AN OVERVIEW ON CREEP AND SHRINKAGE DEFLECTION OF ADMIXTURE BASED CONCRETE

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ABSTRACT. Long-term deflection due to creep and shrinkage of reinforced concrete member is an important parameter for structural designers. The deflections in the concrete member depend primarily on the nonlinear and inelastic properties of concrete & steel and are difficult to predict exactly. Concrete, like many other materials, exhibits time-dependent properties which include creep and shrinkage. Changes in the creep characteristics of concrete due to the addition of mineral admixtures such as fly-ash, silica fumes, blast furnace slag, rice husk ash, are significant and hence must be realistically assessed. In the present paper, an exhaustive literature review has been undertaken to investigate the creep and shrinkage characteristics of admixture based concrete. Also a comparison between analytical and experimental results of instantaneous and time-dependent deflections with varying material compositions has also been made.

Keywords: Admixture, Creep, Shrinkage, Fly Ash, Long-term Deflection

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INTRODUCTION

Admixture is defined as a material other than cement, water and aggregates that is used as an ingredient of concrete and is added immediately before or during mixing to improve the quality of concrete. Fly ash, silica fume, ground granulated blast-furnace slag (GGBFS), rice husk ash etc are some of the commonly used admixtures. They are used to increase the workability and durability of the concrete by reducing water/cement ratio, which naturally increases the strength of concrete. Mineral admixtures like fly ash, GGBFS and silica fume possess little or no cementitious value but if it is present in finely divided form and in the presence of moisture, chemically react with calcium hydroxide, liberated on hydration at ordinary temperature to form compounds, which possessing cementitious properties.

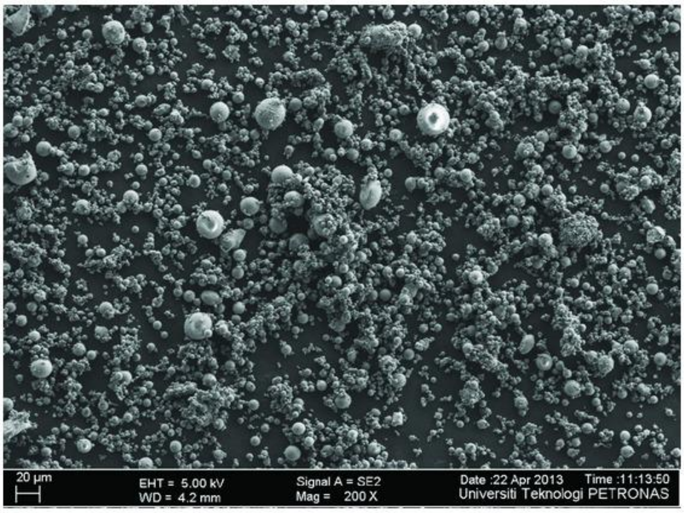

Figure 1 Microstructure of fly ash through field emission scanning electron microscope (FESEM) showing particle size distribution [1].

Fly ash is produced when coal is burnt in thermal power plant. Silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), and some other minor constituents are obtained during burning of coal. The low-lime fly ash similar to class F is the primary variety generated in India and significantly smaller volumes of high lime fly ash i.e. class C are also available. Indian low-lime fly ashes are characterized by a relatively higher concentration of SiO_2 and Al_2O_3 and lower contents of Fe_2O_3. The reactivity of fly ashes is dependent on their glass content and other mineral phases present. Indian fly ashes are more crystalline than those obtained in other countries, the glass content ranges from 47.0 to 60.9% [2]. GGBFS consist of silicates and alumino-silicates of calcium and is a by-product of iron manufactured in a blast furnace. Silica fumes consists of extremely fine particles of average diameter 0.1 micro-meter having pozzolanic characteristic and are highly reactive with $Ca(OH)_2$ produced during hydration of cement . Comparison of percentage of different chemical composition in various admixture are given in Table 1.

Table 1 Comparison of mineral composition in various admixtures

	OPC	FLY ASH [3]	GGBS [4]	SILICA FUME [5]	RICE HUSK ASH [6]
SiO_2, %	22	35-60	34.4	91.4	88.3
Al_2O_3, %	2-6	10-30	9.0	0.09	0.4
Fe_2O_3, %	4-6	4-20	2.58	0.04	0.67
CaO, %	65-70	1-35	44.8	0.93	0.67
MgO, %	2-4	1.98	4.43	0.78	0.44
SO_3, %	1-3	0.35	2.26	0.01	-

CREEP AND SHRINKAGE IN CONCRETE

Creep is the tendency of a solid material to slowly move or deform permanently under the influence of stresses. It occurs as a result of long-term exposure to high levels of stress that are below the yield strength of the material. Creep is more severe in materials that are subjected to heat for long periods and near melting point. Creep always increases with temperature. Generally, creep of concrete decreases with increase in the strength of concrete. Fly ash concrete mixes have higher creep than the normal concrete because of comparatively lower strength. In addition, the creep capacity decreases with the increase in aggregate size or aggregate content and reduction of water/cement ratio. When a concrete member is subjected to a sustained applied load it undergoes an instantaneous deformation at the time of loading followed by a time-dependent one over time. In most of the cases, the time-dependent component is greater than the instantaneous one. Under the hypothesis of constant stress and temperature, the time-dependent response is due to the creep and the shrinkage of the concrete. The total strain developed by concrete over time can be defined as the sum of an instantaneous strain, a creep strain, a shrinkage strain and a temperature strain.

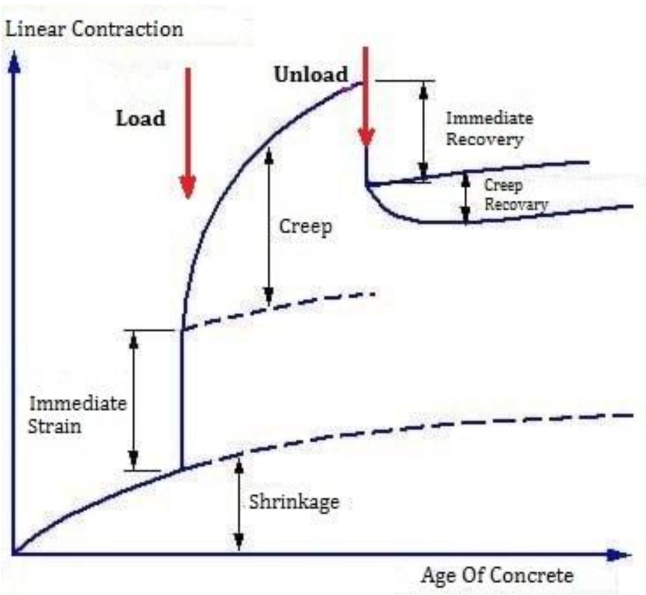

Figure 1 Graphical representation of shrinkage and creep in concrete

Shrinkage is commonly defined as the time-dependent change in volume of a non-stressed concrete specimen at constant temperature and it affects every concrete structure during its service life. Shrinkage is larger on the external surface of a member, i.e. the one exposed to drying, while it decreases when moving towards its inner part. When concrete is exposed to air it tends to shrink, while, when it is subjected to water, it tends to swells. When shrinkage or swelling is restrained some stresses develop. The shrinkage component does not depend on the load history, while, the other two depend on the applied stress. Shrinkage starts soon after the concrete has been poured, as the latter begins to harden, while creep occurs when the concrete is subjected to the sustained load. Usually, shrinkage is divided into four components: plastic shrinkage, chemical shrinkage, thermal shrinkage and drying shrinkage. Plastic shrinkage develops before the concrete has hardened and is associated with the evaporation of the surface water of the mix. Thermal shrinkage is a consequence of the heat induced during the hydration process and does not last more than a few days. Chemical shrinkage (or autogenous shrinkage) is caused by the chemical reaction taking place in the cement paste. The drying shrinkage process starts as soon as the water contained in the concrete paste evaporates in the surrounding environment and, as previously mentioned, it increases in time with a decreasing rate. Since the drying shrinkage strictly depends on the initial water quantity contained in the concrete mix, it is higher for larger values of initial water-cement ratio of the concrete. Creep and shrinkage tend to increase with a decreasing rate over time. It is observed that about 50% of the final creep develops in the first 2-3 months and about 90% after 2-3 years. Similarly, 30% of the final shrinkage is developed in the first 2-3 weeks.

EXPERIMENTAL STUDIES ON CREEP AND SHRINKAGE DEFLECTION OF ADMIXTURE BASED CONCRETE

This section describes briefly the various experimental works that has been reported in literature on the creep and shrinkage characteristic of admixture based concrete.

Tevan [7] had investigated the physical and chemical properties, strength properties and deflections etc of sintered fly ash concrete and found suitable for constructional purposes. The dead weight of structure (constructed using sintered fly ash) was reduced by 30%. Ghosh and Timusk [9] did experimental work on fly ash concrete and found that fly l2ash concrete exhibit significantly lower creep and shrinkage characteristics. Arezoumandi [10] did experimental work on high volume fly ash concrete beams by replacing 50% and 70% cement with fly ash. It was found that similar load-deflection behaviour obtained between the two concrete type i.e. normal concrete and high volume fly ash concrete. Dragas et al. [17] did experimental work on high volume fly ash concrete (50-70% fly ash) to find out the compressive strength, splitting tensile strength, modulus of elasticity, creep and shrinkage characteristics upto a period of 180 days. The superplasticizer was also added to the concrete to make concrete workable. It was found that the compressive strength of HVFA concrete were increased by 22%, due to which the creep and shrinkage gets reduced significantly in comparison to conventional concrete. Laxminarayan et al. [24] did experimental investigation on fly ash based geopolymer concrete. Seven reinforced concrete slabs were casted to study its flexural behaviour under the effect of load. It was found that the reinforced geopolymer concrete slab behave in a similar way to reinforced cement concrete slab. Hence formulations and concepts of ordinary reinforced cement concrete as per IS456-2000 can be used for geopolymer concrete with slight modifications. Soman and Sobha [27] did experimental study to know the flexural behaviour of High Volume Fly Ash (HVFA) concrete beams. The beams were casted by replacing 50% of cement by fly ash. It was observed that HVFAC beams have shown notable improvement in the deflection, cracking behaviour and load carrying capacity. Shariq et al. [29] did experimental investigation on the long term deflection of RC beams containing ground granulated blast furnace slag (GGBFS). The creep deflections were measured upto a period of 150 days under four point sustained loading. The amount of cement replacement by GGBFS was varied between 20 to 60%. It was found that the deflections increases significantly as the percentages of GGBFS have increased. However, the contribution of shrinkage in total deflection slightly decreases with the increase in the contents of GGBFS. Tosik et al. [30] carried out experimental work to know the creep and shrinkage characteristics of HVFA concrete beams. Deflections were recorded for both HVFA concrete beams and conventional concrete beam for a period upto 450 days under sustained loading. It was observed that the deflections of HVFA concrete beams were more than the normal concrete beam.

Tarek [8] did experimental work on RC beams strengthened with GFRP sheets to find out the load deflection behaviour and flexural capacity. The beams were placed in different environmental conditions upto 24 months. The sound durability of the beams were obtained in varied environmental conditions and results of FRP strengthened specimens showed increase in the flexural strength and ductility of RC beams to a great extent. Chami et al. [11] had investigated the time-dependent behaviour of carbon FRP-strengthened concrete beams. For this, twenty-six reinforced concrete beams with dimensions 100x150x 1800 mm were cast to find out creep behaviour. High levels of sustained load were used in order to determine the maximum sustained load that can be applied without any risk of creep failure. The applied sustained loads varied from 59% to 78% of the ultimate static capacities of the un-strengthened beams. It was found that the FRP laminates increases the ultimate strength due to which initial deflection gets reduced and for long term deflection, this effect is negligible. The major creep strains typically occur in the compressed zones concrete of the beams. Shariq et. al [13] did experimental investigation to find out the creep and shrinkage characteristics of GGBFS concrete mix. The time dependent deflections of RC beams (containing GGBFS in the range of 20 - 60%) were measured under two point sustained loading for a period of 150 days. The experiments revealed that the time-dependent deflection of the reinforced concrete beams containing GGBFS was higher than that of plain concrete RC beams. At 150 days, the average creep and shrinkage deflection of RC beams containing 20%, 40% and 60% GGBFS was 1.25, 1.45 and 1.75 times higher than the plain concrete beams. Arockiasamy et al. [14] did an experimental work to find out the long-term behavior of the FRP reinforced beam. The beams were simply supported and subjected to a uniform sustained loading. The beams were instrumented and monitored to observe the changes in the behavior due to creep and shrinkage of concrete regularly for nearly two years. It was found that the time-dependent defection, strain and curvature increases with the increase in the applied moment in the beams. The rate of increase in strains and defections are higher in the initial period of loading and tends to reduce with time under sustained loading. Mias et al. [23] did experimental work on eight glass fibre reinforced polymer (GFRP) RC beams subjected to sustained loading for a period of 250 days. It was found that the time dependent deflections of GFRP beams considerably increased.

Bakoss et al. [12] did experimental study on reinforced concrete beam (continuous and simply supported) to obtain instantaneous and time-dependent beam deflections, together with the time-varying strain distributions at selected cross sections due to creep and shrinkage. The deflections were compared with the values predicted by British and American design code methods and by finite element methods. For continuous beam, it was found that the creep coefficients predicted by different design codes were significantly lower than the measured values whereas the measured shrinkage strain agreed closely with values predicted by various design codes. For the simply supported beams, the measured instantaneous and time-dependent deflections under constant load agreed well with predictions using non-linear finite element analysis. Gilbert and Guo [20] had conducted experimental program to determine the time dependent deflection of large scale reinforced concrete flat slabs under uniformly distributed sustained load for a period of 750 days. It was observed that the deflection increased rapidly over the first two or three months of loading, with more than 50% of the total deflection occurring within ten weeks of initial loading. Mid panel of the slab experienced greater deflections and the measured long time deflection was many times the initial short term deflection, due to the loss of stiffness associated with time dependent cracking under the combined influences of transverse load and drying shrinkage.

NUMERICAL AND ANALYTICAL STUDIES ON CREEP AND SHRINKAGE DEFLECTION OF ADMIXTURE BASED CONCRETE

Arockiasamy et al. [14] developed a computer program and proposed equation of long term deflections. The experimental values of mid span deflections were compared with the proposed equation and good agreement was obtained between analytically and experimentally obtained values. Vijaya [25] proposed approximate method for the calculation of long-term deflections of flat plates and flat slabs. Good agreement was obtained between measured and calculated deflections. Sherif and Walter [26] had calculated the deflection of reinforced concrete flat slabs using effective moment of inertia approach, mean curvature approach and bilinear approach. It was observed that out of these three approaches, mean curvature approach accurately predicts the deflection of flat slabs while other approaches underestimated the slab deflection. Bernard Espion and Pierre Halleux [4] proposed ACI method and CEB (bilinear method) for predicting long term deflection. It was found that CEB method is more reliable and more accurate than ACI method. ACI method tends to overestimate the long-term deflection when environmental conditions were not dry. Ghali and Azarnejad [5] proposed a method of analysis to predict the immediate and time-dependent strain in reinforced concrete sections with or without pre-stressing. The analysis procedure was applied to different examples to show the influence of varying force on the predicted deflections and good agreement was obtained with published experimental data. Rososky et al. [18] did probialistic analysis of time dependent deflections of reinforced concrete flexural member. The non linear creep and shrinkage characteristics were obtained somehow similar to as obtained from the experimental results. Gribniak [20] statistically investigated the long term deflection predictions made by the most of the widely used design codes (Eurocode and Russian code) and a numerical technique proposed by the author. The accuracy was analyzed using test data of 322 reinforced concrete members from 27 test programs reported in the literature. The deflections calculated by using design codes were overestimated and lacks consistency. However, the numerical technique has well captured the time-deflection behavior of reinforced concrete flexural members securing precise predictions. Zhou and Kokai [28] proposed a methodology for incremental deflection of RC members which was based on the Canadian standard for the purpose of protecting non-structural elements.

Gilbert [15] proposed a method for predicting long term deflections of RC beams and slabs. The model were developed to measure long term deflection caused by creep and shrinkage. It was validated against a wide range of test data and provide reliable estimates of deflections. Alvis et.al [16] analytically studied the long term behaviour of determinate RC beam under service load. The test results of various beams were compared with deflection prediction by the numerical schemes and found that a realistic model of creep strains can lead to a good estimates of deflection. Moreover, it was also observed that contribution of shrinkage to overall deformation were significant. Wei-wen yu and George winter [1] proposed methods for calculating instantaneous and long term deflections of beam under sustained load. The methods were checked against the results of 175 deflection tests from nine different investigations and satisfactory results were obtained.

CONCLUDING REMARKS

A detailed review on creep and shrinkage characteristics of admixture based concrete has been provided. Various analytical and experimental studies of time dependent deflections of RC beams and slabs have been undertaken. The literature reveals that very few studies are available on the effect of creep and shrinkage deflection of RC structural members containing admixtures. The overall conclusions of the studies and observations are that the admixtures like fly ash, GGBFS etc increases the time dependent deflection of RC member. However, the contribution of shrinkage deflection in RC structural member is lower because fly ash reduces the drying shrinkage in concrete. As far as the analytical study of the deflection of RC member is concerned, different analytical and numerical approaches were proposed. The deflections of the RC members were calculated by using these approaches and then compared with the experimental values. Good agreement is obtained between the experimental values and the values obtained by analytical and numerical approaches.

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