# Mechanical Properties of High Performance Concrete using Industrial Byproducts

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**ABSTRACT—** ***This paper examines the possibilities of using the combination of byproducts like 20% Bottom ash (BA) as fine aggregate and ordinary Portland cement with optimum replacement levels of 20% Fly ash (FA), 10% Silica fume (SF), 10%Metakaolin (MK) by adopting water cement ratio of 0.45. Conplast SP430 was used as a superplasticizer for better workability for high performance concrete. The mechanical properties Such as Compressive strength (Cubes and cylinders), flexural strength and Modulus of elasticity were determined. The result of this investigation explains the strength characteristics of all mixes. Based on the results obtained the replacement of combination of mixes which is superior for all the mixes and also results were compared with control mix. The data obtained from experimental tests were used to train an Artificial Neural Network (ANN) which can predict the experimental results were compared in the testing data set. As a result, compressive strength, flexural strength and modulus of elasticity can be predicted in a quite short period of time with tiny error rates by using the multilayer feed-forward neural network models than regression techniques.***

**Keywords—** fly ash, silica fume, metakaolin, bottom ash, high performance concrete, compressive strength, flexural strength, modulus of elasticity, regression, artificial neural network.

## 1. INTRODUCTION

Concrete is a widely used construction material around the world, and its properties have been undergoing changes through technological advancement. With a fast population growth and a higher demand for housing and infrastructure, accompanied by recent developments in civil engineering, such as high-rise buildings and long-span bridges, higher compressive strength concrete is needed. Currently, high-performance concrete is used in massive volumes due to its technical and economic advantages. HPC define as "concrete which meets special performance and uniformity requirements that cannot always be achieved routinely by using only conventional materials and normal mixing, placing, and curing practices. The requirement may involve enhancement of characteristics such as placement and compaction without segregation, long – term mechanical properties, early age strength, toughness, volume stability, or service life in severe environments". The cement industry is considered to be one of the most energy consuming industries, which is also responsible for approximately 6-7% of the global man-made $CO_2$ emissions annually. Accordingly, there is a great demand to minimize the quantity of cement used in the construction industry. By far the greatest potential in achieving the goals of sustainable development is the capacity of the concrete industry to reuse various industrial by products and absorb large amounts of recycled materials that otherwise would most likely and up in landfills. In developing countries like India, pozzolanic materials are mainly available as industrial waste bi-products. Fly ash, silica fume, stone dust, blast furnace slag, rice husk ash etc., are some of the industrial wastes and metakaolin is a quality controlled reactive pozzolana made from purified kaolin which possess pozzolanic properties. The demand of natural sand is quite high in the developing countries due to the rapid infrastructural growth. In order to fulfill the requirement of fine aggregate, some alternative material must be found. The cheapest and the easiest way of getting substitute for natural sand is obtained from bottom ash.

In this paper a study made to evaluate the Potential use of Industrial wastes bottom ash by partially replacing the sand and adding Silica fume, Fly ash and Metakaolin with the cement in the production of High performance concrete.

## 2. LITERATURE REVIEW

**Justice et.al., (2005)** investigated the comparative study by replacing 8% by weight of cement with Metakaolin and Silica fume. Metakaolin addition proved to be beneficial, resulting in concrete with considerably higher strengths and greater durability than the normal mixes. The use of finer Metakaolin was more effective in improving concrete properties than the coarser Metakaolin. Addition of Metakaolin exhibited improvements in shrinkage, durability and other strength aspects.**Aggarwal et.al, (2007)** presented the experimental investigations carried out to study the effect of use of bottom ash as a replacement of fine aggregates. The strength development for various percentages (0-50%) replacement of fine aggregates with bottom ash can easily be equated to the strength development of normal concrete at various ages. Compressive strength of bottom ash concrete containing 50% bottom ash is acceptable for most structural applications since the observed compressive strength is more than 20 MPa at 28 days. **Muthupriya et.al., (2010)** investigated the effect of mineral admixtures such as silicafume, metakaolin and fly ash towards the performance of HPC. The compressive strength of HPC with mineral admixtures at the replacement levels of 0%, 5%, 10% and 15% were studied at 3 days, 7 days, 28 days, of curing. The strengths were compared and the optimum replacement level of each mineral admixture was arrived at. The tensile and flexural strength of HPC were obtained at the replacement levels of mineral admixtures at 28 days of curing. From the results it was found that the optimum replacement of silica fume, metakaolin and fly ash are 10%, 10% and 15% respectively. **Vikas Srivastava et.al, (2012)** investigated the suitability of silica fume and metakaolin combination in production of concrete. The optimum combined doses of silica fume and Metakaolin were found out as 6% and 15% (by weight) respectively. The specimens where cast and tested on 7th, 14th and 28 days. The 28th day compressive strength of concrete generally increased with the Metakaolin content for at all the Silica fume contents. The 7th day compressive strength of concrete was found to decrease with the increase in Metakaolin content for all the Silica fume contents. **Jadhav and Chavarekar (2013)** investigated the compressive strength characteristics such as water absorption super plasticizer used in high performance concrete a set of 23 different concrete mixture were cast and tested with different cement replacement levels (0%, 2.5%, 5%, 7.5%, 10% and 12.5%) of Fly ash (FA) with silica fume (SF) as addition ( 0%,2.5%,5%,7.5% 10 % & 12.5% by wt of Cement and/or each trial super plasticizer has been added at constant values to achieve a constant range of slump for desired work ability with a constant water-binder (w/b) ratio of 0.30. The compressive strength of blend effect of fly ash and micro silica concrete (ms & fly) is comparatively greater than 12.19% that of control mix. **Magudeaswaran and Eswaramoorthi (2013)** investigated the strength properties of silica fume and fly ash concrete. This work primarily deals with the strength characteristics such as compressive and split tensile strength. High performance concrete a set of 7 different concrete mixture were cast and tested with different cement replacement levels. The compressive strength increased 61.5 Mpa for the replacement of cement by 10% flyash and 5% silica fume mix and split tensile strength is increased 3.20 for the replacement of cement by 15% flyash and 7.5% silica fume mix.

## 3. EXPERIMENTAL INVESTIGATION

The Experimental investigations were designed to compare the mechanical properties of High Performance Concrete with M30 grade of concrete, Compressive strength, flexural strength and modulus of elasticity. The specimen of Cube of size 150 x 150 x 150 mm, Cylinder specimen of size 150 mm diameter and 300 mm height and Prism of size 100 x100 x 500 mm were cast and cured for 28 days. Three specimens for each mixture were tested for compressive strength, Flexural and modulus of elasticity were recorded.

### 3.1 Material Used

1. **Cement:** Ordinary Portland cement, OPC 43 grade Confirming to IS 8112-1989 was used.
2. **Fine Aggregate:** Locally available river sand Conforming to grading zone III of IS: 383-1970. Its Specific gravity is 2.6 and Fineness modulus 3.2. The sieve analysis of fine aggregate is given in Table 1 and figure 1.

**Table 1. Sieve Analysis of fine aggregate**

| S.no | Aperture size in mm | Weight retained in g | Cummulative percentage of weight retained | Percentage of passing | Limits as per IS:383-1970 Zone III |
|---|---|---|---|---|---|
| 1 | 10 | 0 | 0 | 100 | 100 |
| 2 | 4.75 | 8.7 | 0.87 | 99.13 | 90-100 |
| 3 | 2.36 | 11 | 1.97 | 98.03 | 85-100 |
| 4 | 1.18 | 75 | 9.47 | 90.53 | 75-100 |
| 5 | 0.6 | 296 | 39.07 | 60.93 | 60-79 |
| 6 | 0.3 | 395 | 78.57 | 21.43 | 12-40 |
| 7 | 0.15 | 190 | 97.57 | 2.43 | 0-10 |
| 8 | 0.075 | 24.3 | 100 | 0 | 0 |

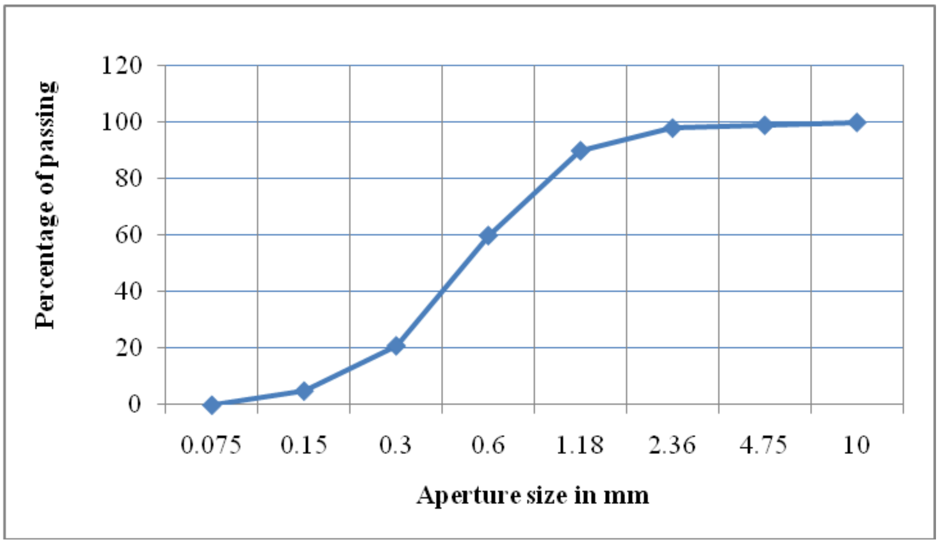



**Figure 1. Grading Curve for the fine aggregate**

3. **Coarse Aggregate:** Locally available crushed stone aggregate of nominal size 20mm and Specific gravity 2.78, and fineness modulus 7.27 Conforming to IS 383-1970 were used. The sieve analysis of Coarse aggregate is given in Table 2 and fig 2.

**Table 2. Sieve Analysis of Coarse aggregate**

| S.no | Aperture size in mm | Weight retained in g | Cummulative percentage of weight retained | Percentage of passing | Limits as per IS:383-1970 |
|---|---|---|---|---|---|
| 1 | 80 | 0 | 0 | 100 | 100 |
| 2 | 40 | 0 | 0 | 100 | 100 |
| 3 | 20 | 870 | 29 | 71 | 95-100 |
| 4 | 10 | 2094 | 98.8 | 1.20 | 0-20 |

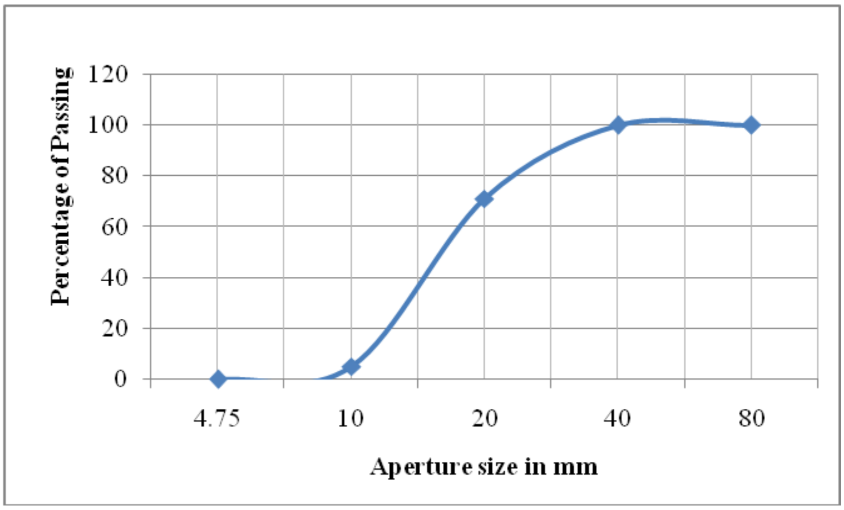



**Figure 2. Grading Curve for the coarse aggregate**

4. **Silica fume:** Silica fume is a byproduct of producing silicon metal or ferronsilicon alloys. Silica fume obtained from M/s ELKEM Pvt.Ltd. Mumbai, was named Elkem-micro silica 920 D Conforming to ASTM C1240. The Specific gravity of silica fume is 2.2

5. **Fly ash:** Fly ash is a byproduct of coal combustion. Fly ash (FA) obtained from Thermal power plant, Neyveli Lignite Corporation, Tamil nadu state, India Confirming to IS 3812-1981. The Specific gravity of Fly ash is 2.

6. **Metakaolin:** Metakaolin is a mineral admixture obtained by refining the kaolin clay which further going to produce amorphous alumino silicate that is having good ability of reactiveness towards concrete. Metakaolin procured from the ASTRA Chemicals, chennai. The appearance of Metakaolin is off White and its Specific gravity is 2.6.

7. **Bottom Ash:** Bottom ash is one of the Industrial byproduct and obtained from thermal power plant, Neyveli Lignite Corporation Ltd, at Neyveli, Tamilnadu in India was used in this study as replacement material for fine aggregates. The Specific gravity and fineness modulus of bottom ash was 2.35 and 2.93 Conforming to IS: 383 – 1970, Zone III. The Sieve Analysis of Bottom ash as given in table 3 and figure 3.

**Table 3. Sieve Analysis of Bottom ash**

| S.no | Aperture size in mm | Weight retained in (g) | Cummulative percentage of weight retained | Percentage of passing | Limits as per IS:383-1970 Zone III |
|---|---|---|---|---|---|
| 1 | 10 | 0 | 0 | 100 | 100 |
| 2 | 4.75 | 7 | 0.7 | 99.3 | 90-100 |
| 3 | 2.36 | 10 | 1.7 | 98.3 | 85-100 |
| 4 | 1.18 | 12 | 2.9 | 97.1 | 75-100 |
| 5 | 0.6 | 227 | 25.6 | 74.4 | 60-79 |
| 6 | 0.3 | 396 | 65.2 | 34.8 | 12-40 |
| 7 | 0.15 | 321 | 97.3 | 2.7 | 0-10 |
| 8 | 0.075 | 27 | 100 | 0 | 0 |

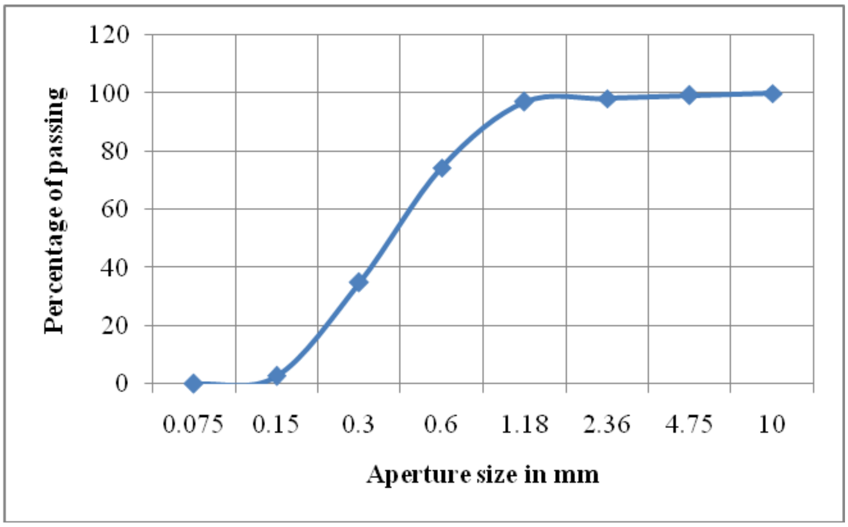



**Figure 3. Grading Curve for the bottom ash**

8. **Superplasticizer:** Chemical admixture based on CONPLAST SP 430 in the form of sulphonated naphthalene polymer complies with IS: 9103-1999 and ASTM 494 type F was used to improve the workability of concrete. Its Specific gravity is 1.22.

9. **Water:** Portable water with pH value of 7 confirming to IS 456-2000 was used for making concrete and curing this specimen as well.

### 3.2 Mix Proportions

The mix proportions for conventional concrete and volume based partial replacement of Ordinary Portland cement (OPC) by Fly ash (FA), Silica fume(SF) and Metakaolin (MK) and also fine aggregate(sand) by Bottom ash. The Conventional concrete used with mix proportion of 1:1.73:3.2 with w/c 0.45. Twelve HPC mixes were prepared for this test by volumetric method. The conventional concrete mix CC and Combinations of HPC mixes (M1-M11) were obtained by replacing 20% Fly ash, 10% Silica fume and 10% MK in the volume of cement and replacing 20% of the volume of sand by Bottom ash (BA). The volume of water is 172.8 lit/$m^3$ and Coarse aggregate (CA) is 1220 kg/$m^3$ were kept constant while the volume of cement, sand and Superplasticizer (SP) were varied for all the mixes. The mix Combinations and mix proportions are given in table 4 and 5.

**Table 4. Mix Combinations**

| S.No | Mix designation | Combinations |
|---|---|---|
| 1 | CC | (C+S+CA) |
| 2 | M1 | (C+FA20%)+S+CA) |
| 3 | M2 | (C+SF10%)+S+CA |
| 4 | M3 | (C+MK10%)+S+CA |
| 5 | M4 | C+(S+BA20%)+CA |
| 6 | M5 | (C+FA20%)+(S+BA20%)+CA) |
| 7 | M6 | (C+SF10%)+(S+BA20%)+CA |
| 8 | M7 | (C+MK10%)+(S+BA20%)+CA |
| 9 | M8 | (C+FA20%+SF10%)+(S+BA20%)+CA |
| 10 | M9 | (C+FA20%+MK10%)+(S+BA20%)+CA |
| 11 | M10 | (C+SF10%+MK10%)+(S+BA20%)+CA |
| 12 | M11 | (C+FA20%+SF10%+MK10%)+(S+BA20%)+CA |

**Table 5. Mix Proportions of Concrete Quantities in (kg/$m^3$)**

| S.No | Mix | Cement(C) (kg/$m^3$) | Fly ash (FA) (kg/$m^3$) | Silica fume (SF) (kg/$m^3$) | Metakaolin (MK) (kg/$m^3$) | Fine aggregate (S) (kg/$m^3$) | Bottom ash (BA) (kg/$m^3$) |
|---|---|---|---|---|---|---|---|
| 1 | CC | 384 | 0 | 0 | 0 | 665 | 0 |
| 2 | M1 | 307.2 | 76.8 | 0 | 0 | 623 | 0 |
| 3 | M2 | 345.6 | 0 | 38.4 | 0 | 644 | 0 |
| 4 | M3 | 345.6 | 0 | 0 | 38.4 | 649 | 0 |
| 5 | M4 | 384 | 0 | 0 | 0 | 508 | 133 |
| 6 | M5 | 307.2 | 76.8 | 0 | 0 | 476 | 133 |
| 7 | M6 | 345.6 | 0 | 38.4 | 0 | 500 | 133 |
| 8 | M7 | 345.6 | 0 | 0 | 38.4 | 508 | 133 |
| 9 | M8 | 268.8 | 76.8 | 38.4 | 0 | 461 | 133 |
| 10 | M9 | 268.8 | 76.8 | 0 | 38.4 | 467 | 133 |
| 11 | M10 | 307.2 | 0 | 38.4 | 38.4 | 492 | 133 |
| 12 | M11 | 230.4 | 76.8 | 38.4 | 38.4 | 463 | 133 |

### 3.3 Workability of fresh Concrete

The workability was measured by conducting Slump cone test in accordance with IS: 1199-1959. The trials were carried out to improve the workability of the fresh concrete by incorporating a superplasticizer. The slump of fresh concrete range is 50-75 mm.

### 3.4 Preparation of Test Specimens

For each mix 3 cubes of Standard size (150x 150x150 mm) were cast to determine the compressive strength, Based on Compressive strength four mixes were selected for further study addition of CC. Therefore 36 cubes, 15 cylinders and 15 prisms and total 66 specimens were cast to conduct the test for mechanical properties. All the test Specimens were cast using steel mould and the concrete were compacted on a vibrating table. The specimens were demoulded after 24 hours and cured in water for 28 days and then to determine the mechanical properties of concrete for all the mixes, all the tests were conducted as per IS 516-1959. The selected 4 mixes are having the maximum compressive strength including CC & M3, M7, M10 and M11.The test results are shown in table 6.

**Table.6 Compressive strength test results**

| S.No | Mix Designation | SP (lit/m$^3$) | Slump (mm) | Compressive strength for 28 days(Mpa) |
|---|---|---|---|---|
| **1** | **CC** | **2.49** | **55** | **36.5** |
| 2 | M1 | 3.37 | 57 | 35 |
| 3 | M2 | 3.97 | 55 | 37 |
| **4** | **M3** | **3.45** | **56** | **42** |
| 5 | M4 | 3.84 | 58 | 34 |
| 6 | M5 | 3.99 | 55 | 36 |
| 7 | M6 | 4.83 | 52 | 39 |
| **8** | **M7** | **4.49** | **57** | **43** |
| 9 | M8 | 4.03 | 59 | 38 |
| 10 | M9 | 3.49 | 58 | 39 |
| **11** | **M10** | **4.60** | **57** | **45** |
| **12** | **M11** | **3.80** | **58** | **40** |

## 4. MECHANICAL PROPERTIES

### Compressive strength

The Selected mixes based on compressive strength results were presented in Table.7 and fig 6 & fig 7. The test results were carried out confirming to IS 516-1959 to obtain compressive strength of concrete at the age of 28 days. The cubes and cylinders were tested using compression testing machine (CTM) of capacity of 2000KN. Normally the strength of the cylinder is taken as 0.8 times the strength of the cube.

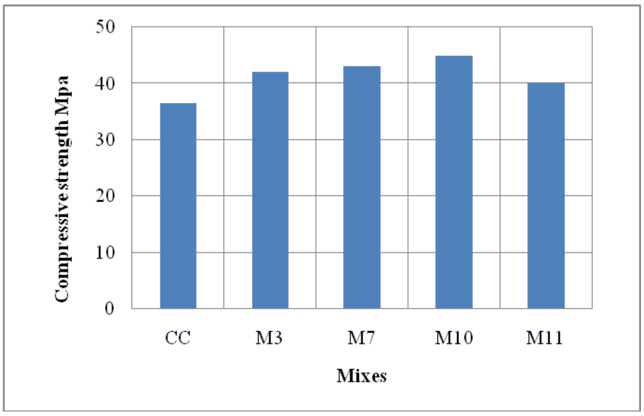



**Figure 6. Compressive strength of Cube**

**Table 7. Compressive strength Test Results**

| S.No | Mix Designation | Compressive strength Cube (Mpa) | Compressive strength Cylinder Mpa |
|---|---|---|---|
| 1 | **CC** | 36.5 | 28 |
| 2 | **M3**(10%MK) | 42 | 31 |
| 3 | **M7**(10%MK+20%BA) | 43 | 33 |
| 4 | **M10**(10%SF+10%MK+20%BA) | 45 | 35 |
| 5 | **M11**(20%FA+10%SF+10%MK+20%BA) | 40 | 30 |

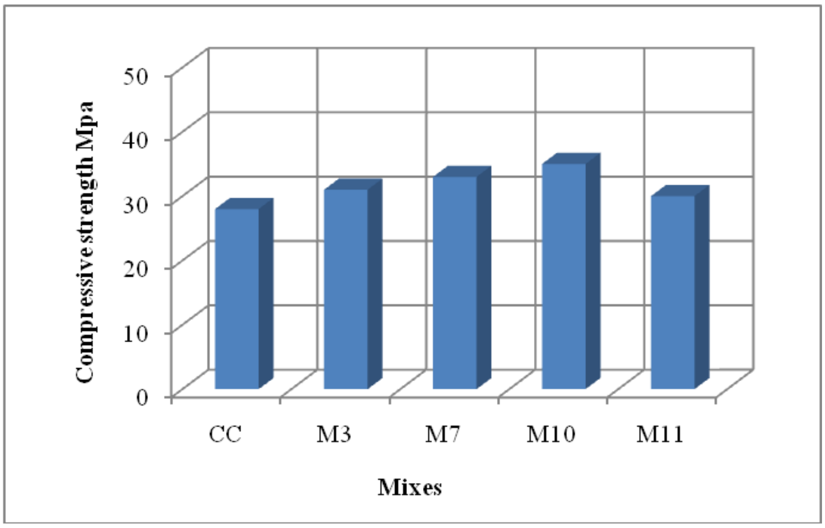



**Figure 7. Compressive strength of Cylinder**

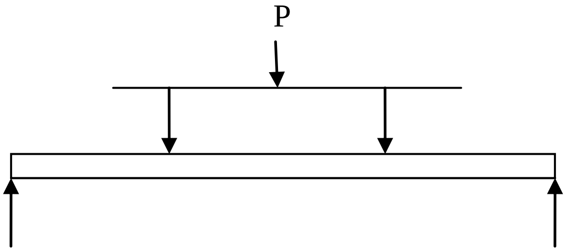
**Flexural Strength**

The Flexural test results were carried out confirming to IS 516-1959. The Prism were tested using 5T capacity Flexural Testing Machine (FTM). The standard prisms were tested in flexure under two point loading. The test set up of specimen under flexural test as shown in fig.8 and test results are shown in table 8 & fig 8.

**Fig 8. Test set up of prism under Flexural testing machine**

| S.No | Mix Designation | Flexural strength in Mpa |
|---|---|---|
| 1 | CC | 5.7 |
| 2 | M3(10%MK) | 7 |
| 3 | M7(10%MK+20%BA) | 7.2 |
| 4 | M10(10%SF+10%MK+20%BA) | 7.5 |
| 5 | M11(20%FA+10%SF+10%MK+20%BA) | 6.8 |

**Table .8 Flexural Strength Test Results**




**Line sketch of flexural strength of prism**

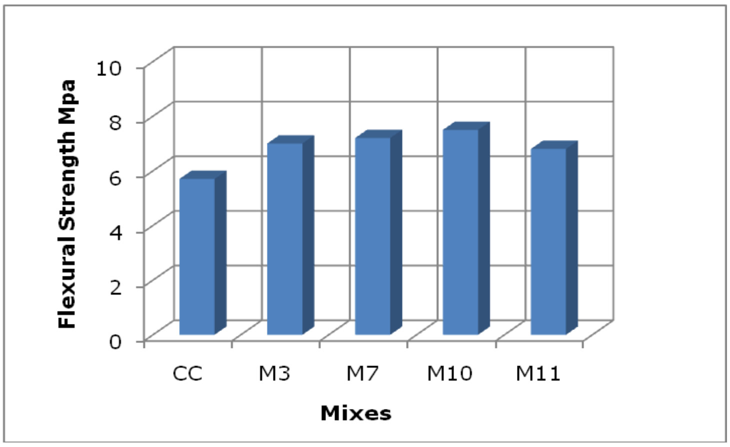



**Figure 9. Flexural strength of Prism**

**Modulus of Elasticity**

The test was carried out confirming to IS 516-1959 to obtain the modulus of elasticity of the concrete. It is determined by subjecting a cylinder specimen to uniaxial compression and measuring the deformation by means of dial gauge fixed between certain gauge length. The method for calculating the modulus of elasticity as the initial tangent modulus is given by the slope of a line drawn tangent to the stress-strain curve at any point of curve. The test set up of modulus of elasticity as shown in fig.10. The table.9 shows the test results of modulus of elasticity.

**Fig 10. Test set up of Modulus of Elasticity**

**Table .9 Modulus of Elasticity (E) Test Results**

| S.No | Mix Designation | Theoretical value IS 456:2000 $E=5000\sqrt{f_{ck}}$ in Mpa | Experimental E value in Mpa |
|---|---|---|---|
| 1 | **CC** | 30207.61 | 28722.81 |
| 2 | **M3**(10%MK) | 32403.70 | 31224.98 |
| 3 | **M7**(10%MK+20%BA) | 32787.19 | 31024.18 |
| 4 | **M10**(10%SF+10%MK+20%BA) | 33541.01 | 32015.62 |
| 5 | **M11**(20%FA+10%SF+10%MK) | 31622.77 | 30207.61 |

## 5. NON DESTRUCTIVE TESTING OF CONCRETE (NDT)

In the non destructive method of testing the Specimen are not loaded to failure. The quality of the concrete was to be evaluated by performing Non-destructive Testing. These tests were conducted on 150 mm concrete cubes. In order to assess the quality of concrete, the following methods of testing were

(i) Rebound Hammer test as per IS: 13311 (Part 2)

(ii) Ultrasonic Pulse Velocity test as per IS: 13311 (Part 1).

**Rebound Hammer Method**

This method is explained in IS: 13311 (part2):1992. Three cubes were prepared from each mixes The Rebound Hammer were applied through 16 readings on each faces of the cubes were noted and the average of Rebound Hammer Number (RHN) were recorded. The results shown in table.10 & 11 and fig.12.

**Ultrasonic Pulse Velocity**

The quality of concrete was assessed using the guidelines given in Table 2 of IS 13311 (Part 1):1992, which involves measurement of the time of travel of electronically generated mechanical pulses through the concrete. The direct transmission method is preferred since the maximum energy of the pulse is being directed at the receiving transducer and this gives maximum sensitivity. The results shown in table.10 & 11 and fig.13.

**Table 10. Non-destructive tests on Cube specimen**

| S.No | CC | | M3 | | M7 | | M10 | | M11 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RHN | UPV | RHN | UPV | RHN | UPV | RHN | UPV | RHN | UPV |
| 1 | 33 | 4132 | 38 | 4214 | 39 | 4335 | 42 | 4412 | 37 | 4312 |
| 2 | 35 | 4167 | 40 | 4249 | 42 | 4373 | 44 | 4438 | 39 | 4335 |
| 3 | 33 | 4178 | 38 | 4273 | 39 | 4398 | 44 | 4478 | 37 | 4362 |
| 4 | 35 | 4155 | 40 | 4237 | 42 | 4360 | 42 | 4438 | 39 | 4335 |
| 5 | 33 | 4132 | 38 | 4213 | 39 | 4347 | 42 | 4412 | 39 | 4312 |
| 6 | 35 | 4143 | 40 | 4237 | 42 | 4360 | 44 | 4437 | 37 | 4335 |
| 7 | 33 | 4178 | 41 | 4261 | 39 | 4398 | 44 | 4478 | 37 | 4362 |
| 8 | 33 | 4166 | 38 | 4237 | 39 | 4360 | 42 | 4437 | 39 | 4335 |
| 9 | 35 | 4121 | 40 | 4213 | 42 | 4323 | 42 | 4411 | 39 | 4312 |
| 10 | 33 | 4144 | 38 | 4237 | 38 | 4347 | 44 | 4437 | 37 | 4335 |
| 11 | 35 | 4178 | 41 | 4261 | 42 | 4398 | 42 | 4477 | 39 | 4370 |
| 12 | 33 | 4143 | 38 | 4225 | 38 | 4347 | 44 | 4437 | 37 | 4332 |
| 13 | 35 | 4121 | 38 | 4213 | 42 | 4323 | 42 | 4411 | 37 | 4312 |
| 14 | 33 | 4144 | 40 | 4237 | 38 | 4347 | 44 | 4437 | 39 | 4335 |
| 15 | 35 | 4178 | 38 | 4261 | 40 | 4398 | 42 | 4477 | 37 | 4370 |
| 16 | 33 | 4121 | 40 | 4225 | 38 | 4347 | 44 | 4411 | 39 | 4312 |
| **Average** | **32** | **4151** | **37** | **4237** | **38** | **4360** | **40** | **4439** | **36** | **4335** |

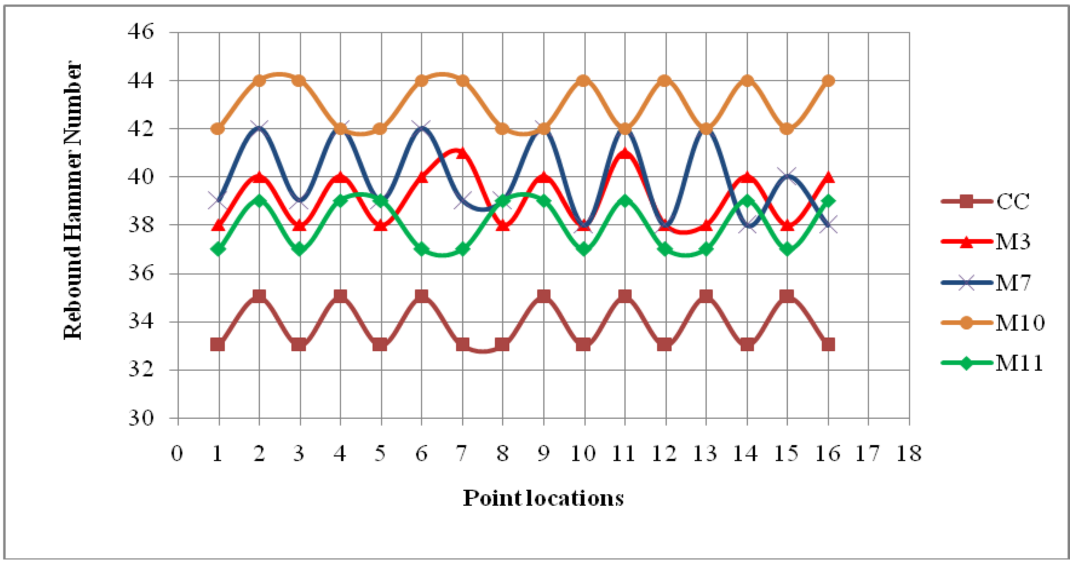



**Figure 12. Rebound Hammer Number**

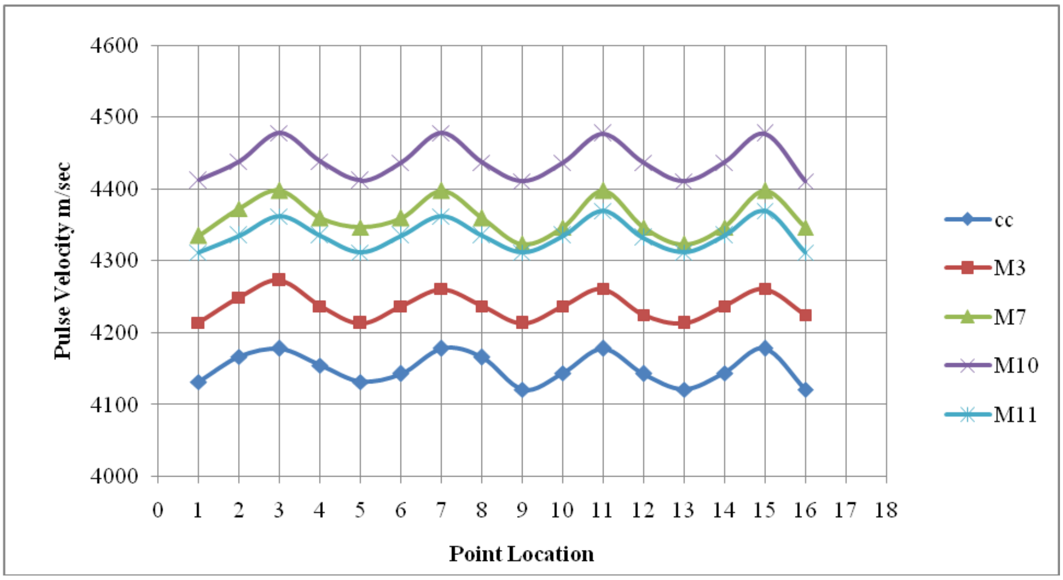



**Figure 13. Ultrasonic Pulse Velocity Test**

**Table.11 Results for NDT test**

| S.No | Mix Designation | Average Rebound number | As per code Quality of concrete | Average Pulse velocity (m/sec) | As per code Concrete quality grading |
|---|---|---|---|---|---|
| 1. | CC | 32 | Good layer | 4151 | Good |
| 2. | M3 | 37 | Good layer | 4237 | Good |
| 3. | M7 | 38 | Good layer | 4360 | Good |
| 4. | M10 | 40 | Good layer | 4439 | Good |
| 5. | M11 | 36 | Good layer | 4335 | Good |

## 6. RESULTS AND DISCUSSION

The test results of concrete specimens were discussed as below

**Compressive strength (Cube)**

The compressive strength of mixes M3, M7, M10, and M11 increases in 15.07%, 17.80%, 23.28%, and 12.32% respectively with compared to CC. According to the result the combination of M10 (10%SF+10%MK+20%BA) shows higher percentage increase in compressive strength than CC.

**Compressive strength (Cylinder)**

The compressive strength of M3, M7, M10 and M11 increases in 16.9%, 20%, 23.07%, 10.77% respectively with compared to CC. the combination of M10 (10%SF+10%MK+20%BA) shows higher percentage increase in compressive strength than CC.

**Flexural strength**

The flexural strength of mixes M3, M7, M10, M11 for 22.80%, 26.31%, 31.57% and 19.29% respectively with compared to CC. the combination of M10 (10%SF+10%MK+20%BA) shows higher percentage increase in compressive strength than CC.

**Modulus of Elasticity**

The modulus of elasticity of concrete mixes increases in 8.71%, 8.01%, 11.464% and 5.16% respectively with compared to CC. the combination of M10 (10%SF+10%MK+20%BA) shows higher percentage increase in compressive strength than CC.

**Rebound Hammer and Ultrasonic pulse velocity**

The rebound number is 30 to 40. The quality of concrete is good layer in all mixes and UPV test the longitudinal pulse velocity is 3500 to 4500 m/sec. the quality of concrete is good. The combination of M10 mix results shows the higher value in all the mixes compared to CC.

## 7. ANALYTICAL INVESTIGATION

**Artificial Neural Network (ANN)**

Artificial neural networks are computing systems that simulate the biological neural systems of human brain. They are based on a simplified modeling of the brain's biological functions exhibiting the ability to learn, think, remember, reason, and solve problems. The model was generated using the nntool (neural network tool) available in MATLAB® software and the input and target values for the training and testing were entered into the appropriate positions. Neural Network Toolbox supports a training algorithms is the Levenberg-Marquardt algorithm (LM).

The values of parameters used in models are number of Input layer neurons is 10 and Number of output layer Neurons 1. For the present study, a multilayer feed forward network is adopted for training purpose. The error is reduced using a back propagation algorithm. In this study, 3 sets of Experimental results that is compressive strength of cube and cylinder and Flexural strength of prism, approximately 30 values have been used for processing of ANN models. A simple neural network and modeling based on back propagation neurons. NN Linear Equation R- value is shown in fig.14, 15, 16 and 17. Predicted data and Error of compressive strength of cubes, cylinders and flexural strength of prism as shown in Table 12.

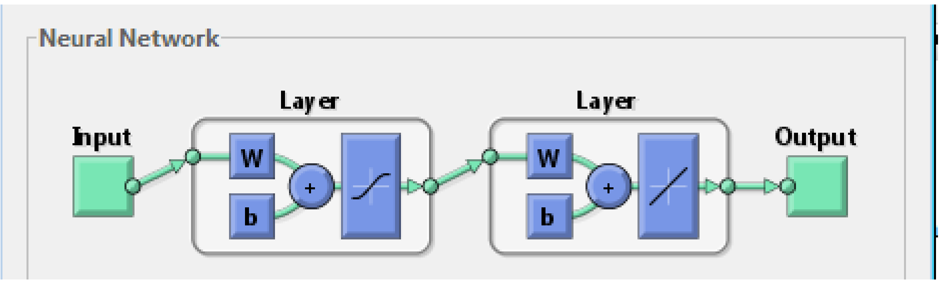



**Fig. 14 Neural Network Modelling**

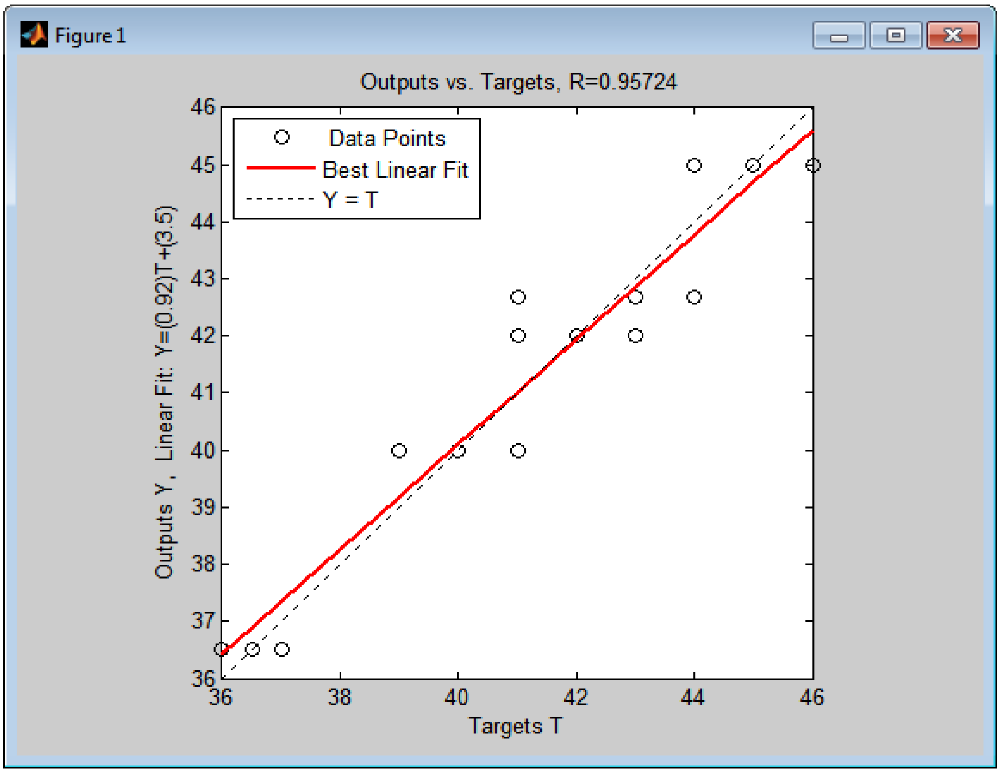



**Fig.15 Regression Analysis of Cube Training, Output Vs Target Values**

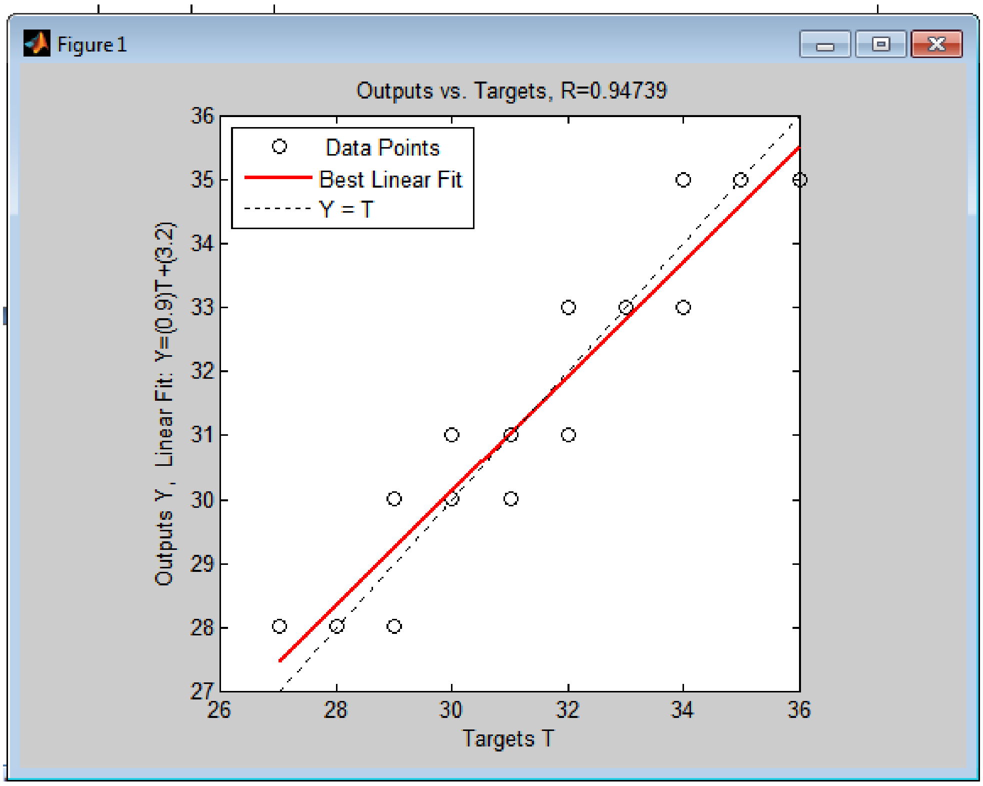



**Fig.16 Regression Analysis of Cylinder Training, Output Vs Target Values**

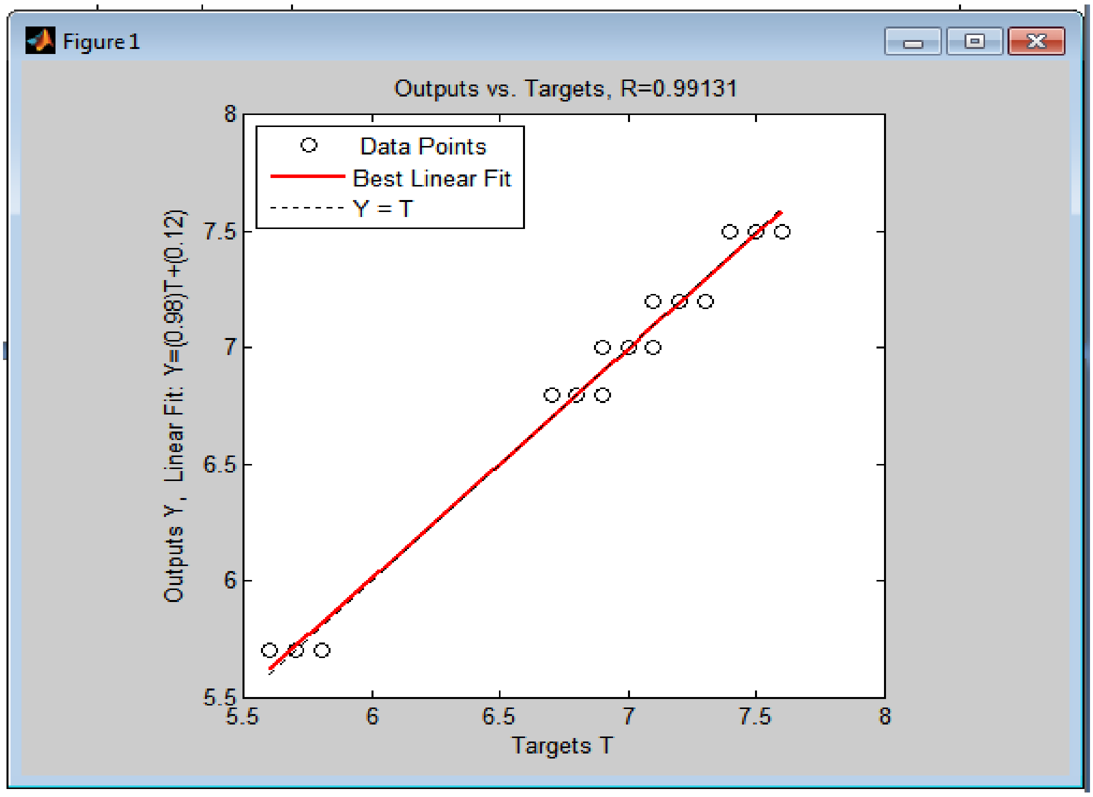



**Fig.17 Regression Analysis of Prism Training, Output Vs Target Values**

## 8. COMPARISON OF EXPERIMENTAL AND ANN RESULTS

The Comparison of these values shows that the neural network modeling is supported better than the Experimental results. It is shown that although the use of the model is not as simple as that of this formula, they provide a more accurate tool for the prediction of the concrete strength. The Comparison between the Experimental and ANN results has been made as shown in fig. 15,16,17 and 18.

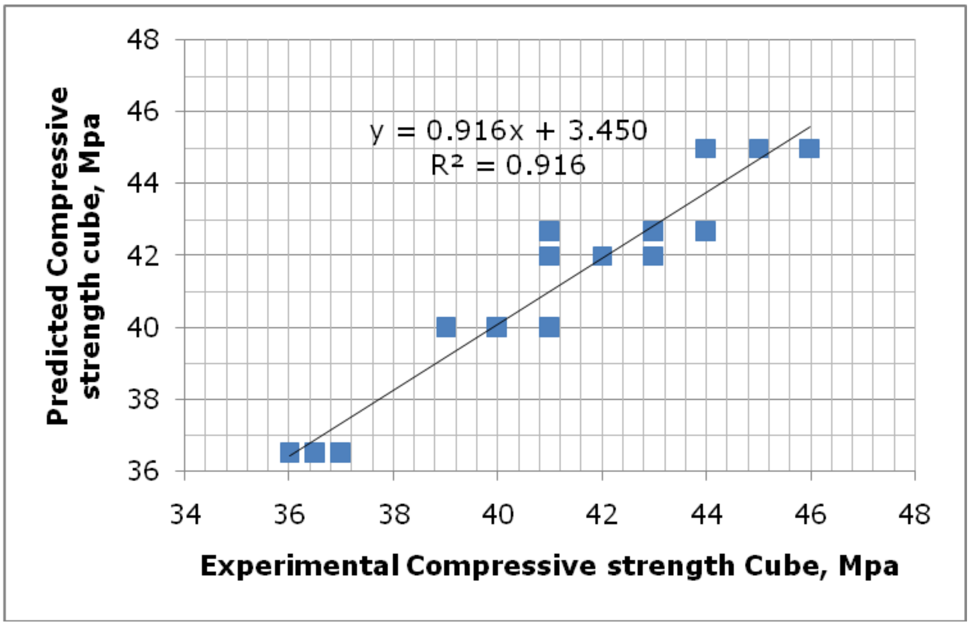



**Fig.18 Comparison of Experimental and Predicted Values of Compressive strength**

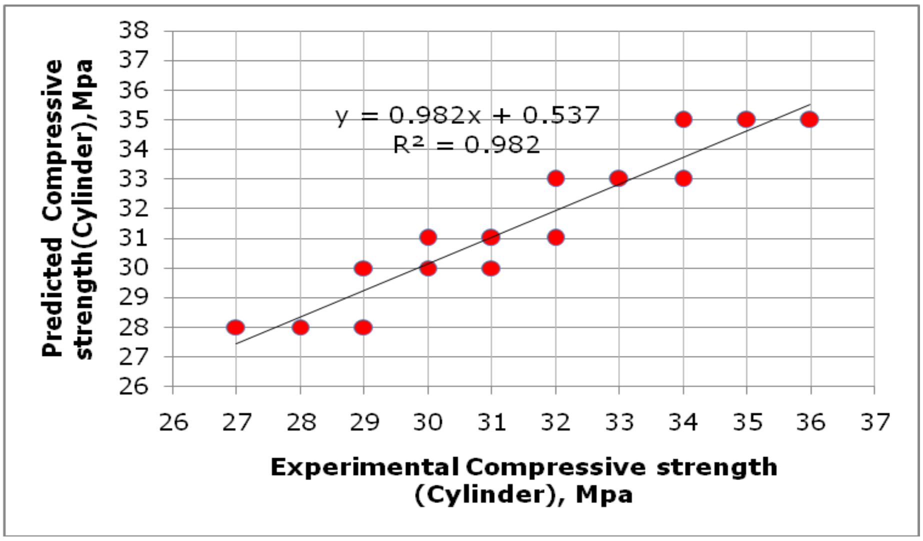



**Fig.19 Comparison of Experimental and Predicted Values of Compressive strength**

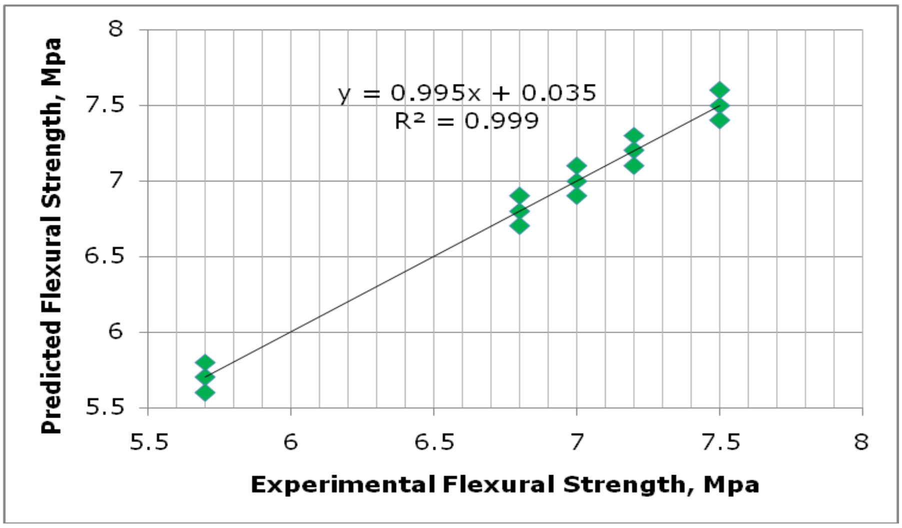



**Fig.20 Comparison of Experimental and Predicted Values of Flexural strength.**

**Table.18. Predicted, Experimental and %Error**

| Mix | Compressive Strength | | | Compressive Strength | | | Flexural Strength | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cube | | | Cylinder | | | Prism | | |
| | Experimental Results | ANN | % Error | Experimental Results | ANN | % Error | Experimental Results | ANN | % Error |
| CC | 36.5 | 36.5 | 0.0000 | 28 | 28 | 0.0000 | 5.7 | 5.7 | -0.0035 |
| M3 | 42 | 42 | 0.0000 | 31 | 30.5 | 1.6129 | 7 | 6.997 | 0.0400 |
| M7 | 43 | 44 | -2.3256 | 33 | 33 | 0.0000 | 7.2 | 7.221 | -0.2903 |
| M10 | 45 | 44 | 2.2222 | 35 | 35 | 0.0000 | 7.5 | 7.498 | 0.0267 |
| M11 | 40 | 40 | 0.0000 | 30 | 30.5 | -1.6667 | 6.8 | 6.762 | 0.5529 |

## 9. CONCLUSION

Based on the results of investigations the following conclusions are made

i. For M30 grade of concrete as the water cement ratio of 0.45 is sufficient to provide the good workability, hence superplasticizer is necessary for making HPC.

ii. The maximum compressive strength increased by the High performance concrete mix M10 cube and cylinder is 23.28%, 23.07%.

iii. The flexural strength and modulus of elasticity of concrete increased by a 31.57% and 11.464% for M10 concrete.

iv. The RHN shows above 35 - 40 the quality of concrete is good. UPV results shows the 3500 - 4500 m/sec. M10 mix shows the higher value compared to CC.

v. The aim of silica fume and metakaolin replacement is to increase strength where as the addition of fly ash is for economy and for improving the strength of hardened concrete.

vi. Bottom ash used as fine aggregates replacement enables the large utilization of waste product. The results encourage the use of metakaolin and silica fume as pozzolanic material for partial replacement in producing high performance concrete.

vii. The ANN predictions are in good agreement with the experimental results for all tests.

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