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BESTMITTEL AND SILICA FUME EFFECT ON CONCRETE COMPRESSIVE STRENGTH WITH SEAWATER CURING

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Abstract

The frequency of tidal floods caused by seawater threatens coastal buildings. This study aims to see how using seawater for concrete treatment affects the resulting compressive strength. This study used additives such as Bestmittel to expedite hardening and boost compressive strength, as well as silica fume to increase porosity and prevent concrete from becoming porous owing to chloride ion intrusion from seawater. The findings of concrete compressive strength tests were achieved through laboratory testing using cylindrical test objects measuring 150 mm in diameter and 300 mm in height. The test specimens were ordinary concrete with 0.6% bestmittel and a Silica Fume combination with varying percentages of 15%, 20%, and 25% substituting partial cement. Meanwhile, the concrete treatment employs both fresh water and seawater. Pressure tests were performed at 14 and 28 days. At 14 days, concrete with fresh water treatment and a bestmittel content of 0.6% and silica fume concentrations of 15%, 20%, and 25% have compressive strengths of 25.53 MPa, 27.11 MPa, and 26.04 MPa, respectively. Meanwhile, it was 26.34 MPa, 27.61 MPa, and 26.75 MPa after 28 days of concrete age. At 14 consecutive days of concrete age, concrete with seawater treatment had a reduced compressive strength. 19.66 MPa, 22.13 MPa, and 23.07 MPa, respectively. Meanwhile, at 28 days, the pressures were 20.53 MPa, 24.77 MPa, and 25.53 MPa. Using 6% bestmittel followed by 15-20% SF can boost the strength of the concrete and let it survive reduced compressive strength due to seawater infiltration.

Keywords: Bestmittel, Silica Fume, Seawater Curing, Compressive Strength

Introduction

The selection of concrete mix for construction in coastal areas necessitates careful consideration because of its susceptibility to seawater submersion. Seawater is comprised of several substances. Chloride (Cl^-), Sodium (Na^+), Sulfate (SO_2^{4-}), Magnesium (Mg^{2+}), Calcium (Ca^{2+}), and Potassium (K^+) are the six most prevalent ions in seawater. These ions constitute approximately 99% of the weight of all sea salts. The salinity level of seawater typically averages approximately 3.5%. Corrosion in reinforced concrete is observed when the concrete is exposed to seawater, forming cathode and anode zones (Adiwijaya, 2015). The ensuing electrolytic process involving these ions harms the adjacent concrete structure (Fahirah, 2007). The primary factor contributing to reinforcement corrosion is the presence of the chloride ions in seawater (Pan et al., 2020; Wang et al., 2019). According to a previous study (Yu et al., 2018), the elevated presence of chloride ions in saltwater increases the susceptibility of steel reinforcement instructions to corrosion over a prolonged period. The phenomenon described leads to swift deterioration of the structural integrity due to the corrosion process affecting the steel reinforcement embedded within concrete (Adiwijaya, 2015; Furuya et al., 2009; Olutoge et al., 2014; Thiago et al., 2013; Wegian, 2010; Zhu et al., 2016). According to Zhu et al. (2016), the ingress of chloride ions into the concrete matrix can lead to extensive corrosion and fractures in the surface of the concrete. Stainless steel is extensively utilized in architectural structures located in coastal regions as a means of safeguarding reinforcing steel from corrosion inside highly corrosive alkaline surroundings (Meng & Zhang, 2016; Thiago et al. et al., 2013). In light of this, stainless steel reinforcement is frequently employed to mitigate the likelihood of corrosion in reinforced concrete and prolong the lifespan of construction in coastal regions (Meng & Zhang, 2016; Tan et al., 2020). Naturally, the expenses associated with stainless steel reinforcement will be elevated.

Conversely, a multitude of elements exert an influence on the strength and durability of the resultant concrete. Sulfur and chloride in seawater can adversely impact concrete's structural integrity and strength. In addition, it should be noted that seawater might impact the water content within the concrete mixture when casting concrete near coastal areas, resulting in prolonged setting time for the concrete. In order to address this issue, one potential solution involves the incorporation of additives and fillers that contain pozzolanic elements, such as silica fume and bestmittel (ASTM C494-81, 2004). Previous research has been conducted incorporating other environment-friendly materials as additional material in concrete (Hulu et al., 2023; Laia et al., 2023; Samosir et al., 2021; Siregar et al., 2021) but not applicable to seawater submersion structure (Anitha et al., 2016; Prasittisopin & Trejo, 2015; Thomas, 2018; Yang et al., 2018).

Incorporating Silica Fume as an addition to cement can potentially enhance the impermeability and density of concrete. It is achieved by effectively filling the voids between concrete particles and reducing the size of pores, leading to improved concrete material performance (Liu et al., 2018). According to another study (Liu et al., 2018), incorporating Silica Fume into concrete can enhance its strength and longevity, reducing susceptibility to cracking and damage. Furthermore, Liu et al. (2018) show that Silica Fume in cement results in small particles filling interstitial voids between cement grains. Consequently, the material exhibits reduced porosity and enhanced resistance to the corrosive effects of seawater. The protection against the entry of chloride ions is achieved by limiting permeability, as these ions can induce carrion in reinforcing steel. Adding Silica Fume to concrete can create a more compact microstructure by decreasing its permeability (Zhang & Li, 2013). Decreased pore volume inside concrete enhances its durability and compressive strength (Erniati et al., 2015; Sutriono et al., 2018).

This substance, derived from waste generated by high-temperature combustion in the ferro-silicon sector, can serve as an additive in concrete to mitigate environmental disruption. Silica fume is a particulate substance characterized by its tiny grain size, enabling it to effectively occupy the empty spaces between cement paste and aggregate materials. In addition, it possesses a pozzolanic characteristic as a substance. Silica fume is defined (ASTM C618, 2023) as a pozzolanic substance characterized by its SiO_2 content over 83%. This high SiO_2 content enables a chemical reaction between SiO_2 and $Ca(OH)_2$, forming hydrated silicates. These hydrated silicates significantly influence the hardness properties of concrete (Haris & Firdaus, 2021; Liu et al., 2018). Due to its pozzolanic characteristic, Silica Fume can react with the lime present in cement. In addition, silica's incorporation into concrete structures facilitates the formation of C-S-H bonds. These bonds are crucial in enhancing the interfacial adhesion between cement and aggregate, particularly during the reaction and release of hydration heat. According to Zhang and Li (2013), the inclusion of Silica Fume in concrete has resulted in a reduction in permeability, an intensification of carbonation, and an elevation in the relative dynamic modulus of elasticity. These effects collectively lead to the enhancement of concrete durability. In general, using Silica Fume in the construction sector has been found to enhance the microstructure, densify the concrete, and enhance its strength and durability (Fattouh & Elsayed, 2023; Uzbas & Aydin, 2020).

In contrast, the utilization of bestmittel as an additional substance presents a cost-effective approach due to its ability to expedite the initial hardening process of concrete and diminish water consumption during casting operations while enhancing the overall quality and strength of the concrete. Bestmittel is classified as a type E chemical additive, categorized explicitly as a water-reducing, and accelerating admixture. The substance serves a dual purpose: to decrease the water content during the concrete mixing process and to expedite the concrete's setting time (ASTM C494-81, 2004; ASTM C494, 2017). According to Indonesian standards, this material is classified as an additive material for class V (SNI S-18-1990-03, 1990). In addition to its role in speeding up concrete hardening, the incorporation of bestmittel at a concentration ranging from 0.2% to 0.6% has been seen to enhance the compressive strength of concrete. Based on the conducted research, the utilization of bestmittel with 0.6% content has demonstrated the potential to enhance the compressive strength of concrete at the age of 28 days, achieving a range of 6% to 9% of the intended compressive strength (Sulistyawati, 2009). Referring to SNI, concrete using bestmittel can increase the compressive strength of concrete but its effectiveness when applied to concrete submerged in sea water needs to be studied further. This study aims to investigate the impact of incorporating Silica Fume and Bestmittel additives on the compressive strength of concrete when subjected to seawater curing, specifically focusing on its applicability for buildings in coastal regions.

Research Methodology

This study employs experimental studies, including testing in the Materials Technology Laboratory at Universitas Kristen Indonesia. Portland Type II cement is utilized, with Bangka sand as the fine aggregate and crushed stone as the coarse aggregate. The water originates from the Construction Materials Technology Laboratory of the Civil Engineering Study Program at Indonesian Christian University. According to the Indonesian standard (Badan Standardisasi Nasional, 2002), the water used in concrete mixtures must be pure and free of harmful chemicals that can degrade the quality of the concrete, such as oil, acid, alkali, salt, or other organic compounds.

This study made use of cylindrical test objects. The test object is 150 mm in diameter and 300 mm in height, which conforms with Indonesian standard requirements. In the laboratory, 60 test objects were created using silica fume admixture and Bestmittel additive. Each concrete test object is cured in fresh and saltwater (Adiwijaya, 2015; Diawarman, 2017; Furuya et al., 2009; Olutoge, F. Adeyemi, Amusan, 2014; Wegian, 2010). Compressive tests were performed at 14 and 28 days of age. Compressive tests on concrete were carried out at 14 days and 28 days when the concrete reached its optimal compressive strength. This research specifically wants to analyze the optimal compressive strength of concrete in sea water which will tend to decrease in the early stages but with the addition of bestmittel and Silica Fume materials it is hoped that it can reduce the decrease in concrete compressive strength when the concrete reaches its optimal compressive strength in 28 days. Meanwhile, silica fume as an admixture varies between 15%, 20%, and 25%, with the additive (bestmittel) accounting for up to 0.6% of the cement weight.

Table 1. The Samples Were Tested with Silica Fume Admixture and Bestmittel Additive

Samples	Concrete Age (days)	Total Samples (cylinder)	
		Normal Curing	Seawater Curing
Normal concrete	14	3	3
	28	3	3
Concrete Mixed B & SF 0%	14	3	3
	28	3	3
Concrete Mixed B & SF 15%	14	3	3
	28	3	3
Concrete Mixed B & SF 20%	14	3	3
	28	3	3
Concrete Mixed B & SF 25%	14	3	3
	28	3	3

According to the product manual, the recommended usage of Bestmittel is 1 kg of every 200 kg to 450 kg of cement. To utilize bestmittel effectively, prepare a solution of 0.5 kg of water proportionate to the cement's weight. Subsequently, prepare a quantity ranging from 0.2% to 0.6% of the cement's weight as the appropriate dosage of bestmittel. Subsequently, the optimal substance is introduced into the supplied water and agitated until it is uniformly dispersed. Subsequently, the optimal substance is introduced into a composite, including sand, gravel, and cement, which has been thoroughly agitated and mixed until achieving a uniform distribution. If the combination exhibits a low viscosity, it is possible to decrease the quantity of water made. The silica fume employed in this study is a finely divided amorphous form of silica generated as a byproduct during the combustion process at elevated temperatures (see Figure 2). Silica (SiO_2) is incorporated as a substitute for a portion of the cement in various proportions, precisely 15%, 20%, and 25% by weight of the cement. The substance in question is an additive material that is manufactured in industrial settings through the process of ferrous silicon combustion. The initial step in the process involves the incorporation of Silica Fume into cement, adhering to the calculations specified by the relevant standards for concrete constructions (SNI 03-2847, 2002; SNI 7656, 2012). Subsequently, the mixture is combined with sand, and gravel is added.

Figure 1. Additive Material of Bestmittel

Figure 2. Admixture Silica Fume

Fume is a pozzolan that is particularly useful for enhancing concrete quality because it contains the ingredient SiO2, which raises the stability and density of concrete, increases workability over a long period, and increases concrete durability. Table 2 shows the characteristics of silica fume.

Table 2. Silica Fume Characteristic as an Admixture in Concrete

Component	Percentage (%)
Silicon Oxide	95.84
Density	0.11
Moisture	1.00

Mix Design of Concrete Samples

The compressive strength of the concrete mixture is calculated to be 25 MPa according to the design as a standard for normal concrete. The water cement ratio (w/c ratio) is set at 0.61, and the maximum size of the coarse aggregate that can be used is 19 millimetres. The design slump value is between 75 and 100 millimetres. A slump test is performed on the concrete mix using a slump cone before it is poured into the mold. The test's purpose is to determine the slump value of the concrete mix by comparing it to the applicable standard (SNI 7656:2012).

pH of Seawater Curing

The pH of seawater used for curing concrete test specimens was also 8.56. It is essential to measure the pH of seawater before the curing process (Akomah & Jackson, 2018; Al Jaaf et al., 2019), as shown in Figure 3.

Figure 3. Seawater pH measuring

Research Results and Discussion

Fine and coarse aggregate sieve tests, mud content tests, fine and coarse aggregate specific gravity tests, abrasion resistance tests, and scratch resistance tests are some of the tests used to verify the appropriateness and qualities of materials for concrete production (SNI 2493, 2011; SNI 7974, 2013). The first batch of tests indicates that the utilized materials are up to snuff for making concrete samples.

The slump outcomes tend to improve when SF is included but will deteriorate when SF accounts for more than 20% of the total. It demonstrates the application of a maximum SF of 20% to achieve optimal workability in concrete. Table 4 displays the results of the obtained slump tests.

Table 3. Slump Test Result

Samples	Slump (cm)		
	Normal Curing	Seawater Curing	Average
Normal Concrete (B-SF) 0%	7.5	7.3	7.4

Samples	Slump (cm)		
	Normal Curing	Seawater Curing	Average
Concrete Mix 6% B + 0%SF	8.0	8.0	8.0
Concrete Mix 6% B + SF 15%	8.3	8.2	8.2
Concrete Mix 6% B + SF 20%	8.4	8.4	8.4
Concrete Mix 6% B + SF 25%	8.1	8.3	8.2

Compressive Strength of Concrete

In order to measure the compressive strength of concrete, also known as the load per unit area, test specimens of concrete are subjected to a predetermined amount of compressive force until they are completely broken (SNI 1974, 2011). Figure 4 displays the findings of experiments conducted at 14 and 28 days with curing in seawater and freshwater. According to Figure 4, the standard compressive strength of concrete is 25.24 MPa, above the target strength to achieve.

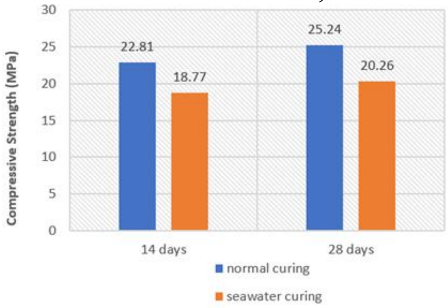

Figure 4. Compressive Strength of Normal Concrete

Whether the concrete is 14 or 28 days old, the compressive strength will decrease with seawater curing. When the concrete was immersed in seawater for 14 days, the compressive strength decreased by 23%, but only minimally at 28 days. It demonstrates that the chloride ions in seawater greatly lower the compressive strength of concrete if no admixtures or additives are introduced to mitigate the reduction in concrete strength.

Figure 5 shows that at 14 days, the optimum concrete compressive strength value was 25.08 MPa or an increase of 11.92% from regular concrete using fresh water curing.

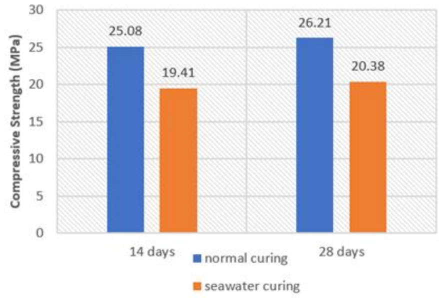

Figure 5. Compressive Strength of 6% B + 0% SF Concrete

In contrast, if seawater curing was used, it was obtained at 19.41 MPa, or an increase of 4.74% compared to regular concrete. Meanwhile, it can be seen that at the age of 28 days, the optimum concrete compressive strength value was 26.21, or an increase of 6.14% from regular concrete using fresh water curing. In contrast, if using seawater curing, it was obtained at 20.38 MPa or an increase of 1.43% compared to regular concrete in seawater curing.

Figure 6 shows that at 14 days, the optimal concrete compressive strength value with freshwater curing was 25.53 MPa, representing an increase of 18.85% over regular concrete.

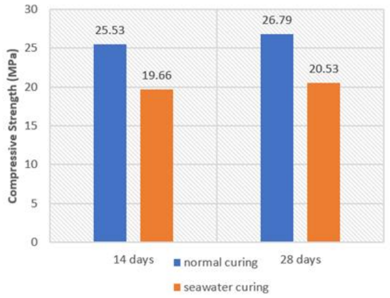

Figure 6. Compressive Strength of 6% B + 15% SF Concrete

In contrast, with seawater curing, it was 19.69 MPa, representing an increase of 17.90%. Then, it can be seen that at 28 days, the optimal concrete compressive strength value was 26.79 MPa, an increase of 9.38% over regular concrete cured with fresh water. In contrast, seawater curing resulted in a value of 20.53 MPa, an increase of 19.91% over regular concrete.

According to the data presented in Figure 7, it is evident that after 14 days, the concrete compressive strength reached its peak value of 27.11 MPa, representing a 14.16% improvement compared to regular concrete cured with fresh water.

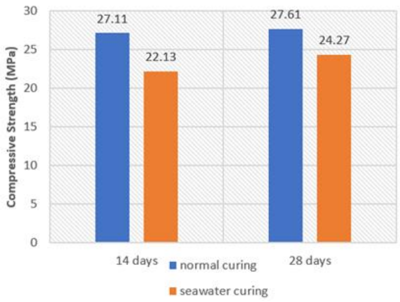

Figure 7. Compressive Strength of 6% B + 20% SF Concrete

Conversely, when saltwater was used for curing, the concrete achieved a compressive strength of 22.13 MPa, indicating a 14.38% enhancement compared to regular concrete. It is evident that at the age of 28 days, the optimal compressive strength of concrete was measured to be 27.61 MPa, indicating a 5.98% increase compared to regular concrete when subjected to freshwater curing. Conversely, when subjected to seawater curing, the compressive strength was determined to be 24.27 MPa, signifying a 26.13% increase compared to regular concrete. It shows that the decrease in normal compressive strength of concrete when submerged in sea water can be reduced by adding Bestmittel and Silica Fume to the concrete. Table 4 presents a comparative analysis of standard concrete and concrete containing 15%, 20%, and 25% silica fume based on the findings of conducted experimental research. The comparison is made regarding the curing conditions in seawater and freshwater. Figure 8 demonstrates that after 14 days, the optimal value for the compressive strength of concrete was 26.04 MPa, representing an increase of 11.92% compared to regular concrete when cured with fresh water.

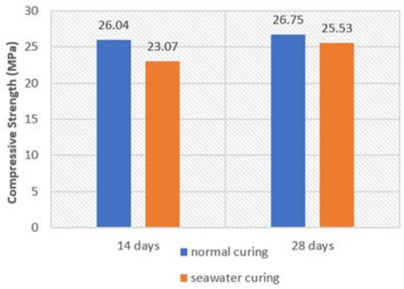

Figure 8. Compressive Strength of 6% B + 25% SF Concrete

On the other hand, when cured with salt water, the value was 23.07 MPa, representing an increase of 4.74.% compared to regular concrete. When using fresh water to cure the concrete, the optimal compressive strength value was 26.75, an increase of 6.14% from regular concrete. On the other hand, when using seawater to cure the concrete, the value was 25.53 MPa, an increase of 1.43% from regular concrete.

Table 4. Changes in Concrete Compressive Strength Due to SF and Bestmittel Additions 6%

Variation SF in Concrete + Bestmittel 6%	Concrete Compressive Strength (MPa)				Reduced concrete compressive strength	
	14 days		28 days		14 days	28 days
	Normal Curing	Seawater Curing	Normal Curing	Seawater Curing	%	%
0% SF	25.08	19.41	26.21	20.38	22.6	22.41
15% SF	25.53	19.66	26.34	20.53	22.9	22.05
20% SF	27.11	22.13	27.61	24.77	18.36	10.28
25% SF	26.04	23.07	26.75	25.53	11.4	5.23

As demonstrated in Figures 9 and 10, the curing procedure with seawater appears to lower the compressive strength of the concrete. At a concrete age of 28 days, however, using a 6% additive (bestmittel) in a standard concrete mix without the inclusion of Silica Fume can raise the compressive strength of the concrete by 5%. This result is comparable to prior studies, which found a 6%-9% improvement in intended compressive strength (Sulistyawati, 2009). Meanwhile, adding 5% -10% silica fume has no noticeable effect compared to the rise due to adding 6% bestmittel to the concrete mixture. This is in line with previous research where the use of bestmittel as much as 6% has the potential to increase the optimal compressive strength of concrete at 28 days.

However, when SF is added at a concentration of 15% to 20%, it can boost the compressive strength of concrete by up to 10%. Adding more than 25% SF reduces the compressive strength of the concrete.

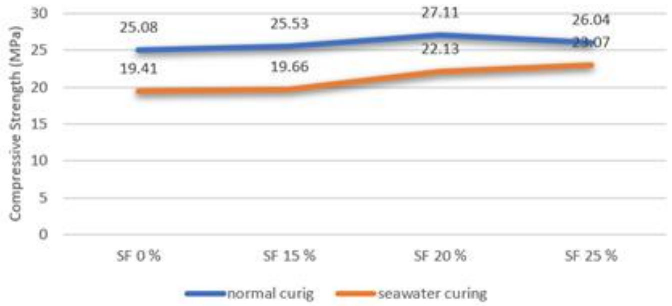

Figure 9. Declining Concrete Compression Test During Seawater Curing 14 Days

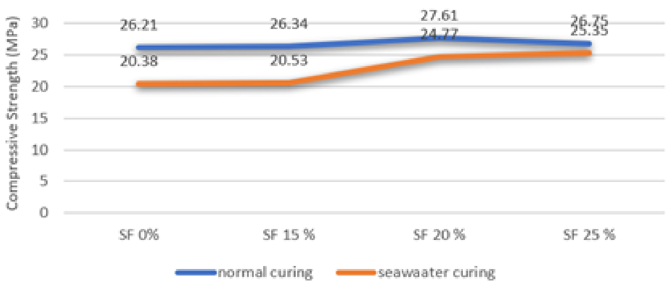

Figure 10. Declining Concrete Compression Test During Seawater During 28 Days

The addition of bestmittel did not enhance the compressive strength of regular concrete at 14 days, following the same trend as the addition of SF up to 15%. Significant changes occur when concrete with 6% bestmittel added with SF 20% is aged 28 days, approximately 6.2%, and then tends to remain constant. When the concrete was soaked in seawater for 28 days, the compressive strength decreased by 23% at 28 days and 22% at 14 days with the addition of 6% Bismittel and up to 15% SF. Significant changes occurred when SF was injected at 15%-20%, with young concrete aged 14 days experiencing the most significant decline, reaching 18.4%. At the same time, concrete aged 28 days only saw a 10.3% decrease compared to freshwater curing. It demonstrates concrete's endurance at 28 days with the addition of SF of 15% -20% since the addition of SF can tolerate the drop in compressive strength due to the entry of seawater. This result is consistent with a prior study, which indicates that tiny particles of Silica Fume will fill the empty spaces between cement grains, making the material less porous and more resistant to seawater entry (Liu et al., 2018).

Conclusion

Using silica fume can minimize porosity in concrete, increasing compressive strength. To boost the compressive strength of the concrete, the recommended level of silica fume added to the concrete mixture is around 15-20%. At a concrete age of 28 days, using a 6% additive (bestmittel) in a regular concrete mixture without including Silica Fume can raise the compressive strength of concrete by 5%. Meanwhile, at 14 days, the addition of bestmittel did not enhance standard concrete's compressive strength, following the same trend as the addition of SF up to 15%. When immersed in seawater for 28 days, the compressive strength of the concrete decreased by 23%.

Meanwhile, the compressive strength decreased by 22% after 14 days of concrete age with the addition of 6% Bismittel and SF up to 15%. Significant changes occurred when SF was injected at 15%-20%, with young concrete aged 14 days experiencing the most significant decline, reaching 18.4%. At the same time, concrete aged 28 days only saw a 10.3% decrease compared to freshwater curing. Adding SF in conjunction with the bestmittel of 6% can survive the decrease in concrete compressive strength caused by seawater intrusion.

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