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DETERMINATION OF FRACTURE PARAMETERS IN BINARY BLENDED SELF COMPACTING CONCRETE (SCC)

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ABSTRACT

Among all the construction materials, concrete is most widely used due to its unique advantages compared to other materials, its application areas increases and become common place each day. Self Compacting Concrete is special type of concrete which places itself in densely-equipped narrow and deep sections with its own weight, tightens without any vibrations, has high resistance or durability characteristics and performances, and has a very fluid- consistency. A Substantial increase in the demand of crack resistance has been noted recently, a structural finite element analysis model has stimulated the failure criteria of rationality and rational constitutive relation. In this study, SCC was investigated via the two-parameter fracture model which needs two fracture parameters namely: the critical stress intensity factor *KI* and the critical crack tip opening displacement $CTOD_c$ to characterize failure of concrete structures. In SCC mix, fly ash and ground granulated blast furnace slag(GGBS) were used as powder materials. Based on maximum loads of SCC specimens produced with different powder materials critical stress intensity factor *KI*and critical crack mouth tip opening displacement $CTOD_c$, fracture parameters were determined. Consequently, it was observed that concrete compressive strength and powder admixture type are effective on fracture parameters of concrete.

Keywords: *Fracture parameters; Two-parameter model; Self-compacting concrete; Fly ash; Ground Granulated Blast Furnace Slag(GGBS).*

I. INTRODUCTION

Self-compacting concrete(SCC) is the current research area today. Many intrinsic properties of the concrete are yet to be understood clearly. Due to the use of chemical and mineral admixtures, the micro cracks study are more essential in SCC compared to conventional Concrete. Fracture Mechanics Science searches for defects like notch, fracture and cavity available in the material increases strain mass and the damage caused by these. These damages are also valid for concrete and reinforced concrete constructions. As concrete has a heterogenic structure, it has been determined that it could not be analyzed by Linear Elastic Fracture Mechanics (LEFM) Principles. Therefore, researchers have developed nonlinear fracture mechanics models that attend to fracture process zone. It is possible to classify these models as Cohesive Crack Models (Work-of-fracture Method, Size Effect Model [3] and Variable-Notch One-Size Specimen Method[4] and Effective Crack Models; Two-Parameter Model [5], Peak-load Method[6] and Effective Crack Model. In this study, self-compacting concrete which have different compounds has been obtained by using GGBS, fly ash. Self-compacting concrete beams produced as notched were subjected to three- point bending tests. With the aid of sample maximum loads obtained, by using Two-parameter Fracture Model *KI* and $CTOD_c$ fracture parameters were determined. When the results of the tests were evaluated, it was seen that powder material types(puzolanic or inert) are effective on SCC's fracture parameters.

II. SELF-COMPACTING CONCRETE

SCC has many advantages over conventional concrete: (a) eliminating the need for vibration; (b) decreasing the construction time and labor cost; (c) improving the filling capacity of highly congested structural members; (d) decreasing the permeability and improving durability of concrete, and (e) facilitating constructability and ensuring good structural performance. SCC has been attracting more and more attention world-widely since its

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introduction in the late 1980's. New applications for SCC are being increasingly explored because of its many advantages over conventional concrete [7].

The functional requirements on a fresh SCC are different from those on a vibrated fresh concrete. Filling of formwork with a liquid suspension requires workability performance which is recommended to be described as follows: (a) filling ability: Complete filling of formwork and encapsulation of reinforcement and inserts horizontal and vertical flow of the concrete within the formwork with maintained homogeneity. (b) Passing ability, passing of obstacles such as narrow sections of the formwork, closely spaced reinforcement etc. without blocking caused by interlocking of aggregate particles. (c) Resistance to segregation: Maintaining of homogeneity throughout mixing and during transportation and casting. The dynamic Stability refers to the resistance to segregation during Placement. The static stability refers to resistance to bleeding, segregation and surface settlement after casting [8].

Although SCC is regularly used in applications every day, the technology still has a very large potential for refinement and further development. SCC will develop to be even more cost effective and thus increase its competitiveness on the market. There are a number of areas having high priority in the further development [9].

III. TWO-PARAMETER FRACTURE MODEL (TPM)

To analyze a concrete structure according to fracture mechanics, fracture parameters of the cementations material must be determined at first. The studies on determining The fracture parameters of concrete were initiated by Kaplan[10].He used the principles of classical linear elastic fracture mechanics (LEFM), which proposes a unique parameter (the critical stress intensity factor K_{Ic} for concrete fracture).However, the subsequent experiments revealed that LEFM is not valid for concrete since K_{Ic} depends on size and geometry. The in applicability of LEFM is because of the existence of an inelastic zone named fracture process zone (FPZ) in front of the crack in concrete. For this reason, several non-linear fracture mechanics models have been developed to characterize FPZ (Figure1).

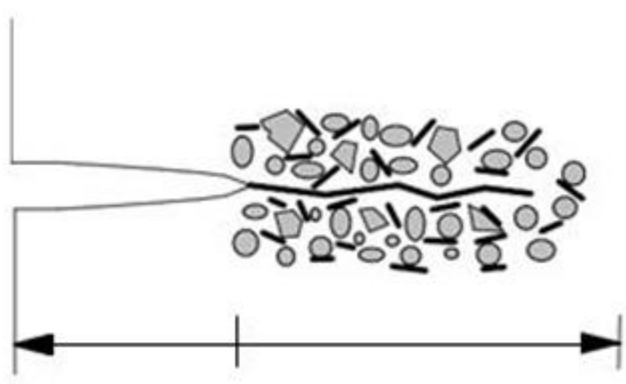

Figure 1 Fracture process zone

These models can be classified as the cohesive crack models(the fictitious crack model by Hillerborg [11] and the crack band model by Bazant [12]) and the effective crack models (the two parameters model (TPM) by Jenq and Shah [5], the effective crack model by Nallathambi and Karihaloo [13] and the size effect model by Bazant and Kazemi [14]). The cohesive crack models simulate FPZ by a closing pressure, which diminishes near the crack tip while the effective crack models simulate FPZ by an effective crack length. The primary aim of these approaches is to determine the critical crack extension (size of FPZ) at the peak load □ a □ a_e □ a_0 in which a_c and $a_0$are the critical crack length at the peak load and the initial crack length respectively. Nevertheless, a_c depends on the structural size, because it decreases as the size increases. Consequently, the non-linear fracture approaches propose that atleast two fracture parameters are required for concrete fracture. However, the results of any fracture model can be easily adapted to the other fracture models of concrete.

A concrete structure fails, according to TPM, when the stress intensity factor K_I and the crack opening displacement CTOD reach their critical values, and $CTOD_c$. These fracture parameters can be calculated by means of the following LEFM equations:

$$K_{Ic}^{s} = \sigma_{Nc}\sqrt{\pi a_c} f_1(\alpha_c)$$

$$CTOD_c = \frac{4\sigma_{Nc} a_c f(\alpha) f(\alpha \quad ,\beta)}{E_c}$$

in which σ_{Nc} is the nominal failure stress, d is the structure size, E_c is the Young's modulus, $\alpha_c = a_c/d$, $\beta = a_c/a_0$ and f_1, f_2, f_3 are the dimensionless functions, which depend on the geometry of the structure and on the load type.

In this approach, the fracture parameters may be deduced from one of two different experimental methods: namely the compliance proposed by RILEM [2], and the peak load methods [4]. The peak-load method is a more simple method than the one introduced by RILEM in determining the fracture parameters of TPM because it requires uncomplicated testing equipment. However, it necessitates three or more distinct specimens due to the randomness of concrete properties. This is true for both methods. These specimens may be identical in size but different in initial crack length or have initial cracks of the same length. but different sizes. For each of the tested specimen, the following equations can be written according to TPM:

$$K_I^i(\sigma_{Nc}^i, a_c^i) \qquad ; i = 1, 2$$

$$CTOD^i(\sigma_{Nc}^i, a_c^i) = CTOD_c$$

In which ide notes the ith specimen. consequently, with this method atleast two tests must be performed instead of one since the K_I is determined which causes the smallest standard deviation in the $CTODC$. In order to obtain this statistical adequacy, totally six specimens, with three different initial crack length and two specimens from each initial crack length, are sufficient in practice[15].

Fracture energy Gf (mean prediction) can be calculated using the following expression

$$G_f = \frac{g\alpha_o}{E_c A}$$

Effective fracture process zone length

$$C_f = \frac{g(\alpha_o)}{g'(\alpha_o)}\left(\frac{C}{A}\right)$$

where

$$g'(\alpha_o) = \frac{dg(\alpha_o)}{d\alpha_o}$$

IV. EXPERIMENTAL STUDIES

According to EN 197-1 [17] CEM I 42.5 N was used in all mixes. Its specific gravity, specific surface area by Blain, and 28 days compressive strength were 3.09, 3490 cm2/g and49.1 MPa respectively. The maximum aggregate size was 16 mm (density of 2.66). The maximum sand grain size was 4 mm (density of 2.61). Mineralogicaly, the aggregate consisted of river. The grading of the aggregate mixture are shown in Table1.The aggregate and sand were air-dried prior to mixing. The super-plasticizer GLENIUM B233 a product from BASF was used in order to produce SCC for all mixes. Two types of powder, fly ash and GGBS, were utilized to obtain SCC mixes. Their physical and chemical properties are given in Table

Table 1 The grading of aggregate (Cumulative percentage passing %)

Sieve size (mm)	16	12.5	10	4.75	1.18	0.6	0.3
Aggregate mixture	100	72	56	42	27	13	4

Table 2 Physical properties of mineral admixtures

Özellikler	Fly ash	GGBS
SiO2 (%)	58.82	33.78
Al2O3 (%)	19.65	17.08
Fe2O3 (%)	10.67	13.2
CaO (%) (CaCO3)	2.18	39.87
MgO (%)	3.92	7.10
SO3 (%)	0.48	--
Specific gravity	2.25	2.62
Blaine (cm2/g)	320	321
45µm geçen	--	2.9%

Mix proportions are given in Table 3. Concrete mixes were made in power-driven revolving type drum mixers. Mix proportions were made.

V. SUPER PLASTICIZER

Super Plasticiser (GLENIUM B233) GLENIUM B233 is an admixture of a new generation based on modified polycarboxlic ether. The product has been primarily developed for application in High performance concrete where highest durability and performance is required. GLENIUM B233 is free of chlorine and low alkali. It is compatible with all types of cements. The product compile with ASTM C494 Type F.

TABLE 3: Properties of GLENIUM B233

Aspect	Yellowish free flowing liquid
Relative Density	1.09, 0.01 at 25°C
PH	7 ± 1
Chlorine iron content	< 0.2%

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TABLE 4:Details Of Mix Proportion

Mix-ID	GGBS 30	GGBSF A20	GGBS 40	GGBSF A15	FA30	FA40	GGBSF A0
W/C	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Water (litres)	180	180	180	180	180	180	180
Cementious (Kg/m3)	450	450	450	450	450	450	450
% of replacement by Fly ash	......	20	....	15	40	30	.....
% of replacement by GGBS	30	20	40	15	....	....	....
Super Plasticiser (%)	0.85	0.8	0.9	0.85	0.75	0.75	0.85
Cement (Kg/m3)	315	270	270	315	270	315	450
Fly Ash (Kg/m3)	....	90	....	67.5	180	135	....
GGBS (Kg/m3)	135	90	180	67.5	....	....	....
Fine Aggregates (Kg/m3)	795	795	795	795	795	795	795
Coarse Aggregate (Kg/m3)	1027	1027	1027	1027	1027	1027	1027

Figure 2 Test specimens

The 150 mm concrete cubes were cast for compressive strength. Specimens 150×150×450mm (spanlength=380mm) were cast in steel moulds for fracture model. The specimens were cast as the notch face is at the bottom. The eight beam specimens were classified into three groups of according to the relative initial crack length a_0/d=0.1,0.2,0.3

All the test specimens were demounted after 24h, and were put into a water-curing tank during 28days.

VI. EXPERIMENTAL RESULTS

Fresh concrete properties were determined. Slump-flow, T50time, V-funnel test, L-box (h1/h2), test and sieve segregation resistance measured, as shown in Table 4. The cube and beam specimens were tested and determined peak loads. Three-point bend beams have been widely used to measure fracture properties of concrete. When the Two-parameter Method (TPM) used to determine fracture parameters of concrete, K^S, $CTOD_c$, G_F and c_f was results.

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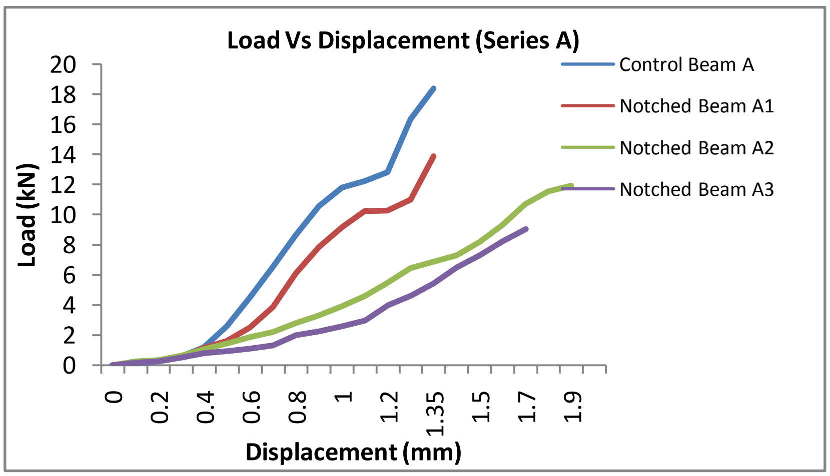
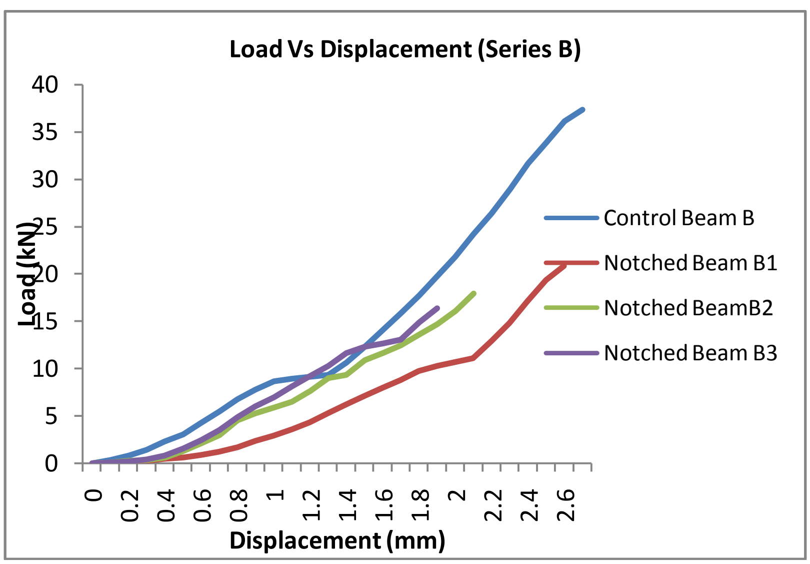
Table 4 Physical properties of mineral admixtures

Series	$T50$ (s)	Flow (cm)	SG (%)	h_1/h_2 (%)	T_v (s)	f_c (MPa)	K^S_{Ic} (MPa√m)	$CTOD_c$ (mm)	G_f (N/m)	c_f (mm)	G_F (N/m)
SF	1	65	0	0.89	5.3	45.7	1.101	0.0177	36.4	27.1	90.9
FA	1.1	70	4	0.86	6.6	41.8	1.136	0.0191	40.5	27.1	101.2
MP	0.8	69	4	0.86	7.2	35.9	1.089	0.0232	40.1	37.3	100.3
REF	-	[15]	-	-	-	31.9	1.334	0.0259	63.9	27.6	159.7





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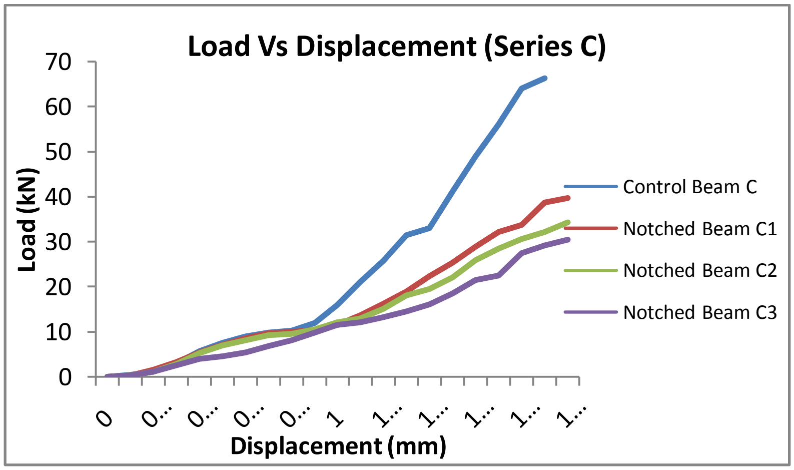

VII. CONCLUSIONS

The conclusions of this study can be said as follows: When the properties of fresh SCC such as slump-flow, v-funnel time, segregation resistance and L-box are considered as a criterion to determine the optimum usage ratio of powder materials (silica fume, fly ash and marble powder) in SCC, it can be said that usage amount below %15 powder content is suitable for improving all these properties.. Based on maximum loads of SCC specimens produced with different powder materials, critical stress intensity factor K and critical crack tip opening displacement $CTOD_c$, fracture parameters were determined. Consequently, it was observed that concrete compressive strength and powder admixture type are effective on fracture parameters of concrete. Fracture energy G_f (also G_F) and fracture process zone length c_f fracture parameters were also determined.

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