ijecs open access www.ijecs.in
International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 6 Issue 10 October 2017, Page No. 22688-22796
Index Copernicus value (2015): 58.10 DOI: 10.18535/ijecs/v6i10.14

Creep of Concrete Using Different Cement Types and Superplasticizer for Concrete Dams

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Abstract
In mass concrete, creep itself may be a cause of cracking when the restrained concrete undergoes a cycle of temperature change due to the development of the heat of hydration and subsequent cooling. Few studies related directly to this matter which based on long-term experimental results. The effects of cement types and superplasticizer on creep of concrete revealed wide variations so that few generalizations could be made. In the current study three types of cement were used; Ordinary Portland cement (O.P.C.), Sulphate resisting cement (S.R.C.), and Blast-Furnace slag cement (S.C.). Superplasticizer was added by ratio 1% of weight of cement. The experimental results showed that the use of O.P.C. reduces creep by 33%- 37% compared with S.R.C. and S.C. concrete mixes. The use of 1% superplasticizer reduces creep by 28%- 34% compared with mixes without admixture. So, it is recommended to use O.P.C with 1% superplastisizer in concrete dams.

Key words: Concrete dams, creep, superplastisizer.

Introduction

The safety of dams is extremely important because failure of such a structure may have disastrous consequences on life and property. It is therefore necessary to develop the concrete mix design used in concrete dams. Creep is defined as the increase in strain under a sustained constant stress after taking into account other time-dependent deformations not associated with stress, viz. shrinkage, swelling and thermal deformations. Thus, creep is reckoned from the initial elastic strain as given by the secant modules of elasticity at the age of loading, Neville and Brooks [1]. Many concrete investigators believe creep and shrinkage are closely related. While creep is associated more with the effect of pressure and the resulting gel water movement, Neville and Brooks [1], Therese [2]. Creep is affected by type of cement in so far as it influences the strength of the concrete at the time of application of load. It is recommended that testes be under taken to assess creep. A similar recommendation applies when admixtures are used that the effect of the superplasticizers on creep is uncertain, Neville and Brooks [1]. When a concrete mass is not insulated from the atmosphere, a temperature gradient exists within the concrete because its interior becomes hot whilst the surface loses heat to the atmosphere. The interior is thus restrained from full thermal expansion, so that a compressive stress is induced in the interior, which is balanced by a tensile stress in the exterior. Both stresses are relieved to some extent by creep but the tensile stress may be sufficient to cause surface cracking. During the cooling phase, there is less relief of stress by creep than in the heating phase because the concrete is more mature, Neville and Brooks [1]. The mass concrete used in dams presents particular characteristics and maturity conditions over time and needs to be studied in detail. In addition, only a few studies related directly to this matter and which are based on long-term in situ experimental results have been presented, Batista et al. [3]. One of the most important phenomena of the delayed behavior of mass concrete used in dams is creep. The accurate evaluation of the full mixed concrete deformability is a key element in the dam’s behavior assessment. Wether to calibrate displacements based on prediction models or to interpret the behavior using structural models, Serra et al. [4]. In concrete dams the heat of hydration dissipation during the set and hardening process and the early age cracking risk are a main concern. For the cracking risk assessment, it is necessary to know the development of the mechanical properties of the concrete placed in situ. Delayed behavior has special relevance in structural engineering, due to the increased of the deformations over time under sustained loading (creep) and due to the stress relaxation under imposed deformations, which is especially important for concrete dams, Serra et al. [5]. When all admixtures are considered together, there is a general increase in deformation caused by the admixtures of approximately 20%. In the absence of test data for a particular admixture, this increase can be assumed for flowing concrete and adjusted for the proposed method when there are changes in mix composition, for example in the case of high-strength concrete, Brooks [6]. Superplasticizers may be used in concrete is to produce concrete with very low water-cement ratio. To achieve high strength concrete, water content of mixture is reduced while maintain the same cement content. The reduced workability is compensates for by incorporating superplasticizers. By this method, water reductions of up to 30% can be achieved and concretes with water-cement ratio as low as 0.28 have been successfully placed, Ranachandrran [7]. aSeveral investigators have published data on creep of superplasticized concrete. However, in each case different concrete, loading and moisture conditions have been used, thus make it direct comparison rather difficult. The general consensus appears to be that concretes made with superplasticizers have approximately the same creep as the reference concrete, although there are exceptions, Ranachandrran [7]. As the humidity content of high-strength concrete is comparatively low, creep is significantly reduced as compared to normal concrete, Wittmann and Beltzung [8]. The effects of cement type, cement content and superplastisizer on concrete creep characteristics are examined. Three types of cement using 350 kg/m^3(590 lb/yd^3) cement content are used for mixes with and without admixture. As in the case of conventional water-reducing admixtures, these admixtures can behave differently with different cement cements. Undesirable effects may occur with certain combinations depending on dosage, chemical type of admixture and chemical composition of the cement itself, ACI committee 212 .lR-81 [9]. The influence of partial replacement of cement by blast-furnace slag or by fly-ash as compared with ordinary Portland (type I) cement creep decreases with an increase in the level of replacement of slag or of fly-ash but, when there is concurrent drying, creep is sometimes higher. When such concrete is to be used it is recommended that tests be undertaken to assess creep, [1]. The creep definition lumps together the basic creep and the drying creep, basic creep occurs under conditions of no moisture movement to or from the environment, drying creep is additional creep caused by drying. The importance of creep in structural concrete lies in the fact that the creep deformation is of same order of magnitude as the elastic deformation, Neville and Brook [1]. It should be noted that reparability of creep and shrinkage is considered to be strictly a matter of definition and convenience, Abdelfatah [10].

Experimental Investigation

Simplified method for analyzing service performance are justified because the prediction and control of time depended deformations and their effects on concrete structures are exceedingly complex when compared with the methods for analysis and design of strength performance, ACI 209R-82 [11]. The main difficulties of concrete behavior characterization with experimental tests are related to the amount of variables involved, namely the types of materials used and therefore to its properties, the contents of each component, the casting and the curing conditions.

Materials

In normal weight aggregate concrete, creep of concrete is due to the creep of cement past since the aggregate is not liable to creep at the level of stress existing in concrete. Because the aggregate is stiffer than the cement paste, the aggregate is restrained the creep in the cement paste. The effect depending upon the elastic modules of aggregate and its volumetric proportion hence the stiffer the aggregate the lower the creep, Neville and Brook [1], Kumar and Kumar [12]. Crushed lime stone, sand O.P.C., S.R.C. and S.C. were used with 350 kg/m^3 (590 lb/yd^3) cement content, Table 1. Potable water and one type of superplasticizer admixture type F conforming to ASTM-C 494-82 [13] were used. Superplasticizer type F is used to achieve a higher strength by decreasing the water cement ratio, achieve high early strength and to reduce permeability. Table 2 shows details of mixes used for creep tests. Dosages of superplasticizer type F are 1% and 2% of weight of cement and its density is 1.24 kg/liter (2.73 lb/liter). One nominal maximum size was used 38.1 mm (1.5 in.) ASTM-C 33-84 [14]. Fig. 1 shows grading curve of used gravel (a), (b). The chosen grading of the coarse aggregate and the limits of the ASTM-C 33-84 [14] are shown in Fig.1 (a). Coarse aggregate abrasion in the Los-Angeles test is equal to 15% according to ASTM-C 131-81 [15]. The specific gravity and the dry bulk unit weight of the crushed lime stone were equal to 2.6 and 1422 kg/m^3 (2379 lb/y^3) respectively. It had absorption of 2.3%. Fig.1(b) shows the grading of the used sand and the limits recommended for fine aggregate for concrete ASTM-C 33-84 [14] the specific gravity and dry bulk unit weight were equal to 2.3 and 1698 kg/m^3 (2863 lb/yd^3) respectively. The fineness modules were 2.4,

Specimens

The standard cylindrical molds 150 mm (6 in.) diameter and 300 mm (12 in.) height were used for concrete. The cylindrical specimens obtained were tested in compression according to ASTM-C39-83b [16] to obtain the compressive strength and the modulus of elasticity of concrete according to (ASTM-C 469-83 [17]. The cylindrical specimens were also tested in spring-loaded creep frame to determine the creep of concrete according to ASTM-C 512-82 [18].Test specimens were stored in water at a temperature of 24 ± 2 ^{o}C (75.2^o F) until the age of 28 days. The proportions of concrete mixes are presented in Table 3.

Loading frame

The loading frame consists of header plates bearing on the ends of the loaded specimens, a load-maintain element was a spring and threaded rods to take the reaction of the loaded system. Fig. 2 shows Loading Frame, adapted from ASTM-C 512-82 [17]. In any loading frame, several specimens may be stacked for simultaneous loading. Fig. 3 Shows test specimens in creep loading frame. The length between header plates not exceeds 1780 mm (70 in.). A hydraulic load-maintaining elements were used, a railroad car springs were used to maintain the load in frames described above. The initial compression was applied by means of a portable jack.

Strain-measuring

The mechanical strain gauge apparatus was used by demec points to accurately determine the strain which occurs in concrete specimens. An invar beam carries two conical datum points, one fixed; the other is pivoted and connected to a dial gage assembly. Two discs are set in the specimens at precise positions determined using a setting bar supplied with the gauge. The gauge points fit into drilled holes in the discs, so when strain takes place the extent can be easily determined. Stain measured on three gage lines, the effective gage length was 150 mm (6 in.) and a dial gauge with 0.001 mm (0.0039 in.) divisions was used. Fig. 4 shows Strain-Measuring apparatus.

Applied stress

According to standard test method for creep of concrete in compression ASTM-C 512-82 [18], load the specimens at an intensity of not more than 40% of the compressive strength at age of loading. After 28 days, all specimens were subjected to a stress 68 kg/cm^2 (967 lb/in.^{2}). Table 3 shows the properties of different mixes. The relation between the relative humidity and temperature at laboratory during test time are presented in Fig. 5 and Fig. 6, respectively.

Items of investigation

The cylinders for creep test, compression test and the modulus of elasticity test were performed at 28 days. Capping was applied at the end of cylindrical specimens used to determine the compressive strength, modulus of elasticity to assure the horizontal level of the surface of loading. Design of mix used was based on the absolute volume equation for one cubic meter according to concrete mixes suggested by ACI 211 R-85 [19].

Results And Discussion

The results of all concrete mixes show that creep increases with time. For (O.P.C.) concrete mixes, Fig. 7 and (S.R.C.) concrete mixes, Fig. 8, using 350 kg/m^3 (590 lb/yd^3) and a slump range 7.5-10cm (3-4 in) the use of admixture with the ratio of 1% to get a slump range 7.5-10cm (3-4 in) results in decreasing creep of concrete with time compared with concrete without admixture. While the use of admixture with the ratio of 2% to get a slump range 7.5-10cm (3-4 in) results in increasing creep of concrete with time compared with concrete without admixture. According to ACI committee 212 1R-81 [9] undesirable creep may occur depending on excessive dosage of superplasticizer type F and chemical composition of the cement itself. For (S.C.) concrete mixes, Fig. 9 using 350 kg/m^3 (590 lb/yd^3) and a slump range 7.5-10cm (3-4 in) the use of admixture with the ratio of 1% to get a slump range 7.5-10cm (3-4 in), up to about 20 days since application of load, the creep of concrete with 1% admixture at a certain time is 34% to 31% less than that of concrete without admixture at that time. After 20 days since application of load, the creep of concrete with 1% admixture at a certain time is 31% less than that of concrete mix without admixture at that time. Creep of Blast furnace slag cement concrete mixes S.C. increases not uniformly with time. These results agree with Neville, A. M., and Brooks, J. J [1]. The (O.P.C.) concrete mix O1 using 350 kg/m^3 (590 lb/yd^3) and a slump range 7.5-10cm (3-4 in) get the lowest creep. Fig. 10 shows that the maximum creep of (O.P.C.) concrete mix is 37% less than that of (S.C.) concrete mix, and 33% less than that of (S.R.C.) concrete mix,. Fig. 11 shows that for (O.P.C.), (S.R.C.) and (S.C.) concrete mixes using 350 kg/m^3 (590 lb/yd^3) and a slump range 7.5-10cm (3-4 in) the use of admixture with the ratio of 1%, the maximum strain of (O.P.C.) concrete mix is 34% less than that of (S.R.C.) concrete mix R2 and 28% less than that of (S.C.) concrete mix S2

Conclusions and Recommendations

A suitable aggregate can help to reduce the coefficient of thermal expansion of concrete and increase its tensile strain capacity. For instance, concrete made with angular aggregate has a greater tensile strain capacity, Neville and Brooks [1]. Based on the results of this experimental investigation, the following conditions could be drown:

1- The O.P.C. concrete mixes with 1% admixture and without admixture have the lowest creep compared with S.R.C. and S.C. concrete mixes.
2- The use of O.P.C. reduces creep by 33%-37% compared with S.R.C. and S.C. concrete mixes.
3- The use of 1% superplasticizer reduces creep by 28%- 34% compared with mixes without admixture.
4- In (S.C.) concrete mixes the creep increases not uniformly with time. Creep decreases with an increase in the level of replacement of slag or of fly ash but, when there is concurrent drying , creep is sometimes higher, [1].
5- Adding 1% superplasticizer of weight of cement decreased creep with time compared with concrete mixes without admixture.
6- Creep is affected by the type of cement and dosage of admixture. So, According to the results of the study, it is recommended to use O.P.C with 1% superplastisizer in concrete dams.
7- It is recommended to assess creep of concrete mixes using different types of admixtures, cement contents and different types of coarse aggregate with larger nominal aggregate size

Acknowledgments

The author would like to express her gratitude to professor doctor Abd El-Wahab Awad -Structural Department, Faculty of Engineering, Alexandria University, for his helpful guides.

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15. ASTM-C 131-81 Standard test method for resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles machine.
16. ASTM-C 39-83 Standard test method for compressive strength of cylindrical concrete specimens.
17. ASTM-C 469-83 Standard test method for static modulus of elasticity and Poisson’s ratio of concrete in compression.
18. ASTM-C 512-83 Standard test method for creep of concrete in compression.
19. ACI Committee 211R-85 Standard practice for selecting proportions for normal, heavy weight and mass concrete. Part 1: Materials and general properties of concrete. ACI Manual of concrete practice. American Concrete Institute, Detroit.

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Table 1– Types of cement used

Indication	Cement type	Egypt descriptions	ASTM descriptions	British descriptions	Place of manufacture
O	Ordinary Portland Cement (O.P.C.)	373 / 91	I	BS12:1978	Max Alex.

DOI: 10.18535/ijecs/v6i10.13

S	Sulphate resisting Portland Cement (S.R.C)	583 / 86	V	BS4027:1980	Max Alex.
B	Blast-Furnace Portland Cement (S.C.)	974 /69	IS	BS146:1973	Max Alex.

Table 2– Details of mixes used for creep tests

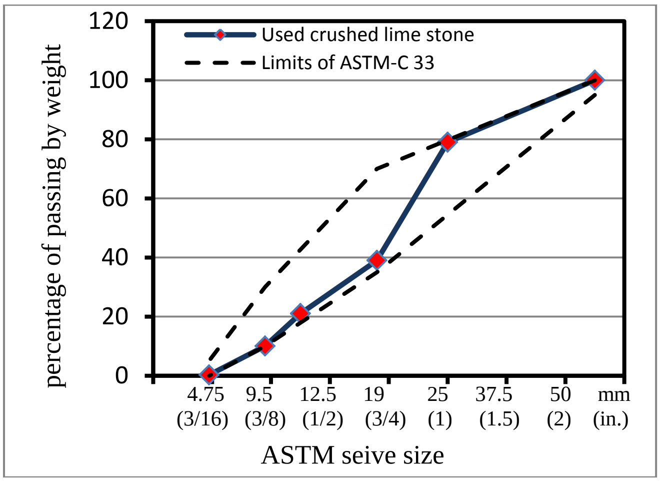
Parameters	Mixes							
Type of cement	Ordinary Portland Cement O.P.C.			Sulphate Resistance Cement S.R.C.			Blast Furnace Slag Cement S.C.	
MIX.	O1	O2	O7	R1	R2	R7	S1	S2
Wt. of cement kg/m^3 (lb/yd^3)	350 (590)	350 (590)	350 (590)	350 (590)	350 (590)	350 (590)	350 (590)	350 (590)
Wt. Of course agg. kg/m^3 (lb/yd^3)	1067 (1799)	1067 (1799)	1067 (1799)	1067 (1799)	1067 (1799)	1067 (1799	1067 (1799)	1067 (1799)
Wt. of water kg/m^3	184.5	160.5	150	184.5	168.5	150	189.5	170.5
Wt. Of sand kg/m^3	687	742	720	687	721	720	673	716
Wt. of adm. kg/m^3 (lb/yd^3)	0 (0)	3.5 (5.9)	7 (11.8)	0 (0)	3.5 (5.9)	7 (11.8)	0 (0)	3.5 (5.9)
Slump mm (in.)	75-100 (3-4)			75-100 (3-4)			75-100 (3-4)	
W / c	0.53	0.46	0.43	0.53	0.48	0.43	0.5	0.41
Agg. / cement	5	5.17	5.1	5.01	5.11	5.1	4.97	5.09

(yd =yard), (lb= pound), (E= modulus of elasticity), (F_c = concrete stress)

Table 3 - Properties of different mixes, w/c ratio, modulus of elasticity, Fc, maximum strain $e_{max.}$, the initial elastic strain e_e and the ratio r (maximum creep strain / initial elastic strain)

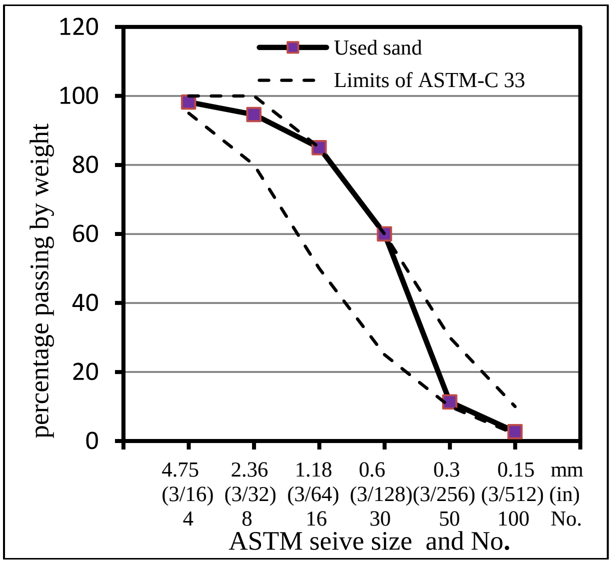
Mix	% of adm.	W / C	Fc kg/cm^2 (lb/in.^{2})	E t/cm^2 (lb/in.^{2})	e_e	$e_{max.}$	r

O1	0	0.53	215 (3056)	180 t/cm^2 (2560*10^3)	378	773.3	2.05
O2	1	0.46	250 kg/cm^2 (3556)	230 t/cm^2 (3271*10^3)	295.6	633.3	2.14
O7	2	0.43	278 kg/cm^2 (3951)	240 t/cm^2 (3411*10^3)	283	940	3.81
R1	0	0.53	314 kg/cm^2 (4466)	201 t/cm^2 (2859*10^3)	338	1160	3.43
R2	1	0.48	339.5 kg/cm^2 (4829)	225 t/cm^2 (3200*10^3)	302	960	3.18
R7	2	0.43	355 kg/cm^2 (5045)	236 t/cm^2 (3354*10^3)	288	1625	5.64
S1	0	0.5	195 kg/cm^2 (2773)	155 t/cm^2 (2205*10^3)	439	1253.3	2.85
S2	1	0.41	283 kg/cm^2 (4025)	200 t/cm^2 (2845*10^3)	340	880	2.59



a- used crushed lime stone

Fig. 1(a), (b)- Grading curve of used gravel



b- used sand

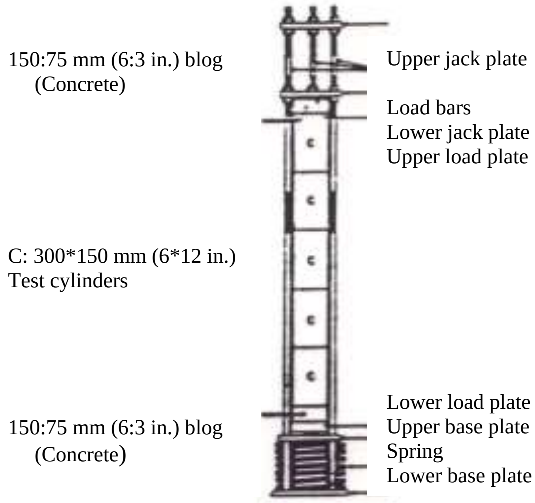


Fig. 2- Loading Frame, adapted from ASTM-C 512-82 [17]

Fig. 3- Test specimens in creep loading frame

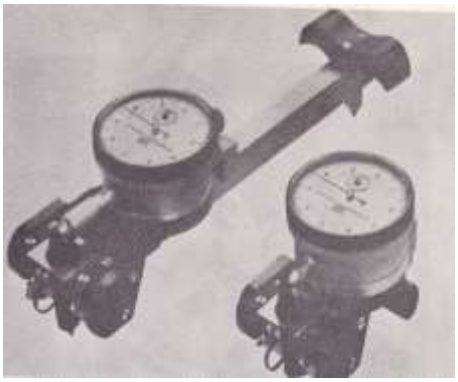


Fig. 4- Strain-Measuring apparatus

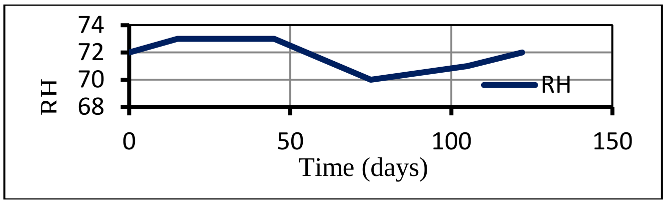


Fig. 5- Relation between test time (days) and relative humidity-percent

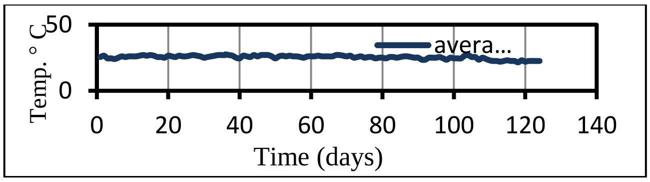


Fig. 6 Relation between test time (days) and temperature (ºF=1.8 ºC+32)

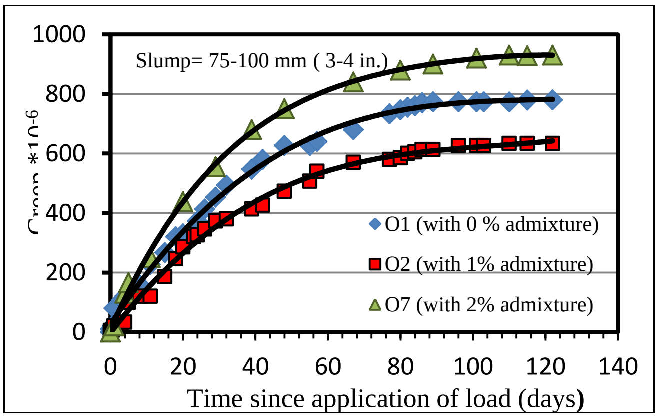


Fig. 7 Creep of (O.P.C.) concrete mixes with and without admixture using 350 kg/m^3 (590 lb/yd^3) cement content subjected to a stress of 68 kg/cm^2 (967.12 lb/in.^{2})

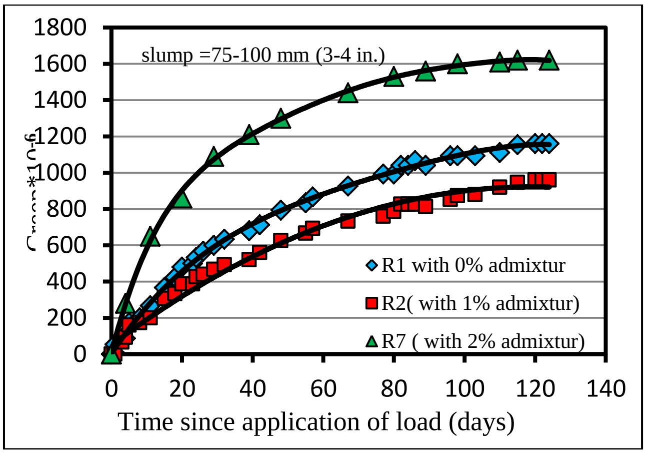


Fig. 8 Creep of (S.R.C.) concrete mixes with and without admixture using 350 kg/m^3 (590 lb/yd^3) cement content subjected to a stress of 68 kg/cm^2 (967.12 lb/in.^{2})

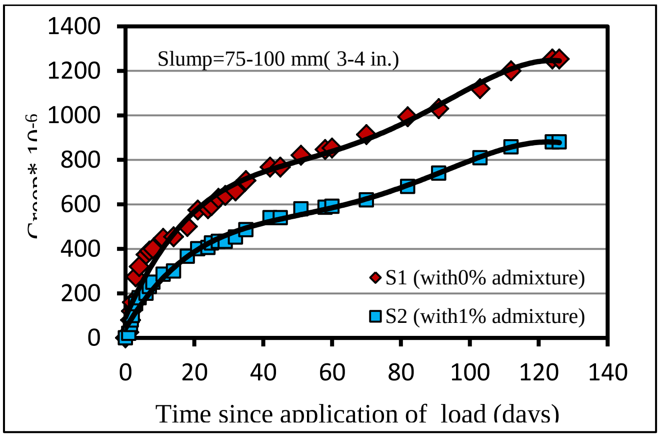


Fig. 9 Creep of (S.C.) concrete mixes with and without admixture using 350 kg/m3 (590 lb/yd3) cement content subjected to a stress of 68 kg/cm2 (967.12 lb/in.2)

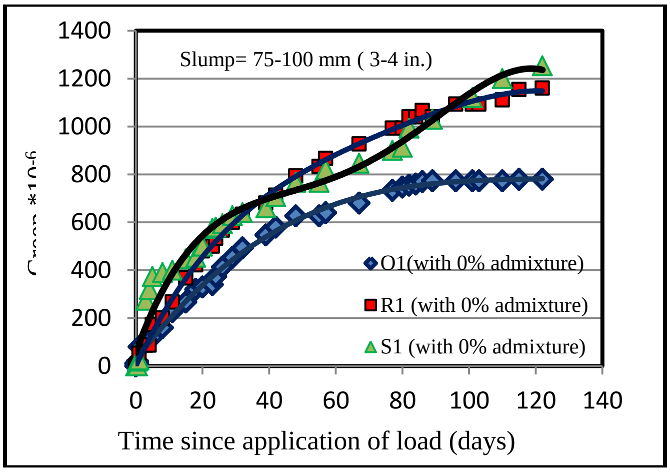


Fig. 10 Creep of concrete using three types of cement, without admixture using 350 kg/m^3 (590

lb/yd^3) cement content subjected to a stress of 68 kg/cm^2 (967.12 lb/in.^{2})

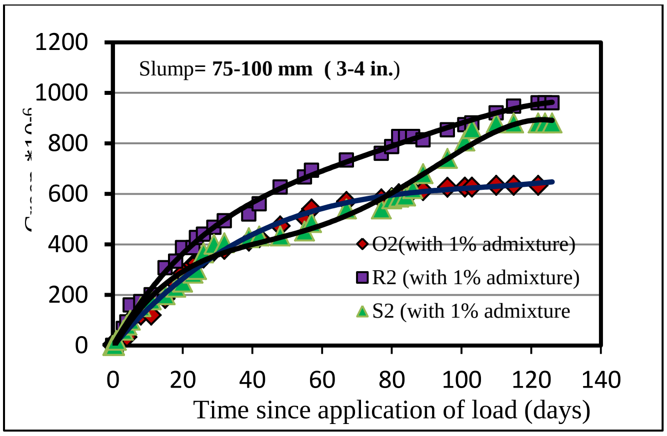


Fig. 11 Creep of concrete using three types of cement, with admixture using 350 kg/m3 (590 lb/yd3) cement content subjected to a stress of 68 kg/cm2 (967.12 lb/in.2)