Available online at
www.mdl.mazedan.com

MTESD

www.mazedan.com
©2022 Mazedan International Research Academy
www.mazedan.com/mtesd

OPTIMISED MIX DESIGN AND ELASTIC MODULUS PREDICTION OF HIGH STRENGTH CONCRETE

SATYAM SANJAY JATI*, BHARATI CHANGHODE

MAZEDAN TRANSACTIONS ON ENGINEERING SYSTEMS DESIGN
e-ISSN: 2582-8061
Article id-MTESD0304005
Vol-3, Issue-4
Received: 18 Nov 2022
Revised: 11 Dec 2022
Accepted: 22 Dec 2022

Citation: Jati, S. S., & Changhode, B. (2022). Optimised Mix Design and Elastic Modulus Prediction of High Strength Concrete. *Mazedan Transactions on Engineering Systems Design*, 3(4), 16-20.

Abstract

The load carrying capacity of any structure or a structural member depends upon the type of concrete used. High strength concrete used in any structure increases the load carrying capacity of that particular structure as compared to the normal strength concrete. In the market, a growing demand for various types of special concrete mixes is there such as high-performance concrete, high strength, low permeability concrete, for use in bridges, marine environment, nuclear power plants etc. To achieve this, the cement is partially replaced with silica fume. And hence this project presents an extensive study to produce concrete of maximum compressive strength using special mineral additive material silica fume and also the study of the property of modulus of elasticity of the specimens of high strength concrete.

The most significant property of concrete is the modulus of elasticity of concrete. It is a very important parameter which reflects the ability of concrete to deform elastically. In order to utilize the full compressive strength, the structure in which high strength concrete is used are generally smaller and require a higher modulus of elasticity to maintain its stiffness. The mechanical properties of HSC are dependent on the properties and proportions of binders and aggregates. Hence, knowledge of the modulus of elasticity of high strength concrete is very important to avoid excessive deformation which provides satisfactory serviceability and the most cost-effective designs.

In the Experimental program, certain trial mixes were prepared which will consist of the replacement of cement content by silica fume in 10%, 15% and 20% and further testing the same mixes for the compressive strength test and further the test of modulus of elasticity.

Keywords: Modulus of elasticity, Mineral Admixture, High-strength concrete, Mix design.

1. INTRODUCTION

We are familiar with the Concrete, that it is the most widely used building material, as it has desirable Engineering properties, it can be molded into any shape and more importantly is produced with cost-effective materials. The quality concrete is efficiently prepared using various types of mineral admixtures, these mineral admixtures are used beneficially and they increase the strength of concrete. Various types of mineral admixtures are used which are waste products of other industries. It will be more beneficial to use high strength concrete for the certain required strength for that particular structure, which will not only increase the strength but also durability of structure. Various parameters of high strength concrete like water-cement ratio, use of mineral as well as chemical admixture, temperature, curing, etc. involves variations. On the basis of observations, the mechanical and environmental performance of concrete depend upon various types of material used in the concrete. The concrete properties depend upon packing of grains and type of curing.

Cement is main ingredient of concrete or mortar which binds all the material used in the mix. The excess cement content in concrete leads to risk of cracking due to drying shrinkage or it may also cause an early age thermal cracking and increased risk of damage due to alkali silica reaction. Because of this harmful effect in concrete which is mainly due to the use of excessive cement content. Indian standard specification IS 456: 2000 specifies the maximum cement content as 450 kg/m3. Besides, the excessive use of cement for the construction purpose leads to increase the demand for cement in the market, and this may cause an increase in the production of cement.

We know that, cement manufacturing at various industries causes a tremendous emission of CO2 which is harmful for environment and human life. Hence to avoid the harmful cause the partial replacement of cement with any of the mineral admixture such as Silica fume, GGBS, fly ash, Rice husk ash, Metakaolin etc. which can considerably give much more strength. And hence some trial mixes are prepared in which cement is replaced with one of the mineral admixtures i.e., silica fume so the different mixes were tested for compressive strength test, Splitting tensile strength test and for the test of modulus of elasticity. By following this replacement phenomenon,

Department of Civil Engineering, G H Raisoni University, Amravati, India
*Corresponding author email- samjati98@gmail.com

we can limit the extensive demand of cement and also using the silica fume which is the industrial byproduct. This not only fulfills the possible demand but also increases the strength and durability of concrete.

High Strength Concrete

High-strength concrete (HSC) is often used in the columns of high-rise buildings, long-span bridges, parking garages, and offshore structures, where improved density, lower permeability, and increased resistance to freeze-thaw and corrosion are required. In these applications, designers can take full advantage of the increased compressive strength of HSC to reduce the amount of steel, reduce column size (to increase usable floor space in high-rise buildings), or allow additional stories. These benefits overshadow the higher cost of raw materials and increased quality control costs involved with HSC.

Modulus of Elasticity

The modulus of elasticity of concrete can be defined as the ratio of normal stress to the corresponding strain for tensile and compressive stresses below the proportionality limit of the material. When the loading is of low intensity and short duration, the initial portion of the stress-strain curve of concrete in compression is linear, justifying the use of modulus of elasticity. When there is sustained load, however, the stress-strain curve will become nonlinear, even at relatively low stresses, due to inelastic creep. Moreover, the effects of creep and shrinkage will make the concrete behave in a non-linear manner.

The elastic modulus has been considered as an important concern for the analysis and design of concrete structures. However, Concrete is not an elastic material which means that, it will not regain its original shape on removal of loading. In addition, the stress-strain curve of concrete is non-linear. Hence, modulus of elasticity and Poisson's ratio, which are elastic constants, are not applicable. However, for simplicity, they are used in the analysis and design of concrete structures, assuming elastic behavior. For the estimation of deformations in particular structure or in any of the structural members the modulus of elasticity of concrete is required. Besides, it is also used for determining the modular ratio. The higher modulus of elasticity of high strength concrete results in reduced deflection and increased tensile strength.

The property modulus of elasticity of concrete is mainly depends upon the compressive strength of concrete, the aggregate proportion in the concrete addition of mineral admixtures, properties of coarse aggregate, the quality of cement paste. Mainly, chemical and mineral admixtures, type of cement and age of concrete are the parameter by which modulus of elasticity of concrete get affected at a lesser extent. The fine and coarse aggregates generally occupy 60% to 75% of the volume of concrete (70% to 85% by mass) and are stiffer than the concrete paste. Therefore, their value of modulus of elasticity will have a significant effect on the modulus of elasticity of concrete. Using the dense aggregates such as basalt than limestone, which results in a higher modulus of elasticity than lightweight aggregates. Suitable grading of aggregates may result in higher content of course aggregate in a concrete mixture. It may result in higher content of course aggregate in concrete mixture if the it specified largest practical maximum size of aggregate and its suitable grading. Such concretes tend to have a higher modulus of elasticity, provided the aggregates used have a higher modulus of elasticity. While, increased size of the coarse aggregate may provide reduced strength in high strength concrete mixes. Increasing the paste content results in decrease the void content of the concrete, which may result in increased the modulus of elasticity. Increasing the water-cement ratio will reduce the value of modulus of elasticity, similar to its effect on the compressive strength of concrete.

A high modulus of elasticity is associated with a higher compressive strength of concrete, although the two are not directly proportional. For example, to increase the modulus of elasticity by 20% it may be necessary to increase the strength by 50%. Aitcin, 2011 observes that the modulus of elasticity of concrete is one of the important parameters as like as the water-cement ratio of the concrete mix.

2. OBJECTIVES

- To develop a mixture proportioning process of making High strength concrete using and silica fume.
- To evaluate the optimum percentage of silica fume and fly ash required.
- To learn the behavior of concrete specimen in terms of modulus of elasticity.
- To conduct a detailed experimental study at age of 7 & 28 days on workability & Compressive strength.

3. MATERIALS USED

Materials

1. Ordinary Portland cement of 53 grade
2. Fine aggregate
3. Coarse aggregate
4. Water

Superplasticizer

we have used PERMA PLAST PC-302. It has a specific gravity 1.15 and dosage may vary in between 0.6% to 2.0% by weight of the cement. It lowers the water-cement ratio in concrete mix upto 0.23.

4. THEORY

The same procedure of mix-proportioning which is used to proportion normal strength concrete cannot be used to proportion high-strength concrete considering both the chemical and mineral admixtures. IS 10262: 2009 can be used to proportion normal as well as high-strength concrete. Generally, the concrete mix having the 28-day strength more than 40 Mpa is the high strength concrete. To gain high strength as per requirement it is beneficial to lower water cement ratio to 0.35 and even lowered as per requirement. By adding silica fume to the mix, it prevents the formation of free calcium hydroxide. Calcium hydroxide may reduce the strength at the cement-aggregate bond. Wherever in the structure present dense rebar cages and as per our requirement of higher strength

the concrete mix with low water-cement ratio and silica fume is less workable which is likely to be problem with the application of high strength concrete. High range water reducers like superplasticizers or hyperplasticizers are commonly added to compensate for the reduced workability. To overcome the surface tension extreme dosages of dispersing agent are used, this permits dense packing of particle. Hence, by considering the parameter of strength and workability at the same time we can produce the cement pastes of very low water-cement ratio.

In high-strength concrete rather than compressive strength the design criterion is the modulus of elasticity. Denser packing of the solids in the mixture results in the improvement of various mechanical properties of concrete. The selection of aggregate must be done carefully for high strength concrete, as weaker aggregates may not be strong enough to resist the imposed load on the concrete, as normally occurs in regular concrete. To obtain the HSC only a dense cementitious matrix is not the sufficient since the aggregate-matrix bond may not be strong enough. In normal strength concrete the zone of interface is often a weak zone, since it tends to be more heterogenous and also porous than the bulk paste matrix.

Adding silica fume in the mixture changes the microstructure of the paste at the interface, which causes it to be dense as that of cement matrix. It provides an efficient bond in between the aggregate and the cement matrix. silica fume mainly has effects are associated with its ability to pack material densely. silica fume has another important characteristic that, it minimizes the internal bleeding of concrete. It also helps in improving the effective bond between the aggregate and the paste. The silica fume particles having the spherical geometry allows them to fill the voids which are present in between the larger and angular cement particles. Because of this

effects at the interfacial zone, aggregate present in the high strength silica fume concrete becomes an active load-bearing components in the concrete, this effect contributes to the overall strength of the concrete.

Modulus of Elasticity

Modulus of elasticity is a mechanical property of concrete which is most significant for the design criterion. Modulus of elasticity influence the structural performance of reinforced concrete structures. At the time while predicting the deformation of the tall buildings' modulus of elasticity act as a significant role as a design parameter.

The properties of the coarse aggregate used in the mix has a relation with the modulus of elasticity of concrete i.e., it governs the modulus of elasticity. As stiffer aggregate or an aggregate with increased in its size is used along with this the modulus of elasticity also increases.

The material of paste and aggregate are combinedly a composite material, in compression modulus of elasticity of concrete is in relation with the mechanical properties of the paste and the aggregate in the composite material. The modulus of elasticity of the aggregate and the paste approaches each other, the stress strain relationship tends to be more linear with the increase in the brittleness of that particular member or structure.

According to the clause 6.2.3.1 of IS 456: 2000 states that, the short-term static modulus of elasticity of concrete, Ec, may be taken as

$$Ec = 5000\sqrt{fck} \quad (1)$$

Ec is in N/mm^2

5. METHODOLOGY

The methodology in the project explains about the step-by-step procedure that is going to be done in the project. The methodology is explained in the following chart.

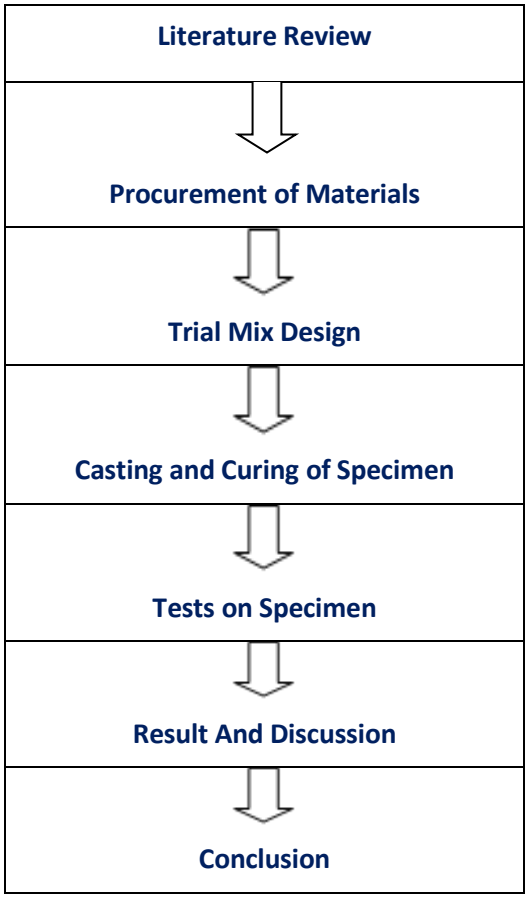


Table 1 Quantities of materials

Materials	Trial mix I (SF=10%)	Trial mix II (SF=15%)	Trial mix III (SF=20%)
Cement (kg/m3)	371	351	330
Silica fume (kg/m3)	41.3	61.9	82.6
Coarse Aggregate (kg/m3)	1032	1032	1032
Fine Aggregate (kg/m3)	768	768	768
Water (ltr)	206	206	206
Superplasticizer (1.0 %)	3.91	3.91	3.91

6. TESTS ON SPECIMENS

The various strength test that are to be done listed as below.

- Compressive strength
- Test on Modulus of Elasticity

Test Specimen Dimension

As per IS recommendations, cube specimens having size 100mm x 100mm x 100mm are casted in cast iron steel moulds for the compressive strength test. For each proportion three numbers of cubes should be casted and tested at the age of 7 & 28 days.

For measuring deformation, cylinders of diameter 150mm and 300mm long are casted using iron moulds. These cylinders are tested at the 28 days of maximum strength gain. Mainly, the modulus of elasticity of the cylinder specimen should measure but initially the most important thing is to get the deformations whenever the cylindrical specimen is subjected to uniaxial compression then the corresponding deformations in cylinder could be measured by fixing dial gauge having 200mm gauge length.

7. RESULT AND DISCUSSION

The compressive strength of the concrete and the modulus of elasticity of concrete are co-related to each other. Whenever the load imposed on a structure

The modulus of elasticity of concrete is generally related to compressive strength. The modulus of concrete under static loading conditions is generally known as its static modulus. The value of the static modulus (E) for concrete is determined on the basis of the uniaxial stress-strain curve obtained from a standard test cylinder.

The stress-strain behavior of HSC depends on material parameters such as aggregate type and experimental parameters that include age at testing, strain rate and interaction between specimen and testing machine. The stress-strain characteristics of concrete are non-linear from the beginning. The initial tangent to the stress-strain curve is regarded as the initial tangent modulus. The modulus of elasticity is determined from the slope (dy/dx) of initial tangent drawn.

Compressive strength test

Table 2 Compressive strength test on specimen with 10% Silica fume

Days	Cube No.	Load (KN)	Strength (N/mm sq.)	Avg. Result (N/mm sq.)
7 days	1	378.3	37.83	39.52
	2	407.7	40.77	
	3	399.6	39.96	
28 days	1	589.1	58.91	57.11
	2	556.3	55.63	
	3	567.9	56.79	

Table 3 Compressive strength test on specimen with 15% Silica fume

Days	Cube No.	Load (KN)	Strength (N/mm sq.)	Avg. Result (N/mm sq.)
7 days	1	395.8	39.58	41.64
	2	435.3	43.53	
	3	418.1	41.81	
28 days	1	645.8	64.58	63.62
	2	634.3	63.43	
	3	628.4	62.84	

Table 4 Compressive strength test on specimen with 20% Silica fume

Days	Cube No.	Load (KN)	Strength (N/mm sq.)	Avg. Result (N/mm sq.)
7 days	1	358.7	35.87	36.44
	2	377.6	37.76	
	3	356.9	35.69	
28 days	1	565.4	56.54	56.68
	2	547.2	54.72	
	3	587.8	58.78	

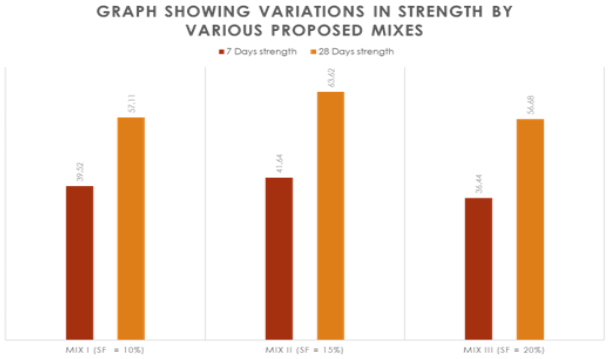


Figure 1 Comparison of compressive strength of the three proposed mixes

Observations of test on modulus of elasticity

Table 5 observation of test on modulus of elasticity

Load (KN) (a)	Deflection(mm) (b)	Strain (mm/mm) c=(b/200)	Stress (N/mm^2) d=(a/17671)	Modulus of Elasticity(E) e=(d/c)
0	0	0	0	0
50	0.01	4.9×10^{-5}	2.83	5.80×10^{-5}
100	0.03	1.5×10^{-4}	5.66	3.87×10^{-5}
150	0.04	2.0×10^{-4}	8.49	4.35×10^{-5}
200	0.05	2.4×10^{-4}	11.32	4.64×10^{-5}
250	0.06	2.9×10^{-4}	14.15	4.83×10^{-5}
300	0.08	3.9×10^{-4}	16.98	4.35×10^{-5}
350	0.11	5.4×10^{-4}	19.81	3.69×10^{-5}
400	0.13	6.3×10^{-4}	22.64	3.57×10^{-5}
450	0.16	7.8×10^{-4}	25.46	3.26×10^{-5}
500	0.18	8.8×10^{-4}	28.29	3.22×10^{-5}
550	0.22	1.1×10^{-3}	31.12	2.90×10^{-5}
600	0.26	1.3×10^{-3}	33.95	2.68×10^{-5}
650	0.31	1.5×10^{-3}	36.78	2.43×10^{-5}
700	0.35	1.7×10^{-3}	39.61	2.32×10^{-5}

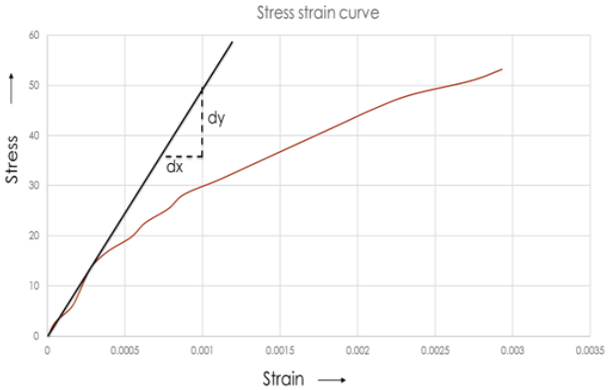


Figure 2 Stress-strain curve

8. CONCLUSION

After observing to the research of various authors the modulus of elasticity of concrete is the most significant mechanical property that is to be taken into consideration for any structure. Following points will give the precise results of research

- Concrete prepared using replacement of cement at certain percentage by silica fume increases strength relatively.
- The concrete mix replaced with 15% of Silica fume with cement gives the Maximum strength as 63.62 N/mm^2 compared to other mixes.
- The strength is minimum when 20% cement by weight is replaced by silica fume.
- The compressive strength is minimum when 10% cement by weight is replaced by SF.
- The compressive strength increases by approx. 6.5% when silica content is increased by 5%.
- The experimental value of modulus of Elasticity of high strength concrete should not be differ by +-20 percent from the values obtained in the theoretical modulus of elasticity as per IS 456: 2000.
- Modulus of Elasticity obtained from the stress-strain curve taking the slope (dy/dx) of initial tangent modulus drawn to the curve, E = 35. 13 x 10-3 N/mm^2.
- As per IS 456: 2000, Modulus of Elasticity theoretically is obtained as E = 39. 88 x 10-3 N/mm^2.

REFERENCES

[1] IS 456:2000 Indian Standard Code of Practice for Plain and Reinforced Cement Concrete, 4th revision, Bureau of Indian Standards, New Delhi, 100.

[2] S 516:1959 (reaffirmed 2018), Method of Tests for Strength of Concrete, Bureau of Indian Standards, New

[3] Zhang, H and Gjvorv, O. E. (1991) “Mechanical Properties of High-Strength Lightweight Concrete”, Materials Journal, Vol. 88, No.3, pp. 240–247.

[4] Crouch, Pitt, J. and Hewitt R. (2007) “Aggregate Effects on Pervious Portland Cement Concrete Static Modulus of Elasticity”, Journal of Materials in Civil Engineering, 2007, Vol. 19, No.7, pp. 561–568.

[5] Aïtcin P (2011) High performance concrete, CRC Press, Boca Raton, Fl.

[6] Neville, M., Properties of Concrete, 4th Edition, 1996, John Wiley & Sons, New York, 844 pp.

[7] ENV 1992-1-1, Eurocode Design of Concrete Structures—Part 1: General Rules and Rules for Buildings, 2004, 225 pp

[8] Subramanian, N. (2019). Building Materials, Testing, and Sustainability, Oxford University Press, New Delhi, 788

[9] Swamy, N. (1985) “High-Strength Concrete-Material Properties and Behavior”, ACI SP87-8, pp. 119–145

[10] Singh, P. Yazdani, N., and Ramirez (2013) “Effect of Time-dependent Concrete Modulus of Elasticity on Prestress Losses in Bridge Girders”, International Journal of Concrete Structures and Materials, Vol. 7, pp. 183-191.

[11] Tomosawa F, Noguchi T. Relationship between compressive strength and modulus of elasticity of high-strength concrete. Journal of Structural and Construction Engineering (Transactions of AIJ) 1995; 60