

EFFECT OF CRUMB RUBBER AND NANO SILICA ON THE CREEP AND DRYING SHRINKAGE OF ROLLER COMPACTED CONCRETE PAVEMENT

Musa Adamu^{1,2}, Bashar S Mohammed^{1*} and Mohd Shahir Liew¹

¹Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak, Malaysia

² Department of Civil Engineering, Bayero University Kano, PMB 3011, Kano, Nigeria

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ABSTRACT: Roller compacted concrete (RCC) pavement is used mostly for heavy duty vehicle operations such as log sorting yards, intermodal yards for containers, parking areas for military vehicles and trucks and automobiles, and aircraft parking ramps. Therefore, it is subjected to long-term loading which can cause permanent deformation. Therefore in this study, the long-term creep and drying shrinkage of RCC pavement up to 1 year was studied. High volume fly ash (HVFA) RCC pavement was developed by replacing 50% cement with fly ash. A total of five RCC pavements were developed; one control mixture, two RCC pavement mixtures and two HVFA RCC pavement mixtures. The four mixtures were developed by replacing 10% fine aggregate with crumb rubber by volume and addition of 1% nano silica by weight of cementitious materials. The results showed that the creep and drying shrinkage of RCC pavement increases with time, and with the incorporation of crumb rubber and HVFA and decreases with the addition of nano-silica. The creep strain of RCC pavement mixtures can be predicted at any given time using their compressive strength and age of testing.

Keywords: *Crumb rubber; Nano silica; High volume fly ash; Roller compacted concrete pavement; Creep; Drying shrinkage.*

1. INTRODUCTION

According to ACI committee 207, "Roller-compacted concrete is a concrete of no slump consistency in its unhardened state that is transported, placed and compacted using earth and rock fill construction equipment. Properties of hardened roller compacted concrete are similar to those of conventional concrete"[1]. Roller compacted concrete differs from conventional concrete due to its consistency requirements and compaction effort needed, with lower water content, lower paste content, higher fine aggregate content, no entrained air [2]. The major advantages of RCC over conventionally placed concrete include high construction speed, reduced construction cost [3, 4]. Roller compacted concrete are mainly used in two areas of applications; in mass concrete dams applications, referred to as roller compacted concrete dams and in heavy-duty pavement applications which include intermodal yards, port facilities, warehouses and large storage areas, airport service areas, highway shoulders, rural roads, local streets and intersections [3]. However, the main difference between a roller compacted concrete dam and a roller compacted concrete pavement is that the former has a lower binder proportion, larger nominal maximum aggregate sizes, lower compressive strength,

higher water/cement ratio and higher consistency than the latter [5]. Some of the advantages of RCC pavement over conventional concrete pavement is lower construction cost and rapid construction. The reduction in the cost of pavement when RCC is used can be up to 30% and 20% compared to the asphaltic pavement and conventional concrete pavement respectively [6]. Another advantage of RCC pavement is reduced labor and workmanship, reduced cement content, no formwork or reinforcement required, early load carrying capacity, more durability, low maintenance, reduced lightening requirements due to its light surface with the corresponding sustainable environment by a reduction in heat absorption and heat radiation [7, 8]. RCC allows for early usage when used in pavement due to its rapid strength gain [7], it can be able to support light traffic immediately after construction as it develops strength quickly [8]. RCC pavement has similar strength and performance properties as conventional concrete, but with the economy and simplicity of construction as that of asphaltic pavement with lower maintenance needed and longer service life [7].

RCC pavement is used mostly for heavy duty vehicle operations such as log sorting yards, intermodal yards for containers, parking areas for military vehicles and trucks and automobiles, and

aircraft parking ramps [9]. Therefore when the RCC pavement is subjected to these heavy vehicles for a long period of time, it can cause permanent deformation. Therefore the creep performance of RCC pavement is very important. Creep is used to measure the long-term deformation of a material under sustained loading, and it normally occurred in the direction of loading. The creep deformation is inelastic and decreases with time. It is proportional to 0% to 40% of the compressive strength of concrete. The creep of RCC is inversely proportional to its compressive strength and elastic modulus [10].

Drying shrinkage, on the other hand, causes a significant change in the volume of RCC pavement due to evaporation of capillary pore water from the pores of the hardened cement matrix. However, due to lower water-to-cementitious materials ratio, the drying shrinkage in RCC pavement will generally be lower than in conventional concrete. Therefore, a lower water-to-cementitious materials ratio in RCC pavement will result in lower drying shrinkage and less cracking. Therefore, the factors affecting drying shrinkage of RCC pavement includes; water-to-cementitious materials ratio, water, and cement content. Furthermore, at the constant water-to-cement ratio, the higher the coarse aggregate content in the RCC mixture, the lower the drying shrinkage will be due to high restraint [11]. As RCC pavement does not support steel reinforcement, dowel bars or tie rods, and drying shrinkage or cracks due to shrinkage is resisted by the tensile strength of the concrete, and restraint provided by the coarse aggregates and the aggregates interlock. Therefore, the drying shrinkage of RCC pavement is also significant.

Benouadah, et al. [12], studied the effect of polypropylene fiber (PPF) on the drying shrinkage of RCC pavement. They prepared six mixes by adding 0, 0.5, 1, 1.5, 2 and 2.5 kg/m³ of PPF. The addition of PPF decreases the drying shrinkage of RCC pavement. The drying shrinkage also increases with age, and the rate of increment for RCC without PPF became stable after 14 days while for RCC with PPF became stable after 7 days. The decrease in shrinkage is due to the fiber network which provides some restraint against drying shrinkage. Gholami and Modarres [13], studied the effect of superplasticizer (SP) on the shrinkage performance of RCC pavement. They added 0%, 1%, 2%, 3% and 4% SP. The total shrinkage of RCC mixtures with SP was lower than RCC mixture without SP (control). The addition of 1%, 2%, 3%, and 4% SP decreases the short-term total shrinkage by 30.3%, 21.9%, 14.4% and 12.5% respectively compared to the control mixture. Similar trends were found for the short term drying shrinkage of the RCC mixtures. With regards to autogenous shrinkage, its values

for all the mixtures were lower than total and drying shrinkage, and its effect with reference to SP addition is similar to the trends for total and drying shrinkages. At long-term curing period, RCC mixtures with SP showed higher total and drying shrinkage values compared to the control mixture.

To the best knowledge of the authors, there is limited or no available literature that studied the creep and drying shrinkage behavior of RCC pavement. Therefore, this study is aimed at studying the creep and drying shrinkage properties of RCC pavement. It is also aimed at studying the effect of crumb rubber, high volume fly ash, and nano silica on the creep and drying shrinkage of RCC pavement.

2. MATERIALS AND METHODS

2.1 Materials

Type I and II cement are mostly used and recommended for use in RCC pavement. Therefore, in this study Type, I ordinary Portland cement which conforms to the requirements of ASTM C150 was used. Class F fly ash which conforms to the requirements of ASTM C612 was used as supplementary cementitious materials (SCM).

Natural sand was used as a fine aggregate with a maximum size of 4.75 mm, specific gravity 2.65, fineness modulus 2.86 and water absorption of 1.24%. Two nominal maximum sizes of coarse aggregates have been used to achieve the desired combined aggregate gradation. These are 19 mm size having a specific gravity of 2.66 and water absorption of 0.48% and 6.35 mm size having a specific gravity of 2.55 and water absorption of 1.05%. Three different crumb rubber sizes have been combined to obtain similar gradation curves to fine aggregate. Several trials of sieve analysis have been conducted in accordance with the requirements of ASTM D 5644. The combination of 40% mesh 30 (0.595 mm), 40% of 1-3 mm and 20% of 3-5 mm have been selected.

One of the requirements for RCC pavement mixture production is using materials finer than 75 μ m (No 200 sieve) to achieve a more cohesive paste with reduced void volume. The recommended amount should be between 2% to 8% of the total aggregates [14-16]. In this study, the same class F fly ash used as SCM was used as a mineral filler.

Strong hydrophobic nano silica size 10 - 25 nm has been used as an additive to the cement. The nano-silica is amorphous in nature therefore, it will

act as both filler and pozzolanic material.

2.2 Mix Design and Proportioning

Mix proportioning has been carried out according to the geotechnical approach to the requirements of ACI 211.3R-02 [17, 18]. This involves the determination of aggregate proportion for recommended combined aggregate gradation curve. This was achieved using a combination of 55% fine aggregate, 20% of 19 mm maximum sized coarse aggregate, 20% of 6.3 mm coarse aggregate, and 5% mineral filler. Next is the determination of optimum water content according to the requirements of ASTM D 1557-12e. This was done by preparing different RCC mixes using the same aggregate proportion for combined aggregate gradation, and varying the cement content at 12%, 13%, 14% and 15% by weight of the dry aggregate. The optimum moisture content for RCC with 12%, 13%, 14% and 15% cement has been found to be 5.46%, 5.56%, 5.92% and

6.09%, respectively. Finally, the relationship between cement content and flexural strength of RCC mixtures was developed. Based on a target flexural strength of 4.8 MPa, 13% cement content was selected to be used in this study.

In this study, five mixtures were prepared by partially replacing cement with HVFA at 50% replacement level, partially replacing 10% fine aggregate with crumb rubber by volume and addition of nano silica (0%, 1%) by weight of cement. Each mix was assigned a designation code based on fly ash, crumb rubber and nano silica used, for example, M10C50F1N refers to RCC mixture with 10% of crumb rubber, 50% HVFA and 1% of nano-silica. The terminology “roller compacted rubbercrete (RCR)” was used in this study for RCC pavement where fine aggregate was partially replaced with crumb rubber. RCR mix proportions are shown in Table 1.

Table 1. Mix Proportion

Mixture	Quantities for 1 kg/m ³ of RCR							
	Cement	Fly Ash	Nano silica	Filler	Fine aggregate	Coarse aggregate-19 mm	Coarse aggregate-6.35 mm	Water
M0C0N	268.69	0	0	103.76	1148.05	415.03	416.85	98.24
M10C0N	268.69	0	0	103.76	1033.25	415.03	416.85	98.24
M10C1N	268.69	0	2.69	103.76	1033.25	415.03	416.85	98.24
M10C50F0N	134.58	102.54	0	103.94	1035.07	415.76	417.58	96.87
M10C50F1N	134.58	102.54	2.37	103.94	1035.07	415.76	417.58	96.87

2.3 Test Procedures

The creep and drying shrinkage test have been carried out in accordance with the guidelines outlined in ASTM C512 [19]. For each mix, six 150 mm × 300 mm cylindrical specimens were prepared; two were tested for compressive strength, two for drying shrinkage, and two for creep test. After casting, the specimens were stored in the curing room at a temperature of 23°C for 24 hours, after which they were demoulded and cured in a clean water tank at a temperature of 23°C until after 7 days. For each creep and drying shrinkage specimen, four Demountable Mechanical (DEMEC) gauge points were attached i.e. two on each diametrically opposite sides, a distance of 200 mm between them.

The creep and drying shrinkage tests were carried out in the laboratory under a controlled temperature of 23°C, and uncontrolled relative humidity between 56% and 64%. Prior to loading,

the 7 days cylindrical compressive strength of each mix were determined. Loads equivalent to 40% of the ultimate compressive strength was applied to the specimens using the hydraulic pump. A 200 mm gauge length DEMEC strain gauge was used to measure the strain readings throughout the test as shown. The strain readings of the creep and drying shrinkage specimens were taken simultaneously before and immediately after loading, at 2 hours and 6 hours after loading. The strain readings were taken continuously daily for 7 days, then weekly for 1 month, and finally monthly for 1 year. It was ensured that the loads do not vary by more than 2% of the actual loads during each measurement period. This was done by measuring the force using the hydraulic pump before taking the strain measurement. The Creep and drying shrinkage strains were calculated using Eqns 1, and 2 respectively. The creep coefficient is taken as the ratio of $C(t_k, t_0)$ to $\varepsilon_{ie}(t_0)$

$$C(t_k, t_0) = [\varepsilon_t(t_k) - \varepsilon_{ie}(t_0) - \varepsilon_{sh}(t_k)] \quad (1)$$

$$\varepsilon_{sh}(t_k, t_0) = (\varepsilon_{sh}(t_k) - \varepsilon_{sh}(t_0)) \quad (2)$$

Where $\varepsilon_{sh}(t_k, t_0)$ is the total creep at time t_k due to applied stress at time t_0 , $\varepsilon_{sh}(t_k)$ is the total strain at time t_k , $\varepsilon_{sh}(t_0)$ is the initial instantaneous elastic strain at time t_0 , $\varepsilon_{sh}(t_k)$ is the corresponding shrinkage strain for the same specimen at time t_k , $\varepsilon_{sh}(t_k, t_0)$ is the shrinkage at time t_k measured from the start of testing, $\varepsilon_{sh}(t_0)$ is the initial shrinkage at start of testing.

The compressive strength was determined in accordance with ASTM C39 using 150 mm diameter by 300 mm height cylinders. For each mixture and each curing periods, two samples were tested and the average value calculated and recorded. The compressive strength was determined at 3, 7, 28, 90, and 365 days after curing period.

3 RESULTS AND DISCUSSION

3.1 Compressive Strength

The results of compressive strength for all the five mixtures is shown in Fig 1. The compressive strength increases with age for all the mixtures due to increased hydration. However, the rate of increase in strength for mixture M10C50F0N was the lowest due to the slower pozzolanic reactivity of fly ash at an early age, which lowered the consumption of calcium hydroxide and production of calcium silicate hydrate, which is the main element for strength development. Partial replacement of fine aggregate with 10% crumb rubber in RCC pavement leads to increase in strength. This might be due to the increased consistency of RCC pavement when crumb rubber is incorporated [16]. This increase paste dispersion, leading to a denser microstructure thereby increasing strength. However, replacing 10% fine aggregate with crumb rubber in HVFA RCC pavement decreases its compressive strength at all age. This can be observed in Fig 1 by comparing the compressive strength values of M10C50F0N and M10C50F1N with that of M0C0N. The decrease in strength is mainly due to poor bonding and increased the thickness of the interfacial transition zone between cement paste and crumb rubber, which results to microcracks formation along the ITZ and consequently premature failure [20].

The addition of 1% nano silica increases the compressive strength of both RCC pavement mixtures and HVFA RCC pavement mixtures at all age of curing. For example, from Fig 1 it can be seen that the strength of M10C1N is higher than that of both M10C0N and M0C0N at all ages of curing. The compressive strength of the mixture

M10C1N is higher than that of the control mix (M0C0N) by 28.89%, 29.25%, and 42.84% at 3, 7, and 28 days respectively. Similarly, the compressive strength of M10C50F1N was higher than that of M10C50F0N by 68.97%, 65.32%, 41.13%, 52.79%, and 26.33% at 3, 7, 28, 90, and 365 days respectively. Therefore nano silica was successful in igniting the pozzolanic reactivity of fly ash at an early age. This can be verified as the rate of increase in strength with the addition of nano silica to HVFA RCC pavement was higher at early ages. The increase in strength with the addition of nano silica is due to the high pozzolanic reaction of nano silica, thereby reacting with the excess $\text{Ca}(\text{OH})_2$ from cement hydration, and producing more calcium-silicate-hydrate gel which leads to increase in strength, densified ITZ between cement paste and crumb rubber, and consequently enhances bonding between crumb rubber and cement paste [16, 21]. Another reason for improving early strength development in HVFA RCC is due to increased nucleation site effects by nano-silica. Nano silica act as a nucleation site which helps in precipitating the hydration products from cement and silicon dioxide from HVFA, thereby accelerating the rate of calcium hydrate silicate production which is the main compound for strength development in RCC [22].

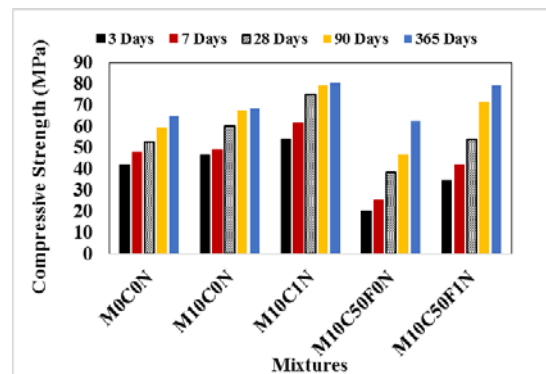


Fig 1. Compressive strength results

3.2 Creep

The creep for all the RCC mixtures was reported in terms of total creep strain and creep coefficients as shown in Fig 2 and Fig 3 respectively. It can be observed that for all the RCC mixtures, both the total creep strain and creep coefficients increases with time. However, the rate of increment was higher during the first one months, then gradual for up to 6 months and tends to be steady during the last 6 months. This is because, at an early age, concrete has lower compressive strength, and will, therefore, deform

easily under sustained loading. With time the concrete continues to gain strength due to the hydration of cement, this, therefore, increases its elastic modulus and consequently reduces its deformation under long time loading [23].

Partial replacement of fine aggregate with crumb rubber increases the creep strain, creep at any time and the creep coefficient. This can be observed in Fig 2, and Fig 3 respectively. For example, compared to the control mixture (M0C0N), the total creep strain of M10C0N was higher by 61.04%, 78.44%, 81.07% and 43.94% at 7, 30, 90, and 365 days respectively. The creep coefficient of M0C0N ranges from 0.218 to 0.549 at 1 day – 365 days, while that of M10C0N ranges from 0.234 to 1.14 at 1 day – 365 days. This might be attributed to lower stiffness of crumb rubber in comparison to fine aggregate it partially replaced, as the stiffer the aggregates the lower the creep of the concrete and vice versa [23].

The partial replacement of cement with HVFA (50%) has a significant effect on the long-term deformation of RCC under sustained loading. This can be analyzed by comparing the total creep strain and creep coefficients of RCC mixtures with and without HVFA. For example, the total creep strain for M10C0N at 7, 30, 90 and 365 days are 311.65, 348.88, 423.54 and 485.89 microns respectively, while the total creep strain for M10C50F0N at 7, 30, 90 and 360 days are 402.35, 490.65, 541.37 and 667.44 microns respectively. Similarly, the creep coefficient of M10C0N ranges from 0.243 – 1.140 at 1 day – 365 days, while that of M10C50F0N ranges from 0.805 – 1.888 at 1 day – 365 days respectively. Similar trend results can be seen by comparing the total creep strain and creep coefficient of M10C1N with that of M10C50F0N. The increase in creep with partial replacement of cement using HVFA can be attributed to the lower strength, stiffness, and modulus of elasticity of the RCC pavement caused by the incorporation of fly ash. This, therefore, resulted in increased deformation under sustained loading as a creep is inversely proportional to strength and modulus of elasticity.

The addition of nano silica decreases the total creep strain and creep coefficients for all RCC mixtures. By comparing the total creep of M10C1N to that of M10C0N from Fig 6, it can be seen that the total creep strain of M10C1N was lower by 68.24%, 74.69%, 82.10% and 63.73% at 7, 30, 90 and 365 days respectively. Similarly, compared to the control mixture, the total creep strain for M10C1N was lower by 58.15%, 54.83%, 67.58%, and 47.79% respectively. Similarly, by comparing the total creep strain of M10C50F1N

by that of M10C50F0N, it can be seen that the creep of the former was lower by 19.34%, 33.85%, 35.45%, and 23.32% at 7, 30, 90, and 365 days respectively compared to the latter. The creep coefficients of M10C50F1N ranges from 0.254 – 1.002 at 1 day – 365 days, while that of M10C50F0N ranges from 0.805 – 1.888 at 1 day to 365 days. However even with the addition of nano silica, the creep strain and creep coefficient of M10C50F1N was lower than that of the control (M0C0N). The reduction in creep of RCC pavement with the addition of nano silica can be attributed to the increased stiffness, modulus of elasticity and compressive strength due to the high filler and high pozzolanic reactivity of nano-silica. This consequently resulted in a decrease in creep as a creep is inversely proportional to compressive strength, stiffness, and modulus of elasticity [23].

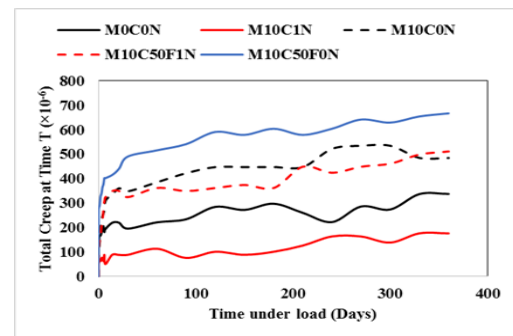


Fig 2. Creep strain of RCC pavement mixtures.

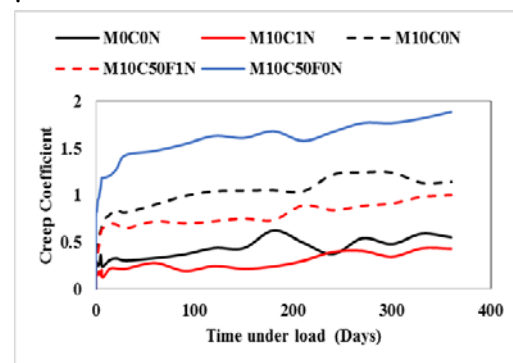


Fig 3. Creep coefficient of RCC pavement mixtures

3.2.1 Relationship between creep, compressive strength, and age of RCC pavement

Creep testing of RCC takes a long time to execute, as the test specimens need to be subjected to a constant loading for up to 1 year. This makes the testing time-consuming. Therefore in this study, multivariable models were developed for each

RCC pavement mixture which can be used to predict its creep strain at any given period of time. The variables considered are a time for curing (3, 7, 28, 90 and 365 days) and compressive strengths at 3, 7, 28, 90 and 365 days. The developed models for M0C0N, M10C0N, M10C1N, M10C50F0N, and M10C50F1N are presented in Table 2.

The ANOVA summary for the multi-variable models is presented in Table 2. It can be seen that all the models have a very high degree of correlations ($R^2 > 0.9$) except for mixture M10C50F1N which also has a high R^2 value greater than 0.8. In addition, all developed models

were all significant at 95% confidence level except for M10C50F1N, meaning that there is only 0.01% chance that the F-values of this size will occur due to noise. Furthermore, the higher Fisher statistical test values (F- Values), and the lower probability values (P- values) further explain the adequacy and significance of the models. With respect to the standard error, all the models have a very low standard error less than 0.2 except for M10C1N, therefore, the creep strain can be predicted with lower error.

Table 2. Developed Relationship between Creep and Compressive strength of RCC

Mixtures	Model	R ²	Error	F-Values	P-Values
M0C0N	$C_{(T)} = 129.9613 * 1.001266^T * 1.00775^{F_C}$	0.993	0.03	142.188	0.0094
M10C0N	$C_{(T)} = 135.388 * T^{0.130115} * F_C^{0.12708}$	0.956	0.044	21.833	0.0438
M10C1N	$C_{(T)} = 0.31844T - 0.24378F_C + 79.223$	0.912	20.338	10.317	0.0884
M10C50F0N	$C_{(T)} = 77.944 * T^{0.021189} * F_C^{0.485754}$	0.994	0.0291	161.566	0.00615
M10C50F1N	$C_{(T)} = 1249.738 * T^{0.245589} * F_C^{-0.54027}$	0.843	0.175	5.3504	0.1575

The predicted versus actual plots for the models are also important factors for checking the adequacy and fitness of the models graphically. Fig 4 shows the predicted versus actual plots for selected RCC samples, it can be seen that the predicted versus actual plots for models M0C0N, M10C0N and M10C1N were all aligned and almost perfectly fitted the straight line, that is to say, they are in agreement and fit with each other, although some points do not fit into the straight line. This is due to the higher standard error of M10C1N model. Therefore, the developed response models are applicable and appropriate for predicting strengths of RCC.

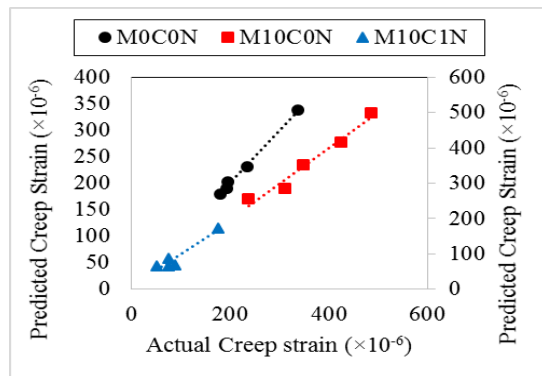


Fig 4. Predicted Vs Actual plots for Creep

3.3 Drying Shrinkage

The result of the drying shrinkage strain of selected RCC mixtures is presented in Fig 5. The drying shrinkage for all the RCC mixtures follows a similar trend i.e. increases with time, and the rate of increment was severe or more pronounced within the first 60 days for all the mixtures except M10C50F0N, after a long time the rate of change of drying shrinkage became minimal. This can be attributed to the higher rate of loss of capillary water from the RCC pores at an early age. Partial replacement of fine aggregate with crumb rubber slightly increases the drying shrinkage strain of RCC pavement, and significantly increases the drying shrinkage of HVFA RCC pavement. For example, by comparing mixtures M10C0N with that of the control mixture (M0C0N), the drying shrinkage of the former was higher than that for the latter by 13.84%, 29.62%, 5.92%, 7.97% and 2.28% at 1, 2, 7, 30, and 365 days respectively. Similarly, by comparing mixture M10C50F0N by M0C0N, the drying shrinkage of the former was higher than that of the latter by 71.59%, 60.34%, 100.27%, 83.64%, and 100.31% at 1, 2, 7, 30, and 365 days respectively. This is due to the higher flexibility and deformation properties of crumb rubber in comparison to fine aggregate, which decreases the internal restraints to drying stresses, consequently increasing drying shrinkage [24].

Another reason can be due to increase in porosity caused by crumb rubber in the hardened RCC matrix. This, therefore, fastens the rate of loss of capillary water from the RCC pores, thereby increasing the drying shrinkage.

It can be observed from Fig 5 that the replacement of cement with HVFA has a significant effect on the drying shrinkage of RCC pavement. As cement paste also plays a role in restraining drying shrinkage, partial replacement of cement with HVFA weakens or decreases the strength of the cement paste thereby making it a little bit flexible due to slower hydration reaction of fly ash, this resulted to increased drying shrinkage, increased porosity caused by the slower hydration of fly ash, and hence resulting to lower C-S-H gel development which is the main hydration product responsible for filling the capillary pores in RCC pavement. This therefore aided in accelerating the loss of moisture from the capillary pores, thus increasing drying shrinkage.

The addition of nano silica decreases the drying shrinkage strain of RCC pavement. By comparing M10C1N with M10C0N, the drying shrinkage of the former was lower than that of the latter by 20.50%, 11.57%, 7.77% and 4.06% at 1, 3, 90 and 120 days. While for HVFA RCC pavement, the drying shrinkage of M10C50F1N was lower than for M10C50F0N by 33.22%, 28%, 27.16%, 30.79% and 28.57% at 1, 7, 30, 90 and 365 days respectively. Farzadnia, et al. [25], reported similar results for palm oil fuel ash (POFA) mortar. The decrease in drying shrinkage with the addition of nano silica is due to decrease in permeability due to the formation of secondary C-S-H from the high pozzolanic reaction of nano-silica. The C-S-H fills the capillary pores in the hardened RCC matrix and hinders the loss of moisture from the capillary pores which consequently decreases drying shrinkage. Another reason can be due to the higher water demand of nano silica which reduces the amount of moisture in the capillaries of the RCC pavement, thereby reducing one of the factors causing drying shrinkage [25].

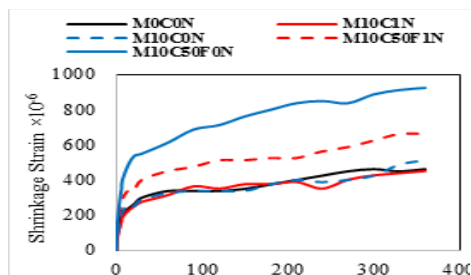


Fig 5. Drying Shrinkage of RCC pavement

4 CONCLUSIONS

The following conclusions can be drawn based on the experimental works and results analysis carried out.

- Partial replacement of fine aggregate with crumb rubber decreases the compressive strength of HVFA RCC pavement.
- The addition of nano silica increases the early strength development in HVFA RCC pavement by igniting the pozzolanic reaction of fly ash at an early age.
- Partial replacement of fine aggregate with crumb rubber increases the creep and drying shrinkage of RCC pavement and HVFA RCC pavement.
- Addition of nano silica decreases the creep and drying shrinkage of both RCC pavement and HVFA RCC pavement.
- The creep strain of RCC pavement at any time can be predicted using its compressive strength and the age of curing as the independent variables.

5. ACKNOWLEDGEMENTS

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