AN EXPERIMENTAL STUDY ON THE EFFECT OF SALT AND SUGAR COMBINATION ON MORTAR PROPERTIES

Lelian ElKhatib  
Faculty of Engineering, Beirut Arab University, Beirut Lebanon, lelianwalkhatib@gmail.com

Jamal Khatib  
Faculty of Engineering, Beirut Arab University, Beirut, Lebanon, j.khatib@bau.edu.lb

Abbas Hassan  
Faculty of Engineering, Beirut Arab University, Beirut, Lebanon, abbas.hassan2001kw@gmail.com

Mohammad Kassem  
Faculty of Engineering, Beirut Arab University, Beirut, Lebanon, Mohammadkassem924@gmail.com

Adel Elkordi  
Faculty of Engineering, Beirut Arab University, Beirut, Lebanon, a.elkordi@bau.edu.lb

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1. INTRODUCTION

Concrete is considered as one of the most used materials in construction (ElKhatib et al., 2023). In recent decades, several studies were performed on mortar/concrete specimens containing cement and aggregate replacement (Kurdi et al., 2001; Khatib et al., 2023a, 2023b; Shebli et al., 2023; Bawab et al., 2021; Joumblat et al., 2023). This replacement may affect the properties of concrete including setting time, compressive strength and absorption (Khatib et al., 2010; Negim et al., 2015; Sonebi et al., 2013; Negim et al., 2014a, 2014b; Wild et al., 1996).

Different chemical admixtures are added to mixes in the form of liquids or powders in order to adjust the properties of concrete (Dransfield, 2003). There are various types of chemical admixtures including accelerators, retarders, air-entraining agents, water reducing agent, etc.

Sugar is an affordable and readily available material that can increase both the initial and final setting times of cement paste by 0.1% (Azad et al., 2020). Sugar in concrete is known as a “concrete strength enhancer” because it increases the compressive strength of concrete while also delaying the setting time (Kassa, 2019; Chand and Dhyani, 2015). Previous scientific research has confirmed that adding sugar to concrete improves its strength properties by 22.4%, 19.6%, and 20.3% after 7, 14, and 28 days, respectively, when compared to concrete without sugar (Azad et al., 2020). However, the effect of sugar on concrete varies depending on the type and dosage of sugar used (Ahmad et al., 2020). For example, Trehalose has no significant effect on the setting time of concrete, and Lactose has only a minor impact (Mazumder, 2016).

In contrast, Sucrose has the most pronounced effect on delaying the setting time when added in excessive amounts (Mazumder, 2016; Li et al., 2023). To illustrate the effectiveness of sugar in delaying the setting time, when 0.06% of crystal solid sugar is added to the concrete, the setting time is delayed by 45 minutes (Devakate and Keerthi, 2017; Abalaka, 2011). Up to 0.1% sugar, the first setting time of cement paste remains within acceptable limits, at 116 minutes (Azad et al., 2020). Initial and final setting times of cement paste increase with higher sugar percentage up to limited value (Usman et al., 2016). The concrete's compressive strength reaches its peak at 0.08% sugar during the entire curing period, with an increase of 22.4%, 19.6%, and 20.3% compared to concrete without sugar after 7, 14, and 28 days, respectively (Azad et al., 2020).

However, adding more than 1% of sugar by total weight of the concrete significantly delays the hydration and setting time for several days (Juenger and Jennings, 2002). Importantly, adding sugar does not make the concrete behave plastically but does make it easier to break up. Moreover, adding sugar as an admixture may affect concrete properties such as durability, shrinkage, and strength (Usman et al., 2016; Nassar et al., 2021).

When the sugar is added to the concrete there are three possible ways that sugar can work in concrete. The first way is that the sugar can make a coat around the cement particles, this happens because of the reaction between sugar and concrete combination which will cause the coating (Usman et al., 2016; Thanoon et al., 2023). The second way it is the sugar can form insoluble complexes by reducing the amount of aluminum and calcium, so this will prevent the reaction between (aluminum and calcium) with water and will be noticed in insoluble complexes (Thanoon et al., 2023). The final way, because sugar is known and its high polarity, this would result in absorption the solid liquid and then stop the connection of crystals and prevent the reaction of tri-calcium silicate hydrate (Juenger and Jennings, 2002).

Furthermore, many studies have been done on the effect of seawater on concrete. For many years, one of the most fascinating areas of research for concrete scientists has been the chemical deterioration of seawater-exposed concrete. While the studies have provided some crucial information, there is still much more to learn and explore in this area. The ions chloride, sodium, magnesium, calcium, and potassium are the major chemical components of saltwater (Akinkurolere et al., 2007; Chen. and Ye, 2023). Sodium chloride (NaCl) is easily the most abundant salt in seawater, with dissolved salts reaching 35000 ppm. The pH of saltwater ranges from 7.4 to 8.4 (Khan et al., 2015).

There is hardly any research that examines the inclusion of both salt and sugar together in mortar mixes. This paper examines the effect of adding salt dosages and sugar dosages to the mortar mix as
a percentage of cement. Also, a mix combining the salt and sugar percentages is performed and examined. Several tests including density, ultrasonic pulse velocity, compressive strength and flexural strength are carried out. Correlations between different tested properties is also performed.

2. EXPERIMENTAL

2.1. Materials

Portland cement Type I conforming EN 197-1 standards is used. The sand used in this mix is of particles passing through 4.75 mm and retaining on 200 μm. Tap water is also used. Regarding salt and sugar they are food consumed materials.

2.2. Chemical Composition

The main chemical ingredient of salt is sodium chloride (NaCl). However, the sugar is sucrose (C\textsubscript{12}H\textsubscript{22}O\textsubscript{11}).

2.3. Mix Proportions

Three different mixes are prepared with different constituents. The cement: sand ratio is taken 1:3 and the water to binder ratio is set constant in all mixes at 0.5.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Cement</th>
<th>Sand</th>
<th>Water</th>
<th>Sugar or Salt</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15% Sugar</td>
<td>479.28</td>
<td>1440</td>
<td>240</td>
<td>0.72</td>
</tr>
<tr>
<td>0.3% Salt</td>
<td>478.56</td>
<td>1440</td>
<td>240</td>
<td>1.44</td>
</tr>
<tr>
<td>Combined (0.15% sugar + 0.3% salt)</td>
<td>477.84</td>
<td>1440</td>
<td>240</td>
<td>(Sugar = 0.72) &amp; (Salt = 1.44)</td>
</tr>
</tbody>
</table>

2.4. Specimens Preparation and Curing

The mortar specimens are mixed by adding sand and cement together, then adding salt and sugar to the water and stirring them properly until all the powder melts. Second, the water is added gradually to the sand and cement and all materials are mixed together until reaching a homogenous mixture. Third, the mortar is poured into the molds by filling 2 layers and tempering properly each layer. Fourth, the top of the molds is leveled properly in order to reach a smooth surface. Fifth, the molds are placed on the vibrator in order to make sure all voids are filled. After 24 hours from casting, the specimens are demoulded. Sixth, the specimens are placed in a water bath until the curing period ends. Finally, the testing is performed at 7, 28, 56 and 90 days of curing. The process of preparing the specimens is shown in Fig. 1.

![Specimens Preparation and Curing](https://digitalcommons.bau.edu.lb/stjournal/vol5/iss2/3)

Fig. 1: Specimens Preparation and Curing
3. TESTING

3.1. Density

Mortar cubes of 50 mm in size and prisms of dimensions 40mmx40mmx160mm are cast and then cured in water for a specific period. After the curing period passes, specimens are taken out of water and tested by weighing them using a digital balance as shown in Fig. 2. The following equation is applied to calculate the density (ASTM C642, 2001):

$$\rho = \frac{M}{V} \quad \text{(1)}$$

Where $\rho$ is density (kg/m$^3$), M is mass (kg) and V is volume (m$^3$)

![Fig. 2: Density Testing](image)

3.2. Ultrasonic Pulse Velocity (UPV)

After the samples were weighted for the density test, same samples are taken for UPV test. This test is carried by a device that produces ultra-waves through the samples. A grease material is placed on the heads of the machine and the test is then applied as displayed in Fig. 3. The following formula is applied to calculate the velocity (ASTM C597, 2009):

$$\text{UPV} = \frac{d}{t} \quad \text{(2)}$$

where UPV is ultrasonic pulse velocity (km/s), d is distance (km) and t is time (s)

![Fig. 3: Ultrasonic Pulse Velocity Testing](image)

3.3. Compressive Strength

After the samples were weighted for the density test and after applying the UPV test, the mortar cubes of 50 mm size are used to check the strength of specimens. A compressive load is applied on the cubes until failure as presented in Fig. 4 (ASTM C109, 2003). The following equation is used to calculate the compressive strength:
\[ f'c = \frac{P}{A} \quad (3) \]

where \( f'c \) is compressive strength (MPa), \( P \) is load (N) and \( A \) is area (mm\(^2\))

Fig. 4: Compressive Strength Testing

### 3.4. Flexural strength

The flexural strength test is applied on prisms with dimensions 40mmx40mmx160mm. The samples are inserted in the machine on a steel support and a rod is placed on the middle of the prism as shown in Fig. 5 (ASTM C348, 2001). The following equation is used to calculate the flexural strength:

\[ \sigma = \frac{3PL}{2bd^2} \quad (4) \]

where \( \sigma \) is flexural strength (MPa), \( P \) is applied load (N), \( L \) is length of prism (mm), \( b \) is width (mm) and \( d \) is depth (mm)

Fig. 5: Flexural Strength Testing
4. RESULTS AND DISCUSSION

4.1. Density

For the samples that contain 0.15% sugar of the total mixture, a gradual increase is observed in density from 7 to 90 days. The density increases from 1996 kg/m$^3$ to 2155 kg/m$^3$. The same trend is also obtained for mortar mix containing 0.3% salt where the density varies from 2067 kg/m$^3$ to 2213 kg/m$^3$. Regarding samples that contain both salt and sugar with 0.15% and 0.3% of the total weight of cement respectively, the same pattern is exhibited where the density values lay between the separate mixes containing salt or sugar. The density is enhanced from 2054 kg/m$^3$ to 2202 kg/m$^3$ when curing period passes from 7 days to 90 days. The enhancement in density values with the increase in curing age can be related to the increase in hydration process (Dada et al., 2019). Results are shown in Table 2.

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Density (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 7</td>
</tr>
<tr>
<td>0.15% Sugar</td>
<td>1996</td>
</tr>
<tr>
<td>0.3% Salt</td>
<td>2067</td>
</tr>
<tr>
<td>Combined</td>
<td>2054</td>
</tr>
</tbody>
</table>

4.2. Ultrasonic Pulse Velocity (UPV)

Fig. 6 shows the ultrasonic pulse velocity (UPV) results for different mortar mixes with different curing ages. An increase in the velocity of ultrasonic waves passing through specimens containing 0.15% sugar of is observed. The UPV values increases from 2.15 km/s to 3.45 km/s as curing age varies between 7 days and 90 days. Also, specimens containing 0.3% salt of the total weight of cement exhibit a similar pattern to the sugar samples but with a higher rate of increase in ultrasonic wave velocity where the values range between 2.76 km/s at 7 days of curing to 4.61 km/s. Also specimens containing both salt and sugar demonstrate the same pattern where an increase in UPV, from 2.30 km/s to 3.56 km/s, is recorded when the curing age increases from 7 days to 90 days. It is noticed that at 90 days of curing, mortar mixes indicate good to excellent qualities.

4.3. Compressive Strength

Fig. 7 shows the variation in compressive strength with respect to curing ages ranging from 7 to 90 days. After applying the compressive strength test, an increase is observed when increasing the curing ages from 7 days to 90 days. For mix containing 0.15% sugar of the total weight of cement, the compressive strength varies from 0.98 MPa to 4.23 MPa. Regarding mix containing 0.3% salt
by weight of cement, the compressive strength changes from 4.98 MPa to 22.17 MPa when the curing age increases from 7 days to 90 days. However, concerning mix with combined salt and sugar percentage, the compressive strength values lay between the values for sugar and salt mixtures. The values vary from 1.24 MPa to 5.44 MPa when the curing age increases from 7 days to 90 days. The increase in compressive strength with curing age is due to the hydration reaction that took place where C-S-H gel is created (El-Mir et al., 2022). Mix containing 0.3% salt records the highest values of compressive strength at all curing ages since salt contain NaCl that can bind the calcium hydroxide compounds leading to an enhancement in compressive strength (Mansyur et al., 2021).

Fig. 8 shows the relative compressive strength at different curing ages for all mortar mixes with respect to 28 days of curing. The relative strength is the strength for each mix at each curing age over the strength at 28 days of curing. The relative strength for mortar mixes varies between 0.51 to 3.44.

![Fig. 7: Compressive strength for different mortar mixes at different curing ages](image)

![Fig. 8: Relative compressive strength for different mortar mixes at different curing ages with respect to 28 days of curing](image)
4.4. Flexural Strength

The flexural strength of different mortar mixes at different curing ages is shown in Fig. 9. Similar to the compressive strength, the flexural strength increases with the increase in curing age. For example, for combined mix, the flexural strength increases from 0.13 MPa to 1.11 MPa when the curing age varies from 7 days to 90 days. Also, like compressive strength, mix containing only salt records the highest values while the lowest flexural strength values are for mix containing sugar. For example, at 90 days of curing, mix containing sugar records a flexural strength value of 0.98 MPa, however, a mix containing salt and combined mix records values of 4.01 MPa and 1.11 MPa respectively. The results of flexural strength have the same trend obtained for compressive strength.

The relative flexural strength with respect to 28 days of curing is present in Fig. 10. Relative strength values vary between 0.31 to 3.77 for different mortar mixes.
4.5. Correlation Between Compressive Strength and Ultrasonic Pulse Velocity

Fig. 11 shows the relationship between compressive strength and UPV. There seems to have an exponential relationship between both tested properties. An increase in compressive strength values is obtained with an increase in UPV values. A strong relationship is obtained where the correlation coefficient records a value $R^2 > 0.90$.

![Graph showing exponential relationship between compressive strength and UPV](image1)

4.6. Correlation Between Compressive Strength and Flexural Strength

Fig. 12 plots the relationship between compressive and flexural strength. There appears to have a good linear relationship between both tested properties. A high correlation coefficient is obtained $R^2 > 0.95$.

![Graph showing linear relationship between compressive strength and flexural strength](image2)

5. CONCLUSION

This paper discusses the effect of addition of either salt, sugar or a combination of salt and sugar on mortar mixes. Mechanical properties including density, ultrasonic pulse velocity, compressive strength and flexural strength are examined. Different correlations between different properties are also examined. Based on the previous results, the following points can be concluded:
• The density of mortar mixes increases with the increase in curing age. Mortar mix containing salt recorded the highest density values at all curing ages.
• The UPV values record the highest ones for mix containing only salt. UPV increases with the increase in curing ages from 7 days to 90 days.
• The compressive strength records the lowest values for mortar mix containing only sugar and the highest values for mix containing only salt. Compressive strength increases with the increase in curing ages between 7 days to 90 days.
• Flexural strength exhibits the same trend as compressive strength. Flexural strength increases with the enhancement in curing ages.
• A high correlation coefficient above 0.90 is obtained for the relationship between compressive strength and UPV.
• An excellent correlation is obtained between compressive strength and flexural strength with a high correlation coefficient above 0.95.

6. FUTURE RECOMMENDATIONS

Different set of mixes with different ratios should be investigated in order to study the effect of the combination between salt and sugar. Also, different durability properties of concrete containing combination of salt and sugar should be examined.

REFERENCES


