[AMN02] Durability of ferro cement structures in aggressive environment by laboratory tests

Faizal Md Hanafiah, Mahyuddin Ramli, Nik Fuaad Bin Nik Abllah

School Of Housing, Building And Planning, University Science Malaysia, 11800 Minden, Penang, Malaysia.

Introduction

The climate in *marine environment*, an area of interface between the land and sea, remains highly humid and corrosive. Strength loss and corrosion in materials result due to the effect of the marine environment. Hence, the marine climate calls for renovation and development of new marine resistant engineering materials of specific properties.

Deterioration of the infrastructure may be due to environmental conditions, age, material degradation and increased loading spectra. *Marine structures* deterioration is one major concern because it effects life, maintenance costs, user convenience and safety. Therefore good performing repair materials and cost effective application of these materials are of interest.

These repair serve two purposes. First, effective materials and efficient construction techniques reduce public inconvenience and as a result user costs. Secondly, materials that reduce the marine structure permeability also provide a protection system against aggressive solution seepage. This protection is believed to delay the corrosion of reinforcing steel, a major factor in marine structure deterioration.

One of the ways to make a material of high mechanical properties with satisfactory durability in various environments and high aesthetic values is through modification of concrete mortar using polymer based admixture. The concept of modification for cement mortars is not new, since considerable research and development of polymer modification have been performed for the past 70 years. As a result, various polymer based admixture have been developed and polymer modified mortar using this material are currently become a popular construction materials because of their good cost-performance balance. To achieve desired concrete properties, experimental research on certain types of polymer based admixture is necessary.

Through researching and finding the optimal admixture quantity, concrete properties can be significantly improved. The wide applications of polymer modification for cement mortar urges researches to carry out extensive work in order to establish a good base for this development. Ferrocement structure seems to have tremendous potentials amongst the composites investigated.

This paper presents the results of the laboratory tests on ferrocement structures in marine environment.

Ferrocement

In general, *ferrocement* is considered as a highly versatile form of composite material made of cement mortar and layers of wire mesh or similar small diameter steel mesh closely bound together to create a stiff structural form. The dispersion of the fibers in the brittle matrix offer not only convenience and practical means of achieving improvements in many of the engineering properties of the material such as fracture, tensile and flexural strength, toughness, fatigue resistance and impact resistance but also provide advantages in terms of fabrication of products and components.

These potential advantages and novelty of the concept have stimulated what is now considered a world wide interest in the use of ferrocement.

Research Significance

This paper provides a comparative study of three (3) polymer admixtures type, namely *Styrene Butadiene Rubber SBR*, *Vinnapas® RE 545 Z* and *Resibond SBR* plus *Silica Fume*, in their ability to increase the bond strength between mortar and reinforcement.

Materials and Methods

The research was conducted through an experimental program with mortar samples in different size and shape. Therefore, the influence of the polymer admixture participation in various percentages was studied concerning compressive strength, flexural strength, modulus of elasticity as well as bond between reinforcement and concrete mortar. Furthermore, the following parameters are also studied; water absorption, shrinkage and influence of various curing conditions on polymer modified mortars.

Experiments were conducted in the laboratories at School Of Housing, Building And Planning, University Science Malaysia, Penang, Malaysia.

Materials

*Ordinary Portland Cement OPC*of ASTM type 1 was used. The fine aggregate was a graded *river sand* and *chipping* with 5.0mm 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 0.8% and a fineness modulus of 2.46. Tap water is supplied by Penang Municipality was use for curing purposes.

Methods

Five (5) types specimens were prepared: *Cube* [10x10x10cm], *Prism* [10x50x10cm] were cast in steel mold while *Ferrocement* specimens were cast with locally manufactured welded mesh [square mesh of 10x10mm size]. 120 specimens of each shape were cast accordingly. Furthermore, two sets of ferrocement *slab* and *beam structures* were also prepared in wooden mold with welded mesh [square mesh of 50x50mm size].

Three types of *curing regimes* were prepared which includes air, artificial marine [salt water] and industrial [acidic liquid] environment. Sets of dry and wet cycle of 3 and 7 days each were prepared for those specimens until the duration of 50, 90, 180, 270 and 360 days. An equal number of specimens for each type were not exposed to cyclic curing were used as *control specimens.*

The mortar mix proportions used in this research were cement:sand:chipping, 1:1:3 all by weight with a water-cement [w/c] ratio of 0.45 for the initial mixes. Irrespective of the final w/c ratio used, all the mixes were designed for a slump of 90-120 mm.

A superplasticiser, CONPLAST 1000 sulphonated naphthalene condensate was used [1.0% and 2.0% by weight of cement]. The amount of cement content used in the mortar mix is therefore, designed based on the following expression,

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

Where,

C is the cement proportion in kg/m^3

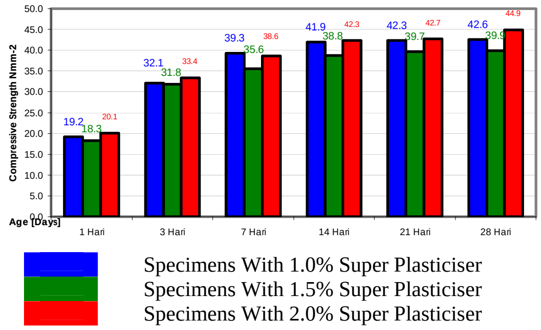
D is the maximum size of aggregate in mm

All specimens were cast and table vibrator was used to facilitate compaction and decrease the amount of air bubbles. Specimens were then demoulded after 24 hours and cured in water at room temperature of 20 ± 2^{o} C and relative humidity 75% for 28 days. Once demoulded, specimens were further cured in two different curing regimes; air curing and salt water curing until testing date.

Results And Discussion.

Compressive Strength.

The compressive strength of the mortars specimens was determined according from the method specified in ***BS 1881: Part 119:1983***. The compressive strength results of all the mixes Trial Mix Programme tested up to 28 days are presented in Figure 2 and 3. From the results, the compressive strength development of modified cement mortars was great enhanced by the presence of admixture Silica Fume and Superplasticiser. The control cement mortars at early aged are also increased in strength until the age of 28 days [Figure 1].



Specimens With 1.0% Super Plasticiser
Specimens With 1.5% Super Plasticiser
Specimens With 2.0% Super Plasticiser

FIGURE 1 Compressive Strength Of Cement Mortars At Early Aged 1-28 Days.

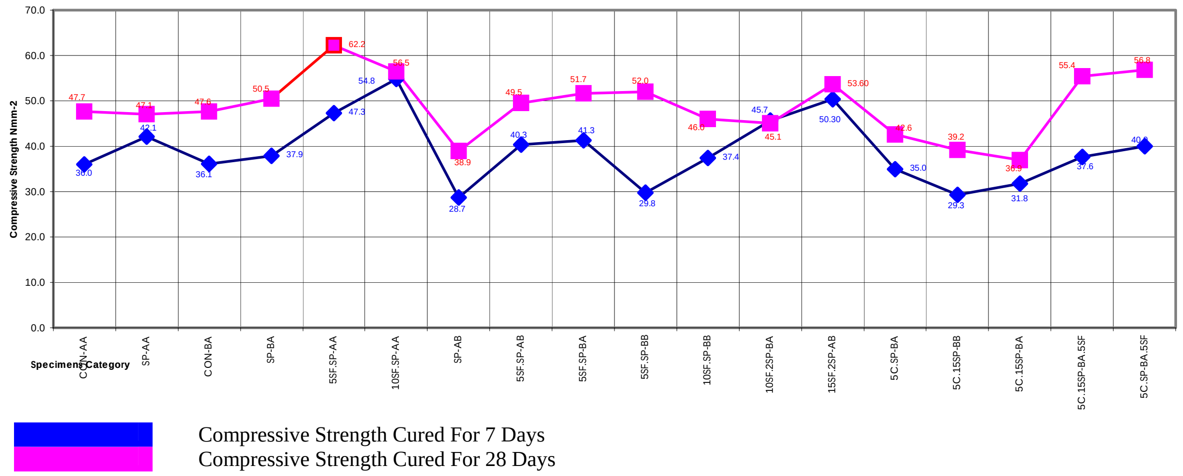


FIGURE 2 Compressive Strength Of Modified Cement Mortars cured for 7 And 28 Days In Water.

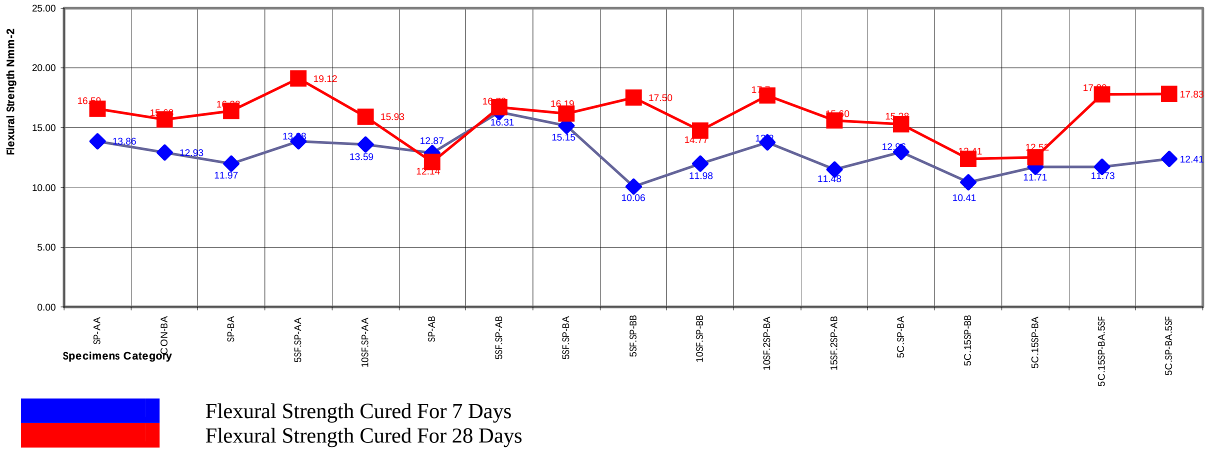


FIGURE 3 Flexural Strength Of Modified Cement Mortars Cured For 7 And 28 Days In Water.

***Flexural Strength*.**

The flexural strength is carried out in accordance with *BS 1881: Part 118:1983* "Method of determination of flexural strength". The flexural strength results of the mixes tested in this Trial Mix Stage are presented in Figure 2 and Figure 3. The results showed that flexural strength of modified cement mortars is significantly increased by addition of admixture Silica Fume and Super Plasticiser CONPLAST 1000.

Those results are interpreted in terms of the contribution of high tensile strength by the admixture themselves and an overall improvement in cement hydrate-aggregate bond. The strength properties of the modified cement mortars are influenced by various factors that tend to interact with each other.

Water Absorption.

The water absorption is calculated from the increase in mass of the specimen and expressed as a percentage of dry specimen multiply by a correction factor derived from the expression accordance with ***BS 1881: Part 122:1983*** as follow:

$$\text{Correction Factor} = \frac{\text{Volume (mm}^2)}{\text{Surface Area (mm) x 12.5}}$$

Modulus Of Elasticity.

The modulus elasticity may be estimated from emphirical formulas, given in the British Code for design of concrete structure, ***BS 8110 : 1985*** is :

E_c (static modulus) = 1.25 E_d - 19.

When it is required to relate the dynamic modulus (Ed) to strength and density, the static modulus was estimated from the following expression as given by *CP 110:1972*:

$$E_c = 0.85\ \rho^2 f_{cu}^{½} \times 10^{-6}.$$

Where,
ρ = density (kg/m^3) and
f_{cu} = cube crushing strength (N/mm^2)

The polymer based admixture modified mortars generally show a lower modulus of elasticity than the unmodified mortars, their magnitude depending on the admixture type and admixture cement ratio. This behavior has great advantages to structural concrete since a lower modulus of elasticity would induce lower stress for the same strain. The modulus of elasticity is not affected by the curing regimes adopted.

Shrinkage And Expansion.

The shrinkage and expansion are carried out in accordance with *British Standard BS 1881 : Part 206 : 1986*. All specimens are subjected to air-curing after 28 days of immersion in water. From the test results, the modified mortars show much lower shrinkage value than the unmodified mortars. This such properties can be an asset to ferrocement structure construction in marine environment since low shrinkage and expansion will also reduce the developments of micro cracks.

Permeability

The permeability of the unmodified and modified mortars specimens were determined from a 50 mm diameter mortar sample with an average depth of 40 mm, using the Leeds Cell Permeability developed by Cabrera and Lynsdale. Prior to testing of permeability, the specimens were conditioned by drying in an oven at a temperature of 105 ± 5^{o}C for a period of 24 hours.

On removal of the samples from the oven, they were allowed to cool for a minimum period of 24 hours before testing. The permeability of the samples is calculated form the expression:

$$K = \frac{4.04 \times P_2^2 \times R \times L\ 10^{-16}}{a \times [\ P_1^2 - P_2^2\ ]}$$

where,
K = intrinsic permeability (m^2)
R = flow rate (cm/s)
L = length of specimen (m)
a = cross sectional area of specimen (m^2)
P_1 = absolute pressure (bar) and
P_2 = pressure at which the flow rate is measured

From the test results, the polymer modified specimens exhibits superior performance compared with the unmodified mortar. The modified mortars have the ability to reduce the permeability of the cement matrix, and significantly reduce the depth of penetration of chloride ions into the mortars. As the cement hydration process continues, the polymer based admixture particles coalesce to form a continuous layer of polymer film which surround the aggregates, and coats the gel resulting in a less porous and a less permeable mortar matrix. This systems should have high durability performance against chloride penetration, chemical attacks and other form of structural deteriorations.

Chloride Determination.

The chloride penetration of the modified mortars was determined form laboratory method described in *BS 1881: Part 124: 1992*. The need to assess the chloride of hardened mortar is most likely to arise in relation to the corrosion risk to embedded reinforcement or ties. Small quantities of chloride (up to approx. 0.01% chloride ion by weight of mortar) will normally be present in modified mortar.

Carbonation.

Carbonation of concrete by attack from atmospheric carbon dioxide will result in a reduction in alkalinity of the concrete, and increase the risk of reinforcement corrosion. This will normally be restricted to a surface layer of only a few millimeters thickness, in a good quality concrete. The extent of carbonation can be easily assessed by treating with phenolphthalein indicator the freshly exposed surfaces of a piece of mortar which has been broken from a prism member after a flexural test.

Conclusions

From the test results and the analysis of the experimental work carried during this research, the following are lists of conclusions and future recommendations.

a. The costs of preparing the polymer based admixture mortars should not be compared to the cost of the production of unmodified mortars. The cost should be compared with the sum of the initial production cost of unmodified mortars plus the cost of the expected repair works during the service life of the structures, especially those exposed to marine and aggressive environment.
b. The presence of polymer based admixture in modified cement mortars improves significantly in every engineering parameter regarding durability except in flexural strength.

Acknowledgements

The authors wished to thank the Ministry Of Science, Technology And Innovation [MOSTI], Malaysia for the National Science Fellowship NSF awarded to Faizal Md Hanafiah. The authors were also grateful to all staff members of Building And Science Department, School Of Housing, Building And Planning, University Science Malaysia, Penang, Malaysia for their timely help to the successful completion of this study.

References

Johnston, C.D., and Mowat, D.N. (1974). *Ferrocement-material behavior in flexure*, Journal Of Structural Division, ASCE, 100: 2053-2069.

Mathews, M.S., Sudhakumar, J., and Jayasree, P.(1993). *Durability studies on ferrocement, Journal of ferrocement*, 23 (1):15-23.

Mansur, M.A., Paramasivam, P., Wee, T.H., Lim, H.B.(1996). *Durability of ferrocement* – A case study, Journal of Ferrocement, 26 (1): 11-19.

Mehta, P.K.(1980). *Durability of concrete in marine environment*, A Review – Conference on Performance of Concrete in Marine Environment, ACI SP-65, 1-20

Neville, A.(1995). Chloride attack of reinforced concrete: an overview, *Materials and Structures*, 28:63-70.

Suryavanshi, A.K., Swamy, R.N., and Cardew, G.E.(1997). Evaluation of diffusion coefficient for chloride diffusion through structural concrete, *Private Communication*.

Andrade, C.(1993). Calculation of chloride diffusion coefficients in concrete from ionic migration measurements, *Cement and Concrete Research*, 23 (3):724-742.

Shah, S.P. (1972). Evaluation of ferrocement as a construction material, *Proc. Of the Conference of New Materials in Concrete Construction, University of Illinois at Chicago Circle, December 1972.*