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An Experimental Investigation on Strength Properties of Metakaolin Based Light Weight Aggregate Concrete Reinforced With Steel Fibers

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Abstract: *At present all the constructions are executed with conventional granite aggregate concrete. If the granite aggregate is reduced by replacing it partially and fully by Metakaolin pellets as aggregate, the behavior and strength properties are interesting to be investigated. In this study an attempt has been made to use the Metakaolin as the basic ingredient in preparation of artificial pelletized metakaol in aggregate using lime and cement as binders. In the present experimentation, addition of Metakaolin pellets replacing the conventional granite aggregate in percentages of 0, 25, 50, 75 and 100% by volume of concrete and also adding the crimped steel fibre in percentages of 0.50, 1.00, 1.50 and 2.00% by weight. The properties such as compressive strength, split tensile strength, modulus of elasticity and flexural strength are studied by casting and testing around 240 samples consisting of 60 numbers of plain cube specimens of size 150x150x150 mm, 120 numbers of cylinders of size 150mm diameter and 300mm height and 60 numbers of plain beams of size 500x100x100 mm for testing after 28 days of curing.*
Key Words: *mechanical properties, light weight aggregate, pelletization, metakaolin.*

I. Introduction

Concrete is the most extensively used construction material in the world. It is only next to water as the most heavily consumed substance and about more than six billion tones is being produced every year. Due to continuous usage of naturally available aggregate 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 aggregate making use of waste materials from industrial by products and wastes. From the earlier studies it appears that much less attention has been paid towards study of using artificial coarse aggregate. An attempt has been made to use Metakaolin as the basic ingredient in preparing artificial coarse aggregate which is also light in nature. And in the past, attempts were made to impart improvement in tensile properties of conventional concrete members by using conventional reinforcing steel bars and pre-stressing techniques along with addition of different types of steel fibre with different aspect ratios.

Lightweight Aggregate

Lightweight aggregates are classified as natural and artificial light weightaggregate Natural lightweight aggregates are Pumice, Scoria, Diatomite and volcanic cinders etc.Artificiallight weight aggregates are Cinder,Brick batsCoke breeze,Foamed slag, Bloated clay, Expanded shale, slates and pelletized aggregate etc.

Lightweight aggregates, 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. This more absorption of water by lightweight aggregate would help in such a way that, internal curing will be maintained for a longer period.

Artificial Light 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. Metakaolin 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 has gained good attention due to quality on par with conventional aggregate. When structural lightweight concrete is used in construction and maintenance of civil engineering structures, the resultant benefits of reduced overall costs, better heat and sound insulation properties and better resistance to fire can be realized. Despite of its lower compressive strength and lower modulus elasticity, pelletized metakaolin aggregate concrete can be potentially used in many kinds of structural elements.

Metakaolin

Generally the raw material in the manufacture of Metakaoline is kaolin clay. Kaolin is a fine, white clay mineral that has been traditionally used in the manufacture of porcelain. Kaolins are classifications of clay minerals, which like all clays, are phyllosilicates, i.e. a layer silicate mineral. The Meta prefix is the term used to denote change. Metakaolin is neither the by-product of an industrial process nor is it entirely natural. It is derived from naturally occurring mineral and is manufactured specially for cementing applications. Metakaolin is produced under carefully controlled conditions to refine its colour, remove inert impurities, and tailor particle size such that, a much high degree of purity and pozzolanic reactivity can be obtained. Metakaolin is white, amorphous, highly reactive aluminum silicate pozzolana forming stabile hydrates after mixing with lime stone in water and providing mortar with hydraulic properties. Heating up of clay with kaolinite $Al_2O_3.2SiO_2.2H_2O$ as the basic mineral component to the temperature of 500 °C - 600°C causes loss of structural water with the result of deformation of crystalline structure of kaolinite and formation of an unhydrated reactive form so called metakaolinite. It is not a by-product.

Because of its extreme fineness and high Metakaolin content is an effective pozzolanic material and it has been found that Metakaolin improves compressive strength, bond strength, and abrasion resistance, reduces permeability and therefore helps in protecting reinforcing steel from Corrosion.

An attempt has been made to use the Metakaolin as the basic ingredient in preparation of artificial aggregate using lime and cement as binders.

Pelletizing Process

One of the common techniques while producing the light weight aggregate is by agglomeration technique. In agglomeration technique the pellet is formed in two ways either by agitation granulation and compaction. Pelletization of Metakaolin is done by using a rotating drum with fixed blades and adjusting inclination. The desired grain size distribution of an artificial light weight aggregate is by means of agglomeration process. Earlier different types of pelletizer machines were used to make the pellet such as disc or pan type, drum type, cone type and mixer type. In the cold bonded method increase of strength of pellets is by increasing the Metakaolin/lime and cement ratio by weight. The dosage of binding agent is more important for making the Metakaolin 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 Metakaolin and binders (Lime and 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 Metakaolin pelletes is as shown in plate 1.

Fibre

Fibre is a small piece of reinforcing material possessing certain characteristic properties. Generally they are circular or rectangular in cross section. The fibre is designated by its volume fraction and its aspect ratio. Volume fraction represents the volume of fibres used per one m^3 of concrete. The aspect ratio of the fibre is the ratio of the length of the fibre to its diameter. The crimped steel fibres are used with mixed aspect ratio of 48.60

Fibre Reinforced Concrete

In the past, attempts were made to impart improvement in tensile properties of concrete members by using conventional reinforcing steel bars and pre-stressing techniques. Although both these methods improved the tensile strength of the concrete members, there is no increase in the inherent tensile strength of concrete. Under loading, the micro cracks present in concrete propagate and open up, owing to the effect of stress concentration and also additional cracks form in places where there are minor defects. The development of such minor cracks is the main cause of inelastic deformation of concrete. It has been recognized that the additions of small, closely spaced and uniformly dispersed discontinuous discrete fibres to concrete would substantially improve its static and dynamic properties. This type of concrete is known as Fibre Reinforced Concrete. Fibre reinforced concrete may be defined as a mixture of cement mortar or cement concrete and discontinuous, discrete, uniformly dispersed and closely spaced fibre. Continuous meshes, woven fabrics and long rods do not fall within the category of discrete fibre type reinforcing elements considered for fibre reinforced concrete. Chemical admixtures and fly ash can be used to improve the workability of fibre reinforced concrete. The addition of fibres to concrete makes it more homogeneous and isotropic and transforms it from a brittle material to a more ductile material.

Review Of Literature

In this section brief review of the available studies related to the present strength properties of cementitious materials are presented. The review covers the study on strength properties of light weight aggregate concrete analytically and experimentally also.

Weigler, H. and Karl, S. Stahlleichtbeton (1) reported that Air entraining agents can be used with Light Weight Aggregate Concrete. It's use reduces the density proportionally to the weight of the paste it replaces, enhances the workability and reduces the segregation and bleeding.

F.W.Lydon (2) stated that for light weight aggregate concrete, it is more relevant for mix design purpose to relate strength to cement content.

As per the conference proceedings, Japan JASS (3) it was reported that, light weight concretes do not specify any density values, and properties are only provided for concrete made with light weight coarse and fine aggregates.

Neville (4) stated that Due to the rapid economic development and growth in the world population, there is a strong demand on natural aggregate usage. Such aggregates are available in many parts of the world and can be used in producing concrete in a wide range of unit weights and suitable strength values for different fields of applications. In Europe ENV 206 (5) it was published that, light weight concrete is classified according to density.

Clarke, J.L (6) stated that Tensile strength of concrete is important when considering cracking. Light weight aggregate concrete presents a flexural and tensile splitting strength slightly inferior to that of normal weight concrete of the same compressive strength.

Owens, P.L. (7) stated that Light weight aggregate concrete has been used for structural purposes since the 20^{th} 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.

EuroLightCon (8) stated that Light weight aggregate concrete (LWAC) has been used for structural purposes since the 20^{th} century. The density of structural LWAC typically ranges from 1400 to 2000 kg/m³ compared with that of about 2400 kg/m³ for normal weight aggregate concrete.

Alduaij et al. (9) studied about light weight concrete using different unit weight aggregates including light weight crushed bricks, light weight expanded clay and normal weight gravel without the use of natural fine aggregate (no-fines concrete). They obtained a light weight concrete with 22 MPa cylinder compressive strength and 1520 kg/m³ dry unit weight at 28 days.

Nevile, A.M. (10) stated that Pumice is a natural material of volcanic origin produced by the release of gases during the solidification of lava and it has been used as aggregate in the production of lightweight concrete in many countries of the world. So far, the use of pumice was dependent on the availability and limited to the countries where it is locally available or easily imported.

L. Calaveri, et.al, (11) 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 experimental investigation made by Dr. V. Bhaskar Desai, et.al, (12), it is observed that with the 30% replacement of conventional granite by light weight aggregate and with 15% replacement of cement by double blended pozzolonic material (metakoline + pumice powder and silicafume + fly ash) the strengths were found to be optimum. In terms of economy considerations a brief report on cost analysis was prepared. From the cost analysis it was observed that there can be savings up to Rs.800 per cubic meter of concrete.

Expermental 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., pelletized metakaolin aggregate. Soaked and surface dry Metakaolin aggregate and crimped steel fiber has been used in the preparation of concrete specimens with various percentage replacements of natural aggregate. The testing and analysis of the results has been done to investigate effect of metakaolin aggregate on the compressive strength, split tensile strength, flexural strength and modulus of elasticity properties. Variations of various combinations have been studied.

Description Of Constituent Materials And Properties Used In The Investigation:

Table1. Properties Of Materials

Sl.No	Name of the material	Properties of material	Result
1	OPC – 53 Grade	Specific Gravity	3.07
		Initial setting time	60 min
		Final Setting time	450 min
		Fineness	4 %
		Normal consistency	33.50 %
2	Fine Aggregate passing 4.75mm sieve	Specific Gravity	2.60
		Fineness modulus	3.33
		Bulk density in compacted state	1766 kg/m^3
		Bulk density in loose state	1500 kg/m^3
3	Metakaolin Aggregate passing 20 – 10 mm	Specific Gravity	1.83
		Fineness modulus	4.11
		Bulk density compacted state	1022 Kg/m^3
		Bulk density loose state	863 kg/m^3
4	Natural Coarse Aggregate passing 20 – 10 mm	Specific Gravity	2.68
		Fineness modulus	4.23
		Bulk density in compacted state	1620 Kg/m^3
		Bulk density in loose state	1480 kg/m^3
5	Water	Locally available potable water which is free from concentration of acids and organic substances has been used in this work.	

The constituent materials are presented in plate 2 to 6.

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.

Mixing, Casting And Curing

The mix adopted here is M_{20} designed mix concrete with the mix proportion of 1:1.55:3.04. It means that 1 part of cement, 1.55 parts of fine aggregate and 3.04 parts of coarse aggregate consisting of granite and partially replaced pre wetted metakaolin aggregate and steel fiber with required replacement are mixed with water cement ratio of 0.5. Keeping the volume of concrete constant with saturated and surface dry Metakaolin aggregate was added to concrete in 5 different volumetric fractions and also adding 4 different volumetric crimped steel fibers to prepare five different mixes which are designated as follows:

Table 2. Designation Of Different Mixes

Sl.No	Name of the Mix	Percentage replacement of conventional coarse aggregate by volume		Percentage of Crimped steel fiber	No of specimens cast
		Natural coarse aggregate	Pelletized Metakaolin aggregate		
1	MF-0	100	0	0.50	12
				1.00	12
				1.50	12
				2.00	12
2	MF-25	75	25	0.50	12
				1.00	12
				1.50	12
				2.00	12
3	MF-50	50	50	0.50	12
				1.00	12
				1.50	12
				2.00	12
4	MF-75	25	75	0.50	12
				1.00	12
				1.50	12
				2.00	12
5	MF-100	0	100	0.50	12
				1.00	12
				1.50	12
				2.00	12

To proceed with the experimental program initially steel moulds of size 150x150x150 mm with different a/w ratios of 0.3, 0.4 ,0.5, and 0.6 along with plain moulds each in 3 no's, 3 cylinders of size

150mm diameter and 300mm height and 3nos of 500x100x100mm mould to cast plain beams 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 after 24 hours of casting.

To start with, all the materials were weighed in the ratio 1:1.55:3.04. first fine aggregate and cement were added and mixed thoroughly and then coarse aggregates with granite and partially replaced with saturated and surface dry Metakaolin aggregate and crimped steel fiber were mixed with them. All of these were mixed thoroughly by hand mixing. No admixture i.e. super plasticizer was added as the slump of mix is around 2.5 cm to 5 cm and compaction factor is 0.92 to 0.93.

Each time three plain cubes, six cylinders and three plain beams were casted. 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.

However the specimens were de moulded 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. The specimens are shown in plate 7.

II. Testing Of Pecimens

Compression Test On Plain Cubes And Cylinders

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 and cylinders of size 150mm diameter x300mm height are tested for crushing strength. The displacements are 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.

Compressive strength = $\frac{\mathbf{P}}{\mathbf{A}}$ N/mm^2

Where P = Load in KN

A = Cross sectional Area ($A = b^2$) of the specimen in mm^2

b = width of the specimen in mm

The test set up of 3000KN compression testing machine with specimens as shown in plate 8.

The variations of cube compressive strength with various percentage replacement of Metakaolin aggregate replacement of natural aggregate and different percentages of adding the crimped steel fiber in concrete for 28 days curing period has been calculated and variations are recorded vide table 3 and graphically vide fig 1 shows the different percentages of Metakaolin aggregate replacing natural aggregate and addition of different percentages of steel fiber in concrete for 28 days curing period.

The cylinder compressive strength results with various percentage replacement of natural aggregate by Metakaolin aggregate with adding the different percentages of steel fiber are presented vide table 4 and graphically represented vide fig 3. The test setup is as shown in plate 9. The compressive strength has been calculated.

Compressive strength = $\frac{\mathbf{P}}{\mathbf{A}}$ N/mm^2

Where P = Load in KN

A = Cross sectional Area ($A = \pi r^2$)of the specimen in mm^2

r = radius of cylinder in mm

Split Tensile Strength Test On Cylinders:

The cylindrical specimen is kept horizontally so that its axes is horizontal between the compressive plates of the 3000 KN digital compression testing machine. Narrow strips of the packing material i.e., plywood is placed between the plates and the cylinder to receive compressive stress. The load is applied uniformly until the cylinder fails, by splitting along the vertical diameter takes place. The load related to specimen failure is recorded. This test is conducted for cylinders with different metakaolin aggregate additions. This test set up is presented in plate 10. The split tensile strength was calculated by the standard formula.

Split tensile strength $= \frac{\mathbf{2P}}{\boldsymbol{\pi}\mathbf{DL}}$ in N/mm^2

Where P = Maximum load in Newton

D = Diameter of the cylinder in mm

L = Length of the cylinder in mm

The results are presented in table 5 and graphically shows the superimposed variation of split tensile strength for replacing of different percentages of metakaolin aggregate by adding different percentages of steel fiber in concrete for 28 days curing period are shown in fig 5 for 28 days of curing period.

Testing Of Beams For Flexural Strength

The loading arrangement to test the specimens for flexure is as follows. The element is simply supported over the span of 500mm. The specimen is checked for its alignment longitudinally and adjusted if necessary. Required packing is given using rubber packing. Care is taken to ensure that two loading points are at the same level. The loading is applied on the specimen using 15 tones pre-calibrated proving ring at regular intervals. The load is transmitted to the element through I - section and two 16mm diameter rods placed at 166.67mm from each support. For each increment of loading the deflection at the centre and at $1/3^{rd}$ points of beam are recorded using dial gauge. Continuous observations were made. Before the ultimate stage the deflection meters are removed and the process of load application is continued. As the load is increased the cracks are widened and extended to top and finally the specimen collapsed in flexure. At this stage the load is recorded as the ultimate load. Making use of the above data flexural strength has been calculated. The test setup is as shown in plate 11.

The flexural strength of beam is calculated using the formula (f) = $\frac{\mathbf{M}}{\mathbf{Z}} = \frac{\mathbf{WL}}{\mathbf{bd^2}}$ in N/mm^2

Where f = Flexural strength of beam in N/mm^2

M = Bending moment in N.mm

Z = $\frac{\mathbf{I}}{\mathbf{y}}$ = Section modulus in mm^3

W = Ultimate load and L, b and d are section dimensions

The results are presented in table 9 and superimposed variation graphically shows different percentages of adding Metakaolin aggregate and steel fiber in concrete for 28 days curing period shown in fig 13 for 28 days curing period.

Flexural strength is also calculated using IS code method

$$f = 0.7\sqrt{f_{ck}}$$

Where f = Flexural strength of beam in N/mm^2

f_{ck} = Compressive strength of cube in N/mm^2

The results are presented in table 10 and the superimposed variation of flexural strength and percentage replacing natural aggregate with metakaolin aggregate are presented graphically shows different percentages of adding steel fiber in concrete for 28 days curing period shown in fig 15

III. Discussion Of Crack Patterns

The presence of cracks is a characteristic structural feature of most cement based materials. Micro cracking may take place first as a consequence of the partial segregation of the aggregates and plastic shrinkage while the fresh concrete is setting. Temperature differences and drying shrinkage promote further cracking of concrete. After the concrete hardens, various factors further promotes the already existing micro cracks and cause the initiation of new ones. It is thought that cracks whatever their origin (mechanical/thermal/chemical etc) can act as major pathways for water or aggressive chemical ions to penetrate into concrete, reducing its strength.

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 along the edge of the cube more predominantly along the top side of casting.

In case of cylinders under compression cracks are developed at top and bottom and with increase in load the cracks are widened at centre. In case of cylinders subjected to split tensile strength the cylinder was splitted into two pieces.

In case of beams the first crack developed at bending zone on tension side of beam and propagates to compression side of beam and the major crack is developed at bending zone only. In general the crack widths are more in light weight aggregate than in normal aggregate concrete. With inclusion of fiber, they act as crack arresters and act as a bridge between the cracks and delay their propagation.

IV. Discussion Of Test Results

Influence Of Metakaolin Aggregate On Cube Compressive Strength:

In the present study Metakaolin aggregate has been replaced by natural aggregate in volumetric percentages of 0, 25, 50, 75 and 100% and also crimped steel fiber in different percentages of 0.50, 1.00, 1.50 and 2.00% has been added to the concrete.

The test results of cube compressive strength for different percentages of Metakaolin aggregate replacing natural aggregate and for the different percentages of crimped steel fiber are presented in table 3 and variations are represented graphically in fig 1 at 28 days of curing. From this table and figure, it is observed that with the percentage increase in Metakaolin aggregate, the cube compressive strength decreases continuously from 0 to 100%. But with the increasing percentage of steel fiber, the cube compressive strength is increased continuously from 0.50 to 2.00% for 28 days curing period.

Further the superimposed variation between percentage decrease in cube compressive strength and percentage of metakaolin aggregate replacing natural aggregate is shown in fig 2. The crack patterns of the specimens are shown in plate 12.

Influence Of Metakaolin Aggregate On Cylinder Compressive Strength

The test results of cylinder compressive strength for different percentages of Metakaolin aggregate replacing natural aggregate and for the different percentages of crimped steel fiber are presented in table 4 and variations are represented graphically in fig 3 at 28 days of curing. From this table and figure, it is observed that with the percentage increase in Metakaolin aggregate, the cylinder compressive strength decreases continuously from 0 to 100%. But with the increasing percentage of steel fiber, the cylinder compressive strength is increased continuously from 0.50 to 2.00% for 28 days curing period.

The super imposed variation between percentage decrease in cylinder compressive strength and percentage of metakaolin aggregate replacing natural aggregate is shown in fig 4 for 28 days curing period.

Influence Of Metakaolin Aggregate On Split Tensile Strength

The test results of split tensile strength for different percentages of Metakaolin aggregate replacing natural aggregate and for the different percentages of crimped steel fiber are presented in table 5 and variations are represented graphically in fig 5 at 28 days of curing. From this table and figure, it is observed that with the percentage increase in metakaolin aggregate, the split tensile strength decreases continuously from 0 to 100%. But with the increasing percentage of steel fiber, the split tensile strength is increased continuously from 0.50 to 2.00% for 28 days curing period.

The super imposed variation between percentage decrease in split tensile strength and percentage of metakaolin aggregate replacing natural aggregate is shown in fig 6 for 28 days curing period.

Influence Of Metakaolin Aggregate On Density

The test results of density for different percentages of metakaolin aggregate replacing natural aggregate and for the different percentages of crimped steel fiber are presented in table 6 and variations are represented graphically in fig 7 at 28 days of curing period. From this table and figure, it is observed that with the percentage increase in metakaolin aggregate, the density decreases continuously from 0 to 100%. But with the increasing percentage of steel fiber, the density get increased continuously from 0.50 to 2.00% for 28 days curing period. The superimposed variation between percentage decrease in density and percentage of metakaolin aggregate replacing natural aggregate is shown in fig 8.

Influence Of Metakaolin Aggregate On **Modulus Of Elasticity Based On I.S. Code Method**

The theoretical modulus of elasticity has been calculated by using IS code formula:

$$E = 5000 * \sqrt{f_{ck}}$$

Where f_{ck} = 28 days Characteristic Compressive strength of concrete in N/mm^2

The test results of young's modulus for different percentages of metakaolin aggregate replacing natural aggregate and for the different percentages of crimped steel fiber are presented in table 7 and variations are represented graphically in fig 9 at 28 days of curing period. From this table and figure, it is observed that with the percentage increase in metakaolin aggregate, the youngs modulus decreases continuously from 0 to 100%. But with the increasing percentage of steel fiber, the youngs modulus increased continuously from 0.50 to 2.00% for 28 days curing period. The superimposed variation between percentage decrease in youngs modulus and percentage of metakaolin aggregate replacing natural aggregate is shown in fig 10.

Influence Of Metakaolin Aggregate On Modulus Of Elasticity Based On Empherical Formula:

The modulus of elasticity values have been calculated from the empirical formula suggested by Takafumi is

$$E = k_1 k_2 * 1.486 * 10^{-3} * f_{ck}^{1/3} * \gamma^2$$

Where f_{ck} = 28 days cube compressive strength in N/mm^2

γ = Density in Kg/m^3

K_1 = 0.95 (correction factor corresponding to coarse aggregate)

K_2 = 1.026 (correction factor corresponding to mineral admixtures)

The test results young's modulus for different percentages of metakaolin aggregate replacing natural aggregate and for the different percentages of crimped steel fiber are presented in table 8 and variations are represented graphically in fig 11 at 28 days of curing period. From this table and figure, it is observed that with the percentage increase in metakaolin aggregate, the youngs modulus decreases continuously from 0 to 100%. But with the increasing percentage of steel fiber, the youngs modulus get increased continuously from 0.50 to 2.00% for 28 days curing period. The superimposed variation between percentage decrease in youngs modulus and percentage of metakaolin aggregate replacing natural aggregate is shown in fig 12.

Influence Of Metakaolin Aggregate On Flexure

The flexural strength of the beam is calculated by using the formula

$$f = \frac{M}{Z} \text{ in N/mm}^2$$

Where M = Bending moment in N.mm

Z =I/y= Section modulus in mm^3

f = Flexural strength of beam in N/mm

W=Ultimate load and L, b and d are section dimensions

The test results of flexural strength for different percentages of metakaolin aggregate replacing natural aggregate and for the different percentages of crimped steel fiber are presented in table 9 and variations are represented graphically in fig 13 at 28 days of curing period. From this table and figure, it is observed that with the percentage increase in metakaolin aggregate, the flexural strength decreases continuously from 0 to 100%. But with the increasing percentage of steel fiber, the flexural strength increased continuously from 0.50 to 2.00% for 28 days curing period. The superimposed variation between percentage decrease in flexural strength and percentage of metakaolin aggregate replacing natural aggregate is shown in fig 14.

Flexural strength is also calculated by using I.S. code method

$$f = 0.7\sqrt{f_{ck}}$$

Where **f = Flexural strength of beam in N/mm²**

f_{ck} = 28 days cube compressive strength of cube in **N/mm²**

The test results of flexural strength for different percentages of metakaolin aggregate replacing natural aggregate and for the different percentages of crimped steel fiber are presented in table 10 and variations are represented graphically in fig 15 at 28 days of curing period. From this table and figure, it is observed that with the percentage increase in metakaolin aggregate, the flexural strength decreases continuously from 0 to 100%. But with the increasing percentage of steel fiber, the flexural strength get increased continuously from 0.50 to 2.00% for 28 days curing period. The superimposed variation between percentage decrease in flexural strength and percentage of metakaolin aggregate replacing natural aggregate is shown in fig 16.

V. Conclusions

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

1. It is observed that the addition of fiber with different volumetric fractions leads to decrease in the workability.
2. The addition of steel fibers offers an increase in compressive and tensile strengths of about 19% and 93.50% respectively for fiber volume fraction equal to 1% at age of 28 days.
3. It is observed that the cube compressive strength decreases continuously with the increase in percentage of pelletized Metakaolin aggregate i.e. from 0 to 100% replacement; further it may be concluded that the compressive strength of material increases with increasing crimped steel fiber content and strength enhances from 2 to 17.72% for 0% replacement and 12.15 to 24.03% for 100% replacement of metakaolin aggregate.
4. The split tensile strength gets decreased continuously with the increase in percentage of metakaolin aggregate i.e. from 0 to 100% replacement; further split tensile strength of material increases with increasing crimped steel fiber content and enhances from 15.08 to 37.43 for 0% replacement and from 62.89 to 134.54% for 0 to 100% replacement.
5. The addition of crimped steel fiber has significantly enhanced the flexural strength. During the test it is clearly observed that the fiber reinforced specimens has greater crack control when compared with plain beams. Further the flexural strength increases with increasing steel fiber content from 0 to 2.00%. Also the strength decreases with increasing replacement of metakaolin aggregate from 0 to 100%.
6. It is also observed that the density increases with increasing the steel fiber content but decreases with the increasing replacement of metakaolin aggregate i.e. from 0 to 100%.
7. The modulus of elasticity gets decreased continuously with increase in percentage of metakaolin aggregate i.e. from 0 to 100% replacement; further young's modulus increases with the increasing steel fiber content.

8. The modulus of elasticity values calculated from empherical formula and from experimental observations is found to be in satisfactory agreement.
9. After examining the results, it indicates that fiber reinforced concrete can be effectively used up to 2.00% of fibers as considered in this investigation.
10. Based on the experimental investigations it is concluded that cold bonded artificial pelletized light weight aggregate manufactured from metakaolin is in no way inferior to the naturally available light weight aggregate.

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Table 3: Cube Compressive Strength Results

Sl. N0	Name of the mix	Percentage volume replacement of coarse aggregate		Compressive strength in N/mm^2 with an addition of steel fiber in percentage				Percentage of decrease or increase in cube compressive strength w.r.t. M-0 with an addition of steel fiber in percentage			
		Natural Aggregate	Pelletized Metakaolin Aggregate	0.50	1.00	1.50	2.00	0.50	1.00	1.50	2.00
1	MF-0	100	0	41.90	44.90	45.48	48.36	0.00	0.00	0.00	0.00
2	MF-25	75	25	34.50	36.59	40.28	42.18	-17.66	-18.51	-11.43	-12.78
3	MF-50	50	50	34.37	35.44	36.03	39.42	-17.97	-21.07	-20.78	-18.49
4	MF-75	25	75	33.38	34.87	35.23	35.51	-20.33	-22.34	-22.54	-26.57
5	MF-100	0	100	29.82	31.50	32.19	32.98	-28.83	-29.84	-29.22	-31.80

Table 4: Cylinder Compressive Strength Results

Sl.N 0	Name of the mix	Percentage volume replacement of coarse aggregate		Compressive strength in N/mm^2 with an addition of percentage of steel fiber in percentage				Percentage of decrease or increase in cube compressive strength w.r.t. M-0 with an addition of steel fiber in Percentage			
		Natural aggregate	Pelletized Metakaolin Aggregate	0.50	1.00	1.50	2.00	0.50	1.00	1.50	2.00
1	M-0	100	0	22.68	25.51	27.62	29.64	0.00	0.00	0.00	0.00
2	M-25	75	25	20.04	20.97	25.68	26.66	-12.00	-18.00	-7.02	-10.05
3	M-50	50	50	17.95	19.50	23.80	24.10	-20.85	-24.00	-14.00	-19.00
4	M-75	25	75	16.16	18.44	20.44	22.68	-29.00	-28.00	-26.00	-23.48
5	M-100	0	100	14.20	18.20	18.72	19.70	-37.38	-29.00	-32.22	-34.00

Table 5: Split Tensile Strength Results

Sl. N0	Name of the mix	Percentage volume replacement coarse of aggregate		Split Tensile strength in N/mm^2 with an addition of steel fiber in Percentage				Percentage of increase or decrease in Split tensile strength w.r.t. M-0 with an addition of steel fiber in Percentage			
		Natural aggregate	Pelletized Metakaolin Aggregate	0.50	1.00	1.50	2.00	0.50	1.00	1.50	2.00
1	M-0	100	0	4.12	4.66	4.72	4.92	0.00	0.00	0.00	0.00

2	M-25	75	25	4.04	4.30	4.72	4.88	-1.94	-8.00	-0.00	-0.81
3	M-50	50	50	3.46	4.22	4.35	4.66	-16.01	-9.44	-8.00	-5.28
4	M-75	25	75	3.41	3.94	4.12	4.55	-17.23	-15.45	-13.00	-8.00
5	M-100	0	100	3.16	3.67	3.69	4.55	-23.30	-21.24	-22.00	-8.00

Table 6: Density Results For 28 Days Curing Period

S .No	Name of the mix	Percentage volume replacement of coarse aggregate		Density in Kg/m^3 with an addition of steel fiber in percentage				Percentage of increase or decrease in Density w.r.t. M.-0 with an addition of steel fiber in Percentage			
		Natural Aggrega te	Pelletized Metakaolin Aggregate	0.50	1.00	1.50	2.00	0.50	1.00	1.50	2.00
1	M-0	100	0	2442.47	2474.57	2498.27	2504.20	-0.00	-0.00	-0.00	-0.00
2	M-25	75	25	2345.19	2350.12	2369.88	2384.20	-3.98	-5.03	-5.14	-4.79
3	M-50	50	50	2241.48	2242.47	2256.79	2261.73	-8.23	-9.38	-9.67	-9.68
4	M-75	25	75	2142.72	2152.59	2172.84	2213.83	-12.27	-13.01	-13.03	-11.60
5	M-100	0	100	2025.68	2060.74	2115.06	2170.37	-17.06	-16.72	-15.34	-13.33

Table 7: Young's Modulus Results Based On I.S. Code Method (E=5000 $\sqrt{F_{ck}}$)

S.NO	Name of the mix	Percentage volume replacement of coarse aggregate		Young's Modulus in N/mm² * 10^4 With an addition of steel fiber in percentage				Percentage of increase or decrease in Young's modulus w.r.t. M-0 With an addition of steel fiber in Percentage			
		Natural aggregate	pelletized metakaolin aggregate	0.50	1.00	1.50	2.00	0.50	1.00	1.50	2.00
1	M-0	100	0	3.24	3.35	3.37	3.48	0.00	0.00	0.00	0.00
2	M-25	75	25	2.94	3.02	3.17	3.25	-9.26	-9.73	-5.89	-6.61
3	M-50	50	50	2.93	2.98	3.00	3.14	-9.43	-11.16	-10.99	-9.72
4	M-75	25	75	2.89	2.95	2.97	2.98	-10.74	-11.87	-11.99	-14.31
5	M-100	0	100	2.73	2.81	2.84	2.87	-15.64	-16.24	-15.87	-17.42

Table 8: Young's Modulus Results Based On Empirical Formula

S.NO	Name of the mix	Percentage volume replacement of coarse aggregate (%)		Young's modulus $E=k_1*k_2*1.486*10^{-3}*\sigma_b^{1/3}*\gamma^2*10^4$ in N/mm² where k_1=0.95, k_2=1.026 with an addition of steel fiber in percentage				Percentage of increase or decrease in Young's modulus w.r.t. M-0 With an addition of steel fiber in Percentage			
		Natural aggregate	Pelletized Metakaolin aggregate	0.50	1.00	1.50	2.00	0.50	1.00	1.50	2.00
1	M-0	100	0	3.00	3.15	3.23	3.31	0.00	0.00	0.00	0.00
2	M-25	75	25	2.59	2.66	2.79	2.87	-13.59	-15.75	-13.58	-13.39
3	M-50	50	50	2.37	2.39	2.44	2.52	-21.16	-24.11	-24.49	-23.80
4	M-75	25	75	2.14	2.19	2.24	2.33	-28.65	-30.44	-30.53	-29.49
5	M-100	0	100	1.84	1.94	2.06	2.19	-38.59	-38.38	-36.12	-33.88

Table 9: Flexural Strength Results

S.N0	Name of the mix	Percentage volume replacement of coarse aggregate		Flexural strength in N/mm^2 with an addition of steel fiber in percentage				Percentage of decrease or increase in Flexural strength w..r.t. M-0 with an addition of steel fiber in percentage			
		Natural aggregate	Pelletized Metakaolin Aggregate	0.5	1	1.5	2	0.5	1	1.5	2
1	M-0	100	0	5.45	5.80	5.80	6.32	0.00	0.00	0.00	0.00
2	M-25	75	25	4.19	4.22	5.09	5.27	-23.12	-27.24	-12.24	-16.61
3	M-50	50	50	3.69	4.22	4.39	4.57	-32.29	-27.24	-24.31	-27.69
4	M-75	25	75	3.16	3.69	4.22	4.39	-42.02	-36.38	-27.24	-30.54
5	M-100	0	100	2.46	2.81	3.16	3.69	-54.86	-51.55	-45.52	-41.61

Table 10: Flexural Strength Results Based On Is Code Method

S.N0	Name of the mix	Percentage volume replacement of coarse aggregate		Flexural strength in N/mm² with an addition of steel fiber in percentage				Percentage of increase or decrease in Flexural strength as per IS code w.r.t. M-0 with an addition of steel fiber in percentage			
		Natural aggregate	Pelletized Metakaolin Aggregate	0.50	1.00	1.50	2.00	0.50	1.00	1.50	2.00
1	M-0	100	0	4.53	4.69	4.72	4.87	0.00	0.00	0.00	0.00
2	M-25	75	25	4.11	4.23	4.44	4.55	-9.26	-9.73	-5.89	-6.61
3	M-50	50	50	4.10	4.17	4.20	4.39	-9.43	-11.16	-10.99	-9.72
4	M-75	25	75	4.04	4.13	4.15	4.17	-10.74	-11.87	-11.99	-14.31
5	M-100	0	100	3.82	3.93	3.97	4.02	-15.64	-16.24	-15.87	-17.42

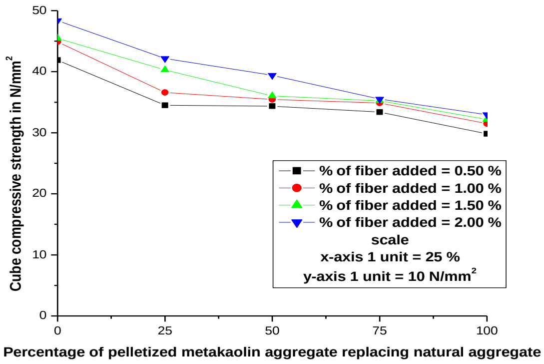

Fig 1. Superimposed variation between cube compressive strength and percentage of pelletized metakaolin aggregate replacing natural aggregate

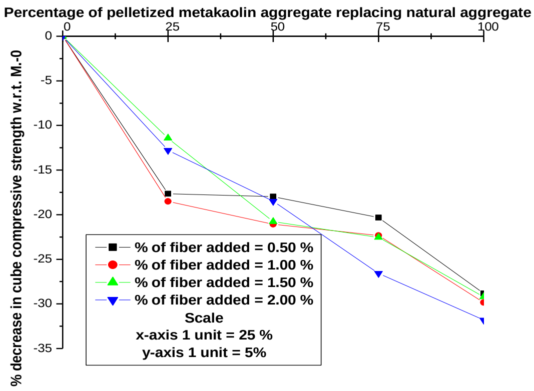

Fig 2. Superimposed variation between percentage decrease in cube compressive strength w.r.t. M-0 and percentage of pelletized metakaolin aggregate replacing natural aggregate

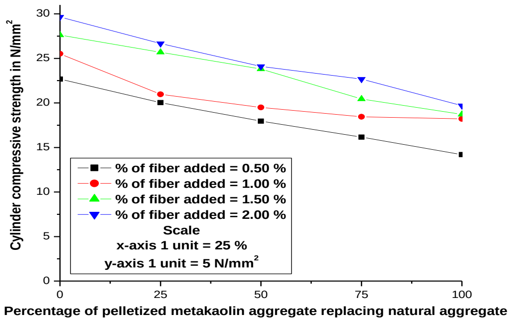

Fig 3. Super imposed variation between cylinder compressive strength and percentage of pelletized metakaolin aggregate replacing natural aggregate

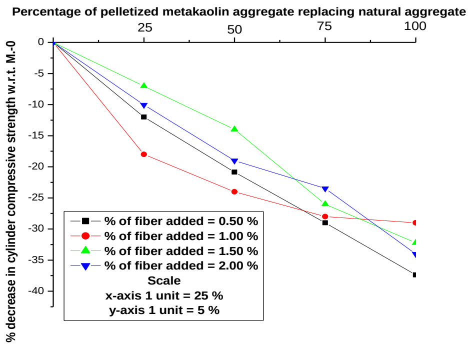

Fig 4. Super imposed variation between percentage decrease in cylinder compressive strength w.r.t. M-0 and percentage of pelletized metakaolin aggregate replacing natural aggregate

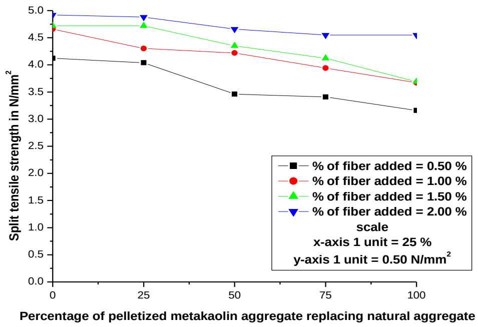

Fig 5. Superimposed variation between split tensile strength and percentage of pelletized metakaolin aggregate replacing natural aggregate

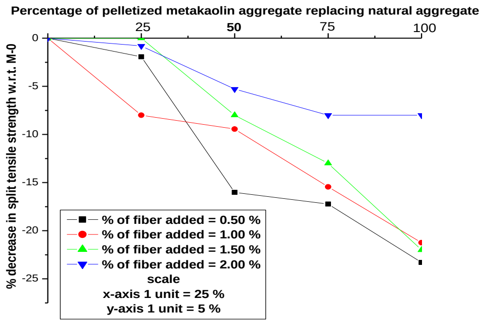

Fig 6. Super imposed variation between percentage decrease in split tensile strength and percentage of pelletized metakaolin aggregate replacing natural aggregate

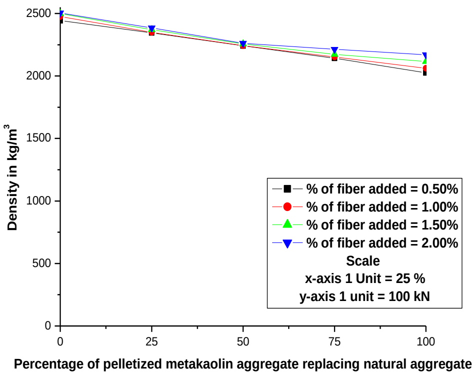

Fig 7. Super imposed variation between density and percentage of pelletized metakaolin aggregate replacing natural aggregate

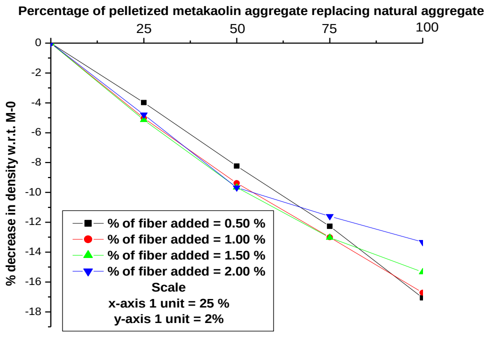

Fig 8. Superimposed variation between percentage decrease in density w.r.t. M-0 and percentage of pelletized metakaolin aggregate replacing natural aggregate

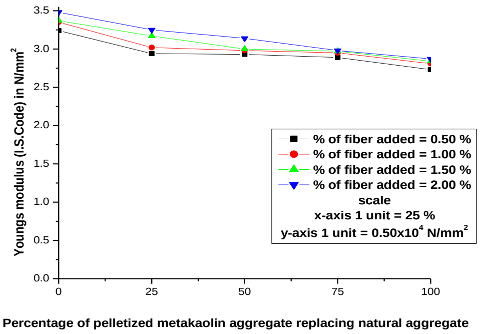

Fig 9. Super imposed variation between youngs modulus (I.S.Code Method) and percentage of pelletized metakaolin aggregate replacing natural aggregate

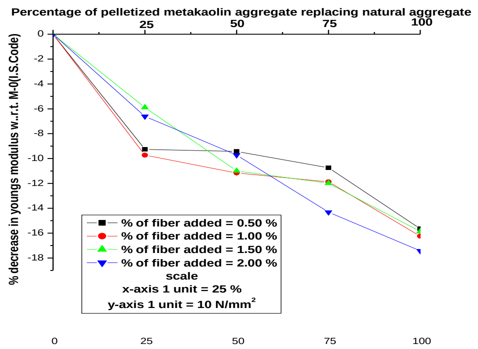

Fig 10. Super imposed variation between percentage decrease in youngs modulus (I.S.Code Method) and percentage of pelletized metakaolin aggregate replacing natural aggregate

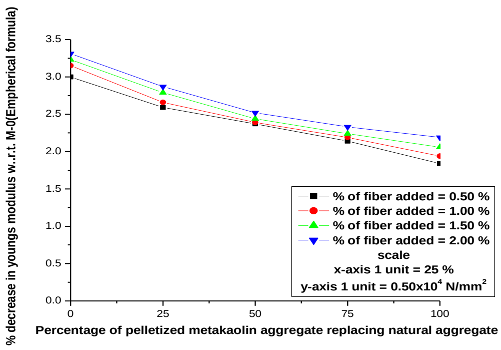

Fig 11. Super imposed variation between youngs modulus (Empherical formula) and percentage of pelletized metakaolin aggregate replacing natural aggregate

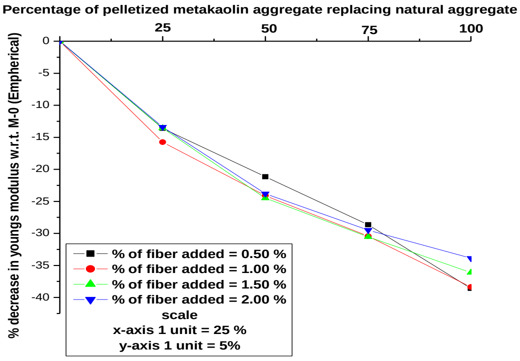

Fig 12. Super imposed variation between percentage decrease in youngs modulus (Empherical formula) and percentage of pelletized metakaolin aggregate replacing natural aggregate

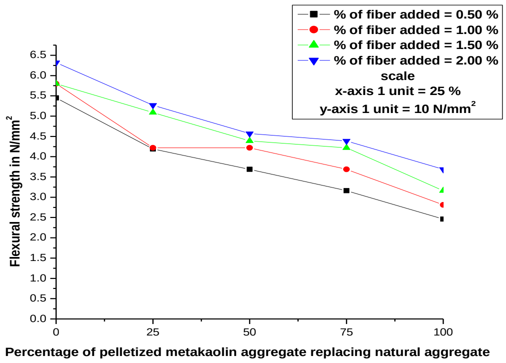

Fig 13. Super imposed variation between flexural strength and percentage of pelletized metakaolin aggregate replacing natural aggregate

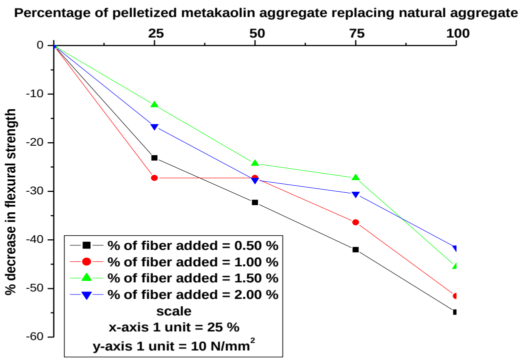

Fig 14. Super imposed variation between percentage decrease in flexural and percentage of pelletized metakaolin aggregate replacing natural aggregate

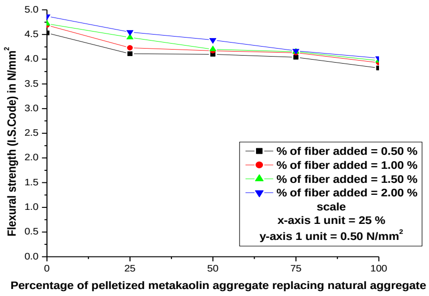

Fig 15. Super imposed variation between flexural strength (I.S.Code) and percentage of pelletized metakaolin aggregate replacing natural aggregate

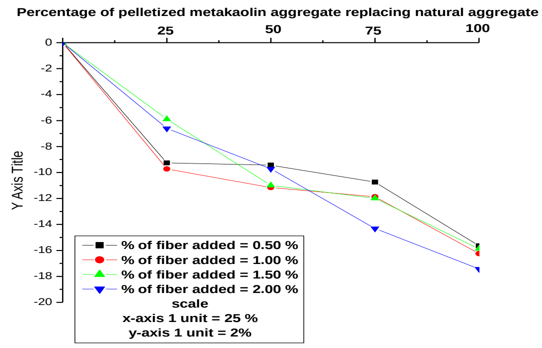

Fig 16. Super imposed variation between percentage decrease in flexural strength (I.S.Code) and percentage of pelletized metakaolin aggregate replacing natural aggregate

Plate1. Pelletization drum

Plate2. Mixed aspect fiber

Plate 3. River sand

Plate4. Cement

Plate5.Conventional Coarse Aggregate

Plate6. Metakaolin aggregate

Plate7.Specimens before testing

Plate8.Test set up of cube compressive strength

Plate9. Test set up of Cylinder compressive strength

Plate 10. Test Set up of Split Tensile strength

Plate11. Test set up of beam for flexural strength

Plate12. Crack patterns of specimens after testing.