Journal of Engineering and Applied Sciences 6 (3): 191-199, 2011
ISSN: 1816-949X

Engineering Properties of Epoxy Polymer Cement Concrete Reinforced with Glass Fibers

D.S. Hazimmah, S. Mohd and H.T. Cheng
Faculty of Civil Engineering and Earth Resources,
University Malaysia Pahang, 25000 Kuantan Pahang, Malaysia

Abstract: Previous research on mechanical properties and fracture behavior of concrete reinforced with glass fibers and some results are presented. It is well known that high strength concrete displays a brittle behavior and less tough characteristics than normal strength concrete. This type of behavior can be enhanced by incorporating various types of fibers or various types of matrix which lead to better mechanical properties and fracture properties. In this study, an experimental study on epoxy polymer cement concrete reinforced with glass fibers and steel fibers both used at a relatively low volume fraction is presented. Polymer concrete is a composite material formed by polymerizing a monomer and aggregate mixture. The polymerized monomer acts as the aggregates binder. In this research, the polymer is epoxy resin mixed with cement and aggregates as used in the foundry industry. Initiators and promoters are added to the resin prior to its mixing with the inorganic aggregates to initiate the curing reaction. Compressive, splitting, three-point bending and impact test methods have been used to characterize reinforced concrete materials and the results are analyzed statistically. Fracture behavior of steel fibers and glass fibers reinforced epoxy polymer cement concrete is investigated. This is a direct method to calculate two size independent fracture parameters, i.e., the critical stress intensity factor, K_{IC} and the Crack Tip Opening Displacement (CTOD). Beams with central notch, fewer than three points bending using attached clip gauge to measure the CTOD are tested. The glass fibers were also pre-treated with silane to improve the adhesion between fibers and resin and fracture properties.

Key words: Epoxy resin polymer cement concrete, mechanical properties, fracture properties, K_{IC}, CTOD, Malaysia

INTRODUCTION

Composite materials is a materials system composed of suitably arranged mixture or combination of two or more micro or macro constituents with an interface separating them that differ in form and chemical composition and are essentially insoluble in each other. The engineering importance of a composite material is that two or more distinctly different materials combine to form a composite material that possesses properties that are superior or important in some other manner to the properties of the individual components. Examples of composite materials are fiber-reinforced plastics, concrete, asphalt, wood and several miscellaneous types of composite materials (Smith and Hashemi, 2006).

In this research, the composite materials as composite constructions that will be investigated is glass fiber reinforced epoxy polymer cement concrete. Concrete is major engineering material used for structural construction. Civil engineers use concrete for example in the design and construction of bridges, buildings, dams, retainer and barrier walls and road pavement. As a construction material concrete, offers many advantages including flexibility in design since, it can be cast, economy, durability, fire resistance, ability to be fabricated on site and aesthetic appearance. Disadvantages of concrete from engineering standpoint include low tensile strength, low ductility and some shrinkage (Smith and Hashemi, 2006).

To study the mechanical and fracture properties of fiber reinforced concrete as composite construction, glass fiber and steel fiber and have been selected as reinforcement and epoxy resin as matrix with cement in this research.

The objectives of the research: To determine the effect of epoxy resin content on the compressive, bending, splitting and fracture properties of fibers reinforced epoxy polymer cement concrete. To determine the effect of fibers additions on the compressive, bending, splitting and

Corresponding Author: D.S. Hazimmah, Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, 25000 Kuantan Pahang, Malaysia

fracture properties of fibers reinforced epoxy polymer cement concrete. To study the performance on fracture properties of fibers reinforced epoxy polymer cement concrete.

Literature review: In construction of civil engineering, composite construction has developed significantly since, its origin approximately 100 years ago when the idea that the concrete fire protection around columns might be able to serve some structural purpose or that concrete bridge deck might with advantage be made to act in conjunction with the supporting steel beams was first proposed. In those countries where steelwork enjoys a particularly high market share, e.g., for high-rise buildings in the UK and Sweden, the extensive use of composite construction is a major factor.

Early approaches to the design of composite structures generally amounted to little more than the application of basic mechanics to this new system. Composite construction is now generally, regarded as a structural type in its own right with the attendant set of design codes and guidance documents (Nethercot, 2003). The term composite construction is normally understood within the context of buildings and other civil engineering structures to imply the use of steel and concrete formed together into a component in such a way that the resulting arrangement functions as a single item. The aim is to achieve a higher level of performance that would have been the case had two materials functioned separately. Thus, the design must recognize inherent difference in properties and ensure that the structural system properly accommodates these. The utilization of composite action has been recognized as an effective way of enhancing structural performance (Nethercot, 2003). In this research, the usage of composites in civil engineering especially in bridge application should be investigated continuously and comparison between different materials must be done.

The study of performance of composite construction between glass reinforced epoxy polymer cement concrete and steel reinforced epoxy polymer cement concrete will be done on mechanical and fracture properties of these different composites. Consideration of behavior, under uniform uniaxial stress in tension and compression facilitates initial understanding of how composite performance is quantified. This initial understanding can then be extended to more complex loading conditions such as shear and bending that are often of greater interest in practical application.

In the study of direct tension, the characteristic of fibers influenced the composite performance. However, interfacial shear strength is naturally influenced by the matrix as well as fiber. For compression test, the improvement depends on the orientation of the fibers (primarily in horizontal plane during slurry infiltration) relative to the axis of loading. Both compressive strength (based on peak load) and toughness (based on total area under the curve) are generally, highest when the fibers are primarily in the plane of lateral tensile strain perpendicular to the applied compressive load.

Strengthening by fiber reinforcement: In most unidirectional fiber-reinforced composites, the fibers do not run continuously from one end of the component to the other. If the fiber length is significantly less than the component dimensions, then the material is known as a discontinuous fiber-reinforced composite. When a discontinuous fiber with a high elastic modulus is embedded in a low-modulus material and the resulting composite is loaded in the fiber direction, the fibers carry a higher load than does the matrix. This is the principle of fiber strengthening.

However, several conditions must be met in order to achieve maximum strengthening of the composite from the fibers. One requirement is that the fiber length exceeds some critical (minimum value). (The most common geometrical shape for the reinforcing phase in a high-performance structural composite is a fiber. The reason for this is that the strength of a brittle material is inversely related to the square root of its maximum flaw size and the chance of having a large in a given length of fiber decreases as the cross-sectional area decreases. When this observation is combined with the need for significant surface area for load transfer from the matrix to the reinforcing phase, the advantage of long and slender fibers become apparent.

Characteristics of fiber materials: Attractive fibers for composite reinforcement must have high strength and high elastic modulus. They must also be suitable for production in small diameters. Fibers have been successfully fabricated from metals, ceramics and polymers. The fiber properties tabulated include tensile strength, elastic modulus, density and coefficient of thermal expansion. Polymers are frequently used to bind glass fibers together in omposites.

The fibers are made from oxide glasses containing various fractions of oxide of silicon, sodium, aluminium, calcium, magnesium, potassium and boron. Glass fibers are categorized on the basis of their compositions and corresponding properties as E, C or S-glass. E-glass fibers are very good electrical insulators, C-glass fibers have high chemical corrosion resistance and S-glass fibers have high strength and can withstand high temperatures.

Table 1: Properties of typical fibers used in composite materials

Fibers	Density (g cm^{-3})	Elastic modulus (GPa)	Tensile strength (MPa)	Axial CTE/°C
E-glass	2.6	72	1.7×10^3	5.0×10^{-6}
S-glass	2.5	87	2.5×10^3	5.6×10^{-6}
PAN-based C-fiber	1.7-1.9	230-370	1.8×10^3	-0.5×10^{-6}
Pitch-based C-fiber	1.6-1.8	41-140	1.4×10^3	-0.9×10^{-6}
Single-crystal graphite	2.25	1000	20.6×10^3	-
Kevlar-49	1.44	131	3.8×10^3	-
Kevlar-149	1.47	186	3.4×10^3	-
Spectra (polyethylene)	0.97	117	2.6×10^3	-
Boron	2.5	400	2.8×10^3	4.9×10^{-6}
FP (alumina)	3.9	379	1.38×10^3	6.7×10^{-6}
SiC particles	3.3	430	3.5×10^3	4.9×10^{-6}
SiC whiskers	3.5	580	8.0×10^3	4.9×10^{-6}
SiC fibers	2.6-3.3	180-430	$2\text{-}3.5\times10^3$	4.9×10^{-6}
Stainless steel	8.0	198	$0.7\text{-}1.0\times10^3$	18.0×10^{-6}
Tungsten	19.3	360	3.8×10^3	11.6×10^{-6}
Molybdenum	10.2	310	2.45×10^3	6.0×10^{-6}

CTE = Coefficient of Thermal Expansion

Table 1 shows typical properties of glass fibers. A variety of metals can be used to draw high-strength wires which can serve as metal fibers. The most prominent metal fibers include beryllium alloys which have high strength, high modulus and low density steel and tungsten. The strength of metal fibers is consistent and reproducible. The 1st synthetic polymer reinforcing fibers were nylon and polyester.

These fibers have reasonable strength and modulus, giving good toughness. They are generally used in soft matrices such as reinforcements of rubbers in tires, belts and hoses. These materials represented a significant increase in strength and modulus over conventional nylons and polyesters, revolutionizing the development of stiff, strong, lightweight (all polymers) composites.

In summary, the ideal fiber material for strengthening and stiffening a matrix requires the following attributes: low density, high tensile strength, high modulus of elasticity, high flexibility and the ability to form a strong interface with the matrix.

Characteristics of matrix materials: Matrix can be polymers, ceramics or metals. In this research, the matrix is concrete (ceramics). The primary purposes or matrix materials are to provide lateral support to the fibers and transfer loads. They are a source of toughness in the composite since, the majority of fiber materials are brittle. Cracks that have propagated, through a brittle fiber are stopped when their tips encounter relatively tougher matrix materials. An exception to ductile matrix materials is ceramic matrix materials which are inherently brittle. Composites using ceramic matrices such as reinforced concrete are used in compressive load application or the brittle behavior is countered by carefully tailoring the interface properties. Typical matrix materials and their properties are shown in Table 2.

Table 2: Typical properties of matrix materials

Material	Density (g cm^{-3})	Elastic modulus (GPa)	Tensile strength (Mpa)	Axial CTE /(°C)
Epoxy	1.05-1.35	2.8-4.5	55-130	$30\text{-}45\times10^{-6}$
Polyester	1.12-1.46	2-4.4	30-70	$40\text{-}60\times10^{-6}$
Copper	8.9	120	400	16.5×10^{-6}
Ti-6Al-4V	4.5	110	1000	18×10^{-6}
Stainless steel	8.0	198	700-1000	23.6×10^{-6}
High strength aluminium alloys	2.7	70	250-480	13.8×10^{-6}
Magnesia (MgO)	3.6	210-310	97-130	1.5×10^{-6}
Lithium-alumino-silicate	2.0	100	100-150	4.8×10^{-6}
Silicon carbide	3.2	400-440	310	$30\text{-}45\times10^{-6}$

Polymer concrete: Polymers are being increasingly used in civil-engineering applications as adhesives, modifiers and matrix materials in concrete. As structural and repair materials, polymers and their composites must be able to withstand high stresses under extreme service conditions. Polymer Concrete (PC) is a composite material formed by combining a mineral aggregate such as sand and gravel with a polymerizing monomer. The versatility in formulation and processing has led PC to many applications such as patching and overlays for highway pavements and bridge decks, flooring and precast articles of various kinds. PC is a high-strength; rapid-setting material and its current applications warrant mainly fine-aggregate fillers. Both thermosetting polymers (cross-linked polymers) such as epoxies and polyesters and thermoplastic polymers such as acrylics (methyl methacrylates) are commonly used as binders in PC. Emergence of this new family of construction material has dictated the need for better characterization of material behavior and standardization of testing procedures.

Better characterization of PC based on the mechanical properties of polymers and aggregates will result in more efficient and economical use of this high-strength material. Past studies of the behavior of PC systems are primarily ad hoc in nature with very little emphasis placed on either understanding the fundamental behavior mechanisms or on developing behavior models to predict the responses of the composite. In order to be cost effective for a given aggregate and polymer system, the least amount of polymer should be used in the PC formulation to achieve acceptable strength and stiffness. Bares concluded that optimum properties are obtained in the ratio of 1:7 to 1:12 by weight of polymer to aggregate depending on the particle size, porosity, characteristics of particle surface and workability.

Studies of epoxy polymer have shown that the strength, failure strain, modulus, failure mode and stress-strain relationship are influenced by curing agent, curing method, temperature and strain rate. But information on polyester polymer is limited. Studies on PC with Methyl Methacrylate (MMA) binder have shown that curing and testing temperature, loading rate and aggregate type have varying influence on the PC behavior. Since, polyester resins are extensively used in PC as binders, it is appropriate to characterize the polymer under working conditions and to consider the effect of polymer content, strain rate, method of curing and temperature on the mechanical behavior of PC (Vipulanandan and Paul, 1993).

Epoxy resin: Epoxy resins have well-established record in a wide range of composite parts, structures and concrete repair. The structure of the resin can be engineered to yield, a number of different products with varying levels of performance. Epoxies are used primarily for fabricating high performance composites with superior mechanical properties, resistance to corrosive liquids and environments, superior electrical properties, good performance at elevated temperatures, good adhesion to a substrate or a combination of these benefits. Epoxy resins do not, however have particularly good UV resistance. Since, the viscosity of epoxy is much higher than most polyester resin, requires a post-cure (elevated heat) to obtain ultimate mechanical properties making epoxies more difficult to use.

RESEARCH PROBLEMS

The basic approach of this study is to evaluate the mechanical and fracture properties of epoxy Polymer Cement Concrete (PCC) reinforced with glass fibers and steel fibers subjected to bending, splitting and compressive strength. In order to provide a focus for this present investigation, it is possible to design the optimum composites composition in term of different resin content and fiber volumes. In this research, steel fiber also is used as comparison with glass fibers.

From the previous study on mechanical characterization and impact behavior of concrete reinforced with natural fibers, it was observed that natural fibers enhanced the mechanical properties and impact resistance of concrete compared to glass fibers. With the same approach on glass fibers and steel fibers and different types of concrete which is by using cement mixed with epoxy polymer rather than the cement itself will be used in the research.

From the previous study on experimental results of concrete reinforced with natural fibers and glass fibers, it were shown in Table 3 on mechanical properties such as compression, flexural and splitting strengths of plain and fiber reinforced concrete (Al-Oraimi and Seibi, 1995). From the results, the addition of glass and natural fibers to plain concrete shows a decrease in compressive strength. Nevertheless, both reinforcements show comparable results indicating the importance of natural fibers (Al-Oraimi and Seibi, 1995).

Table 3: Summary of compression, flexural and splitting strengths of plain and fiber reinforced concrete

Types of concrete	Compression strength	Flexural strength	Splitting
	(N mm^{-2}) (V%)		
Plain	77.0 (1.2)	10.4 (2.2)	4.50 (6.5)
Glass fibers			
0.10	65.0 (1.1)	10.2 (1.2)	4.30 (1.1)
0.15	67.3 (7.4)	10.1 (1.1)	4.15 (2.8)
0.20	61.8 (1.6)	9.6 (2.8)	4.13 (1.3)
Natural fibers			
0.05	62.3 (4.8)	9.9 (1.5)	4.40 (1.1)
0.10	65.0 (1.3)	9.8 (2.4)	4.10 (1.7)
0.15	60.2 (1.3)	9.4 (2.0)	3.80 (3.0)

Table 4: Summary of toughness indices I_5, I_{10} (after ASTM C1018) and B/3A (after Barr and Hasso)

Types of concrete	I_5 area up to 3δ/area up to δ	I_{10} area up to 3δ/area up to δ	B/3A× 100%	Normalized impact energy absorbed
Plain	-	-	-	1.00
Glass fibers				
0.1	3.34	4.23	47.2	1.09
0.15	3.20	4.50	44.5	1.17
0.2	3.10	4.77	37.0	1.24
Natural fibers				
0.05	3.15	4.55	45.0	1.10
0.1	3.40	4.80	40.4	1.20
0.15	3.25	4.75	39.6	1.29

The flexural strengths of plain and reinforced concrete mixes were evaluated using 100×100×500 mm prisms. The prisms were subjected to three point bending and tested by means of universal DARTEC machine. From the results, the general trend for addition of glass and natural fibers to plain concrete tend to reduce the flexural strength similar to the compressive strength results (Al-Oraimi and Seibi, 1995).

For splitting tensile strength, the results show the decrease in strength as compared to plain concrete (Al-Oraimi and Seibi, 1995). The toughness indices I_5, I_{10} and B/3A were evaluated from the area below load deflection graphs. These results were shown in Table 4 (Al-Oraimi and Seibi, 1995).

It showed that there was almost a uniform nature of the toughness indices values. Although, the toughness indices values showed a small increase with increasing fiber content, the effect is almost insignificantly, particularly in the case of glass fiber mixes. In contrast, it was clear from the load-deflection graphs that the inclusion of fibers has a significant effect on the shape of the post-cracking load-deflection curve. The main conclusion here was that the I_5 toughness index did not take into account a sufficiently long portion of the post-peak curve to capture the additional effect of the fibers. The load-deflection graph observed the development of the toughness (Al-Oraimi and Seibi, 1995).

Table 5: Results for epoxy polymer concrete

Types	K_{IC} (MPa $\sqrt{m}$)	CTOD (MPa $\sqrt{m}$)
E1	2.002	0.025
E2	2.323	0.008
E3	2.039	0.011
E4	2.207	0.010
E5	1.862	0.028
E6	2.214	0.014
E7	1.976	0.019

The impact test results of plain and reinforced concrete samples obtained from the modified Charpy tester that showed in Table 5 in terms of normalized Impact Energy absorbed'. These values were obtained by dividing the energy absorbed by plain concrete. These results were also in Fig. 1 showed the normalized energy absorbed as a function of the fiber content.

It could be seen that the increase of energy absorbed was associated with the increase of the percentages of fibers (Al-Oraimi and Seibi, 1995).

In addition, it could be seen that the natural fibers improved the impact resistant of concrete and compared to glass fibers. This increase of energy absorbed was attributed to fiber-pullout observed during testing (Al-Oraimi and Seibi, 1995).

For fracture test (Reis and Ferreira, 2004), it was analyzed to evaluate K_{IC}, the critical stress intensity factor and CTODc, the critical crack tip opening displacement, by the two parameter fracture method described in RILEMs reports.

The Young modulus (E) was calculated from the measured initial compliance C_i using equation:

$$E = \frac{6Sa_0 V_1(\alpha)}{C_i W^2 B}$$

Where:

S = Specimen loading span
a_0 = Initial notch depth
H_0 = Thickness of clip gauge holder
W = Beam depth
B = Width and $V_1(\alpha)$ is defined as:

$$V_1(\alpha) = 0.76 - 2.28\alpha + 3.78\alpha^2 - 2.04\alpha^3 + \frac{0.66}{(1-\alpha)^2}$$

and:

$$\alpha = \frac{(a_0 + H_0)}{(W + H_0)}$$

Based on finite element analysis (Reis and Ferreira, 2004), the contribution of the clip gauge holder thickness (H_0) is included in function V_1 (Al-Oraimi and Seibi, 1995). To calculate K_{IC}, the effective critical crack length a_1 which is a_0+stable crack growth at peak load should be determined 1st. To obtain the value of a_1 the following equation has to be solved:

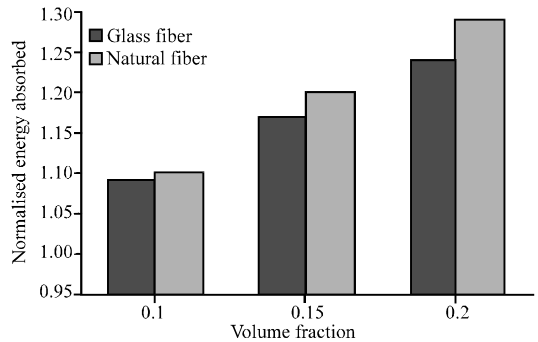

Fig. 1: Normalized impact energy of reinforced concrete

$$E = \frac{6Sa_1 V_1(\alpha_1)}{C_u W^2 B}$$

where, C_u is the unloading compliance at peak load which is assumed to be the same as the unloading compliance at about 95% of the peak load in the post-peak stage and α_1 is:

$$\alpha_1 = \frac{(a_1 + H_0)}{(W + H_0)}$$

The value of the critical stress intensity factor, K_{IC} is then calculated using:

$$K_{IC} = \frac{3P_{max} S\sqrt{\pi a_1}\, F(\alpha)}{2BW}$$

Where:

P_{max} = Peak load
a_1 = Effective critical crack length and F (α) is given by:

$$F(\alpha) = \frac{11.99 - \alpha(1-\alpha)(2.15 - 3.93\alpha + 2.7\alpha^2)}{\sqrt{\pi}\,(1+2\alpha)(1-\alpha)^{3/2}}$$

Where:

$$A = \frac{a_1}{W}$$

The value of CTODc is calculated using Equation as:

$$CTODc = \frac{6P_{max}Sa_1\, V_1(\alpha)x \begin{Bmatrix}(1-\beta)^2 + \\ (-1.149\alpha 1.081)(\beta\beta^2)\end{Bmatrix}^{1/2}}{2BW}$$

Figure 2-4 shown the results from previous study on assessment of fracture properties of epoxy polymer

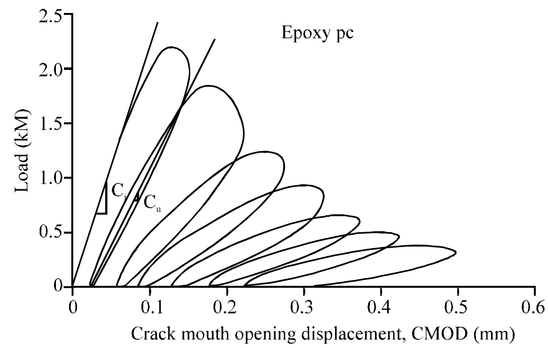

Fig. 2: Load vs. CMOD curve for epoxy PC, specimen #1

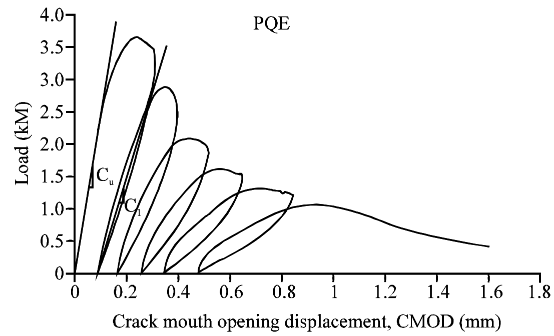

Fig. 3: Load vs. CMOD curve for carbon reinforced epoxy PC, specimen #1

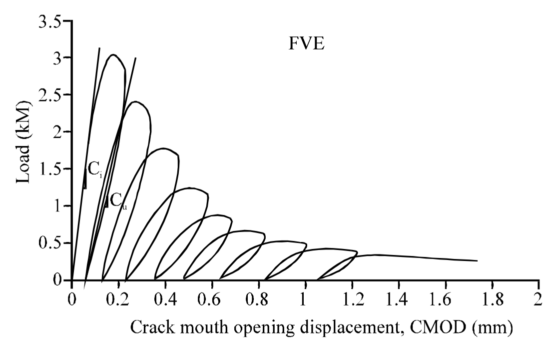

Fig. 4: Load vs. CMOD curve for glass reinforced epoxy PC, specimen #1

concrete reinforced with glass fiber compared with epoxy polymer reinforced with carbon fiber (Reis and Ferreira, 2004). From Fig. 2-4, the results obtained from the two parameter methods, it was clear that the carbon fiber reinforcement improved the fracture toughness of polymer concrete by 29% while glass fiber represented a smaller improvement by 13%. However when compared to ordinary portland cement concrete, it was clear that polymer concrete had higher fracture values when compared with almost every cement concrete composition. For example in the RILEM recommendation

Table 6: Results for carbon-reinforced epoxy polymer concrete

Types	K_{IC} (MPa $\sqrt{m}$)	CTOD (MPa $\sqrt{m}$)
FCE1	2.711	0.038
FCE2	2.586	0.059
FCE3	2.711	0.046
FCE4	2.925	0.032
FCE5	2.610	0.029
FCE6	2.766	0.056
FCE7	2.635	0.014

Table 7: Results for glass-reinforced epoxy polymer concrete

Types	K_{IC} (MPa $\sqrt{m}$)	CTOD (MPa $\sqrt{m}$)
FVE1	2.294	0.025
FVE2	2.576	0.016
FVE3	2.379	0.025
FVE4	2.437	0.011
FVE5	2.340	0.021
FCE6	2.292	0.013
FCE7	2.272	0.007

the values of K_{IC} for different compositions of cement concrete vary from 0.740-1.530, meant that even the higher value has 36% less fracture toughness than the epoxy polymer concrete considered in the previous research (Reis and Ferreira, 2004). The previous study on reinforcements increased the values of TPM parameters, K_{IC} by three times when compared to cement concrete, showed that polymer concrete had higher resistance to crack opening than ordinary cement concrete (Reis and Ferreira, 2004). These results can be shown clearly and significantly from Table 5-7 as following (Reis and Ferreira, 2004) (Table 6 and 7):

Experimental details

Mix details and sample preparation: The preparation of glass fiber reinforced epoxy polymer cement concrete and steel fiber reinforced epoxy polymer cement concrete was carried out carefully to achieve the required quality of final matrix. The cement used was a local ordinary portland cement, the fine aggregate was dredged sand corresponding to zone two grading and the course aggregate used was 14 mm maximum size. The water-cement ratio was kept constant throughout the work at 0.34 along with the use of additives which give a satisfactory workability for all mixes used. The ordinary portland cement corresponding to ASTM type 1 cement was used in all mixture proportions. River sand with retained 1.18 mm was used as the fine aggregate.

The epoxy resin system that will be used in this research is emulsion polymer that can be mixed with water and cement as matrix. The fibers were added in percentage by weight (of the total wet solid) in multiples of 0.05 from 0.1-0.2%. The steel fibers from sika products in approximately 35 mm single length added also to the mix. The mixing of fiber concrete was standardized as follows: first the dry ingredients were mixed in the rotating pan for 1 min, the water being added during the next

Table 8: Materials formulation for mechanical testing

Types	*Fiber content (%) steel/glass fiber	Additives content (%) using sika-fume	Epoxy resin content (%)
Fiber reinforced	0.10	6	10
epoxy polymer	0.15	6	10
cement concrete	0.20	6	10
	0.10	6	20
	0.15	6	20
	0.20	6	20
	0.10	6	30
	0.15	6	30
	0.20	6	30

Table 9: Materials formulation for fracture test

Types	*Fiber content (%) steel/glass fiber	Additives content (%) using sika-fume	Resin content (%)
Fiber reinforced	0	6	10
epoxy polymer	1	6	10
cement concrete	2	6	10
	0	6	*20
	1	6	*20
	2	6	*20
	0	6	30
	1	6	30
	2	6	30

2 min and a good consistency was achieved. The epoxy resin then added into the wet cement followed by the fiber is added in small increments by sprinkling them onto the surface of the mix until all the fibers had been absorbed into the matrix. This technique was performed to prevent balling or interlocking of the fibers.

For the materials formulations of the epoxy resin, fiber contents and additives in percentages are showed in Table 8 and 9. The main materials for concrete used are a mix of 1:2. 2:2. 8, cement: fine aggregates: coarse aggregates. The fiber contents are chosen from previous studies in fiber reinforced concrete. About 20% of epoxy resin in mass was a standard content for previous studies which defined an optimum formulation for polymer concrete. The fiber contents also are chosen from optimized formula. From each mix of fiber reinforced epoxy polymer cement concrete three control cubes of the basic mix and also three cubes after the addition of fibers were cast. These control specimens were used to assess the compressive strength of the mixes at 28 days. Each mix consisted of six beams (100×100×500 mm), three cylinders (150×300 mm) and 6 100 mm cubes. All specimens were compacted by means of a vibrating table, cured under water for 28 days and tested at room temperature (25°C). For fracture test, the fibers are blended in the polymer concrete mix by 1 and 2% of the total weight, respectively and the fibers lengths considered is in average, 6 mm long.

The chopped glass fibers are supplied by PPG with no sizing and soaked in a 2% silane, A 174 solution, an adhesion promoter solution which improves the strength of composite system. The steel fibers from sika products

Table 10: Details of test specimens for mechanical testing

Series	Cylinders (150×300 mm)	Cubes (100×100×100 mm)	Beam(100×100×500 mm)
Splitting	√	X	X
Compressive	√	√	X
Bending	√	X	√
Charpy	X	X	√

Table 11: Details of test specimens for fracture testing

Series	Specimen size (30×60×600 mm)
Fracture	√

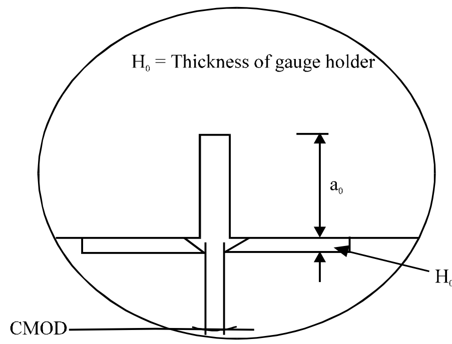

Fig. 5: Geometry and dimensions near the notch, H_0 = 1.5 mm and a_0/W = 1/3

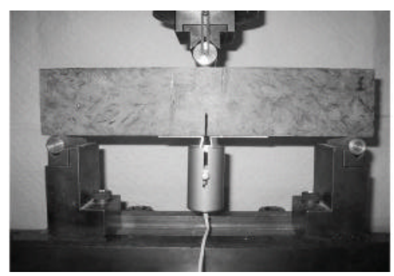

Fig. 6: Model 1 fracture test setup

in approximately 35 mm single length added also to the mix. Epoxy polymer cement concrete specimens are compacted in a steel mold of dimensions of 30, 60 and 600 mm and then cut to final size according to RILEM report. The specimens are initially cured at room temperature for 24 h. Epoxy specimens were then post-cured for 7 h at 60_C.

The specimens are notched using a 2 mm diamond saw to a 20 mm depth. The epoxy polymer cement concrete specimens are tested using a INSTRON. The Crack Mouth Opening Displacement (CMOD) is measured using a COD gauge clipped to the bottom of the beam and held in position by two 1.5 mm (H_0) steel knife edges glued to the specimen (Fig. 5). In this test, the relation a_0 = W ¼ 1 = 3 holds. This approach is the same as proposed in BSI and RILEM (Fig. 6). The description of the experiment can be shown in the Table 10 and 11.

Testing procedure: Three point bending and impact tests are employed in this experimental study to determine the mechanical properties and study the fracture behavior of fabricated plain concrete, reinforced concrete and reinforced polymer cement concrete samples. All tests are carried out at room temperature (25°C) by means of a universal DARTEC machine and a modified Charpy test machine. Initially, a series of tests is performed on 100×100×500 mm test beams using the three point bending test method.

These tests are carried out under load control at a rate of O-2 kN sec using a DARTEC machine. A calibrated load cell was used to measure the applied load at the centre of simply supported beams with loading span of 450 mm. The deflection of the loading roller relative to the end supports was measured by a Linear Variable Differential Transformer (LVDT). The output signals from both the load-cell and the LVDT were recorded using an X-Y chart recorder. This test method is essentially used to measure the flexural strength and the toughness indices. The flexural strength was measured using the following simple bending equation:

$$\sigma_f = \frac{3PL}{2a^3}$$

Where:

P = Maximum load recorded during testing
L = Specimen span
a = Specimen length of a square cross-section

The units used throughout this experiment are SI units The load-deflection curves obtained from the X-Y chart recorder were then analyzed to measure the flexural strength and the toughness indices for all samples. The toughness indices are evaluated using the area under the load deflection curves based on multiples of the 1st crack principle.

The toughness indices I_5, I_{10} and B/3A were evaluated according to ASTM C1O18 and Barr and Hasso. In addition, splitting tensile and compressive strengths were measured using Brazilian and cube test methods. Similar, samples to the ones used in the three point bending were then tested using the Charpy test machine to study the behavior of plain and reinforced concrete beams under impact stress.

The Charpy test machine was modified in such a way that the loading configuration is the same as the three point bending test. The modification consisted mainly of manufacturing a new pendulum and adding two supports with considerable heights welded to the base of the machine and placed in front of the strands. The pendulum consists of a shorter arm, connected to a hammer designed in such a way that the contact between the striker-or tup and the specimen occurs throughout, the beam's width in order to take into account the distance between the centre of the specimen in the new location and the vertical axis of the impact tester.

The weight of the pendulum was chosen in such way that the original scale can be used to measure the energy absorbed by the samples during impact. The test beams supported near the ends were struck at the mid-span and completely fractured in one blow. The energy to fracture for each specimen was then read from the scale.

CONCLUSION

Polymer concrete had very promising properties which might place this material in the building and public works market in the near future. From the previous study, strength was generally marginally decrease by the addition of glass and natural fibers. Besides, natural fibers enhancing toughness and improve impact resistance compared to glass fibers. Fracture, properties can be improved by the addition of short glass fibers or steel fibers. In previous research work, the fracture properties of the fiber reinforced polymer concrete were evaluated by the two parameter model, a testing procedure that produced insight into the stress intensity factor K_{IC} and the critical crack tip opening displacement, CTODc. This method, although presenting some difficulties related to the 95% stop and restart was simple to use and produces accurate and reliable information on fracture properties. The use of fibers improves every material property studied in the two parameter model when compared to epoxy polymer concrete with no reinforcement. Polymer concrete has better fracture performance than plain cement concrete overall. This TPM approach can be considered as one of the simplest fracture model for composites if design charts and crack growth are used. Therefore in this research, the glass fiber and steel fiber will be used as fibers and in existence of or adding new matrix such, as epoxy resin into wet cement that will be bind together will gain better toughness, impact resistance and fracture properties of composites constructions in the future.

REFERENCES

Al-Oraimi, S.K. and A.C. Seibi, 1995. Mechanical characterization and impact behaviour of concrete reinforced with natural fibres. Composite Struct., 32: 165-171.

Nethercot, D.A., 2003. Composite Construction. Spon Press, Taylor and Francis Group, London and New York.

Reis, J.M.L. and A.J.M. Ferreira, 2004. Assessment of fracture properties of epoxy polymer concrete reinforced with short carbon and glass fibers. Constr. Build. Mater., 18: 523-528.

Smith, W.F. and J. Hashemi, 2006. Foundations of Materials Science and Engineering. 4rd Edn., McGraw-Hill, New York.

Vipulanandan, C. and E. Paul, 1993. Characterization of polyester polymer and polymer concrete. J. Mater. Civil Eng., 5: 62-82.