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An Experimental Investigation of Effect of Maximum Aggregate Size on Mode-1 Fracture Parameters of Steel Fibre Reinforced Normal Strength Concrete

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ABSTRACT

The fracture mechanics theories promise better predictions about the life and durability of a structure in presence of cracks. Mode I crack propagation in fiber-reinforced concrete (SFRC) is simulated by a fracture mechanics approach by using Size Effect Law. The present experimental investigation consisting of tests on geometrically similar notched prismatic specimens made from plain concrete and fiber concrete with 0.5%, 1% & 1.5% of steel fibers. The MAS taken in this study are 20mm, 16mm, 10mm. The notched specimens are tested with three point bending test. Theories of fracture mechanics tend to incorporate the fracture energy (Gf) of concrete as an important property in addition to other properties of concrete like Young's modulus (E), Cohesive Fracture Zone (Cf), Failure stress(σn) and Brittleness number (β). From the curves of P-δ, P-CMOD, β-d, σn-d the Fracture Energy parameters are determined. Different relations are established by varying percentage of steel fibres and Maximum Aggregate Size against load which are used to determine the Fracture toughness. The post peak behavior of concrete is determined by using the area under p-δ curves.

Keywords: Three Point Bending Test, Compressive Strength, Split Tensile Strength

I. INTRODUCTION

Crack formation in concrete is often at the origin of serious damage due to corrosion. The fictitious crack model (FCM) as developed originally by Hillerborg (1976) is a powerful tool to predict crack formation in composite materials such as concrete. For a realistic prediction we need fracture energy and strain softening of the material. Strength is an important parameter among others such as ductility, self-compacting ability, low shrinkage, high modulus or wear resistance. In this contribution we will consider crack formation of normal concrete. Fracture energy and strain softening depend on the composite structure of the material. It is essentially governed by the mechanical interaction of the aggregates with the cement-based matrix. Failures have occurred for many reasons, including uncertainties in the loading or environment, defects in the materials, inadequacies in design, and deficiencies in construction or maintenance. Design against fracture has a technology of its own, and this is a very active area of current research. This module will provide an introduction to an important aspect of this field, since without an understanding of fracture the methods in stress analysis discussed previously would be of little use. We will focus on fractures due to simple tensile overstress, but the designer is cautioned again about the need to consider absolutely as many factors as possible that might lead to failure, especially when life is at risk. Unfortunately, this renders the material increasingly brittle, so that cracks can form and propagate catastrophically with very little warning. An unfortunate number of engineering disasters are related directly to this phenomenon, and engineers involved in structural design must be aware of the procedures now available to safeguard against brittle fracture.

Fracture mechanics is the science of studying the behavior of progressive crack extension in structures subjected to an applied load. Steel Fiber Reinforced

Concrete (SFRC) became in the recent decades a very popular and attractive material in structural engineering because of its good mechanical performance. The most important advantages are hindrance of macro-cracks development, delay in micro-cracks propagation to macroscopic level and the improved ductility after micro-cracks formation. SFRC is also tough and demonstrates high residual strengths after appearing of the first crack. The concept of using fibers to improve the mechanical properties of concrete is known for many decades. Adding fiber, enhance the compressive, tensile and shear strengths, flexural toughness, durability and resistance to impact. The mechanical properties of FRC depend on the type and the content of the added fibers. Steel fibers, randomly distributed in matrix, show its effect after matrix cracking by delaying the crack formation and limiting the crack propagation by reducing the crack tip opening displacement (CTOD). The addition of steel fibers into concrete at a certain volume fraction improves the ductility of concrete. Steel fibers also contribute the steel fiber-matrix bond strength by increasing fracture toughness of SFRC. Steel fibers in the matrix act as crack arresters by bridging mechanism; undergo a pull-out process, delay crack formation and limit crack propagation. The use of steel fibers greatly increases its energy absorption and ductility. The performance of steel fibers depends on fiber type and orientation of fibers in matrix, aspect ratio (length/diameter) volume fraction and tensile strength of fiber as well as matrix strength influence performance the of SFRC. SFRC has a wide-range of applications such as; pavements and overlays, industrial floors, precast products, hydraulic and marine structures, repairing and retrofitting of reinforced concrete structures, tunnel lining and slope stabilization works.

II. METHODS AND MATERIAL

Cement:
Ordinary Portland cement conforming to IS 12269 – 1983 was used for the concrete mix and Specific gravity was found to be 3.5

Fine Aggregate:
The fine aggregate (sand) used in the work was obtained from a nearby river course. The fine aggregate that falls in zone –II was used. The specific gravity was found to be 2.60.

Coarse aggregate:
Crushed coarse aggregate of 20mm, 16 mm, 10 mm retained was used in the mixes. Uniform properties were to be adopted for all the beams for entire work. Specific Gravity of coarse aggregate is 2.78.

Water:
Potable water supplied by the college was used in the work.

Steel Fibres:
Crimped Steel Fibres were used of length 30mm and 0.5mm mean diameter at a Volume fraction of 0.5%, 1% & 1.5%.

Moulds:
Standard cast iron cubes and cylinders moulds were used for casting of cubes and cylinders. Three casted iron moulds were prepared for casting of beams of sizes as follows **(l*h*b)**

1. 350*75*100 mm
2. 650*150*100 mm
3. 1250*300*100 mm

Vibrator:

To compact the concrete needle vibrator is used for compacting the Test specimens.

Casting:

The moulds were tightly fitted and all the joints were sealed by plaster of Paris in order to prevent leakage of cement slurry through the joints. The inner side of the moulds was thoroughly oiled before going for concreting. The mix proportions were put in miller and thoroughly mixed.

The prepared concrete was placed in the moulds and is compacted using needle vibrators. The same process is adopted for all specimens. After specimens were compacted the top surface is leveled with a trowel.

Curing:

The specimens were removed from the moulds after 24 hours of casting and were placed in water for curing.

Marble Cutter:
The beams were cut with a marble cutter in to the hardened concrete

III. RESULTS AND DISCUSSION

All the specimens were tested on the LOADING FRAME of 100 TONS capacity under displacement control at a rate of 0.02mm/min. After 28days of curing the samples were taken out from the curing tank and kept for dry. Then notch is provided at the centre of the beam with notch to depth ratio of

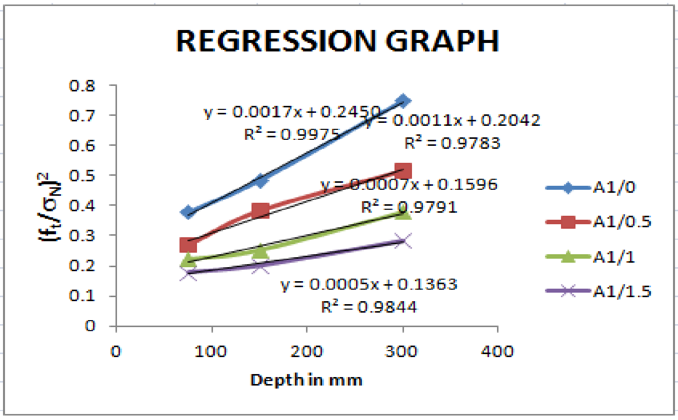
0.15. After this the sample was coated with white wash. One day later the sample was kept for testing. The notched beam specimen was kept on the supports of testing machine as shown in below figure . When performing a test, a gradually increased load is applied to the notched beam until a stress level is reached which results in crack propagation.

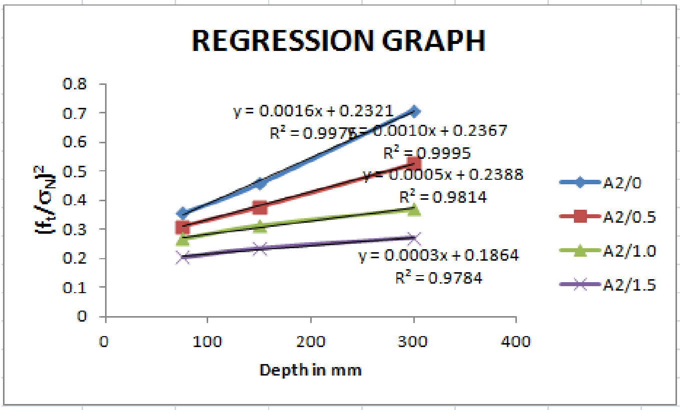
Mechanical Properties of Concrete

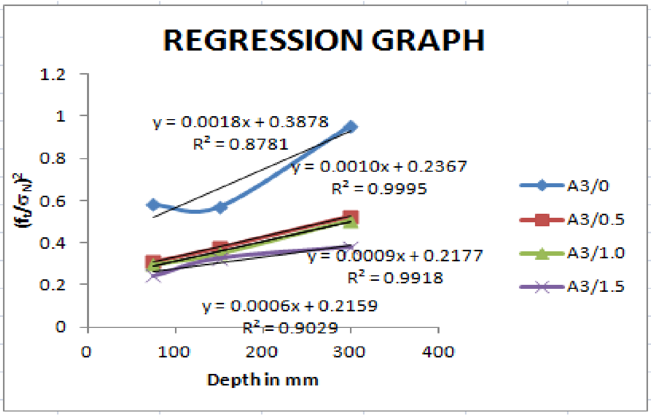
GRADE	SIZE OF AGGREGATE	STEEL FIBRES %	PROPORTIONS	Fck(N/mm2)	Ft (N/mm2)
M20	10mm	0	0.5:1:1.46:2.54	28.00	2.8
		0.5	0.5:1:1.46:2.54	32.22	3.4
		1	0.5:1:1.46:2.54	42.81	3.98
		1.5	0.5:1:1.46:2.54	38.66	4.2
	16mm	0	0.5:1:1.38:2.98	28.18	2.92
		0.5	0.5:1:1.38:2.98	33.77	3.40
		1	0.5:1:1.38:2.98	42.00	3.78
		1.5	0.5:1:1.38:2.98	36.51	3.85
	20mm	0	0.5:1:1.425:3.1	27.20	3.0
		0.5	0.5:1:1.425:3.1	35.30	3.80
		1	0.5:1:1.425:3.1	39.44	4.0
		1.5	0.5:1:1.425:3.1	36.37	4.1
M30	10mm	0	0.46:1:1.29:2.55	34.66	3.5
		0.5	0.46:1:1.29:2.55	41.25	4.0
		1	0.46:1:1.29:2.55	48.22	4.3
		1.5	0.46:1:1.29:2.55	44.54	4.3
	16mm	0	0.46:1:1.28:2.88	33.92	3.5
		0.5	0.46:1:1.28:2.88	39.78	4.2
		1	0.46:1:1.28:2.88	51.55	4.4
		1.5	0.46:1:1.28:2.88	45.6	4.45
	20mm	0	0.46:1:1.26:3.12	37.33	3.4
		0.5	0.46:1:1.26:3.12	42.53	4.1
		1	0.46:1:1.26:3.12	53.03	4.4
		1.5	0.46:1:1.26:3.12	51.12	4.5

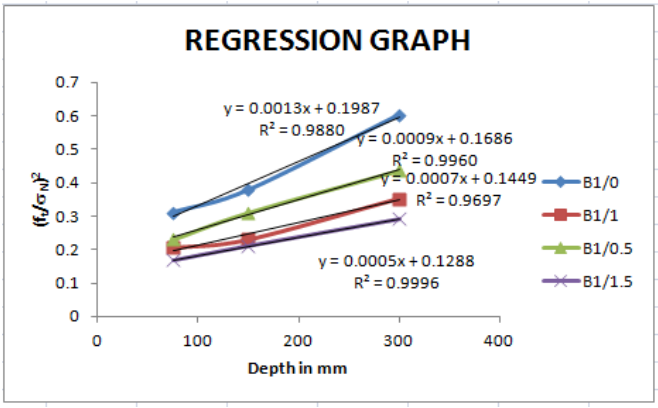
GRADE OF CONCRETE	BEAM (S,M,L)	28 DAYS COMPRESSIVE STRENGTH fck(Mpa)	SPLIT TENSILE STRENGTH ft(Mpa)	DIRECT TENSILE STRENGTH ft(Mpa)	F(α)	G(α)	E (Gpa)
M20	A1/0	27.2	3	1.98	0.987	0.458834	26.076
	A1/0.5	35.3	3.8	2.507	0.987	0.458834	29.706
	A1/1	39.44	4	2.64	0.987	0.458834	31.400
	A1/1.5	36.37	4.1	2.70	0.987	0.458834	30.153
	A2/0	28.18	2.92	1.9272	0.987	0.458834	26.542
	A2/0.5	33.77	3.4	2.244	0.987	0.458834	29.055
	A2/1	42	3.78	2.4948	0.987	0.458834	32.403
	A2/1.5	36.51	3.85	2.541	0.987	0.458834	30.210
	A3/0	28	2.8	1.848	0.987	0.458834	26.457
	A3/0.5	33.22	3.4	2.244	0.9687	0.458834	28.381
	A3/1	42.81	3.98	2.6268	0.987	0.458834	32.714
	A3/1.5	38.66	4.2	2.772	0.987	0.458834	31.088
M30	B1/0	37.3	3.4	2.244	0.987	0.458834	30.54
	B1/0.5	42.53	4.1	2.706	0.987	0.458834	32.61
	B1/1	53.03	4.4	2.904	0.987	0.458834	36.41
	B1/1.5	48.5	4.5	2.97	0.987	0.458834	34.82
	B2/0	33.92	3.5	2.31	0.987	0.458834	29.12
	B2/0.5	39.78	4.2	2.772	0.987	0.458834	31.535
	B2/1	51.55	4.4	2.904	0.987	0.458834	35.899
	B2/1.5	45.6	4.45	2.937	0.987	0.458834	33.76
	B3/0	34.66	3.5	2.31	0.987	0.458834	29.436
	B3/0.5	41.25	4	2.64	0.987	0.458834	32.11
	B3/1	48.22	4.3	2.838	0.987	0.458834	34.72
	B3/1.5	44.54	4.3	2.838	0.987	0.458834	33.69

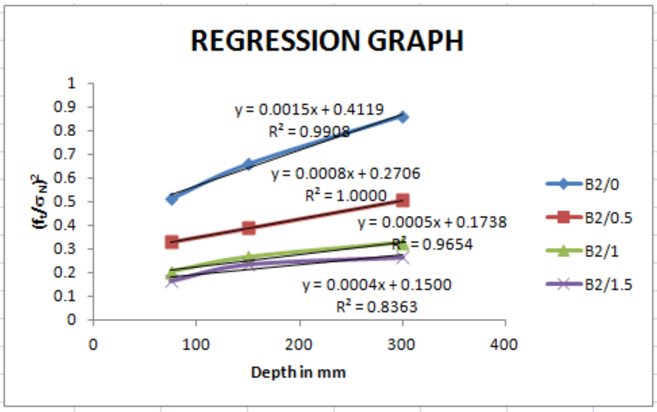
Regression Graphs for M20&M30:

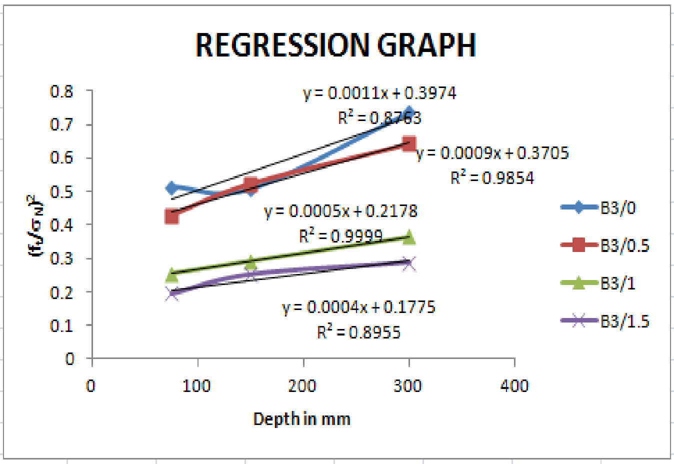












IV. CONCLUSION

Based on the tests carried out on 144 geometrically identical specimens the results obtained were analyzed as below.

- With increase in Maximum aggregate size (MAS) and percentage of steel fibres the fracture energy(Gf) is increases.
- With increase in MAS from **10mm to 20mm,** failure stress increases by **80%** for **A** series and **86%** for **B** series. With increase in percentage of steel fibres from **0% to 1.5%** Failure Stress(σn) increases by **47.5%** in **A** series and **55.08%** in **B** series.
- With increase in MAS from **10mm to 20mm** ,Brittleness number increases by **66.9%** in **A** series and **33.4%** in **B** series. with increase in percentage of steel fibres from **0% to 1.5%** Brittleness number decreases by **52.76%** in **A** series and **59.5** in **B** series.
- With increase in MAS from**10mm to 20mm**, Fracture Process Zone(FPZ)i.e. Cf decreases by **64.89%** in **A** series and **42.31%** in **B** series. with increase in percentage of steel fibers from **0% to 1.5%** FPZ(Cf) increases by **52.85%** in **A** series and **59.32%** in **B** series.

With increase in MAS and percentage of steel fibers the post peak behavior (p-δ) of concrete improves.

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