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Creep Behavior of Nano Silica Concrete under Different Stress Levels

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Abstract: Concrete structures have a long term behavior based on many factors such as material properties, load history and distribution, geometry of the structure, and the environmental conditions. Researchers are frequently pushing the limits to develop the performance of concrete with the aid of advanced chemical admixtures and supplementary cementations materials like nano silica (NS), silica fume, fly ash, blast furnace slag, steel slag. In this study, creep behavior of NS concrete was investigated. The dimensions of concrete specimens used for measuring creep strains were 100x100x400 mm. All creep specimens were subjected to a nominal stress of 30% and 50% of concrete compressive strength. Immediately after loading, the initial measurements were recorded. Because of the loss of loading due to shrinkage and creep strains, which occurs with time, each creep specimen was reloaded again at 2, 9, and 30 days, and every 28 days thereafter, after the first application of load. It was found that all specimens containing NS have larger values of creep than the control concrete. The specimens which contain 4% NS had the lowest values of creep and that contain 2% NS had the largest values of creep if they compared to other NS specimens.

[Ihab A. Adam, Osama Hodhod, Hasan Alesnawi and Eman A. Abd Elazeem. **Creep Behavior of Nano Silica Concrete under Different Stress Levels.** *Life Sci J* 2019;16(9):67-77]. ISSN: 1097-8135 (Print) / ISSN: 2372-613X (Online). http://www.lifesciencesite.com. 9. doi:10.7537/marslsj160919.09.

Keywords: Nano Silica; Creep; Compressive Strength; Cement Content; w/c.

1. Introduction

Evolution of concrete has started from normal grade concrete of grade 5 to 45. Those grades were popular for general construction purposes and provide adequate strength. Normal grade concrete mixtures usually contain cement less than 350 kg/m^{3}and traditional types of aggregates [1]. After that, a new technology for concrete was created like high strength concrete (HSC) which can withstand compressive strength ranging from 50MPato 90MPa [2, 3]. HSC requires more cement content, high quality aggregates, low water/cement ratio, and adequate super plasticizer. Additives and supplementary cementatious materials such as silica fume (SF), fly ash (FA), and metakaolin (MK) were implemented due to its ability to increase strength at adequate percentage of cement replacement [4 - 10].

Nanoconcrete is a concrete that utilizes nano materials which particles size is less than 100nm [2, 11- 16]. It is believed that adding nanomaterials to concrete improves the strength of concrete by improving bulk properties. Nano particles can perform as super filler by refining the transition zone and producing more dense concrete. By acting as good filler, their change in the cement matrix happens to provide a new nano scale structure. Small voids, porosity, and deterioration of concrete caused by alkalisilica reaction will be successfully eliminated. Nano materials are considered as new binding agents which particles are smaller in size than cement. This leads to an improvement in the structure of hydration gel providing an arranged and solid hydration structure. Moreover, by the combination of filling action and additional chemical reaction in hydration process, a new concrete called nano concrete with durable and enhanced performance has been developed [17, 18]. In general, NS is produced from micro based silica. Positive reactions created by NS in concrete are similar to those of silica fume in terms of performance strength and durability enhancement [19-21]. Studies showed that concrete with addition of NS gained early strength similar to that of silica fume. It was also revealed that incorporating NS in concrete improves workability properties of concrete. The reason behind the workability improvement is the round shape of NS which provides a ball bearing maneuver in cement particles. However, the disadvantage of NS is its high price and unavailability in certain countries.

In nearly all reinforced concrete structures, concrete is subjected to sustained stresses, and the load-induced strains (as well as shrinkage strains) has significant effects on the behavior of the structure. The reinforced concrete design engineers possibly encounter far more problems to predict long-term behavior of structure than any other problems. They, verily, need to know the creep and shrinkage behavior of concrete and must be able to take them into account in the analysis of concrete structures.

Most of researches focused on studying the effect of NS on the mechanical properties of concrete, therefore, the main objective of this study is to increase and improve our knowledge of the time-dependent behavior of NS concrete. Many factors, that would affect the time-dependent behavior of NS, were investigated. Experimental setup was prepared for concrete specimens to practically explore the effect of adding NS on the concrete compressive strength and creep behavior.

2. Materials

The experimental program, which was carried out at Construction Research Institute (CRI) of the National Water Research Center (NWRC), has been designed to intensively investigate the time-dependent deformations in terms of creep strains. Mechanical properties were measured in terms of compressive strength at different ages after casting. Experimental specimens were classified into two groups (A) and (B) as shown in Table 1 and Table 2, respectively. All creep specimens were subjected to creep stress levels of 30% and 50% of the compressive strength [22].

Proper construction materials were used to realize specimens tested in the current study. Properties of the used materials are presented hereafter.

2.1 Cement

Commercially available Ordinary Portland Cement (CEM I 42.5 N) with Blain Surface area of 3500 cm^2/g and specific gravity of 3.15 from Suez Cement Company was used. It was produced according to Egyptian Standard Specification. Chemical composition of the cement is shown in Table 3.

Table 1. Mix proportions of group (A) mixtures.

Code	NS%	Weight per unit volume (kg/m^3)					
		NS	SP	Cement	Dolomite	Sand	Water
A-N0	0	0	8	400	1200	600	160
A-N2	2	8	10				
A-N3	3	12	12				
A-N4	4	16	12				

Table 2. Mix proportions of group (B) mixtures.

Code	NS %	Weight per unit volume (kg/m^3)					
		NS	SP	Cement	Dolomite	Sand	Water
B-N0	0	0	8	550	1200	600	220
B-N2	2	8	10				
B-N3	3	12	12				
B-N4	4	16	12				

Table 3. Chemical composition of cement.

Chemical Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	NaO	K_2O
%	20.39	5.6	4.3	63.07	2.91	0.7	0.38	0.35

2.2. Nano Silica

NS with average particle size ranging from 10 to 75nm and surface area ranging from 400 to 600m^2/g was used. The physical properties of NS particles are presented in Table 4. The morphologies of NS were determined through Transmission Electron Microscopy, (TEM) at central metallurgical research institute as shown in Fig. 1. It was shown that NS particles are represented by highly agglomerated clusters with the size of 10 to 75nm.

XRD pattern of the NS sample as displayed in Fig. 2 showed that the silica is observed at a peak centered at 2 Theta (ϴ) = 23 °, which reveals the amorphous nature of nano silica particles.

Table 4. Physical properties of nanosilica particles.

Diameter (nm)	Surface area (m^2/g)	Density (g/cm^3)	Purity (%)
10-75	400-600	0.15	99.9

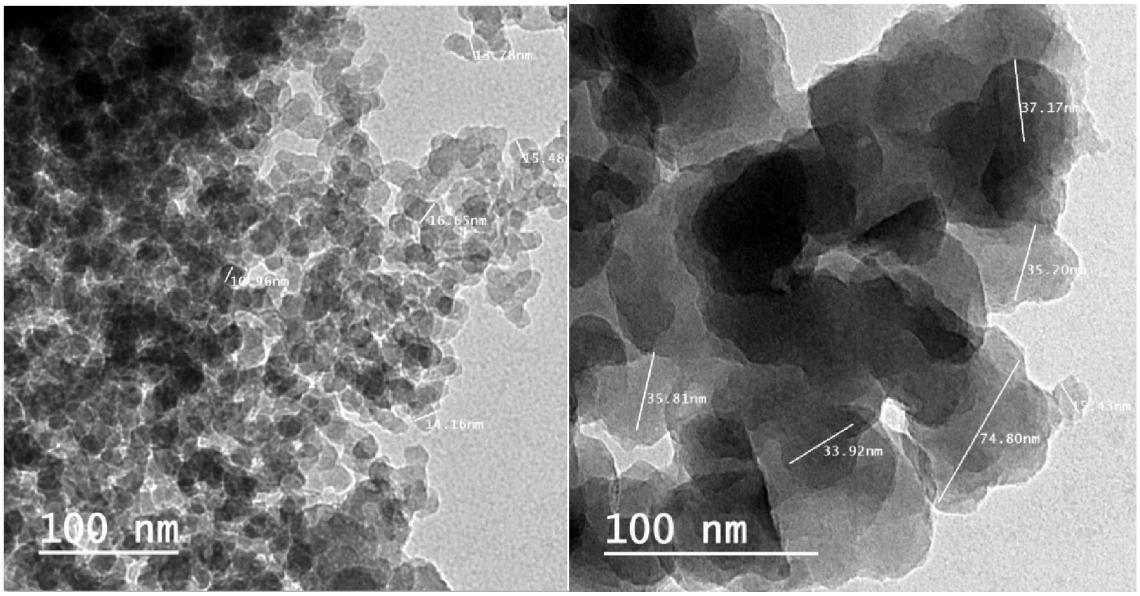

Figure 1. TEM photographs of nano silica.

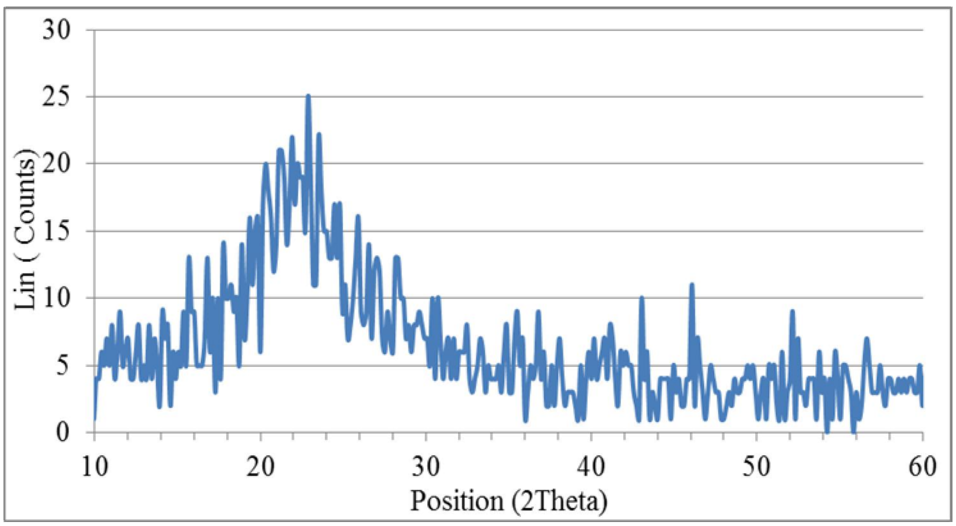

Figure 2. XRD of nano silica.

2.3. Aggregates

The fine aggregate, which used in specimens, was natural siliceous sand with a specific gravity of 2.64 and fineness modulus of 2.34. The coarse aggregate was dolomite with a nominal maximum size of 12 mm.

2.4. Superplasticizer

Superplasticizer admixture was a polycarboxylic acid based with density of 1.10 g/cm^3. The superplasticizer was a high range water reducer with no effect on setting time of concrete. The recommended dosage is 1% to 3% of cement weight and the content was carefully adjusted for each mix to ensure that no segregation would occur.

3. Preparation of Specimens

3.1. Mixing Procedures

As a first step, superplasticizer was mixed with a small part of mixing water in a mixer, and then nano particles were added and stirred at a high speed for 5minutes. The concrete mixtures were produced using a rotating drum mixer of 100litres capacity. Oiling of the mixer (disposal of the first mix) was carried out before preparing the first intended mix. The oiling operation eliminated the effect of the mixer dryness or wetness condition on the first mix. Also, it eliminated any doubts regarding the use of a damp drum mixer on the results of the first mix. As a second step, coarse aggregates, sand, and cement were mixed for 2minutes in the mixer, and then the mixture of water, superplasticizer and nano particles were slowly poured in and stirred for another 2minutes to achieve suitable workability.

3.2. Casting

Creep strain was measured on prismatic specimens of 100 x 100mm cross section and 400mm in length. All creep specimens were cast with a central tube duct so that a single steel bar could be used for stressing.

3.3. Curing

Specimens were stored in lab until de-molding. The molds were detached after one day and all specimens were cured in water at 20°C until testing. Before testing, specimens were taken out from water to fix the gauge points.

4. Tests

4.1. Slump Tests

Workability of concrete were measured by concrete slump test which was performed for each batch of fresh concrete. The dose of superplasticizer was adjusted to maintain the required level of workability.

4.2. Compressive Strength Tests

Compressive strength test was performed on cubes of 150x150x150mm in dimensions at 7, 28, 56, and 90 days after casting as shown in Fig.3. All specimens were continuously fully water-cured until the time of testing.

Figure 3. Compressive strength test.

4.3. Creep Tests

The time-dependent strain measurements of creep test specimens were conducted according to the recommendations provided by Acker [22]. At the intended day of the beginning of the test, specimens were taken out from water to dry and clean its surface from any moisture or impurities. Just before loading, three cubes were tested in compression to obtain the compressive strength in order to determine the creep stress level.

For each specimen, one pair of gauge points (with an effective gauge length of 300 mm) was glued on each surface of two opposite sides except the casting surface and its opposite side, as shown in Fig. 4. Creep strains were measured using mechanical strain gauge device with an accuracy of 0.001 mm and 300 mm gauge length. Moreover, electrical strain gauges were installed on the embedded steel bars (used to stress creep specimens) to adjust and maintain the required and constant creep stress [23].

It is a common practice to consider the applied creep stress as a proportion of the concrete compressive strength at the time of loading. This ratio is known as stress/strength ratio. The stress/strength ratio is an essential and vital factor in the investigation of creep deformation of concrete. It has been established that creep is proportional to the applied stress (until a certain stress level) and inversely proportional to the strength at the time of application of the load. For a given stress/strength ratio, creep is the same regardless of how stress and strength have been varied, provided their ratio is constant. The linear relation between the applied stress and creep has been found from a wide range of experiments. However, the upper limit of this linear relation has been often a subject of discussion. In terms of the stress/strength ratio, an upper limit between 0.23 and 0.75 has been observed [24].

All creep specimens were subjected to a nominal stress of 30% and 50% of compressive strength. Immediately after loading, the initial measurements were recorded. Because of the loss of loading due to shrinkage and creep strains, which occurs with time, each creep specimen was reloaded again at 2, 9, and 30 days, and every 28 days thereafter, after the first application of load.

Figure 4. Creep specimen.

5. Results and Discussion

5.1. Effect of Nano Silica on Compressive Strength

The compressive strength at different ages of all investigated specimens (0%, 2%, 3%, and 4% NS) is shown in Fig. 5 and Fig. 6 for group (A) and group (B), respectively. It was found that the compressive strength increased obviously by increasing the ratio of NS. At the early age of 7, the compressive strength slightly increased in specimens that contain NS. The slight increase in the early age compressive strength indicates the presence of relatively large number of small size agglomerates in the NS mixture. Such agglomerates need longer time to react with the excess CH to form additional CSH gel which is a main factor affecting the compressive strength increase.

As for the age of 28 days and later ages, adding NS significantly increased the compressive strength values. The compressive strength at 28 days increased by about 40% and 30% by the addition of 4% NS to concrete mixes containing cement of 400Kg/m^3 and 550Kg/m^3, respectively compared to control mix. This can be attributed to the action of NS as nuclei for cement phases to promote cement hydration because of its pozzolanic reactivity with CH increasing the production of CSH gel that has an important positive effect on the cohesion between aggregates and the mechanical properties of concrete. It was stated that nanoparticles can fill a notable part of voids existing in the matrix of cement paste even in agglomerated manner, due to their ultrafine dimension [25]. Although at early stages agglomerates may significantly affect strength gain, larger and/or agglomerated particles that had not completely dissolved in solution will reduce the porosity in the pores/capillaries of the CSH gel by packing into some of these voids. The density of the CSH will somewhat increase in the plastic form and convert into a more dense compressive bearing structure after the hydration process completion by the 28thday.

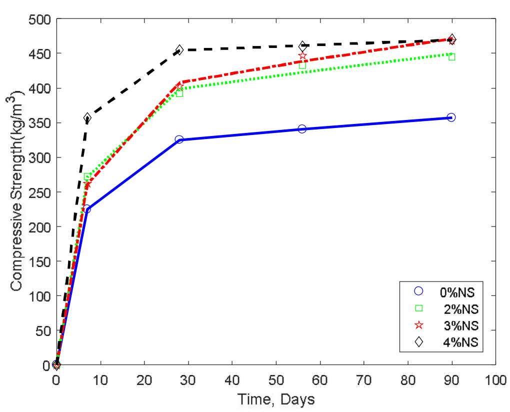

Figure 5. Effect of NS on compressive strength of group (A).

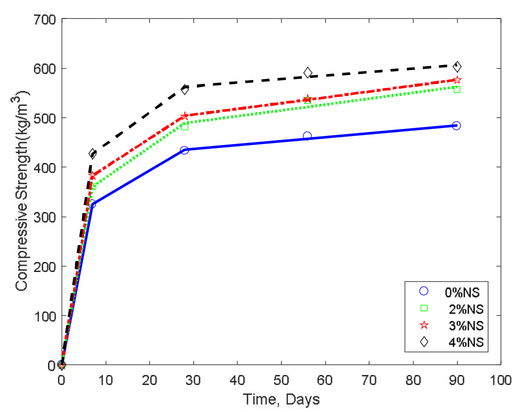

Figure 6. Effect of NS on compressive strength of group (B).

The effect of NS on compressive strength of concrete mixes containing 400 kg/m^3 cement is more profound than its effect on concrete mixes containing 550 kg/m^3 cement. This is valid for all used NS percentages.

Adding NS to concrete mixes containing 400 kg/m^3 cement by 2%, 3%, and 4% results in an increase in 28-days compressive strength by 20%, 25%, and 40%, respectively. While the corresponding increase in compressive strength of concrete mixes containing 550 kg/m^3 cement is 11%, 16%, and 30%, respectively.

5.2. Effect of Nano Silica on Creep Behavior

Concrete specimens of group (A) and group (B) were tested to study the creep behavior in terms of creep coefficient under creep stress of 30% and 50% of compressive strength as shown in Figs. (7-10). It can be easily observed from these figures that adding NS to concrete considerably increases the creep coefficient of all concrete specimens of both group (A) and group (B) compared with control specimens. This is valid for both creep stresses of 30 % and 50% and more profound for ages more than 10 days after loading.

It is well known that creep coefficient vary inversely with compressive strength of concrete [26]. However, referring to Fig. 5 and Fig. 6 of compressive strength results and Figs. (7-10), it can be observed that the adding NS to concrete increases both compressive strength and creep coefficient compared with control specimens. This agrees with the findings of [25, 27 & 28] who concluded that higher drying shrinkage and creep of NS concrete could be attributed to the presence of higher amounts of gel water adhering to the increasing amount of finer C-S-H, and its release during drying and loading.

As for concrete specimens containing NS, it was observed that increasing NS percent results in an obvious decrease of creep coefficient. In other words, creep coefficient appears to vary inversely with NS percent. An opposite relation was observed between the percentage NS and compressive strength as shown in Fig. 5 and Fig. 6. Hence, the relation between compressive strength and creep coefficient of NS concrete is similar to that of conventional concrete with no NS. The above mentioned conclusions are valid and true for both group (A) and group (B).

5.3. Effect of Cement Content on Creep Behavior

Figures (11 – 14) show the effect of cement content on creep coefficient of NS concrete and control concrete under creep stress level of 30% of compressive strength. While Figs. (15 - 18) show the corresponding effect of cement content under creep stress level of 50% of compressive strength. Generally, it was observed that there is an inverse relationship between cement content and creep coefficient, thus increasing the cement content from 400 Kg/m^3 to 550 Kg/m^3 led to a significant decrease in creep coefficient. At the end of test period (180 days under loading), creep coefficient was decreased by 24%, 20%, 23%, and 31% for 0%, 2%, 3%, and 4% NS specimens, respectively, under creep stress level of 30% of compressive strength. The corresponding reduction on creep coefficient for specimens loaded by creep stress level of 50% of compressive strength was 34%, 25%, 31%, and 35% for 0%, 2%, 3%, and 4% NS specimens, respectively.

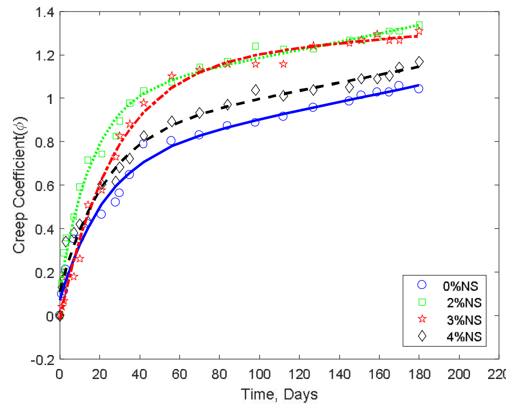

Figure 7. Effect of NS on creep coefficient of group (A) under creep stress of 30%**.**

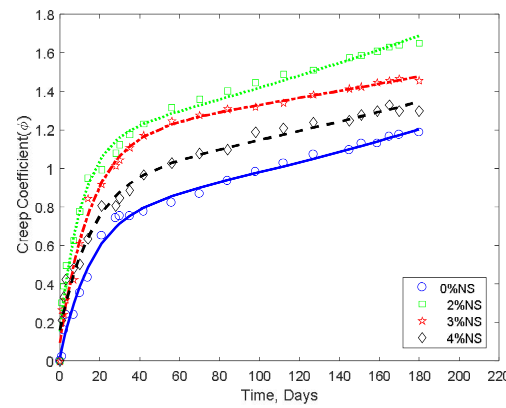

Figure 8. Effect of NS on creep coefficient of group (A) under creep stress of 50%

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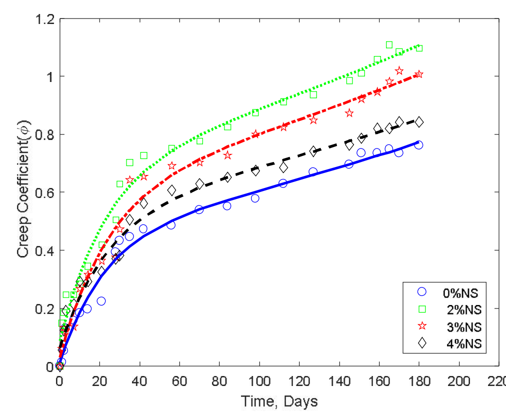

Figure 9. Effect of NS on creep coefficient of group (B) under creep stress of 30%**.**

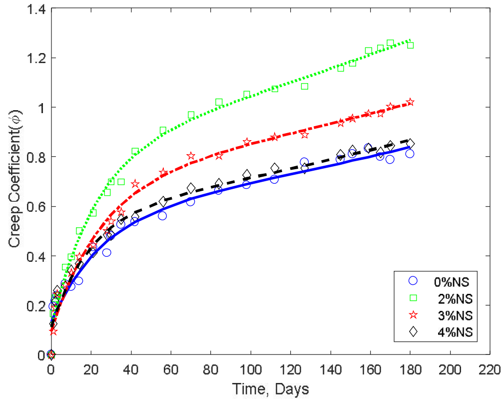

Figure 10. Effect of ns on creep coefficient of group (b) under creep stress of 50%**.**

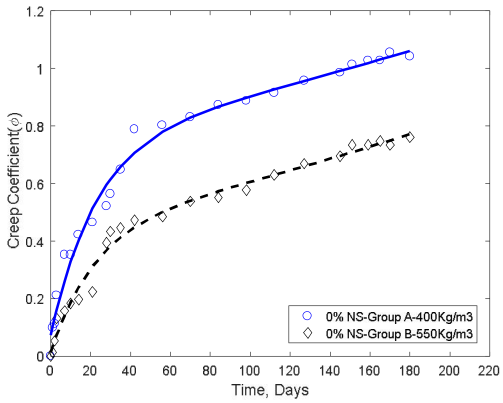

Figure 11. effect of cement content on creep coefficient of 0% ns concrete under creep stress of 30%.

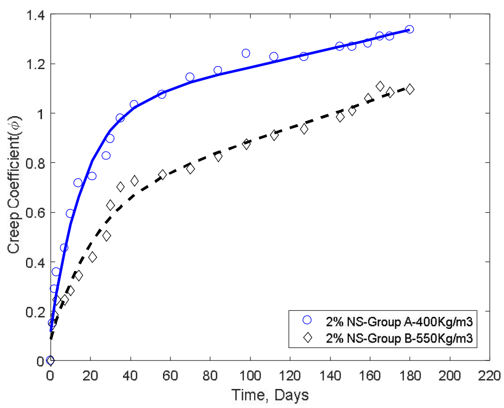

Figure 12. **effect of cement content on creep coefficient of 2% ns concrete under creep stress of 30%**.

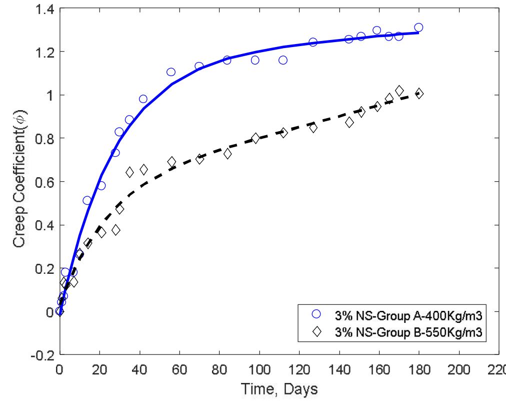

Figure 13. Effect of cement content on creep coefficient of 3% NS concrete under creep stress of 30%**.**

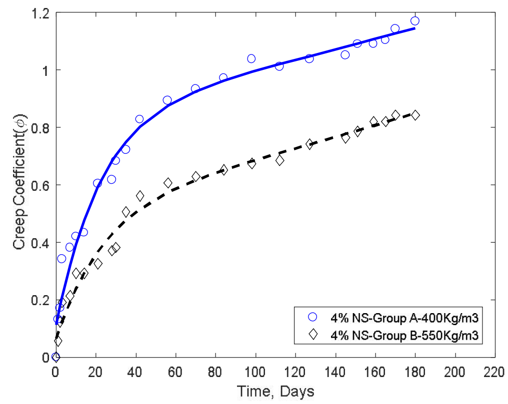

Figure 14. Effect of cement content on creep coefficient of 4% NS concrete under creep stress of 30%**.**

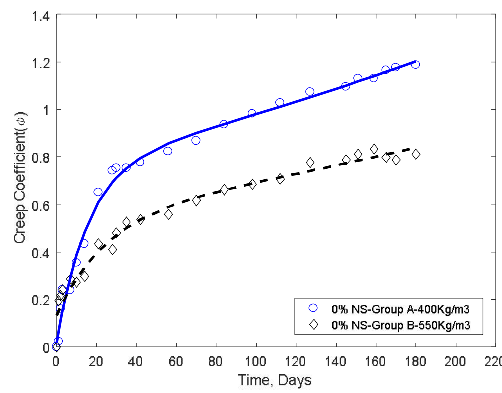

Figure 15. Effect of cement content on creep coefficient of 0% NS concrete under creep stress of 50%**.**

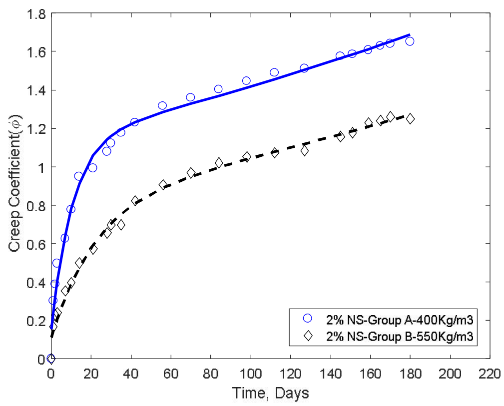

Figure 16. Effect of cement content on creep coefficient of 2% NS concrete under creep stress of 50%.

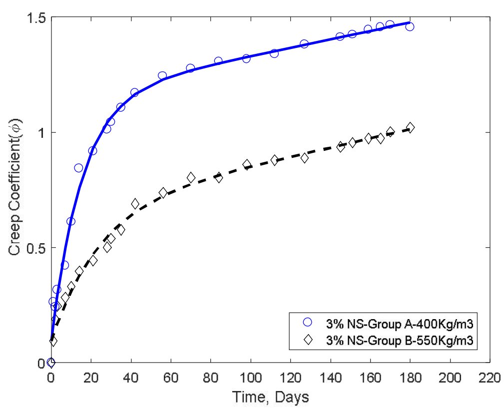

Figure 17. Effect of cement content on creep coefficient of 3% NS concrete under creep stress of 50%.

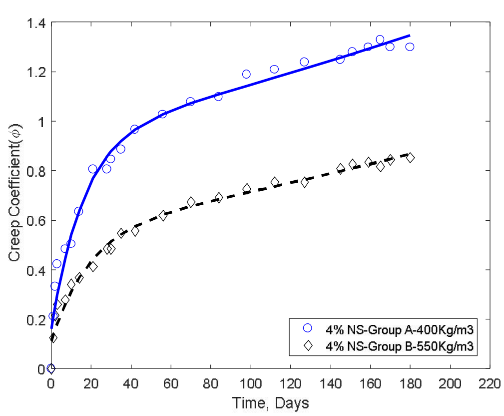

Figure 18. Effect of cement content on creep coefficient of 4% NS concrete under creep stress of 50%.

5.4. Effect of Creep stress level on Creep Behaviour

Figures from 19 to 22 display the effect of creep stress level on creep coefficient for 0%, 2%, 3%, and 4% NS specimens with cement content of 400 kg/m^3, while Figs. (23 - 26) show the corresponding effect of creep stress level on creep coefficient for 0%, 2%, 3%, and 4% NS specimens with cement content of 550 kg/m^3, respectively.

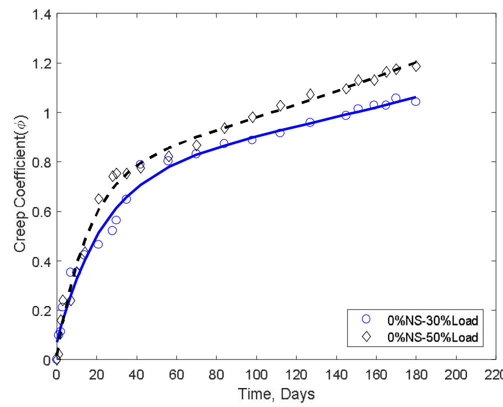

Figure 19. Effect of creep stress level on creep coefficient of 0% NS concrete and C=400Kg/m^3.

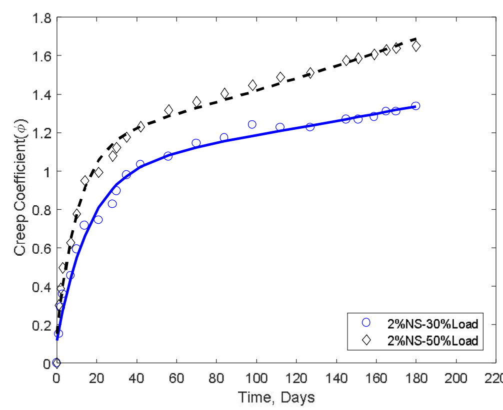

Figure 20. Effect of creep stress level on creep coefficient of 2% NS concrete and C=400Kg/m^3.

Generally, it can be seen from these figures that increasing creep stress level increases the creep coefficient of all tested control and NS specimens. As for group (A) specimens containing cement content of 400 kg/m^3, at the end of test period (180 days under loading), creep coefficient was increased by 16%, 23%, 12%, and 13% for 0%, 2%, 3%, and 4% NS specimens, respectively. The effect of creep stress level on creep coefficient of group (B) specimens containing cement content of 550 kg/m^3 is less pronounced than its effect on group (A) specimens. The effect of creep stress level on creep coefficient of concrete containing 2% NS specimens with cement content of 550 kg/m^3 follows the same trend as for specimens with cement content of 400 kg/m^3. On the other hand, the corresponding effect on 0%, 3%, and 4% NS specimens is somewhat different and less clear, particularly at older ages under loading (more than 100 days). Therefore, more researches are needed and recommended to declare the effect of creep stress level on creep coefficient of NS concrete containing high cement contents.

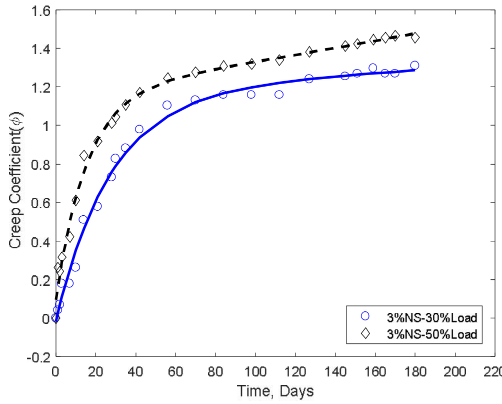

Figure 21. Effect of creep stress level on creepco efficient of 3% NS concrete and C= 400Kg/m^3.

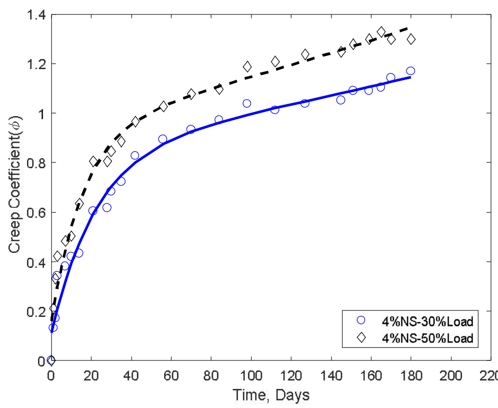

Figure 22. Effect of creep stress level on creep coefficient of 4% NS concrete and C= 400Kg/m^3.

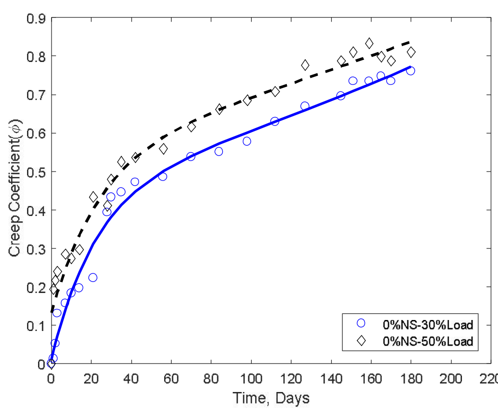

Figure 23. Effect of creep stress level on creep coefficient of 0% NS concrete and C= 550 Kg/m^3.

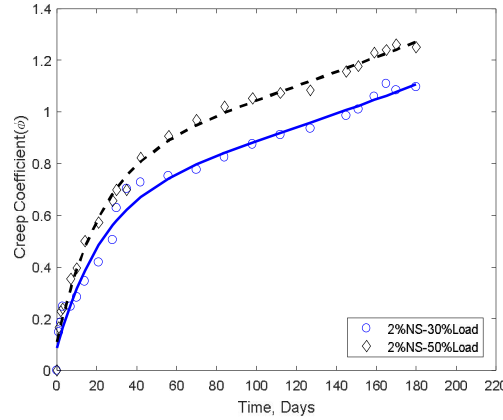

Figure 24. Effect of creep stress level on creep coefficient of 2% NS concrete and C= 550Kg/m^3.

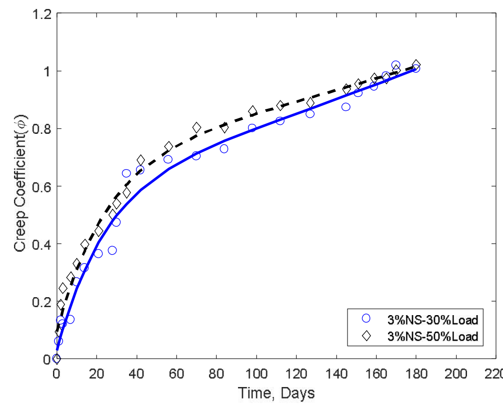

Figure 25. Effect of creep stress level on creep coefficient of 3% NS concrete and C= 550Kg/m^3.

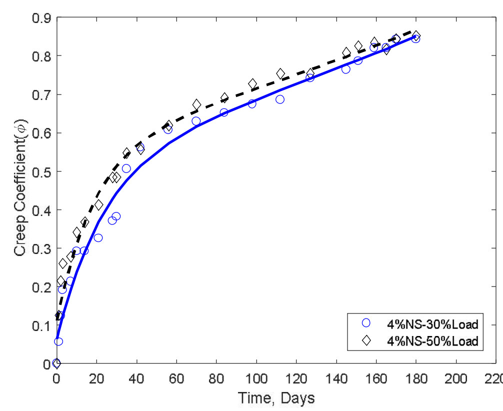

Figure 26. Effect of creep stress level on creep coefficient of 4% NS concrete and C= 550Kg/m^3.

Conclusions

The main objective of this research work was to improve our knowledge of the time-dependent behavior of NS in concrete. The compressive strength of four mixes containing 0%, 2%, 3%, and 4% NS was investigated at different ages. It was found that the compressive strength increases obviously by increasing the ratio of NS by about 23%, 25%, and 25% for 2%, 3%, and 4% NS specimens respectively after 28 days. Time-dependent behavior of NS in concrete was investigated in terms of creep coefficient. The creep test indicated that all specimens containing NS have larger values of creep coefficient than the normal concrete and the specimens which contain 4% NS have the lowest values of creep and that contain 2% NS have the largest values of creep coefficient if they compared to other NS specimens.

It was observed that there is an inverse relationship between the cement content and creep coefficient since increasing the cement content led to a significant decrease in creep coefficient.

The effect of creep stress level on creep coefficient of group (B) specimens containing cement content of 550 kg/m^3 is less pronounced that its effect on group (A) specimens.

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9/20/2019