Fracture Mechanics of Concrete Structures,
Proceedings FRAMCOS-2, edited by Folker H. Wittmann,
AEDIFICATIO Publishers, D-79104 Freiburg (1995)

EFFECT OF CONCRETE MATERIALS ON FRACTURE PERFORMANCE

N.-Q. Feng, X.-H. Ji, Q.-F. Zhuang, and J.-T. Ding
Department of Civil Engineering, Tsinghua University, Beijing, P.R. China

Abstract

The paper investigates the effect of some mixing parameters and the components characteristics on the fracture energy G_f and fracture toughness K_{IC} of concrete. G_f and K_{IC} of concrete decrease with increasing water/cement ratio, affected greatly by Dmax of coarse aggregate, rise with the addition of coarse aggregate to pure cement paste with lower W/C, and increase gradually with increasing volume content of coarse aggregate. The influence of sand ratio on G_f is not obvious.

1 Raw Materials

1. Cement : #525 portland cement.
2. Coarse aggregate: crushed gravel, D_{max} =30 mm, qualified grading, specific gravity 2.65, bulk density 1450 kg/m^3.
3. Fine aggregate: river sand, qualified grading, specific gravity 2.65, bulk density 1450 kg/m^3.
4. Naphthalene superplasticizer Brand NF.
5. Potable water.

2 Experiments

The influences of water/cement ratio, maximum aggregate size D_{max}, sand ratio and volume content of coarse aggregate on concrete fracture performance is investigated in this paper. Experiments include the following series.

1. Series 1: Influence of water/cement ratio on fracture performance of concrete.
   Concrete mixtures and 28d compressive strengths are listed in Table 1.
2. Series 2: Influence of coarse aggregate on fracture performance of concrete (Table 2)
3. Series 3: Influence of sand ratio on G_f and K_{IC} of concrete (Table 3)
4. Series 4: Influence of the volume content of coarse aggregate on G_f and K_{IC} of cement paste (Table 4)

Table 1. Mixing proportion and 28d compressive strength of concrete

No.	W/C (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	NF (kg/m^3)	Compressive strength (MPa)
1	0.25	740	185	526	1119	7.4	81.6
2	0.30	617	185	566	1202	6.2	85.3
3	0.40	463	185	615	1307	------	78.7
4	0.50	370	185	645	1370	------	70.5
5	0.60	303	185	665	1412	------	58.0

Table 2. Mixing proportion and 28d compressive strength of concrete with varying aggregate grain size

No.	D (mm)	W/C	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Compressive strength (MPa)
1	5 ~ 10	0.40	463	185	615	1307	70.1
2	10 ~ 15	0.40	463	185	615	1307	72.4
3	15 ~ 20	0.40	463	185	615	1307	58.4
4	20 ~ 25	0.40	463	185	615	1307	67.1
5	25 ~ 30	0.40	463	185	615	1307	69.1

Table 3. Mixing proportion and 28d compressive strength of concrete with various sand ratios

No.	Sand ratio (%)	W/C	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Compressive strength (MPa)
1	20	0.40	463	185	384	1538	68.3
2	40	0.40	463	185	769	1153	69.9
3	60	0.40	463	185	1153	769	73.5
4	80	0.40	463	185	1538	384	67.0
5	100	0.40	463	185	1922	0	64.4

Table 4. Relative mixing proportion and 90d-compressive strength of cement paste with various volume contents of coarse aggregate

No.	Volume content of coarse aggregate(%)	Cement	Water	Gravel	Compressive strength (MPa)
1	0	1	0.32	0	95.5
2	25	1	0.32	0.44	71.1
3	50	1	0.32	1.32	74.2
4	75	1	0.32	3.96	76.9

Note:Specimens were tested after 90 days of standard curing.

3 Results and Discussion

3.1 Influence of water cement ratio on Gf and K_{IC} of concrete (Series 1)

Fracture Energy is measured with wedge-splitting method recommended by RILEM. Dimension of specimens for compressive strength is 10 × 10 × 10cm. The strength thus obtained is multiplied by a convertion factor of 0.95.

Compressive strength of concrete decreases with the increase of W/C, but it decreases at W/C=0.25 because the concrete is not compacted enough at moulding (Fig. 1). So does the relationship between Gf, K_{IC} of concrete and W/C (Fig. 2): the values of Gf and K_{IC} are also relatively small at W/C=0.25, and decrease with increasing W/C in the range of 0.3~0.6.

3.2 Influence of aggregate grain-size on Gf and K_{IC} of concrete (Series 2)

The area covered by the P-COD (load versus crack opening displacement) curve increases with the grain size of coarse aggregate, and the fracture

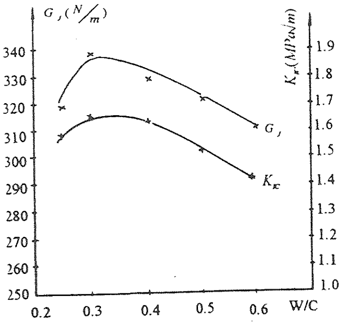

Fig. 1 Relation between Gf, K_{IC} and W/C of concrete

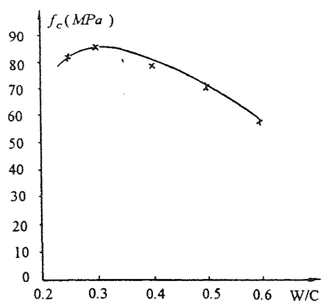

Fig. 2 Relation between compressive strength and W/C of concrete

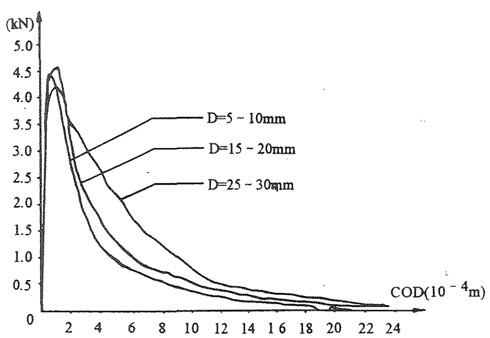

Fig. 3 Whole curves of P-COD

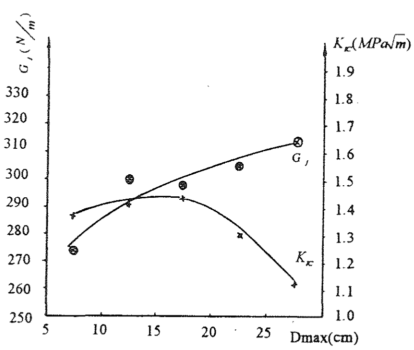

Fig. 4 Relation between Gf, K_{IC} and Dmax of coarse aggregate

energy Gf increases correspondingly (Fig. 3). Gf also increases with the maximum aggregate size Dmax (Fig. 4), which is in agreement with the rule from Fig. 3. But there is no obvious vaying rule for K_{IC} (Fig. 4): K_{IC} increases slightly with increasing Dmax at the beginning, but decreases instead after D_{max}>20mm. Enlarging the aggregate size will result in the growing tendency for water films to accumulate next to the aggregate surface, thus weaken the mortar-aggregate transition zone. Hence the peak value of P-COD curve decreases and so does the value of K_{IC} (Fig. 5).

3.3 Influence of sand ratio on Gf and K_{IC} of concrete (Series 3)

There exists an optimum sand ratio of 50~60%, at which the fracture energy reaches the highest (Fig. 6). There is also a similar sand ratio for concrete workability. The optimum value for fracture energy is larger than for workability.

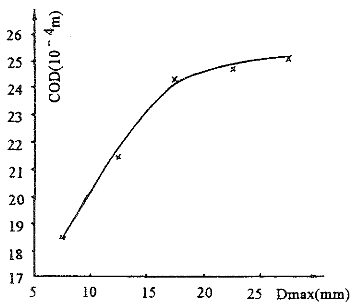

Fig.5 Relation between CODmax and Dmax of coarse aggregate

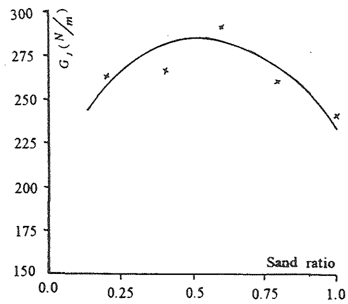

Fig.6 Relation between Gf and sand proportion of concrete

3.4 Influence of the volume content of coarse aggregate on Gf and K_{IC} of concrete (Series 4)

Gf and K_{IC} of pure cement paste and concrete are definitely different (Fig. 7). Gf and K_{IC} of cement paste are both lower, and increase continuously with increasing content of coarse aggregate. This is because of the brittle fracture, the straightly forward crack propagation and the less energy consumed by the cement paste. As for concrete, the crack-arrest by aggregate grains, the micro crack zone at the main crack front, and the roughness of the cracking section greatly increase the total fracture area and so the fracture energy, thus Gf and K_{IC} of concrete increase with Va.

It can be seen from Fig.8 that neat paste has the highest compressive strength. Compressive strength decreases at the adding of coarse aggregate and rises to some extent later with increasing amount of coarse aggregate, but its maximum value is still less than pure cement paste. This can be explained by the low strength of aggregate and the weak transition zones.

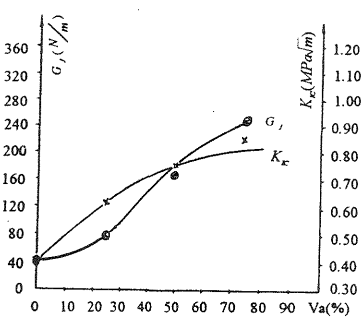

Fig.7 Relation between Gf, K_{IC} and coarse aggregate volume content

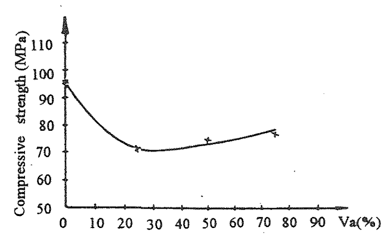

Fig.8 Relation between compressive strength and coarse aggregate volume content

4 Conclusions

1. With increasing water/cement ratio, concrete strength decreases, and so do the fracture energy and fracture toughness accordingly.
2. Dmax of coarse aggregate affect greatly on the fracture performance of concrete. G_f increases with Dmax. It is found that Dmax exerts less influences on fracture toughness than on fracture energy.
3. The influence of sand ratio on the fracture energy of concrete is not obvious. An optimum sand ratio exists, at which the maximum fracture energy reaches.
4. G_f and K_{IC} are both raised at the addition of coarse aggregate into neat paste at lower W/C, and increase gradually with increasing volume content of coarse aggregate.