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AN EXPERIMENTAL INVESTIGATION ON GEOPOLYMER CONCRETE WITH FERRO CEMENT

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ABSTRACT

This project presents the experimental investigation of the resistance of geopolymer mortar slabs to impact loading. The results obtained show that the addition of the above mesh reinforcement has increased the impact residual strength ratio of geopolymer ferrocement by 4-28 that of the reference plain ferrocement mortar slab. The combination of 1 layer of weld mesh and 4 layers of chicken mesh of geopolymer ferrocement specimens show the best performance in the test, i.e. energy absorbed, residual impact strength ratio (I-rs), It was concluded that the increase in Volume fraction of reinforcement V-r, increases the energy absorption and also residual impact strength ratio of geopolymer ferrocement than that of ferrocement specimens.

I INTRODUCTION

Concrete usage around the world is second only to water. Ordinary Portland cement (OPC) is conventionally used as the primary binder to produce concrete. The environmental issues associated with the production of OPC are well known. The amount of the carbon dioxide released during the manufacture of OPC due to the calcinations of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. In addition, the extent of energy required to produce OPC is only next to steel and aluminum.

On the other hand, the abundant availability of fly ash worldwide creates opportunity to utilize this by-product of burning coal, as a substitute for OPC to manufacture cement products. When used as a partial replacement of OPC, in the presence of water and in ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel. The development and application of high volume fly ash concrete, which enabled the replacement of OPC up to 60% by mass is a significant development.

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In 1978, Davidovits proposed that binders could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminum in source materials of geological origin or by-product materials such as fly ash and rice husk ash. He termed these binders as geopolymer.

II CONSTITUENTS OF GEOPOLYMER

2.1 SOURCE MATERIALS

Fly ash is one of the residues generated in the combustion of coal. Fly ash is generally captured from the

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chimneys of power generation facilities. Fly ash consists of fine, powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature. The carbonaceous material in fly ash is composed of angular particles. The particle size distribution of most bituminous coal fly ashes is generally similar to that of silt (less than a 0.075 mm).

These ash particles consist of silica, alumina, oxides of iron, calcium, and magnesium and toxic heavy metals like lead, arsenic, cobalt, and copper. This poses problems in the form of land use, health hazards, and environmental impact.

In addition to economic and ecological benefits, the use of fly ash in concrete improves its workability, reduces segregation, bleeding, heat evolution and permeability, inhibits alkali-aggregate reaction, and enhances sulfate resistance. Chemical components of fly ash obtained from various types of coal is shown in Table 1.1.

CLASS F FLYASH

The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 10% lime (CaO).possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water in order to react and produce cementitious compounds. Alternatively, the addition of a chemical activator such as sodium silicate to a Class F Fly ash can lead to the formation of a geopolymer.

CLASS C FLYASH

Fly ash produced from the burning of younger lignite or sub-bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulfate (SO_4) contents are generally higher in Class C fly ashes. Class C fly ash usually has cementitious properties in addition to pozzolanic properties due to free lime, whereas Class F is rarely cementitious when mixed with water alone.

CHEMICAL COMPONENTS OF FLYASH OBTAINED FROM VARIOUS TYPES OF COAL:

Components	Bituminous coal (%)	Sub-Bituminous coal (%)	Lignite coal (%)
SiO_2	20-60	40-60	15-45
Al_2O_3	5-35	20-30	20-25
Fe_2O_3	10-40	4-10	4-15
CaO	1-12	5-30	15-40
Loss of Ignition	0-15	0-3	0-5

ALKALINE LIQUIDS

The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate. Alkaline liquid plays an important rolein the polymerization process. Reactions occur at a high rate when the alkaline liquid contains soluble silicate, either sodium or potassium silicate, compared to the use of only alkaline hydroxides. Addition of sodium silicate

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solution to the sodium hydroxide solution as the alkaline liquid enhanced the reaction between the source material and the solution. Furthermore, after a study of the geopolymerisation of sixteen natural Al-Si minerals, they found that generally the NaOH solution caused a higher extent of dissolution of minerals than the KOH solution.

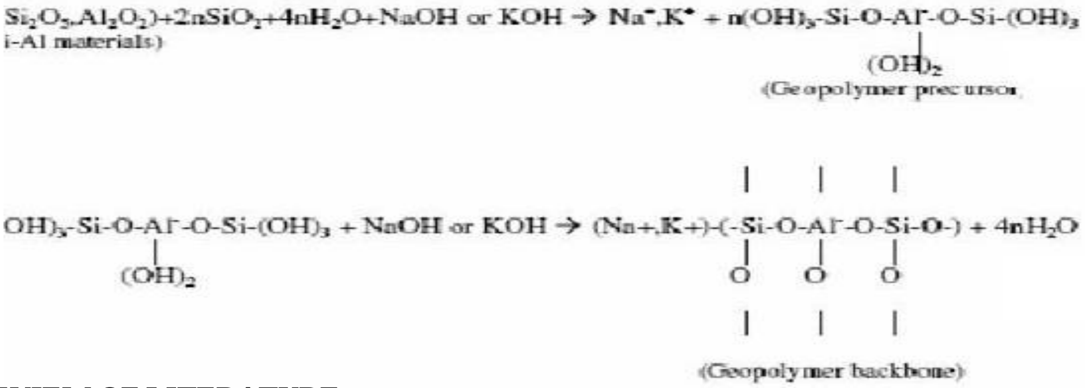
GEOPOLYMERS

Alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or in byproduct materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerisation process, the term 'Geopolymer' is used to represent these binders.

Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous instead of crystalline. The polymerisation process involves a substantially fast chemical reactionunder alkaline condition on Si-Al minerals, those results in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds, as follows

Mn [-(SiO2)z–AlO2]n.wH2O

The equation shows that,



III REVIEW OF LITERATURE

GENERAL

There is a wide range of research undergoing for the use of Geopolymer Concrete. For our investigation, some important publications were reviewed to have a broad idea about Geopolymer Concrete and they have been listed in the references at the end of the report.

FLYASH

According to the American Concrete Institute (ACI) Committee 116R, fly ash is defined as 'the finely divided residue that results from the combustion of ground or powderedcoal and that is transported by flue gasses from the combustion zone to the particle removal system' **(ACI Committee 232 2004)**. Fly ash is removed from the combustion gases by the dust collection system, either mechanically or by using electrostatic precipitators, before they are discharged to the atmosphere. Fly ash particles are typically spherical, finer than Portland cement and lime, ranging in diameter from less than 1µm to no more than 150 µm.

CHEMICAL COMPONENTS OF FLYASH OBTAINED FROM VARIOUS TYPES OF COAL:

Components	Bituminous coal (%)	Sub-Bituminous coal (%)	Lignite coal (%)
SiO2	20-60	40-60	15-45
Al2O3	5-35	20-30	20-25
Fe2O3	10-40	4-10	4-15
CaO	1-12	5-30	15-40
Loss of Ignition	0-15	0-3	0-5

GEOPOLYMERS

Davidovits (1999) proposed the possible applications of the geopolymers depending on the molar ratio of Si to Al, as given in Table.

APPLICATIONS OF GEOPOLYMERS:

Si/Al	Application
1	Bricks, ceramics, fire protection
2	Low CO2 cements, concrete, radioactive & toxic waste encapsulation
3	Heat resistance composites, foundry equipments, fibre glass composites
>3	Sealants for industry
20<Si/Al<35	Fire resistance and heat resistance fibre Composites

COMPRESSIVE STRENGTH DEVELOPMENT IN GEOPOLYMER MORTAR USING FERRO CEMENT TECHNOLOGY

DEFINTION OF FERRO CEMENT:

Ferro cement is a thin walled reinforced concrete commonly constructed of hydraulic mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable materials.

REINFORCED CEMENT CONCRETE and FERROCEMENT :

Physical Properties

- Thickness- Less than 25 mm
- Reinforcement- Distributed uniformly
- Matrix-Cement Mortar

Mechanical

- Homogenous and Isotropic- Two Way action

- Tensile Strength- High. Also high modulus of rupture.
- Specific Surface of Reinforcement-High
- Ductility-High increases with increase in layers
- Smaller crack widths-Multiple cracking
- Durability-GI wire and small cracks
- Fire Resistance- Ok.

CONSTRUCTION PROCEDURES

Four Major Stages of Construction- Placement of wire mesh in a proper position, Mortar mixing, Mortar Preparation and Curing.

Preparation and Placement of wire mesh:

- Wire meshes usually the main reinforcement except for highly stressed structures.
- Galvanized wire mesh is preferable.
- No. of layers of wire mesh usually vary from two to eight.
- Square woven wire meshes-Ensure Isotropicity

Mortar Preparation

- Consistent design strength- Usually 1:2 cement to sand and a w/c ratio of 0.6
- High Strength, High Performance Mortar-reduced workability-Use of mineral and chemical admixtures.
- Hand mixing-Most of the times.

Plastering

- Most critical phase-Plastering by hand, fingers and trowels are used.
- Single stage and Two stage technique

Curing

- Curing to promote hydration of cement under controlled temperature.
- Moist Curing- keeping mortar in contact with water for at least 10-14 Days. Spraying of flooding by covering surface with wet sand or earth etc
- Impermeable Cover Curing- Water proof paper-prevent evaporation of water.
- Steam Curing- After 4 to 5 hours of casting- 70 degrees temperature

PROPERTIES OF FERRO CEMENT TECHNOLOGY:

- Very High quality Control
- Prefabricated products readily available
- Easy production & Installation - of product & machinery - At site
- Manpower can be Easily trained at site
- Very useful in rural areas

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- No extra time required. Fast production - 262 sqft of Roof ready in One shift
- 50-75% lighter than conventional techniques
- 41% more insulating than RCC
- Cost effective - 15%-50% cheaper than conventional techniques Environment friendly - 40% less cement & sand.

EXPERIMENTAL PROGRAM

Based on the extensive literature review an attempt has been made to verify the possibility of preparing low calcium (ASTM Class F) fly ash based geopolymer concrete economically to suit the Indian conditions.

In order to develop the fly ash based geopolymer concrete technology, therefore, a rigorous trail-and error process was adopted. In order to simplify the development process, the compressive strength was selected as the benchmark parameter. The focus of the study was mainly on the engineering properties of fly ash based geopolymer concrete and also for partial replacement of fly ash with cement. The current practice used in the manufacture and testing of Ordinary Portland Cement (OPC) concrete was followed, even for geopolymer concrete. It is to ease the promotion of this 'new' material to the concrete construction industry.

Although geopolymer concrete can be made from various source materials, in the present study only low-calicum (ASTM class F) dry fly ash was used, as it is easily available at low price in India. Also, as in the case of OPC, even in the geo-polymer concrete, the aggregates occupy 50-75 % of the total mass of matrix.

Materials

Alkaline Liquid

In the present study we have used a combination of sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) solutions. The sodium hydroxide solids were either a technical grade in flakes form (3 mm), 98% purity, and obtained from National scientific company, Vijayawada, or a commercial grade in pellets form with 97% purity, obtained from National Scientific centre, Vijayawada.

Sodium Silicate and Sodium Hydroxide Solution

Galvanized iron mesh:

Galvanized Iron Wire mesh: The galvanized iron wire mesh of square grid fabric is used in the Ferro cement. The properties of the wire mesh are

Galvanized iron mesh Properties :

Diameter of wire mesh (mm)	Grid spacing of mesh wire (mm)		Yield strength of mesh wire (Mpa)	Ultimate strength (Mpa)
	Longitudinal	Transverse		
0.46	2.80	2.80	270	450

Moulds and Equipment

1. **Cubes:** Standard cube moulds of 100 x100 x 100mm made of cast iron were used for casting and testing specimens in compression**.**
2. **Thin plates:** Standard cast iron moulds of size 200x100x100mm were used for casting and testing specimen for compressive strength of mortar.

IV RESULTS AND DISCUSSIONS OF RESULTS

CALCULATIONS OF MORTAR CUBES:

Size of the cube = 7.07cm

Volume of the cube = $3.53*10^{4}$ m^3

Density of geo polymer concrete = 2200kg/m^3

Weight required = density*volume = $3.53*10^{4}$$m^3$*2200kg/$m^3$ = 0.777kg (take 800gms) Take fly ash to sand ratio as 1:3

Fly ash =200gms

Ennore sand=600gms

Take ennore sand as a combination of grade1, grade 2, grade 3. Each 200gms

Take sodium silicate to sodium hydroxide in different ratio as 1.5, 2, 2.5, 3, 3.5. Make the alkaline solution 24hrs before the preparation of mortar cubes

One day oven curing is there to get strength (60ºc) 7day compressive strength is to be find.

V CALCULATIONS

For Cement Mortar Prisms & Geopolymer Mortar Prisms

Size of the mortar cube = 200*100*100 = 0.002 m3 Density of Geopolymer mortar = 2200 Kg/m3

Weight of the cube = 2200*0.002 = 4.4 Kg.

For 1:1 Ratio of Flyash & Fine aggregate

Alkaline / Flyash = 0.38, Sodium silicate/ Sodium hydroxide = 2.5; Flyash = 2.2 Kg,

Fine aggregate = 2.2 Kg;

Alkaline solution = 836 ml, Sodium silicate = 598 ml,

Sodium hydroxide = 238 ml,

Wt. of NaOH = 76.16 gms (taking Molarity M=8).

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For 1:1.5 Ratio of Flyash & Fine aggregate

Alkaline / Flyash = 0.40, Sodium silicate/ Sodium hydroxide = 2.5; Flyash = 1.76 Kg,

Fine aggregate = 2.64 Kg;

Alkaline solution = 704 ml, Sodium silicate = 503 ml,

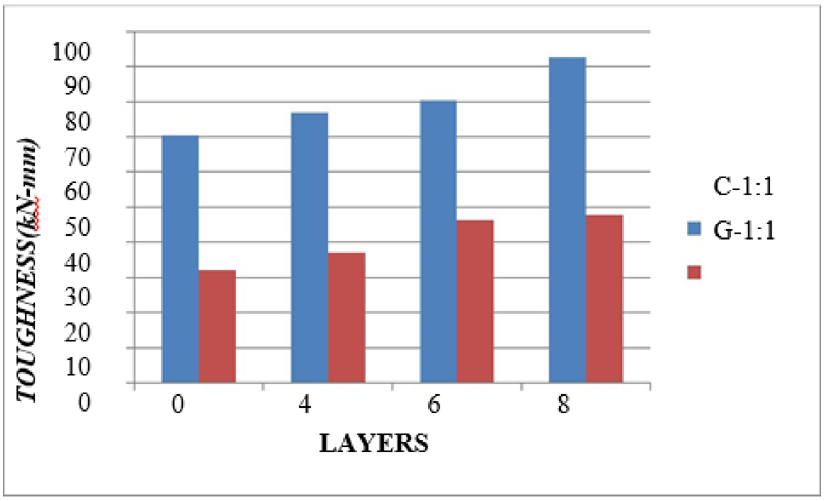
Sodium hydroxide = 201 ml,

Mortar cubes compressive strength values:

Na2SiO3/ NaOH	COMPRESSIVE STRENGTH (N/mm2)
1.5	12
2	13
2.5	15
3	11
3.5	10

Variation of toughness for different layers:-

LAYERS	CEMENT MORTAR (C) - 1:1	GEOPOLYMER MORTAR (G) - 1:1	CEMENT MORTAR (C) - 1:1.5	GEOPOLYMER MORTAR (G) – 1:1.5
0	70.33	32.06	63.32	30.89
4	76.94	36.98	73.81	35.05
6	80.43	46.2	75.42	40.54
8	92.52	47.3	80.43	44.54



Graphical representation of toughness with no.of layers for ratio **1:1**

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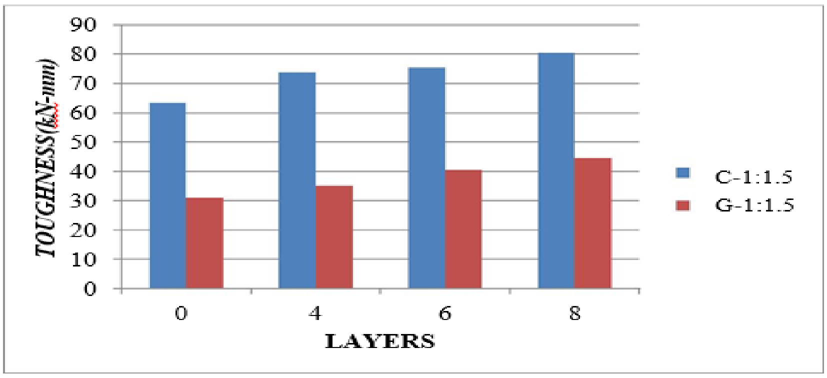

Fig 5.5.2 Graphical representation of toughness with no.of layers for ratio 1:1.5.

Table 1 **Stress - Strain and load-displacement values for C 1:1 (0layers)**

Displacement (mm)	Load (kN)	Strain	Stress (N/mm^2)	Initial tangent line	Area
0	0	0	0	0	0
0.001	10	0.000005	1	0.9588	0.005
0.005	20	0.000025	2	4.794	0.06
0.021	30	0.000105	3	20.1348	0.4
0.035	40	0.000175	4	33.558	0.49
0.061	50	0.000305	5	58.4868	1.17
0.076	55	0.00038	5.5	72.8688	0.7875
0.089	60	0.000445	6	85.3332	0.7475
0.123	70	0.000615	7	117.9324	2.21
0.145	75	0.000725	7.5	139.026	1.596
0.167	80	0.000835	8	160.1196	1.705
0.189	85	0.000945	8.5	181.2132	1.815
0.212	90	0.00106	9	203.2656	2.0125
0.245	95	0.001225	9.5	234.906	3.0525
0.267	100	0.001335	10	255.9996	2.145
0.298	110	0.00149	11	285.7224	3.255
0.312	120	0.00156	12	299.1456	1.61
0.334	130	0.00167	13	320.2392	2.75
0.378	140	0.00189	14	362.4264	5.94
0.412	150	0.00206	15	395.0256	4.93
0.456	170	0.00228	17	437.2128	7.04
0.5	180	0.0025	18	479.4	7.7
0.534	180	0.00267	18	511.9992	6.12
0.567	200	0.002835	20	543.6396	6.27
0.632	170	0.00316	17	605.9616	12.025
				Toughness	70.33

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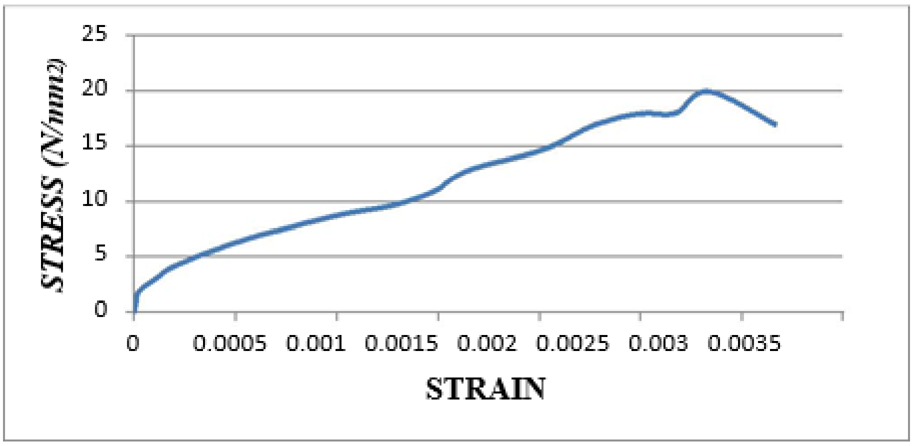

Fig 2.1 Graphical representation for stress-strain curve for **C 1:1** (**0**layers).

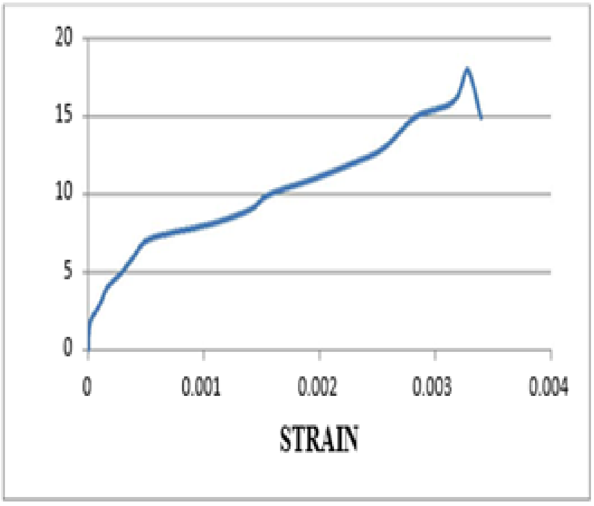

Fig 2.1 Graphical representation of stress-strain curve for **C 1:1.5**(0 layers).

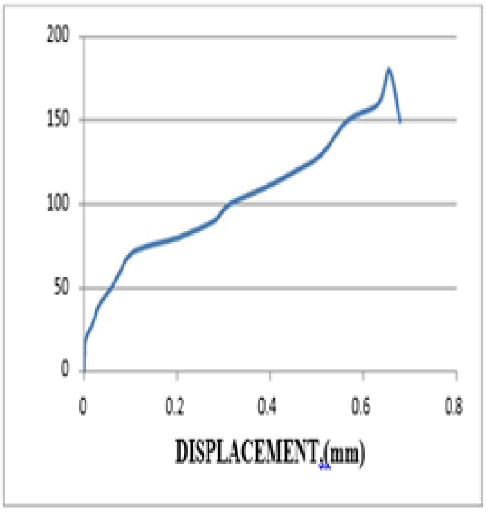

Fig 2.2 Graphical representation of load-displacement curve for **C 1:1.5**(0layers).

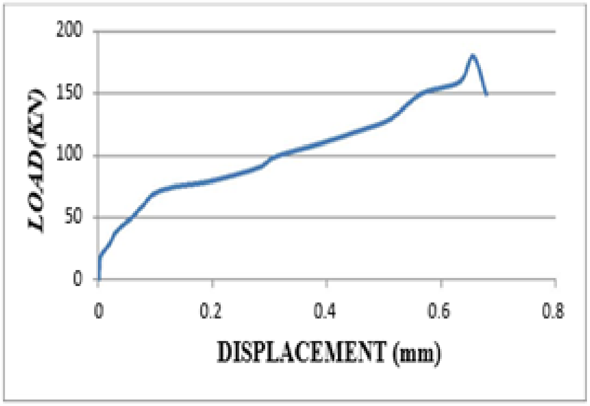

Fig 2.2 Graphical representation of load-displacement for **C 1:1**(0 layers).

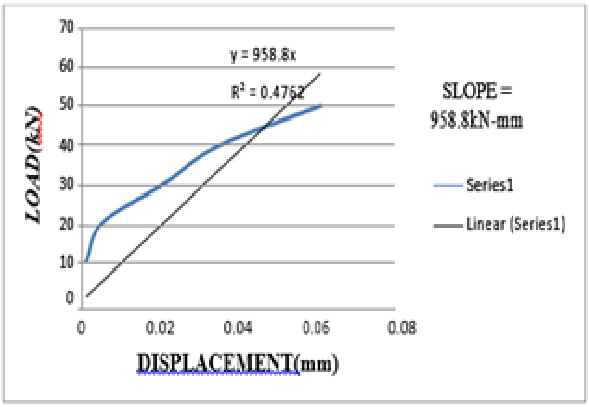

Fig 2.3 linear fit for **C 1:1**(**0** layers)

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Table 2 **Stress - Strain and load-displacement values for C 1:1.5 (0layers):-**

DISPLACEMENT (mm)	LOAD (KN)	STRAIN	STRESS (N/mm2)	INITIAL TANGENT LINE	AREA
0	0	0	0	0	
0.001	10	0.000005	1	1.013	0.005
0.005	20	0.000025	2	5.065	0.06
0.021	30	0.000105	3	21.273	0.4
0.032	40	0.00016	4	32.416	0.385
0.058	50	0.00029	5	58.754	1.17
0.067	55	0.000335	5.5	67.871	0.4725
0.078	60	0.00039	6	79.014	0.6325
0.098	70	0.00049	7	99.274	1.3
0.134	75	0.00067	7.5	135.742	2.61
0.2	80	0.001	8	202.6	5.115
0.278	90	0.00139	9	281.614	6.63
0.312	100	0.00156	10	316.056	3.23
0.389	110	0.001945	11	394.057	8.085
0.456	120	0.00228	12	461.928	7.705
0.511	130	0.002555	13	517.643	6.875
0.565	150	0.002825	15	572.345	7.56
0.632	160	0.00316	16	640.216	10.385
0.656	180	0.00328	18	664.528	4.08
0.678	150	0.00339	15	686.814	3.63
				toughness	63.33kN-mm

Recommendations for further research:

- We used fly ash obtained from bituminous coal which contains 10% CaO, fly ash from sub bituminous coal shall also be determined.
- Rice husk ash and GGBS shall be tried instead of fly ash and properties shall be determined.
- Investigation should be made on Structural members like beams, columns, and slabs using geopolymer as binder.
- Using oven curing technology to improve initial strength of geo polymer members.

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