# STUDY OF STATIC AND DYNAMIC MODULUS OF ELASTICITY OF UHPC WITH AND WITHOUT COARSE AGGREGATES

**Santhosh K[1], Adithya Shenoy[2], Sooraj Kumar[3], Adithya Tantri[4], Aishwarya Lakshmi[5]**

*1, 2,3,4 Department of Civil Engineering, Alva's Institute of Engineering and Technology,Moodabidri, India.*

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**Abstract -** *Ultra high performance concrete leads to innovative aggregate rearrangements under its self-weight at initial semi-liquefied state. It allows the complete flexibility in the orientation of aggregates during mixing and placing. Aggregates play a major role in concrete mix because its general presence varies from 70% to 80%. In this research, a study has been made on mix properties of ultra-high performance concrete in the presence and absence of coarse aggregates with three different water-binder ratios. Elasticity properties of prepared mixes are evaluated at dynamic and static conditions. Comparison and co relations of these result reveals the 3% difference and it signifies the accuracy of the work. The overall study reveals that mixes with the presence of aggregates in concrete exhibits significantly improved results but workability is reduced.*

***Key words: Uhpc, Particle Packing Density, Static Modulus Of Elasticity and Dynamic Modulus Of Elasticity***

## 1. INTRODUCTION

Concrete is the most consumed construction material in the world. With the advancing times and evolution of buildings, various special concretes have been developed to cater to the growing needs of the civil engineering fraternity. Ultra High Performance Concrete (UHPC) is one such material which exhibits high strength and durability properties and has been used in very significant structures like high rise buildings and nuclear power plants among others. The change from normal concrete to UHPC has resulted in less cumbersome sections and lighter structural components, resulting in lighter, more efficient and aesthetically pleasing structures.

The UHPC consists of combinations of different mineral admixtures, chemical admixtures which help in adopting low water binder ratio, fine aggregates, with or without well-graded coarse aggregates and discrete fiber reinforcement. The compressive strength of UHPC is greater than 120MPa and tensile strength is greater than 5MPa. UHPC is not a self-compacting concrete but it shows the rheological properties namely fill ability, flow ability and segregation resistance of Self Compacting Concrete.

Modulus of Elasticity of concrete is a key property as its study will help in the better understanding of concrete as a material. Scientists have been conducting advanced research to understand the elastic behavior of concrete as an indicator for its strength and stiffness. In this paper, a study on the elastic behavior of six different mixes of concrete has been carried out.

## 2. MATERALS

### 2.1 Cement

53 grade of ordinary Portland cement confirming to IS: 12269 – 1987. It has the specific gravity of 3.15.

### 2.2 Micro Silica

It is the waste product silicon metal or ferrosilicon alloy industries. It mainly consists of SiO2 about 93.5%. The specific gravity of micro silica is 2.2. Chemical constituents are shown in Table 2.1

**Table 2.1:** Composition of Micro-silica

| Name of the Composition | Contents |
|---|---|
| $SiO_2$ | 93.58% |
| $Fe_2O_3$ | 0.25% |
| $Al_2O_3$ | 0.20% |
| CaO | 0.38% |
| MgO | 0.49% |
| Others | 5.11% |

### 2.3 Metakoaline

Metakaolin is produced by heating kaolin to a temperature of 1200 to 1650°F. It has specific gravity of 2.56 and surface area of 8 to 25 m2/gm. Average particle size is less than 2.5µm. Chemical constituents of metakoaline shown in Table 2.2.

**Table 2.2** Chemical Constituents of Metakaoline.

| Name of the Composition | Contents |
|---|---|
| $SiO_2$ | 52% |
| $Fe_2O_3$ | 1.70% |
| $Al_2O_3$ | 42% |
| CaO | 0.50% |
| MgO | 0.50% |
| Others | 3.51% |

### 2.4 Quartz Sand

It is made up of a lattice of silica (SiO2) tetrahedral. The hardness of the quartz sand is 7 as per Mohs scale and its density is 2.65 g/cm3. There are 3 different sizes of quartz sand are used in this experiment work. They are 60mesh, 100mesh and 200mesh.

### 2.5 Fine Aggregate

The M sand is used as a fine aggregate conforming to the requirements of IS: 383-1970. It has a specific gravity of 2.63 and water absorption is about 3.5%.

### 2.6 Coarse Aggregate

The 12mm down size coarse aggregates conforming to the requirements of IS: 383-1970 are used in this experimental work. Coarse aggregate has rough texture and angular shape, so which is more suitable for UHPC to gain the strength.

### 2.7 Steel Fibres

A hooked type steel fibres are used in this experimental work. Length of the steel fibres is 30mm and diameter is 0.5mm, aspect ratio is 60. The specific gravity of the hooked steel fibres is 7.86 and it has tensile strength of 1100MPa.

### 2.8 Chemical Admixtures

Talrakplast PC is used as a chemical admixture. It is a P C based new generation Hyper Plasticizer specially designed for Self Compacting Concrete. Characteristics of PC: DNY M70 of PCE based super plasticizer; water reduction capacity is about 40%. Specific Gravity of this admixture is 1.10

### 2.9 Water

Normal tap water is for mixing and curing all the concrete specimens, Ph is almost neutral.

## 3. EXPERIMENTAL WORK

### 3.1 Particle Packing Density Mix Approach

There are non codal references for the mix design of higher grade concrete. Therefore mix design can be done by using particle packing density mix approach. Particle Packing gives indirect measurement of geometry of the concrete mass and also gives the cement paste to be required to fill the void content in present in the concrete. To achieve the optimized particle packing density, particle is selected in such a way that, smaller size particle fill up the voids between the larger particle and so on. The voids between the aggregate particles are filled by the cement paste and excess of paste will form a thin coating around each aggregate present in the mix.

In order to achieve optimized particle packing density fine sand is sieved in to different size particles, such as particles passing through 1.18mm, 0.6mm, 0.3mm and 150mm sieve.

Total quantities of particle passing through 150mm sieve are negligible compared to quantity of other size particles. There for quartz sand of sizes 0.25mm (60 meshes), 0.15mm (100 mesh) and 0.75mm (200mesh) are used to full fill the requirements of very fine particles. The sieve analysis is done by adding different percentage of sieved particles. Number of trial is carried out by varying the percentage of different sieved particles to achieve S curve as per Indian standard.

This experimental study consists of 6 mixes. Mix 1,2 and 3 are mixes without any coarse aggregates and mixes 4,5 and 6 consist of both fine and coarse aggregate. In all the mixes, 5% of cement is replaced by metakoaline and 10% of cement is replaced by micro silica. 20% of M-sand is replaced by quartz sand. Experimental work carried out for different water cement ratio 0.3, 0.26 and 0.22. The various mix designations along with their constituents is as shown in tables 3.1 and 3.2

**Table 3.1:** Mixes without coarse aggregates

| Materials | % by weight of cement | | |
|---|---|---|---|
| Mix | 1 | 2 | 3 |
| Cement | 1 | 1 | 1 |
| Micro silica fume | 0.1 | 0.1 | 0.1 |
| High reactivity metakaoline | 0.05 | 0.05 | 0.05 |
| M-Sand | 1.72 | 1.72 | 1.72 |
| Coarse Aggregates | - | - | - |
| Quartz sand | 0.32 | 0.32 | 0.32 |
| Steel Fibres | 0.00575 | 0.00575 | 0.00575 |
| Water Binder ratio | 0.30 | 0.26 | 0.22 |

**Table 3.2:** Mixes containing coarse aggregates

| Materials | % by weight of cement | | |
|---|---|---|---|
| Mix | 4 | 5 | 6 |
| Cement | 1 | 1 | 1 |
| Micro silica fume | 0.1 | 0.1 | 0.1 |
| High reactivity Metakoaline | 0.05 | 0.05 | 0.05 |
| M-Sand | 0.85 | 0.85 | 0.85 |
| Coarse Aggregates | 0.77 | 0.77 | 0.77 |
| Quartz sand | 0.32 | 0.32 | 0.32 |
| Steel Fibres | 0.00575 | 0.00575 | 0.00575 |
| Water Binder ratio | 0.30 | 0.26 | 0.22 |

## 3.2 Mixing

The mixing of concrete ingredient is done by using pan mixer of 4 liters capacity. First dry mix is prepared by mixing the aggregates, cement steel fibers and mineral admixture. Then water and superplasticizers are added. Chemical admixture is added by percentage wise. For the each percentage fresh properties are checked as per EFNARC 2005. The mixing is done for different water cement ratio 0.3, 0.26 and 0.22. For the each water cement modulus of elasticity is determined.

## 3.3 Fresh Properties

The fresh concrete properties such as filling ability, passing ability, and resistance to segregation of the concrete sample are based on the EFNARC 2015. No single test method is available, to determine the fresh properties concrete. There for each mix is tested by different test methods to full fill the fresh concrete properties such slump flow test, V funnel, L box, U box and J ring.

## 3.4 Casting

For the modulus of elasticity test 100 mm diameter and 200mm height cylinders are used. After confirming the fresh properties, fresh concrete is poured in to steel cylindrical mould. After 24 hour it is demoulded and kept in water for curing.

### 3.5 Modulus of Elasticity

Modulus of elasticity is a significant indicator of the stiffness of hardened concrete. Static and dynamic modulus of concrete has been determined for the various mixes.

Static Modulus of Elasticity was determined by compressing concrete cylinders of diameter 150mm and length 300mm. Stress strain curves were plotted for these mixes and slope of the line of best fit gives the static modulus of elasticity.

Dynamic Modulus of Elasticity was determined from the results of the Ultrasonic Pulse Velocity test. The average velocity of travel is then calculated and Dynamic Modulus of elasticity is given as

$$E = \frac{Q*(1-2\mu)*(1+\mu)*V^2}{(1-\mu)}$$

as prescribed in IS 13311(Part 1)

## 4. RESULTS & DISCUSSIONS

### 4.1 Fresh properties

The results of the slump flow test, L box test, U box test, V funnel test and J ring test are as indicated in the table shown below. It is observed that with reduction of water content, mixes have shown reduced workability. It is also notable that the mixes with no coarse aggregates, i.e., 1,2 and 3 have exhibited better workability as compared to 4,5 and 6. Of all the mixes, mix 1 has exhibited the best workability.

**Table 4.1:** Fresh Properties of the various mixes

| Mix | Slump flow (mm) | L Box | U Box (mm) | V Funnel (s) | T5 test (s) | J Ring (s) |
|---|---|---|---|---|---|---|
| 1 | 780 | 0.95 | 0 | 8 | 11 | 4 |
| 2 | 710 | 0.9 | 1 | 10 | 13 | 6 |
| 3 | 660 | 0.85 | 1 | 12 | 15 | 8 |
| 4 | 760 | 0.9 | 1 | 9 | 10 | 5 |
| 5 | 680 | 0.85 | 1 | 11 | 13 | 8 |
| 6 | 630 | 0.85 | 2 | 12 | 15 | 10 |

As seen from the table, Mix 1 has exhibited the best performance with reference to fresh properties. It can also be observed that all mixes conform to the requirements as prescribed by the EFNARC standards

### 4.2 Static Modulus of Elasticity

Static modulus of elasticity obtained for various mixes are as shown in Table 4.2

**Table 4.2:** Static modulus of elasticity

| Mix designation | Water Binder Ratio | Static Modulus of Elasticity (GPa) |
|---|---|---|
| 1 | 0.30 | 58.95 |
| 2 | 0.26 | 59.98 |
| 3 | 0.22 | 60.70 |
| 4 | 0.30 | 60.17 |
| 5 | 0.26 | 61.40 |
| 6 | 0.22 | 62.21 |

It was observed that with reduction of water-binder ratio, Young's modulus increased steadily. Among the various mixes analyzed, Mix 6 exhibited the best Modulus of Elasticity of 62.21 GPa whereas mix 1 has shown the least value of 58.95 GPa. It is also noticeable that mixes with the inclusion of coarse aggregates has increased the Modulus of Elasticity significantly. These characteristics are as illustrated in Figure 4.1.

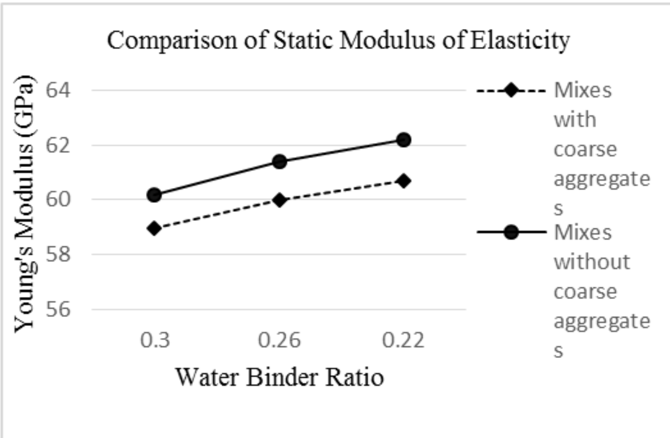


**Figure 4.1:** Variation of Static Modulus of Elasticity

### 4.3 Dynamic Modulus of Elasticity

Dynamic modulus of Elasticity and average velocity of travel of various mixes is as given in table 4.3.

**Table 4.3:** Velocity and dynamic modulus of elasticity

| Mix | Water Binder Ratio | Average Velocity (km/s) | Dynamic Modulus of Elasticity (GPa) |
|---|---|---|---|
| 1 | 0.30 | 71.3 | 60.26 |
| 2 | 0.26 | 72.6 | 61.36 |
| 3 | 0.22 | 74.8 | 62.47 |
| 4 | 0.30 | 72.8 | 61.88 |
| 5 | 0.26 | 74.3 | 63.18 |
| 6 | 0.22 | 75.7 | 64.03 |

From the experimental study, it was found that Dynamic Modulus of Elasticity was a maximum for Mix 6, 64.03 GPa and minimum observed was 60.26 GPa for Mix 1. Characteristics are similar to static modulus where the presence of coarse aggregates has resulted in a noticeable rise in the modulus of elasticity, as illustrated in Figure 4.2 and Figure 4.3.

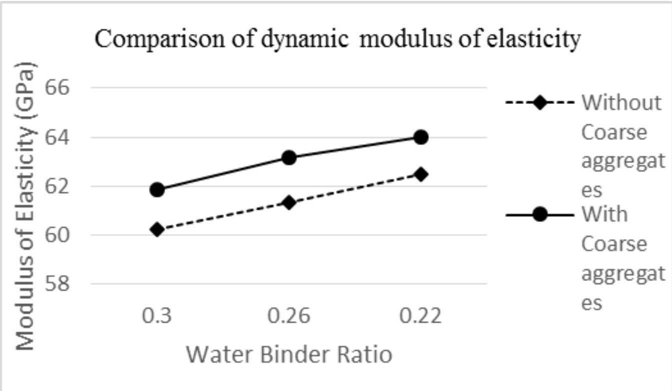


**Figure 4.2** Variation of Dynamic Modulus of Elasticity

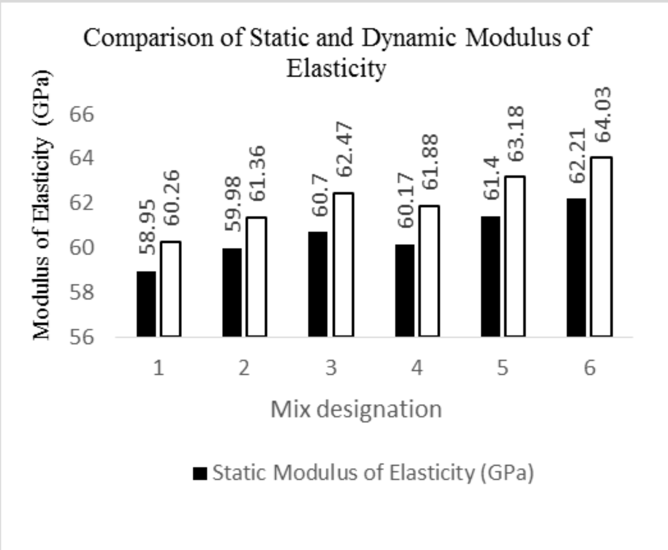


**Figure 4.3** Comparative characteristics

The comparison has shown a good correlation of the two moduli. All values have shown a variation in the range of 2.21% to 2.97%.

## 5. CONCLUSIONS

After extensive experimental study and analysis, the following conclusions were arrived at.

- Fresh properties improve with increase in water binder ratio and even more so in the absence of coarse aggregates.
- Static and dynamic modulus of elasticity have increased with reduced water content and even more so in the presence of coarse aggregates.
- Static and Dynamic testing have correlated results and variation between them is within 3% of each other

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