

## CASE STUDY

# Effect of sulphonated naphthalene formaldehyde superplasticizer on the mechanical and durability properties of concrete produced using locally sourced fine aggregate from Ghana

Mark Bediako<sup>1\*</sup>, Timothy K. Ametefe<sup>1</sup>

Received: 4th August, 2023 / Accepted: 25th February, 2024

Published online: 8th March, 2024

## Abstract

The use of superplasticizers is very uncommon in many developing countries. However, its inclusion in concrete enhances concrete's mechanical and durability properties. There is a yawning gap in the literature on the performance of Sulphonated Naphthalene Formaldehyde (SNF) superplasticizers in concrete, especially in the sub-Saharan construction industry where the quality of aggregates used in production is questionable. This study produced two batches of concrete produced with locally sourced pit sand, with characteristic strength of 30 MPa. One batch was without the SNF superplasticizer to serve as a control, whereas the other batch was made with the incorporation of the superplasticizer. The fresh properties of slump and air content and the hardened properties of compressive and flexural strength, elastic, and dynamic moduli were investigated. Further, durability indicators comprising sorption, water absorption, sorptivity, chloride penetration, electrical surface resistivity, and acid attack were investigated. The results of the study demonstrated that the incorporation of SNF superplasticizers in concrete resulted in improved workability and a reduction in ion mobility within the concrete. This was attributed to a decrease in the presence of interconnected pores, leading to notable enhancements in mechanical properties such as increased strength, as well as improvements in both elastic and dynamic moduli. Moreover, concrete containing SNF superplasticizer protects the concrete much better from acid attack than those without SNF superplasticizer. The study recommends the use of SNF superplasticizers in concrete for improved workability, reduced ion movement via fewer interconnected pores, and enhanced mechanical properties, potentially boosting overall durability.

**Keywords:** SNF Superplasticizer, Fresh Properties, Hardened Properties, Durability Indicators, Acid Attack, Local Sand

## Introduction

Achieving the designed strength and durability of concrete are without doubt the topmost priority of building engineers. However, it is a major struggle to achieve these parameters owing to the difficulty in controlling the required amount of water, especially in the field. To increase the flowability of concrete, much more water is added to the mix in many informal construction sites. The introduction of more water could result in increased porosity after the water evaporates. Theoretically, the amount of water required for cement to hydrate fully is about 25 % of the mass of cement (Flatt *et al.*, 1998). Unfortunately, achieving flowable concrete with about 25% water content based on cement mass is nearly impossible.

The discovery of superplasticizers (SPs) has paved the way for building engineers to achieve the desired mechanical properties and enhance the durability of concrete. For instance, high early and late strength development, enhanced modulus of elasticity, and reduced porosity then lead to improvement in the durability of concrete (Ramachandra *et al.*, 2016; Parra *et al.*, 2011; Aruntas *et al.*, 2008). The use of superplasticizers for concrete is widely known in the concrete industry of many developed countries. Concretes including lightweight concrete, heavyweight concrete, pre-stressed concrete, vacuum concrete, self-compacting concrete, autoclaved aerated concrete, and fiber-reinforced concrete (FRC) have all seen enhanced technical properties after the introduction of SPs as a constituent (Aruntas *et al.*, 2008). However, in many developing countries, using SPs is not well known. Many building engineers in most developing countries including West African nations are still used to the traditional method of concrete formulation. The prevalence of an informal concrete industry reinforces the reliance on prescriptive ratios for

concrete mixes among many practicing engineers. These engineers from this part of Africa are very faithful to the prescriptive European Standards and therefore unable to throw off that feeling of inertia. At many construction sites in Ghana and other West African countries, less workable concrete is made workable by introducing more water. As already mentioned, increasing water to aid workability, which is associated with high porosity, has a negative performance on the mechanical and durability properties of concrete. The problem of poor-grade concrete due to the introduction of high porosity is widespread in many developing countries including Ghana, Nigeria, Togo, Burkina Faso, Cote d'Ivoire and Benin. Advanced and developed countries do achieve enhanced mechanical and durability properties through the use of superplasticizers. For instance, in Japan, it is reported that there is almost no concrete production without superplasticizers (Flatt *et al.*, 1998). Despite the crucial role that superplasticizers play in cement hydration for achieving optimal performance, many authors tend to understate or be less explicit about the significant contributions of superplasticizers in concrete (Pereira *et al.*, 2012; Sathyan *et al.*, 2019)

The other problem aside from the control of water content is the quality of fine aggregates used in the concrete matrix. The availability of sand for construction works is becoming rare due to excessive mining as a result of the increasing demand for shelter and other infrastructural facilities especially in developing countries including Ghana (Peprah, 2013). This has resulted in a high cost of sand for construction work. Local contractors source sand from any available pit located near their construction sites. The difficulty in transporting of quality sand from the right sources in the rainy season, coupled with the high cost of the sand, results in sourcing sand from nearby pits. This in turn results in the production of poor-grade concrete. The use of SNF superplasticizer may have the potential to improve the properties of concrete produced under such situations (Flatt *et al.*, 1998; Sathyan *et al.*, 2019)

\*Corresponding author: b23mark@gmail.com

<sup>1</sup>CSIR-Building and Road Research Institute, Advanced Material Science Division, Kumasi, Ghana

SPs in concrete disperse the cement through either electrostatic or steric repulsive forces causing the repulsion of cement powder and an increase in shear potential. This results in enhanced workability of the concrete without any addition of water that can introduce more pores and reduce the mechanical and durability behavior of concrete. The use of second-generation superplasticizers such as SNF and Sulphonated Melamine Formaldehyde (SMF) as well as new-generation superplasticizers in the form of polycarboxylate ethers (PCEs) have been used successfully in improving the technical properties of concrete. Therefore, the need to provide sufficient information on works that have successfully used superplasticizers to improve concrete properties is of great essence.

Compressive strength is a common parameter that is usually used as an indicator to check the load-bearing capacity of a structure. The involvement of SPs in concrete enhances the compressive strength properties. Aruntaş *et al.* (2008) found out from their work where they used fiber-reinforced concrete that SPs involvement increased the strength of concrete more than the control concrete after curing for 28, 90, and 180 days. Matias *et al.* (2013) introduced SPs in concrete prepared with recycled coarse aggregates as a replacement for natural coarse aggregates. It is well established that saturation of recycled aggregates leads to concrete strength loss. However, with the incorporation of SPs, Matias *et al.* (2013) did offset the strength loss due to saturation and generated a strength of concrete similar to the control concrete. Sardinha *et al.* (2016) in their study on replacing cement content with fine marble dust found that the incorporation of superplasticizers led to an increase in the strength of the concrete even with a decreased content of cement. Many other researchers have also shown in their research that SPs in the form of SNFs and PCEs have been observed to impart higher compressive strength of concrete (Bravo *et al.*, 2017; Andrade Neto *et al.*, 2021). Compressive strength enhancement of concrete containing SPs than that without SPs is attributed to the introduction of compacity with the involvement of SPs and low water-cement ratio while maintaining higher consistency (Pereira *et al.*, 2012; Manomi *et al.*, 2018; Arslan *et al.*, 2019). The study of Tkaczewska (2014) showed that voids are reduced when SPs find themselves in concrete. This, therefore, increases the strength of the early and late strength of concrete.

The flexural strength of concrete determines the bending loads a concrete beam can carry before failure. This strength property is very crucial for structural design. Many studies have shown that the application of SPs in concrete improves flexural strength. Al-Hussaini *et al.* (2020) studied the influence of SPs on waste plastic fiber concrete. Their findings indicated that the addition of SP increased the flexural behavior of the concrete at a late curing period of 28 days. The flexural strength increase of the concrete with SP was over 289 % compared to the control concrete. The reason for that improved flexural behavior was because of the enhanced workability and reduced water content of the concrete containing the SP. Reduced water content improves the density of concrete.

The modulus of elasticity of concrete is an indication of its stiffness or resistance to deformation (Bheel *et al.*, 2020). This parameter directly relates to the shortening of concrete components under compressive stress and due to creep and shrinkage (Alsalmán *et al.*, 2017). The creeping effect or stress shortening causes the redistribution of internal stresses between columns, beams, or walls in reinforced concrete structures. At the moment, there is no consensus on the ideal procedure for the determination of modulus of elasticity (MoE) because of the nonlinear nature of concrete under stress-strain deformation.

For static elastic modulus, different empirical models exist in various standards and codes relating the MoE to compressive strength (ACI 318-14; ACI 363R-10; Ma *et al.*, 2004). Static elastic modulus was investigated by Pereira *et al.* (2012) by using two different superplasticizers, lignosulphate and polycarboxylate ether for concrete containing recycled coarse aggregates. The work indicated that the use of superplasticizers significantly increases the MoE between 20.7 % (lignosulphate) and 33.0 % (PCE) above the concrete without a superplasticizer. The reason for the improved performance of the static elastic modulus of concrete containing SP is attributed to the improved bonding at the interfacial transition zone between cement and the coarse aggregates (Bravo *et al.*, 2017). Zhu and Bartos (2005) have indicated that the aggregate paste transition zone becomes dense and stiffer, hence improving the stiffness of the concrete.

The dynamic elastic modulus is vital for applications where the concrete is subjected to dynamic load applications where sudden load occurs in concrete structures. Many models have generated a correlation between static elastic modulus and dynamic modulus using the pulsonic velocity under a non-destructive testing (NDT) method (Pal, 2019). These models could be found in the ACI, EN, and IS codes as well as those developed by researchers (Popovics, 2008; ACI 318-14; ACI 363R-10; Ma *et al.*, 2004; Noguchi *et al.*, 2009). There is not so much work performed in the area of dynamic elastic modulus that relates to concrete with and without chemical and mineral admixtures. The durability of concrete is defined as the ability of the concrete to resist weathering action, chemical attack, abrasion, or any other process of deterioration; that is, durable concrete will retain its original form, quality, and serviceability when exposed to its environment (Patel and Shah, 2016). The methods used to assess the durability of concrete include transport mechanisms such as sorptivity, porosity, water absorption, and sorption. The transport properties explain the nature of pore size in a concrete material. Studies including chloride migration and penetration as well as sulphate and acidic attacks are common methods used to assess the performance of concrete against chemical attacks.

The studies of Sardinha *et al.* (2016) established that including superplasticizers in marble dust incorporated concretes allowed a decrease in water absorption due to their capacity to reduce the water-to-cement ratio (w/c), reducing the porosity of concrete as well. Najimi *et al.* (2012) studied the effect of natural zeolite on the durability properties of concrete. Their study replaced cement by weight at 15 and 30 % and incorporated a melamine-based superplasticizer. After 28 days of curing, the water penetration depths of 15 % and 30 % zeolite concretes were, respectively, reduced by about 13 % and 40 % in comparison with the control specimens. At the age of 90 days, the performances of 15 % and 30 % zeolite concrete were almost similar and about 33 % better than non-zeolite concrete. Many authors have reported the reason for such behaviour of concrete to lower sorptivity. SPs improve the hydration of cement and the compactness of the concrete matrix, hence making the concrete less permeable (Law *et al.*, 2014; Sathyan *et al.*, 2016).

Ramachandran *et al.* (2016) produced three different concretes; one without superplasticizer (NC), another with SNF superplasticizer (SP), and the other with fly ash and SNF superplasticizer (FA). Their results showed that the concretes labelled FA and SP had lower permeability than the concrete without SP and/or FA. The performance with respect to chloride permeability was much lower in the combined effect of FA and SP. This performance is attributed to the compactness of concrete with the inclusion of SPs. SPs are

known to reduce the w/c ratio of concrete and at the same time improve the workability of concrete. Tkaczewska (2014) has posited that as the water-to-cement ratio is decreased, the total porosity is also decreased and hence an improved density of the concrete.

In this study, the main objective was to provide sufficient data regarding the use of SPs and their effect on the mechanical and durability behavior of concrete produced using locally sourced pit sand. In achieving this, both the fresh and hardened properties of the concrete were investigated. In terms of the fresh properties, the slump, the fresh density, and the air voids were determined. The hardened state properties investigated

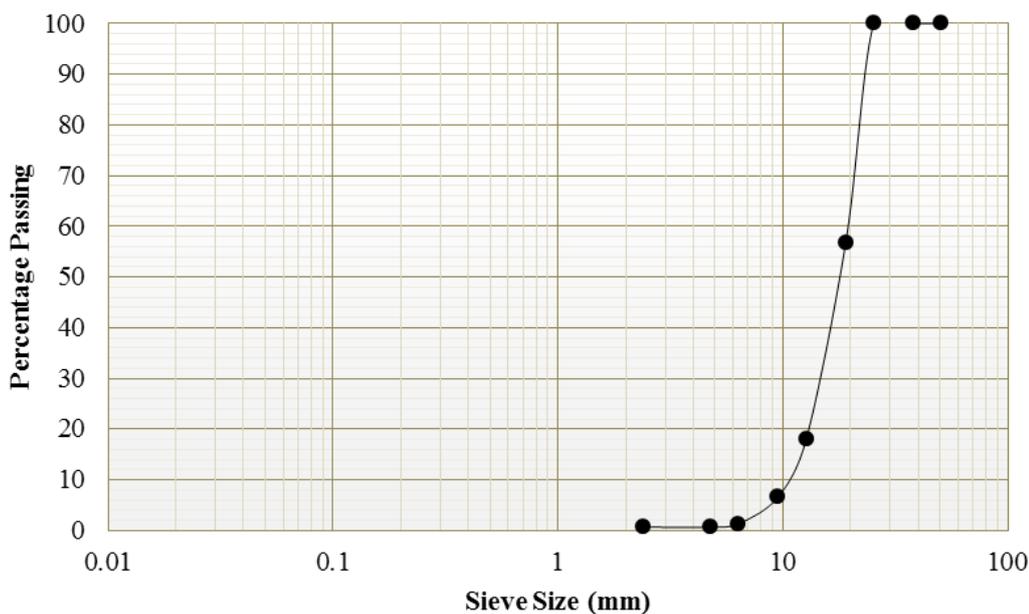
included compressive and flexural strength, elastic and dynamic moduli. The durability studies performed included water absorption, porosity, sorptivity, electrical surface resistivity, chloride penetration and acid attack. With the acid attack, not much has been investigated in terms of concrete with and without SNF superplasticizers.

**Materials and Experimental procedure**

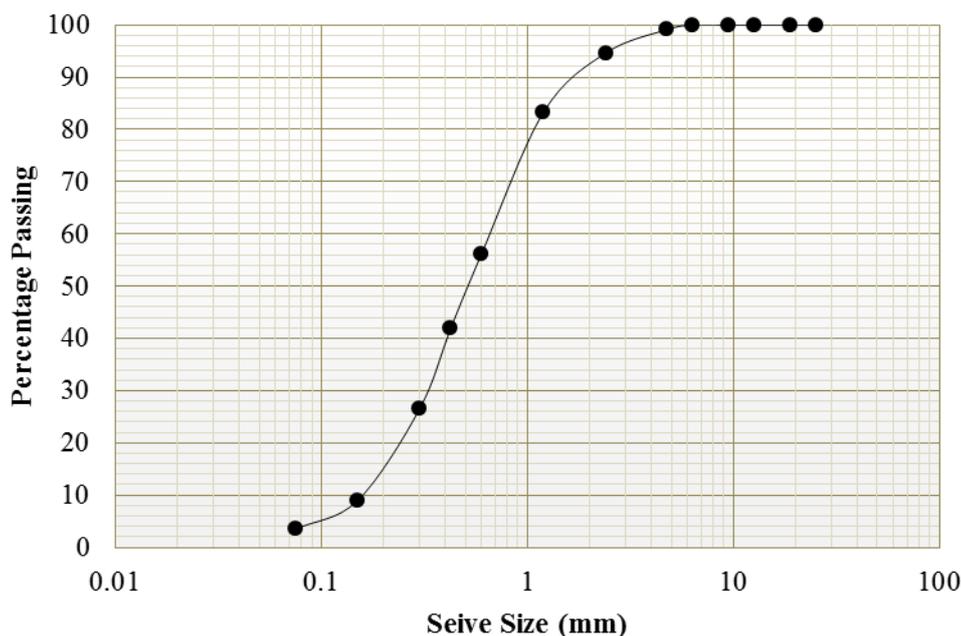
The materials used included Portland cement, aggregates (coarse and fine), potable water and a superplasticizer. The Portland cement (GHACEM super strong 42.5R) was obtained from a retail shop at Fumesua, Ashanti region. The chemical

**Table 1** Chemical composition of Portland cement

Chemical	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	SiO <sub>2</sub>	Na <sub>2</sub> O	CaO	K <sub>2</sub> O	SO <sub>3</sub>	Cl	LOI	IR
Quantity (%)	4.71	3.4	1.99	19.88	0.28	62.13	1.005	2.603	0.001	2.53	1.02



**Figure 1** Particle size distribution curve of coarse aggregates



**Figure 2** Particle size distribution curve for the locally sourced pit sand

properties of the Portland cement are shown in Table 1. The coarse aggregates were obtained from a local quarry site in the Ashanti region whereas the fine aggregates were also obtained from a local pit where sand is weaned at Juaben in the Ashanti region. This site is a newly discovered area, however, there is little data on the performance of the pit sand in concrete. Figures 1 and 2 show the particle size distributions of the aggregates. Sulphonated naphthalene formaldehyde (SNF) with 40 % solid content was obtained from a chemical producer in Ghana. The SNF was branded as Muraplast FK 48. Potable water used was obtained from the running tap in the CSIR-BRRI Civil Engineering Laboratory.

## Experimental procedure

### Concrete mix design and preparation

In performing the design mix, it was guided by the EN 206-1 (2000) standard. The characteristic strength of 30MPa and a slump of S3 (100-150 mm) were used for the design. The EN 206 uses tables and figures to obtain parameters of the mix such as free water-cement ratio, the wet density and the content of fine aggregates. For the mix containing the SNFs, the water content was reduced by 10 %. This reduction was per the manufacturer's product information which states that the product could reduce the water content of a concrete mix by up to 10 %.

After the mix design, the slump of the concrete was first determined through an iterative means using the slump cone. Figure 3 shows a test of the concrete slump. After achieving the required slump, the constituents of the concrete were proportioned and mixed in a concrete mixer of volume 0.5 m<sup>3</sup>. Prior to the proportioning and mixing, the volume of moulds per the test in context was estimated to receive the mixed concrete.

### Test on fresh properties

The fresh property of the mixtures was evaluated in terms of the slump and air content. The slump was carried out immediately after the mixing was completed in accordance with the test procedures in BS 12350-2 (2009). The slump



Figure 3 Determination of the slump of concrete

obtained for the mixtures is an indication of the workability of the mixtures which is correlated to its practical application. The air content of the fresh concrete was determined in accordance with the ASTM 231 (2014). Figure 4 shows the setup for the air content meter of concrete.

### Test on hardened properties

Compression tests were performed according to EN 12390-3 (2009). The test machine used was the model Matest servo machine with a maximum load capacity of 1500 kN, while the loading rate adopted was 2.4 KN/s. The tests were carried out at 1, 3, 7, 28, 60 and 90 days of water curing.

The flexural strength of the concrete mixtures was evaluated using prism samples with a dimension of 100 mm × 100 mm × 500 mm and the test procedures in BS EN 12390-5 (2009) were followed. The flexural strength was evaluated at 28 days.

The static modulus of elasticity in compression was measured according to BS EN 12390-13 (2013) at 28 days. For the test, cylindrical specimens with a height of 200mm and a diameter of 100 mm were prepared. Two strain gauges with a length of 40 mm were placed on opposite sides, at the middle of each specimen. The setup for the MoE is shown in Figure 5.

The dynamic modulus of elasticity ( $E_D$ ) was performed on the specimens prepared for flexural strength at 28 days.  $E_D$  was determined by applying the UPV method by ASTM C597-2 (2016) and calculated using Equation (1). Tests on the hardened concrete were performed on three specimens.

$$E_D = V^2 Q \frac{(1+n)(1-2n)}{1-n} \quad (1)$$

Where  $E_D$  = dynamic elastic modulus,  $V$  = velocity in km/s,  $Q$  = concrete density in kg/m<sup>3</sup> and  $n$  = Poisson's ratio (0.30 for low strength concrete).



Figure 4 Setup of air content meter



Figure 5 Setup for the MoE

### Durability indicators

A sorption test was performed on the concrete specimens using the ASTM C1757 (2013) method. The concrete samples were oven-dried at 50 °C until a constant weight was obtained. The concrete samples were immersed in water for 30 minutes. Equation (2) was used to determine the sorption values.

$$\text{Sorption} = \frac{W-D}{A \times d} \quad (2)$$

Where  $W$  = mass of specimen after immersion in grams,  $D$  = mass of oven-dried specimen in grams,  $A$  = the surface area of the specimen in square millimetres ( $6L^2$ , Where  $L$  = length of cube), and  $d$  = density of water (0.001) in grams per cubic millimetre.

Water absorption values of concrete specimens with and without SNF after 28 of moist curing were measured as per ASTM C642 (2013). The difference between the saturated mass and oven-dry mass ( $105 \pm C$ ) expressed as a fractional percentage of oven-dry mass gives the water absorption.

Sorptivity tests were performed at 28 days using cubic specimens with dimensions  $100 \times 100 \times 100 \text{ mm}^3$  in accordance with ASTM C-1585 (2004).

Porosity of the concrete was performed in accordance with ASTM C642 (2013). Saturated concrete samples were weighed and then oven-dried at a temperature of  $105 \pm 5 \text{ }^\circ\text{C}$  until a constant weight was achieved. The porosity was calculated using Equation (3).

$$\text{Sorption} = \frac{W_{24} - W_{od}}{V_c} \times 100\% \quad (3)$$

Where  $P$  is porosity (%),  $W_{24}$  is weight of concrete after 24 hours immersion in water,  $W_{od}$  is oven-dried weight and  $V_c$  is the volume of the concrete cube.

Rapid chloride permeability test was conducted per ASTM C1202 (2019). Two specimens of 100 mm in diameter and 50 mm in thickness which had been conditioned according to the standard were subjected to a 60 V potential for 6 h. The total charge that had passed through the concrete specimens was determined and used to evaluate the chloride permeability of each concrete mixture. The electrical resistivity meter was used to measure the surface resistivity (SR) of the specimens. This

non-destructive laboratory test method measures the electrical resistivity of water-saturated concrete and provides an indication of its permeability. Electric current flows more easily in concrete when pores are saturated. The test result is a function of the electrical resistance of the specimen. A schematic figure of the electrical resistivity meter is shown in Figure 6. Equation (4) was used to evaluate the electrical resistivity of concrete under saturated conditions.

$$\rho = R \frac{A}{L} = \frac{VA}{LU} \quad (4)$$

Where  $R$  is the electric resistance, ( $k\Omega\text{cm}$ ),  $I$ , current (Amp.),  $V$ , voltage (Volts),  $\rho$  electric resistivity ( $X_m$ ),  $L$ , length (cm), and  $A$  ( $\text{cm}^2$ ) is the area of the test specimen

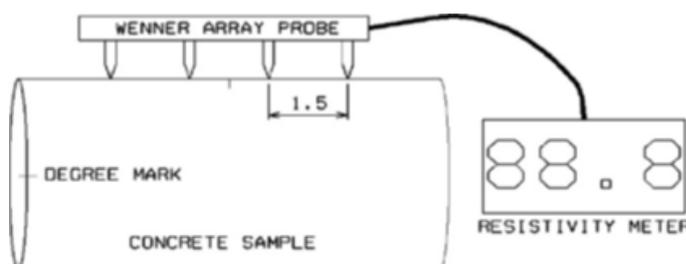


Figure 6 Schematic figure of electrical resistivity meter (FM 5-578, 2004)

Acid attack was performed in accordance with ASTM C267-01. Concrete cured for 28 days in moisture were transferred into 5 % sulphuric acid solution. The weights of the specimens were determined and recorded at 7, 14, 21 and 28 days. Compressive strength change factor (CSCF) was performed using Equation (5).

$$\text{CSCF} = \frac{f_{Icu_{28 \text{ days}}} - f_{Icu_{\text{immersed samples}}}}{f_{Icu_{28 \text{ days}}}} \times 100 \quad (5)$$

Ultra-sonic pulse velocity analysis was conducted in accordance with ASTM C597 (2016) on concrete prisms. Pulses of longitudinal stress waves were generated by an electro-acoustical transducer (emitter) that was held in contact with one surface of the concrete under test. After traversing through the concrete, the pulses were received and converted into electrical energy by a second transducer (receiver) located a distance  $L$  from the transmitting transducer. The transit time  $T$  was measured electronically. The pulse velocity  $V$  was calculated by dividing  $L$  by  $T$ . Sufficient coupling agent and pressure was applied to the transducers to ensure stable transit times.

## Results and Discussion

### Fresh properties

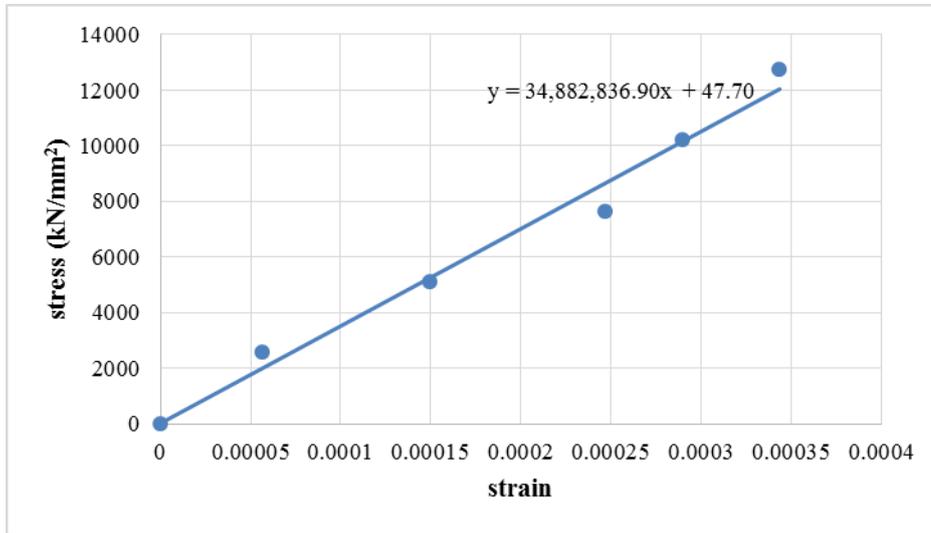
The slump and the air content results of the control and SNF concrete are shown in Table 2. The slump for the control and the SNF concretes were 108 and 130mm respectively. Both mixes satisfied the S3 workability requirement which is 100-150mm. However, the inclusion of the SNF made the concrete more workable than the control concrete. With the air content, the introduction of SNF did not have a significant impact on air content compared to the control.

Table 2 Slump and air content of concrete

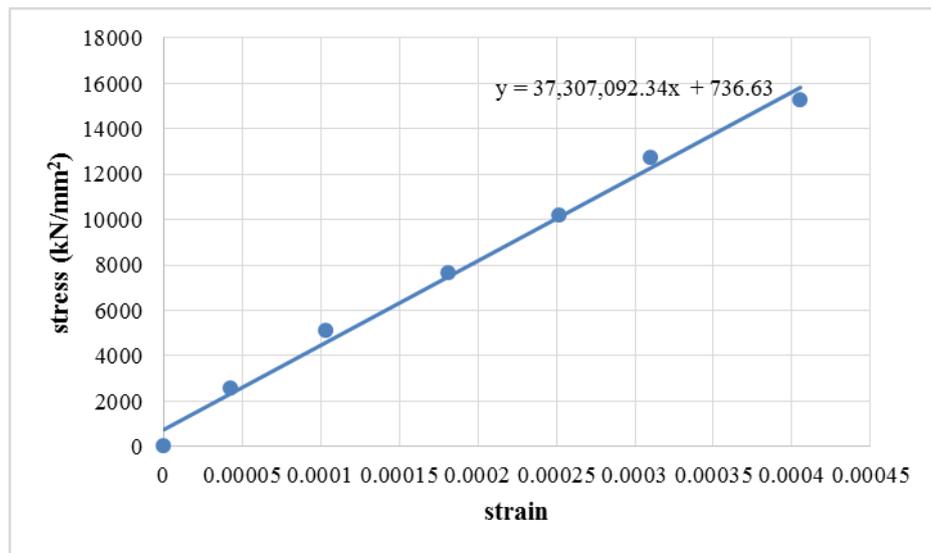
Mix	Slump (mm)	Air content (%)
CON	108	2.5
SNF	130	2.8

**Table 3** Compressive and flexural strength, elastic and dynamic moduli of CON and SNF concrete

Mix	Compressive strength (MPa) (CoV)						Flexural Str. (MPa) (CoV)	E <sub>D</sub> (GPa) (CoV)
	1d	3d	7d	28d	60d	90d		
CON	14.37	22.42	27.65	28.66	33.93	34.44	4.6(1.55)	36.645 (0.81)
	(3.91)	(5.92)	(8.25)	(3.51)	(3.60)	(4.07)		
SNF	16.50	29.82	31.73	36.61	36.44	38.44	4.9 (8.66)	38.561 (1.00)
	(6.13)	(7.74)	(4.06)	(4.00)	(8.10)	(4.007)		



**Figure 7** MoE of control (CON) concrete



**Figure 8** MoE of superplasticised (SNF) concrete

**Hardened properties**

Table 3 presents the results of the parameters classified as hardened properties and they include compressive and flexural strength, and dynamic ( $E_D$ ) moduli. In Figures 4 and 5, the static elastic modulus ( $E_s$ ) of the concretes is shown. The compressive strength of the CON ranges between 14 and 34 MPa, CoV from 3.51 to 8.25 whereas that of the SNF concrete was between 16 and 38 MPa, and CoV from 4.00 to 8.10. The SNF concrete attained a higher strength at all periods than the control concrete ranging between 7 and 33 %. Tkaczewska (2014) has explained that the introduction of SPs reduces the voids in the concrete matrix. With the reduction of voids, the compacity of the concrete containing SP increased with a low water-to-cement ratio while maintaining higher consistency (Pereira *et al.*, 2012; Manomi *et al.*, 2018; Arslan *et al.*, 2019).

Flexural strength of the concretes, CON and SNF were 4.6 and 4.9 MPa respectively indicating that there was a marginal increase in the SNF concrete. This shows that the addition of the SNF does not necessarily compromise the flexural behavior of concrete. With the dynamic modulus of elasticity, it varied from approximately 37 GPa (CON) to approximately 39GPa (SNF). The results indicated that SNF addition to concrete resulted in an increase and it was approximately 5 % at the 28 days of curing. According to Pederneiras *et al* (2021), a more compact and less porous cement system results in higher stiffness and, hence, high dynamic modulus.

The MoE results of the CON and SNF concretes are shown in Figures 4 and 5 respectively. The MoE values of the CON and SNF concretes were approximately 34.9 GPa and 37.3 GPa respectively. The introduction of the superplasticizer increased

the MoE of the SNF over CON concrete by approximately 7%. The enhancement of the MoE with the incorporation of SNF superplasticizer indicates that there was a stronger interfacial transition bond between the cement paste and the aggregates than the concrete without the superplasticizer. This reason is supported by the studies of many researchers including Bheel *et al.* (2020) and Evram *et al.* (2020).

Table 4 outlines the results of the UPV analysis on the CON and SNF concrete prisms. From the table, the traverse time respectively were 110.7 and 108.2  $\mu$ s for CON and SNF concretes. The SNF concrete recorded a lower traverse time, about 2% lower than that of the CON. The velocity of the CON and SNF concrete were 4.517 and 4.623 km/s respectively, signifying an excellent concrete quality for both mixes. However, the velocity obtained for the SNF concrete was about 2% greater than that of the control. The increase in the velocity of the SNF concrete can be attributed to the formation of a well-dense and compact concrete matrix obtained as a result of the incorporation of the SNF.

**Table 4** Traverse time and velocity of CON and SNF concrete

Mix	Traverse time ( $\mu$ s)	Velocity (km/s)
CON	110.7	4.517
SNF	108.2	4.623

### Durability

Table 5 presents the results of the durability indicators which include sorption, water absorption (WA), porosity, chloride penetration and electrical surface resistivity (SR) of the concretes. The results of the rate of water absorption are depicted in Figures 6 and 7. From the table, the sorption, water absorption, porosity and chloride penetration of the SNF

concretes were lower than the CON concretes with percentage reductions of 19.7%, 12.5%, 11.2% and 17.9% respectively.

The reduction in the sorption, water absorption and porosity suggest that the introduction of SNF caused a decreased in the sizes of the interconnected pores in the concrete. Zeyad *et al.* (2019) have explained that pore size reduction restricts water movement through the free voids in concrete. The restriction of charges through the SNF concrete indicates a better solidification of the concrete. The performance of the SNF concrete falls in line with the observations of Zeyad *et al.* (2020).

From Figures 9 and 10, the initial sorptivity coefficient of SNF was 12% lower than CON. However, the secondary sorptivity coefficient of SNF was 8% lower than CON. High initial sorptivity coefficient of the SNF concrete may be attributable to the presence of large pores and then as the pores changed to smaller one, the SNF attained a lower sorptivity coefficient.

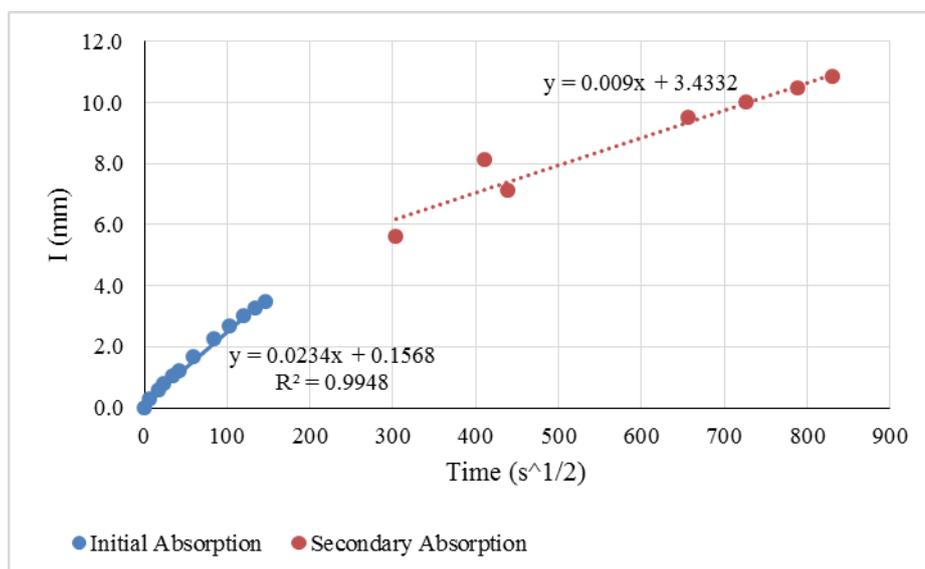
Table 5 also shows that the electrical surface resistivity increased from 5.46 (CON) to 10.07 (SNF). The increment was approximately 84% at 28 days of curing. Studies by Dhandapani *et al.* (2018), Dhandapani and Santhanam (2017) and Feliú *et al.* (1996) have all stated that electrical resistivity is among appropriate ways to examine concrete ability to resist chloride penetration in concrete. Thus, the performance of SNF concrete suggest a better resistance to chloride penetration than the CON concrete

### Acid attack

Figure 11 depicts the weight losses of the CON and SNF concretes exposed in acidic environment for 7, 14, 21 and 28 days. From the figure, the SNF concrete had higher weight losses at the various exposure periods, ranging between 3 and 7% than the CON concrete which was between -0.07 and 3%. Table 6 displays the compressive strength of the concrete after

**Table 5** Sorption, water absorption, porosity, chloride penetration and electrical surface resistivity of CON and SNF concrete

Mix	Durability test at 28 days				
	Sorption (CoV)	WA (%) (CoV)	Porosity (%) (CoV)	RCPT (C)(CoV)	SR (k $\Omega$ cm) (CoV)
CON	1.095	5.21 (1.81)	12.55 (2.18)	3657 (1.46)	5.46 (13.97)
SNF	0.879	4.56 (1.28)	11.14 (0.82)	3002 (3.25)	10.07 (4.61)



**Figure 9** Rate of water absorption of control concrete

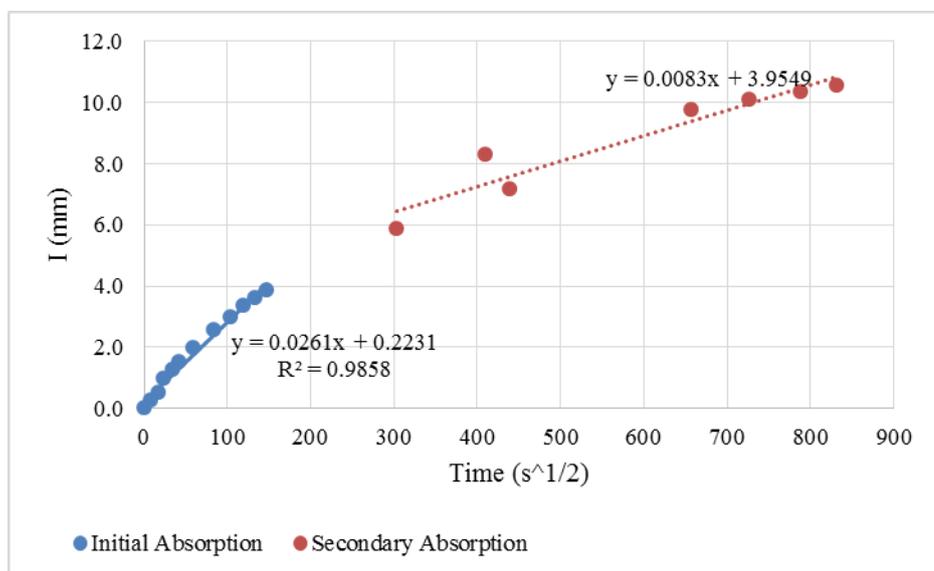


Figure 10 Rate of water absorption in SNF concrete

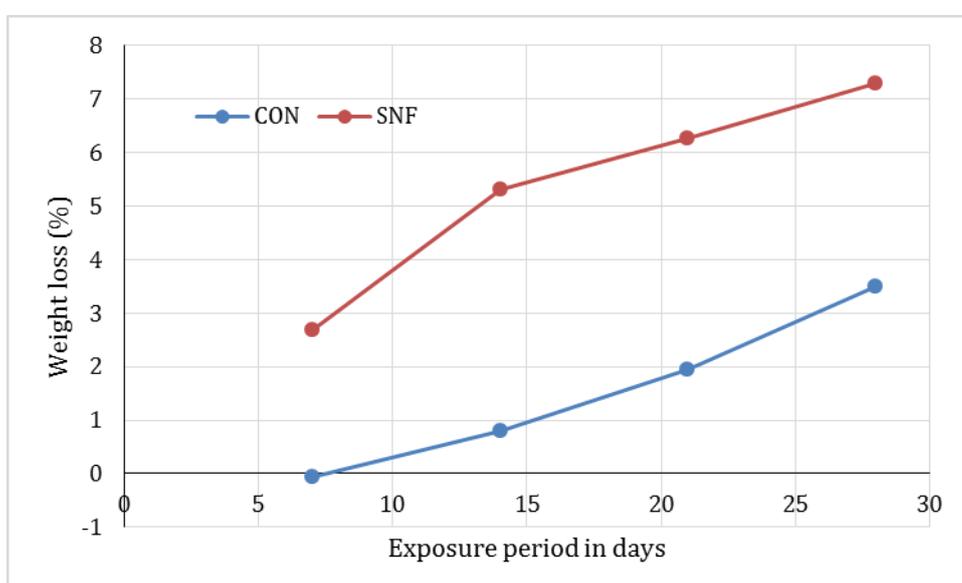


Figure 11 Weight loss of concretes after exposure

Table 6 Compressive strength of concrete cured after 328 days and after exposure for 28 days in acid

Mix	Achieved strength after mix design (MPa)	Strength after exposure at 28 days (MPa)	CSCF (%)
CON	28.7	9.7	66.1
SNF	36.6	13.7	62.7

the exposure in the acidic medium. The compressive strength change factor (CSCF) varied from 66.1 % for the CON concrete to 62.7 % for the SNF concrete. This suggest that SNF concrete have a better resistance to acid than without SNF (CON). Figures 12 and 13 respectively show the Visual observation of the CON and SNF concrete specimen at various ages in acidic solution.

It could be observed that the mass loss and the strength loss exhibited contradictory outcomes. Goyal *et al.* (2009) posit that mass loss is not a reliable index for measuring efficiency of concrete against acidic attack. Furthermore, the high mass loss in the SNF is attributable to the decrease in the water-cement ratio with altering cement content. This therefore leads to the formation of more gypsum compounds on the surface of the concrete, causing expansion and ultimate

deterioration. With strength measurements, Goya *et al.* (2009) mention that it takes consideration of the whole concrete matrix. Therefore, SNFs gives better protection of the inner matrix of the concrete much better than concrete without SNFs in acidic environment.

### Conclusions

The work investigated the mechanical and durability properties of concrete with one batch containing SNF superplasticizer and the other without the superplasticizer. The characteristic strength of 30 MPa was used for the concrete design. The fresh properties of the concrete involving slump and air content and the hardened properties including compressive and flexural strengths, elastic and dynamic modulus were investigated. Durability indicators involving sorption, water absorption,



**Figure 12** Visual observation of the control (CON) concrete specimen at various ages in acidic solution



**Figure 13** Visual observation of the SNF concrete specimen at various ages in acidic solution

porosity, chloride penetration, electrical surface resistivity and acid attack were also investigated. From the results of the study, the following conclusions were made:

1. The use of SNF superplasticizer improves the workability of concrete. However, there is no significant effect in terms of the air content of the concrete
2. The inclusion of SNF superplasticizers enhanced the compressive and flexural strength as well as the static and dynamic modulus of concrete. The enhancement in the hardened properties is attributable to the compactness, the strong cement matrix-aggregate bond, and the elimination of voids in the concrete.
3. The addition of SNF significantly restricts the movement of ions in concrete thus improving the durability of concrete. This was observed from the sorption, water absorption, sorptivity, chloride penetration and electrical surface resistance test.
4. The inclusion of SNF in concrete protects the overall concrete matrix much better in the acidic medium than with concrete without SNF superplasticizers

The investigation underscores the potential benefits of integrating SNF in concrete production. Given its observed positive effects on both mechanical strength and durability properties, this study advocates for the adoption of SNF superplasticizers in concrete formulations tailored for regional construction needs, facilitating improved quality and longevity in concrete structures within Ghana's construction industry.

### Conflict of Interest Declaration

The authors declare that there are no conflicts of interest regarding the publication of this article.

### Acknowledgment

The authors are grateful to the technicians at the Materials Laboratory of CSIR-BRRI and the Construction and Civil

Engineering Laboratory at AAMUSTED for their support in carrying out the study.

### References

- ACI Committee 363 (2010), Report on High-Strength Concrete, ACI, Farmington Hills, MI, 27 pp.
- Alsaman, A., Dang, C.N., Prinz, G.S., Hale, W.M. (2017). Evaluation of modulus of elasticity of ultra-high performance concrete. *Construction and Building Materials* 153, pp. 918–928. <https://doi.org/10.1016/j.conbuildmat.2017.07.158>.
- Al-Hussaini, O. M., AL-Baghdadi, W. H., Al-Labban, S. N., Jabal, Q. A. (2020). Investigation the properties of waste plastic fiber concrete modified with HP-570 Super-Plasticizer. *IOP Conference Series: Materials Science and Engineering*, 978(1), 012026. <https://doi.org/10.1088/1757-899x/978/1/012026>.
- American Society for Testing and Material. (2004). Standard test method for measurement of rate of absorption of water by hydraulic-cement concretes, ASTM C 1585 – 04.
- American Society for Testing and Material. (2013). Standard test method for determination of one-point, bulk water sorption of dried concrete, ASTM C 1757 – 13.
- American Society for Testing and Material. (2013). Standard test method for density, absorption, and voids in hardened concrete, ASTM C 642 – 13.
- American Society for Testing and Material. (2014). Standard test method for air content of freshly mixed concrete by the pressure method, ASTM C231-14.
- American Society for Testing and Material. (2016). Standard test method for pulse velocity through concrete; American society for testing and materials: West Conshohocken, PA, USA, 2016
- American Society for Testing and Material. (2019). Standard test method for electrical indication of concrete's ability to resist chloride ion penetration, ASTM International, West Conshohocken, PA, 2019, [www.astm.org](http://www.astm.org).
- Andrade Neto, J. da S., de França, M.J.S., Amorim Júnior, N.S. de, Ribeiro, D.V. (2021). Effects of adding sugarcane bagasse ash on the properties and durability of concrete. *Construction and Building Materials* 266, 120959. <https://doi.org/10.1016/j.conbuildmat.2020.120959>.

- Arslan, H., Aytac, U.S., Bilir, T., Sen, S. (2019). The synthesis of a new chitosan based superplasticizer and investigation of its effects on concrete properties. *Construction and Building Materials* 204, pp. 541–549. <https://doi.org/10.1016/j.conbuildmat.2019.01.209>.
- Aruntaş, H.Y., Cemalgil, S., Şimşek, O., Durmuş, G., Erdal, M. (2008). Effects of super plasticizer and curing conditions on properties of concrete with and without fiber. *Materials Letters* 62, pp. 3441–3443. <https://doi.org/10.1016/j.matlet.2008.02.064>.
- Bheel, N., Ibrahim, M.H.W., Adesina, A., Kennedy, C., Shar, I.A. (2020). Mechanical performance of concrete incorporating wheat straw ash as partial replacement of cement. *Journal of Building Pathology and Rehabilitation* 6. <https://doi.org/10.1007/s41024-020-00099-7>.
- Bheel, N., Mahro, S.K., Adesina, A. (2020). Influence of coconut shell ash on workability, mechanical properties, and embodied carbon of concrete. *Environmental Science and Pollution Research* 28, 5682–5692. <https://doi.org/10.1007/s11356-020-10882-1>.
- Bravo, M., de Brito, J., Evangelista, L., Pacheco, J. (2017). Superplasticizer's efficiency on the mechanical properties of recycled aggregates concrete: Influence of recycled aggregates composition and incorporation ratio. *Construction and Building Materials* 153, pp. 129–138. <https://doi.org/10.1016/j.conbuildmat.2017.07.103>.
- Building Code Requirements for Structural Concrete. (2014). Commentary on building code requirements for structural concrete (ACI 318R-14), Farmington Hills, MI, 317 pp.
- Dhandapani, Y., Sakthivel, T., Santhanam, M., Gettu, R., Pillai, R.G. (2018). Mechanical properties and durability performance of concretes with Limestone Calcined Clay Cement (LC3). *Cement and Concrete Research* 107, pp. 136–151. <https://doi.org/10.1016/j.cemconres.2018.02.005>.
- Dhandapani, Y., Santhanam, M. (2017). Assessment of pore structure evolution in the limestone calcined clay cementitious system and its implications for performance. *Cement and Concrete Composites* 84, pp. 36–47. <https://doi.org/10.1016/j.cemconcomp.2017.08.012>.
- European Committee for Standardization. (2000). Specification, performance, production and conformity, BS EN 206-1:2000.
- European Committee for Standardization. (2009). Testing fresh concrete Part 2: Slump-test, BS EN 12350-2:2009
- European Committee for Standardization. (2009). Testing hardened concrete. compressive strength of test specimens, BS EN 12390-3:2009.
- European Committee for Standardization. (2009). Testing hardened concrete. Flexural strength of test specimens, BS EN 12390-5:2009.
- European Committee for Standardization. (2013). Testing hardened concrete. Determination of secant modulus of elasticity in compression, BS EN 12390-13:2009.
- Evrarn, A., Akçaoğlu, T., Ramyar, K., Çubukçuoğlu, B. (2020). Effects of waste electronic plastic and marble dust on hardened properties of high strength concrete. *Construction and Building Materials* 263, 120928. <https://doi.org/10.1016/j.conbuildmat.2020.120928>.
- Feliu, S., Andrade, C., González, J.A., Alonso, C. (1996). A new method for in-situ measurement of electrical resistivity of reinforced concrete. *Materials and Structures* 29, pp. 362–365. <https://doi.org/10.1007/bf02486344>.
- Flatt R.J., Houst Y.F., Oesch R., Bowen P., Hofmann, H., Widmer J., Sulser, U., Maeder, U. and Bürge, T.A. (1998). Analysis of superplasticizers used in concrete, *Analisis Magazine*, 26(2).
- FM 5-578. (2004). Florida method of test for concrete resistivity as an electrical indicator of its permeability.
- Goyal, S., Kumar, M., Sidhu, D.S., Bhattacharjee, B. (2009). Resistance of mineral admixture concrete to acid attack. *Journal of Advanced Concrete Technology* 7, pp. 273–283. <https://doi.org/10.3151/jact.7.273>.
- Law, D.W., Adam, A.A., Molyneaux, T.K., Patnaikuni, I., Wardhono, A. (2014). Long term durability properties of class F fly ash geopolymer concrete. *Materials and Structures* 48, pp. 721–731. <https://doi.org/10.1617/s11527-014-0268-9>.
- Ma, J., Dehn, F., Tue, N.V., Orgass, M., Schmidt, D. (2004). Comparative investigations on ultra-high performance concrete with and without coarse aggregates, In: *Proceedings of the 1st International Symposium on Ultra-High Performance Concrete*, Kassel, Germany, 2004, pp. 205 – 212.
- Maia Pederneiras, C., Veiga, R., de Brito, J. (2021). Incorporation of natural fibres in rendering mortars for the durability of walls. *Infrastructures* 6, 82. <https://doi.org/10.3390/infrastructures6060082>
- Manomi, N., Sathyan, D., Anand, K.B. (2018). Coupled effect of superplasticizer dosage and fly ash content on strength and durability of concrete. *Materials Today: Proceedings* 5, pp. 24033–24042. <https://doi.org/10.1016/j.matpr.2018.10.196>.
- Manomi, N., Sathyan, D., Anand, K.B. (2018). Coupled effect of superplasticizer dosage and fly ash content on strength and durability of concrete. *Materials Today: Proceedings* 5, pp. 24033–24042. <https://doi.org/10.1016/j.matpr.2018.10.196>.
- Matias, D., de Brito, J., Rosa, A., Pedro, D. (2013). Mechanical properties of concrete produced with recycled coarse aggregates – influence of the use of superplasticizers. *Construction and Building Materials* 44, pp. 101–109. <https://doi.org/10.1016/j.conbuildmat.2013.03.011>.
- Najimi, M., Sobhani, J., Ahmadi, B., Shekarchi, M. (2012). An experimental study on durability properties of concrete containing zeolite as a highly reactive natural pozzolan. *Construction and Building Materials* 35, pp. 1023–1033. <https://doi.org/10.1016/j.conbuildmat.2012.04.038>.
- Noguchi, T., Tomosawa, F., Nemati, K. M., Chiaia, B. M., Fantilli, A. P. (2009). A practical equation for Modulus of elasticity of concrete, *ACI Struct. J.* 106, 690–696.
- Pal, P. (2019). Dynamic Poisson's ratio and modulus of elasticity of Pozzolana Portland cement concrete. *International Journal of Engineering and Technology Innovation*, 9(2), pp. 131-144.
- Parra, C., Valcuende, M., Gómez, F. (2011). Splitting tensile strength and modulus of elasticity of self-compacting concrete. *Construction and Building Materials* 25, 201–207. <https://doi.org/10.1016/j.conbuildmat.2010.06.037>.
- Patel, V., Shah, N. (2016). Durability Study of M70 Grade Structural Concrete. *Iranian Journal of Science and Technology, Transactions of Civil Engineering* 41, pp. 241–248. <https://doi.org/10.1007/s40996-016-0046-8>.
- Pereira, P., Evangelista, L., de Brito, J. (2012). The effect of superplasticisers on the workability and compressive strength of concrete made with fine recycled concrete aggregates. *Construction and Building Materials* 28, pp. 722–729. <https://doi.org/10.1016/j.conbuildmat.2011.10.050>.
- Pereira, P., Evangelista, L., de Brito, J. (2012). The effect of superplasticizers on the mechanical performance of concrete made with fine recycled concrete aggregates. *Cement and Concrete Composites* 34, pp. 1044–1052.

- <https://doi.org/10.1016/j.cemconcomp.2012.06.009>.
- Popovics, J. S. (2008). A study of static and dynamic modulus of elasticity of concrete. University of Illinois, Urbana, IL. ACI-CRC Final Report.
- Ramachandran, D., George, R.P., Vishwakarma, V., Kamachi Mudali, U. (2016). Strength and durability studies of fly ash concrete in sea water environments compared with normal and superplasticizer concrete. *KSCE Journal of Civil Engineering* 21, pp. 1282–1290. <https://doi.org/10.1007/s12205-016-0272-4>.
- Sardinha, M., de Brito, J., Rodrigues, R. (2016). Durability properties of structural concrete containing very fine aggregates of marble sludge. *Construction and Building Materials* 119, pp. 45–52. <https://doi.org/10.1016/j.conbuildmat.2016.05.071>.
- Sathyan, D., & Anand, K. B. (2019). Influence of superplasticizer family on the durability characteristics of fly ash incorporated cement concrete. *Construction and Building Materials* 204, pp. 864–874. <https://doi.org/10.1016/j.conbuildmat.2019.01>.
- Tkaczewska, E. (2014). Effect of the superplasticizer type on the properties of the fly ash blended cement. *Construction and Building Materials*, 70, pp. 388–393. <https://doi.org/10.1016/j.conbuildmat.2014.07.096>.
- Zeyad, A.M., Khan, A.H., Tayeh, B.A. (2020). Durability and strength characteristics of high-strength concrete incorporated with volcanic pumice powder and polypropylene fibers. *Journal of Materials Research and Technology*, 9, pp. 806–818. <https://doi.org/10.1016/j.jmrt.2019.11.021>.
- Zeyad, A.M., Tayeh, B.A., Yusuf, M.O. (2019). Strength and transport characteristics of volcanic pumice powder based high strength concrete. *Construction and Building Materials*, 216, pp. 314–324. <https://doi.org/10.1016/j.conbuildmat.2019.05.026>
- Zhu, W., Bartos, P. J. M. (2005). Microstructure and properties of interfacial transition zone in SCC. In: Yu Z, Shi C, Khayat KH, Xie Y, editors. Proceedings of 1st international symposium on design performance and use of self-consolidating concrete. Changsha: RILEM Publications S.A.R.L. p.319–27.