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Influence of Coarse Aggregate Size on Fracture Properties of Fibre Reinforced Self Compacting Concrete Using Wedge Split Test

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ABSTRACT

Fracture properties of concrete are mainly influenced by the aggregate size, aggregate volume, aggregate type, type and volume of fibre content. The fracture behavior of concrete can be studied by three point bend test and wedge split test. However, wedge split test is a stable fracture test that can be conducted with or without a deformation controlled machine. The ease of wedge split test is that it can be used to evaluate the fracture properties of existing structures by taking the core samples. The present study investigates on effect of aggregate size on fracture parameters of fibre reinforced self compacting concrete using wedge split test. The experimental program consisted of casting three self compacting concrete mixes obtained by modified Nansu method with three varying coarse aggregate sizes (20mm, 16mm, and 12.5mm). Concrete cubes of standard size 150mm × 150mm × 150mm with central cast groove of width 30mm and depth 22mm were cast, cured and tested under wedge split test. Each mix is divided into two categories i.e., specimens with guided notch and other without guided notch. The experimental results on fracture properties of fibre reinforced SCC depicted the increase in fracture energy with an increase in coarse aggregate size. However, it was also observed that higher peak stress was obtained in smaller aggregate size specimens and the post peak behavior is steeper than the higher size aggregate specimens.

1. INTRODUCTION

Self compacting concrete (SCC), a special concrete is being used enormously in present constructions because of reduced labour cost and noise pollution to the environment. From structural aspect, SCC provides high workability for fresh concrete and able to flow, fill and pass under its own weight (Okamura and Ouchi, 2003). The voids in SCC are negligible when compared to normal vibrated concrete. Because of high compactness, the microstructure of hardened concrete has strong interlocking of the particles. This property of interlocking changes the fracture/failure mechanism

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depending on the material properties and proportions (Shah, 1997). Fibres in SCC enhance the tensile properties of concrete. Cracks are the primary cause for the member to fail or fracture and they travel through the weakest path. In concrete, cracks propagates in any one of the three paths i.e., through the matrix, aggregates and matrix-aggregate interface (Amparano et al., 2000). Fracture properties are evaluated using wedge split test (WST) because of its high stability in test method as it can be performed under both displacement and deformation control. WST was first proposed by Linsbauer and Tschegg in 1986 and later in 1990, it was developed by Bruhwiler and F.H. Wittmann. Bruhwiler (Löfgren *et al.*, 2004, 2005, 2008). For the present study, three aggregate sizes were chosen to study the fracture mechanism in fibre reinforced self compacting concrete. WST was used for fracture and fatigue study of concrete (Elser and Tschegg, 1996; Kim and Kim, 1999).

2. TEST METHODOLOGY FOR WEDGE SPLIT TEST

Wedge split test is a Mode I type of failure test. The specimens are of cubical or cylindrical shape for laboratory purpose and core samples for existing structures. The standard cube of size 150 mm ×150 mm ×150mm with a cast groove of 30mm wide and 22mm deep for wedge split test specimen were cast. The vertical load (F_v) is applied through the two steel plates provided on the top of the specimen. The load F_v is transferred as splitting force Fsp through roller bearing. A starter notch (to ensure crack propagation) and a guide notch (to prevent horizontal cracking) are sawed (NT Build 511, 2005). The schematic diagram for test specimens and test setup for the wedge split test were shown in Figure 1(a) and 1(b). The splitting force F_{sp} is calculated using the formula in equation (1). The fracture energy G_f is calculated from the area under the Load - CMOD curve and area of the ligament. The splitting force F_{sp} is given by

$$F_{sp} = \frac{F_v}{2\tan(\alpha)} \frac{1-\mu\tan(\alpha)}{1+\mu\cot(\alpha)} \qquad \text{---------------- Eq. (1)}$$

where,

α is the wedge angle (here α =15º)

μ is the coefficient of friction for the roller bearing. The coefficient of friction is normally varied from 0.1% to 0.5%.

If friction is neglected $F_{sp} = \dfrac{F_v}{2\tan(\alpha)} = 1.866 \times F_v$ ------------------ Eq. (2)

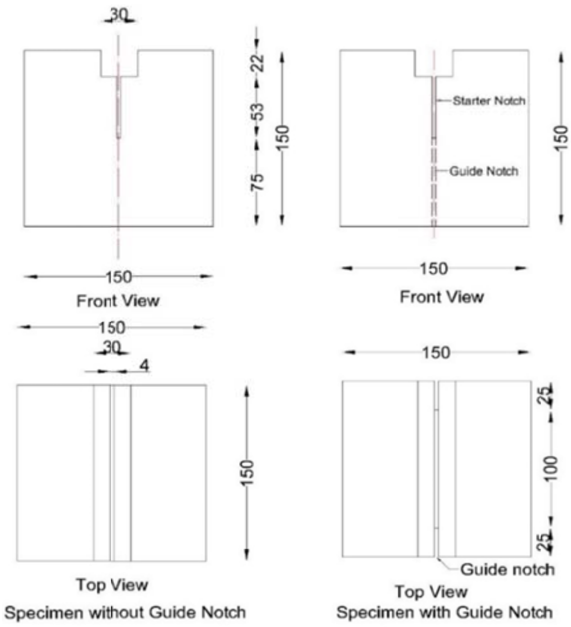
The specific fracture energy, $G_{f\ CMOD}$ is determined from the load-CMOD curves obtained from test results.

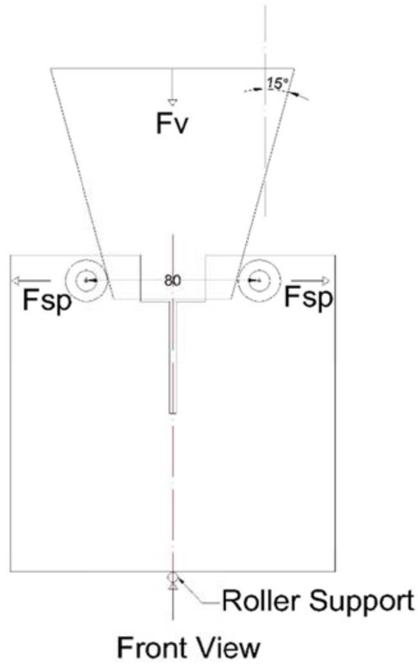
$$G_{F\ CMOD} = \frac{W_{F\ CMOD}}{A_{lig}} \qquad \text{------------------ Eq. (3)}$$

Where,

$W_{F\ CMOD}$ is the area under the curve the F_{split} load- CMOD curve

A_{lig} is the area of the ligament





edge

2. EXPERIMENTAL PROGRAM

The present study investigates the influence of coarse aggregate size on fracture properties of Fibre Reinforced self compacting concrete using wedge split test. The mix (Mix A, Mix B, Mix C) proportions for fibre reinforced SCC were obtained after trial mixes according to Nansu method (2001) to get the properties of SCC viz., filling ability, passing ability, flowability and resistance to segregation and mix proportions are tabulated in Table 1. The study includes tests on fresh properties of fibre reinforced self compacting concrete, compressive strength test, wedge split test (Mode I) for fracture properties evaluation.

Three cubes of size 150mm × 150mm × 150mm for compression test and six wedge split test specimens with and without guide notch of 150mm × 150mm × 150mm with a cast grove are cast. After 28 days of conventional water curing cubes were tested for compression test as per IS 516 (1999) and a day before testing of wedge split test specimens, they were sawed for a starter notch of 53mm deep and a guide notch of 25mm wide on either faces of cast groove.

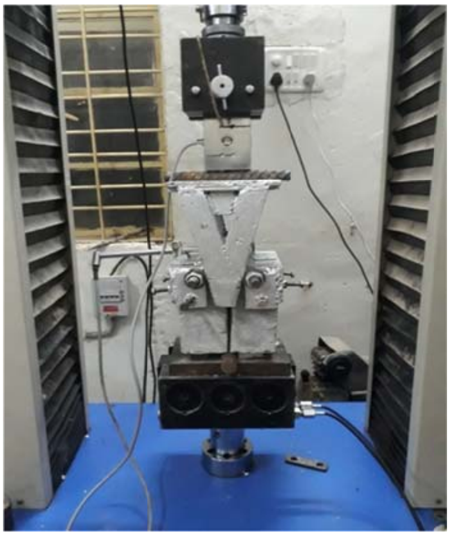


Figure 2. Experimental Test setup
for Wedge Split test

2.1 MATERIALS

The materials used for the present study are:

2.1.1. Cement

Cement used in the investigation was ordinary Portland Cement (OPC) 53 grade conforming to IS 12269. The specific gravity and specific surface area of the cement was 3.14 and 225 m^2/g respectively; its initial and final setting times were 85min and 510min.

2.1.2. Fine aggregate

The fine aggregate conformed to Zone II according to IS 383 (BIS, 2016) obtained from a nearby river source. The specific gravity of FA was 2.64 and the bulk density of the sand was 1.45 g/cm^3.

2.1.3. Coarse aggregate

Well graded coarse aggregate from a local crushing unit was used a coarse aggregate according to IS 383: 2016. The specific gravity and the bulk density of CA was 2.8 was 1.5 g/cm^3 respectively.

2.1.4 Water

For mixing concrete and curing specimens potable water was used in the experimental work.

2.1.5 Flyash

Class F flyash according to IS 3812 : 2013 was procured from thermal power plant. The specific gravity was 2.11.

2.1.6. Super plasticizer

Polycarboxylic ether based high-range water-reducing admixtures conforming to ASTM C494 (ASTM, 2016), commonly called super plasticizers, were used to improve the flowability, passing ability and filling ability without compromising compressive strength.

2.1.7. Fibres

Hooked end steel fibres of length 35mm and diameter of 0.5mm having aspect ratio (l/d) of 70. A quantity of 0.5% by volume of concrete are added to concrete during dry mixing of the ingredients.

Table 1. Mix proportions of Fibre Reinforced Self Compacting Concrete

Constituents	**Mix A (20mm)**	**Mix B (16mm)**	**Mix C (12.5mm)**
Cement (Kg/m^3)	450	450	450
Flyash (Kg/m^3)	150	150	150
Water (l/m^3)	190	190	190
Fine Aggregate (Kg/m^3)	835	835	835
Coarse Aggregate (Kg/m^3)	710	710	710
20-16mm	142	-	-
16-12.5mm	142	213	-
12.5-10mm	213	284	497
10-4.75mm	213	213	213

3. RESULTS AND DISCUSSIONS

3.1. Tests on fresh properties of Fibre Reinforced Self Compacting Concrete

Slump test, T50, V funnel, J ring, L box, T5min tests are performed on fresh fibre reinforced self compacting concrete and the results are tabulated in Table 3. The mix with higher coarse aggregate size i.e., 20mm was highly workable than 16mm and 12.5mm. Among 20mm, 16mm and 12.5mm the dispersion of the particles for 12.5mm would be difficult for the same amount of super plasticizer because the smaller size coarse aggregate has more specific surface area than the larger size aggregate.

Table 3. Fresh properties of Fibre Reinforced Self Compacting Concrete

	Slump(mm)	**T50(sec)**	**V funnel (sec)**	**T 5min (sec)**	**L box**	**J ring**
EFNARC	**550-850**	**2-5**	**6-12**	**9-15**	**0.8-1.0**	**0-10**
Mix A	650	3.35	11	13	0.92	8
Mix B	650	3.5	13	15.56	0.89	9
Mix C	640	4	13	16	0.88	9

3.2. COMPRESSIVE STRENGTH TEST

After 28 days of curing, cubes are tested for compressive strength as per IS 516 (1999). The test was performed on compressive strength testing machine of capacity 3000kN. The results are plotted in Figure 3. It was observed that with the decrease in coarse aggregate size compressive strength was decreased this is due to increase in stiffness.

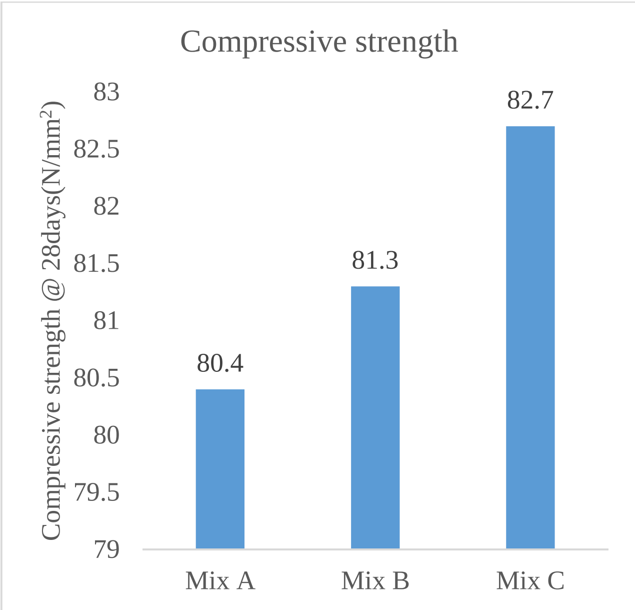


Figure 3. Compressive strength results of Fibre Reinforced Self compacting Concrete

3.3 WEDGE SPLIT TEST

Splitting force Vs. CMOD graphs are plotted for both without guide notch and with guide notch and are shown in figures 4 and 5. The graphs for both the guide notch and without guide notch resulted in a similar trend. The graphs depict that the smaller size coarse aggregate i.e., 12.5mm has shown higher peak stress and higher size coarse aggregate i.e., 20mm has shown efficient post peak. The post peak for Mix C had a sudden drop this is due to the propagation of the crack through the aggregate, because the relative strength of interfacial transition zone (ITZ) was higher than the aggregate strength and for Mix A, the post peak was prominent, as the crack propagation was between the matrix and aggregate thus, pulling out the aggregate from the matrix. Therefore, the energy consumption was higher with an increase in coarse aggregate size. Fracture energy was calculated by using the area under the curve divided by ligament area. The ligament area dimensions for with guide notch is 100mm × 75mm and for without guide notch is 150mm × 75mm and the energies are calculated and are plotted in Figure 6. It was observed that fracture energy is higher for without guide notch specimens than the with guide notch specimens, this is because the crack branching occurs and the energy dissipation increases.

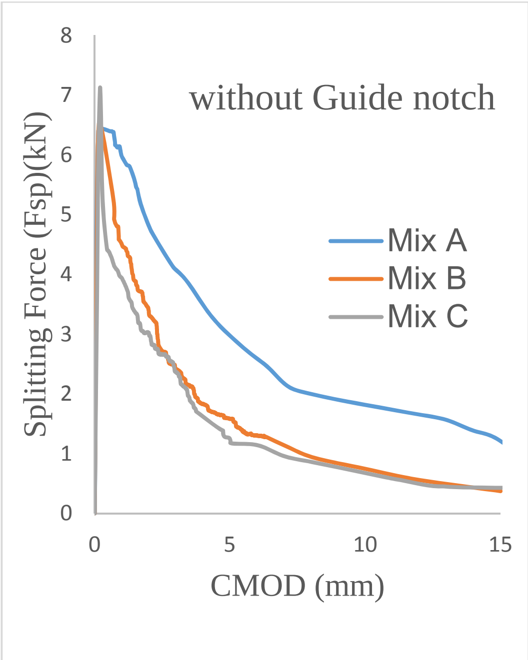


Figure 4. Splitting force vs. CMOD for without guide notch specimens

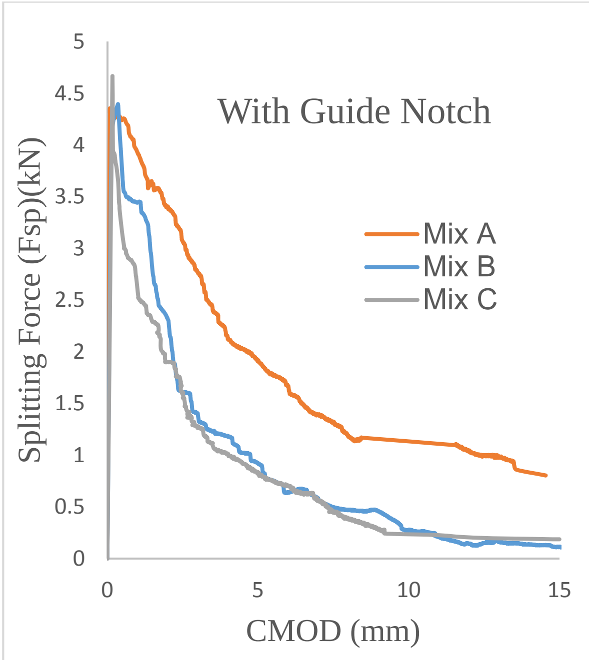


Figure 5. Splitting force vs. CMOD for with guide notch specimens

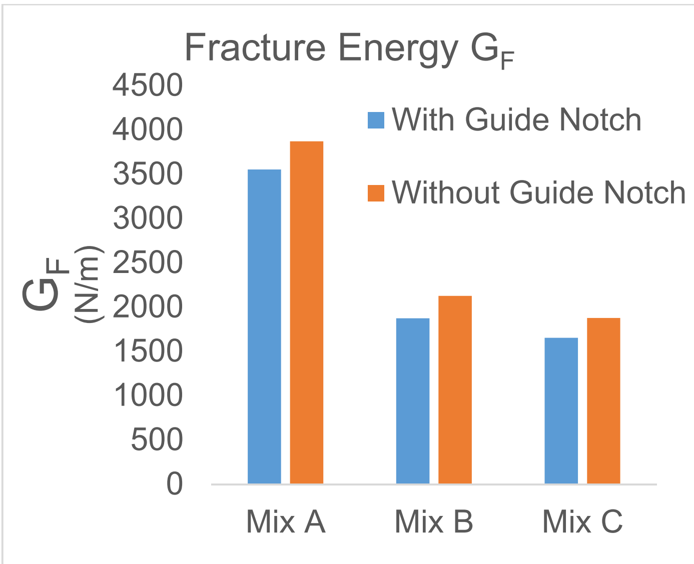


Figure 6. Fracture Energy variation for with Guide notch and without Guide notch

4. CONCLUSIONS

From the present investigation, the influence of coarse aggregate size on fracture properties of fibre reinforced self compacting concrete are summarized as follows:

- With the increase in coarse aggregate size, the mix achieved high workability for fibre reinforced Self compacting concrete.
- The fracture energy increases with increase in the size of coarse aggregate. In addition, It is also observed that the brittleness increases with decrease in coarse aggregate size.
- The energy consumption for without guide notch specimens was higher than the guide notch specimens due to the confined crack path in guide notch specimens.

REFERENCES

Alyhya, W. S. *et al.* (2016) 'Influence of mix composition and strength on the fracture properties of self-compacting concrete', *Construction and Building Materials*, 110, pp. 312–322. doi: 10.1016/j.conbuildmat.2016.02.037.
Amparano, F. E., Xi, Y. and Roh, Y.-S. (2000) 'Experimental study on the effect of aggregate content on fracture behavior of concrete', *Engineering Fracture Mechanics*, 67, pp. 65–84. doi: doi:10.1016/S0013-7944(00)00036-9.
Beygi, M. H. A. *et al.* (2014) 'Evaluation of the effect of maximum aggregate size on fracture behavior of self compacting concrete', *Construction and Building Materials*, 55, pp. 202–211.
Beygi, M. H. A. *et al.* (2014) 'The influence of coarse aggregate size and volume on the fracture behavior and brittleness of self-compacting concrete', *Cement and Concrete Research*. Elsevier Ltd, 66, pp. 75–90. doi: 10.1016/j.cemconres.2014.06.008.
Bideci, A. *et al.* (2017) 'Fracture energy and mechanical characteristics of self-compacting concretes including waste bladder tyre', *Construction and Building Materials*, 149, pp. 669–678. doi: 10.1016/j.conbuildmat.2017.05.191.
Brühwiler, E. and Wittmann, F. H. (1990) 'The wedge splitting test, a new method of performing stable fracture mechanics tests', *Engineering Fracture Mechanics*, 35(1–3), pp. 117–125. doi: 10.1016/0013-7944(90)90189-N.
Cifuentes, H. and Karihaloo, B. L. (2013) 'Determination of size-independent specific fracture energy of normal- and high-strength self-compacting concrete from wedge splitting tests', *Construction and Building Materials*, 48, pp. 548–553. doi: 10.1016/j.conbuildmat.2013.07.062.
Elser, M. and Tschegg, E. K. (1996) 'Fracture reinforced behaviour of polypropylene-fibre- concrete under biaxial loading : an experimental investigation', 56, pp. 933–945.
Ghasemi, M., Ghasemi, M. R. and Mousavi, S. R. (2018) 'Investigating the effects of maximum aggregate size on self-compacting steel fiber reinforced concrete fracture parameters', *Construction and Building Materials*. Elsevier Ltd, 162, pp. 674–682. doi: 10.1016/j.conbuildmat.2017.11.141.
Guidelines, T. E. and Concrete, S. (2005) 'ERMCO The European Guidelines for Self-Compacting Concrete', (May).

Jin, S., Gruber, D. and Harmuth, H. (2014) 'Determination of Young's modulus, fracture energy and tensile strength of refractories by inverse estimation of a wedge splitting procedure', *Engineering Fracture Mechanics*, 116, pp. 228–236. doi: 10.1016/j.engfracmech.2013.11.010.
Kim, J. K. and Kim, Y. Y. (1999) 'Fatigue crack growth of high-strength concrete in wedge-splitting test', *Cement and Concrete Research*, 29(5), pp. 705–712. doi: 10.1016/S0008-8846(99)00025-3.
Korte, S. *et al.* (2014) 'Static and fatigue fracture mechanics properties of self-compacting concrete using three-point bending tests and wedge-splitting tests', *Construction and Building Materials*, 57, pp. 1–8. doi: 10.1016/j.conbuildmat.2014.01.090.
Kozul, R. and Darwin, D. (1997) 'Effects of Aggregate Type, Size and Content on Concrete Strength and Fracture Energy', (43), p. 85.
Level, S. (1998) 'Combined Effects of Coarse Aggregates and Strength Level', 7355(Cc), pp. 0–7.
Löfgren, I. (2004) 'The wedge splitting test - a test method for assessment of fracture parameters of FRC?', *FraMCos-5*, 2(January 2004). Available at: http://framcos.org/FraMCoS-5/Lofgren.Wedge.pdf.
Löfgren, I., Olesen, J. F. and Flansbjer, M. (2005) 'Application of WST-method for fracture testing of fibre- reinforced concrete', (0170).
Löfgren, I., Stang, H. and Olesen, J. F. (2004) 'Wedge Splitting Test - A Test to Determine Fracture Properties of FRC', *6th Rilem Symposium on Fiber Reinforced Concrete (FRC), BEFIB 2004*, 46(0), pp. 379–388.
Löfgren, I., Stang, H. and Olesen, J. F. (2005) 'Fracture Properties of FRC Determined through Inverse Analysis of Wedge Splitting and Three-Point Bending Tests', *Journal of Advanced Concrete Technology*, 3(3), pp. 423–434. doi: 10.3151/jact.3.423.
Löfgren, I., Stang, H. and Olesen, J. F. (2008) 'The WST method, a fracture mechanics test method for FRC', *Materials and Structures/Materiaux et Constructions*, 41(1), pp. 197–211. doi: 10.1617/s11527-007-9231-3.
NT Build 511 (2005) 'North Test BUILD 511 - Wedge splitting test method (WST): Fracture testing of fibre-reinforced ocncrete (Mode I)', 04032, pp. 1–6.
Okamura, H. and Ouchi, M. (2003) 'Self-Compacting Concrete', *Journal of Advanced Concrete Technology*. doi: 10.3151/jact.1.5.
Østergaard, L. and Danmarks Tekniske Universitet. BYG.DTU (2003) *Early-age fracture mechanics and cracking of concrete : experiments and modelling*.
Østergaard, L. and Olesen, J. F. (2004) 'Comparative study of fracture mechanical test methods for concrete', *FraMCos-5*.
Plata, L. (1993) 'The fracture energy (G F) of high-strength concretes', pp. 381–386.
Şahma, M., Yaman, I. O. and Tokyay, M. (2006) 'Self-Compacting Concrete With High Volumes of Fly Ash', *Self*.
Shah, S. P. (1997) 'An Overview of the Fracture Mechanics of Concrete', *Cement, Concrete and Aggregates*, 19(2), pp. 79–86. doi: 10.1520/CCA10319J.
Sitek, M. *et al.* (2014) 'Numerical simulations of a wedge splitting test for high-strength concrete', *Procedia Engineering*, 91(TFoCE), pp. 99–104. doi: 10.1016/j.proeng.2014.12.021.
Skoček, J. and Stang, H. (2008) 'Inverse analysis of the wedge-splitting test',

Engineering Fracture Mechanics, 75(10), pp. 3173–3188. doi: 10.1016/j.engfracmech.2007.12.003.
Xiao, J. *et al.* (2004) 'Wedge splitting test on fracture behaviour of ultra high strength concrete', *Construction and Building Materials*, 18(6), pp. 359–365. doi: 10.1016/j.conbuildmat.2004.04.016.