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Effect of NaCl on the Mechanical Properties of Structural Lightweight Concrete Reinforced with Fibers

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Abstract

Foamed concrete is a versatile material that has been of great significance and been the subject of large industrial demand in recent years for a wide range of construction projects. The foam agent is used to produce lightweight concrete. In this study, the slump flow of foamed concrete was measured, along with the hardening properties of compressive strength, splitting tensile strength, and flexural strength. Glass fibers (GF) and polypropylene fibers (PPF) were used, the volume fractions of GF and PPF being 0.06, 0.2, 0.4, and 0.6 %, and 0.2, 0.6, 1, and 1.4 %, respectively. Additionally, the study focuses on saltwater curing. The saltwater used was sodium chloride solution (NaCl) in the order of 5 % concentration of NaCl in water. The results show that saltwater curing decreased the mechanical properties of, and caused degradation in, foamed concrete. However, the addition of fibers to the foamed concrete improved the performance of such concrete in saltwater curing. GF gave the best results, compared with PPF, whereas use of 0.6 % GF in foamed concrete contributed the least reduction, of 0.2, 0.25, and 0.5 %, in compressive strength, splitting tensile strength and flexural strength, respectively.

Keywords: Lightweight concrete, foamed concrete, glass fibers (GF), polypropylene fibers (PPF), saltwater, sodium chloride (NaCl)

Introduction

Structural lightweight concrete is similar to normal weight concrete, but has a lower density [1]. Structural lightweight concrete is defined as concrete having compressive strength up to 17 MPa, with a bulk density of less than 1950 kg/m^3, Structural lightweight concrete can be 25 % lighter than normal-weight concrete with a compressive strength up to 60 MPa [2]. Foamed concrete is defined as a cellular material constituted of a cement-sand matrix including a great number of small pores roughly 0.1 - 1.0 mm in size and which are consistently distributed in the matrix [3,4]. Glass fibers (GF) advance the strength of the material by increasing the force required for deformation and develop the toughness by increasing the energy required for crack propagation [5]. Polypropylene fibers (PPF) are the most common of the synthetics. They are chemically inert, hydrophobic and lightweight [1].

Seawater is a complex mix of many salts containing living matter, suspended silt, dissolved gases, and decaying organic material. Salt concentration in sea water is about 3.5 % as average, and this percentage varies from sea to sea depending on the geographical location [6]. **Figure 1** shows percentages of seawater compounds [7].

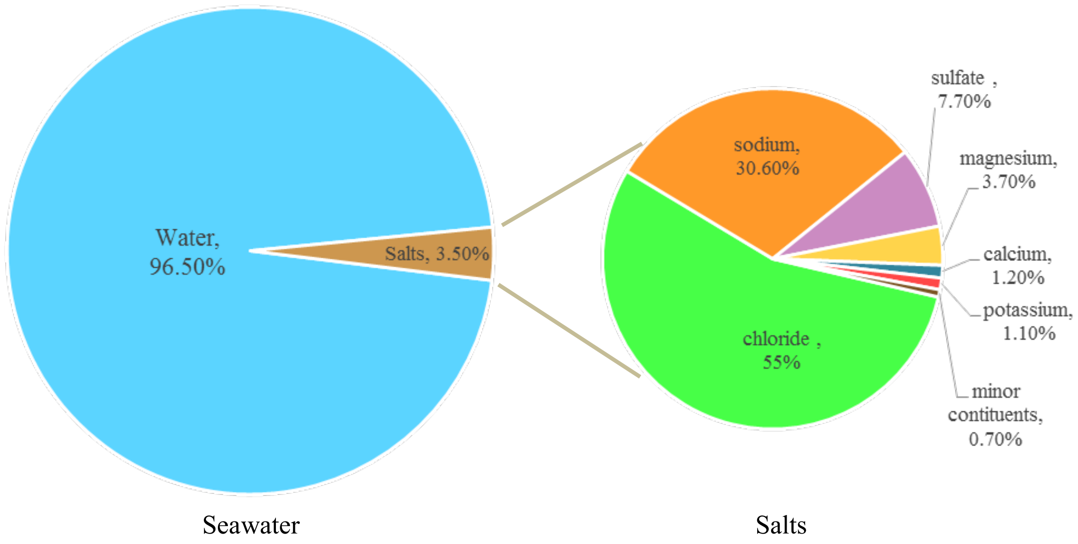

Figure 1 Compounds of seawater [7].

Sodium chloride, when used in mixing water, causes an increase in the compressive strength of concrete at a concentration of 25 gm per 1 kg of solution, with additional reduction in water vapour transmission. However, NaCl is seen to have uneven effects in concrete, causes set acceleration in some types of cement, and has retarding effects in others [8]. When concrete is exposed to a chloride-exposed environment, the tricalcium aluminate (C_3A) phase in the concrete reacts with the chloride and forms Friedels salt ($3CaO.Al_2O_3.CaCl_2.10H_2O$) (Calcium chloroaluminate) [9]. Chloride ions may cause a contrary effect on hardened concrete in a variety of ways. It may attack concrete in different forms; this is generally attributable to the formation of Friedels salt. Also, the creation of excess calcium chloride may cause increased permeability in concrete. The process of chloride attack on concrete may be explained by the following series of chemical reactions [10-12].

$$\underset{\text{(Calcium Hydroxide)}}{Ca(OH)_2} + \underset{\text{(Sodium Chloride)}}{2NaCl} \longrightarrow \underset{\text{(Calcium Chloride)}}{CaCl_2} + \underset{\text{(Sodium Hydroxide)}}{2NaOH}$$

$$\underset{\text{(Calcium Chloride)}}{CaCl_2} + \underset{\text{(Tri-Calcium Aluminate)}}{3CaO.Al_2O_3} + 10H_2O \longrightarrow \underset{\substack{\text{(Calcium Chloroaluminate)}\\ \text{(Friedels Salt)}}}{3CaO.Al_2O_3.CaCl_2.10H_2O}$$

Therefore, this research aimed to investigate the use of glass and polypropylene fibers with structural lightweight concrete, and to study the properties of such concrete after saltwater curing.

Experimental

Proportioning and preparation of foamed concrete

Ordinary Portland cement (type I) was used in a mixture to produce foamed concrete. The specific gravity and fineness modulus of the fine aggregate were 2.63 and 2.69, respectively. The grading limits were rendered using ASTM C 33 [13] as shown in **Table 1**. Natural tap water (plain water) was used in this study for the mixing and normal curing of foamed concrete. Foam agent was used to achieve foamed concrete; the type of foam agent (NEOPOR) (leycoChem LEYDE GmbH Germany) was an organic material. The foaming agent was diluted in 40 parts of water before use, according to the manufacturer recommendations. The glass fibers used in the foamed concrete were of straight shape, with lengths of 12 mm and density of 2.68 g/cm^3. The polypropylene fibers had a crimped shape, were 45 mm long and 1 mm of diameter, and were of a density of 0.9 g/cm^3. The mix proportion used in this study was 1:2.25 (ACI 211.2) [14]. Many trial mixes were studied by varying the mix parameter to obtain a lightweight structure. The mix proportion used 456 kg/m^3 cement, 1046 kg/m^3 fine aggregate, 228 kg/m^3 water, and 1 kg/m^3 foam agent. Various volume fractions of glass and polypropylene fibers were used. The volume fractions of GF for mixes N1, N2, N3, and N4 were 0.06, 0.2, 0.4, and 0.6 %, respectively. The volume fractions of PPF for mixes N5, N6, N7, and N8 were 0.2, 0.6, 1.0, and 1.4 %, respectively.

Table 1 Grading of fine aggregate.

Sieve No. (mm)	Passing (%)	Limits of ASTM C 33
No.4 (4.75)	100	95 - 100
No.8 (2.36)	80.96	80 - 100
No.16 (1.18)	66.33	50 - 85
No.30 (0.6)	51.5	25 - 60
No.50 (0.3)	24.65	5 - 30
No.100 (0.15)	7.26	0 - 10

Tests procedure

Slump flow (flowability)

The flowability of foamed concrete was one of the fresh concrete properties that were tested. The slump flow indicates workability of the mix according to ASTM C 1611 [15]. Filling a cone was used to place the concrete into the mold. The concrete was placed in one lift without tamping or vibration. The mold was raised, and the concrete was allowed to spread. After spreading ceased, 2 diameters of the concrete mass were measured in approximate orthogonal directions, and the slump flow was the average of the 2 diameters. The following Eq. (1) was used to calculate the slump flow;

$$Slump\ flow\ (mm) = \frac{d1+d2}{2} \tag{1}$$

where d1 is the largest diameter of the circular spread of the concrete (mm), and
d2 is the circular spread of the concrete (mm) at an angle approximately perpendicular to d1.

Compressive strength

The compressive strength of foamed concrete was also tested. The average of 3 cubes was used to determine the compressive strength at 28 days according to BS 1881: part 116 [16]. A uniaxial testing machine with 2000 kN capacity was used and a loading rate of 0.5 kN/s was applied. The following Eq. (2) was used to calculate the compressive strength;

$$f_c = \frac{P}{A} \tag{2}$$

where f_c is compressive strength (MPa),
P is maximum applied load indicated by the testing machine (N), and
A is area exposed for load (mm²).

Splitting tensile strength

The average of the 3 cylinder specimens (100×200 mm) was used to determine the splitting tensile strength at 28 days; the test was carried out in accordance with ASTM C 496 [17]. The following Eq. (3) was used to determine the splitting tensile strength;

$$T = \frac{2P}{\pi l d} \tag{3}$$

where T is splitting tensile strength (MPa),
P is maximum applied load indicated by the testing machine (N),
l is length (mm), and
d is diameter (mm).

Flexural strength

Prisms of 100×100×400 mm were used to determine the flexural strength of the foamed concrete according to ASTM C 78 [18]. The average of the 3 prisms was used to determine the flexural strength at 28 days for 2 types of curing. The following Eq. (4) was used to determine the flexural strength;

$$R = \frac{PL}{bd^2} \tag{4}$$

where R is flexural strength (modulus of rupture) (MPa),
P is maximum applied load indicated by the testing machine (N),
L is span length (mm),
b is average width of specimen, at the fracture (mm), and
d is average depth of specimen, at the fracture (mm).

Results and discussion

Slump flow

Slump flow is the average of the 2 diameters in approximate orthogonal directions; they were measured for each mix proportion of the foamed concrete. The slump flow test was done according to ASTM C 1611 [15]. The slump flow for the reference mix (N0) was 535 mm. The inclusion of 0.6 % of glass fibers reduced the value of the slump flow to 390 mm. However, the use of 1.4 % of polypropylene fibers reduced the slump flow to 445 mm. The slump flow of foamed concrete mixes reduced as the fiber volume fraction increased [19]. Therefore, it can be stated that polypropylene fibers showed a lesser effect on the slump flow of foamed concrete than that of glass fibers.

Compressive strength

For foamed concrete reinforced with glass fibers, compressive strength increased with percentage increase of glass fibers, as shown in **Figure 2**. Compressive strength of foamed concrete decreased in saltwater curing, compared with plain water curing of foamed concrete. The compressive strength of the reference mix (N0) cured with saltwater decreased by about 9 % at 28 days, compared with the same mix cured in plain water. The compressive strength of a mix with 0.6 % glass fibers (N4) cured with saltwater decreased by about 2 % at 28 days, compared with the plain water curing. Therefore, it can be said that this percentage of glass fibers would significantly enhance the compressive strength of foamed concrete against saltwater. For foamed concrete reinforced with polypropylene fibers, the polypropylene fibers caused significant reduction in the compressive strength of such concrete, as shown in **Figure 3**. The compressive strength of foamed concrete reinforced with polypropylene fibers decreased in the case of saltwater curing, compared with plain water curing. It can be noted that the compressive strength at 28 days reduced by about 7.3, 5.9, 6.2, and 7.7 %, due to the addition of 0.2, 0.6, 1, and 1.4 % of polypropylene fibers, respectively. These reductions were obtained for the specimens cured with saltwater compared with the specimens cured with plain water. **Figure 4** shows the reduction percentages in the compressive strength of foamed concrete reinforced with fibers and cured in saltwater.

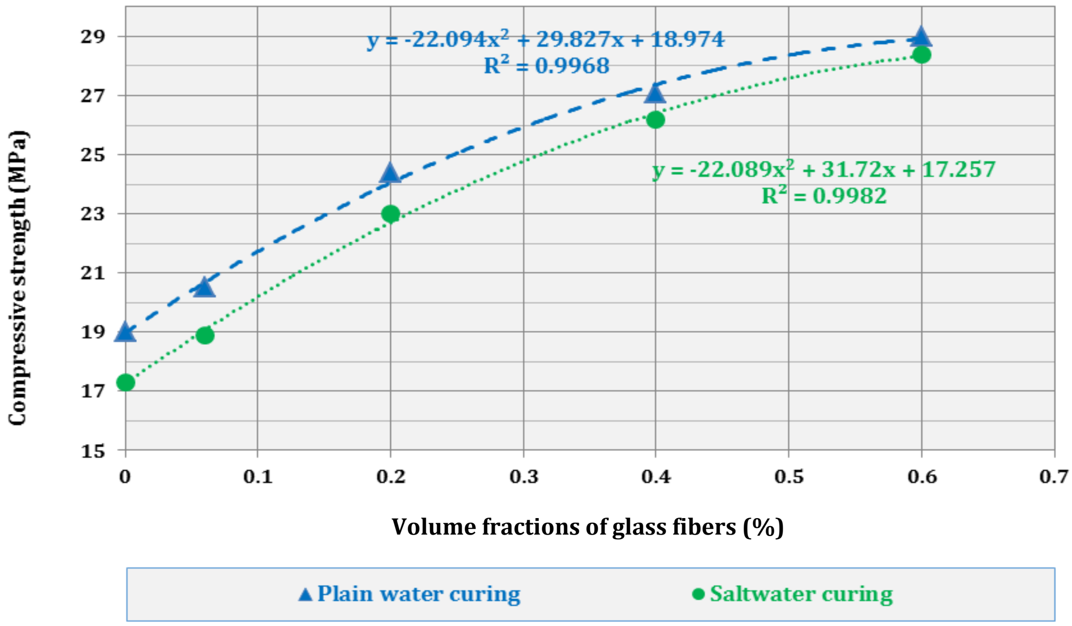

Figure 2 Effect of glass fibers on compressive strength of foamed concrete at 28 days.

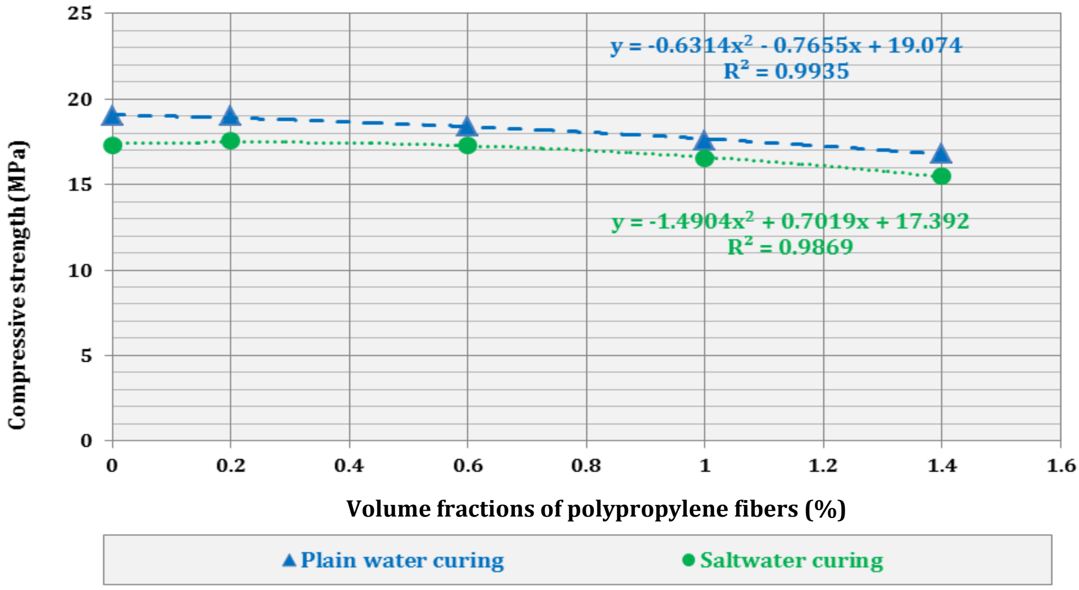

Figure 3 Effect of polypropylene fibers on compressive strength of foamed concrete at 28 days.

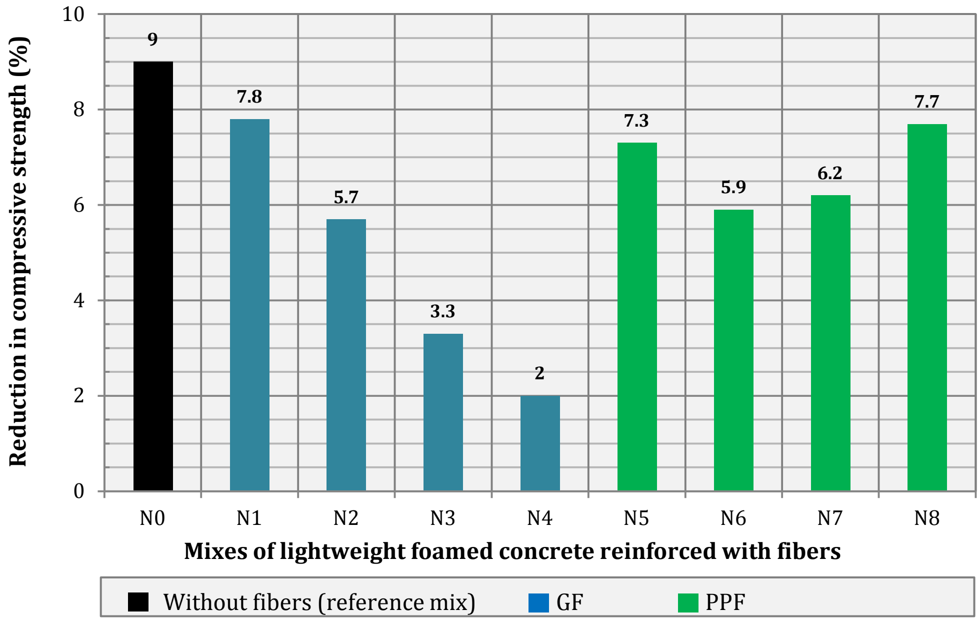

Figure 4 Reduction in the compressive strength of foamed concrete exposed to saltwater at 28 days.

Splitting tensile strength

In foamed concrete reinforced with glass fibers, splitting tensile strength improved with percentage increase of glass fibers. This strength of the concrete was affected by saltwater curing, and the splitting tensile strength of foamed concrete decreased through saltwater curing, compared with plain water curing. **Figure 5** shows the effect of glass fibers on the splitting tensile strength for foamed concrete at 28 days. The splitting tensile strength of the reference mix (N0) cured in saltwater decreased by about 7.8 %, as compared with the reference mix cured in plain water. The splitting tensile strength of the mix (0.6 % glass fibers) decreased by about 2.5 % due to saltwater curing, compared with plain water curing mixes. On the other hand, for foamed concrete reinforced with polypropylene fibers, the polypropylene fibers caused increases in the splitting tensile strength. The splitting tensile strength of foamed concrete reinforced with polypropylene fibers decreased when the specimens were cured in saltwater, compared with plain water curing, as shown in **Figure 6**. It can be noticed that the splitting tensile strength of foamed concrete at 28 days reduced by about 6.1, 5.6, 6.5, and 6 % with the addition of 0.2, 0.6, 1, and 1.4 % of polypropylene fibers, respectively, compared with plain water curing. **Figure 7** shows the reduction percentages in the splitting tensile strength of foamed concrete reinforced with fibers and cured in saltwater.

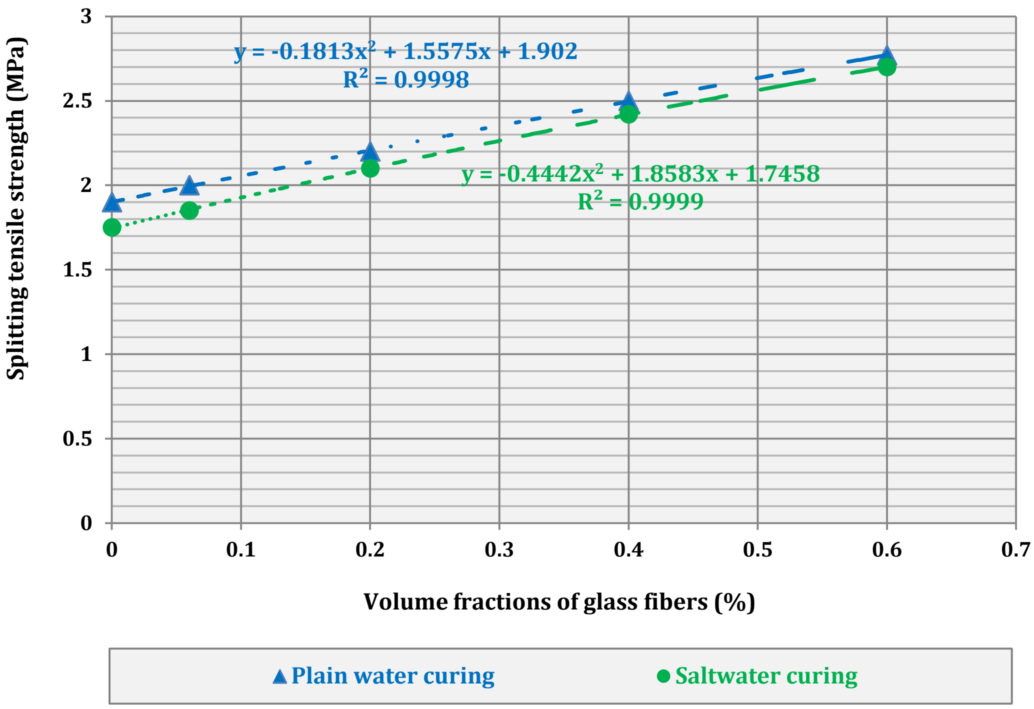

Figure 5 Effect of glass fibers on splitting tensile strength at 28 days.

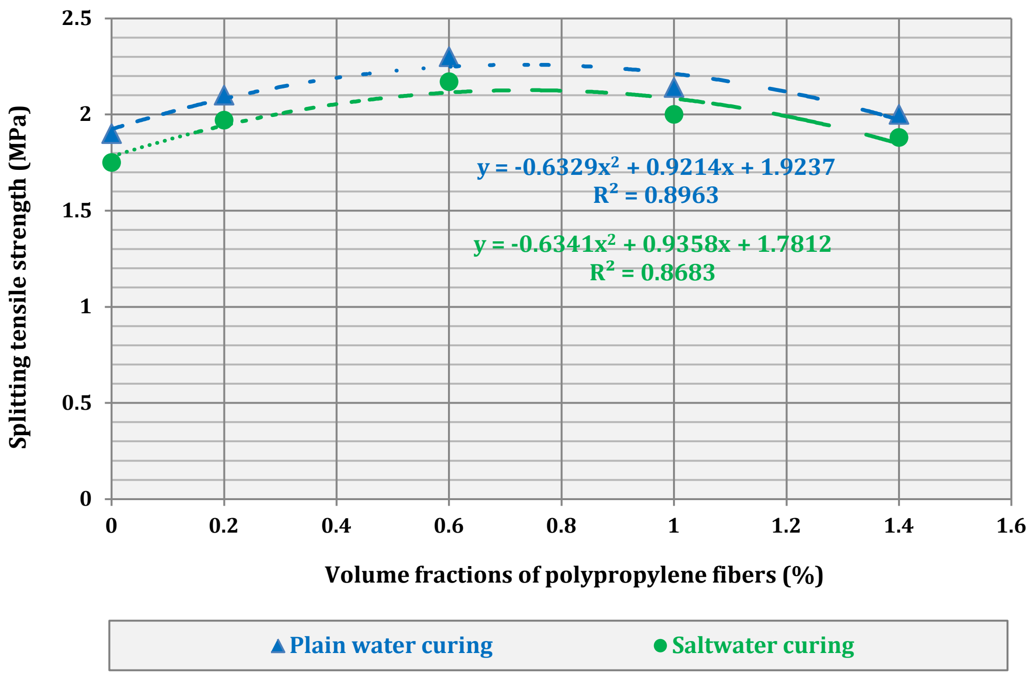

Figure 6 Effect of polypropylene fibers with splitting tensile strength at 28 days.

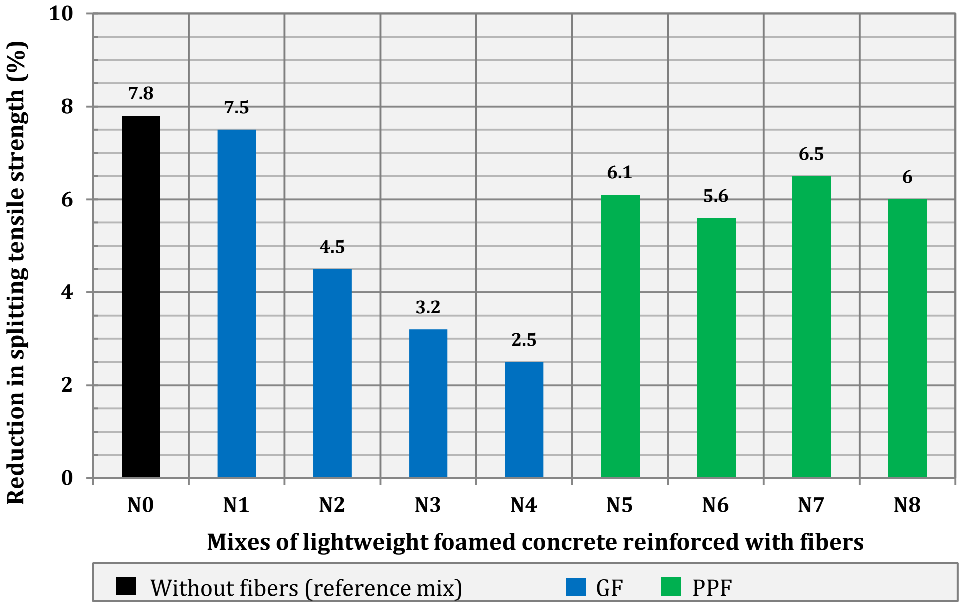

Figure 7 Reduction in the splitting tensile strength of foamed concrete exposed to saltwater at 28 days.

Flexural strength

The flexural strength of the foamed concrete reinforced with glass fibers reduced due to saltwater curing, compared with the plain water curing of foamed concrete, as shown in **Figure 8**. The results of the flexural strength for 0.0, 0.06, 0.2, 0.4, and 0.6 % specimens cured in saltwater showed a noticeable decrease by about 10.5, 10, 8, 7, and 5 %, respectively, at 28 days, compared with the specimens cured in plain water. For foamed concrete reinforced with polypropylene fibers, the polypropylene fibers caused a reduction in the flexural strength. The flexural strength of foamed concrete reinforced with polypropylene fibers decreased due to saltwater curing, compared with plain water curing. Such decreases in the flexural strength at 28 days reduced by about 9.1, 7.8, 8.6, and 9 % with the addition of 0.2, 0.6, 1, and 1.4 % of polypropylene fibers, respectively. **Figure 9** presents the effect of polypropylene fibers on the flexural strength of foamed concrete at 28 days. **Figure 10** presents the reduction percentages in the flexural strength of foamed concrete reinforced with fibers for the specimens cured in saltwater.

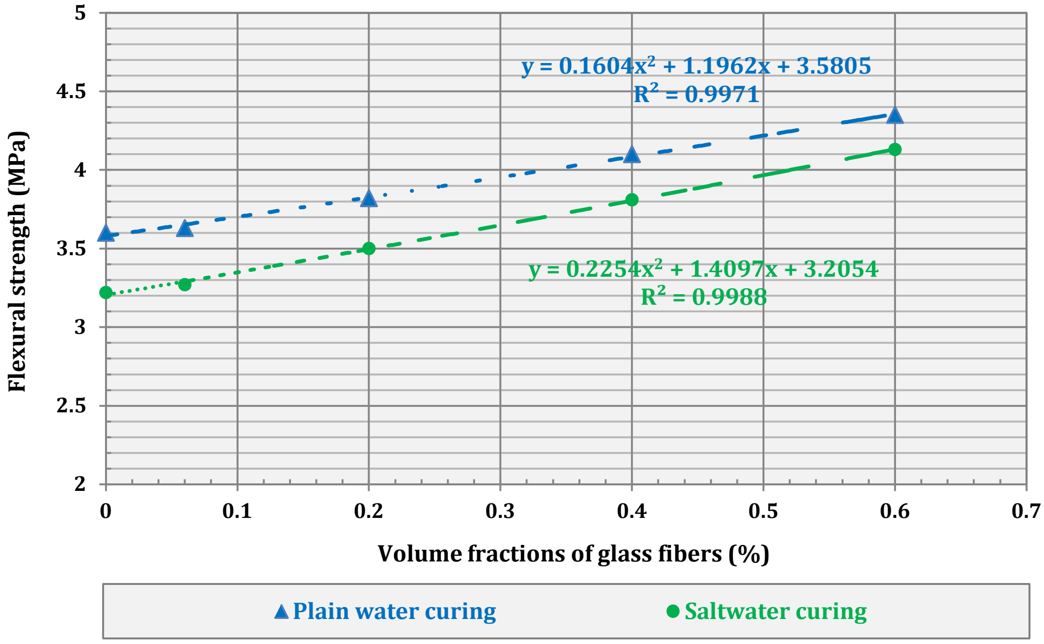

Figure 8 Relationship between proportion of glass fibres with flexural strength at 28 days.

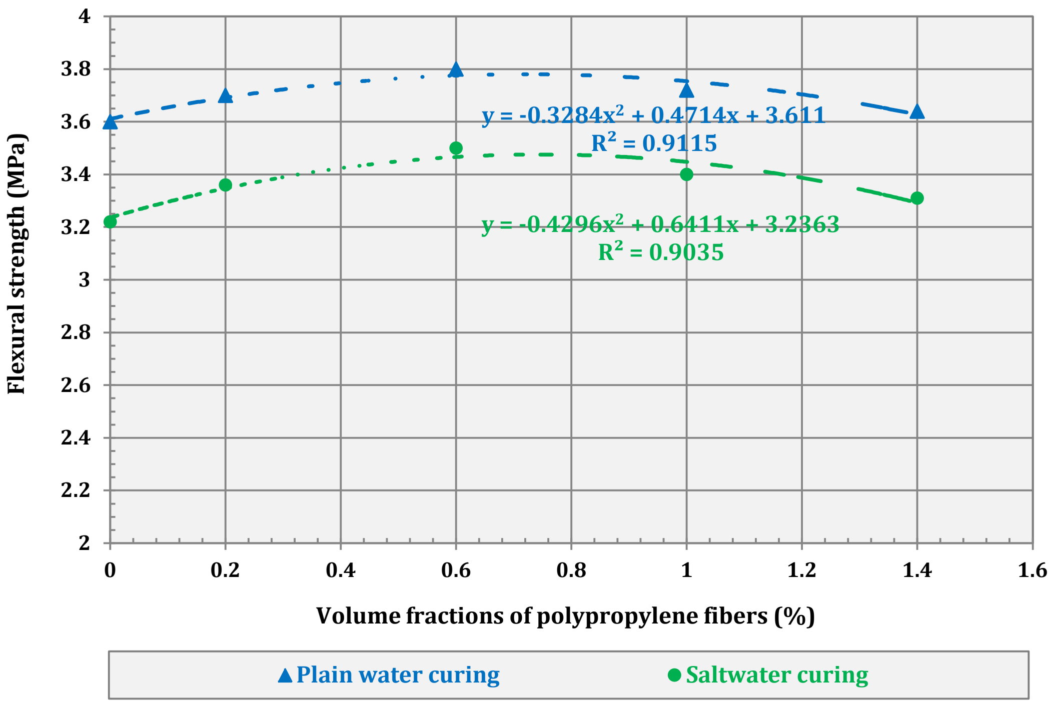

Figure 9 Relationship between proportion of polypropylene fibres with flexural strength at 28 days.

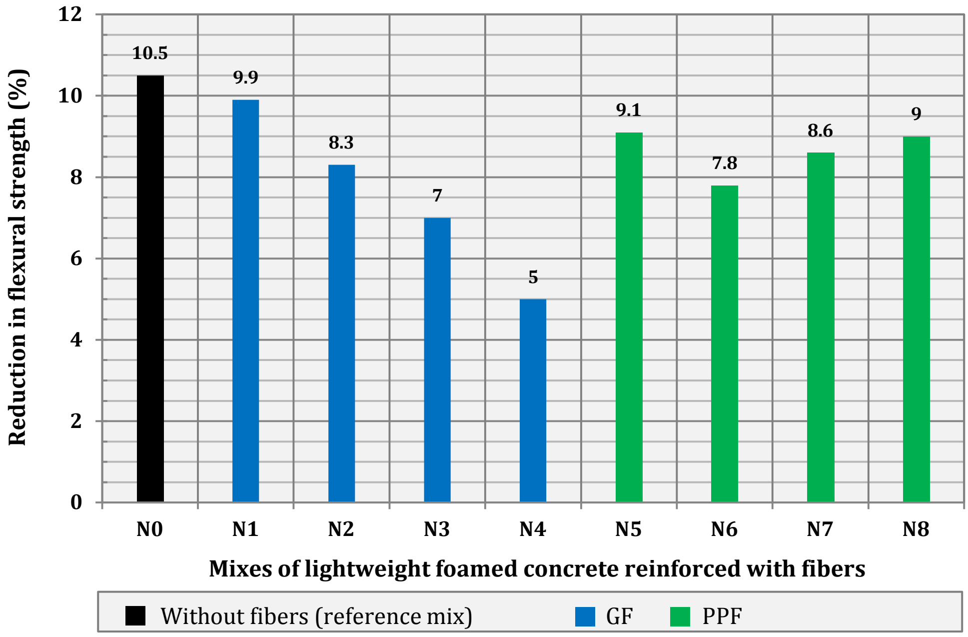

Figure 10 Reduction in the flexural strength of foamed concrete exposed to saltwater at 28 days.

Conclusions

1) The slump flows of foamed concrete are reduced when the proportions of fibers rises. They are influenced mainly as a result of glass fiber additions. Meanwhile, the use of polypropylene slightly reduces the slump flows of such concrete.

2) The effect of saltwater (sodium chloride) curing on the mechanical properties of foamed concrete is significant. Thus, saltwater curing decreases the mechanical properties of foamed concrete. The maximum percentage of glass fibers shows the least reduction in compressive strength when exposed to saltwater curing. This is probably due to the glass fibers type which are resistant to acid and alkalis. The foamed concrete reinforced with glass fibers gives the best results (increases in compressive strength, splitting tensile strength, and flexural strength), and the least reduction in all mechanical properties when exposed to saltwater, as compared with plain water curing. Also, the glass fibers are significant, and have a great effect on durability, when compared with polypropylene fibers.

3) The splitting tensile strength of foamed concrete advances with a percentage increase in glass fibers. The highest proportion of glass fiber inclusion is also durable against saltwater. Polypropylene fibers also increase the splitting tensile strength of foamed concrete, but to a slighter extent then glass.

4) The flexural strength of foamed concrete increases with fiber increases. The glass fibers also show the greatest performance when compared with polypropylene. Also, the maximum proportion of glass fibers allows indications the minimum reduction in flexural strength when exposed to saltwater curing.

References

[1] SH Kosmatka, B Kerkhoff and WS Panarese. *Design and Control of Concrete Mixtures*. 14th ed. Portland Cement Association, USA, 2003.
[2] Z Li. *Advanced Concrete Technology*. John Wiley & Sons, Hoboken, New Jersey, 2011.
[3] MO Mydin and YC Wang Mechanical properties of foamed concrete exposed to high temperatures. *Constr. Build. Mater*. 2012; **26**, 638-54.

[4] SH Sulaiman. 2012, Water Permeability and Carbonation on Foamed Concrete. Master dissertation, University Tun Hussein Onn Malaysia, Malaysia, 2012.
[5] K Chandramouli, RP Srinivasa, N Pannirselvam, ST Seshadri and P Sravana. Strength properties of glass fibre concrete. *ARPN J. Eng. Appl. Sci.* 2010; **5**, 1-6.
[6] MS Islam, SK Kaushik and MM Islam. Physical and mechanical behavior of concrete in seawater under high hydrostatic pressure. *J. Inst. Eng. Malaysia* 2005; **66**, 46-52.
[7] Encyclopedia of Earth, Available at: http://editors.eol.org/eoearth/wiki/Seawater, accessed December 2013.
[8] AE Abalaka and AD Babalaga. Effects of sodium chloride solutions on compressive strength development of concrete containing rice husk ash. *ATBU J. Environ. Tech.* 2011; **4**, 33-40.
[9] PJ Ramadhansyah, MZM Salwa, AW Mahyun, BH Abu Bakar, MAM Johari and CWC Norazman. Properties of concrete containing rice husk ash under sodium chloride subjected to wetting and drying. *Proc. Eng.* 2012; **50**, 305-13.
[10] MM Islam, MS Islam, BC Mondal and MR Islam. Strength behavior of concrete using slag with cement in seawater environment. *J. Civil Eng.* 2010; **38**, 129-40.
[11] MM Islam, MS Islam, M Al-Amin and MdM Islam. Suitability of seawater on curing and compressive strength of structural concrete. *J. Civil Eng.* 2012; **40**, 37-45.
[12] F Pruckner and OE Gjørv. Effect of CaCl2 and NaCl additions on concrete corrosivity. *Cement Concr. Res.* 2004; **34**, 1209-17.
[13] ASTM C 33. *Standard Specification for Concrete Aggregates*. Annual Book of ASTM Standards, USA, 2002.
[14] ACI 211.2. *Standard Practice for Selecting Proportions for Structural Lightweight Concrete*. American Concrete Institute, USA, 1998.
[15] ASTM C 1611. *Standard test Method for Slump Flow of Self-Consolidating Concrete*. Annual Book of ASTM Standards, USA, 2005.
[16] British Standard Institution. *Compressive Strength of Test Specimens*. BSI, UK, 1983.
[17] ASTM C 496. *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*. Annual Book of ASTM Standards, USA, 2005.
[18] ASTM C 78. *Standard Test Method for Flexural Strength of Concrete (using simple beam with third-point loading)*. Annual Book of ASTM Standards, USA, 2002.
[19] MM Kamal, MA Safan, ZA Etman and MA Abd-elbaki. Effect of polypropylene fibers on development of fresh and hardened properties of recycled self-compacting concrete. *Int. J. Eng. Adv. Tech.* 2013; **2**, 86-94.