PROPERTIES OF LATEX FERROCEMENT IN FLEXURE

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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 a versatile construction material. 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. (Mathews, et al, 1993). 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 (Ramesht, et al, 1993). 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. (Sri Ravindrarajah, et al, 1986). 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 polymer modification of mortar and concrete. To achieve desired mortar and concrete properties, experimental research on certain types of polymer admixture is necessary. The Research has shows that polymer modification on mortar and concrete can improve properties significantly. This paper dissevers investigation carried out to 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 PROGRAMME

The research programme encompasses the laboratory investigation on the structural, the deformation behaviour and characteristic of polymer 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 polymer modified ferrocements specimens, as shown in Figure 1.

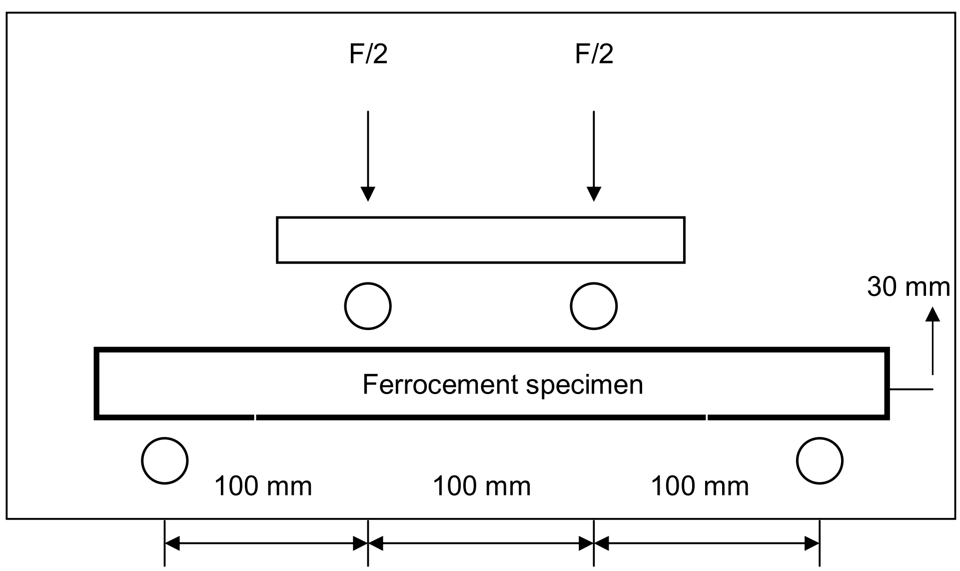

Figure 1. Test set-up for flexural test of ferrocement

Three different polymer modification systems was employed in this study, namely styrene butadiene rubber latex (SBR), natural rubber latex (NR) 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.

Table 1. Material properties of polymer latexes

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^oC
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 mesh	1.0	12.0 x 12.0	93.7	231.2	1.1

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

$$C = \frac{700}{\sqrt[5]{D}} \tag{1.0}$$

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.

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)
FEKAW (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
FEGA (Natural rubber latex ferrocement)	500	10	1.8	1500	0.45	140

When designing the mix, the percentage of water present in the polymer 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°C ± 2°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.

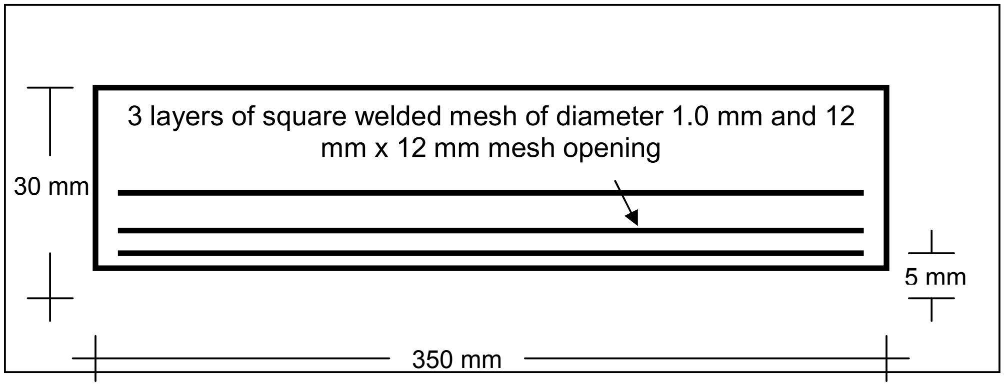

Figure 2. A schematic diagram of ferrocement test specimen

The flexural test was conducted in a TORSEE testing machine as shown in Figure 3. The 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.

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

3. TEST RESULTS AND DISCUSSIONS

3.1 Properties of Ferrocement Mortar

The mechanical properties of mortar used for the ferrocement specimens are presented in Figure 4 to 6, each data presented was obtained from an average of three test results. The tests results show that the compressive strength of the polymer modified cement mortars are always lower than that of the unmodified control, FEKAW. The FESBR mix exhibits higher strengths than that of the FEER and FEGA mixes. This is attributed to the fact that these exists a soft layer of the polymer 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, 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 results also show that the polymer modification has significantly improved the mechanical properties of the cement mortars particularly, their flexural strengths and their resistance to crack development.

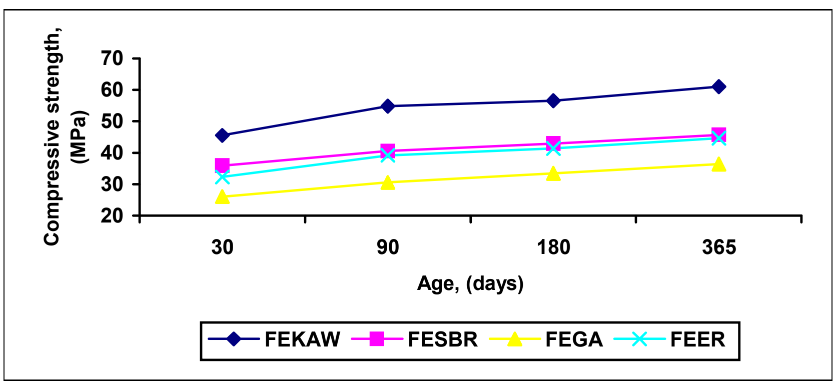

Figure 4. Compressive strength of mortars for ferrocement

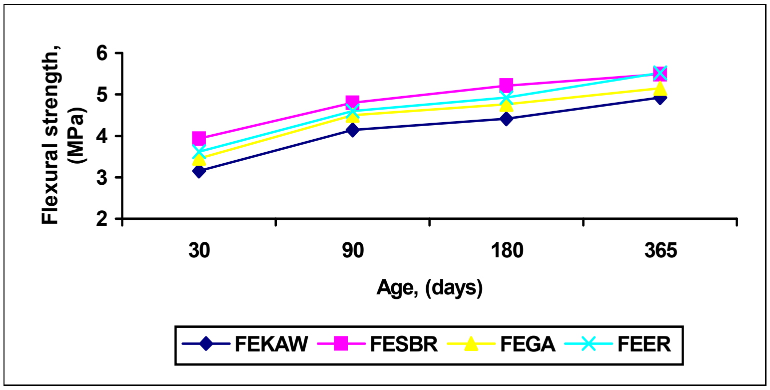

Figure 5. Flexural strength of mortars for ferrocement

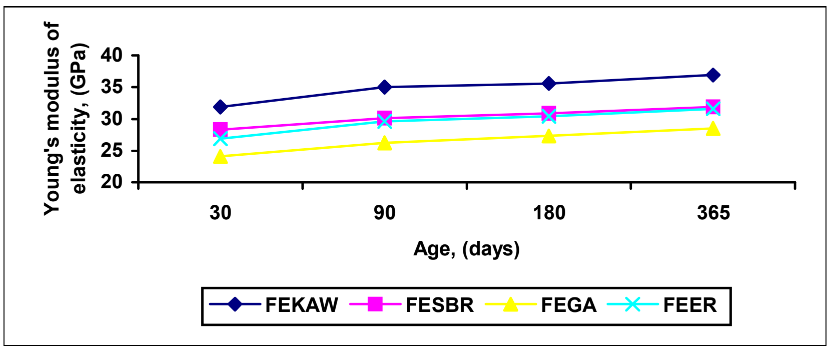

Figure 6. Young's modulus elasticity of mortars for ferrocement

3.2 Crack Developments

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} (Exp)	F_{cr} (Pred)	Ratio F_{cr} Exp/Pred	F_u (Exp)	F_u (Pred)	Ratio F_u Exp/Pred	F_{cr} / F_u
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} (Exp)	F_{cr} (Pred)	Ratio F_{cr} Exp/Pred	F_u (Exp)	F_u (Pred)	Ratio F_u Exp/Pred	F_{cr} / F_u
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 a result of polymer film formation, which bind the aggregate and cement particles into a durable cement matrix (Ramli, 1997).

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} (Exp)	F_{cr} (Pred)	Ratio F_{cr} Exp/Pred	F_u (Exp)	F_u (Pred)	Ratio F_u Exp/Pred	F_{cr} / F_u
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} (Exp)	F_{cr} (Pred)	Ratio F_{cr} Exp/Pred	F_u (Exp)	F_u (Pred)	Ratio F_u Exp/Pred	F_{cr} / F_u
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 Crack Width

The estimation of crack width can be predicted using the following simplified approach (Swamy, 1984):

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

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 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, polymer modified ferrocements (FESBR, FEGA and FEER) are having lower average crack widths than that of the unmodified control ferrocement, FEKAW. All the test specimens indicate the increase in the average crack width with respect to the increasing age of curing.

Table 8. Average crack width for ferrocement in static flexure

Type of Specimen	Average crack width (mm)							
	30 days (Exp)	30 days (Pred)	90 days (Exp)	90 days (Pred)	180 days (Exp)	180 days (Pred)	365 days (Exp)	365 days (Pred)
FEKAW	1.82	1.3659	1.85	1.3710	1.86	1.3710	1.92	1.3767
FESBR	1.75	1.3544	1.78	1.3603	1.79	1.3664	1.85	1.3659
FEGA	1.82	1.3373	1.83	1.3493	1.84	1.3551	1.87	1.3542
FEER	1.76	1.3489	1.79	1.3608	1.79	1.3603	1.86	1.3661

3.4 Crack Spacing

The average crack spacing can be predicted using the following expression (Singh, 1994):

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

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 (Naaman, 1997) 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:

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

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 m^2/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 9 show that the average crack spacing obtained from the experiment is always lower than that of the predicted ones. For polymer-modified ferrocements, the average crack spacing is lower than that of the unmodified control ferrocement.

Table 9. Average crack spacing for ferrocement in static flexure

Type of Specimen	Average crack spacing (mm)			
	30 days	90 days	180 days	365 days
FEKAW	24.3	27.5	29.7	33.1
FESBR	19.4	22.1	0	24.7
FEGA	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

3.5 Load-Deflection Characteristics

Typical load-deflection curves for the four ages of curing conditions are presented in Figures 7 to 10. From Figure 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, respectively.

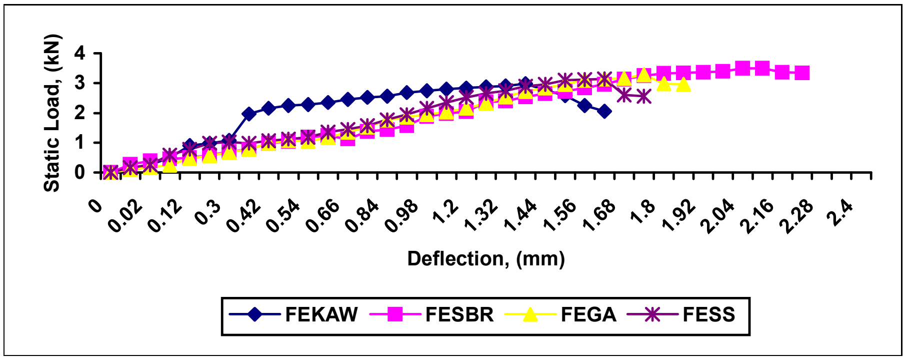

Figure 7. Load-deflection curve of ferrocement at 30 days

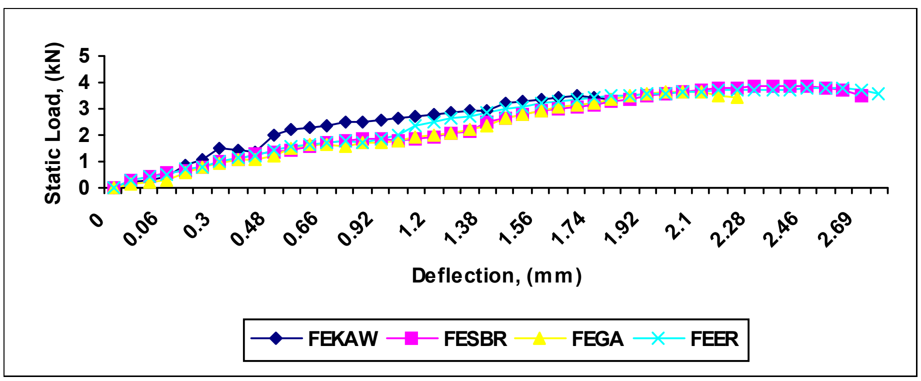

Figure 8. Load-deflection curve of ferrocement at 90 days

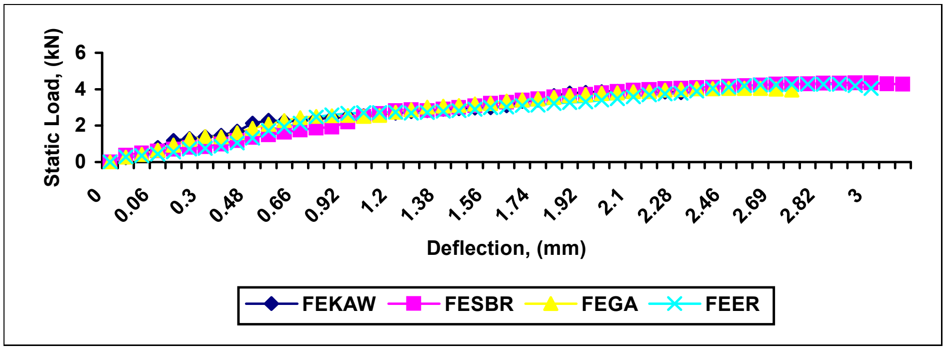

Figure 9. Load-deflection curve of ferrocement at 180 days

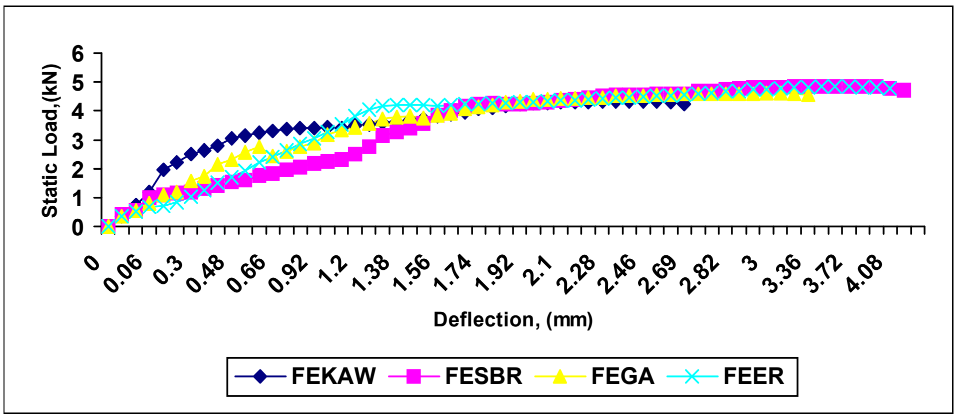

Figure 10. Load-deflection curve of ferrocement at 365 days

The deflection curve of ferrocement at 365 days is presented in Figure 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 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 FEGA 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, FEGA 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, polymer modified ferrocements show higher first crack load, maximum load and deflection than that of the unmodified control ferrocement, FEKAW. 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 7 to 10, the load-deflection curves of ferrocement have been reported to have three distinct stages (Naaman, et al, 1971) 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.

4. CONCLUSIONS

The main conclusions and recommendations are as follows:

1. The results show that polymer modification has improved the mechanical properties of cement mortars, particularly their flexural strength.
2. The first crack load of the polymer-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 polymer modified specimens are attributed to the increased in flexural capacity as result of polymer film formation, which bind the aggregate and cement particles into a durable matrix.
4. Polymer 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.

5. ACKNOWLEDGEMENTS

We extend our gratitude to the Research Creativity and Management Office, Universiti Sains Malaysia, for funding this research and to the School of Housing, Building and Planning, Universiti Sains Malaysia for facilitating the field equipments. Specials thanks are also who rendered their timely help to the successful completion of this project research.

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