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Experimental Investigation and Comparative Study on the Strength of Ordinary Concrete and LWC Using Vermiculite Mineral

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Abstract:

In recent development scenario, the lightweight concrete is a versatile material, which offers a range of technical, economic and environmental –enhancing and preserving advantage and is designed to become a dominant material in the millennium. For structural application of light weight concrete, the density is often more important than the strength. A decreased density for the same strength level reduces the self weight, foundation size and construction cost. Structural lightweight aggregate concrete is generally used to reduce dead weight of the structure as well as to reduce the risk of seismic damage to a structure because the seismic forces that will influence the civil engineering structures are proportional to the mass of those structures. In this study, structural light weight aggregate concrete was designed with the use of natural vermiculite aggregate that will provide an advantage of reducing dead weight of structure and to obtain a more economical structural light weight concrete by the use of vermiculite power as a partial replacement of sand. Five mixes were produced with the cement content of 356 kg/m^3 and water cement ratio 0.45. More over the group had proportion of **0%, 5%, 10%, 15% and 20%** as vermiculite replacement. The main scope of our project is to learn and gather knowledge of strength, and density. It may help us to get clear idea about the light weight concrete, using vermiculite.

Keywords: Vermiculite, LWC (Light weight concrete), Compressive strength, Flexural Strength for beam.

I. INTRODUCTION

Vermiculite is a member of the phyllosilicate mineral group and is micaceous in nature. It is found in many parts of the world but only a limited number of sources are worked as commercial deposits. The vermiculite is mined and refined using a variety of techniques and supplied commercially in a range of particle size grades of vermiculite concentrate (unexpanded).Vermiculite is the name used in commerce for a group of micaceous minerals that expand or exfoliate many times (commercial varieties exfoliate 8 to 20 times or more) the original thickness when heated. They show the characteristic micaceous structure of basal cleavage and occur as soft, pliable inelastic laminar. Their basal cleavages are not so perfect as those of mica. Vermiculite exists in a wide range of colours from black through various shades of brown to yellow. Its chemical composition varies widely consisting of a complex hydrated aluminium, magnesium silicate and hence the analysis of the mineral is of little use in determining the vermiculite for commercial utility; a technical trial of the material provides the only satisfactory test. Vermiculite owes its commercial utility to its property of exfoliation when heated. It exfoliates into a yellow to bronze coloured mass giving an appearance of a cluster of worms - vermicular, an Italian word for worm from which it has derived its name as vermiculite. Some authorities quote the Latin word vermicular from which the name vermiculite might have been derived.

II. PROPERTIES OF VERMICULITE

A. Classification of vermiculite

Class : Silicates (SiO_4)
Subclass : Phylosilicates (The Sheet Structures)
Groups : The Clays and the Monmorillonite / Steatite Group

The different varieties of vermiculite are,

- Batavite ,Copper
- Eastonite (of hamilton)
- Lucasite (of chatard)

B. Characteristics of vermiculite

Color: Brown to golden brown, can also be white, colorless, or yellow
Luster : Pearly to greasy
Transparency : Translucent crystals
Cleavage : Perfect in one direction
Fracture : Uneven to lamellar
Hardness: About 1.5, which can sometimes leave marks on paper
Specific Gravity : 2.3-2.5
Streak : white
Crystal System : monoclinic, 2/m

C. Physical characteristics

Crystal Habit: Pseudo hexagonal tabular crystals ("books"), also compact or lamellar masses or microscopic crystals

Sintering temp : 1260 Degrees C
Melting Point : 1330 Degrees C
Specific Heat : 1.8 kJ/kg.K.
pH value : 8.0-9.5
Thermal Conductivity :0.062-0.0656W/Mk

D. Fineness

Horticulture Vermiculite : 1-2mm, 2-4mm
Expanded Vermiculite : 0-1mm, 1-3mm, 2-4mm
Insulation Vermiculite : 0-1mm, 0-2mm, 0-3mm

E. Shape and size

In general, the vermiculite particles are typically platelets, ranging in diameter from 0.04 µ to 4mm. The particle shape and size mainly depend upon the mineralogical phases and collection system. The particle shape affects the water demand of a standard paste and as the number of platelets' particles increase, the water demand decreases. It was also reported that as the size of vermiculite decreases the requirement of water for mortars containing vermiculite increases. Studies on cement pastes showed that the spherical particles of fly ash initiate the nucleation leading to the mechanical interlocking of the needles and plates, which is responsible for the strength. It was also observed that the particle size distribution mainly influence vermiculite reactivity at early ages while chemical composition and amorphous phase play a predominant role at the later ages.

F. Density

The density of vermiculite depends on the constituents (iron, silicon, alumina and silica, magnesium etc). The density of raw vermiculite is 50 to 90 lbs. per cu. ft. While that of the exfoliated one is 5-10 lbs. per cu. ft. It. The colour of fly ash may vary from light tan or grey to almost black depending on the type and quality of the coal used and combustion process.

G. Chemical characteristics

Vermiculite is a fine particulate material with the main chemical constituents being SiO2, AlO3, Fe2O3 and CaO which are responsible for its pozzolanic activity. It also consists of MgO, Mn2O3, P2O5, SO3, Na2O and. There is a possibility for variation in composition from plant to plant and even in one plant from time to time. SiO_2 38-46,MgO 16-24,Al_2O_3 11-16,Fe_2O_3 8-13,K_2O 4-6,CaO 1-3,$TiO_2$1-3,MnO .1-0.2,Cr_2O_3 0.05-0.2,Na_2O 0.1-0.3. Vermiculite crystallizes in the monoclinic system, and the crystal faces are often marked with triangular lines at 60 degrees and 120 degrees. X-ray studies have indicated that vermiculite constitutes a specific type with a definite structure differing from that of mica or chlorite. The main composition are in vermiculite are Silica,31-41% Alumina,10-17% Iron oxides,5-22% Magnesium oxide,11-13%.

H. Chemical reaction of vermiculite in ordinary Portland cement concrete:

The principle product of the reactions of fly ash with calcium hydroxide and alkali in concrete is the same as that of the hydration of ordinary Portland cement, i.e. Calcium Silicate Hydrate (C-S-H). The morphology of the vermiculite reaction product is suggested to be more gel-like and denser than that from ordinary Portland cement.

Fig.1 Vermiculite

Structure and commercial use of vermiculite:

Vermiculite is a 2:1 clay, meaning it has 2 tetrahedral sheets for every one octahedral sheet. It is limited expansion clay with a medium shrink-swell capacity. Vermiculite has a high caution exchange capacity at 100-150 meq/100g. Vermiculite clays are weathered micas in which the potassium ions between the molecular sheets are replaced by magnesium and iron ions.

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I. Commercial uses

- As an additive to fireproof wallboard
- As a component of the interior fill for fire stop pillows, along with graphite
- As a carrier for dry handling and slow release of agricultural chemicals
- As a growing medium for hydroponics.
- As a hot topping: both exfoliated and crude vermiculite have been used for hot topping in the steel industry. When poured onto molten metal crude vermiculite exfoliates immediately and forms an insulating layer allowing the material to be transported to the next production process without losing too much heat.

J. Applications

Vermiculite is always used in exfoliated form. When exfoliated it possesses +-nearly 10 to 11 times less bulk density than the original volume. In commerce, vermiculite which expands more than 10 times the original volume. In commerce, vermiculite which expands more than 10 times the original volume is regarded of good quality. With an expansion below 10 times the original volume, vermiculite is considered of low grade. The low bulk density, comparative high refractoriness, low thermal conductivity and chemical inertness make vermiculite satisfactory for many types of thermal and acoustic insulations. One of its large commercial uses is as an aggregate in light weight concrete and hard wall-plaster because of its acoustic and thermal insulating and fire-resisting qualities. The density of raw vermiculite is 50 to 90 lbs. per cu. ft.While that of the exfoliated one is 5-10 lbs. per cu. ft. It is therefore extensively used in concrete work to save weight. Vermiculite concrete weighs 20-25 per cu. ft. as against and concrete which weighs about 100 lbs. per cu. ft. Vermiculite concrete has the same advantages as concrete made with pumice and perlite. Refractory insulations both in the form of loose vermiculite fill and vermiculite bricks are used in furnaces and kilns up to 1100ºC. About 60% of the \/7+- pr*7\sent world consumptions is in the form of loose fill when the expanded m+ is merely purred like dry sand into wall spaces or applied over ceiling constructions or attics of residential buildings with a view to insulating homes against cold in winter and heat in summer.

One inch of Unify, a trade name of particular expanded vermiculite, holds back as much of 2½ ft. brick wall or wall of concrete 3¾ ft. thick. As a light-weight aggregate it is extensively used in prefabricated houses. Vermiculite concrete in the form of monolithic cast is used in sound-absorbing panels in sheds. Vermiculite, being a granular expanded aggregate with numerous air voids, when mixed with a suitable binder develops sound insulating properties. Vermiculite plaster is widely used for better acoustics and reduction of noise in auditoriums, wireless studios, theatres, hospitals etc.

Vermiculite mixed with three parts of gypsum is used as plaster for sound-absorbing purposes. A new building material called Pyrok, consisting of vermiculite bonded with lime and cement is marketed in England. More than hundred major and minor uses of vermiculite have been developed in the fields of agriculture, pesticides, lubricants, disinfectants, insulating bricks.
A Canadian steel company ships red hot steel ingots for a distance of 288 km from open hearth to mill plant, embedded in loose vermiculite. A temperature loss of less than 9 per cent is reported. The vermiculite is reused.

Unaffiliated vermiculate has a few minor uses, such as for circulation in drilling mud and in the annealing of steel. When un exfoliated vermiculate is reacted with concentrated H2SO4, it produces a pure form of silica in flake form. This product is known as 'samisilite'.

K. Lightweight concrete

Beneficial effects of supplementary cementing materials like vermiculite, on reducing the weight of the concrete.

- Formation of a denser microstructure of calcium silicate hydrate (CSH) due to the additional hydration products formed by pozzolanic reactions.
- Modification of the pore structure of the cement paste. The products of reaction of vermiculite particles taking place within the capillary pores of the cement hydrate may block some pores and make them discontinuous. The average pore size becomes smaller, although the total porosity may remain the same.
- Increased impermeability of concrete. This results from denser microstructure of the cement paste, increased volume of reaction products and improvement in the workability of concrete, which permits fuller compaction.
- Lower electrical conductivity of concrete. Addition of vermiculite has been found to increase the resistance to the flow of (electrochemical) corrosion currents in concrete.
- Increased chloride binding. Presence of aluminate phases in vermiculite encourages binding of chloride ions in the pore solutions. Chloride binding is also aided by adsorption on the surfaces of the vermiculite
- pH value of the pore solution is maintained. Alkalinity in pore solutions in the cement paste is not due to $Ca(OH)_2$ alone. Alkalies, aluminate and silicate hydrates also contribute to the pH value. This has been established by elaborate tests, which showed the pH value in hydrating systems with pozzolana or slag to be at least 12 or more.

Lightweight aggregate concrete can be produced using a variety of lightweight aggregates.

L. Lightweight aggregates originate from either:

- Natural materials, like volcanic pumice.
- The thermal treatment of natural raw materials like clay, slate or shale i.e. Leca.
- Manufacture from industrial by-products such as fly ash, i.e. Lytag.
- Processing of industrial by-products like FBA or slag.

The required properties of the lightweight concrete will have a bearing on the best type of lightweight aggregate to use. If little structural requirement, but high thermal insulation properties, are needed then a light, weak aggregate can be used. This will result in relatively low strength concrete. Lightweight aggregate concretes can, however, be used for structural applications, with strengths equivalent to normal weight concrete.

The benefits of using lightweight aggregate concrete include:

Reduction in dead loads making savings in foundations and reinforcement.

- Improved thermal properties.
- Improved fire resistance.
- Savings in transporting and handling precast units on site.
- Reduction in formwork and propping.

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M. Foamed concrete

Foamed concrete is a highly workable, low-density material which can incorporate up to 50 per cent entrained air. It is generally self-leveling, self-compacting and may be pumped. Foamed concrete is ideal for filling redundant voids such as disused fuel tanks, sewer systems, pipelines, and culverts - particularly where access is difficult. It is a recognized medium for the reinstatement of temporary road trenches. Good thermal insulation properties make foamed concrete also suitable for sub-screeds and filling under-floor voids.

- Autoclaved aerated concrete (AAC)

AAC was first commercially produced in 1923 in Sweden. Since then, AAC construction systems such as masonry units, reinforced floor/roof and wall panels and lintels have been used on all continents and every climatic condition. AAC can also be sawn by hand, sculpted and penetrated by nails, screws and fixings.

- Advantages of light weight concrete

Fireproof; the fireproofing characteristics of vermiculite concrete are recognized nationwide by insurance companies, state rating bureaus and local building officials. Underwriters' Laboratories have assigned up to 4-Hour ratings to systems that employed vermiculite as one of the components.

Insulation; Vermiculite concrete has excellent insulating properties. Three inches of vermiculite concrete is equivalent to 1 1’2" of rigid board insulation laid over steel decks. One inch of vermiculite concrete is equal in insulating value to 20 inches of regular concrete.

Ease of Application Vermiculite insulating concrete is easily placed by modern specially designed pumping equipment. Up to 25,000 square feet can readily be placed in one day.

Special features: Reroofing Slope to drain systems employing vermiculite concrete and polystyrene vent board provide an economical solution to existing flat roofs.

Substrates Vermiculite concrete is suitable for installation over most structurally sound roofing systems with structural decks of concrete, metal, or wood. Care must be taken to properly vent decks poured over impervious materials.

N. Special contents in light weight concrete

- Light Weight

  Density range from 650Kg/m^3 to 1850Kg/m^3 as compared to 1800 Kg/m^3 to2400Kg/m^3 for conventional brick and concrete respectively. Despite millions of tiny air filled cells, it is strong and durable. There is Lightweight advantage for the structure design, leading to savings in supporting structures and foundation. **Compressive Strength:** 2.0 to7.0 N/mm^2

- Excellent Acoustic Performance

  It can be used as effective sound barrier and for acoustic solutions. Hence, highly suitable for partition walls, floor screens / roofing and panel material in auditoriums.

- Earthquake Resistant

  Since lighter than concrete & brick, the lightness of the material increases resistance against earthquake.

- Insulation

Superior thermal insulation properties compared to that of conventional brick and concrete, so reduces the heating and cooling expenses. In buildings, light-weight concrete will produce a higher fire rated structure.

- Workability:

  Products made from lightweight concrete are lightweight, making them easy to place using less skilled labour. The bricks can be sawed, drilled and shaped like wood using standard hand tools, regular screws and nails. It is simpler than brick or concrete.
- Lifespan Weather proof, termite resistant and fire proof.
- Savings in Material

Reduces dead weight of filler walls in framed structures by more than 50% as compared to brickwork resulting in substantial savings. Due to the bigger and uniform shape of blocks, there is a saving in bed mortar and plaster thickness. In most cases the higher cost of the light-weight concrete is offset by a reduction of structural elements, less reinforcing steel and reduced volume of concrete.

- Water Absorption

Closed cellular structures and hence have lower water absorption.

- Skim Coating

  Do not require plaster and water repellent paint suffices. Wallpapers and plasters can also be applied directly to the surface.

Modulus of Elasticity

The modulus of elasticity of the concrete with lightweight aggregates is lower, 0.5 – 0.75 to that of the normal concrete. Therefore more deflection is there in lightweight concrete. Scope and objective of present investigation Structural lightweight aggregate concrete is an important and versatile material, which offers a range of technical, economic and environmental-enhancing and preserving advantages and is designed to become a dominant material in the new millennium. It has many and varied applications: multistory building frames and floors, curtain walls, shell roofs, folded plates, bridges, pre stressed and pre-cast elements of all types and others. Structural lightweight aggregate concrete generally used to reduce dead weight of structure as well as to reduce the risk of earthquake damages to a structure because the earthquake forces that will influence the civil engineering structures and buildings are proportional to the mass of those structures and buildings.

Thus, reducing to the mass of structure or building is utmost important to reduce their risk due to earthquake acceleration. Also, reduction in the dead weight of a construction could result in a decrease in the cross-section of columns, beams, plates and foundations. Higher strength/weight ratio, better tensile strain capacity, lower coefficient of thermal expansion and superior heat and sound isolation characteristics due to air voids of the lightweight aggregates are advantages of structural lightweight aggregate concrete. Structural lightweight aggregate concrete is an important and versatile material, which offers a range of technical, economic and environmental-enhancing and preserving advantages and is designed to become a dominant material in the new millennium. It has many and varied applications: multi-storey building frames and floors, curtain walls, shell roofs, folded plates, bridges, pre stressed and pre-cast elements of all types and others. Structural light weight aggregate concrete generally used to reduce dead weight of structure as well as to reduce the risk of earthquake damages to a structure because the earthquake forces that will influence the civil engineering structures and buildings are proportional to

the mass of those structures and buildings. Thus, reducing to the mass of structure or building is utmost important to reduce their risk due to earthquake acceleration. Also, reduction in the dead weight of a construction could result in a decrease in the cross-section of columns, beams, plates and foundations. Higher strength/weight ratio, better tensile strain capacity, lower coefficient of thermal expansion and superior heat and sound isolation characteristics due to air voids of the lightweight aggregates are advantages of structural lightweight aggregate concrete.
To study the strength vermiculite blended concrete under various replacement levels (5 %, 10 %, 15 %, 20 %, in comparison to Portland Pozzolona Portland cement concrete.

To find out the tolerable limit of replacement of vermiculite in cement for durable steel reinforced concrete.

Materials used
Ordinary Portland cement : Conforming to IS 456 – 2000
Graded fine aggregates : Local clean river sand (fineness modulus of medium sand equal to 2.46) conforming to grading zone III of IS-383 - 1970 was used.
Graded coarse aggregates : Locally available well graded aggregates of normal size greater than 4.75 mm and less than 12 mm.
Vermiculite used The vermiculite collected from Andhra mines, India was used in as modified form by physical, chemical and thermal activation. The composition of Ordinary Portland cement (OPC) and Vermiculite (VER) used are reported in Table 1

TABLE 1 Composition of OPC and vermiculite

Constituents	OPC (%)	Vermiculite (%)
SiO_2	22.14	46
Fe_2O_3	3.35	13
Al_2O_3	11.85	16
CaO	58.76	3
MgO	1.3	16
Loss on Ignition	2.6	0

Test on hardened concrete:

- Compressive Strength – Cube

Compressive strength test: (7, 14, 28 days curing result)
150 mm x 150 mm x 150 mm concrete cubes were cast using 1:1.5:3 mix with W/C ratio of 0.53. Specimens with Ordinary Portland cement and OPC replaced by vermiculite at 5 %, 10 %, 15 %, 20 % replacement levels were cast. During moulding, the cubes were mechanically vibrated.

The average compressive strength for Ordinary Portland cement and vermiculite blended concrete (5% - 10% replacement levels) for different curing periods. vermiculite blended concrete shows adequate in compressive strength up to 20 %. After 14 days curing, the vermiculite system up to 20% performs well comparing to control concrete.

TABLE 2 Size of the mould and specimen prepared

Sample	**Size of the mould(mm)**	**Specimen prepared**
7 days cube	150×150×150	18
14 days cube	150×150×150	18
28 days cube	150×150×150	18

Fig.2 Curing of Concrete

III. COMPRESSIVE STRENGTH OF CONCRETE

TABLE 3 Compressive strength of vermiculite replaced concrete after 7 days of curing

% of replacement	Average Compressive strength (N/mm^2)
0%	28
5%	27
10%	25
15%	23.5
20%	23

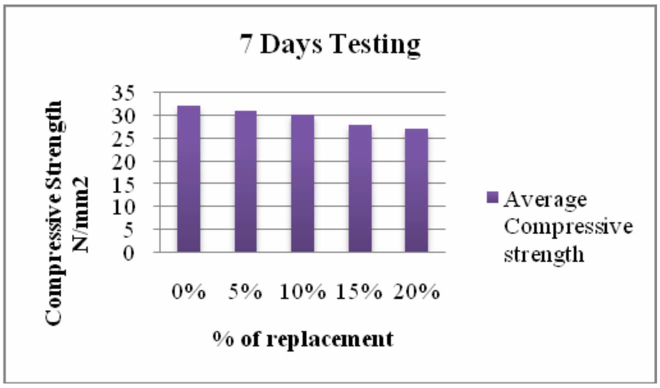

Fig.3 7 days test results

TABLE 4 Compressive strength of vermiculite replaced concrete after 14 days of curing

% of replacement	Average Compressive strength (N/mm^2)
0%	33
5%	32
10%	30
15%	29
20%	27

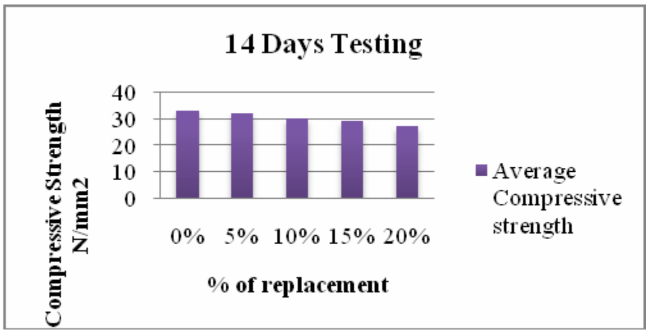

Fig.4 14 days test results

Concrete cubes

TABLE 5 Compressive strength of vermiculite replaced concrete after 28 days of curing

% of replacement	Average Compressive strength (N/mm^2)
0%	34
5%	33
10%	31
15%	29
20%	28

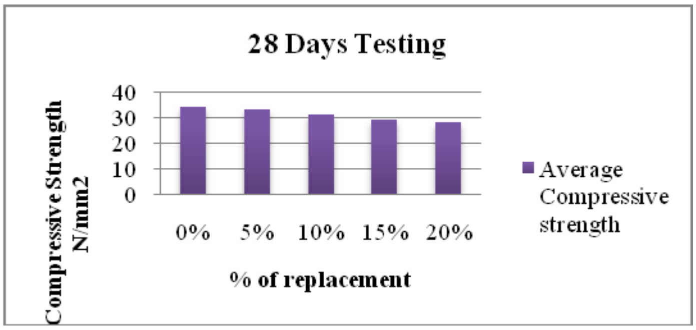

Fig.5 14 days test results

Density of vermiculite concrete:

Table shows the densities of vermiculite concrete at different replacement levels. When compared to control concrete, all the vermiculite replaced concretes are showing lesser densities.

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TABLE.6 DENSITIES OF VERMICULITE CONCRETE IN DIFFERENT REPLACEMENTS 7 days

SPECIMEN NO.	Volume (m^3)	Bulk density (Kg/m^3)
0 (Control)	0.003375	2533
5%	0.003375	2421.28
10%	0.003375	2315
15%	0.003375	2270
20%	0.003375	2259

TABLE.7 DENSITIES OF VERMICULITE CONCRETE IN DIFFERENT REPLACEMENTS 14 days

SPECIMEN NO.	Volume (m^3)	Bulk density (Kg/m^3)
0 (Control)	0.003375	2513.58
5%	0.003375	2346.667
10%	0.003375	2344.691
15%	0.003375	2270
20%	0.003375	2186.667

TABLE 8 DENSITIES OF VERMICULITE CONCRETE IN DIFFERENT REPLACEMENTS 28 days

SPECIMEN NO.	Volume (m^3)	Bulk density (Kg/m^3)
0 (Control)	0.003375	2548.14
5%	0.003375	2412.84
10%	0.003375	2247.9

15%	0.003375	2188.642
20%	0.003375	2141.23

DESIGN OF BEAM FOR FLEXURE

TABLE 9 Design of Beam for Flexure

DESIGN OF BEAM FOR FLEXURE	
Grade of Concrete	M30
Grade of steel	Fe 415
Length of Beam	1.00 m
Effective span Length	0.9 m
Breath of beam	150mm
Depth of Beam	200mm
Loading Method	Single Point Load (mid span)
End Condition	Simply Supported

TABLE 10 Flexural Test Results for Beam Specimen with fully Control

Specimen Details	First Crack load (kN)	Ultimate Load (kN)	Deflection at Ultimate Load (mm)
S1	70	83	0.92
S2	72	80	0.94
S3	71	86	0.96

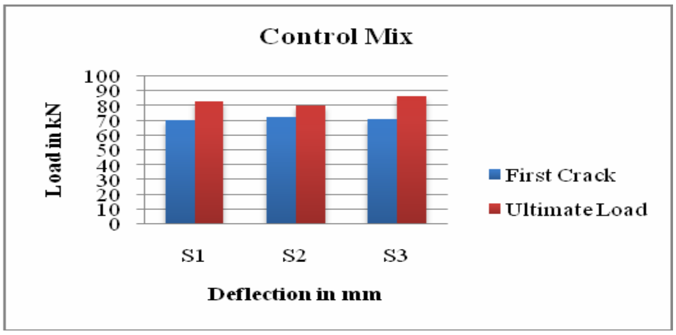

Fig.6 Beam Test Result for Control Mix

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TABLE 11 Flexural Test Results for Beam Specimen with 5% of Vermiculite

Specimen Details	First Crack load (kN)	Ultimate Load (kN)	Deflection at Ultimate Load (mm)
S1	70	79	1.03
S2	74	78	1.08
S3	75	80	1.1

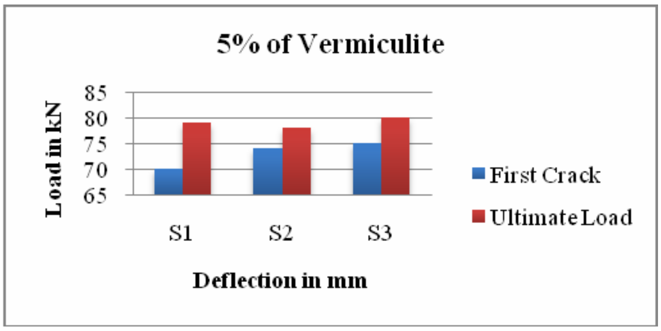

Fig.7 Beam Test Result for 5% of Vermiculite

TABLE 12 Flexural Test Results for Beam Specimen with 10% of Vermiculite

Specimen Details	First Crack load (kN)	Ultimate Load (kN)	Deflection at Ultimate Load (mm)
S1	50	70	0.97
S2	53	68	0.96
S3	52	62	0.94

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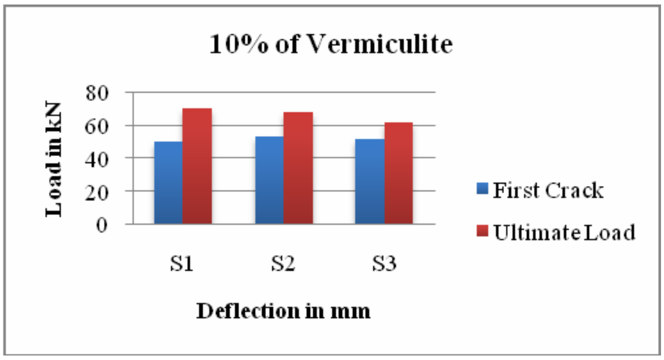

Fig.8 Beam Test Result for 10% of Vermiculite

TABLE 13 Flexural Test Results for Beam Specimen with 15% of Vermiculite

Specimen Details	First Crack load (kN)	Ultimate Load (kN)	Deflection at Ultimate Load (mm)
S1	35	45	2.5
S2	30	42	2.8
S3	33	40	2.1

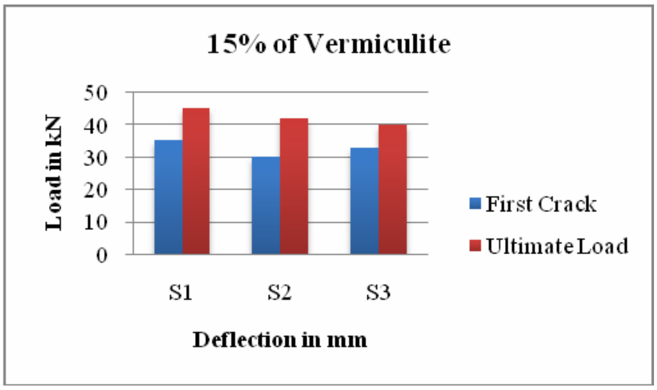

Fig.9 Beam Test Result for 15% of Vermiculite

TABLE 14 Flexural Test Results for Beam Specimen with 20% of Vermiculite

Specimen Details	First Crack load (kN)	Ultimate Load (kN)	Deflection at Ultimate Load (mm)
S1	30	36	2.5
S2	31	38	2.8

S3	33	37	2.1

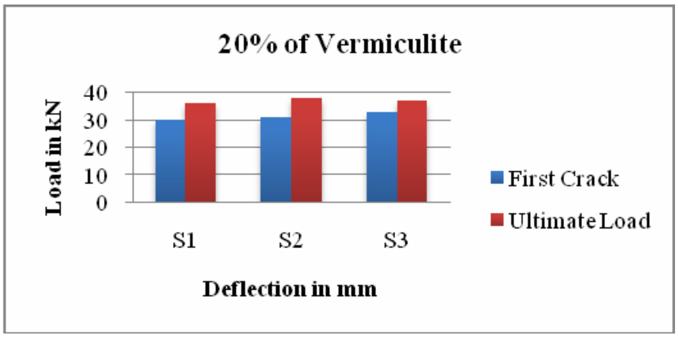

Fig.10 Beam Test Result for 20% of Vermiculite

CONCLUSION

The following points are concluded from our project work.

- After 28 days curing, Vermiculite replaced concrete shows marginal decrease in compressive strength upto 20 % when compared to control concrete.
- Workability is not good after 15% replacement of vermiculite.
- According to the result as we discussed – upto 10% of vermiculite replacement may gives less deflection at ultimate load
- While compared to 5%, 10%, 20% replacement of vermiculite – 5% replacement may carries a positive analysis result
- Weight point of view – around 7 – 8 kg only (whereas normal concrete – leads to 8-9 kg)
- After experimental work – 5% replacement may carries a better result so it is best usage for further construction use

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