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An Experimental Investigation on Mode-II Fracture of Light Weight Pumice Aggregate Concrete

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ABSTRACT: *Shear strength is a property of major significance for wide range of civil engineering materials and structures. Shear and punching shear failures particularly in deep beams in corbels and in concrete flat slabs are considered to be more critical and catastrophic than other types of failures. To study such failures the past literature suggests best suited geometry as Double Centered Notched (DCN) specimen geometry proposed by Sri Prakash Desai and Sri Bhaskar Desai. In the present scenario light weight aggregate has been the subject of extensive research which affects the strength properties of cement concrete. Light weight aggregate concrete has become more popular in recent advancements owing to the tremendous advantages it offers over the conventional concrete but at the same time light in weight and strong enough to be used for structural purposes. In this present experimental investigation an attempt is made to study the Mode-II fracture properties of natural light weight aggregate concrete, such as pumice aggregate (which is volcanic based and imported from Turkey) concrete. By varying the percentage of light weight pumice aggregate in concrete replacing the conventional granite aggregate in percentages like 0%, 25%, 50%, 75% and 100% by volume of concrete, the mode-II fracture property such as in plane shear strength is studied. Finally an analysis is carried out regarding Mode-II fracture properties of pumice concrete and it is concluded that shear strength is decreased continuously with increase in percentage of pumice.*

Key words: *Pelletization, light weight aggregate, cold bond.*

I. Introduction

Due to poor design and the material deficiencies in the form of pre-existing flaws initiating the cracks and fractures which are responsible for the failure of structures. With the advancement in the new construction materials with high strength and stress analysis methods were developed which enable a more reliable determination of local stresses, which permits the safety factors to be reduced resulting in weight savings.

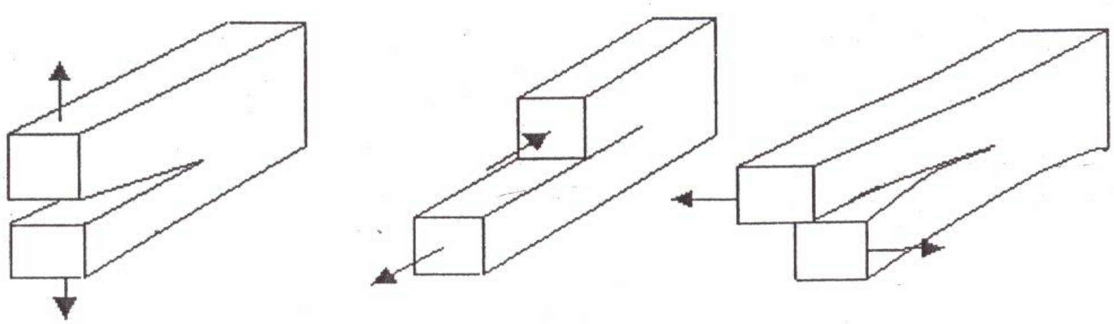
Consequently, structures designed with high strength materials have low margins of safety. But the service stresses with aggressive environment may be high enough to induce cracks, particularly if pre-existing flaws or high stress concentrations are present. The high strength materials have a low crack resistance (fracture toughness). The residual strength under the presence of cracks is low. When small cracks exist, structures designed with high strength materials may fail at stresses below the highest service stress that they are designed.

The occurrence of low stress fractures in high strength materials induced the development of fracture mechanics. Fracture mechanics is a method of characterizing the fracture behavior in terms of structural parameters that can be easily understood by the engineer i.e. Stresses, crack size etc.

Fracture mechanics can deliver the methodology to compensate the inadequacies of conventional design concepts. The conventional design criteria are adequate for many engineering structures, but they are insufficient when there is the likelihood of cracks. Now the fracture mechanics has become a useful tool in the design with high strength materials.

II. Modes of Cracking

A crack in a structural component can be stressed in three different modes, which are as shown in Fig 1.



Mode I: Opening Mode **Mode II: In-plane shear Mode** **III: Out of plane Shear**

Fig 1. Different modes of cracking

Normal stresses give rise to the "Opening mode" denoted as Mode-I in which the displacements of the crack surfaces are perpendicular to the plane of the crack. In-plane shear results in Mode-II or "Sliding mode", in which the displacement of the crack surfaces is in the plane of the crack and perpendicular to the leading edge of the crack (crack front). The "Tearing mode" or Mode-III is caused by out-of-plane shear, in which the crack surface displacements are in the plane of the crack and parallel to the leading edge of the crack.

III. Light Weight Aggregate

Structural lightweight aggregate concretes are considered as alternatives to concretes made with dense natural aggregates because of the relatively high strength to unit weight ratio that can be achieved. One of the disadvantage of conventional concrete is the high self weight of concrete. Density of the normal concrete is in the order of 2200 to 2600Kg/m^3. This heavy self weight will make it to some extent an uneconomical structural material. Attempts have been made and lightweight aggregate concrete have been introduced whose density varies from 300 to 1850Kg/m^3.

PUMICE: Increasing utilization of lightweight materials in structural applications making use of pumice stone, has gained importance. Therefore, the need arises to analyze the materials to be used in construction experimentally in detail. Pumice stone has been used since centuries in the world. Pumice aggregate can be found in many places around the world where volcanoes are present. Pumice is a natural sponge-like material of volcanic origin composed of molten lava rapidly cooling and trapping millions of tiny air bubbles.

Review of Literature: In this paper brief reviews of the available studies related to the present Mode-II fracture of cementitious materials are presented. The review covers the study on mode-II fracture parameters analytically and experimentally, light weight aggregate concrete properties etc.

Aggarwal and Giare (1) investigated that critical strain energy release rate in Mode-II is less than half of that in Mode-I or Mode-III indicating that in the case of fibrous composites, the fracture toughness tests in Mode-II may be more important than the tests in mode-I and Mode-III.

Symmetrically notched "Four point shear test specimen was used by Bazant and Pfeiffer (2,3) to study the shear strength of concrete and mortar beams and they concluded that the ratio of fracture energy for Mode II to Mode I is about 24 times for concrete and 25 times for mortar.

Punch Through Shear Specimen Geometries: Prakash Desayi, Raghu Prasad B.K, and Bhaskar Desai.V, (4, 5, 6, 7, 8, 9 and 10) arrived at Double Central Notched specimen geometry which fails in predominant Mode-II failure; They also made finite element analysis to arrive at stress intensity factor. Using this DCN geometry lot of experimental investigation using cement paste, mortar, plain concrete was carried out.

V. Bhaskar Desai, D. Jagan Mohan, V. Vijay kumar (11) studied the mechanical properties like compressive, split tensile strength, modulus of elasticity and flexural behavior of partial replacement of normal coarse aggregate by Hematite aggregate.

Bhaskar Desai. V, Balaji Rao . K, Jagan Mohan . D (12,13) studied the properties like compressive strength, split tensile strength, mode-II fracture properties by using DCN specimen and the fracture toughness values in Mode-II (K_{IIc}) are calculated from the theoritical equations suggested by the earlier researchers and are compared with those obtained from load verses deflection (p-δ) diagrams.

K. Balaji Rao, V. Baskar Desai, D. Jagan Mohan, (14) made probabilistic analysis of Mode-II fracture energy of concrete. The experimentally observed values of mean, minimum and maximum G_{IIF} are compared with their respective values obtained from probabilistic analysis, which are found to be in good agreement. The results of K-S tests performed for different (a/w) ratios and different percentage replacements, an equation is proposed for estimation of characteristic Mode-II Fracture energy.

Light Weight Aggregate Concrete: Owens, P.L. (15) has stated that Light weight aggregate concrete has been used for structural purposes since the 20th century. The Light weight aggregate concrete is a material with low unit weight and often made with spherical aggregates. The density of structural Light weight aggregate concrete typically ranges from 1400 to 2000 kg/m³ compared with that of about 2400 kg/m³ for normal weight aggregate concrete.

Pumice Aggregate: L. Calaveri et.al (16) discussed the properties of lightweight pumice stone concrete (LWPSC) and suggested that pumice can really be considered an alternative to common artificial light weight aggregate, taking into account the performance pointed out by loading tests carried out on structural systems made of LWPSC.

From the brief literature survey conducted in this investigation it is observed that even though primary properties are studied on pumice aggregate concrete, little work is reported on Mode-II fracture properties of pumice aggregate concrete. Hence the present study has been under taken.

IV. Experimental Investigation

An experimental study has been conducted on concrete with partial replacement of conventional coarse aggregate i.e., granite by light weight aggregate i.e., Pumice in Mode-II fracture with few different volumetric fractional additions ranging from 0% to 100%. Concrete of basic M_{20} design mix is used in the present investigation. The test programme consists of carrying out shear strength tests on notched specimens having different a/w ratios. Analysis of the results has been done to investigate the strength variation and shear strength variation in Mode-II fracture with addition of different percentages of Pumice. Variations of various combinations have been studied.

Properties of Constituent Materials: The constituents used in the present investigation are presented in table 1 and constituent materials are shown in plate 1.

Table 1: Properties of Constituent Materials in M_{20} Grade of Concrete

Sl.No	Name of the material	Properties of material	
1	OPC – 53 Grade	Specific Gravity	3.07
		Initial setting time	33 min
		Final Setting time	489 min
		Fineness	4 %
		Normal consistency	33.50 %
2	Fine Aggregate passing 4.75mm sieve	Specific Gravity	2.60
		Fineness modulus	4.10
3	Coarse Aggregate passing 20 – 10 mm	Specific Gravity	2.68
		Fineness modulus	3.37
		Bulk density compacted	1620 Kg/m^3
4	Pumice Aggregate passing 20-10mm	Specific Gravity	1.14
		Fineness modulus	5.85
		Bulk density compacted	570 Kg/m^3
		Water absorption	21.50 %

Mix Design of Concrete: The concrete mix has been designed for M_{20} grade concrete using ISI method. The mix proportion obtained is 1:1.55:3.04 with constant water cement ratio 0.50.

Test Programme: In this present investigation it is aimed to study the shear strength variations in Mode-II fracture of concrete by modifying the conventional concrete with Pumice in percentages of 0%, 25%, 50%, 75% & 100%, by volume of concrete and designated as mixes P-0, P-25, P-50, P-75 & P-100 respectively as shown in table 2.

Table: 2 Details of Mix Designation

Name of the Mix	Percentage replacement of Pumice aggregate		No of specimens cast	
	Natural Aggregate	Pumice Aggregate	DCN Specimens	Plain Specimens
P-0	100	0	12	3
P-25	75	25	12	3
P-50	50	50	12	3
P-75	25	75	12	3
P-100	0	100	12	3
		Total	60	15

To proceed with the experimental programme initially steel moulds of size 150x150x150 mm with different a/w ratios of 0.3, 0.4 ,0.5, and 0.6 were taken and these moulds were cleaned without dust particles and were brushed with machine oil on all inner faces to facilitate easy removal of specimens afterwards. These moulds are presented in plate 2. To start with, all the materials were weighed in the ratio 1:1.55:3.04. Keeping the volume of concrete constant with saturated and surface dry pumice aggregate was added to concrete in 5 different volumetric fractions to prepare five different mixes which are designated as shown in table 2. First fine aggregate and cement were added and mixed thoroughly and then coarse aggregate with granite and partially replaced Pumice was mixed with them. All of these were mixed thoroughly by hand mixing.

Each time 12 cube specimens with a/w ratios 0.3, 0.4, 0.5, and 0.6 along with 3 plain cubes were cast. Plate 2 shows the arrangement of different notches to suit a/w ratios 0.3, 0.4, 0.5, and 0.6. For all test specimens, moulds were kept on the vibrating table and the concrete was poured into the moulds in three layers, each layer being compacted thoroughly with tamping rod to avoid honey combing. Finally all specimens were vibrated on the table vibrator after filling up the moulds up to the brim. The vibration was effected for 7 seconds and it was maintained constant for all specimens and all other castings. The steel plates forming notches are removed after 3 hour of casting carefully and neatly finished.

However the specimens were demoulded after 24 hours of casting and were kept immersed in a clean water tank for curing. After 28 days of curing the specimens were taken out of water and were allowed to dry under shade for few hours.

V. Testing Of Plain and DCN Specimens

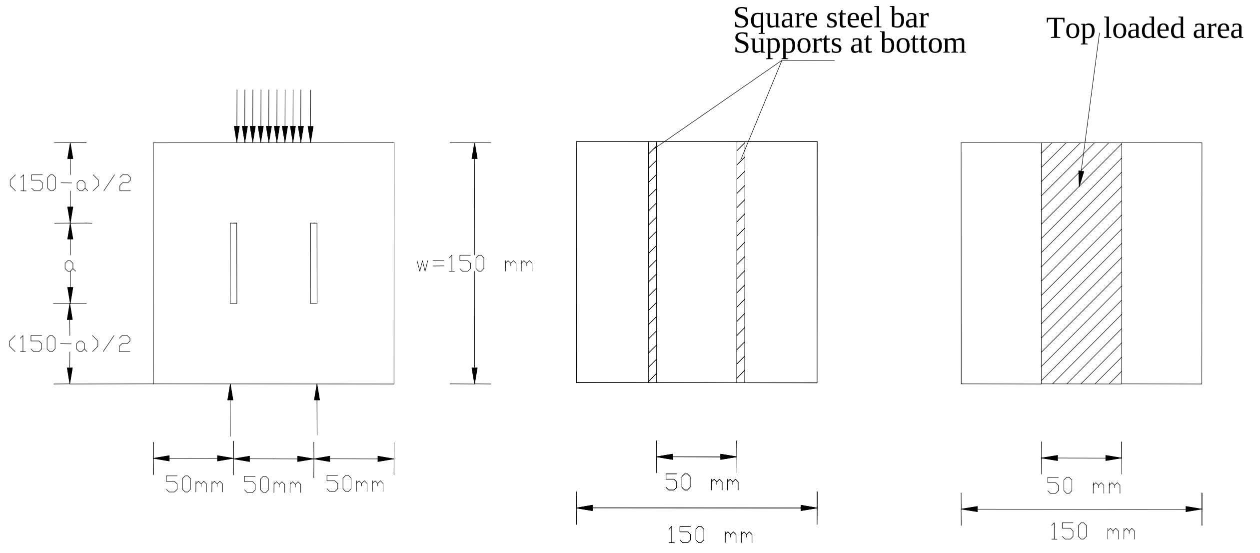
The compression test on the Plain cubes & DCN cubes was conducted on 2000KN digital compression testing machines. The rate of load being applied at 0.1KN/sec.

The specimens after being removed from water were allowed to dry under shade for 24 hours and white washed for easy identification of minute cracks, while testing.

The plain cube specimens were placed on the plate of the hydraulic ram of the compression testing machine such that load was applied centrally. The top plate of the testing machine was brought into contact with the surface of the plain cube specimen to enable loading.

For testing double centered notched (DCN) specimen of size 150x150x150mm, notched were introduced at one third portion centrally as shown in fig 2.

The notch depths provided were 45,60,75 and 90mm running throughout the width of the specimen. Thus the values of a/w ratio were 0.3, 0.4, 0.5, and 0.6 where ‘a’ is the notch depth and ‘w’ is the specimen depth 150mm. The distance between the notches is kept constant at 50mm and width of the notch was 2mm.



(a) Loading and support arrangement in elevation while testing

(b) Bottom view while testing

(c) Top view while testing

Fig 2. Details of DCN test specimen geometry

VI. Discussion of Crack Patterns

In case of cubes under compression initial cracks are developed at top and propagated to bottom with increase in load and the cracks are widened at failure. The crack patterns obtained for DCN specimen geometry for the four notch depths and cement concrete mixes are presented in plates 5 to 9. During testing, for most of the specimens with a/w= 0.3 initial hair line cracks started at the top of one or both the notches, and as the load was increased further, the cracks widened and propagated at an inclination and sometimes to the middle of the top loaded zone. Simultaneously the cracks formed at the bottom of one or both the notches and propagated downwards visible inclination. In some cases cracks branched into two either at the two edges of the supporting square bar at bottom or at the edge of the loaded length at top or at both places.

In a few cases, initial cracks started at the bottom of the one or both notches. As the load was increased propagation of theses cracks at an inclination was observed along with the formation of cracks at top of the notches. These cracks finally propagated toward the middle of the top loaded zone leading to failure of the specimen. Hence failure of the specimens with a/w = 0.3, could be attributed to the flexure cum shear type of failure.

For most of the specimens with a/w = 0.4, 0.5, 0.6, as the load was applied formation of initial hair line cracks at the top of one or both the notches was observed. With the increase of load propagation of these cracks in more or less vertical direction along with the formation of new cracks at the bottom of one or both the notches was observed. Finally the specimens failed by shearing along the notches. In most of the cases the cracks branched into two to join either the two edges of the supporting square bars at bottom or at the edge of the loaded length at top or at both places. In this case also, in a few specimens, initial cracks started at the bottom of one or both the notches. As the load was increased propagation of these cracks in more or less vertical direction along with formation of new cracks at top of the one or both the notches was observed leading to final collapse of the specimens along the notches.

Thus except for some of the specimens of lower notch-depth ratio i.e., 0.3, the specimens of other higher a/w ratios of cement concrete failed all along the notches in more or less vertical fashion.

VII. Discussion of Test Results

Influence of Pumice on Cube Compressive Strength: In the present study the influence of pumice has been studied by replacing it with the natural coarse aggregate in volumetric percentages of 0%, 25%, 50%, 75% and 100%. The variation between cube compressive strength and percentage of pumice replacing the natural aggregate results is as shown in table 3 and the graphical representation of superimposed variation is as shown in fig 3 for 28 days of curing. By observing the table of results as well as graphical representation, with the percentage increase of pumice the cube compressive strength decreases continuously from 0 to 100%. The test set up is presented in plate 3.

Discussion on the Effect of Pumice on DCN Specimens: All the DCN specimens with different a/w ratios i.e., 0.3, 0.4, 0.5, and 0.6 and with different percentage of Pumice i.e., 0%, 25%, 50%, 75%, 100%, were tested in Mode-II arrangement (in-plane shear) as shown in fig 2. The corresponding first crack loads, ultimate loads and the percentage of increase or decrease are presented in table 4 to 7. The In-plane shear stress was calculated by the standard formula.

In-plane shear stress = $\frac{P}{A}$

Where, P = Ultimate or First crack Load in 'N'
A = Shear area in 'mm^2' which is = 2B (w-a).
B = Width or breadth of the specimen = 150 mm
w = Depth of the specimen = 150 mm
a = Notch depth varies i.e 45, 60, 75 and 90mm

The variations of the above parameters versus percentage of pumice are graphically presented in fig 4 to 7. The first crack load and ultimate load in In-plane shear stress is decreased with increase in replacement of percentage of pumice for all A/W ratios from 0.30 to 0.60. The test set up of DCN specimen is presented in plate 4.

Calculation of Stress Intensity Factor (K_{IIC}): The stress intensity factors for cement concrete mixes have been determined using two approaches viz.,(i) Fracture energy approach, (ii) Finite element analysis approach, that is making use of the formulae arrived at through the finite element analysis proposed by Prakash Desayi et al (17).

Fracture-Energy Approach: In this approach, P (load)-δ (displacement) diagrams were plotted to a suitable scale separately for each a/w ratio and for each percentage of Pumice. A sample P-δ diagram is presented in fig 8. In these diagrams the points shown by arrows indicate the loads at first crack and ultimate load. From the P-δ diagrams, the areas included between the X-axis and the P-δ curves were calculated using simpson's 1/3 rule. The areas so obtained are presented in the table 8.

Then the fracture energy (G) was determined as the area under P-δ diagram per unit shear area. The shear area (A) = 2B (W-a)

Where B= width or breadth of the specimen = 150 mm
W= depth of the specimen = 150 mm
a = notch-depth.

From the fracture energy values so obtained, the critical stress intensity factors for Mode-II, K_{IIC} were calculated using the standard relation i.e. $G = K^2_{IIc}(1-\upsilon^2)/E$

Where υ = poison's ratio
E = modulus of elasticity in N/mm^2 = $5000\sqrt{f_{ck}}$
f_{ck} = 28 days cube compressive strength in N/mm².

Finite Element Analysis Approach: In this approach, the expression for K_{IIC} in terms of a/w using the least square curve fitting method done by Prakash Desayi et al (17) was considered as

$K_{IIC}/(P\sqrt{(\pi a)}/2) = 6.881-11.355(a/w)+15.599(a/w)^2-6.33(a/w)^3$

Where P =total load/ loaded area
a =depth of notch
w = depth of DCN specimen = 150mm

Comparing the K_{IIC} values calculated from the two approaches it may be observed that the K_{IIC} values obtained from fracture energy approach are found to be lesser.

VIII. Conclusions

From the limited experimental study the following conclusions are seem to be valid:

1. From the study it is observed that the cube compressive strength is decreased continuously with the increase in percentage of Pumice i.e., from 0% to 100% replacing of conventional aggregate by Pumice aggregate.
2. It is observed that the first crack load as well as ultimate load in mode-II is decreased with the increase in percentage of pumice from 0% to 100%.
3. It is also observed that the first crack load as well as ultimate load in Mode-II is decreased with increased a/w ratios.
4. It is observed that In-plane shear stress at first crack load as well as ultimate load is decreased with increasing percentage of pumice.
5. It is also found that the In-Plane shear stress at first crack load and Ultimate load in Mode-II are decreased with increased a/w ratios.
6. The K_{IIC} values calculated from the fracture energy approach are found to be lesser than those values arrived from Finite element analysis.
7. In both the approaches the K_{IIC} values are found to decrease continuously with the percentage increase in Pumice aggregate content.

Table 3: Cube Compressive Strength Results

S. No	Name of the mix	Percentage replacement of coarse aggregate		Compressive strength (N/mm^2)	Percentage increase or decrease in Cube compressive strength w.r.t. P-0
		Natural coarse aggregate	Pumice aggregate		
1.	P-0	100	0	41.08	0.00
2.	P-25	75	25	34.18	-16.80
3.	P-50	50	50	22.28	-45.76
4.	P-75	25	75	16.12	-60.76
5.	P-100	0	100	12.87	-68.67

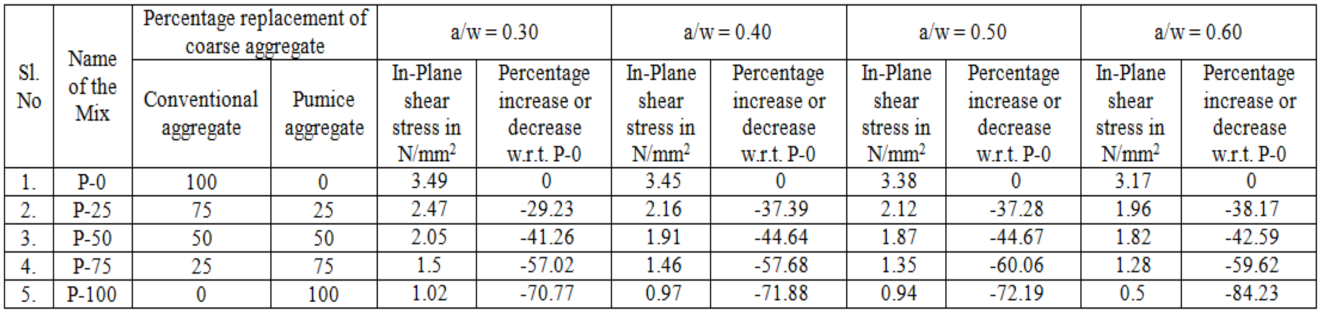
Table 4: First Crack Load and Percentage Increase or Decrease in First Crack Load in Mode-Ii of DCN Specimens with A/W Ratio = 0.30, 0.40, 0.50, 0.60.

Sl. No	Name of the Mix	Percentage replacement of coarse aggregate		a/w = 0.30		a/w = 0.40		a/w = 0.50		a/w = 0.60	
		Conventional aggregate	Pumice aggregate	First crack load in KN	Percentage increase or decrease in First crack load w.r.t. P-0	First crack load in KN	Percentage increase or decrease in First crack load w.r.t. P-0	First crack load in KN	Percentage increase or decrease in First crack load w.r.t. P-0	First crack load in KN	Percentage increase or decrease in First crack load w.r.t. P-0
1.	P-0	100	0	110.00	0.0	93.00	0.0	76.00	0.0	57.00	0.0
2.	P-25	75	25	77.67	-29.39	58.33	-37.28	47.67	-37.28	35.33	-38.02
3.	P-50	50	50	64.67	-41.21	51.67	-44.44	42.00	-44.74	32.67	-42.68
4.	P-75	25	75	47.33	-56.97	39.33	-57.71	30.33	-60.09	23.00	-59.65
5.	P-100	0	100	32.00	-70.91	26.00	-72.04	21.00	-72.37	9.00	-84.21

Table 5: Ultimate Load and Percentage Increase or Decrease in Ultimate Load in Mode-II of DCN Specimens with A/W Ratio = 0.30, 0.40, 0.50, 0.60

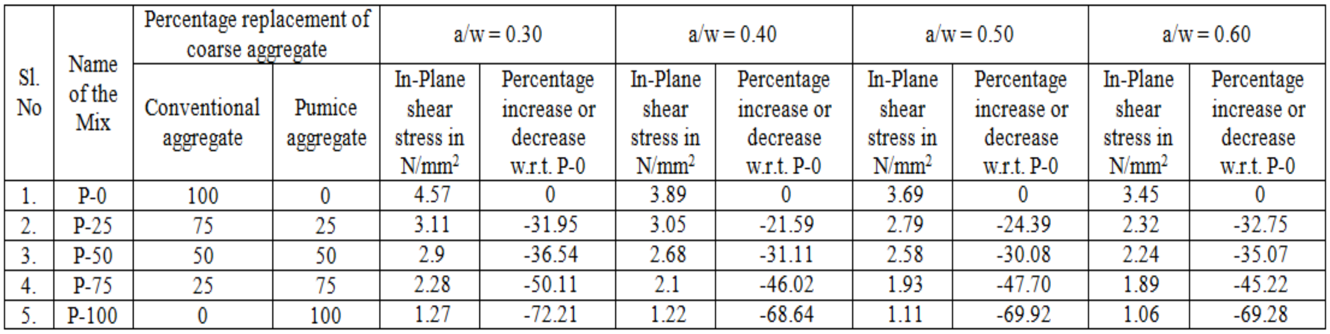
Sl. No	Name of the Mix	Percentage replacement of coarse aggregate		a/w = 0.30		a/w = 0.40		a/w = 0.50		a/w = 0.60	
		Conventional aggregate	Pumice aggregate	Ultimate load in KN	Percentage increase or decrease in Ultimate load w.r.t. P-0	Ultimate load in KN	Percentage increase or decrease in Ultimate load w.r.t. P-0	Ultimate load in KN	Percentage increase or decrease in Ultimate load w.r.t. P-0	Ultimate load in KN	Percentage increase or decrease in Ultimate load w.r.t. P-0
1.	P-0	100	0	144.00	0.0	105.00	0.0	83.00	0.0	62.00	0.0
2.	P-25	75	25	98.00	-31.94	82.33	-21.59	62.67	-24.49	41.67	-32.79
3.	P-50	50	50	91.33	-36.58	72.33	-31.11	58.00	-30.12	40.33	-34.95
4.	P-75	25	75	71.67	-50.23	56.67	-46.03	43.33	-47.80	34.00	-45.16
5.	P-100	0	100	40.00	-72.22	33.00	-68.57	25.00	-69.88	19.00	-69.35

Table 6: In-Plane Shear Stress and Percentage Increase Of Decrease in In-Plane Shear Stress at First Crack Load in Mode-II of DCN Specimens with A/W Ratio = 0.30, 0.40, 0.50, 0.60



Sl. No	Name of the Mix	Percentage replacement of coarse aggregate		a/w = 0.30		a/w = 0.40		a/w = 0.50		a/w = 0.60	
		Conventional aggregate	Pumice aggregate	In-Plane shear stress in N/mm^2	Percentage increase or decrease w.r.t. P-0	In-Plane shear stress in N/mm^2	Percentage increase or decrease w.r.t. P-0	In-Plane shear stress in N/mm^2	Percentage increase or decrease w.r.t. P-0	In-Plane shear stress in N/mm^2	Percentage increase or decrease w.r.t. P-0
1.	P-0	100	0	3.49	0	3.45	0	3.38	0	3.17	0
2.	P-25	75	25	2.47	-29.23	2.16	-37.39	2.12	-37.28	1.96	-38.17
3.	P-50	50	50	2.05	-41.26	1.91	-44.64	1.87	-44.67	1.82	-42.59
4.	P-75	25	75	1.5	-57.02	1.46	-57.68	1.35	-60.06	1.28	-59.62
5.	P-100	0	100	1.02	-70.77	0.97	-71.88	0.94	-72.19	0.5	-84.23

Table 7: In-Plane Shear Stress and Percentage Increase Of Decrease in In-Plane Shear Stress at Ultimate Load in Mode-II of DCN Specimens with A/W Ratio = 0.30, 0.40, 0.50, 0.60.



Sl. No	Name of the Mix	Percentage replacement of coarse aggregate		a/w = 0.30		a/w = 0.40		a/w = 0.50		a/w = 0.60	
		Conventional aggregate	Pumice aggregate	In-Plane shear stress in N/mm^2	Percentage increase or decrease w.r.t. P-0	In-Plane shear stress in N/mm^2	Percentage increase or decrease w.r.t. P-0	In-Plane shear stress in N/mm^2	Percentage increase or decrease w.r.t. P-0	In-Plane shear stress in N/mm^2	Percentage increase or decrease w.r.t. P-0
1.	P-0	100	0	4.57	0	3.89	0	3.69	0	3.45	0
2.	P-25	75	25	3.11	-31.95	3.05	-21.59	2.79	-24.39	2.32	-32.75
3.	P-50	50	50	2.9	-36.54	2.68	-31.11	2.58	-30.08	2.24	-35.07
4.	P-75	25	75	2.28	-50.11	2.1	-46.02	1.93	-47.70	1.89	-45.22
5.	P-100	0	100	1.27	-72.21	1.22	-68.64	1.11	-69.92	1.06	-69.28

Table 8: Variation between K_{IIC} Verses $a/_{w}$ Ratio Using Formula Obtained From Fracture Energy Approach and Finite Element Analysis

S. No	Name of the mix	Percentage by volume replacement of coarse aggregate		f_{ck} N/mm^2	$a/_{w}$ ratio	Area under p-δ diagram KN-mm	Stress Intensity factor (K_{IIC}) $MN/m^{3/2}$	
		Natural Coarse aggregate	Percentage of Pumice				From Fracture energy	From finite element analysis
1.	P-0	100	0	41.08	0.3	97.980	10.06	24.02
					0.4	57.920	8.36	19.03
					0.5	33.990	7.01	16.37
					0.6	28.105	7.13	13.41
2.	P-25	75	25	34.18	0.3	54.858	7.19	16.35
					0.4	40.238	6.65	14.93
					0.5	30.459	6.34	12.37
					0.6	23.930	6.28	9.02
3.	P-50	50	50	22.28	0.3	42.043	5.66	15.24
					0.4	40.417	5.99	13.12
					0.5	26.785	5.95	11.44
					0.6	20.375	5.21	8.73
4.	P-75	25	75	16.12	0.3	41.978	5.21	11.96
					0.4	38.405	5.38	10.28
					0.5	22.903	4.55	8.55
					0.6	19.850	4.74	7.36
5.	P-100	0	100	12.87	0.3	29.800	4.15	6.67
					0.4	22.610	3.90	5.98
					0.5	9.315	2.75	4.93
					0.6	8.030	2.85	4.11

REFERENCES

[1] Agarwal, B.D. and Giare, G.S., “Fracture toughness of short-fiber composites in Modes-I and II”, Engineering Fracture Mechanics, Vol. 15, No. 1, 1981, pp.219-230.

[2] Bazant , Z.,p, and Pfeiffer, P.A., “Shear fracture tests of concrete”, materials and structures (RKLEM) , 1984, vol. 19, pp.111-121.

[3] Bazant , Z.,p, and Pfeiffer, P.A., “Tests on shear fracture and strain softening in concrete”, proceedings of second symposium on interaction of Non-nuclear Munition with structures Florida, USA, April 1985, pp. 254-264.

[4] Bhaskar Desai . V, “Some studies on Mode - II fracture and stress – strain behavior in shear of cementitious materials”, Ph.D thesis, Indian Institute of Science, Banglore”.

[5] Prakash Desayi, Raghu Prasad .B.K, and Bhaskar Desai . V, “Experimental determination of K_{IIc} from compliance and fracture energy”, proceedings national seminar on Aerostructures, organized by IIT, Kanpur, India, 29-30, Dec, 1993, pp. 33-34.

[6] Prakash desayi, B.K.Raghu Prasad and V.Bhaskar Desai, “Mode – II fracture of cementitious materials- part – I : Studies on specimens of some new geometries”, Journal of Structural Engineering, Vol.26, No.1, April 1999, pp.11-18.

[7] Prakash desayi, B.K.Raghu Prasad and V.Bhaskar Desai, “Mode – II fracture of cementitious materials- part – II: Fracture toughness of cement paste, mortar, concrete and no-fines concrete. Journal of structural engg Vol. 26, No. 1, April 1999, pp. 19-27.

[8] Prakash desayi, B.K.Raghu Prasad and V.Bhaskar Desai, “Mode – II fracture of cementtiotus materials- part – III: Studies on shear strength and slip of cement paste, mortar, concrete and no-fines concrete. Journal of structural engg Vol. 26, No.2, July 1999, pp. 91-97.

[9] Prakash desayi, B.K.Raghu Prasad and V.Bhaskar Desai, conducted Mode-II fracture of cementitious materials- part-IV: Fracture toughness, shear strength and slip of fibre reinforced cement mortar and concrete. Journal of structural engg. Vol. 26, No. 4, Jan 2000, pp. 267-273.

[10] Prakash desayi, B.K.Raghu Prasad and V.Bhaskar Desai, conducted Mode-II fracture of cementitious materials- part-V: Size effect on fracture toughness shear strength and slip of cement mortar and concrete reinforced with and without fibers. Journal of structural engg, Vol, 27, No. 2, July 2000, pp.99-104.

[11] V. Bhaskar Desai, D. Jagan Mohan, V. Vijay kumar, “ Some studies on strength properties of Metallic aggregates”, Proceedings of the International conference on advance in concrete composites and structures, January 2005, pp. 235-246.

[12] V. Bhaskar Desai, K. Balaji Rao, D. Jagan Mohan, “Some studies on Mode-II fracture of heavy weight Metallic aggregate cement concrete”, An International Research of Engineering sciences and technologies, Vol. 1, No. 2, October 2008, pp. 41-47.

[13] V. Bhaskar Desai, K. Balaji Rao, D. Jagan Mohan, “experimental investigations on Mode-II fracture of concrete with crushed granite stone fine aggregate replacing sand”, Materials research, received March 2011.

[14] K. Balaji Rao, V. Bhaskar Desai, D. Jagan Mohan, “Probabilistic analysis of Mode-II Fracture of Concrete with crushed granite stone fine aggregate replacing sand”, Construction and building Materials, Vol. 27, No, 1, Febrauary 2012, pp. 319-330.

[15] Owens, P.L. (1993). “Light weight aggregates for structural concrete,” Structural Light weight Aggregate Concrete, Chapman & Hall, London, pp.1-18.

[16] L. Cavaleri , N. Miraglia and M. Papia, “Pumice Concrete for structural wall panels”, Engineering structures, Vol. 25, No. 1,Jan 2003, pp. 115-125.

[17] Bhaskar Desai. V, “Some studies on Mode - II fracture and stress – strain behavior in shear of cementitious materials”, Ph.D thesis, Indian Institute of Science, Bangalore”.

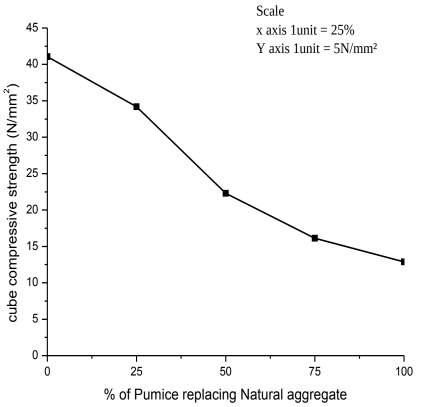


Fig 3: Variation between Cube compressive strength and percentage of Pumice replacing Natural aggregate

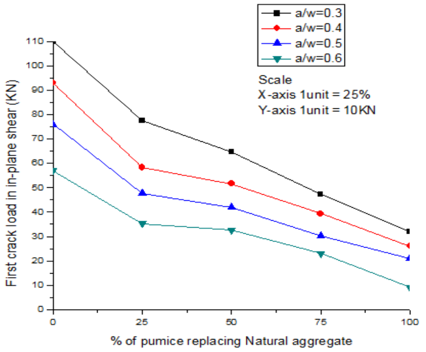


Fig 4: Variation between first crack load in in-Plane shear and Percentage of Pumice replacing Natural aggregate with a/w=0.3,0.4,0.5,0.6

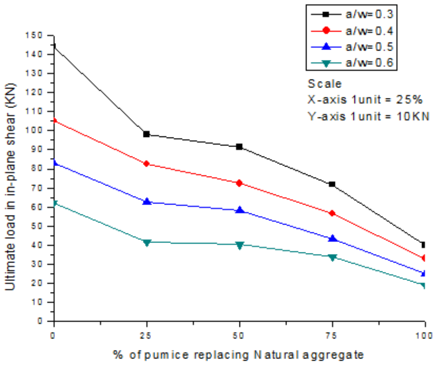


Fig 5: Variation between ultimate load in in-Plane shear and percentage of Pumice replacing Natural aggregate with a/w=0.3,0.4,0.5,0.6

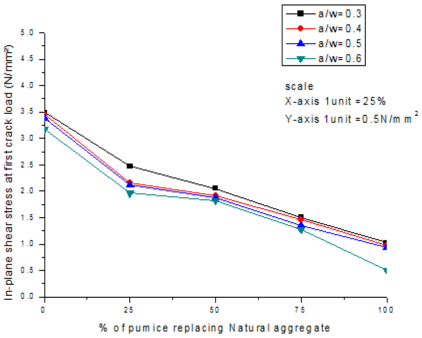


Fig 6: Super imposed variation between in-Plane shear stress at first crack load and percentage of Pumice replacing Natural aggregate with a/w=0.3,0.4,0.5,0.6

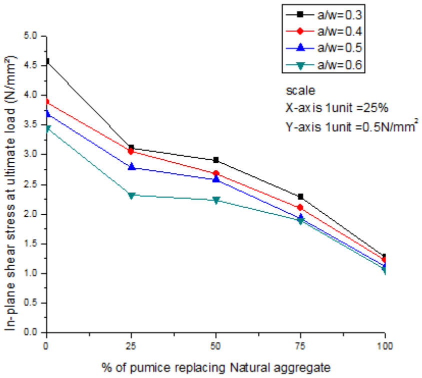


Fig 7: Super imposed variation between in-Plane shear stress at ultimate load and Percentage of Pumice replacing Natural aggregate with a/w=0.3,0.4,0.5,0.6

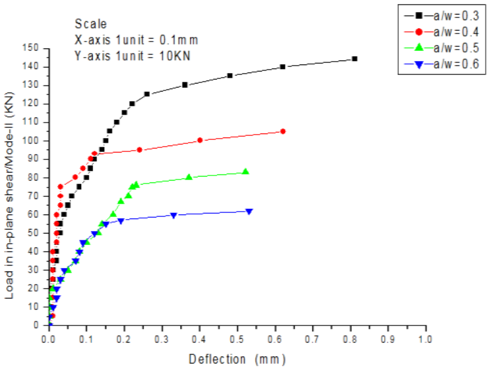


Fig 8: Super imposed variation between In-plane shear load and deflection for 0 % Pumice replacing natural aggregate with a/w=0.3,0.4,0.5,0.6

Plate 1. Ingredients of concrete

Plate. 2 View of the moulds with double centered notches

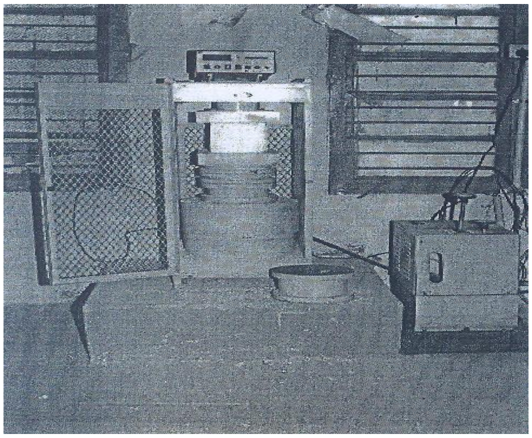


Plate 3. Test setup for cube compressive strength test

Plate 4. Test setup for DCN specimen

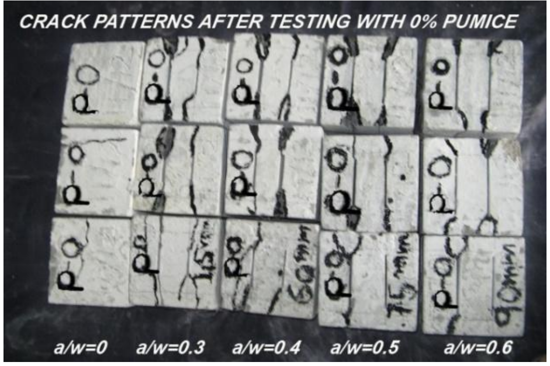


Plate 5. Crack pattern of the specimens after testing with 0% of pumice

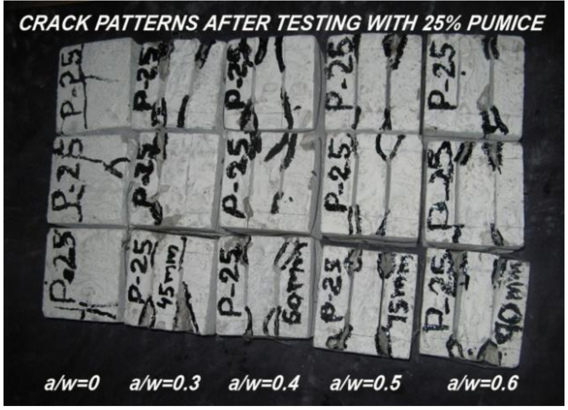


Plate 6. Crack pattern of the specimens after testing with 25% of pumice

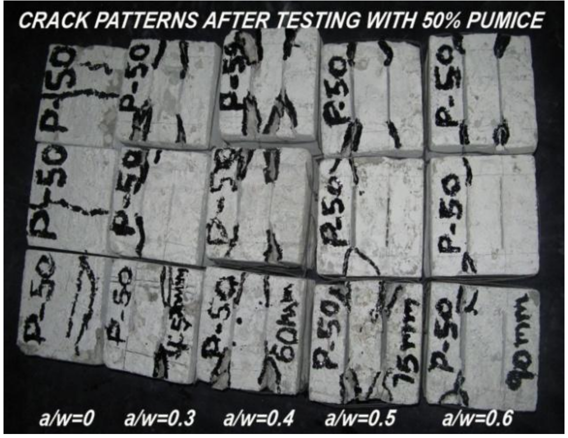


Plate 7. Crack pattern of the specimens after testing with 50% of pumice

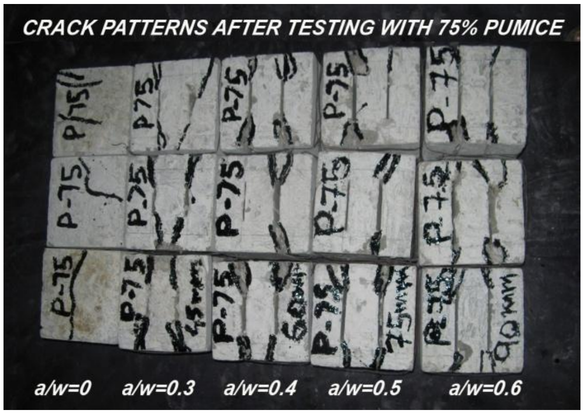


Plate 8. Crack pattern of the specimens after testing with 75% of pumice

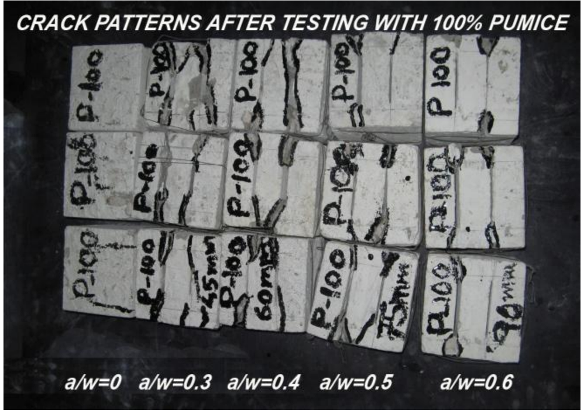


Plate 9. Crack pattern of the specimens after testing with 100% of pumice