is shown below: -

$$k = \frac{2P_2 v l \times 2.02 \times 10^{-6}}{A (P_1^2 - P_2^2)} \quad (4.3)$$

Where k is intrinsic permeability (m^2)

v is the flow rate (cm^3/s)

l is thickness of specimen (m)

A is cross-sectional area of specimen (m^2)

P_1 is absolute applied pressure (bar), i.e atmospheric pressure + gauge pressure

P_2 is pressure at which the flow rate is measured, usually 1 bar

Hence, the equation of intrinsic permeability may be written as :

$$k = \frac{2P_2 v l \times 2.02 \times 10^{-6}}{A (P_1^2 - P_2^2)} \quad (4.4)$$

Air permeability tests conducted on samples of cement mortar-sized diameter 50 mm and the average thickness of between 36 to 40 mm taken from the prism 100 mm x 100 mm x 500 mm, after flexural strength test conducted. For each type of design, unmodified mortar control, (CONTROL), SBCM II, SBCM I, ACM II and ACM I there are five (5) samples sized 50 mm in diameter used for two (2) methods of preservation in 28 days curing in water and continue in salt water until the test period and 28 days curing in water and in air until the test period. Testing time period was prescribed 7, 14, 28, 56, 90, 180 and 365 days. In this test the effects of polymer modification, exposure conditions and period of preservation will be studied and made comparisons.

Results of air permeability tests are conducted for all polymer modified cement mortars showed permeability will decrease with increasing polymer content and curing period. Test results also showed the air permeability of all polymer modified cement mortars are smaller compared with the unmodified mortar control, (CONTROL). This is because the space that exists in the structure of cement mortars has been covered with the polymer particles as a continuous process of cement hydration. Test results also show the modifications in the polymer cement mortar system have a smaller permeability quality. Permeability characteristics in a small system is a polymer modified cement mortars due to polymer particles have a smaller size than the particles of cement and sand. This gives the advantage to polymer particles cover the small spaces that exist and also covers the aggregate particles and cement layer.

Effects of preservation methods on the value of air permeability for all the specimens of cement mortar CONTROL, SBCM II, SBCM I, ACM II and ACM I for two (2) different methods of preservation of curing in salt water and curing in air is shown in Figures 4.3 and 4.4 . The use of polymer materials in the cement mortar has successfully reduced the value of air permeability for two different methods of preservation in the salt water and in the air. Value of air permeability test results carried out to find all the cement mortar permeability will decrease with increasing curing period. Test results showed, the value of permeability for polymer modified cement mortar is different. This factor depends on the type and quantity of polymer used and the method of preservation work.

The average value of air permeability for the test specimens experienced a period of preservation in salt water, control of cement mortar, (CONTROL) is $1.53 \times 10^{-16} \text{ m}^2$, SBCM II is $0.25 \times 10^{-16} \text{ m}^2$, ACM II is $1.10 \times 10^{-16} \text{ m}^2$, SBCM I is $0.39 \times 10^{-16} \text{ m}^2$ and ACM I is $1.66 \times 10^{-16} \text{ m}^2$. While to test the specimens experienced a period of preservation in the air, the CONTROL is $1.46 \times 10^{-16} \text{ m}^2$, SBCM II is $0.26 \times 10^{-16} \text{ m}^2$, ACM II is $1.04 \times 10^{-16} \text{ m}^2$, SBCM I is $0.40 \times 10^{-16} \text{ m}^2$ and ACM I is $1.62 \times 10^{-16} \text{ m}^2$. Analysis of test results showed, the effect of different preservation methods are not so significant an impact on the rate of permeability characteristics of cement mortar for all tests. This method of preservation factors showed less affect the value of permeability.

Refers to the relationship between preservation time and permeability values for both methods of preservation, shows there is reduction in the value of permeability factor preservation period of time for all specimens of cement mortar experience in preservation and preservation of salt water in the air

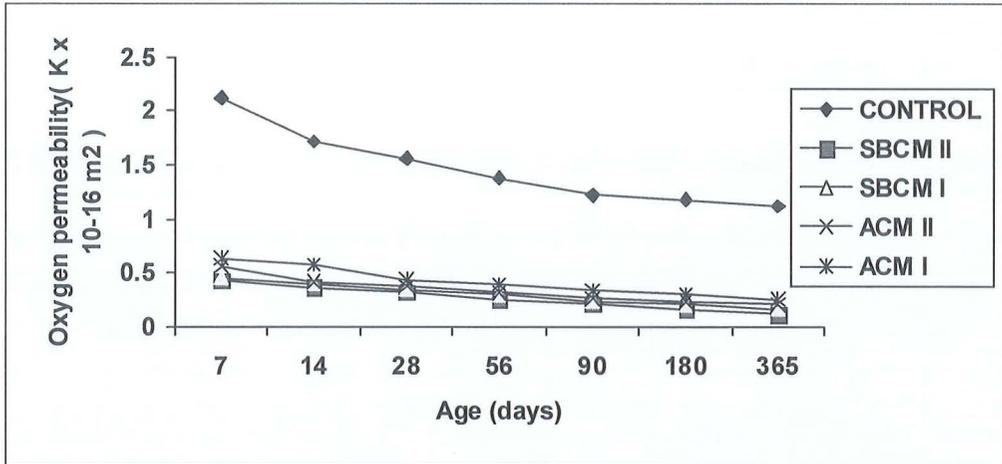


Figure 4.3 : Oxygen permeability of cement mortar – curing 28 days in water and followed by salt water curing ($K \times 10^{-16} m^2$)

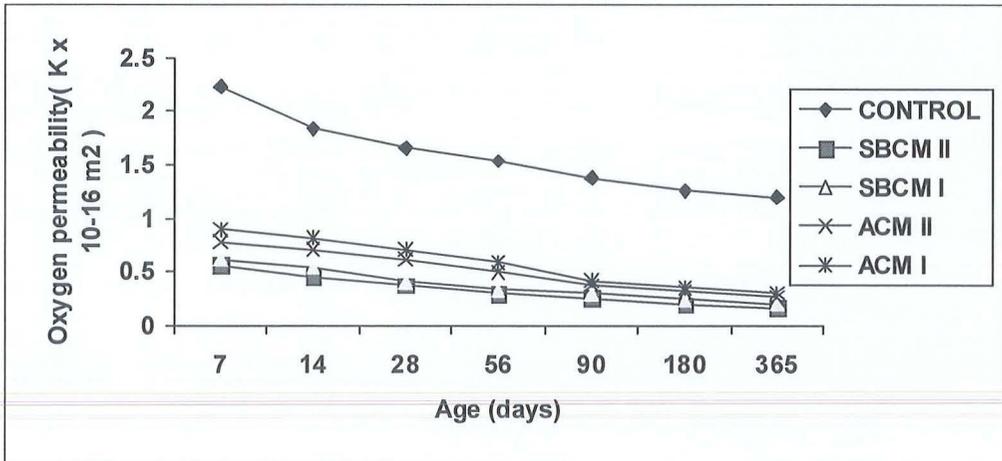
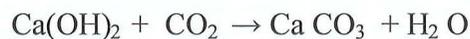


Figure 4.4 : Oxygen permeability of cement mortar – curing 28 days in water and followed by air curing ($K \times 10^{-16} m^2$)

4.4 Carbonation

High alkalization rates are caused by calcium hydroxide ($\text{Ca}(\text{OH})_2$) the period may be reduced by exposure to the reaction of carbon dioxide (CO_2) in the atmosphere and also through reactions other acid gases. This condition is defined as carbonation and it depends on exposure period which made. This reaction is not only damage mortar texture or concrete but will also the formation of pores due to immune-air pores on the surface of cement mortar. This carbonation reaction in form of this equation is as follows:-



Precipitation of calcium carbonate (Ca CO_3), which has a pH value around 9.4 and carbonation occurred, is actually caused by changes in pH by carbon dioxide (CO_2). However the actual situation, carbonation which occurred is influenced by elements of acid in the air that has reduced the alkaline nature of cement mortar or concrete. This reaction is not only damage the texture of cement mortar or concrete will even reduce the formation of pores due to immune-air pores on the surface of cement mortar or concrete. Carbonation rates depending on several factors such as the mortar content, the ratio of water and chemical mix, environmental conditions, compaction methods, curing methods and others. Exposure of cement mortar or concrete in aqueous environment having lower carbonation rate compare with air environment. This is because carbon dioxide only slightly soluble in water compared with other gases such as oxygen and others. While a high level of humidity will also cause the acid gases difficult to penetrate the hard texture of cement mortar or concrete. At low humidity, it will not allow retaliation occurred

because of lack of water. Highest carbonation rate that occurred in the relative humidity is between 50 and 70%.

The results of carbonation tests are shown in Figures 4.5 and 4.6. The results show that, all polymer-modified cement mortar exhibited lower rate of carbonation than that of the unmodified mortar, CONTROL. The increase in polymer loading and lower-binder ratio have also reduced the rate of carbonation as shown in SBCM II and ACM II mixes. The depth of carbonation of unmodified mortar increase fairly quickly in the beginning up to 56 days for prolonged salt water curing and 7 days for prolonged air curing.

However, in polymer modified cement mortars there was no carbonation taking place until 180 days for prolonged salt water curing and 56 days for prolonged air curing, when the carbonation process started to occur. For, SBCM II specimen the carbonation depth at 365 days was about 0.24 mm compared to that of unmodified mortar, CONTROL was about 2.48 mm for prolonged salt water curing.

For prolonged air curing, the carbonation depth for SBCM at 365 days was about 0.32 mm compared to that of the unmodified mortar, CONTROL was about 4.42 mm.

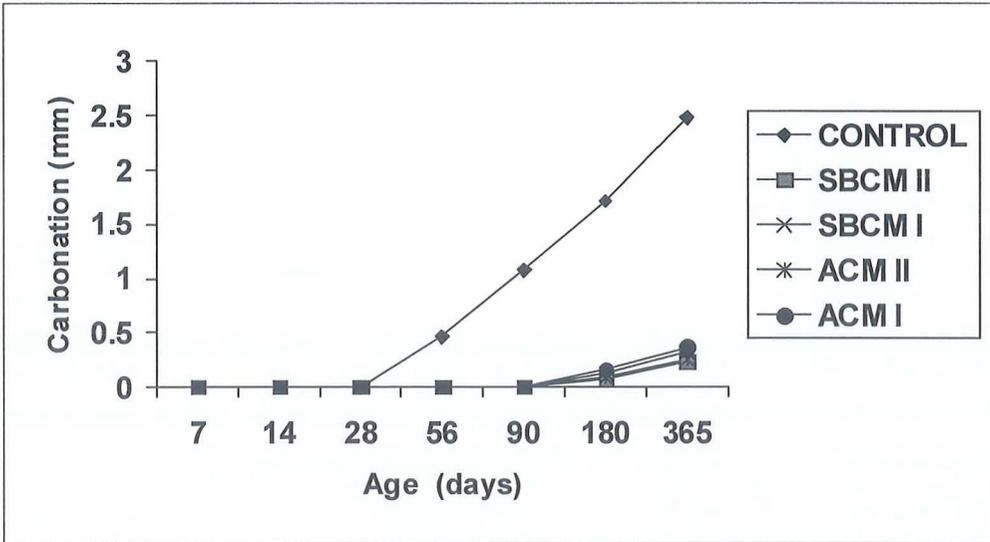


Figure 4.5 : Carbonation of cement mortar – curing 28 days in water and followed by salt water curing (mm)

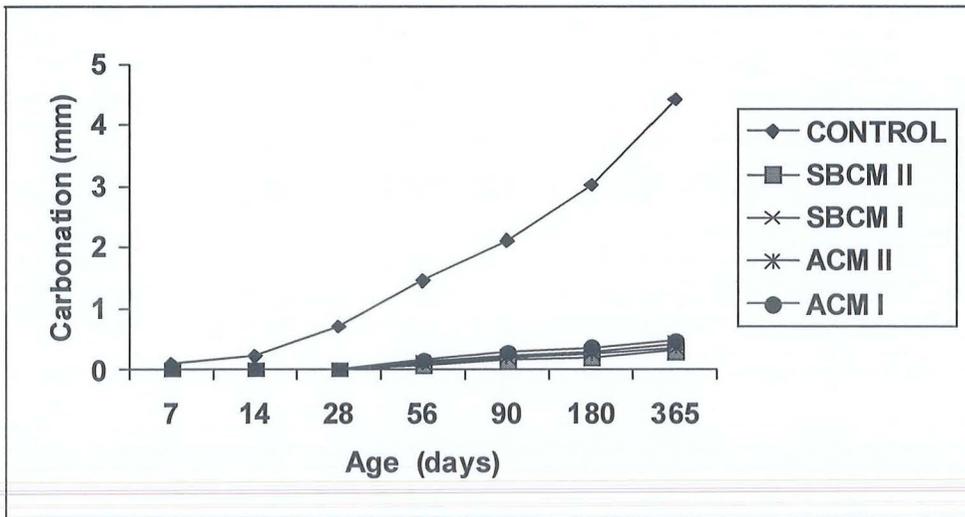


Figure 4.6 : Carbonation of cement mortar – curing 28 days in water and followed by air curing (mm)

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Referring to the main research objective, namely to study durability performance of polymer modified cement system in the mortar structure. Therefore in this research, the characteristics of SBCM II, SBCM I, ACM II and ACM I compared with CONTROL have been studied in relationship with features such as density, compressive strength, flexural strength, modulus of elasticity, dimension change and the quality of velocity pulse mortar the quality of pulse velocity. In addition the effect of different preservation methods and types of polymer materials used has also been discussed from the point of durability strength.

While the performance characteristics of polymer modified cement mortar resistance to carbonation, water absorption, and air permeability has made a detailed study. Analysis is carried out in terms of the effects of polymer modification is used, the effects of curing methods that have been carried out, the relationship between the value of air permeability with the compressive and also water absorption rate. This is because cement mortar or concrete of good features do not necessarily indicate the nature of engineering features the same durability as indicated by the cement mortar and ordinary concrete.

Based on results from objective analysis and research has been conducted on this polymer modified. The main conclusion result of research carried out is as follows: -

- a. Polymer material mixture in cement mortar is giving more effect on flexural strength compared to compressive strength. This is due to the polymer mixture has formed a thin layer of polymer that successfully cover the empty pores between the matrices of cement mortar and aggregate and form a strong monolithic structure.
- b. In addition mixing polymer materials in the ordinary cement mortars have also been reduced density polymer modified cement mortar. This is due to polymer materials used in the experiment testing this would have gravity between 1.00 to 1.10 g/cm³ compared with ordinary Portland cement, is 3.10 g/cm³.
- c. Modulus of elasticity test result, showing polymer modified cement mortars have a small value of modulus of elasticity compared than ordinary cement mortar. This factor give advantage in structural strength, because can reduce tension and strain. This very well on structure experience tension, high strain and temperature variation such as area coating or surface, for example road, runway and others.

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- d. Analysis also found that test results, increased hydration of cement are more aggressive in the early stages of the process at the time of the formation of a thin layer of polymer. Therefore, curing methods during 28 days in the early stages and environments exposed to salt water and air is a curing method for polymer modified cement mortar.
- e. This is because theoretically with early curing in water can reduce cement hydration and also to help the formation of a thin polymer layer around the particles of cement and aggregate. Concentration of polymer particles will cause the cement and aggregate particles will be covered together. Continuous removal of air from the process of hydration and evaporation, polymer particles eventually merged with layers intertwine through the hydration of cement and aggregate particles. This layer of particles and aggregates with layers of plastic semi-connected will be responsible for controlling moisture around the particles-particles of cement and allow cement hydration process continues to occur.
- f. Dimensional changes of shrinkage and expansion of the polymer modified cement mortars namely SBCM II, SBCM I, ACM II and ACM I would be smaller compared to unmodified cement mortar, CONTROL. This factor will be able to reduce the occurrence of cracks that can weaken the structure due to the effects of changes in these dimensions.

- g. Uses of polymer materials in the ordinary cement mortar have a positive effect on the performance characteristics of ordinary cement mortar. Test results showed the mixing polymer materials in the ordinary cement mortar have been successfully reduced water absorption and carbonation rate. This because with polymer material mixture in ordinary cement mortar has form formed a common co-phase matrix. Formation of co-phase matrix has formed a thin polymer layer covering the pores empty between cement and aggregate particles and the bonds become stronger. This will be able to reduce water absorption and carbonation rate.
- h. Effect modification of polymer in the mixture of ordinary cement mortars also showed rates of air permeability of polymer modified cement mortar latex Styrene Butadiene Copolymer mortar @ solid content 49.9% (SBCM II), Styrene Butadiene Copolymer mortar @ solid content 45.8% (SBCM I), Acrylic Resins mortar @ solid content 50 % (ACM II) and Acrylic Resins mortar @ solid content 46 % (ACM I) is smaller than unmodified cement mortar, CONTROL. Characteristics of low air permeability rates in the polymer modified cement mortar are caused by polymer particles have a smaller size than the particles of cement and aggregate. This gives the advantage to polymer particles cover the small spaces that exist and cover aggregate particles and cement layers.

5.2 SUGGESTIONS FOR FURTHER STUDY

Suggestions for further study from research carried out this study the durability performance of polymer modified cement system in the mortar structure. Therefore, to study further suggested that selection of polymer materials more stable in terms of solid content, particle size, the form of either liquid or powder material properties and reaction with a mixture of other materials is the primary factor affecting the test results characteristics of strength and durability in the design mix polymer modified cement mortar. Therefore, further studies in the selection of stable polymer material properties need to be considered before designing a mixture of polymer modified cement mortars.

In addition mixing polymer materials in the further study, made in the proposed quantity of different research studies have been carried out, i.e. 20%, 25% and 30%. Apart from that also the composition of material mix ratio of different cement and aggregate example 1: 2 and 1: 4 with different aggregate size also proposed. The aim is to see the characteristics of strength and durability of polymer modified cement mortars based on different variations. Also suggested that exposure test specimens made in the natural environmental conditions such as in sea water environment, polluted environment and so on. Results of performance tests strength and durability can be obtained in a real environment.

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Structural behaviour of polymer modified ferrocement in concrete structure development

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ABSTRACT

This paper discusses the structural behaviour of latex modified ferrocement in comparison with conventional ferrocement particularly when exposed to severe environmental conditions. The development of strength, deformability and fracture properties were slightly different from conventional ferrocement. Test result indicates a significant improvement in reducing and bridging micro cracks, especially in the prepeak load region. Fracture toughness and deformability increased significantly. However, the post peak behaviour was quite similar to conventional ferrocement.

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Introduction

Ferrocement is a versatile construction material and it is a type of thin walled reinforced concrete commonly consisted of cement mortar reinforced with closely spaced layers of continuous and relatively small wire mesh [1]. It can be successfully used in the construction of many structures such as water tanks, sunshades, secondary roofing slabs, shell and folded plate elements and boats. These structures in services may be subjected to moderate and the success of ferrocement as a building material depends upon its durability [2]. The durability of a ferrocement structure may be defined as its ability to resist weathering action, chemical attack, abrasion, cracking and any other process of destruction [9].

For ferrocement to be durable, it is essential for component materials, namely mortar and wire-mesh reinforcement, and the bond between these materials to retain their strength with time when exposed to any environment [11].

The transformation of ferrocement materials into a high durability and performance material is a great challenge. One of the ways to enhance the material to have high is through a latex modification of mortar and concrete. To achieve desired mortar and concrete properties, experimental research on certain types of latex admixture is necessary. The Research has shows that latex modification on mortar and concrete can improve properties significantly. This paper dissevers investigation carried out to evaluate the structural behaviour of latex modified ferrocement under static flexure.

This includes load-deflection characteristics, first crack strength, crack width and crack spacing of ferrocement elements exposed to air and salt water environments.

Research Programme

The research programme encompasses the laboratory investigation on the structural, the deformation behaviour and characteristic of latex modified ferrocement elements cured in

air and salt-water environments. The tests include determination of load and deflection characteristics, moments, crack widths, crack spacing, and the number of cracks when subjected to static flexure.

The compressive and flexural strengths of the mortar used in the ferrocement test specimens were determined from the mortar cube, 100 mm x 100 mm x 100 mm and mortar prisms, 100 mm x 100 mm x 500 mm according to BS 1881: part 116: 1983 and BS 1881: Part 118: 1983, respectively. The structural properties of ferrocement were determined from the test specimens, 125 mm x 350 mm x 30 mm, reinforced with 3 layer of square welded mesh with volume fraction of 0.65% and the diameter is 1.0 mm. A four-point loading was used over a simply supported span of 300 mm to determine the load-deflection properties, crack width and crack spacing of the latex modified ferrocement specimens.

Three different latex modification systems was employed in this study, namely styrene butadiene rubber latex (SBR), natural rubber latex (NL) and epoxy resin (ER), in their ability to increase the bond strength between mortar and reinforcement. The material properties are listed in Table 1. The fine aggregate was a graded river sand with 5.0 mm maximum size and complied with the grading limit of zone F of BS 882. The sand has a specific gravity of 2.65, water absorption of 0.80% and a fineness modulus of 2.46. Ordinary Portland cement of ASTM type I was used.

The type of wire mesh used for the entire ferrocement test programme consisted of a square welded mesh of wire diameter 1.0 mm, and a mesh opening of 12.0 mm x 12.0 mm. The characteristics of the wire are listed in Table 2.

The mortar mix proportions used in this study has a design mix ratio of 1:3 (1 part cement to 3 part of sand by weight) with a water-cement ratio of 0.45. Irrespective of the final (w/c) ratio used, all the mixes were designed for a slump of 130 – 150 mm.

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The amount of cement content used in the mortar mix is therefore, designed based on the following expression [7].

$$C = \frac{700}{\sqrt[3]{D}} \quad (1.0)$$

Where:

C is the cement proportion in kg/m^3 .

D is the maximum size of aggregate in mm.

The maximum size of fine aggregate in the mix proportion is 5.0 mm, then the cement content should be used is about 500 kg/m^3 . The mix proportion is shown in Table 3.

When designing the mix, the percentage of water present in the latex dispersion was taken into account for determining the mixing water.

A superplasticizer, sulphonated naphthalene condensate, was used. All ferrocement specimens were cast in steel moulds and compacted using external vibrator. The samples were demoulded after 24 hours and then cured in water for 28 days at a temperature of $28^\circ\text{C} \pm 2^\circ\text{C}$.

Once demoulded, the specimens were further subjected alternate curing in air and salt water for seven and three days respectively for each side until the time of test. The ferrocement specimens were tested at to the ages of 30, 90, 180 and 365 days. The ferrocement test specimens used in the entire test programme were having.

The load-deflection properties, crack width and crack spacing of the ferrocement specimens was conducted in a TORSEE testing machine. The specimen was subjected to a static load at the loading points. In the middle of the tensile face of ferrocement specimen, to measure the static deflection, the first crack load and the ultimate loads of ferrocement.

The crack widths were measured at the bottom-most of the vertical face of the specimen in the constant bending moment region. The number of cracks appears within the 100 mm midspan of the specimens was noted and the width of each crack was measured using a handheld microscope.

Test Results and Discussions

Properties of Ferrocement Mortar

The mechanical properties of mortar used for the ferrocement specimens are presented in Figure 1 to 3, each data presented was obtained from an average of three test results. The tests results show that the compressive strength of the latex modified cement mortars are always lower than that of the unmodified control, FECON. The FESBR mix exhibits higher strengths than that of the FEER and FENL mixes.

This is attributed to the fact that these exists a soft layer of the latex films in the cement matrix which fill the voids and coat the aggregates and the cement particles, resulting a cement matrix of a much lower compressive strength. Although the compressive strength of the unmodified control, FECON is higher than those of the latex-modified mixes, its flexural strength is lower than that of the latex-modified specimens (FESBR, FENL, and FEER).

Similarly, the Young's modulus of elasticity of the unmodified mortar, FECON, is marginally higher than that of the latex-modified mortars.

The test results also show that the latex modification has significantly improved the mechanical properties of the cement mortars particularly, their flexural strengths and their resistance to crack development.

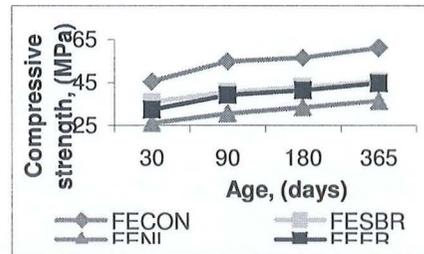


Fig. 1 Compressive strength of mortars for ferrocement

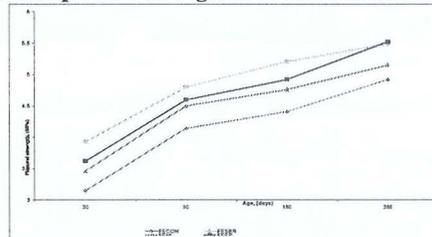


Fig. 2 Flexural strength of mortars for ferrocement

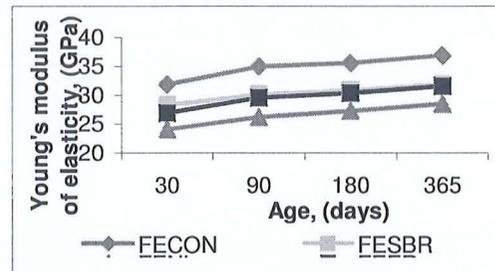


Fig. 3 Young's modulus elasticity of mortars for ferrocement

Crack Developments

The experimental and predicted values of the first crack (F_{cr}) and ultimate (F_u) loads are presented in Figures 4 and 5. From Figure 4, the ratio of the first crack load from experimental, $F_{cr}(\text{Exp})$ to the predicted first crack load, $F_{cr}(\text{Pred})$, varies between 0.83 to 2.10, and latex-modified mixes have generally higher the ratio of the first crack load, F_{cr} compared to the unmodified control, FECON. The FESBR and FEER mixes exhibits higher the ratio of the first crack load, F_{cr} than that of the FENL and FECON mixes. The mixes attained the ratio of the first crack load, F_{cr} of about 0.85 and 0.87 at 30 days and 2.10 and 2.05 at 365 days.

The ratio of the experimental (Exp) and predicted (Pred) values of the ultimate load, F_u , is presented in Figure 5. From these results, all latex-modified mixes show higher the ratio of the ultimate load strength, F_u , compared with unmodified control, FECON. A higher the ratio of the first crack, F_{cr} and ultimate, F_u loads in the latex modified ferrocements are attributed to the increased in flexural capacity as a result of latex film formation, which bind the aggregate and cement particles into a durable cement matrix [8].

Crack Width

The estimation of crack width can be predicted (Pred) using the following simplified approach [12]:

$$W_{av} = S\beta\epsilon_s \quad (2.0)$$

Where:

W_{av} is the average crack width.

S is the mesh opening.

β is the ratio of distance to the neutral axis from the extreme tensile fibre and from the extreme tensile fibre and from the outermost of steel.

ϵ_s is the strain in the extreme tensile layer of mesh.

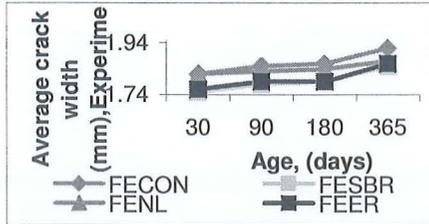


Fig. 6 The average crack width (mm) from experimental (Exp) value for ferrocement in static flexure

The test results are presented in Figures 6 and 7 show that, the experimental (Exp) and predicted (Pred) values of the average crack widths. Based on the test result, the predicted values of the average crack widths are found to be lower than those of the experimental values. The result also indicate that, latex modified ferrocements (FESBR, FENL and FEER) are having lower average crack widths than that of the unmodified control ferrocement, FECON. This indicates that latex-modified ferrocements exhibit higher resistance to crack than the unmodified control. All the test specimens indicate the increase in the average crack width with respect to the increasing age of curing.

Lower crack widths in all latexr-modified ferrocements indicate that latex modification improves the bonding between aggregate, cement and latex particles by formation of latex films, bridging and cementing them into a durable matrix and exhibiting higher resistance to crack development.

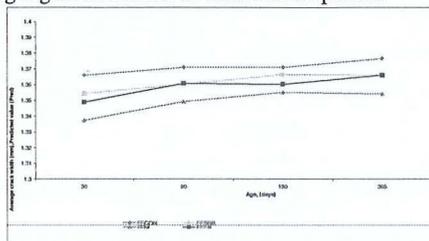


Fig. 7 The average crack width (mm) from Predicted (Pred) value for ferrocement in static flexure

Crack Spacing

The average crack spacing can be predicted using the following expression [10] :

$$(Al)_{av} = \frac{\theta}{n} \frac{1}{S_{RL}} \tag{3.0}$$

Where:

$(Al)_{av}$ is average crack spacing.

θ is a factor relating average crack spacing to maximum crack spacing.

n is the ratio of bond strength to matrix tensile strength, and

S_{RL} is specific surface of reinforcement in the loading direction.

The factor $\frac{\theta}{n}$ can be approximated through a direct relation between $(Al)_{av}$ and S_{RL} . It was reported by Naaman [4] that the value of θ/n lies between 1 and 2.7, when $\frac{\theta}{n} = 1$ seems to predict very well the experimental data for square meshes, while $\frac{\theta}{n} = 2.7$ in when smooth longitudinal wires are used.

Another parameter which determining the cracking behaviour of ferrocement is the specific surface, S_R of reinforcement. The specific surface is related to the volume fraction of steel mesh, given by the following expression:

$$S_R = \frac{4V_f}{\phi} \tag{4.0}$$

Where ϕ is the diameter of the wire mesh.

For 1.0 mm diameter, with a volume fraction, V_f of 0.65% the specific surface S_R is $0.026 \text{ m}^2/\text{m}^3$. Taking the factor of $\frac{\theta}{n} = 1$, then the average crack spacing of the specimen is equals 38.0 mm.

The results in Table 4 show that the average crack spacing obtained from the experiment is always lower than that of the predicted ones. For latex-modified ferrocements, the average crack spacing is lower than that of the unmodified control ferrocement.

Typical load-deflection curves for the four ages of curing conditions are presented in Figures 8 to 11. From Figure 10, the first crack load for FECON occurred at about 1.23 kN and a deflection of about 0.24 mm. For FESBR at about 1.55 kN and a deflection of about 0.56 mm, FENL at about 1.34 kN and a deflection of about 0.44 mm and FEER at a about 1.34 kN and a deflection of about 0.44 mm. The maximum load before failure for FECON is about 3.72 kN, and the maximum deflection is about 1.38 mm. The maximum load and deflection for FESBR is 4.36 kN and 2.10 mm, FENL is 4.10 kN and 1.74 mm and FEER is 4.23 kN and 2.22 mm, respectively.

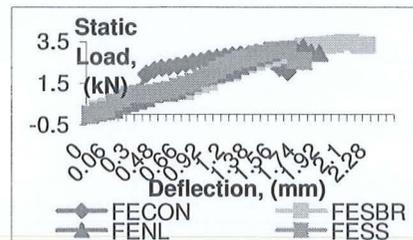


Fig. 8 Load-deflection curve of ferrocement at 30 days

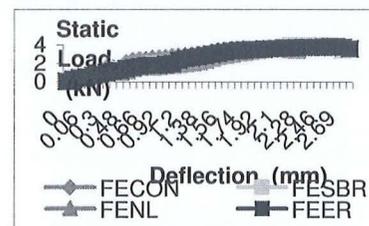


Fig. 9 Load-deflection curve of ferrocement at 90 days

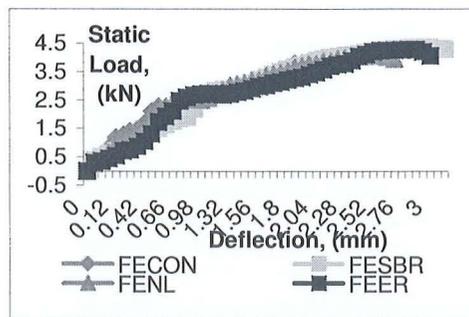


Fig. 10 Load-deflection curve of ferrocement at 180 days

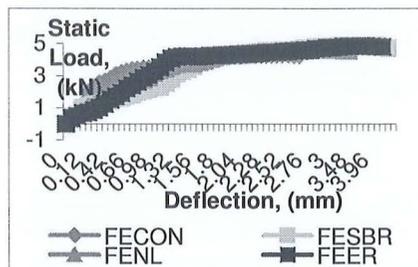


Fig. 11 Load-deflection curve of ferrocement at 365 days

The deflection curve of ferrocement at 365 days is presented in Figure 11. The first crack load occurred for FECON at about 3.43 kN and a deflection is about 0.98 mm. The specimen achieved its maximum load of about 4.34 kN and a maximum deflection of this specimen before failure of about 2.52 mm. For FESBR, the first crack load is about 4.28 kN and a deflection is about 1.80 mm, for FENL the maximum load is about 3.82 kN and a deflection is about 1.44 mm and for FEER is about 4.21 kN and 1.50 mm respectively. The maximum load and deflection before failure for FESBR is 4.86 kN and 3.96 mm, FENL is about 4.61 kN and 3.12 mm and FEER is about 4.85 kN and 3.72 mm, respectively.

Based on the test result, latex modified ferrocements show higher first crack load, maximum load and deflection than that of the unmodified control ferrocement, FECON. The result also indicates that, the first crack load, maximum load and a deflection values are found to increase with the increasing age of curing. From Figures 8 to 11, the load-deflection curves of ferrocement have been reported to have three distinct stages by Naaman et al. [5] namely; before cracking mortar, after the first cracking of mortar but before the yielding of steel and, after yielding of steel meshes when the slopes becomes almost parallel to the axis of deflection.

Conclusions

From the test results and the analysis of the experimental work carried out in this study the following are the main conclusions and recommendations are as follows:

1. The results show that latex modification has improved the mechanical properties of cement mortars, particularly their flexural strength.

2. The first crack load of the latex modified and unmodified ferrocements shows higher predicted values than that of the experimental at 30 days of curing.
3. The higher first crack loads in the latex modified specimens are attributed to the increased in flexural capacity as result of latex film formation, which bind the aggregate and cement particles into a durable matrix.
4. Latex modification has led to the increase in the maximum load, the first crack load and the deflection value increase with the increasing age of curing.

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Table 1 Material properties of polymer latexes

Properties	NL	SBR	ER
Colour	White liquid	White liquid	Clear liquid
Odour	Ammonia gas	Slight	Slight
PH	10.56	8.5 – 11.0	-
Water solubility	Soluble	Soluble	Insoluble
Relative density (g/cm ³)	0.94	1.01–1.025	1.16 at 25°C
Solids content (%)	61.52	46.5 – 49.5	100
Particle size	-	0.15 μ m	-

Table 2 Characteristics of wire mesh

Type of wire	Diameter of wire (mm)	Mesh size (mm)	Yield strength (MPa)	Ultimate Strength (MPa)	Young's Modulus of Elasticity (Gpa)
Square welded wire mesh	1.0	12.0 x 12.0	93.7	231.2	1.1

Table 3 Design mixes for ferrocement specimens

Type of ferrocement	Cement (kg/m ³)	Polymer (%)	Super plasticizer (%)	Sand (kg/m ³)	W/c	Slump (mm)
FECON (Unmodified control ferrocement)	500	0	1.5	1500	0.45	150
FESBR (Styrene butadiene rubber latex ferrocement)	500	10	0	1500	0.35	140
FEER (Epoxy resin ferrocement)	500	10	1.5	1500	0.45	145
FENL (Natural rubber latex ferrocement)	500	10	1.8	1500	0.45	140

Table 4 Average crack spacing for ferrocement in static flexure

Type of Specimen	Average crack spacing (mm)			
	30 days	90 days	180 days	365 days
FECON	24.3	27.5	29.7	33.1
FESBR	19.4	22.1	0	24.7
FENL	18.6	20.4	24.4	25.1
FEER	20.4	22.0	0	26.3
Predicted spacing	38.0	38.0	38.0	38.0

DURABILITY STUDY OF POLYMER MODIFIED FERROCEMENT IN CONCRETE STRUCTURE DEVELOPMENT

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Abstract. *This paper discusses the durability study of polymer-modified ferrocement in comparison with conventional ferrocement particularly when exposed to severe environmental conditions. The development of strength, deformability and fracture properties were slightly different from conventional ferrocement. Test result indicates a significant improvement in reducing and bridging micro cracks, especially in the prepeak load region. Fracture toughness and deformability increased significantly. However, the post peak behaviour was quite similar to conventional ferrocement.*

Keywords. *Deformability; early age performance; polymer modified ferrocement; micro cracks; prepeak; postpeak; strength development.*

1. INTRODUCTION

Ferrocement is known for its high durability performance in corrosive environments and its successful use in these structures may be an example and incentive asset to other major engineering applications [1-4]. The transformation of ferrocement materials into a high durability and high performance material is a great challenge. One of the ways to make a material of high mechanical properties and high aesthetic values is through a polymer modification of mortar and concrete. To achieve desired mortar and concrete properties, experimental research on certain types of polymer admixture is necessary. Through researching and finding the optimal admixture quantity, mortar and concrete properties can be significantly improved. The wide applications of polymer modification for mortar and concrete urge researchers to carry out extensive work in order to establish a good base for this development. Hence, the main objective of the experimental investigation is to study and evaluate the characteristics of polymer-modified ferrocement under static flexure. This includes load-deflection characteristics, first crack strength, crack width and crack spacing of ferrocement elements exposed to air and salt water environments.

2. RESEARCH METHODOLOGY AND EXPERIMENTAL PROGRAMME

The objective of the research methodology is to study and evaluate the deformation characteristic of polymer modified ferrocement elements cured in air and salt-water environments. The test included determination of load and deflection characteristics, cracking moments, crack widths, crack spacing, and number of cracks developed in ferrocement elements to a static flexural loading.

The compressive and flexural strengths of the mortar used in the ferrocement test specimens were determined from the mortar cube, 100 mm x 100 mm x 100 mm and mortar prisms, 100 mm x 100 mm x 500 mm according to BS 1881: part 116: 1983 and BS 1881: Part 118: 1983, respectively. The flexural properties of ferrocement were determined from the test specimens, 125 mm x 350 mm x 30 mm, reinforced with 3 layer of square welded mesh with volume fraction of 0.65% and the diameter is 1.0 mm. A four-point loading was used over a simply supported span of 300 mm to determine the load-deflection properties, crack width and crack spacing in the polymer modified ferrocements, as shown in Figure 1.

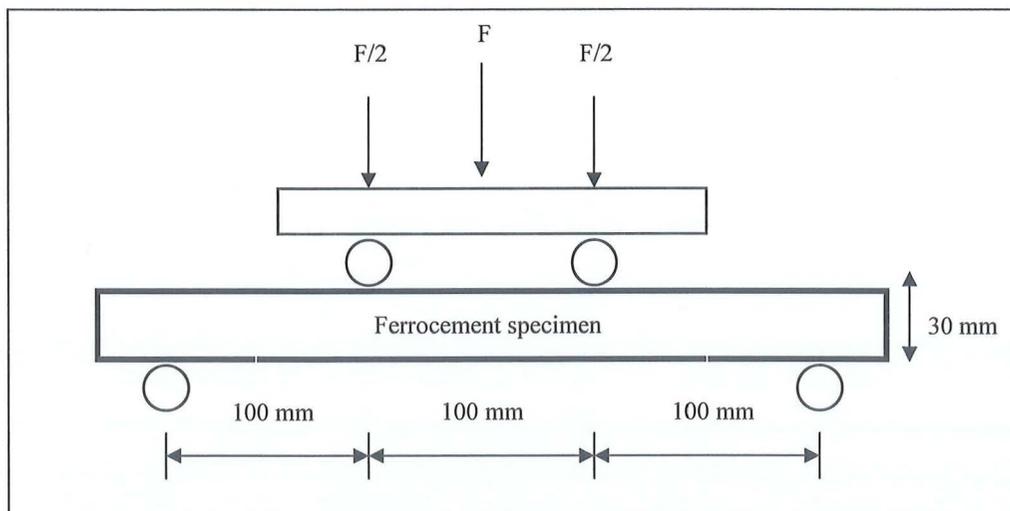


Figure 1. Test set-up for flexural test of ferrocement

Three different polymer modification systems was employed in this study, namely styrene butadiene rubber latex (SBR) (10% by weight of cement), natural rubber latex (NR) (10% by weight of cement) and epoxy resin (ER) (10% by weight of cement), in their ability to increase the bond strength between mortar and reinforcement. The material properties are listed in Table 1. The fine aggregate was graded river sand with 5.0 mm maximum size and complied with the grading limit of zone F of BS 882. The sand has a specific gravity of 2.65, absorption of 0.80% and a fineness modulus of 2.46. Ordinary Portland cement of ASTM type I was used.

Table 1. Material properties of polymer

Properties	NR	SBR	ER
Colour	White liquid	White liquid	Clear liquid
Odour	Ammonia gas	Slight	slight
PH	10.56	8.5 – 11.0	-
Water solubility	soluble	soluble	insoluble
Relative density (g/cm ³)	0.94	1.01-1.025	1.16 at 25 °C
Solids content (%)	61.52	46.5 – 49.5	100
Particle size	-	0.15 μm	-

The type of wire mesh used for the entire ferrocement test programme consisted of a square welded mesh of wire diameter 1.0 mm, and a mesh opening of 12.0 mm x 12.0 mm. The characteristics of the wire are listed in Table 2.

Table 2. Characteristics of wire mesh

Type of wire	Diameter of wire (mm)	Mesh size (mm)	Yield strength (MPa)	Ultimate Strength (MPa)	Young's Modulus of Elasticity (Gpa)
Square welded wire	1.0	12.0 x 12.0	93.7	231.2	1.1

mesh					
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The mortar mix proportions used in this study were cement : sand : 1 : 3, all by weight with a water-cement ratio of 0.45 for initial mixes. Irrespective of the final (w/c) ratio used, all the mixes were designed for a slump of 130 – 150 mm. The amount of cement content used in the mortar mix is therefore, designed based on the following expression [5].

$$C = \frac{700}{\sqrt[5]{D}} \quad (1.0)$$

Where:

- C is the cement proportion in kg/m³
- D is the maximum size of aggregate in mm

The maximum size of fine aggregate in the mix proportion is 5.0 mm, then the cement content should be used is about 500 kg/m³. The mix proportion is shown in Table 3.

Table 3. Design mixes for ferrocement specimens

Type of ferrocement	Cement (kg/m ³)	Polymer (%)	Superplasticiser (%)	Sand (kg/m ³)	W/c	Slump (mm)
FEKAW	500	0	1.5	1500	0.45	150
FESBR	500	10	0	1500	0.35	140
FEER	500	10	1.5	1500	0.45	145
FEGA	500	10	1.8	1500	0.45	140

FEKAW (Unmodified control ferrocement), FESBR (Styrene butadiene rubber latex ferrocement), FEER (Epoxy resin ferrocement), FEGA (Natural rubber latex ferrocement)

When designing the mix, the percentage of water present in the polymer dispersion was taken into account for determining the mixing water. A superplasticiser, sulphonated naphthalene condensate, was used (by weight of cement). All ferrocement specimens were cast in steel moulds, an external vibrator was used to facilitate compaction and decrease the amount of air bubbles. The samples were demoulded after 24 hours and then cured in water for 28 days. Once demoulded, the specimens were further cured in air and salt water cyclically for seven and three days each until the time of test. Prior to testing, the ferrocement specimens were subjected to the ages of 30, 90, 180 and 365 days. The test specimens, 125 mm x 350 mm x 30 mm as shown in Figure 2.

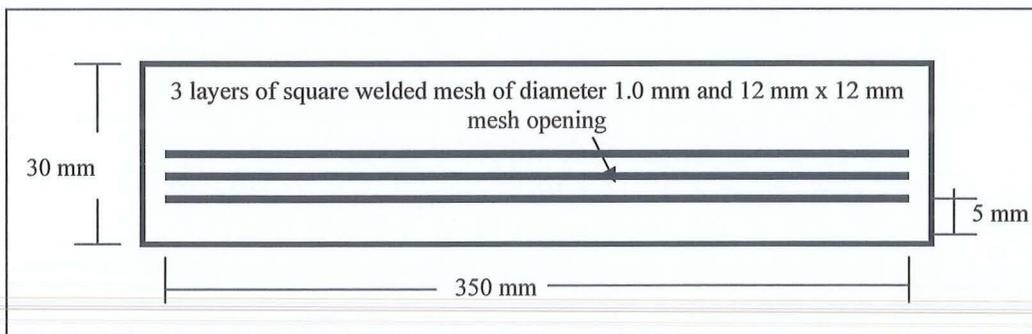


Figure 2. A schematic diagram of ferrocement test specimen

The flexural test was conducted in a TORSEE testing machine as shown in Figure 3. The deflection of the specimen was measured at the loading points, and was manually plotted. The strain gauge was bonded in the middle of each tensile reinforcement to measure the deflection of the first crack and ultimate loads of the ferrocement specimens the cracks widths were measured at the bottom-most of the vertical face of the specimen in the constant bending moment region. The number of cracks within the central 100 mm of the specimens was noted and the width of each crack was measured using a microscope.

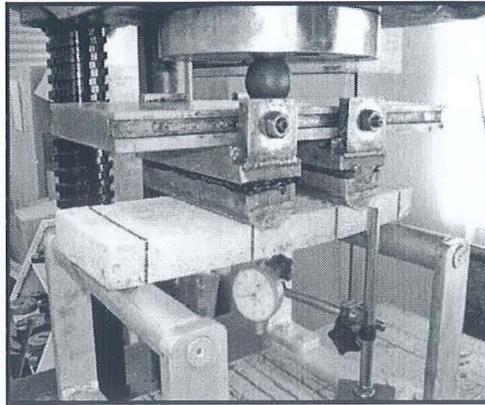


Figure 3. Experimental set-up for flexural test of ferrocement

3. TEST RESULTS AND DISCUSSIONS

3.1 Mechanical Properties

The mechanical properties of mortar used for the ferrocement specimens are presented in Figure 4. to 6., each data presented here was obtained from an average of three test result. The test results are show that the compressive strength of the polymer modified cement mortars are always lower than that of the unmodified control, FEKAW, with the FESBR mix showing higher strengths than the FEER and FEGA mixes. This is attributed to the fact that the polymer films present in the matrix are fairly soft compares to that of cement matrix, and when they fill the voids and coat the aggregates and the cement particles, the resulting matrix will have a much lower compressive strength. Although the compressive strength of the unmodified control, FEKAW is higher than those of the polymer-modified mixes, its flexural strength is lower than that of the polymer-modified specimens (FESBR, FEGA, and FEER). Similarly, the Young's modulus of elasticity of the unmodified mortar, FEKAW, is marginally higher than that of the polymer-modified mortars. The test result also show that polymer modification has significantly improved the mechanical properties of cement mortars in particularly, the flexural strength of all polymer-modified cement mortars has been greatly.

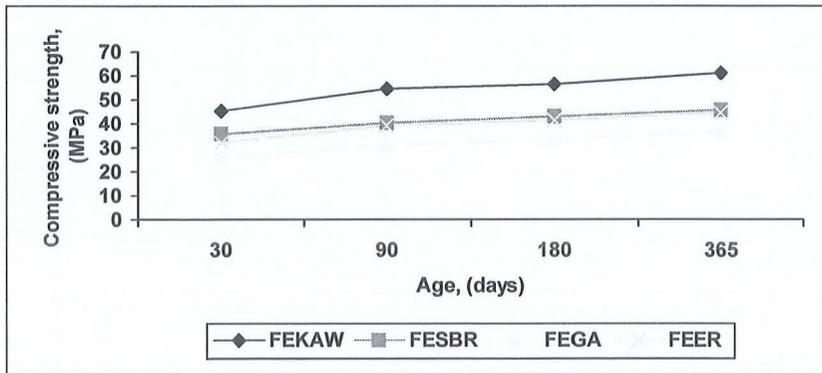


Figure 4. Compressive strength of mortars for ferrocement

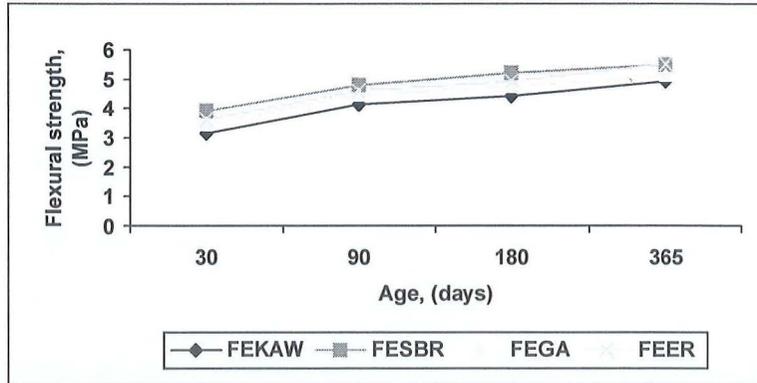


Figure 5. Flexural strength of mortars for ferrocement

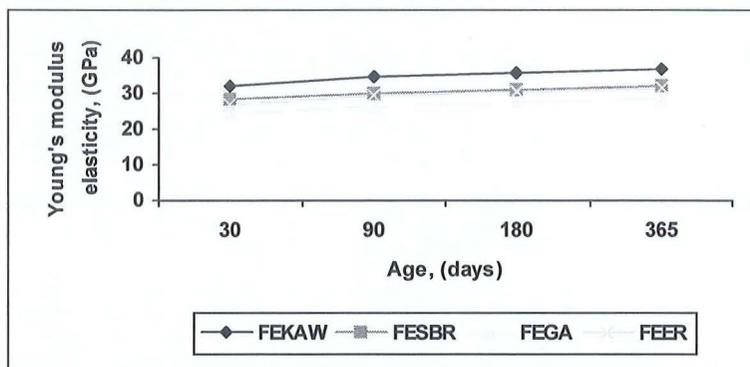


Figure 6. Young's modulus elasticity of mortars for ferrocement

3.2 First Crack Strength and Ultimate Load

The experimental and predicted values of the first crack and ultimate loads are presented in Tables 4. to 7. from Table 4., the predicted values of first crack load of the specimens at 30 days curing are found to be higher than those of the experimental values. The ratio of the first crack load from experiment, F_{cr} (Exp) to the predicted first crack load, F_{cr} (pred) varies between 0.83 to 0.87 and FEGA mix shows the lowest first crack load. While the ultimate loads of specimens obtained from the experiment F_u (exp) are higher than those obtained from calculation, F_u (pred).

Table 4. Experimental and predicted values of crack and ultimate loads at 30 days

Type of specimen	First crack load, F_{cr} (kN)			Ultimate load, F_u (kN)			Ratio F_{cr} / F_u
	F_{cr} (Exp)	F_{cr} (Pred)	Ratio F_{cr} Exp/Pred	F_u (Exp)	F_u (Pred)	Ratio F_u Exp/Pred	
FEKAW	0.98	1.17	0.84	2.98	2.14	1.39	0.33
FESBR	1.24	1.46	0.85	3.49	2.12	1.65	0.36
FEGA	1.07	1.29	0.83	3.28	2.09	1.62	0.33
FEER	1.17	1.35	0.87	3.38	2.11	1.60	0.35

The test results in Table 5. show that, the experimental values for the first crack load of the specimens at 90 days are higher than those obtained from the calculation. All the specimens also record higher ultimate loads from experiment.

Table 5. Experimental and predicted values of crack and ultimate loads at 90 days

Type of specimen	First crack load, F_{cr} (kN)			Ultimate load, F_u (kN)			Ratio F_{cr} / F_u
	F_{cr} (Exp)	F_{cr} (Pred)	Ratio F_{cr} Exp/Pred	F_u (Exp)	F_u (Pred)	Ratio F_u Exp/Pred	
FEKAW	1.50	1.54	0.97	3.50	2.15	1.63	0.43
FESBR	1.87	1.79	1.04	3.86	2.13	1.81	0.48
FEGA	1.67	1.68	0.99	3.65	2.11	1.73	0.46
FEER	1.80	1.71	1.05	3.78	2.13	1.77	0.48

Tables 6. and 7. show experimental and predicted values of first crack and ultimate loads strength of ferrocements subjected to 180 days and 365 days of curing. A higher first crack and ultimate loads in the polymer modified ferrocements are attributed to the increased in flexural capacity as result of polymer film formation, which bind the aggregate and cement particles into a monolithic structure.

Table 6. Experimental and predicted values of crack and ultimate loads at 180 days

Type of specimen	First crack load, F_{cr} (kN)			Ultimate load, F_u (kN)			Ratio F_{cr} / F_u
	F_{cr} (Exp)	F_{cr} (Pred)	Ratio F_{cr} Exp/Pred	F_u (Exp)	F_u (Pred)	Ratio F_u Exp/Pred	
FEKAW	2.29	1.64	1.40	3.89	2.15	1.81	0.59
FESBR	2.86	1.94	1.47	4.34	2.14	2.03	0.66
FEGA	2.55	1.77	1.44	4.05	2.12	1.91	0.63
FEER	2.74	1.83	1.50	4.28	2.13	2.01	0.64

Table 7. Experimental and predicted values of crack and ultimate loads at 365 days

Type of specimen	First crack load, F_{cr} (kN)			Ultimate load, F_u (kN)			Ratio F_{cr} / F_u
	F_{cr} (Exp)	F_{cr} (Pred)	Ratio F_{cr} Exp/Pred	F_u (Exp)	F_u (Pred)	Ratio F_u Exp/Pred	
FEKAW	3.43	1.83	1.87	4.34	2.16	2.01	0.79
FESBR	4.28	2.04	2.10	4.86	2.14	2.27	0.88
FEGA	3.82	1.92	1.99	4.61	2.12	2.17	0.83
FEER	4.21	2.05	2.05	4.85	2.14	2.27	0.87

3.3 Load-Deflection Characteristics

Typical load-deflection curves for the four ages of curing conditions are presented in Figs. 7. to 10. from Fig. 7., the first crack load for FEKAW occurred at about 1.23 kN and a deflection of about 0.24 mm. For FESBR at about 1.55 kN and a deflection of about 0.56 mm, FEGA at about 1.34 kN and a deflection of about 0.44 mm and FEER at a about 1.34 kN and a deflection of about 0.44 mm. The maximum load before failure for FEKAW is about 3.72 kN, and the maximum deflection is about 1.38 mm. The maximum load and deflection for FESBR is 4.36 kN and 2.10 mm, FEGA is 4.10 kN and 1.74 mm and FEER is 4.23 kN and 2.22 mm.

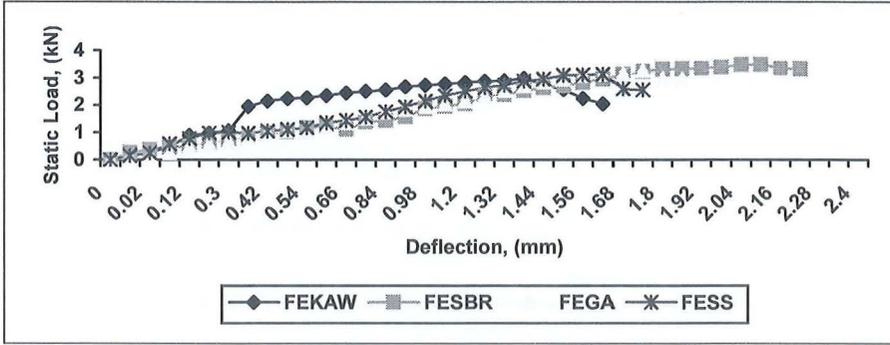


Figure 7. Load-deflection curve of ferrocement at 30 days

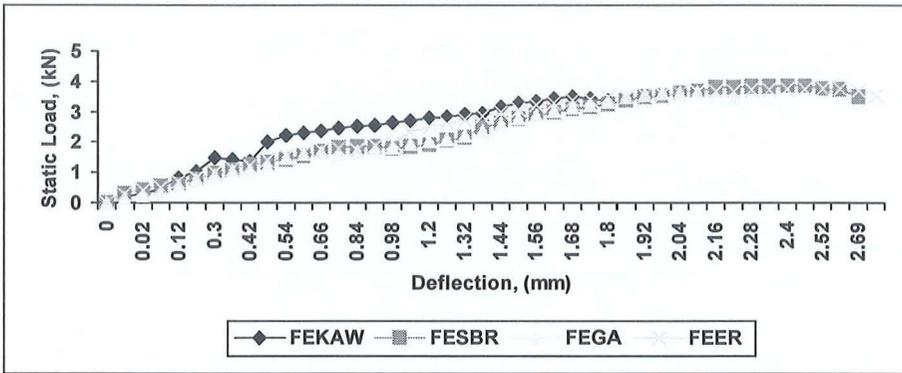


Figure 8. Load-deflection curve of ferrocement at 90 days

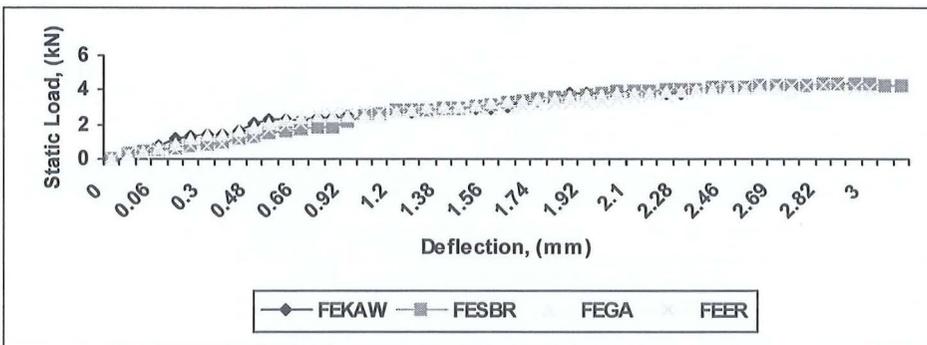


Figure 9. Load-deflection curve of ferrocement at 180 days

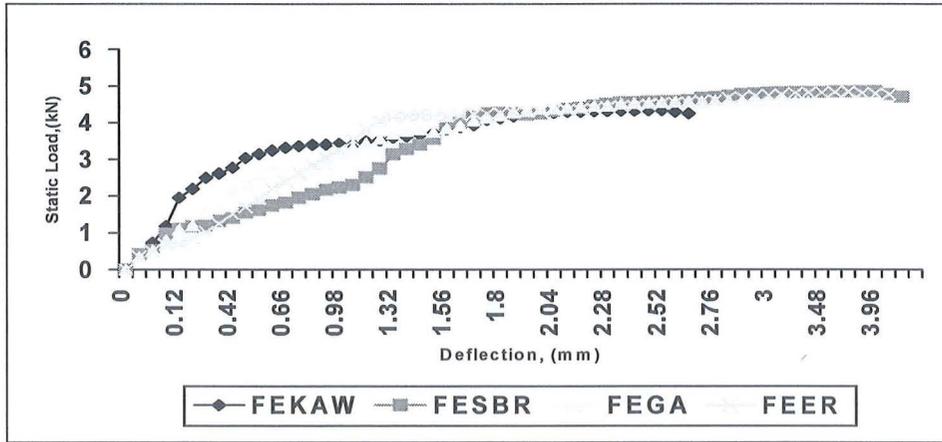


Figure 10. Load-deflection curve of ferrocement at 365 days

The deflection curve of ferrocement at 365 days is presented in Fig. 10. The first crack load occurred for FEKAW at about 3.43 kN and a deflection is about 0.98 mm. The specimen achieved its maximum load is about 4.34 kN and a maximum deflection of this specimen before failure is of about 2.52 mm. For FESBR, the first crack load is about 4.28 kN and a deflection is about 1.80 mm, FEGA is about 3.82 kN and a deflection is about 1.44 mm and FEER is about 4.21 kN and a deflection is about 1.50 mm. The maximum load and deflection before failure for FESBR is 4.86 kN and 3.96 mm, FEGA is about 4.61 kN and 3.12 mm and FEER is about 4.85 kN and 3.72 mm.

Based on the test result, polymer modified ferrocements are shows higher first crack load, maximum load and a deflection value than that of the unmodified control ferrocement, FEKAW. The result also indicates that, the first crack load, maximum load and a deflection value are found to increase with the increasing age of curing. From Figs 7. to 10., the load-deflection curves of ferrocement have been reported to have three distinct stages [6], namely; before cracking mortar, after the first cracking of mortar but before the yielding of steel and, after yielding of steel meshes when the slopes becomes almost parallel to the axis of deflection.

3.4 Crack Width

The estimation of crack width can be predicted using the following simplified approach [7]:

$$W_{av} = S\beta\varepsilon_s \quad (2.0)$$

Where:

W_{av} is the average crack width

S is the mesh opening

β is the ratio of distance to the neutral axis from the extreme tensile fibre and from the extreme tensile fibre and from the outermost of steel

ε_s is the strain in the extreme tensile layer of mesh

The test results in Table 8. shows that, the experimental (Exp) and predicted (Pred) values of the average crack widths. Based on the test result, the predicted values of the average crack widths are found to be lower than those of the experimental values. The result also indicate that, polymer modified ferrocements (FESBR, FEGA and FEER) are shows lower average crack widths than that of unmodified control ferrocement, FEKAW. All the test specimens indicate that, the increase in average crack width with respect the increasing age of curing.

4. CONCLUSIONS

From the test results and the analysis of the experimental work carried out in this study the following are the main conclusions and recommendations:

1. From the mechanical properties test results are show that the compressive strength and Young's modulus of elasticity of the polymer-modified cement mortars are lower than that of unmodified control. The test result also shows that polymer modification has significantly improved the mechanical properties of cement mortars in particularly, the flexural strength of all polymer-modified cement mortars has been greatly.
2. The predicted values of first crack load of polymer-modified and unmodified control ferrocements are always higher than that of the experimental values at 30 days of curing. The ratio of the first crack load from experiment to the predicted first crack load varies between 0.83 to 0.87. While the ultimate loads of specimens obtained from the experiment are higher than those from prediction.
3. For 90, 180 and 365 days of curing, the test result that the experimental values for the first crack and ultimate loads are higher than those obtained from the calculation. A higher first crack and ultimate loads in the polymer modified ferrocements are attributed to the increased in flexural capacity as result of polymer film formation, which bind the aggregate and cement particles into a monolithic structure.
4. Based on the test result, polymer modified ferrocements are shows higher first crack load, maximum load and a deflection value than that of the unmodified control ferrocement. The result also indicates that, the first crack load, maximum load and a deflection value are found to increase with the increasing age of curing.
5. The average crack width of specimens determined from calculation is always lower than the experimental values. Lower crack widths in all polymer modified ferrocements indicate that polymer modification improves the bonding between aggregate, cement and polymer particles by the formation of polymer films, bridging and cementing them into a durable matrix and exhibiting higher resistance to crack development.
6. The average crack spacing obtained from the experiment is always lower than the calculation as based on Eq. (3.0), the average crack spacing in all specimens is 38.0 mm. For polymer-modified ferrocements, the average crack spacing is lower than that unmodified control ferrocement.

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