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Effect of GGBFS on age dependent static modulus of elasticity of concrete

Mohd. Shariq [a,*], Jagdish Prasad [b], H. Abbas [c]

[a] Civil Engineering Section, University Polytechnic, Faculty of Engineering & Technology, Aligarh Muslim University, Aligarh, India
[b] Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, India
[c] Specialty Units for Safety and Preservation of Structures, Department of Civil Engineering, King Saud University, Riyadh, Saudi Arabia

HIGHLIGHTS

- ▶ Effect of GGBFS on modulus of elasticity of concrete is studied.
- ▶ Static modulus of elasticity of GGBFS based concrete is lower than plain concrete.
- ▶ Model is developed for time-dependent static modulus of elasticity of GGBFS concrete.

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ABSTRACT

This paper presents the results of experimental investigations into the time-dependent static elastic modulus of concrete containing GGBFS. The static modulus of elasticity was determined at the ages of 3, 7, 28, 56, 90, 150 and 180 days for twelve concrete mixes using the cylindrical specimens of plain and GGBFS concrete. The amount of cement replacement by GGBFS was varied from 20% to 60%. The static modulus of elasticity of concrete containing GGBFS has been found to be lower than the plain concrete for all replacements of cement at all ages and for all the mixes. The experimental results of time dependent static modulus of elasticity of concrete were compared with available models. A new model for time-dependent static modulus of elasticity of concrete containing GGBFS has been proposed.

1. Introduction

Ground granulated blast furnace slag (GGBFS) as a mineral admixture has become an essential constituent of concrete. It serves the dual purpose of imparting high resistance to chemical attack in marine environment as well as substantially reducing the heat of hydration. In mass concreting, either low heat cement is used or GGBFS is used to control the heat of hydration in high strength cement. The use of GGBFS alters the concrete characteristics such as creep, modulus of rupture, modulus of elasticity, bond with steel and tensile strength [1]. These properties have profound bearing on the performance of reinforced and prestressed concrete.

The static modulus of elasticity is an important property of concrete in the analysis of composite section to determine the transformed section properties. The initial modulus of elasticity is required to determine the elastic shortening and member camber at the time of release of prestress. The static modulus of elasticity at later ages is useful to predict creep coefficient for calculating losses in prestressed concrete members, and deflection of the reinforced concrete members.

Literature shows [1–7] that the static modulus of elasticity of concrete is not constant and varies with grade of concrete, material properties and testing methods. The influence of GGBFS on static modulus of elasticity depends upon the origin of GGBFS. Malhotra [8] reported that little difference was observed between static modulus of plain concrete and that of GGBFS based concrete when GGBFS of South African origin was used. No difference was found between modulus of elasticity of plain concrete and concrete containing slag of Japanese origin. The slag from the United Kingdom showed lower modulus of elasticity than the modulus of elasticity of plain concrete at early ages and for higher percentages of slag. ACI committee 233 [9] reported that the same modulus of elasticity was found for plain and GGBFS based concrete when equal amount of slag was used with cement. Swamy and Bouikni [1] and Jin and Li [10] reported little difference between modulus of elasticity of plain concrete and concrete containing GGBFS. Hale et al. [11] studied the influence of slag cement on the fresh and hardened properties of concrete to be used in pavements and bridge structures. Three different Type I cements were examined along with four different concrete mixtures containing varying amounts of slag cement and fly ash. The results showed that the addition of slag cement was largely positive for all type I cements, whereas the addition of fly ash produced mixed effects.

* Corresponding author. Tel.: +91 9897903968.
E-mail address: mshariqdce@gmail.com (M. Shariq).

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Yazıcı et al. [12] investigated the influence of curing conditions (standard, autoclave and steam curing) on the mechanical properties of reactive powder concrete produced with class-C fly ash and GGBFS. The test results showed that the compressive strength of RPC increased considerably after steam and autoclaving compared to the standard curing, whereas, steam and autoclave curing decreased the flexural strength and toughness. Increasing the GGBFS and/or fly ash content improved the toughness of RPC under all curing regimes considerably. Topcu et al. [13] employed composite material models to estimate the modulus of elasticity of slag concrete using the cement and aggregate phases. Johari et al. [14] observed the influence of cementitious material such as silica fume, flyash, GGBFS on the properties of high strength concrete. They concluded that the effect of the different cementitious material on the elastic modulus of high strength concrete is rather small compared to their effect on strength. Kuder et al. [15] studied the effect of high volumes of fly ash and slag (60–90% of OPC) on the mechanical performance of self-consolidating concrete. They observed similar engineering properties (compressive strength, elastic modulus, creep and shrinkage) as conventional concrete at later ages (>28 day). Rupnow [16] studied ternary cementitious combinations involving fly ash, silica fume and GGBFS. The results showed that these mixes are more resistant to early age cracking due to the lower modulus at early ages allowing for more creep.

It is well understood that the static modulus of elasticity is an instantaneous stress–strain relationship and can be obtained from the compression tests on concrete cylinders. Now, due to the use of mineral and chemical admixtures, the accurate estimation of static modulus of elasticity of concrete is essential for the designers in computing the prestress losses, deflections and displacements for the analysis of prestressed and reinforced concrete structures. The present research paper deals with some aspects related to the time-dependent modulus of elasticity of concrete when GGBFS is used in the mix.

2. Experimental program

2.1. Material properties

The properties of mix ingredients such as cement, fine aggregate, coarse aggregate, water and GGBFS conformed to the specifications laid down in the relevant Indian Standard codes [17].

Ordinary Portland Cement 43 grade (OPC 43) was used throughout the investigation and stored in airtight silos to prevent exposure to moisture. The physical properties of cement determined as per IS 4031 [17] are given in Table 1. The permissible values specified by the code [18] are also specified. The GGBFS used in the present investigation was procured from the Indorama cement industry, Raipur, Maharashtra, India and also stored in airtight silos. The physical properties of GGBFS are given in Table 2. The requirements of BS code [19] are also specified.

The locally available river sand passing through IS: 480 sieve (aperture 4.75 mm square) and retained on IS: 15 sieve (150 μm size) was used as fine aggregate. The physical properties of the fine aggregate are given in Table 3 [20]. The locally available crushed stone aggregate of maximum nominal size of 16 mm was used as coarse aggregate. The physical properties of coarse aggregate are also given in Table 3 [20]. In the present investigation potable water was used for mixing and curing which was free from injurious amount of deleterious materials [21].

Table 1
Physical properties of ordinary Portland cement.

Characteristics	Value obtained experimentally	Values specified by IS: 8112 [18]
Blaine's fineness (m^2/kg)	245	225 (Min.)
Specific gravity	3.15	–
Soundness (mm) (By Le Chatelier test)	1.5	10 (Max.)
Normal consistency (%) (percent of cement by weight)	27	30
Setting time (minutes)		
(i) Initial	105	30 (Min.)
(ii) Final	180	600 (Max.)
Compressive strength (MPa)		
(i) 3-days	24.9	23.0
(ii) 7-days	34.4	33.0
(iii) 28-days	45.9	43.0

Table 2
Physical properties of GGBFS.

Characteristic	Observed value	Requirement as per BS: 6699 [19]
Fineness (m^2/kg)	340	275 (Min.)
Specific gravity	2.86	–
Soundness (mm) (Le Chatelier expansion)	1.5	10 (Max.)
Normal consistency (%)		
(i) OPC + 20% GGBFS	28.5	–
(ii) OPC + 40% GGBFS	29.5	
(iii) OPC + 60% GGBFS	31.0	
Setting time (minutes)		
(i) Initial	150	Not less than OPC
(ii) Final	309	–
Compressive strength (MPa)[a]		
(i) 7-days	25	12.0 (Min.)
(ii) 28-days	40	32.5 (Min.)

[a] 70% GGBFS and 30% OPC.

Table 3
Physical properties of aggregates.

Characteristic	Fine aggregate	Coarse aggregate
Grading	Zone-II of IS: 383 [20]	–
Fineness modulus	2.45	6.8
Specific gravity	2.61	2.63
Density (loose) (kN/m^3)	15.4	14.3
Water absorption (%)	0.85	1.5

2.2. Mixture proportions

Three plain concrete mixes designated as M10, M20 and M30 with strength of 46.5, 37.0 and 27.0 MPa respectively were prepared based on the trial method [22]. In all the mixes, the ratio of fine aggregate to coarse aggregate was kept fixed at 0.6 from the consideration of the maximum density of combined aggregate. Initially, coarse and fine aggregates were mixed thoroughly for about 1 min and then cement was added to this dry mix and turned over twice or thrice in the dry state itself for about 1 min so as to get the uniform mix in dry condition. Then required quantity of water was added and casting of specimens was done. The details of the designed mixes and the properties of fresh concrete are given in Table 4.

GGBFS concrete mixes were prepared after re-proportioning the three plain concrete mixes. The ratio of fine aggregate to coarse aggregate was kept constant throughout the investigation. The cement in the plain concrete mixes was directly replaced by the equal weights of 20%, 40% and 60% of GGBFS to obtain corresponding GGBFS based concrete. GGBFS replacement up to 40% may be useful for reinforced cement concrete and prestressed concrete, whereas, 60% replacement may be used for mass concrete works. The water to binder ratio for a particular mix was also kept constant. The details of GGBFS based concrete mixes and the properties are also given in Table 4. It may be seen from Table 4 that there are four mixes – one plain and three GGBFS based – in the three mix groups (M1, M2 and M3). Thus there are twelve concrete mixes, as given in the table.

2.3. Casting and testing procedure

For static modulus of elasticity, cylindrical specimens (150 mm diameter and 300 mm long) were prepared for the measurement of static modulus of elasticity of concretes. The material was weighed in required proportions. The weighed ingredients were thoroughly mixed for 2 min in a rotating drum type mixer. The mix was poured in the moulds in three layers on the vibration table and each layer was vibrated for half a minute. After 2 h of casting the cylinders were capped with a thin layer of cement-sand paste. To avoid the shrinkage in this cement-sand paste the paste was prepared half an hour before its application. To find early age static modulus of elasticity of concrete, the tests were carried out on surface dry condition after 3, 7 and 28 days of curing of the specimens. After 28 days curing remaining samples were taken out from the curing tank and stored at room temperature for testing at later ages. These specimens were tested at the ages of 56, 90, 150 and 180 days.