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# An Experiment on Incorporation of Bentonite Clay in Mortar

**N Manoj Kumar, I Saikrishnamacharyulu, M Hitesh Kumar, Satyasri U. B Sarangi**

***Abstract*: Mortar refers to a binding paste which is workable in nature and consistency, used as a binder in construction activities such as stone bonding in stone masonry, brick bonding in brick masonry and as well as in concrete works. Mortar is often used as a means for decorative works attaining to its workable nature, which in this project I have intended to enhance. Mortar is further used as a sealant in order to fill cracks and gaps within the structure. The term mortar is taken from the Latin term " mortarium" which means crushed. Mortar is often prepared by mixing a suitable binder, fine aggregate or in simpler terms sand and water by a fixed proportion by mass or volume. The ratio of the constituents depends on the quality and magnitude of the work being done. Mortar gains its strength due to the various chemical reactions that occur while the mortar is being cured in water, gaining 99% strength in 28 days. The most used binder in modern times is Portland cement, which was used at the onset of 20$^{th}$ century. A common binder prevailing in the past was lime and the associated mortar mix was called lime mortar. A major part of this project lies in the use of clay as a substitute for sand in mortar. Clay refers to a fine-grained soil deriving its origin from naturally occurring rocks that have undergone chemical weathering. Clay mineral can be classified into three types i.e. Kaolinite, montmorillonite and illite. The type of clay that has been used in this experiment is Bentonite which is a volcanic in origin and has montmorillonite as a major constituent. Clay has water entrapped within its structure and the amount of water depends on the type of clay mineral being dealt with. One of the major properties of clay that I have tried to exploit in this project is its plastic nature i.e. the ability of the soil to gain resistance against shear failure by sliding as they get into a dry state as opposed to possessing very little or no resistance to the same when they absorb water. Attaining help of various properties of clay, in this project I will try to evaluate the various properties of a mortar cube by mixing a fixed proportion by mass of clay in the same and present my observations***

***Keywords* : Mortar, clay incorporation compressive strength.**

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## I. INTRODUCTION

### Mortar

In civil engineering, mortar refers to the binder material used in construction for various purposes. Mortar can be used to achieve bonding between bricks, stones or concrete blocks to build a structure. Mortar can also be used for setting tiles in flooring works or setting tiles on walls for aesthetic purposes. The mortar comprises of non-reactive silica based crystals generally referred to as sand and a binder. In modern world the most extensively used binder is cement while its predecessor lime was used in pre 20$^{th}$ century. Maintaining a proper water cement ratio will result in the attainment of a suitable degree of plasticity to render an appropriate workability for the easy placing of the mortar in various surfaces as well as giving a suitable strength to take up the load coming onto it from the structure it is being used for.

The proportions of the various ingredients that make up mortar depends on the type of work being done. A standard ratio of 1:3 i.e. one part cement to 3 parts of sand batched by weight gives a good quality to the mortar and this above ratio is used for the testing purpose of mortar cubes as well as to determine the grade of cement used. Sometimes coloring agents are added in the mortar to promote aesthetic purposes.

Mortar attains its strength after drying and keeps on gaining strength while the curing period. Mortar proves indispensable in distributing the loads uniformly throughout the structure and providing resistance when it comes to the effect of weather and plays a vital role of rain proofing the building. The mortar, when dried and cured becomes hard and makes the individual brick or concrete block structure as a rigid structure. For construction works various types of mortar is used depending on the constituents of the mixture. Some prevailing kinds are as follows:

- Cement mortar
- Lime mortar
- Surkhi mortar
- Mud mortar
- Gauged mortar

Cement mortar is the most used one in today' s world while surkhi mortar which is composed of lime as binding material and surkhi as aggregate is the most economical one. Gauged mortar uses both cement and lime as binding material.

## BENTONITE CLAY

Bentonite aluminum phyllosilicate clay consisting mostly of montmorillonite. It was named by Wilbur C. Knight in 1898 after the Cretaceous Benton Shale near Rock River, Wyoming. The different types of bentonite are each named after the respective dominant element, such as potassium (K), sodium (Na), calcium (Ca), and aluminum (Al). Experts debate a number of nomenclatorial problems with the classification of bentonite clays. Bentonite usually forms from weathering of volcanic ash, most often in the presence of water.

However, the term bentonite, as well as a similar clay called tonstein, has been used to describe clay beds of uncertain origin. For industrial purposes, two main classes of bentonite exist: sodium and calcium bentonite. In stratigraphy and tephrochronology, completely devitrified (weathered volcanic glass) ash-fall beds are commonly referred to as K-bentonites when the dominant clay species is illite. In addition to montmorillonite and illite another common clay species that is sometimes dominant is kaolinite. Kaolinite-dominated clays are commonly referred to as tonsteins and are typically associated with coal.

Bentonite occurs in rocks that were deposited in the Ordovician to Neogene periods (about 488.3 to 2.6 million years ago). In the United States the principal producers are Wyoming, Montana, California, Arizona, and Colorado. Important world producers are Greece, Japan, Italy, Brazil, Romania, Germany, Mexico, Argentina, Spain, India, Hungary, Poland, Canada, Turkey, and Cyprus.

These have been used to seal dams; in bonding foundry sands, asbestos, and mineral wool; as drilling muds; in Portland cements and concrete, ceramics, emulsions, insecticides, soaps, pharmaceuticals, and paints; in the manufacture of paper; for clarifying water, juices, and liquors; and as a water softener to remove calcium from hard water. Calcium bentonites are non-swelling and break down to a finely granular aggregate that is widely used as an absorbent clay sometimes called fuller's earth.

## II PROPERTIES OF CLAY

This experiment is aimed to find the various change in the properties of the standard mortar mix after subsequent addition of bentonite clay. The Bentonite clay that was used in the experiment has the following characteristic property according to IS2911 (PART-I/SEC-2)-1979:

| SL.NO | PROPERTY | REMARKS |
|---|---|---|
| 1 | Chemical Composition | $Al_2H_2Na_2O_{13}Si_4$ |
| 2 | Color | Off-White to Tan |
| 3 | Swelling Index | 2 times of dry volume |
| 4 | Particle size | 250 mesh (60 micron) |
| 5 | Bulk Density, g/cc | 1.10 1.12 Approximate |
| 6 | Moisture content, % by weight | 12.0 Maximum |
| 7 | pH | 8.5 to 11 |
| 8 | TDS, ppm | 12-14 |
| 9 | Liquid limit, ml/100 g | 300-450 |
| 10 | Loss on drying(% weight) | 6-8% |
| 11 | Sand content, % | 1.2 Maximum 7 |
| 12 | Marsh Viscosity | 37 Approximate |
| 13 | Gel Formation Index | 45 |
| 14 | Suspension, % | 90 |
| 15 | Methyl Blue Index | 350-400 |
| 16 | Melting Point, $^oC$ | >450 |
| 17 | Moh's Hardness | 1-2 |

| SL.NO | PARTICLE SIZE | PERCENTAGE |
|---|---|---|
| 1 | Greater than 1 mm | 33.33 |
| 2 | Between 1 mm and 500 micron | 33.33 |
| 3 | Smaller than 500 micron | 33.33 |

## III EXPERIMENTAL PROCEDURE

### Casting of control cube:

In order to test the relative changes in the properties of the clay incorporated mortar we need to first cast a standard mortar of cement and sand in a fixed ratio of 1:3 by weight. Since the cubes are intended for comparison purpose, I used the fine aggregate passing from 600 micron sieve for ease in the casting process. The sand that is preferably used in casting of mortar cubes shall be of quartz, of light, gray or whitish variety and shall be free from silt. The sand grains shall be angular, the shape of grains approximating to the spherical form, elongated and flattened grains being present only in very small quantities.Standard sand shall pass through 2 mm IS sieve and shall be retained on 90 microns IS sieve with the following particle size distribution:

Additionally another mortar cube adhering to the above mentioned gradation of the fine aggregate was casted for the purpose of testing.

According to American Society for Testing and Materials mortar cubes are casted in a square cast of sides of 7.06 cm resulting in a surface area of 50 $cm^2$. The binder material that is the cement used is Portland Pozzolana cement (PPC) of grade 53.

200 grams of cement and 600 grams of sand were taken in a pan. The cement and sand was mixed in dry condition with a trowel for one minute and then water was added. The quantity of water was taken as 50% of the cement content that is 100 grams. The mixture was mixed for more than 3 minutes and less than 4 minutes till the mixture attains a uniform color. Immediately after mixing the mortar, it was placed in the cube mold and prod with the help of the rod. The mortar shall be prodded 20 times in about 8 sec to ensure elimination of entrained air. After 24 hours the cube was removed from the mold and immediately submerged in water till testing.

## CASTING OF CLAY REPLACED MORTAR CUBES:

For the casting of the clay incorporated mortar cubes a similar approach was taken as described previously, the only change being in the replacement of a certain percentage of the fine aggregate by clay. For the purpose of this study 9 cubes of replaced clay was casted. The weight batching data of the various casted cubes are as follows:

| Sl.No | Cube Type | Cement(in grams) | Sand(in grams) | Clay(in grams) |
|---|---|---|---|---|
| 1 | Control cube | 200 | 600 | - |
| 2 | 3% clay replaced | 200 | 582 | 18 |
| 3 | 5% clay replaced | 200 | 570 | 30 |
| 4 | 7% clay replaced | 200 | 558 | 42 |
| 5 | 10% clay replaced | 200 | 540 | 60 |
| 6 | 15% clay replaced | 200 | 510 | 90 |
| 7 | 20% clay replaced | 200 | 480 | 120 |
| 8 | 25% clay replaced | 200 | 450 | 150 |
| 9 | 30% clay replaced | 200 | 420 | 180 |

After the mixing of the mixture till a homogenous color is obtained or from 3 minutes to 4 minutes, the mix was placed in molds with marking of the percentage of clay replaced and properly compacted. The top surface of the mortar was made smooth using the trowel and the specimen were left to dry for 24 hours. After 24 hours the cubes were removed from the molds and put in water till the testing day. Care should be taken that the water used for the above curing purpose should be clean without any suspended particulates and the water should not be stirred too often as it might affect the surface smoothness of the clay incorporated cubes.

## IV COMPRESSION TEST OF THE MORTAR CUBES

With the assistance of a Digital Universal Testing Machine the compression test of the mortar cubes were done to determine the compressive strength of the mortar cubes and a lode versus displacement graph was obtained for the various specimen. The rate of loading should be 350 kg/cm$^2$/minute and uniform.

The cubes, after 7 days of curing period inside water were taken out just before the compression test and the surface of the cubes were dried using a piece of cloth. Then the cubes were placed on their smooth and even side inside the universal testing machine and a gradual compressive load was provided at the above mentioned rate

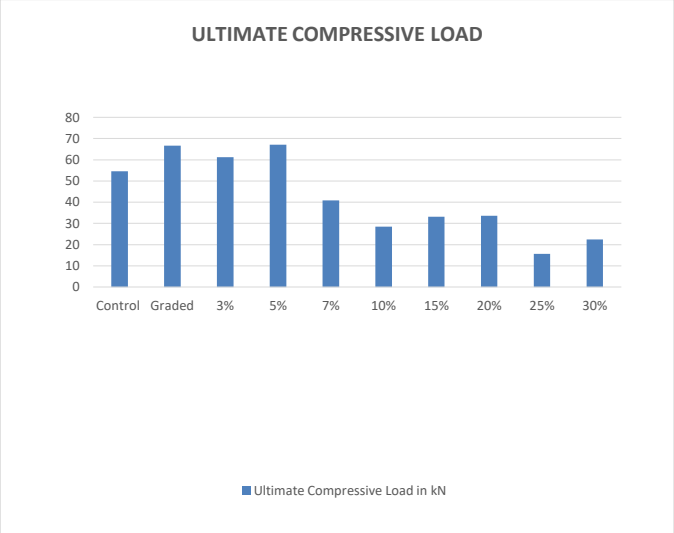
The use of ungraded sand in the mortar specimen served the purpose of easing the experiment as well as provided a subsequent decrease in the testing time too.

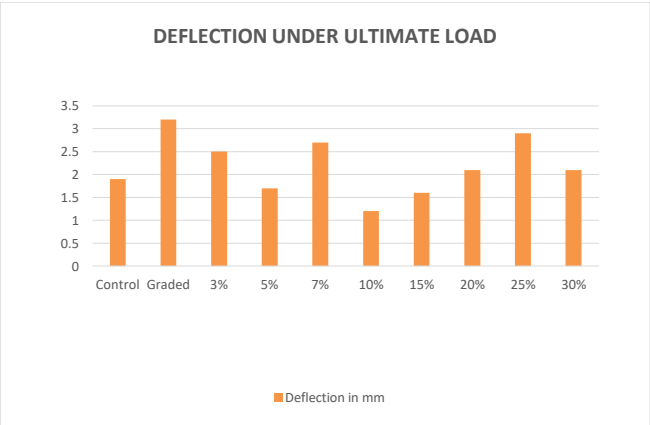
## V RESULTS & DISCUSSIONS

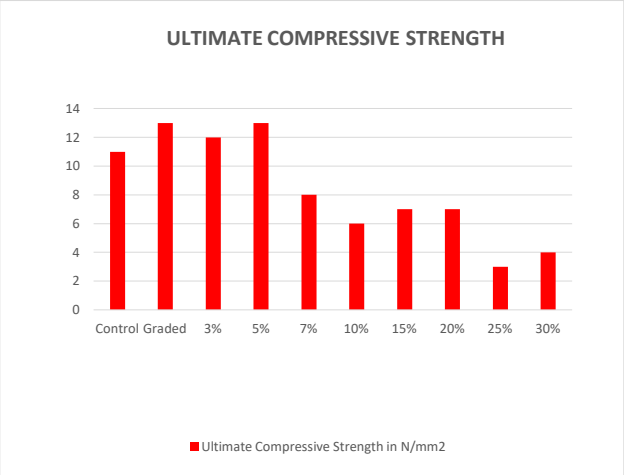
| Sl.No | Cube Specimen | Ultimate Compressive load (in N) | Ultimate Compressive Strength ( in | Deflection at Ultimate Load |
|---|---|---|---|---|
| 1 | Control cube | 54,680 | 11 | 1.900 |
| 2 | Sand Graded cube | 66,600 | 13 | 3.200 |
| 3 | 3% clay replaced | 61,240 | 12 | 2.500 |
| 4 | 5% clay replaced | 67,080 | 13 | 1.700 |
| 5 | 7% clay replaced | 40.820 | 8 | 2.700 |
| 6 | 10% clay replaced | 28,480 | 6 | 1.200 |
| 7 | 15% clay replaced | 33.100 | 7 | 1.600 |
| 8 | 20% clay replaced | 33,660 | 7 | 2.100 |
| 9 | 25% clay replaced | 15,600 | 3 | 2.900 |
| 10 | 30% clay replaced | 22,360 | 4 | 2.100 |

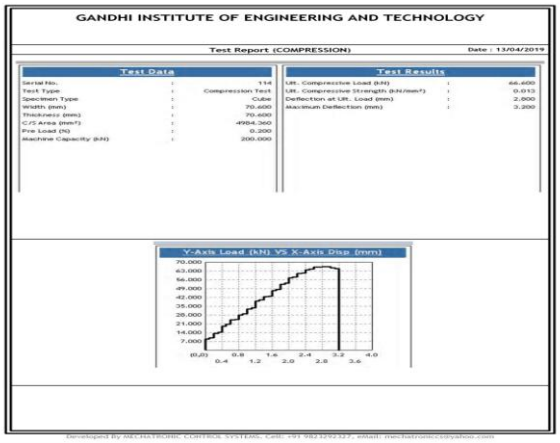
The compressive strength data are obtained by dividing the compressive load by 5000 mm$^2$ which is the surface area of a single mortar cube.

## VI GRAPHICAL REPRESENTATION

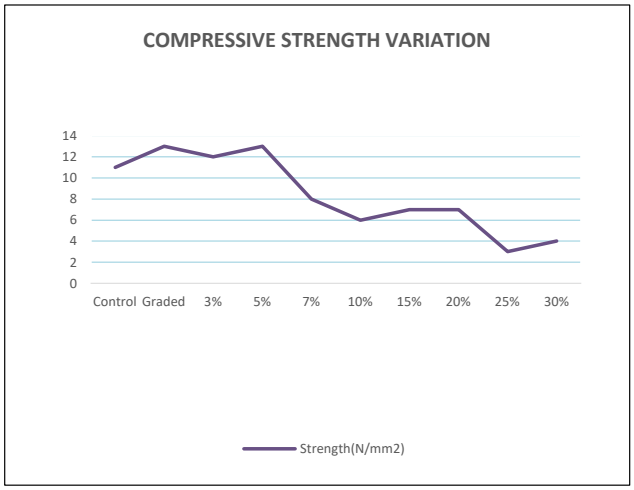


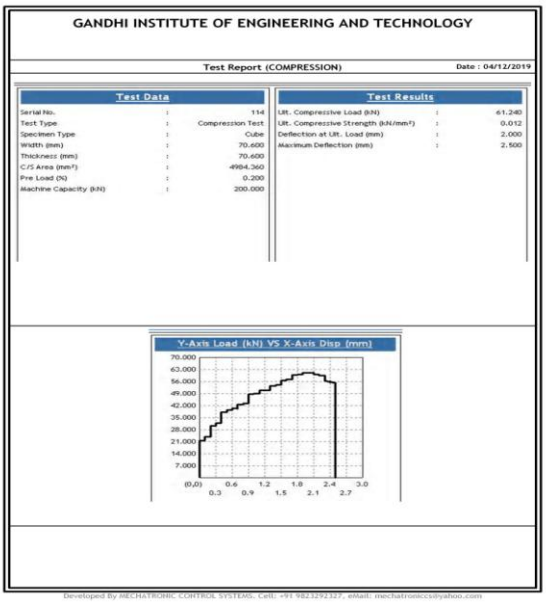





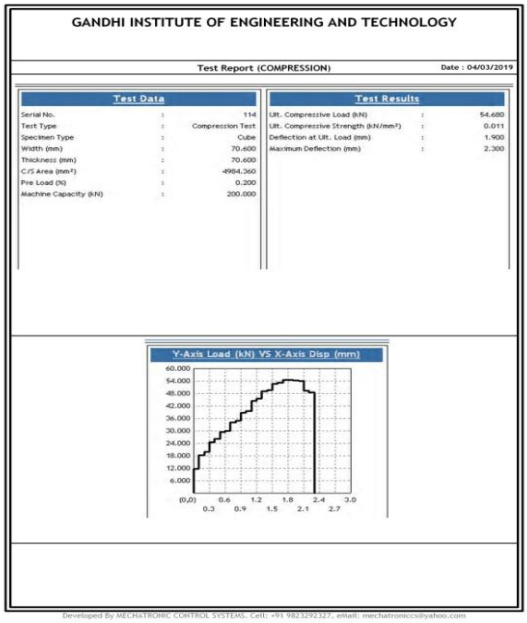

GRADED CUBE



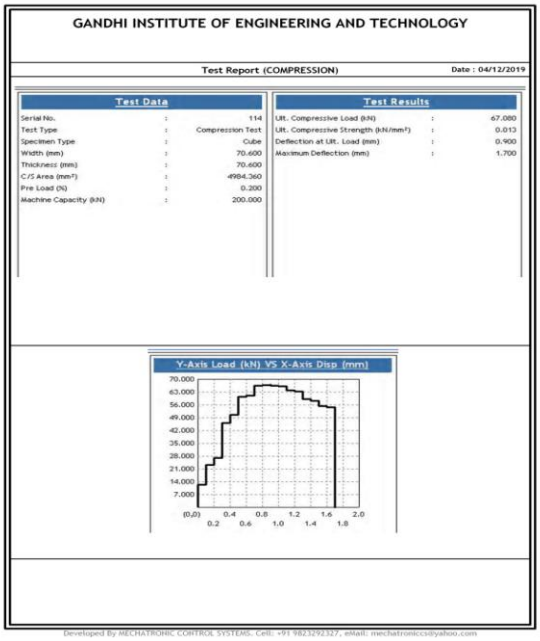




3% CUBE SPECIMEN

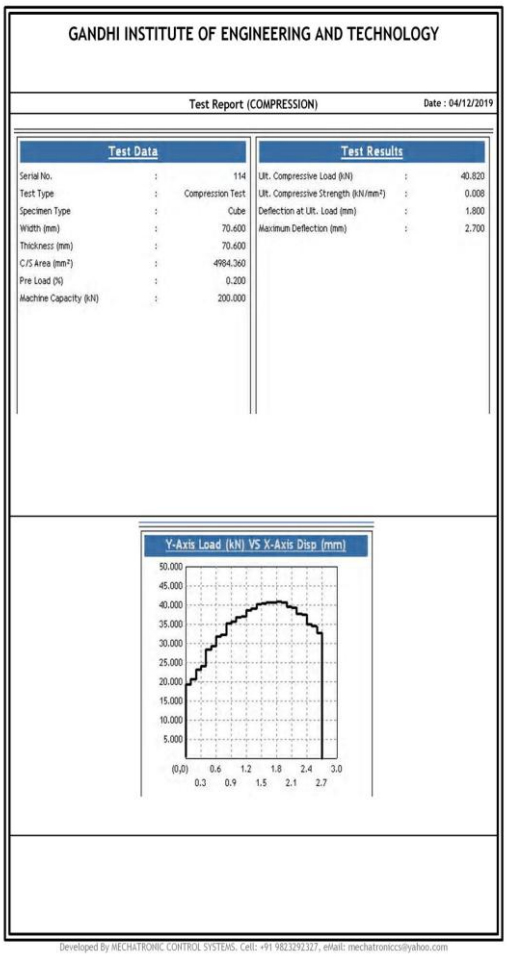
## VII LOAD VERSUS DISPLACEMENT GRAPHS




CONTROL CUBE




5% CUBE SPECIMEN



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Test Report (COMPRESSION) Date : 04/12/2019

| Test Data | | |
|---|---|---|
| Serial No. | : | 114 |
| Test Type | : | Compression Test |
| Specimen Type | : | Cube |
| Width (mm) | : | 70.600 |
| Thickness (mm) | : | 70.600 |
| C/S Area (mm²) | : | 4984.360 |
| Pre Load (%) | : | 0.200 |
| Machine Capacity (kN) | : | 200.000 |

| Test Results | | |
|---|---|---|
| Ult. Compressive Load (kN) | : | 40.820 |
| Ult. Compressive Strength (kN/mm²) | : | 0.008 |
| Deflection at Ult. Load (mm) | : | 1.800 |
| Maximum Deflection (mm) | : | 2.700 |



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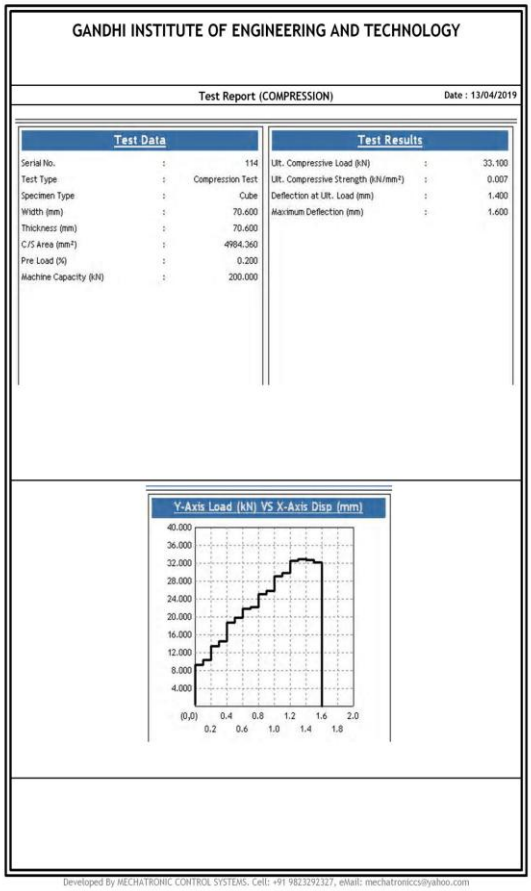
**7% CUBE SPECIMEN**



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Test Report (COMPRESSION) Date : 13/04/2019

| Test Data | | |
|---|---|---|
| Serial No. | : | 114 |
| Test Type | : | Compression Test |
| Specimen Type | : | Cube |
| Width (mm) | : | 70.600 |
| Thickness (mm) | : | 70.600 |
| C/S Area (mm²) | : | 4984.360 |
| Pre Load (%) | : | 0.200 |
| Machine Capacity (kN) | : | 200.000 |

| Test Results | | |
|---|---|---|
| Ult. Compressive Load (kN) | : | 33.100 |
| Ult. Compressive Strength (kN/mm²) | : | 0.007 |
| Deflection at Ult. Load (mm) | : | 1.400 |
| Maximum Deflection (mm) | : | 1.600 |



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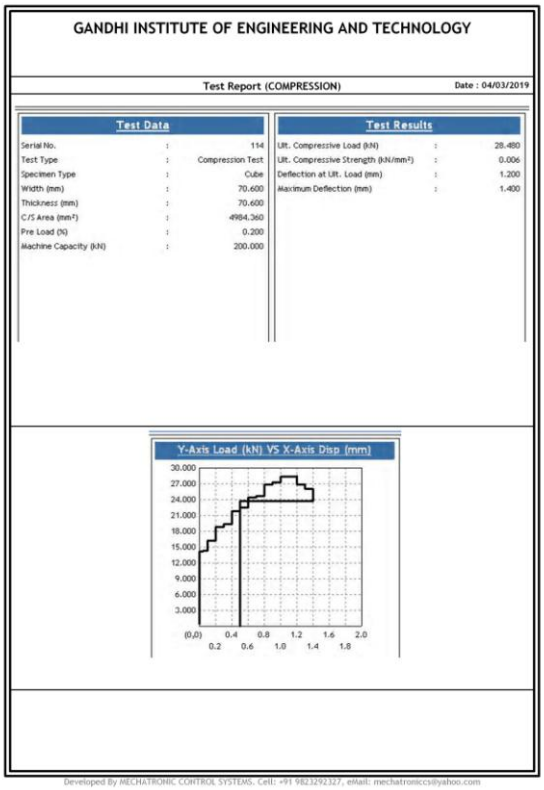
**15% CUBE SPECIMEN**



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Test Report (COMPRESSION) Date : 04/03/2019

| Test Data | | |
|---|---|---|
| Serial No. | : | 114 |
| Test Type | : | Compression Test |
| Specimen Type | : | Cube |
| Width (mm) | : | 70.600 |
| Thickness (mm) | : | 70.600 |
| C/S Area (mm²) | : | 4984.360 |
| Pre Load (%) | : | 0.200 |
| Machine Capacity (kN) | : | 200.000 |

| Test Results | | |
|---|---|---|
| Ult. Compressive Load (kN) | : | 28.480 |
| Ult. Compressive Strength (kN/mm²) | : | 0.006 |
| Deflection at Ult. Load (mm) | : | 1.200 |
| Maximum Deflection (mm) | : | 1.400 |



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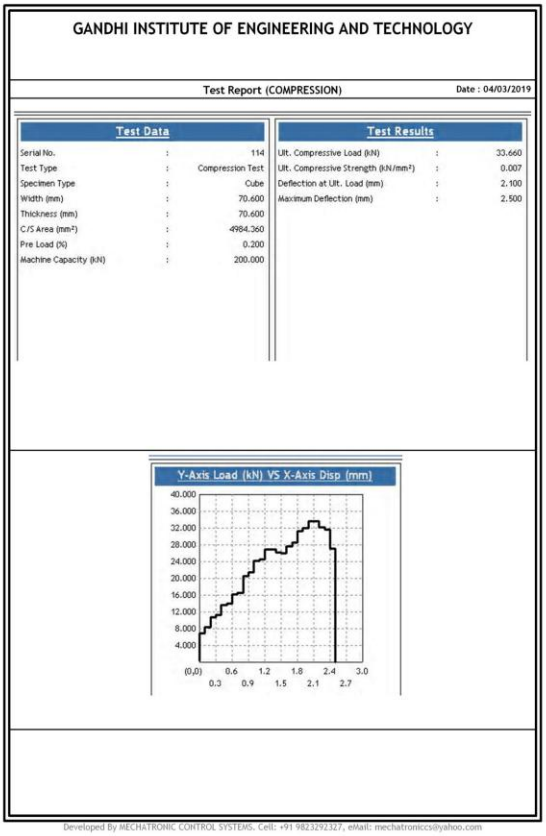
**10% CUBE SPECIMEN**



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Test Report (COMPRESSION) Date : 04/03/2019

| Test Data | | |
|---|---|---|
| Serial No. | : | 114 |
| Test Type | : | Compression Test |
| Specimen Type | : | Cube |
| Width (mm) | : | 70.600 |
| Thickness (mm) | : | 70.600 |
| C/S Area (mm²) | : | 4984.360 |
| Pre Load (%) | : | 0.200 |
| Machine Capacity (kN) | : | 200.000 |

| Test Results | | |
|---|---|---|
| Ult. Compressive Load (kN) | : | 33.660 |
| Ult. Compressive Strength (kN/mm²) | : | 0.007 |
| Deflection at Ult. Load (mm) | : | 2.100 |
| Maximum Deflection (mm) | : | 2.500 |



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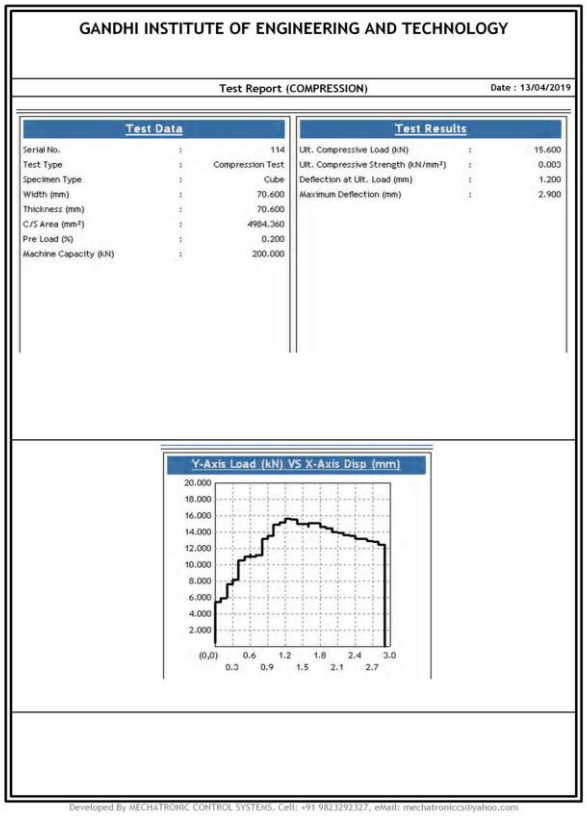
**20% CUBE SPECIMEN**



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Test Report (COMPRESSION) Date : 13/04/2019

| Test Data | | |
|---|---|---|
| Serial No. | : | 114 |
| Test Type | : | Compression Test |
| Specimen Type | : | Cube |
| Width (mm) | : | 70.600 |
| Thickness (mm) | : | 70.600 |
| C/S Area (mm²) | : | 4984.360 |
| Pre Load (%) | : | 0.200 |
| Machine Capacity (kN) | : | 200.000 |

| Test Results | | |
|---|---|---|
| Ult. Compressive Load (kN) | : | 15.600 |
| Ult. Compressive Strength (kN/mm²) | : | 0.003 |
| Deflection at Ult. Load (mm) | : | 1.200 |
| Maximum Deflection (mm) | : | 2.900 |



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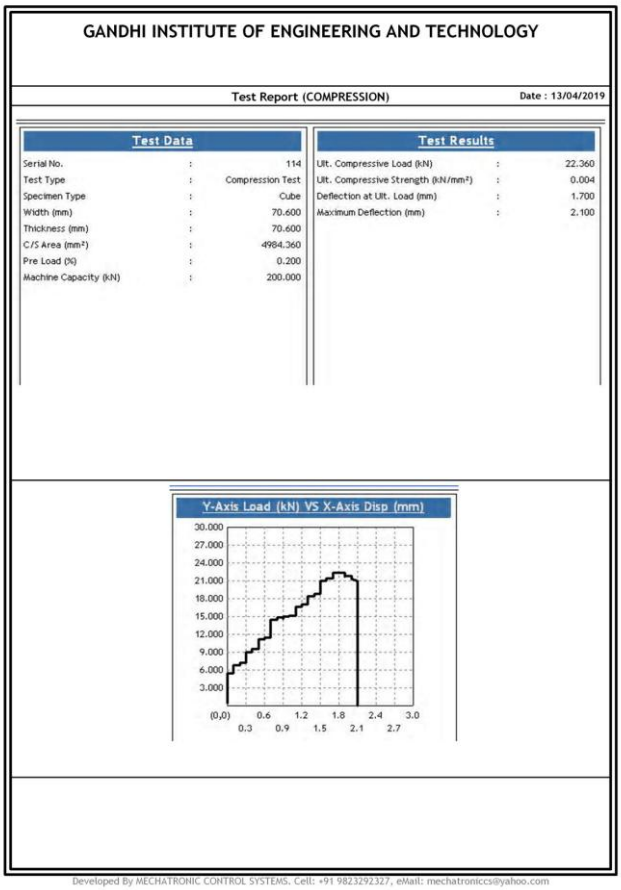
**25% CUBE SPECIMEN**



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Test Report (COMPRESSION) Date : 13/04/2019

| Test Data | | |
|---|---|---|
| Serial No. | : | 114 |
| Test Type | : | Compression Test |
| Specimen Type | : | Cube |
| Width (mm) | : | 70.600 |
| Thickness (mm) | : | 70.600 |
| C/S Area (mm²) | : | 4984.360 |
| Pre Load (%) | : | 0.200 |
| Machine Capacity (kN) | : | 200.000 |

| Test Results | | |
|---|---|---|
| Ult. Compressive Load (kN) | : | 22.360 |
| Ult. Compressive Strength (kN/mm²) | : | 0.004 |
| Deflection at Ult. Load (mm) | : | 1.700 |
| Maximum Deflection (mm) | : | 2.100 |



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**30% CUBE SPECIMEN**

## VIII OBSERVATIONS

- The first observation that was made was during the mixing of the mortar. As the percentage of clay was gradually increased the plasticity of the mortar mixture started increasing and hence the workability started increasing. But the specimen where sand was replaced by 25% by weight by clay posed a certain degree of difficulty in mixing the mortar due to relatively high plasticity.
- The amount of water that was being used for the mixing had to be gradually increased from 100 grams to 135 grams as the percentage of clay was increased in the mortar mix.
- There was a subtle color change in the casted cube in which clay was added. The color started getting lighter and lighter grey as the percentage of clay was increased.
- Upon the removal of clay from the mold after 24 hours and on close inspection of the surface, it was found that the mortar cube specimen where clay was replaced were smoother in texture than the standard cement sand mortar cube.
- There was no swelling or shrinking of the clay incorporated mortar cubes whatsoever. But a minor volumetric change was observed in the cubes where 25% and 30% by weight clay was incorporated.
- As the percentage of clay increased in the cubes the stickiness property of the mixture also increased.
- A general observation was made that the cubes with 3% and 5% replacement of clay took more load than the control cube without showing relatively less cracks.

## IX CONCLUSION

1. As the percentage of clay was increased from 3% to 20% it was found that easy of using or placing the mortar on a surface was getting easier, in other words the workability of the mortar mix increased. But due to the excess plasticity upon subsequent increase in the amount of clay it was difficult to handle the mixture since it was sticky.
2. Due to the smooth texture of the clay incorporated mortar mixture it can be used as the inner wall plaster to get a better finish than the usual mortar mix thereby avoiding the cost of wall putty which is costly. Using the mortar mix reduces the cost of construction.
3. The instances where there are deposits of naturally occurring clay at the construction zone, the clay is excavated and thrown away due to the unsuitability of construction works on clayey soil. To avoid the dumping cost that clay can be incorporated in the mortar to make the project more cost effective.
4. Due to the lighter color of the mortar mix the lighting of the unpainted room improves to some extent.
5. Since the plasticity and the workability of the mortar increased on addition of clay and the best workability being achieved at 15% according to my observations this particular mix can be used for decorative purposes where making various aesthetic designs would be easier than using normal cement mortar mixture.
6. Since addition of 3% and 5% clay improved the strength as well as the surface smoothness of the mortar cubes hence that above replacement percentage can be adopted in construction works for more strength and finishing.

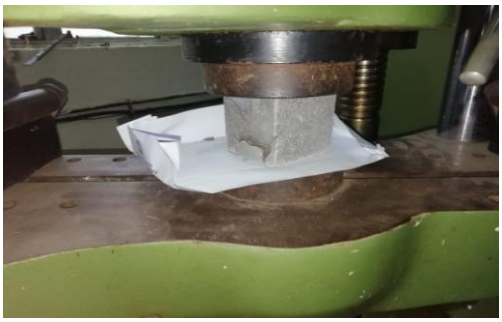
## Photographs

**Cubes being cured**

**Compression test using UTM**

**Filling a hole in the wall using 15% clay replaced mortar**

**Observation of shrinkage in 25% and 30% clay replaced specimen**



**Cube under compression**

**Crushed Cubes**

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