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A Study of the Effects of Saltwater on the Formation, Curing and Strength of Concrete

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Concrete; Compressive Strength; Salt Water; Ion Concentration; Curing..

Abstract

Concrete is extensively used in all construction works such as buildings, bridges, roads and dams worldwide. It is made by simply combining cement, aggregate, sand and water in the appropriate proportion. This paper reports on an investigational study on the outcome of using saltwater in coastal regions for blending and curing concrete since palatable water is a deficient asset on the earth. As most of the ions in seawater comprise Na, Mg, Cl^- and SO_4^{2-}, this research aimed to observe how concrete behaves after the addition of NaCl and $MgSO_4$ salt separately for mixing concrete and curing at different concentrations. Concrete cylinders were cured using fresh water as well as saltwater separately. A total specimen of 42 cylinders was cast with 100%, 75% and 50% ion concentrations of NaCl, $MgSO_4$ and freshwater specimens prepared for the reference concrete, which were exhibited for 7 days and 28 days of curing. A comparatively higher compressive strength was found for a 50% salt concentration of $MgSO_4$ and for 75% salt concentration of NaCl. The comparison of compressive strength using NaCl and MgSO4 samples between this research and previous researches was derived for 7 days and 28 days. A correlation between the compressive strength and ion concentrations of NaCl and $MgSO_4$ for 28 dayswas derived by performing linear regression analysis. The relations obtained by this analysis can be utilized for further prediction of compressive strength at any other ion concentrations of these salts.

1. Introduction

Concrete is the chief building constituent used in construction on account of its strength, durability, reflectivity and versatility. In particular, concrete is a multifarious material made of cement, sand, coarse aggregate and water (Emmanuel *et al.*, 2012). Its decent workability consents it to be effortlessly used

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in any form starting from massive block, fences and foundations to identical thin shell ridges (Emmanuel *et al.*, 2012). It is difficult to find an alternative material of any constituent of concrete that is as appropriate as such substantial from economic and durability points of view. As stated by Osei (2000) and Water Encyclopedia (2012) the main figures of water comprise approximately five seventh of the total surface of the earths. Construction work in coastal regions is continuously challenging owing to the shortage of potable water for mixing water in making concrete and for curing purposes. Components used for concrete preparation are not renewable and are available in nature in limited amounts, which can be in shortage as a result of overuse (Balakrishna & Chamanthi, 2017; Islam *et al.*, 2012; Landage *et al.*, 2008; Raheem *et al.*, 2013). Concrete is widely used in offshore construction, concrete piers, decks, breakwaters, retaining walls, harbours and docks (Adeyemi *et al.*, 2014; Emmanuel *et al.*, 2012). Mega offshore infrastructure made of concrete, such as power plants, airports and waste disposal facilities, offers opportunities to release the pressure of urban congestion and pollution (Adeyemi *et al.*, 2014; Kumar, 2000).

Water is a key component of making concrete because it effectively gets in on chemical reactions with cement and the building industry demands a huge amount of freshwater (Tiwari *et al.*, 2014; Usman & Nura, 2015). Investigation into saving fresh water and finding alternatives to mixing water for construction work is currently highly needed (Landage *et al.*, 2008; Mbadike & Elinwa, 2011; Safiuddin *et al.*, 2007). This contest of building and upholding durable concrete structures in seaside atmospheres has become a severe matter for the communities of those regions.

Researchers have tried to discover an alternative by keeping comparative mechanical behavior from concrete to minimize the consumption of essential components for construction works. In seaside zones, ample drinking water is not available and the surface water may contain excessive salts due to seawater intrusion during tidal-waves. On the other hand, the scarcity of fresh mixing water and the availability of abundant sources of sea water have created an opportunity to study alternative availabilities of sea water in preparation and curing concrete work. After performing X-ray Diffraction (XRD), many researchers has revealed that the inorganic structure and geographical source of sea-sand are alike to river sand (Hasdemir *et al.*, 2016; Liu *et al.*, 2014).

Adebakin (2003) defined fresh water as that cleansed spread of water which is drained of any mode of layers. According to Emmanuel *et al.*(2012) and Prascal *et al.* (2006),the chemical act of salt-water on concrete is mostly as a result of outbreak by magnesium sulfate ($MgSO_4$). The chemical distribution of seawater comprises ions of chloride, magnesium, calcium and potassium (Raheem *et al.*, 2013) and the salt is 78% NaCl, 10.5% $MgCl_2$, 5% $MgSO_4$, 3.9% $CaSO_4$, 2.3% K_2SO_4 and 0.3% KBr by weight percentages (Tiwari *et al.*, 2014). Gawande *et al.*

(2017) inspected the significances of salt water and fresh water on concrete. In that study saltwater was used for both mixing and curing.

Several researchers investigated the effects of using seawater in making of concrete on the various important properties of the resultant concrete among which workability, strength and durability are notable (Xiao *et al.*, 2017). Usually, maximum of the present studies clinched that the workability of concrete declines with a rise in the amount of seashell (Safi *et al.*, 2015; Yang *et al.*, 2005; Yang *et al.*, 2010). Beside,in a naval atmosphere, the dispersion constant of chloride from the exterior atmosphere into sea-sand concrete has been seen to rise with the rise of water to cement ratio (Cao *et al.*, 2010; Huiguang *et al.*, 2011). Huan *et al.* (2007) investigated the connection between permeability and the amount of Cl^- in sand and clinched that the permeability of mortar had a habit of declining with growing in NaCl concentration.

Concrete specimens cast and cured with freshwater exhibited notable gains in compressive strength over a 150-day duration, in contrast, specimens produced and cured with ocean water showed moderate strength development, although slightly inferior when compared to concrete elements cured with freshwater (Akinsola *et al.*, 2012).

Nagabhushana *et al.* (2017) investigated the impact of different salt quantities (ranging from 25 to 45 grams/litre of NaC1) on concrete compressive strength and showed that there was an enhancement in compressive strength for a moderate percentage of salt content, while an increase in salt content beyond that led to a decrease in concrete compressive strength that suggests a nuanced relationship between salt content and concrete strength (Qingyong *et al.*,2018). Accordingly, Wegian (2010) pointed a declined behavior in concrete compressive strength as the duration of exposure increased. This decrease in strength could potentially be linked to the composition of salt crystallization, which could impact the concrete's ability to gain strength over time.

Prascal *et al.* (2006) observed that the chemical action of seawater on concrete is primarily linked to the impact of magnesium sulphate ($MgSO_4$). Interestingly, during the initial stages of attack, there might be a temporary increase in concrete strength, which is then followed by a subsequent loss of strength preceding the eventual expansion that occurs.

The studies collectively suggest that exposure to saltwater or high salt content can have varying effects on concrete compressive strength. Freshwater curing generally yields better results, while saltwater curing can lead to improvements in certain cases (Sai *et al.*, 2014).A comparative evaluation showed the effect of sea water over fresh water for conventional and pervious concrete cured with freshwater and saltwater and average compressive strength found a

4.2% higher at 28 days for conventional concrete and a 14.72% higher for pervious concrete (Agrawal *et al.*, 2017).

In this study a water solution with a similar concentration of seawater was prepared considering NaCl as a major constituent and $MgSO_4$ as sulfate containing salt to observe their individual effects on concrete and simultaneously intended to replace potable water with seawater. The study examines the impact of NaCl and $MgSO_4$ salt on the compressive strength of concrete by using salt water for preparing the concrete mix as well as for curing purpose. Another aim of this research was to derive the connection between the compressive strength and ion concentrations of NaCl and $MgSO_4$ for 28 days by performing linear regression analysis.

2. Materials and Methods

2.1 Materials

The current research was performed using a crushed angular brick aggregate of 1 in ultimate size with FM 5.23 as coarse aggregate and local sand passing through a 0.19 in sieve with FM 1.85 as fine aggregate. Cementitious material was chosen by the Portland Composite Cement (PCC) category, which adheres to the European standards CEM II-M (S-V-L) 42.5 N. Fresh potable water without any chemical substances or suspended molecules was used for blending and curing fresh water concrete specimens and making salt water solutions. Salt water solutions of $MgSO_4$ and NaCl salt at three different concentrations (100%, 75% and 50%) were prepared for casting and curing the concrete specimens. Figure 1 represents brick aggregate, sample $MgSO_4$ salt and mixing of concrete. Figure 2 represents the gradation curve for fine and coarse aggregate respectively.

(a) Brick aggregate (b) $MgSO_4$ salt (c) Concrete preparation

Figure 1: The Gradation curve for fine and coarse aggregate.

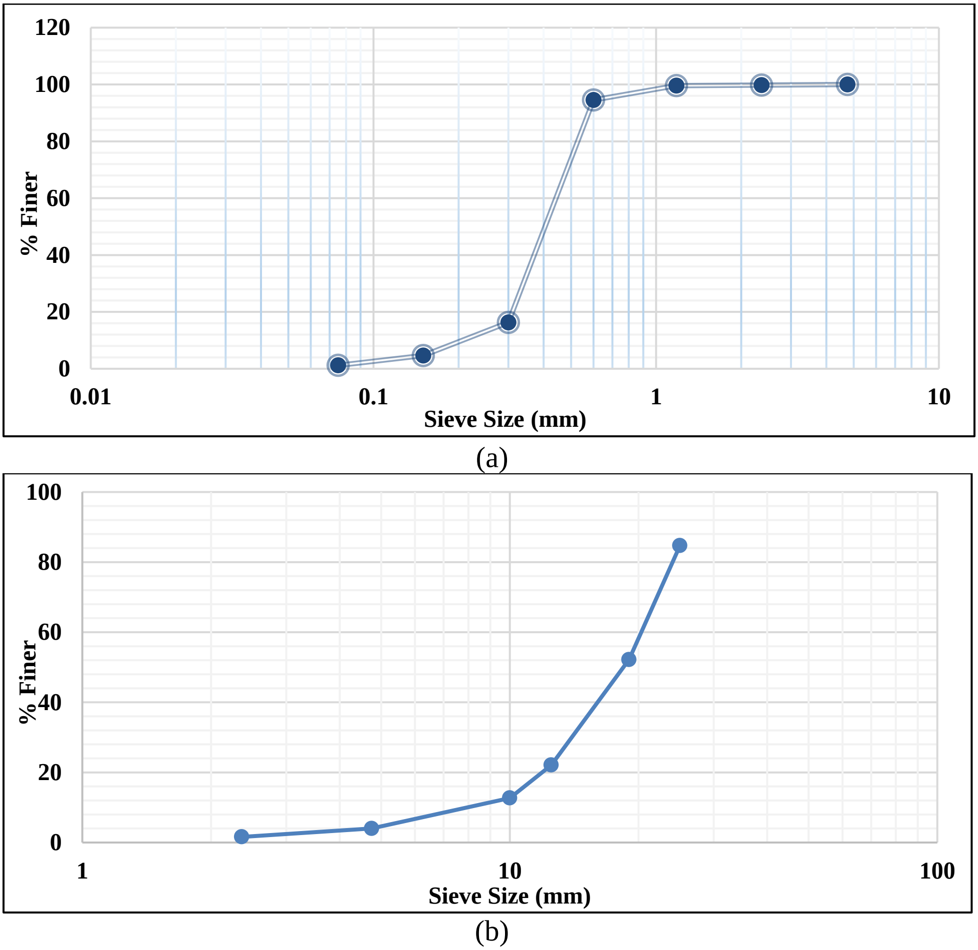


Figure 2: Gradation curve for (a) fine aggregate and (b) coarse aggregate

NaCl and $MgSO_4$ salts were chosen in this study because they are considerable salt constituents of seawater and from the chemical ion concentrations of seawater as presented in Table 1 (Britannica.com). Chloride, sodium, sulfate and magnesium are the major ions in seawater. The significant salt component of seawater is NaCl and to examine its effect on concrete, NaCl solution was selected as casting and curing water in this investigation. On the other hand, to see the impact of sulfate on concrete, $MgSO_4$ solution was used as casting and curing material, since sulfate attack on concrete can be the prominent reason for reducing strength, cracking, expansion and disintegration of constituent elements. Furthermore, the effect of magnesium salt on concrete is not avoidable since it causes considerable damage.

For each salt category, salt solutions were prepared at three different concentrations. A solution of 100% concentration was prepared with a similar seawater concentration. Solutions of 75% and 50% concentrations were formulated by mixing with 25% and 50% freshwater, respectively.

Table 1: Major concentrations of salt constituents in seawater (Britannica.com)

Chemical ions contributing to saltwater salinity	Concentration in 0/0 (parts per thousand) in typical saltwater	Proportion of total salinity
Chloride	19.34	55.03
Sodium	10.75	30.59
Sulphate	2.70	7.68
Magnesium	1.29	3.68
Calcium	0.41	1.18
Potassium	0.39	1.11
Bicarbonate	0.14	0.41
Bromide	0.06	0.19
Borate	0.02	0.08
Strontium	0.01	0.04
Fluoride	0.001	0.003
Other	less than 0.001	less than 0.001

2.2 Methodology

To investigate the effect of two major salts (NaCl and $MgSO_4$) of seawater on concrete compressive strength, first, concrete was made by properly mixing the specified cementitious material, fine aggregate and coarse aggregate in saturated surface dry condition (SSD) with fresh water and salt water concentrations as shown in Table 2 and cast in cylindrical molds(4 inch X 8 inch). The mixing ratio of 1:1.5:3 with a water cement ratio of 0.5 was maintained. Concrete batching was performed by weighing the materials using a manual weight balance and for100% concentration of $MgSO_4$ water, each of the 6 specimens required 1.95 liters of water, 3.9 kg of cement, 5.85 kg of sand, and 11.70 kg of aggregate. Similarly, the same quantities of water, cement, sand, and aggregate were needed for 75% and 50% concentrations of $MgSO_4$ water for those 6 specimens. Same methodology was applied to concrete specimens with different concentrations of NaCl water. Consistent material quantities across various concentrations of both $MgSO_4$ and NaCl water, was kept to analyze how these different solutions impact the properties of the resulting concrete.To easily remove the concrete from the mold after setting, the molds were waxed with oil before placing the concrete into them. Cylindrical molds were filled in three layers with concrete by one-third height and all layers were individually compacted 25 times with tamping rods.

The concrete samples were taken off from the molds after casting for 24 hours, then this samples were marked and cured at room temperature. Separate curing tanks were organized with fresh water and salt water solutions of different concentrations and specimens were submerged into tanks accordingly. The curing water quality was maintained the same as the casting water for all salt solution specimens. After completion of the 7 and 28 day curing sessions, the concrete specimens were taken off from the water and reserved in the laboratory for 24 hours before testing. The compressive strength test was accomplished on cylinder specimens using the compression testing machine following ASTM C39 / C39M,ACI 318-19 standards. Cylinders were positioned between the compressive plates and compressed at an even rate till failure. The maximum failure load of each specimen was read from the machine and the compressive strengths of the specimens were determined by the formula (maximum load (lb)/average cross-sectional area (in^2) of the sample). Finally, the average compressive strength was obtained for each hydration period and the result was compared for different samples. Figure 3 represents sample preparation and test set up for compressive strength test.

Figure 3: Sample preparation and test set up for compressive strength test

Table 2: Matrix of specimens with different salts used in casting and curing

Sample name	Samples for 7 day strength	Samples for 28 day strength	Salt type	Salt conc. [as of Sea water]	Salt quantity (g/l) [Atomic mass]	Water used for mixing and curing of concrete
M1	3	3		100%	3.376	$MgSO_4$ salt water (100% conc.)
M2	3	3	$MgSO_4$	75%	2.532	$MgSO_4$ salt water (75% conc.)
M3	3	3		50%	1.688	$MgSO_4$ salt water (50% conc.)
N1	3	3		100%	31.870	NaCl salt water (100% conc.)
N2	3	3	NaCl	75%	23.903	NaCl salt water (75% conc.)
N3	3	3		50%	15.940	NaCl salt water (50% conc.)
FW	3	3	-	0%	-	Clean potable water

M1, M2, and M3: Samples cast and cured with $MgSO_4$ solution of 100%, 75% and 50% concentrations, respectively.
N1, N2, and N3: Samples cast and cured with NaCl solution of 100%, 75% and 50% concentrations, respectively.
FW: Samples cast and cured with fresh potable water.

3. Results and Discussion

Figure 4 comprises of the slump value result for all three samples using NaCl and $MgSO_4$ salt solutions along with the fresh concrete prepared with 0% salt concentration. This figure indicates that workability reduces significantly with increasing NaCl concentration where maximum slump of 0.95 in is noted at 50% concentration. No significant reduction is observed for $MgSO_4$ salt concentration where maximum slump of 0.97 in is noted at 50% concentration as same as NaCl.

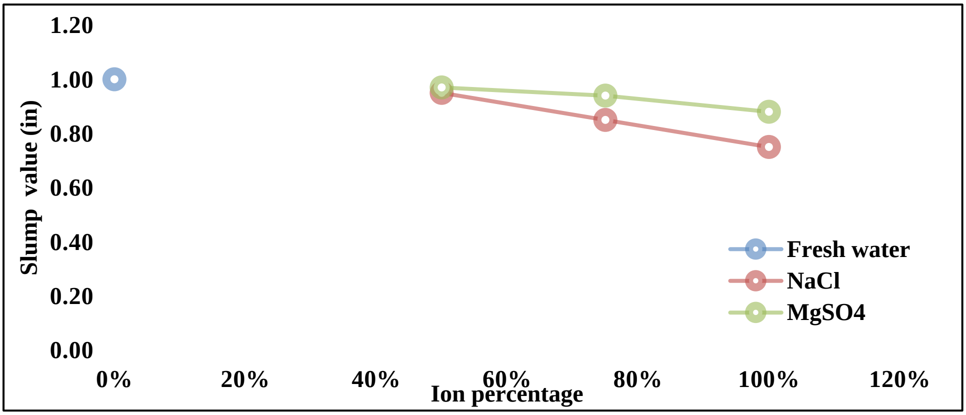
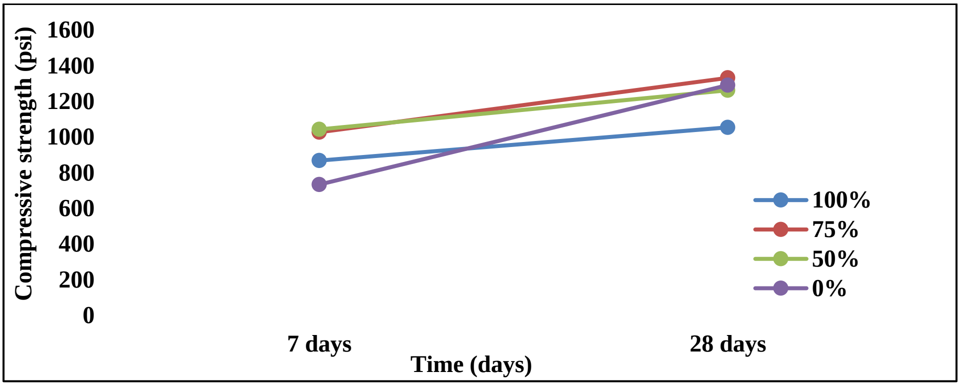


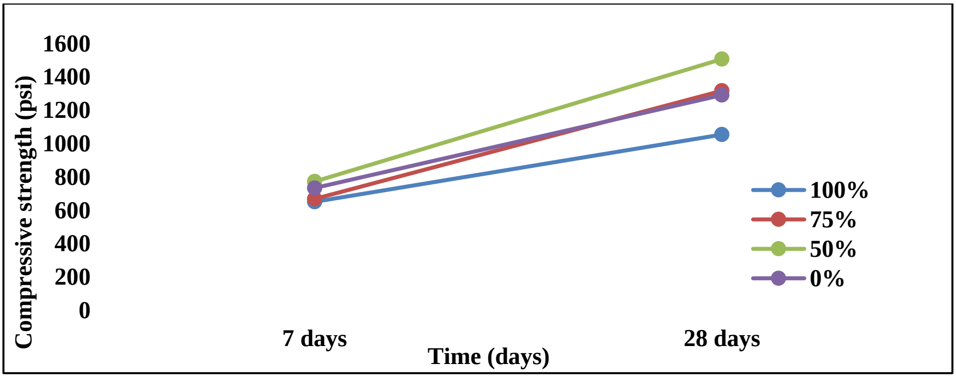
Figure 4: Slump value vs different salt concentrations

Figure 5 comprises of the concrete compressive strength results for all three samples at 7 and 28 days using NaCl and $MgSO_4$ salt solutions along with the reference concrete prepared with 0% salt concentration

From the graphical illustration of compressive strength vs time in Figure 5, it can be portrayed that, in the case of NaCl samples, the strength development rate is slower compared to the reference concrete. However, it is recovered with time by samples of 50% and 75% NaCl and the strength gained at 28 days is almost the same as the reference concrete for the 50% NaCl sample and higher than the reference concrete for the 75% NaCl sample. Moreover, high early age strength is noticeable for NaCl samples based on reference concrete. On the other hand, the responses of the 50% and 75% $MgSO_4$ samples are almost identical to that of the reference concrete, whereas the 50% $MgSO_4$ sample represents a comparatively high strength at 28 days. In the past, many researchers investigated the impacts of using seawater in making of concrete on the early and long term strength of the resultant concrete (Xiao *et al.*, 2017). It has been presented by those researches that concrete prepared with saltwater gains its initial strength quicker than that of normal concrete, but both type of concrete gain similar long-term strength. After using NaCl it was reported in Fatokun (2005) that growth in strength reduces the spread of water vapour. In that research it was also said that, an optimum strength at 3.6% was recorded and considerable salinity could be endured formerly the strength fell down from the novel water concrete strength.



(a)



(b)

Figure 5: Compressive strength vs time for (a) NaCl and (b) $MgSO_4$ samples

It is also detected from Figure 5 that for the reference concrete, the strength increases by 43.15% from 7 days to 28 days which is 17.37% for the 50 % NaCl sample, 22.86% for the 75 % NaCl sample and 17.73% for the 100 % NaCl sample which is almost the same as 50% sample. On the other hand, strength enhancement is 49.23% from 7 days to 28 days for the 50% $MgSO_4$ sample, which is almost the same as 49.73% for the 75% $MgSO_4$ sample and 38.23% for the 100% $MgSO_4$ sample.

If we compare the 7-day strength for the NaCl sample with $MgSO_4$ sample we will see that for the 50% sample by using NaCl, strength is 25.92% higher than that of $MgSO_4$. For the 75% sample, the strength is 34.92% higher for the NaCl sample than for $MgSO_4$. For the 100% sample, the NaCl strength is 24.9% higher than that of $MgSO_4$. This proves that for all percentages, the NaCl strength is higher than the $MgSO_4$ strength at 7 days.

From the comparison of the 28 day strength for the NaCl sample with the $MgSO_4$ sample, it can be portrayed that for the 50% sample, the strength is almost same for NaCl and $MgSO_4$ as the variation is only 1.12%. For the 75% sample, the strength is 16.24% higher for the NaCl sample than for $MgSO_4$. For 100% sample, strength is same as 1055 psi for NaCl as well as $MgSO_4$.

It is extensively acknowledged over the world that chloride ion has a prominent consequence on the corrosion of regular steel in reinforced concrete which will bring negative effect on strength gaining. Other researchers like Chen *et al.* (2017) have also shown that for mixing water if seawater is used, it results in significant corrosion of steel reinforcement. The results gained by Fukute *et al.* (2017)exhibited that the impact of using seawater as mixing water on steel corrosion was insignificant as no clear variation was detected in terms of depth of steel corrosion among freshwater concrete seawater concrete. This outcome also validates our result as we got more strength by using NaCl than $MgSO_4$.

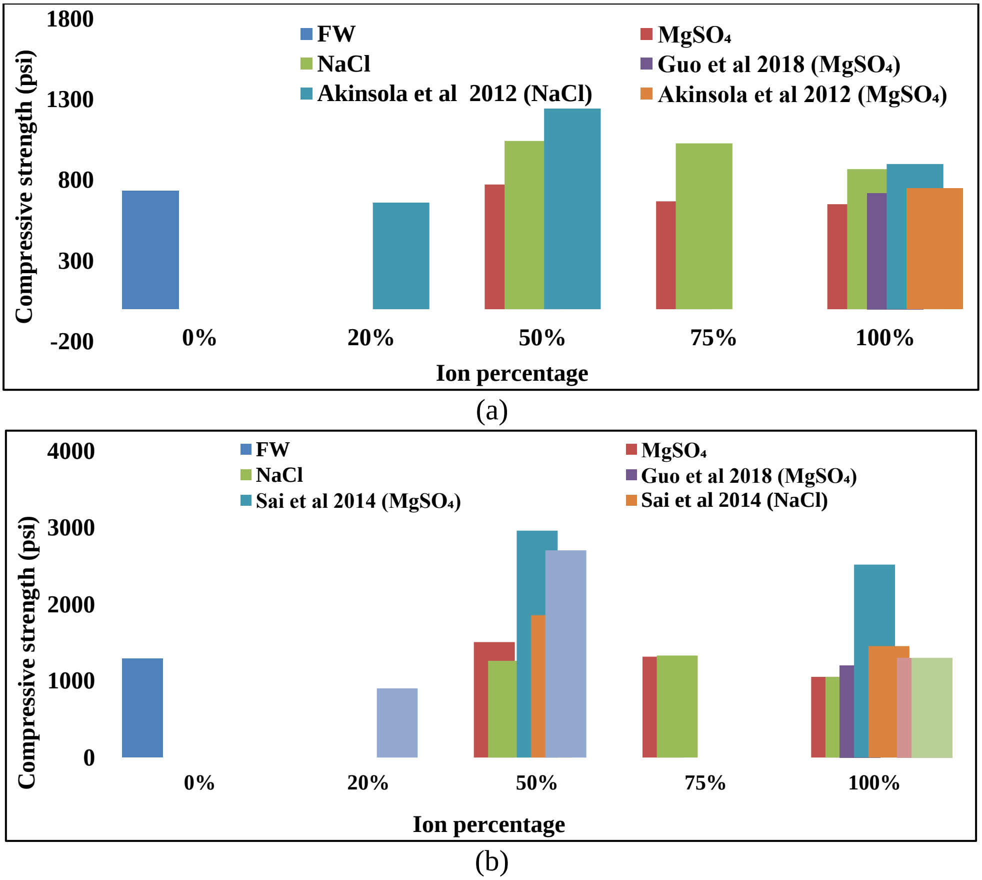
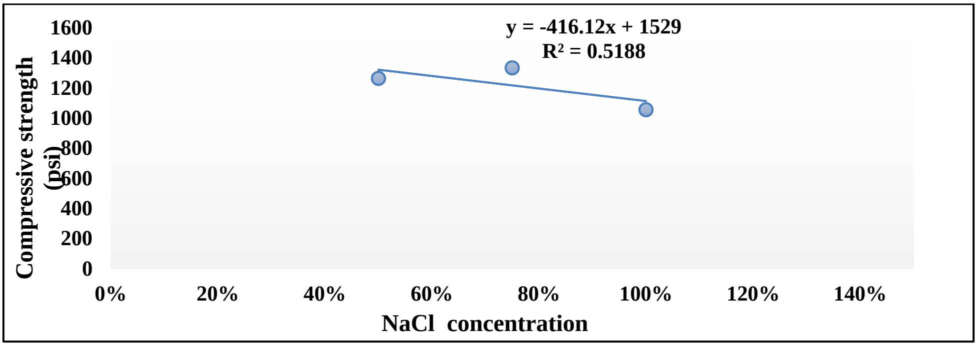


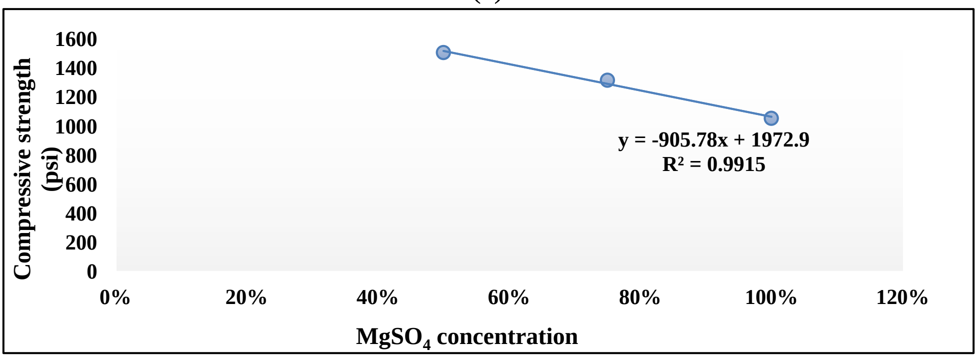
Figure 6: Comparison of compressive strength using NaCl and $MgSO_4$ samples between this research and previous researches (a) 7 days (b) 28 days

Figure 6 displays the correlation of concrete compressive strength for different concentrations of NaCl and $MgSO_4$ along with fresh water between current study and existing literatures at 7 days and 28 days. For the 7-day strength, it is evidently observed from the diagram that for current study the strength values of the $MgSO_4$ samples are closer to the reference concrete as clarified by Akinsola *et al.* (2012) as well as Guo *et al.* (2018). In contrast, NaCl samples represent noticeably high strength paralleled to $MgSO_4$ samples and fresh concrete for the current study. Akinsola *et al.* (2012) got maximum strength of 1544 psi at 50% NaCl concentration but received a low strength of 661 psi at 20% NaCl concentration.

In this research at 28 days, 50% NaCl and 75% NaCl samples are giving strength nearer to the fresh concrete strength. Also the strength deviation is minor between NaCl and $MgSO_4$ samples at 28 days as clarified by Wegian *et al.* (2010).A strength upsurge is detected for the 50% $MgSO_4$ sample as like in the study conducted by Akinsola *et al.* (2012) and Sai *et al.* (2014).



(a)



(b)

Figure 7: Compressive strength versus salt concentration at 28 days (a) NaCl and (b) $MgSO_4$

The relation of compressive strength with NaCl and $MgSO_4$ concentration for 28 days was derived by performing linear regression analysis as presented in Figure 7 (a, b). In the future, one can predict compressive strength at 28 days after knowing NaCl or $MgSO_4$ concentration from these equations as shown in Figure 7 (a, b).

5. Conclusion

In this experimental research, two main types of concrete mixtures were prepared using two salts with different concentrations. The overall findings are listed below:

The slump value decreases with increasing salt concentrations of both NaCl and $MgSO_4$ salt.

The concrete compressive strength increases with time for all the concentrations of NaCl and $MgSO_4$ salt, indicating that the concentrations of salts do not have any effect on time.

Using $MgSO_4$ salt, the maximum 28 day concrete compressive strength is attained as 1507.89 psi for a 50 % salt concentration.

Using NaCl salt, the maximum 28 day concrete compressive strength is attained as 1332.55 psi for a 75 % salt concentration.

From the regression analysis of the 28 days concrete compressive strength and the NaCl and $MgSO_4$ salt concentrations, it can be revealed that the similarity between the compressive strength and $MgSO_4$ concentration is satisfactory, as clarified by a regression coefficient value of ~1.

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Conflict of interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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