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# Some Studies on Mode-Ii Fracture Of Artificial Light Weight Wood Ash Pelletized Aggregate Concrete

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***ABSTRACT :*** *The recent advancements in the construction industry necessitate the development of new materials which have high performance than the ordinary conventional concrete. In the present scenario light weight aggregate has been the subject of extensive research which affects the shear strength properties of cement concrete. The adaptation of certain class of light weight concrete gives an outlet for industrial waste which would otherwise create problem for disposal. An attempt has been made to prepare artificial light weight aggregate concrete by using pelletized wood ash aggregate. 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. This area has received greater attention in recent years due to various attempts which have been made to develop Mode-II (sliding shear) test specimen geometries for investigating the shear type of failures in cementitous materials. In this area number of test specimen geometries is proposed for Mode-II fracture of cementitous materials. Out of these the best suited is suggested as Double Centered Notched (DCN) specimen geometry proposed by Sri Prakash Desai and Sri Bhaskar Desai.In this present experimental investigation an attempt is made to study the Mode II fracture properties of light weight aggregate concrete made with Wood ash pellets. The Wood ash pellets were prepared by mixing of 47% Wood ash, 47% lime, 6% cement and 12.50% of water by overall weight of the sample, using pelletization machine. By varying the percentages of Wood ash pellets in concrete replacing the conventional granite aggregate in percentages of 0, 25, 50, 75, 100 by volume of concrete, different mixes were prepared. The property of in plane shear strength is studied by casting and testing around 150 samples consisting of 120 notched specimens of size 150mm x150mm x 150mm with different notch depth ratios and 30 no of plain cubes of size 150 x 150 x 150mm for testing after 28 days and 90 days of curing to study about long term effect beyond 28 days.*

***KEY WORDS:*** *light weight aggregate, Mode II fracture, shear strength, wood ash pettlets.*

## I. INTRODUCTION:

Due to continuous usage of naturally available aggregates within short length of time these natural resources get depleted and it will be left nothing for future generations. Hence there is a necessity for preparing artificial aggregates making use of waste materials from agricultural produce and industrial wastes. From the earlier studies it appears that much less attention has been made towards the study of using artificial coarse aggregate. An attempt has been made to use wood ash as the basic ingredient in preparing artificial coarse aggregate which is also light in nature.

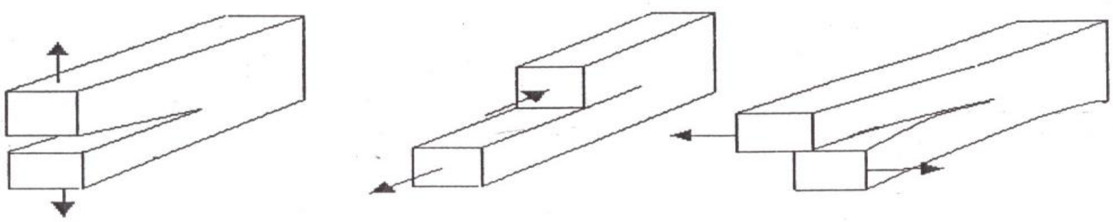
**ARTIFICIAL LEIGHT WEIGHT AGGREGATE:** The production of concrete requires aggregate as inert filler to provide bulk volume as well as stiffness. Crushed aggregate are normally used in concrete which can be depleting the natural resources and necessitates an alternate building material. This led to widespread research on using a viable waste material as aggregate. Wood ash is one promising material which can be used as both cementitous materials as well as to produce light weight aggregate. The use of cost effective construction materials has accelerated in recent times due to the increase in demand of light weight concrete for mass applications. This necessitates the complete replacement or partial replacement of concrete constituents to bring down the escalating construction costs. In recent times, the addition of artificial aggregate has shown a reasonable cut down in the construction costs and had gained good attention due to quality on par with conventional aggregate. Despite of its lower compressive strength and lower modulus elasticity, Wood ash concrete can be potentially used in many kinds of structural elements. Lightweight aggregate, due to their cellular structure, can absorb more water than normal weight aggregates.

In a 24-hour absorption test, they generally absorb 5 to 20% by mass of dry aggregate, depending on the pore structure of the aggregate. Normally, under conditions of outdoor storage in stockpiles, total moisture content does not exceed two-thirds of that value. Due to this more absorption of water by lightweight aggregate, internal curing will be maintained for a longer period.

## II. PELLETIZING PROCESS:

The desired grain size distribution of an artificial light weight aggregate is by means of agglomeration process. The Pelletization process is used to manufacture light weight Coarse aggregate. Some of the parameters need to be considered for the efficiency of the production of pellets are speed of revolution of pelletizer disc, moisture content, angle of pelletizer disc and duration of Pelletization (HariKrishnan and RamaMurthy, 2006)[1]. The different types of pelletizer machine were used to make the pellets such as disc or pan type, drum type, cone type and mixer type. With mixer type pelletizer small grains are formed initially and are subsequently increased. In the cold bonded method increase of strength of pellets is by increase of the Wood ash/ lime & cement ratio by weight. Moisture content and angle of drum parameter also influence the size growth of pellets. The dosage of binding agent is more important for making the Wood ash balls. Initially some percentage of water is added in the binder and remaining water is sprayed during the rotation Period because while rotating without water in the drum the Wood ash and binders (Lime & Cement) tend to form lumps and does not increase the even distribution of particle size. The pellets are formed approximately in duration of 6 to 7 minutes. The cold bonded pellets are hardened by normal water curing method. The setup of machine for manufacture of Wood ash aggregate is as shown in plate 1.

**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**

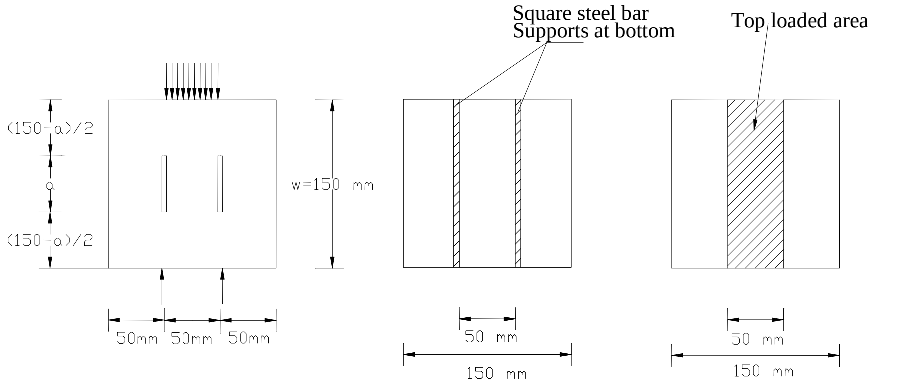
**Fig.1: Different modes of cracking**

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. With the inter disciplinary research and development in material science and engineering have lead to the development of several important composite construction materials such as concrete made with partial replacement of conventional aggregate by light weight aggregate such as pumice. In this present experimental investigation an attempt made to study the Mode-II fracture properties of light weight aggregate concrete, such as Wood ash aggregate concrete since in recent years an attempt has been made only on normal aggregate, on partial replacement of normal concrete with heavy weight aggregate etc.

## III. REVIEW OF LITERATURE:

A brief review 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. Aggarwal and Giare (2) investigated that critical strain energy release rate in Mode-II is less than half of that 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 (3,5) 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. Watekins and Liu (4) conducted the finite element analysis technique simulating in-plane shear mode, Mode II, has been used to analyse fracture behaviour in a short shear beam specimen in plain concrete and fracture toughness, $K_{IIC}$ values are determined. Devies et al (6) conducted tests on mortar cubes subjected to shear loading, and both analytical and experimental approaches are used in evaluating the fracture toughness of mortar. Davies (7) conducted numerical study of punch-through shear specimen in analysis and the average values for $K_{IIC}$ in compression shear were found in the range of 1.8 to 2.0 $MNm^{-3/2}$. Bhaskar Desai. V, Balaji Rao. K, Jagan Mohan. D (8) 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 ($K_{IIC}$) were calculated from the theoritical equations suggested by the earlier researchers and were compared with those obtained from load verses deflection (p-δ) diagrams. The details of DCN specimen geometry are presented in fig 2.




(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**

## IV. EXPERIMENTAL INVESTIGATION

Mix design has been conducted for $M_{20}$ concrete making use of ISI method of mix design using normal constituents of concrete. An experimental study has been conducted on concrete with partial to complete replacement of conventional coarse aggregate i.e., Granite by light weight aggregate i.e., Wood ash Aggregate to know the shear strength using Double Centered Notched (DCN) specimens having different a/w ratios of 0.30, 0.40, 0.50 and 0.60. Analysis of the results has been done to investigate the shear strength variation in Mode-II fracture with addition of different percentages of Wood ash Aggregate. Variations of various combinations have been studied. The constituent materials are used in the present investigation are presented in table.1.

**CONSTITUENT MATERIALS:** The constituent materials used in the present investigation for making artificial light weight aggregate are wood ash, lime, cement, conventional aggregate and pelletzed wood ash aggregate.

**TABLE 1: PROPERTIES OF CONSTITUENT MATERIALS IN $M_{20}$ GRADE CONCRETE**

| Sl.No | Name of the material | Properties of material | |
|---|---|---|---|
| 1 | OPC – 53 Grade | Specific Gravity | 3.07 |
| | | Initial setting time | 60 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 | 4.35 |
| | | Compacted density | 1766 $kg/m^3$ |
| | | Loosest density | 1500 $kg/m^3$ |

| | | | |
|---|---|---|---|
| 3 | Coarse Aggregate passing 20 – 10 mm | Specific Gravity | 2.68 |
| | | Fineness modulus | 4.63 |
| | | Bulk density compacted | 1620 Kg/m$^3$ |
| | | Bulk density loosest | 1480 kg/m$^3$ |
| 4 | Wood ash pelletized Aggregate passing 20 – 10 mm | Specific Gravity | 1.68 |
| | | Fineness modulus | 5.49 |
| | | Bulk density compacted | 1105 kg/m$^3$ |
| | | Bulk density loose | 1056 kg/m$^3$ |

The constituent material of WA aggregate is presented plate 2.

**TEST PROGRAMME:** In this present investigation it is aimed to study the Mode-II fracture properties of concrete by modifying the conventional aggregate with Wood ash aggregate which is replaced in percentages of 0%, 25%, 50%, 75% & 100%, by volume/weight of natural aggregate in concrete and designated as mixes WA-0, WA-25, WA-50, WA-75 & WA-100 respectively as shown in table 2.

**MIXING, CASTING AND CURING:**The mix adopted here is $M_{20}$ designed mix concrete with the mix proportion of 1:1.55:3.04 with constant water cement ratio of 0.5. Keeping the volume of concrete constant, first fine aggregate and cement were added and then granite coarse aggregate and partially replaced pre wetted surface dry wood ash aggregate was added to concrete in 5 different volumetric fractions to prepare five different mixes which are designated as shown in table 2.

**TABLE: 2 DETAILS OF MIX DESIGNATION**

| Name of the Mix | Replacement of Coarse Aggregate by Volume percentage | | No of specimens cast | |
|---|---|---|---|---|
| | Natural Aggregate | Pelletized Wood ash Aggregate | DCN specimens | Plain specimens |
| WA- 0 | 100 | 0 | 24 | 6 |
| WA- 25 | 75 | 25 | 24 | 6 |
| WA- 50 | 50 | 50 | 24 | 6 |
| WA- 75 | 25 | 75 | 24 | 6 |
| WA- 100 | 0 | 100 | 24 | 6 |
| | | Total | 120 | 30 |

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. Plate 3 and 4 shows the cubes and DCN specimens respectively after casting. The steel plates forming notches were removed after 3 hours of casting carefully and neatly finished . However the specimens were de moulded after 24 hours of casting and were kept immersed in a clean water tank for curing. After 28 and 90 days of curing the specimens were taken out of water and were allowed to dry under shade for few hours.

**TESTING OF SPECIMENS:**

**COMPRESSION TEST ON PLAIN CUBES:** Compression test is done as per IS: 516-1959. All the concrete specimens were tested in a 3000KN capacity automatic compression testing machine with 0.5KN/sec rate of loading until the specimens are crushed. Concrete cubes of size 150mm x150mm x 150mm are tested for compressive strength. The displacements were automatically recorded through 3000KN digital compression testing machine. The maximum load applied to the specimens has been recorded and dividing the failure load by the area of the specimen, the compressive strength has been calculated. The test set up of 3000KN compression testing machine with specimens as shown in plate 5.

Compressive strength = $\frac{Load}{Area}$ in N/mm$^2$

Variations of cube compressive strength with various percentage replacements of wood ash replacement of natural aggregate in concrete for 28 and 90 days curing has been calculated and variations are recorded vide table 3, and graphically super imposed variations are represented for the above periods vide fig 3.

**MODE-II FRACTURE TEST ON DCN SPECIMENS:** The Mode-II fracture test on the double centered notched cubes was conducted in 3000KN digital high arm compression testing machine. The rate of loading was applied at 0.5KN/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.

For testing double centered notched (DCN) specimen of size 150x150x150mm, supports in the form of square steel bar throughout the width were introduced at one third portion slightly away from notches as shown in fig 2. Uniformly distributed load was applied over the central one third part between the notches and steel supports of square cross section were provided at bottom slightly along the outer edges of the central 1/3 portion so that it could get punched and sheared through along the notches on the application of loading. The test set up is shown vide plate 7.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.For Double centered notch specimens the ultimate loads were recorded through 3000KN high arm digital compression testing machine. The test results were recorded vide table no 4 to 7 for ultimate load in Mode-II for DCN samples with a/w ratios of 0.3, 0.40, 0.50 & 0.60. Superimposed Variations for percentage of Wood ash aggregate replacing natural aggregate and ultimate load for 28 and 90 days are represented graphically vide fig 4 & 5. Also Superimposed Variations for percentage of Wood ash aggregate replacing natural aggregate and in-plane shear stress for 28 and 90 days are represented graphically vide fig 6 & 7.

## V. DISCUSSION OF TEST RESULTS:

**INFLUENCE OF PELLETIZED WOOD ASH AGGREGATE ON CUBE COMPRESSIVE STRENGTH:** In the present study Wood ash aggregate has been replaced by natural aggregate in volumetric percentages of 0, 25%, 50%, 75% and 100%. The variation of compressive strength versus percentage replacement of Wood ash aggregate with natural aggregate is presented in table 3 and superimposed graphical variation for the two periods of curing are represented in fig 3. From this figure and table, it is observed that the decrease in compressive strength of concrete with 100 % replacement of Wood ash aggregate with natural aggregate is 77.82 % at 28 days and 71.45% at 90 days of curing. The cube compressive strength is found to increase considerably from 28 days to 90 days of curing. The target mean strength of $M_{20}$ grade of concrete i.e., 26.6 N/mm² has been found to be achieved when the natural aggregate is replaced even with 25% of Wood ash aggregate after 90 days of curing as tabulated in table 3.

**INFLUENCE OF PELLETIZD WOOD ASH AGGREGATE ON ULTIMATE LOAD:**

All the DCN specimens with different a/w ratios i.e., 0.3, 0.4, 0.5, and 0.6 and with different percentages of Wood ash aggregates i.e., 0%, 25%, 50%, 75%, 100%, were tested with load in Mode-II (in-plane shear). The variations of ultimate loads versus percentage of Wood ash aggregate replacement of natural aggregate in concrete are presented in the tables 4 to 7.Super imposed variation of percentage decrease in ultimate load verses percentage of Wood ash aggregate replacement of natural aggregate in concrete are represented vide fig 4 & 5 for different a/w ratios (i.e., 0.3, 0.4, 0.5, 0.6). From the above figs, it may be observed that with the addition of Wood ash aggregate the ultimate load in in-plane shear of the specimens decreases continuously up to 100% replacement of natural aggregate by Wood ash aggregates and increases with age i.e. from 28 days to 90 days of curing.

**INFLUENCE OF PELLETIZD WOOD ASH AGGREGATE ON IN-PLANE SHEAR STRESS:** The In-plane shear stress at ultimate load for different percentage replacements of Wood ash aggregate (0-100%) and for different notch depth ratios for 28 and 90 days are presented in tables 4 to 7. Also the super imposed variations of in-plane shear stress versus percentage replacement of Wood ash aggregate with a/w ratios of 0.3, 0.40, 0.50 and 0.60 are presented vide fig 6 & 7 for 28 and 90 days curing. It is observed that In-plane shear stress is decreasing continuously with the increase in percentage replacement of conventional granite aggregate by Wood ash aggregate (i.e., 0%, 25%, 50%, 75%, 100%) and increasing with age from 28 to 90 days of curing for notch depth ratios of 0.30, 0.40, 0.50 and 0.60.

**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 (8).

**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 WA aggregate. A sample P-δ diagram is presented in fig 8. 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 $\upsilon$ = poison's ratio
E = modulus of elasticity in $N/mm^2 = 5000\sqrt{f_{ck}}$
$f_{ck}$ = 28 days cube compressive strength in $N/mm^2$.

## 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 (8) 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.

**TABLE 3: CUBE COMPRESSIVE STRENGTH**

| Sl. No | Name of the mix | Percentage by volume replacement of coarse aggregate | | Compressive strength $N/mm^2$ | | Percentage of decrease in compressive strength | |
|---|---|---|---|---|---|---|---|
| | | Natural aggregate | Pelletized Wood ash Aggregate | 28 Days | 90 days | 28 Days | 90 days |
| 1 | WA-0 | 100 | 0 | 41.08 | 47.39 | 0.00 | 0.00 |
| 2 | WA-25 | 75 | 25 | 20.93 | 35.02 | -49.05 | -23.21 |
| 3 | WA-50 | 50 | 50 | 16.93 | 18.74 | -58.79 | -60.46 |
| 4 | WA-75 | 25 | 75 | 13.32 | 14.93 | -67.58 | -68.50 |
| 5 | WA-100 | 0 | 100 | 9.11 | 13.53 | -77.82 | -71.45 |

**TABLE 4: ULTIMATE LOAD AND PERCENTAGE OF INCREASE OR DECREASE IN ULTIMATE LOAD IN MODE-II OF DCN SPECIMENS WITH a/w= 0.3 & 0.40**

| Sl. No | Name of the mix | Percentage by volume replacement of coarse aggregate | | Ultimate load in KN ( a/w= 0.30 ) | | Percentage of increase or decrease in Ultimate load of N.A. | | Ultimate load in KN (a/w= 0.40 ) | | Percentage of increase or decrease in Ultimate load of N.A. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Natural aggregate | Pelletized Wood ash Aggregate | 28 days | 90 days | 28 days | 90 days | 28 days | 90 days | 28 days | 90 days |
| 1 | WA-0 | 100 | 0 | 144.00 | 194.67 | 0.00 | 0.00 | 105.00 | 138.00 | 0.00 | 0.00 |
| 2 | WA-25 | 75 | 25 | 142.00 | 182.33 | -1.39 | -6.34 | 103.89 | 121.67 | -1.06 | -11.83 |
| 3 | WA-50 | 50 | 50 | 108.67 | 131.67 | -24.53 | -32.36 | 102.67 | 119.00 | -2.22 | -13.77 |
| 4 | WA-75 | 25 | 75 | 94.00 | 99.33 | -31.02 | -51.71 | 74.00 | 86.67 | -29.52 | -37.20 |
| 5 | WA-100 | 0 | 100 | 65.33 | 67.67 | -53.01 | -66.44 | 63.00 | 76.33 | -40.00 | -44.69 |

**TABLE 5: PERCENTAGE OF INCREASE OR DECREASE IN ULTIMATE LOAD IN MODE-II OF DCN SPECIMENS WITH a/w= 0.50 & 0.60**

| Sl. No | Name of the mix | Percentage by volume replacement of coarse aggregate | | Ultimate load in KN ( a/w= 0.50 ) | | Percentage of increase or decrease in Ultimate load of N.A. | | Ultimate load in KN (a/w= 0.60 ) | | Percentage of increase or decrease in Ultimate load of N.A. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Natural aggregate | Pelletized Wood ash Aggregate | 28 days | 28 days | 90 days | 28 days | 90 days | 28 days | 90 days | 28 days |
| 1 | WA-0 | 100 | 0 | 116.00 | 124.67 | 0.00 | 0.00 | 90.33 | 95.67 | 0.00 | 0.00 |
| 2 | WA-25 | 75 | 25 | 95.00 | 125.67 | -18.10 | -2.92 | 88.67 | 92.33 | -1.84 | -3.49 |
| 3 | WA-50 | 50 | 50 | 93.33 | 95.00 | -19.54 | -24.41 | 78.33 | 82.00 | -13.28 | -14.29 |
| 4 | WA-75 | 25 | 75 | 70.67 | 73.00 | -39.08 | -38.73 | 64.00 | 72.33 | -29.15 | -24.40 |
| 5 | WA-100 | 0 | 100 | 57.33 | 70.67 | -50.58 | -47.48 | 51.67 | 55.00 | -42.80 | -42.51 |

**TABLE 6: IN-PLANE SHEAR STRESS (MODE-II) FOR DCN SPECIMENS WITH a/w= 0.30 & 0.40 WITH PERCENTAGE DECREASE**

| Sl. No | Name of the mix | Percentage by volume replacement of coarse aggregate | | In-plane shear stress in N/mm$^2$ ( **a/w= 0.30** ) | | Percentage of increase or decrease in Ultimate load with N.A. | | In-plane shear stress in N/mm$^2$ ( **a/w= 0.40**) | | Percentage of increase or decrease in Ultimate load with N.A. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Natural aggregate | Pelletized Wood ash Aggregate | 28 days | 90 days | 28 days | 90 days | 28 days | 90 days | 28 days | 90 days |
| 1 | WA-0 | 100 | 0 | 4.57 | 6.18 | 0.00 | 0.00 | 5.21 | 5.32 | 0.00 | 0.00 |
| 2 | WA-25 | 75 | 25 | 3.50 | 5.79 | -30.57 | -6.74 | 3.89 | 5.26 | -33.93 | -1.14 |
| 3 | WA-50 | 50 | 50 | 3.45 | 4.18 | -32.46 | -47.85 | 3.80 | 5.11 | -37.11 | -4.11 |
| 4 | WA-75 | 25 | 75 | 2.98 | 2.99 | -53.36 | -106.69 | 2.83 | 2.83 | -84.10 | -87.99 |
| 5 | WA100 | 0 | 100 | 2.07 | 2.73 | -120.77 | -126.37 | 2.33 | 2.74 | -123.61 | -94.16 |

**TABLE 7: IN-PLANE SHEAR STRESS (MODE-II) FOR DCN SPECIMENS WITH a/w= 0.50 & 0.60 WITH PERCENTAGE DECREASE**

| Sl. No | Name of the mix | Percentage by volume replacement of coarse aggregate | | In-plane shear stress in N/Sq.mm ( **a/w= 0.50** ) | | Percentage of increase or decrease in Ultimate load with N.A. | | In-plane shear stress in N/Sq.mm ( **a/w= 0.60** ) | | Percentage of increase or decrease in Ultimate load with N.A. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Natural aggregate | Pelletized Wood ash Aggregate | 28 days | 90 days | 28 days | 90 days | 28 days | 90 days | 28 days | 90 days |
| 1 | WA-0 | 100 | 0 | 5.16 | 5.58 | 0.00 | 0.00 | 5.48 | 6.80 | 0.00 | 0.00 |
| 2 | WA-25 | 75 | 25 | 4.15 | 5.54 | -24.34 | -0.72 | 4.56 | 5.31 | -20.18 | -28.06 |
| 3 | WA-50 | 50 | 50 | 3.69 | 4.62 | -39.84 | -20.78 | 4.02 | 4.35 | -36.32 | -56.32 |
| 4 | WA-75 | 25 | 75 | 3.14 | 3.14 | -64.33 | -77.71 | 3.45 | 3.55 | -58.84 | -91.55 |
| 5 | WA100 | 0 | 100 | 2.55 | 2.62 | -102.35 | -112.98 | 2.87 | 3.06 | -90.94 | -122.22 |

**TABLE 8. VARIATION BETWEEN $K_{IIC}$ VERSES a/w RATIO USING FORMULA OBTAINED FROM FRACTURE ENERGY APPROACH AND FINITE ELEMENT ANALYSIS FOR 28 & 90 DAYS CURING PERIOD**

| Sl. No | Name of the mix | Percentage by volume replacement of coarse aggregate | | a/w Ratio | Area under p-δ diagram kN-mm | | Stress Intensity factor ($K_{IIC}$) $MN/m^{3/2}$ (28 Days) | | Stress Intensity factor ($K_{IIC}$) $MN/m^{3/2}$ (90 Days) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Natural aggregate | Pelletized Wood ash Aggregate | | 28 days | 90 days | $K_{IIC}$ From Fracture Energy approach $MN/m^{3/2}$ | $K_{IIC}$ From Finite Element Analysis $MN/m^{3/2}$ | $K_{IIC}$ From Fracture Energy approach $MN/m^{3/2}$ | $K_{IIC}$ From Finite Element Analysis $MN/m^{3/2}$ |
| 1 | WA-0 | 100 | 0 | 0.30 | 89.59 | 126.40 | 9.70 | 24.03 | 11.94 | 32.49 |
| | | | | 0.40 | 51.63 | 69.80 | 7.95 | 19.04 | 9.75 | 25.02 |
| | | | | 0.50 | 33.99 | 60.20 | 7.18 | 16.38 | 9.58 | 24.60 |
| | | | | 0.60 | 28.11 | 43.50 | 7.07 | 13.42 | 9.27 | 20.70 |
| 2 | WA-25 | 75 | 25 | 0.30 | 10.78 | 51.86 | 2.81 | 25.51 | 8.72 | 30.42 |
| | | | | 0.40 | 9.92 | 15.62 | 2.66 | 23.70 | 4.04 | 26.47 |
| | | | | 0.50 | 7.56 | 10.08 | 2.75 | 22.89 | 3.51 | 26.05 |
| | | | | 0.60 | 6.88 | 6.00 | 2.63 | 21.35 | 3.32 | 24.80 |
| 3 | WA-50 | 50 | 50 | 0.30 | 8.34 | 11.23 | 2.32 | 18.62 | 3.29 | 25.75 |
| | | | | 0.40 | 6.68 | 8.12 | 2.29 | 18.42 | 3.02 | 21.97 |
| | | | | 0.50 | 5.65 | 4.77 | 2.21 | 18.14 | 2.65 | 18.75 |
| | | | | 0.60 | 4.89 | 4.15 | 2.23 | 17.75 | 2.54 | 16.88 |
| 4 | WA-75 | 25 | 75 | 0.30 | 6.25 | 130.85 | 2.06 | 16.58 | 10.89 | 15.69 |
| | | | | 0.40 | 4.88 | 63.92 | 1.98 | 15.72 | 9.00 | 13.95 |
| | | | | 0.50 | 4.37 | 42.77 | 1.94 | 15.65 | 8.24 | 13.85 |
| | | | | 0.60 | 3.48 | 34.41 | 1.78 | 15.20 | 6.03 | 13.42 |
| 5 | WA100 | 0 | 100 | 0.30 | 6.99 | 112.39 | 2.74 | 11.84 | 9.78 | 13.84 |
| | | | | 0.40 | 5.08 | 54.577 | 1.77 | 11.29 | 8.06 | 11.90 |
| | | | | 0.50 | 3.66 | 41.24 | 1.67 | 11.42 | 6.40 | 11.31 |
| | | | | 0.60 | 3.24 | 16.41 | 1.62 | 11.18 | 4.94 | 10.90 |

## VI. CONCLUSIONS:

From the limited experimental study carried out in this investigation the following conclusions are seem to be valid.

[1] The pelletized wood ash aggregate are lighter and porous in nature, having bulk density around 1105 $kg/m^3$ which is less than that for conventional aggregate, hence it is light weight aggregate.

[2] From the study it is observed that the cube compressive strength is observed to decrease continuously with the increase in percentage of WA Aggregate i.e., from 0 to 100% replacement of conventional aggregate by WA Aggregate.

[3] It is also observed that more than the target mean strength of $M_{20}$ concrete is achieved when natural aggregate replaced with 25% of WA aggregate as tabulated in table 3 for 90 days of curing.

[4] Ultimate load in Mode-II fracture is found to decrease continuously with the percentage increase in WA Aggregate content, and also observed that the ultimate load is increased with increasing curing period from 28 days to 90 days.

[5] From the figs and tables 6 & 7, it may be observed that In-plane shear stress at ultimate load decreases continuously with increase in the percentage of WA aggregate and increases with increasing curing period.

[6] The $K_{IIC}$ values calculated from the fracture energy approach are found to be lesser than 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 wood ash aggregate content.

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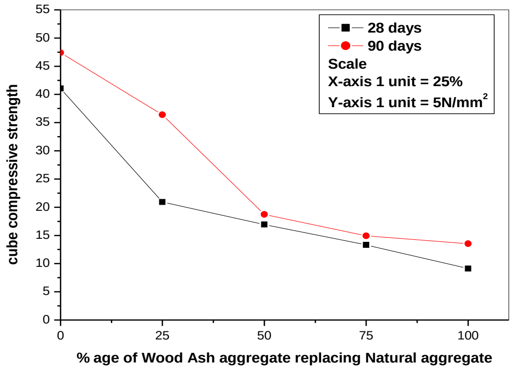


**Fig 3. Superimposed Variation between Cube Compressive Strength and Percentage of Pelletized Wood Ash Aggregate Replacing Natural Aggregate**

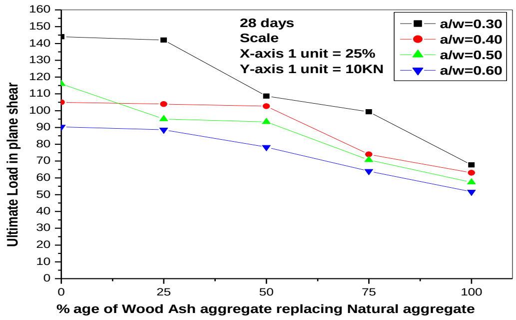


**Fig 4. Superimposed Variation Between Ultimate Load And Percentage Of Pelletized Wood Ash Aggregate Replacing Natural Aggregate For 28 Days Curing Period With A/W = 0.30, 0.40, 0.50 And 0.60**

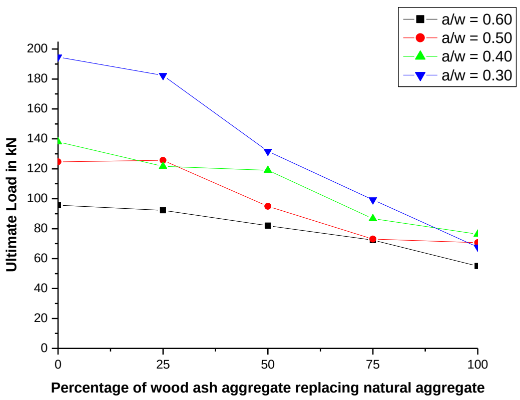


**Fig 5. Superimposed Variation Between Ultimate Load And Percentage Of Pelletized Wood Ash Aggregate Replacing Natural Aggregate For 90 Days Curing Period With A/W = 0.30, 0.40, 0.50, 0.60.**

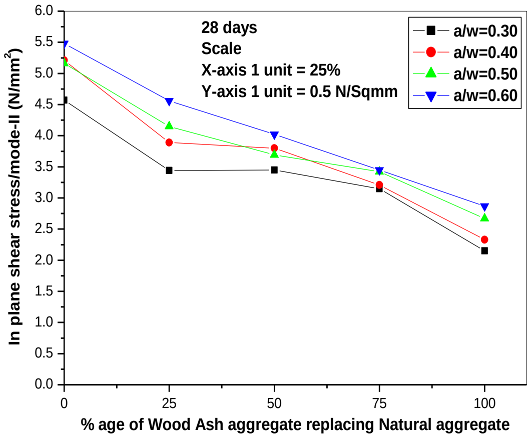


**Fig 6. Superimposed Variation Between In-Plane Shear Stress And Percentage Of Pelletized Wood Ash Aggregate Replacing Natural Aggregate For 28 Days Curing Period With A/W = 0.30, 0.40, 0.50 And 0.60**

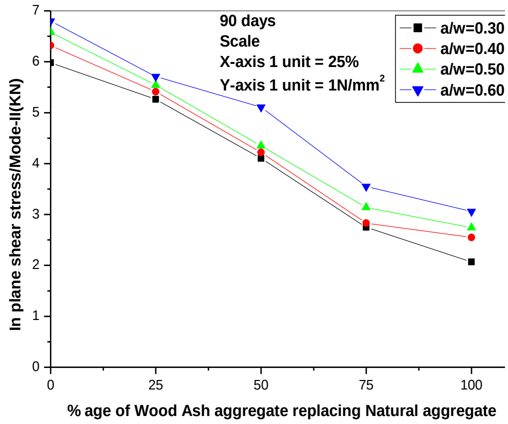


**Fig 7. Superimposed Variation Between In-Plane Shear Stress And Percentage Of Pelletized Wood Ash Aggregate Replacing Natural Aggregate For 90 Days Curing Period With A/W = 0.30, 0.40, 0.50 And 0.60**

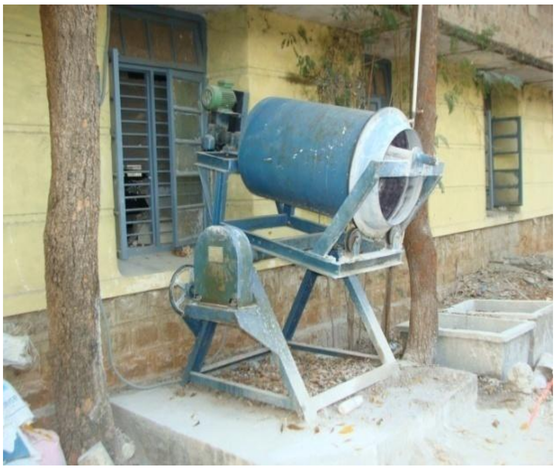

**Plate 1. Pelletization machine**

**Plate 2. Pelletized coarse aggregate**

**Plate 3. Plain cubes in green state**

**Plate 4. DCN specimens in green state**

**Plate 5. Test set up of cube compressive strength**

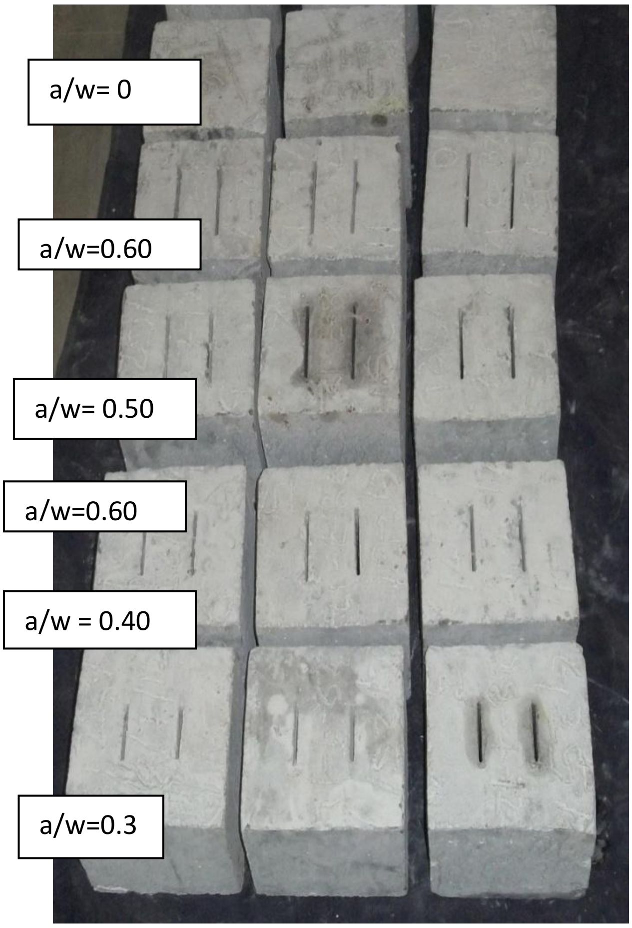


**Plate 6. Dcn specimens before testing**


**Plate 7. Test set up of dcn cubes**