FRACTURE TOUGHNESS DETERMINATION OF PLAIN CEMENT CONCRETE USING BRICK AGGRIGATE IN MARINE WATER

M. R. Alam[1], M. R. Mukhlis[2*], M. F. Rahman[1] & M. Shaheduzzaman[1]

[1]*Department of Civil Engineering, Chittagong University of Engineering and Technology, Chittagong, Bangladesh*
[2]*Institute of Earthquake Engineering Research, Chittagong University of Engineering and Technology, Chittagong, Bangladesh*
[*]*Corresponding Author: raihan.ce@live.com*

ABSTRACT
Fracture toughness of plain cement concrete using brick aggregate cured in marine water has been determined in this study. To determine the fracture toughness value for different depths having initial crack, thirty beams using brick chips were made according to ASTM specifications. During the casting of test specimen initial crack was introduced. Range of initial crack depths was taken 30%, 35% and 45% of the beam depth. Test specimens were then cured in marine water for 28 days. Experimental failure load for each beam, with the specified initial crack depth, was determined using the 4-point bending test of the beam. Fracture toughness values were then determined for failure loads and crack depths using the equation given by ASTM specifications for 4-point loading. Fracture toughness of concrete using brick aggregate cured in marine water in the study was found in the range of 0.376 to 0.608. The experimental investigation refers that the fracture toughness value increases with the decreasing of crack depth and increasing of beam width.

Keywords: Fracture toughness, plain cement concrete, brick aggregate, marine water

INTRODUCTION
The resistance of a material to failure from fracture starting from a pre-existing crack is known as fracture toughness (Cardarelli, 2000). Most structural parts have flaws or defects present in them. These defects may be produced during manufacturing for fabrication process. The defects may be sharp corners, tool marks or damage due to shaping or construction.

When a fracture in the form of crack develops in the structure, its load bearing capacity reduces significantly. If it develops in the major structural components such as beams/girders, columns/piers, shear wall, retaining walls, dams, etc., to a significant amount, the entire structure could collapse within a minutes. Since inherent flaws (micro level) exist in concrete material and it could be activated for any accidental combination of loads, it is important to pay attention in minimizing flaws in any concrete structural elements and inhibiting their growth under normal and accidental loads. It is also important to study the behavior of concrete with inherent flaws under static or dynamic loading. For this reason fracture toughness test of concrete is important. The high strength materials have a low crack resistance (Fracture toughness) the residual strength under the presence of cracks is low. When only small cracks exist, structures designed in high strength materials may fail at stresses below the highest service stress they were designed for. The structure is made fail-safe by selecting materials with low growth rate and high residual strength and by adopting a design with inherent crack stopping capabilities (Broek, 1989). Due to the application of repeated loads or due to a combination of loads and environmental attack the existing crack will grow with time. The longer the crack, the higher the stress concentration induced by it. This implies that the rate of crack propagation will increase with time. For the presence of crack, the strength of the structure decrease. After a certain time the residual strength has become so low that the structure cannot withstand accidental high loads that may occur in service. From this moment on the structure is liable to fail. If such accidental high loads do not occur, the crack will continue to grow until the residual strength has become so low that fracture occurs under normal service loading. Some of the structures are designed to carry service loads that are high enough to initiate cracks, particularly when pre-existing flaws or stress concentrations are present. The designer has to anticipate this possibility of cracking and consequently he has to accept a certain risk that the structure will fail. In order to ensure the safety of a structure, the designer must estimate the load carrying capacity of a structure after the propagation of cracks (Broek, 1984).

Brick chips are widely used for construction in rigid pavement, bridge, culvert, buildings, water tank, and drainage purposes in the countries like Bangladesh, India, Pakistan and many other countries. Cracks are formed in the concrete using brick aggregate due to the presence of void, improper curing, temperature changes, moisture content, w/c ratio, presence of joints in the structure. For the presence of cracks, the strength of the structure decrease.

Recent publications have shown that fracture mechanics has now been established as a fundamental approach that can explain certain nonlinear aspects of concrete behavior, help to prevent brittle failures of the structure and be an important aid in materials engineering (Kishen, 2005). Applications of fracture mechanics to failure of concrete structures have been demonstrated that experimental phenomena associated with the failure of concrete such as size effect on tensile strength and brittleness of concrete can be interpreted properly through fracture mechanics (Shah et. al., 1992). Fracture toughness of large concrete specimens have been investigated and found that fracture toughness increases initially as crack propagates but that a length-independent value is reached asymptotically and concluded that failure of large size concrete elements can be predicted realistically using linear elastic fracture mechanics (Wittmann et. al., 1985). Naturally cracked beams (pre-cracked) yield higher failure loads and stress-intensity values than notched beams with the same crack length (Swartz et al., 1982).

Fracture toughness for the concrete using brick chips cured in normal water are determined by researchers but for the concrete using brick aggregate cured in marine water are rarely determined. Since brick chips are the very important material for construction and also the marine water is a huge resource of water that can be used for curing, it is aimed to determine the fracture toughness for concrete using brick chips cured in marine water in order to determine the service load under presence of cracks in the structure and to raise awareness of the engineer during the design of the structure.

FRACTURE TOUGHNESS BY STANDARD ASTM TEST PROCEDURE

The Fracture toughness K_{IC} is the material toughness at the onset of fracture. The ASTM E1290-08 Standard suggests the formula for fracture toughness calculated based on the empirical equation (Eq. 1) given by (Srawley et. al.,1976) for single edge straight through cracked rectangular beam under four-point loading as given below:

$$K_{IC} = \frac{P\,(l_1 - l_2)\sqrt{a}}{BW^2} * \frac{3}{2(1-\frac{a}{W})^{\frac{3}{2}}} * \{\,1.989 - 1.33\,\frac{a}{W} - \frac{\left[3.49 - 0.68\frac{a}{W} + 1.35\left(\frac{a}{W}\right)^2\right] * \frac{a}{W} * (1-\frac{a}{W})}{(1+\frac{a}{W})^2} \qquad (1)$$

Where,
K_{IC} = Fracture toughness in MPa√m
P = Load
l_1 = Center to center support length
l_2 = Loading span
B = Width of the beam
W = Depth of the beam
a = Crack depth

Materials and Test Specifications:

All beams were tested by following ASTM specification. Materials and test specifications are given in the following Table 1-

Table 1: Materials and Test specifications

Mixing ratio:	1: 1.5: 3
Type of cement:	Portland cement
Type of sand:	Local sand
Size of fine aggregate:	#16 passing & #30 retaining, #30 passing & #50 Retaining, #50 passing & #100 retaining = (1:2:3)
Size of coarse aggregate:	25 mm passing 19 mm retaining
Size of cylinder:	Diameter = 152 mm; Height =305 mm
w/c ratio:	0.365

Different test results of cement, sand, aggregate and plain concrete are given in the following Table 2-

Table 2: Different Test results of Cement, Sand, Aggregate and Plain Concrete

Name of test	Test results
F.M. (Fineness Modulus) of sand	2.49
Slump value (average of 05 tests)	79 mm
7 days compressive strength of cement mortar (average of 10 tests)	25.9 MPa
28 days compressive strength of cement mortar (average of 10 tests)	33.5 MPa
7 days tensile strength of cement mortar (average of 10 tests)	2.25 MPa
28 days tensile strength of cement mortar (average of 10 tests)	3.30 MPa
28 days cylinder compressive strength of cement concrete with brick aggregates (average of 15 tests)	19.0 MPa
Aggregate crushing value of brick aggregate (average of 03 tests)	38.33%

Preparation of Test Specimens

Six uncrack beams, six beams with 30% depth of crack and standard width (152 mm), six beams with 35% depth of crack and standard width (152 mm), four beams with 45% depth of crack (76 mm width), four beams with 45% depth of crack (102 mm width) and four beams with 45% depth of crack (127 mm width) were cast by using brick chips. Steel plates of 1 mm thickness were provided during casting for producing pre-cracked beam having 1 mm crack width as shown in [Fig. 1].

Fig. 1: Casting of pre-cracked beams inserting steel plates

The details of different test specimens are given in the following Table 3-

Table 3: Details of different test specimens

Test Specimen ID	Total no. of Test Specimen	Beam dimensions (mm)	Crack depth (% of beam depth)
1-1 to 1-6	6	813×152×203	uncrack
2-1 to 2-6	6	813×152×203	35
3-1 to 3-6	6	813×152×203	30
4-1 to 4-4	4	813×127×203	45
5-1 to 5-4	4	813×102×203	45
6-1 to 6-4	4	813×76×203	45

Standard ASTM Test Procedure:

In specified formwork the specimens were casted. The formwork was removed after 24 hours and specimens were kept under marine water for curing for 28 days. Marine water was collected directly from Patenga sea beach of Chittagong. Specimens were removed after 28 days from the water and kept in dry place for 24 hours to evaporate the moisture from their external surface. Loading positions and supporting positions were clearly marked and uneven surfaces were made smooth surface by using sand paper and Weir brush. Swivelling supports (in one vertical plane, perpendicular to the length) were provided at a distance 12.5 mm from both ends of the beam. Four-point loading positions were fixed at one-fourth of span length from both supports. This loading was chosen for obtaining pure bending at the middle-half portion of the beam where crack was present. Load was applied on the beam monotonically without any jerk and it was increased continuously at a rate of 10kN/min until the test specimen failed. Failure load was recorded from a digital load meter. A dial gauge with a sensitivity of 0.01 mm was used for measuring the load point deflection. Displacement controlled load was applied on the specimen. Load was recorded at each 5 division increments of the dial gauge up to failure load. All specimens were tested under simply supported conditions. Experimental setups for standard ASTM Test procedure are shown in the following figures:

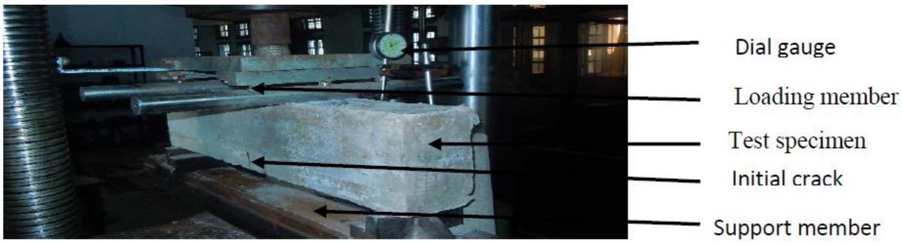

Fig. 2: Experimental setup for standard ASTM Test

Fig. 3: Experimental setup of crack beam by using brick chips

Fig. 4: Failure of crack beam by using brick chips

Fig. 5: Experimental setup of uncrack beam by using brick chips

Fig. 6: Failure of uncrack beam by using brick chips

RESULTS AND DISCUSSIONS

The crack depth and peak load for each test beam and the corresponding computed fracture toughness are shown in Table 4. From this table it is seen that the magnitude of the maximum load varies with the depth of crack as well as width of the test beam. The peak load capacity decreases with the increasing depth of crack which can be easily described by the a/W ratios, where a/W is the ratio between depth of crack (a) and height of beam (W). Three types of a/W ratios used in the standard ASTM test procedure which are 0.3, 0.35, 0.45 among which test beams with a/W ratio 0.3 have shown larger peak load capacity whether test beams with a/W ratio 0.45 have shown smaller peak load capacity. In the other hand, peak load capacity decreases with the decreasing width of beam. Test beam with 152 mm width has shown larger peak load capacity whether test beam with 76 mm width has shown smaller peak load capacity.

Figure 7, 8, 9, 10 and 11 show the load-deflection plot for cracked beam with different depth of crack and width of test beam made with brick aggregates cured in marine water. Figure 12 shows the load-deflection curves for combined average load. From all the load- deflection curves it is seen that material behaves almost linearly at the beginning of the applied load and becomes nonlinear near the peak load. A part of this non-linearity could be attributed to the coalescence of tensile micro-cracks (development of fracture process zone) before the subsequent crack extension. The remaining part is due to the nonlinear compression behavior near maximum loads. It was found that when the load reached its maximum value, the test specimen began to lose its resistance very fast, which could not be plotted properly. For this reason, only the load deflection plots up to peak load have been showed in this study. The peak load was then used to determine the fracture toughness according to Eq. (1).

Table 4: Fracture Toughness of cracked Test Specimens

Sl no.	Test Specimen ID	Beam Dimension (mm)	Crack Depth (% of beam depth)	Load (KN)	Fracture toughness K_{IC}(MPa√m)
1	2-01	813×152×203	35	8.1	0.394
2	2-02			9.7	0.472
3	2-03			8.3	0.404
4	2-04			9.1	0.443
5	2-05			9.8	0.477
6	2-06			9.0	0.438
7	3-01	813×152×203	30	12.5	0.547
8	3-02			11.2	0.490
9	3-03			13.9	0.608
10	3-04			11.5	0.503
11	3-05			12.6	0.551
12	3-06			13.0	0.567
13	4-01	813×127×203	45	8.0	0.479
14	4-02			8.5	0.509
15	4-03			8.2	0.491
16	4-04			9.1	0.545
17	5-01	813×102×203	45	6.9	0.409
18	5-02			7.3	0.433
19	5-03			6.7	0.397
20	5-04			7.1	0.421
21	6-01	813×76×203	45	5.5	0.405
22	6-02			5.3	0.390
23	6-03			5.2	0.383
24	6-04			5.1	0.376

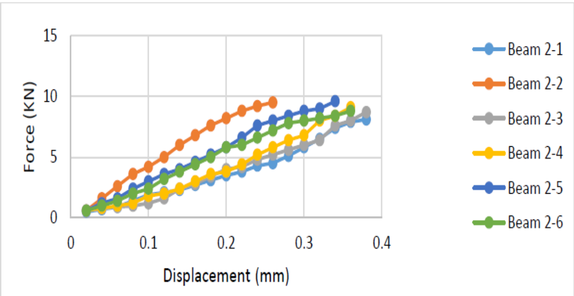

Fig. 7: Load deformation curves for crack of 35% depth of beam (152 mm beam width)

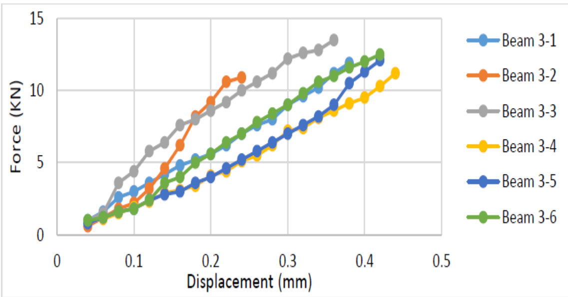

Fig. 8: Load deformation curves for crack of 30% depth of beam (152 mm beam width)

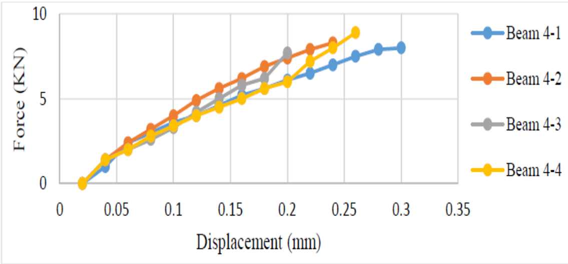

Fig. 9: Load deformation curves for crack of 45% depth of beam (127 mm beam width)

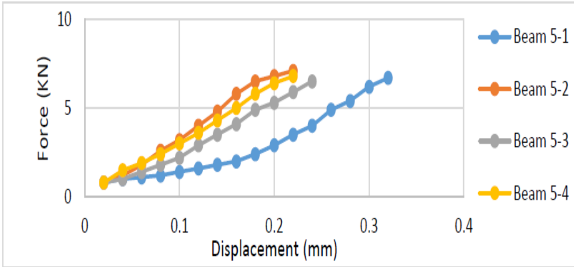

Fig. 10: Load deformation curves for crack of 45% depth of beam (102 mm beam width)

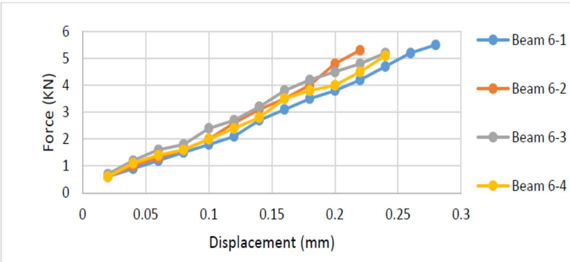

Fig. 11: Load deformation curves for crack of 45% depth of beam (76 mm beam width)

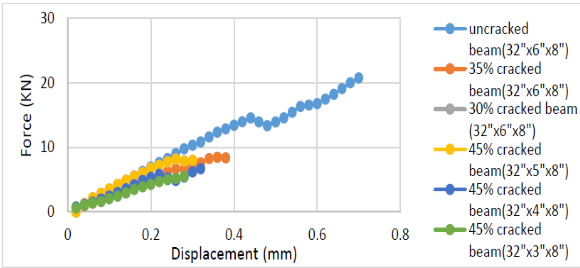

Fig. 12: Load deformation curves for combined average load

CONCLUSIONS

- The fracture toughness values obtained from the experimental study with marine water curing increases with the decreasing of crack depth and increasing of beam width.
- It was found in case of beam with different crack depths, the failure loads of beam decrease when the crack depth increases.
- When the width of beams decreases, the failure load also decreases having constant crack depth.

REFERENCES

Broek, D., 1989, *The practical use of fracture mechanics*, 1st edition, Kluwer Academic Publishers, Dordrecht/ Boston/ London, pp. 5-14

Broek, D., 1984, *Elementary Engineering Fracture Mechanics*, 3rd printing, Martinus Nijhoff Publishers, Hague, Netherlands, pp. 4-10

Cardarelli, F., 2000, *Materials Handbook: A Concise Desktop Reference*, 2nd edition, Springer-Verlag London Limited, pp.16

Kishen, J.M.C., 2005, Recent developments in safety assessment of concrete gravity dams, *Current Science*; 89(4), 650-656

Shah, S.P. and Ouyang, C., 1992, Measurement and modeling of fracture processes in concrete in Materials Science of Concrete, *American Ceramic Society*, Westerville, OH, Vol.III, edited by Scalny, J., 243-270

Srawley, J. E. and Gross, B., 1976, Side-cracked plates subjected to combined direct and dending Forces, Cracks and Fractures, *ASTM STP*; 601, 559-579

Swartz, S.E., Hu, K. K. and Huang, C.M.J., 1982, Stress intensity factor for plain concrete in bending-prenotched versus precracked beams, *Experimental Mechanics*, 412-417

Wittmann, F.H. and Metzener-Gheorghita, I., 1985, Fracture toughness of concrete determined on large specimens, *Materials and Structures*; 18, 93-95