



Evaluation of Using fly Ash Pozzolans and iron Smelting Slag Along with Water-Cement-Based Polymers on the Mechanical Characteristics and Durability of Concretes Used in the Persian Gulf Environmental Conditions

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Abstract

This experimental study aimed to investigate the effectiveness of incorporating fly ash pozzolans, iron smelting slag, and water-cement-based polymers in enhancing the mechanical properties and durability of concrete structures in the harsh environmental conditions of the Persian Gulf. The study addressed the issue of premature deterioration and reduced useful life of concrete structures in the region, particularly in the country's southern coasts. The results showed that increasing the cement grade led to higher compressive strength of the samples, and carbonation reduced the flux by filling the pores and creating a barrier against chloride ion penetration. Additionally, the passing flux decreased with a reduction in the water-to-cement ratio and an increase in the percentage of fly ash. The study also found that the chloride ion penetration depth decreased by decreasing the water-to-cement ratio and increasing the percentage of fly ash. The study demonstrated the effectiveness of fly ash pozzolans in filling the holes, providing high strength to concrete, and improving its durability by converting ettringite to C-S-H gel. These results could contribute to the development of more sustainable and durable concrete structures in the region. Future research could focus on investigating the influence of other factors, such as the size and shape of the aggregates and the curing conditions, on the properties and performance of concrete.

Keywords: Concrete, Pozzolan, Slag, Polymer, Persian Gulf

1. Introduction

The reliability of concrete structures has always been raised as a problem on the country's southern coasts (the Oman Sea Basin and the Persian Gulf) due to the increasing development



of the country's strategic areas in the Persian Gulf basin. Premature destruction and severe reduction of the useful life of concrete structures are among these problems. [1] Therefore, increasing the useful life of concrete structures requires more investigation of destructive processes, including the penetration of chloride ions and corrosion in concrete. Improper standards and wrong technical specifications regarding the selection of materials, implementation methods, and the structure's performance can lead to concrete failure [2]. For example, European and American standards for projects in the Persian Gulf region with different weather, materials, and building materials and the skills of different people reduce the durability and reliability of concrete structures in the mentioned regions. The operation of the structure is also faced with severe issues [3].

Pollution of water, soil, and atmosphere with harmful chemical elements for concrete, as well as high humidity, temperature, and solar radiation in Persian Gulf coastal areas, contributes to the destruction of structures and increases the rate of damage. Laboratory studies have shown that the salts in the water of the Persian Gulf are higher than in most of the world's waters [4]. The high amount of chloride in this water has destroyed all coastal and marine structures. The amount of chloride in the water is about 24000–20000 PPM, and the amount of sulfate is about 3700–3000 PPM [5, 6]. In addition, the underground waters of this region are heavily polluted with chloride and sulfate ions [5]. Due to its proximity to the equator, air temperatures in the Persian Gulf range from 37 to 41 °C during the hottest months. The concrete surface temperature under direct sunlight reaches 70 to 75 °C, and the relative humidity varies between 48 and 81% [4].

From the perspective of the durability of concrete structures, the environmental conditions of the Persian Gulf, especially its coasts, are very aggressive and corrosive compared to other parts of the world [7]. Many concrete structures in this region have been damaged quickly, indicating the importance of paying attention to corrosion and choosing the optimal treatment methods [8]. Combining appropriate materials, concrete design with unique specifications for these areas, concrete implementation by craftsmen, and proper and adequate processing can solve many concrete problems [9]. Hence, the National Concrete Reliability Code in the Persian Gulf and Oman Sea was proposed by the Building and Housing Research Center to construct and control concrete in these areas [10]. The penetration of ions, gases, and liquids from the surface of the concrete is the essential characteristic determining the durability of concrete structures in different conditions, including marine environments [7]. The complexity of the tests and devices, the test's length, and the results' dispersion are significant problems with some of these methods [11]. The water absorption test, water penetration under pressure, gas penetration, oxygen, and chloride ion conduction in concrete can be mentioned as penetration tests [11].



Flows in the Persian Gulf mainly have three origins: density, wind, and tide, but the leading and most important water flow in the Persian Gulf is counter-clockwise, caused by the difference in water density [12]. The higher salinity of the water in the Persian Gulf basin compared to the ocean has caused the emergence of this stream from the Indian Ocean to the Persian Gulf [13]. Water with average ocean salinity enters the Persian Gulf through the Strait of Hormuz, moves towards the northwest parallel to the coasts of Iran, and changes direction towards the south in the western part of the basin. The water becomes denser due to evaporation, its salinity increases and becomes denser after traveling the southern parts, exiting the Strait of Hormuz basin [14]. The amount of salt in Persian Gulf water ranges from 27 to 41 mg/l. The water salinity increases from the north to the south, which can be attributed to the decrease in water depth and salt domes [15]. The freshwater entering the Persian Gulf is mainly limited to the runoff from the Zagros, Turkey, and Iraq mountains, among which the Karun, Tigris, and Euphrates rivers are the most abundant [16]. The incoming water on the south bank is shallow. The water of the Persian Gulf has much salt due to intense evaporation, and the evaporation rate is almost six times the amount of rainfall and water input from the rivers leading to the Persian Gulf. The highest amount of evaporation occurs in the south of the Persian Gulf. As mentioned, his evaporation causes the formation of a dense layer of water in the basin of the Persian Gulf, which enters the Sea of Oman after exiting the Strait of Hormuz [17].

The Persian Gulf, due to its extreme weather conditions and unique geographical location, poses a significant risk to hardened and freshly poured concrete structures. Main factors hindering the construction of reinforced concrete structures in this region include high humidity, poor concrete quality, and a shortage of skilled and specialized labor. The high cost of these structures highlights the importance of maintaining and preventing their destruction. Strategies such as using anti-corrosion agents and developing specialized concrete mixes for the Persian Gulf region can aid in prolonging the lifespan of concrete structures in this area [18-20].

This study aimed to achieve a polymer concrete appropriate and specific to the climate of the Persian Gulf coast using fly ash pozzolans and iron smelting slag along with water-cement-based polymers on the mechanical characteristics of concrete. Polymer concrete can solve all the concerns and deficiencies in concrete structures with remarkable mechanical properties compared to conventional concrete, although its price is much higher than cement concrete. Considering the good mechanical properties of polymer concrete, the use of this type of concrete can be increased by reducing construction costs.



2. Research literature

Koushkbaghi et al (2019) examined the mechanical properties and durability of geopolymer concretes by varying the monomer and recycled concrete proportions. The mechanical properties were assessed using metakaolin as a source of aluminosilicate and recycled concrete (RCA) as a partial replacement of natural aggregates. Sodium silicate (SS) and sodium hydroxide (SH) were used to compare their effect on the mechanical properties and durability of geopolymer concrete, alongside varying percentages of RCA. The impact of RCA on the microstructure of geopolymers was investigated using scanning electron microscopy (SEM). The results showed that increasing the SS/SH ratio enhanced the compressive strength of geopolymer concrete. The use of RCA caused a reduction in the compressive strength by up to 28%; however, it still remained suitable for structural applications. Furthermore, an increased SS/SH ratio resulted in a decrease in chloride ion permeability and absorption of geopolymer concrete. Morphological analysis indicated that an increased SS/SH ratio led to a reduction in the width of the purification in the interphase transition zone (ITZ) between RCA and the bonding phase. The polymer products became more uniform and homogeneous as the monomer ratio approached sufficiency. Moreover, the geopolymer binder with an SS/SH ratio of three exhibited a higher density and lower porosity compared to smaller ratios. Recycling and utilizing demolition waste in the production of geopolymer concrete can contribute significantly to the sustainability of the construction industry in terms of technical, economic, and environmental aspects [21].

Shaban et al (2019) conducted a study to improve the properties of recycled concrete using cost-effective and eco-friendly techniques. The use of recycled concrete aggregate (RCA) as an alternative to natural aggregate (NA) in the construction industry is becoming more common, but the poor quality of the mortar in RCA can negatively impact the performance of the resulting concrete. To enhance the quality of RCA, the authors suggest soaking it in different types of pozzolan powders (e.g. metal ash, silica fume, and nano-silica) at different dosages and soaking times. The physical and mechanical properties of the RCA were analyzed before and after the solid surface treatment. The study's findings indicate that RCA quality can be improved using this method, which can contribute to the sustainability of the construction industry from technical, economic, and environmental perspectives [22].

The surface morphology of RCA was analyzed using SEM-EDS to investigate the impact of porcelain soaking on RCA's microstructure. The results demonstrate that the porcelain soaking technique can effectively improve the stability of the mortar and enhance the properties of RCA. Through testing different Pozzolan sulfates and treatment durations, soaking RCA in 40% FA and C and 3% NSF for 4 hours exhibited the most significant effects, such as a 50-55% reduction in water absorption and a 10-11% increase in particle density. Moreover,



treating RCA with a soaking time of 4 hours using a mixture of 40% FA and SF, 40% FA and C, and 3% NSF showed similar recovery performance, with reductions in abrasion values of 31%, 35%, and 33%, respectively. Microstructure analysis revealed that RCA became more homogeneous at a low Ca/Si ratio. The physical properties of RCA, including water absorption and porosity, and mechanical properties and durability with regards to resistance to crushing and wear reduction, were significantly improved through the suggested treatment method [23].

Najimi et al. (2019) conducted a study on the engineering properties of active concrete that is based on natural pozzolan or slag. This investigation focused on the engineering characteristics of alkaline-active concretes made with hybrid amino acid precursors. The study involved the use of different ratios of natural pozzolan, a low-calcium precursor, and blast furnace slag, a high-calcium precursor, along with varying concentrations and compositions of sodium hydroxide and active sodium silicate. The parameters under investigation included a combination of aluminosilicate precursors (with natural pozzolan/slag ratios of 30:70, 50:50, and 70:30, respectively), sodium hydroxide concentrations (1, 75, and 2.5 MB), and an active compound (sodium silicate/hydroxide sodium ratios of 20:80, 25:75, and 30:70). The resulting concrete mixtures underwent testing for shrinkage, setting time, unit weight, compressive strength, tensile strength, elastic modulus, and drying shrinkage, as well as absorption and chloride penetration. The performance of the activated alkali concrete was also compared with that of Portland cement concrete. The results indicated that alkali-activated concretes could be designed to perform similarly or even better than Portland cement concrete. Based on the overall performance, the equal ratio of natural pozzolan and slag (50:50) and a combination of 30:70 sodium silicate and sodium hydroxide as the precursor and activator compound, respectively, produced optimal results. The optimum sodium hydroxide concentration depended on the precursor and activator compounds, as well as on new expectations for strength, secondary dimensions, and transport properties [24].

Gonzalo et al. (2019) conducted a study on the use of recycled tire fibers treated with gamma radiation to enhance polymer concrete. Although polyethylene polymer concrete is widely used due to its cost-effectiveness and versatility, it has some drawbacks, including a low elastic modulus, high porosity, and poor chemical resistance. One potential solution is the addition of recycled fibers, but the effects of these fibers and gamma radiation on other types of concrete are not well understood. The researchers prepared concrete using polyester resin and silica sand, where the latter was partially replaced with recycled tire fibers (0.3, 0.6, 0.9, and 1.2 vol%), and applied gamma radiation at 50 and 100 kGy. They evaluated the mechanical properties of the concrete, including compression and flexural strength, and observed significant improvements in the properties due to the morphological and structural changes induced by the recycled tire fibers. [25].



In 2019, Ding et al. investigated the pressure sensitivity of smart polymer concrete that is based on steel slag. Previous studies have shown that concrete that contains conductive materials such as graphite, carbon fiber, and steel slag are both pressure-sensitive and pressure-resistant. However, the strength of this type of concrete cannot be changed uniformly, which limits its use as a measuring material. To address this issue, the authors prepared a new type of smart polymer concrete block by adding graphite slag and steel to epoxy resin concrete, and tested the pressure-sensitive properties under integrated compression. The results indicated that the strength of the concrete increased with increasing pressure under uniform compression, and the trend was unidirectional [26].

Concrete is a widely used construction material in the Persian Gulf region, but the harsh environmental conditions can lead to its degradation, compromising the durability and mechanical characteristics of structures. Fly ash pozzolans and iron smelting slag are two such materials that have been investigated. In a study by Al-Swaidani et al. [27], it was found that the inclusion of fly ash pozzolans in concrete enhanced its mechanical properties and reduced chloride ion penetration. Al-Jabri et al. [28] investigated the influence of using iron smelting slag as a partial replacement for cement, and found that it improved concrete's durability in chloride-rich environments. Saberian et al. [29] studied the effect of combining fly ash pozzolans and iron smelting slag and found that the combination enhanced both the mechanical and durability properties of concrete. Another study by Al-Busaidi et al. [30] evaluated the effect of using both fly ash pozzolans and iron smelting slag on concrete's mechanical properties, finding that the combination can significantly enhance its compressive strength and reduce chloride ion penetration. Al-Saidi et al. [31] investigated the impact of using water-cement-based polymers and found that they improved the mechanical properties of concrete, such as its compressive and tensile strengths. Al-Khafaji et al. [32] evaluated the effect of using fly ash pozzolans and iron smelting slag on the durability of reinforced concrete and found that their use reduced the corrosion rate of reinforced concrete, enhancing its durability. In a study by Al-Sulaimani et al. [33], it was found that using fly ash pozzolans reduced the water demand of concrete, making it more workable and easier to place. Al-Jaidi et al. [34] studied the impact of using a hybrid material consisting of fly ash pozzolans and iron smelting slag, finding that it significantly enhanced the mechanical and durability properties of concrete. Finally, Al-Salman et al. [35] investigated the effect of using water-cement-based polymers on the chloride ion penetration of concrete and found that their use reduced chloride ion ingress. In conclusion, the use of fly ash pozzolans, iron smelting slag, and water-cement-based polymers in concrete can significantly enhance its mechanical and durability properties, making it more resistant to degradation in the harsh environmental conditions of the Persian Gulf region. In this paper, the concept of "mutual contact effect" was proposed to explain the phenomenon, according to which the steel slag and sand are like the "island" in the form of the "ocean" conductive matrix.



and the steel slag in the smart polymer concrete has a conductive interface layer. The pressure sensitivity of the block is mainly due to the interfacial contact effect between the surface and the conductive adhesion matrix.

3. Proposed method

This study was conducted based on laboratory studies, and the data were collected through laboratory samples. The experiments in this research include the following:

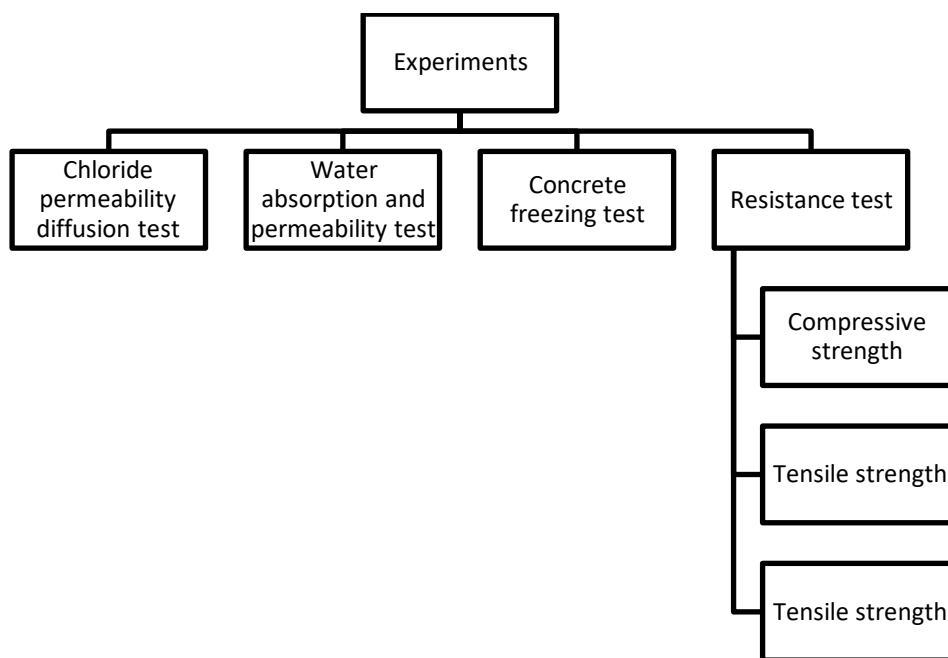


Figure 1. Flowchart of experiments

3.1. Specifications of the materials

The materials used in fiber-reinforced concrete include cement, water, and fine aggregate, which are reinforced with polymers and pozzolans. This concrete may contain additional fillers, pozzolan materials, and additives according to the specific requirements for a specific application.

3.1.1. Aggregates

As almost three-quarters of concrete is made of stone materials, the quality of those materials can significantly impact the final properties of the concrete [36]. The strength of stone materials is decisive for the strength of concrete, and other characteristics of aggregates, such as surface texture, shape, geometric dimensions, and the condition of their internal voids, can significantly impact the durability and performance of concrete [37, 38]. The type and size of stone materials



used in fiber-reinforced concrete differ depending on the concrete's application [39]. The aggregates used should have high durability and no reactivity with cement [40]. The aggregates used in fiber-reinforced concrete are mainly refined grains (aggregates that pass through sieve No. 4) [39]. Coarse aggregates (aggregates larger than 4.75 mm) are also used in making this concrete in some cases and according to the conditions of using these sections [39]. In the presence of coarse aggregate, concrete should be examined for color, hardness, size, strength, durability, and performance [41]. Many types of aggregates used in ordinary concrete may also be used in fiber-reinforced concrete, among which marble, limestone, and granite can be mentioned [42]. Using smooth and flat aggregates increases the possibility of separating the grains from the concrete surface and creates an uneven surface [43]. The size of the most prominent grain in concrete should be at most 6 mm. If this value is exceeded, the concrete production process fails, leading to unevenness on the concrete surface [44].

Only fine-grained silica sand is used in the study that will be analyzed in the following sections [45]. To ensure high-quality concrete, compliance with the requirements of ASTM C33 is mandatory [46]. ASTM C33 specifies the characteristics of aggregates used in concrete, including grading, size, shape, and surface texture, to ensure that the aggregates meet the desired quality and performance standards. Adherence to these standards can improve the durability and overall performance of concrete structures.

3.1.2. Fine grain materials

Aggregates smaller than sieve No. 4, with dimensions less than 4.75 mm, are referred to as sand and are used in concrete preparation in two forms: river sand and broken mountain sand [47]. Silica sand is used in producing fiber-reinforced concrete and must comply with the granulation regulations as well as all the requirements outlined in ASTM C33 [48]. Silica sand used in fiber-reinforced concrete has the following characteristics:

1. All sand should be washed and dried thoroughly. In this case, the sand will be free of pollution and mud, and it will also be possible to control the ratio of water to cement more easily.
2. Silica sand has round or irregular grains (flaky or needle shapes should be avoided). These sands should have a uniform surface texture (a honeycomb texture should not be used).
3. The chemical structure in silica sand should follow the values in Table 1.

The size of silica sand grains is different based on the production method of fiber-reinforced concrete. Therefore, using the pre-mix method, the maximum size of the grains should be 2.4



mm (100% of the grains pass through sieve number 7). In the spray method, the maximum size of the grains is 1.2 mm (100% of the grains pass through sieve number 14).

Table 1. Characteristics of silica sand

Chemical compounds	The maximum percentage of materials in silica sand
Silica (SiO ₂)	96-98%
Soluble salts (sulfates, chlorides, and alkaline substances such as Na ₂ O, K ₂ O, and CaO)	1%
Clay and organic materials	0.5%
Loss due to combustion	0.5%
Moisture	2%

The following limits are considered for the sand grading used in fiber-reinforced concrete in PCI-MNL-130-09 regulations [49].

$\leq 3\%$ of the material passed through sieve No. 200 ($\mu 75$) (0-1)

$\leq 5\%$ of the material passed through sieve No. 100 ($\mu 150$) (0-2)

All sand should pass through a #20 sieve (850 μ m) to prevent the spray gun head from clogging. In case of excessive use of materials passing through sieve No. 200, these materials cause a color change in concrete as an unwanted factor. In addition, using excellent materials reduces resistance, increases the amount of water required, increases the amount of loss due to shrinkage, and reduces slump [49].

Using suitable sand in concrete production reduces the loss due to drying by up to 20% and increases the bending strength. The silica sand used in this research is produced in the Chirook factory. The grading of the sand used is shown in Table 2, and other characteristics of this sand are shown in Table 3.

Table 2. Granulation of sand used

Sieve No.	Sieve size (mm)	The weight remaining on the sieve (gr)	Cumulative balance weight (gr)	The percentage of residue on the sieve	Cumulative percentage on the sieve	The percentage of passing through the sieve
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#4	4.75	0	0	0	0	100
#8	2.36	0.1	0.1	0.01	0.01	99.99
#16	1.18	2	2.1	0.2	0.21	99.79
#30	0.6	354.04	356.14	35.404	35.614	64.386
#50	0.3	460.14	816.28	46.014	81.63	18.372
#100	0.15	154.45	970.73	15.445	97.075	2.927
Last sieve	–	29.48	1000.21	2.948	100.02	0

Table 3. Chemical composition of the sand

Types of elements	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	L.O.I ¹
The percentage of materials in the sand	-99 97	-7.1 4.0	-6.0 2.0	-2.0 07.0	0	-01.0 0	-06.0 02.0	-35.0 01.0

According to Tables 2 and 3, the percentage of materials passed through sieve No. 100 is 2.927, which complies with the limits of PCI regulations.

3.1.2 Cement

Cement is the primary binding material in concrete, and its chemical properties can vary based on the type and percentage of its compounds. The two most common types of cement used in the production of glass fiber-reinforced concrete (GFRC) are ordinary Portland cement (OPC) and rapid hardening Portland cement (RHPC). RHPC has a finer particle size than OPC, making it chemically similar to OPC but with a higher initial strength due to faster setting times [50]. Portland cement can be mentioned as another type of cement used in producing fiber-reinforced concrete. This cement is made of materials that contain only a tiny amount of iron. In addition to limestone, Chinese clay is used instead of ordinary clay to produce white Portland cement. Portland cement produces sections with a bright and white final surface. Since white cement is more expensive than ordinary Portland cement, special attention should be paid to sorting, mixing, and transporting this cement. The processing period of concrete containing white cement requires excellent care because it gets dirty quickly in the early stages of its life,

¹Loss of Ignition



and cleaning it is also time-consuming and challenging. Other types of cement, such as high-alumina and sulfate-resistant cement, can also be used for special applications in producing fiber-reinforced concrete. In this article, type 1 Portland cement is used, and the physical and chemical characteristics of this cement are presented in the following tables.

Table 4. Physical characteristics of the applied cement

Physical characteristic	Unique surface (m ² /kg)	Setting time		Compressive strength (MPa)		
		Initial (minute)	Secondary (hours)	Three days	Seven days	28 days
Amount	2900	90	4	13	24	36.5

Table 5. Chemical characteristics of cement

Chemical compounds	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O
The percentage of cement	21.68	5.9	3.2	63.5	1.8	1.7	0.2	0.7

3.1.3 Water

The quality and requirements for water used in fiber-reinforced concrete are similar to those used in ordinary concrete. Water used in concrete mixing should be clean and free from harmful substances such as iron oxide, acids, alkaline substances, salts, organic matter, chloride ions, or any other impurities that can affect the setting, strength, durability, color, and surface appearance of concrete, as well as corrode reinforcements. Therefore, the suitability of water for concrete mixing and processing should be carefully considered. If non-potable water is used, chemical compounds in the water should be measured according to ASTM regulations [51].

Table 6. Regulations limits for non-potable water

Chemical compounds	Maximum acceptable amount (ppm)	Standard used (ASTM)
Dissolved carbon dioxide	600	D513
Calcium + magnesium	400	D511
Chlorides	500	D512
Phosphate	100	D4327
Boron	100	D3082



Alkaline substances	600	D4191
Mud	2000	D1888
pH	6-8	D1067
Soluble solids	2000	D1603

The water used in this research was prepared from Bushehr drinking water in Iran, whose quality is acceptable.

3.1.4 Super lubricant

The components of Portland cement have surface charges, which convert to masses in the presence of water. These lumps cause some water to be trapped between the cement particles and reduce the effectiveness of concrete. The pelletization of these fibers due to static electricity is one of the most critical problems with using them in concrete. Thus, more water is needed than is needed to complete the hydration process and compensate for this decrease in efficiency. Super-lubricating materials are used to keep the water-to-cement ratio constant and prevent the use of more water. The super-lubricant increases the fluidity of the concrete by neutralizing the charges on the surface of the cement particles.

3.2 Evaluation of the proposed method

Carboxylated concrete additive polymers are an efficient and unique product based on polycarboxylate ether. Polycarboxylate polymers in concrete reduce the concrete's mixing water and improve the dispersion of cement particles. Carboxylated polymer additives can reduce the water content of concrete by up to 30%, increase the capillary pores of the concrete, increase water absorption and permeability, and increase the concrete's resistance strength.

Cement requires an additive that can minimize the particles of cement components and disperse the constituent particles of cement uniformly throughout the mixture. Concrete additives can prevent cement particles from sticking to each other with the property of electrostatic repulsion and create spatial hindrance in polycarboxylate ethers, thus minimizing the need for cement in water. Carboxylated polymer additive is the focus of researchers' attention due to its high ability to reduce water to prepare and produce cement with high strength, high fluidity, and self-compacting ability in cement. Using carboxylate additives for concrete increases concrete structures' durability and service life in corrosive environments such as the Persian Gulf.

The carboxylate polymer additive has no adverse effect on setting time or other properties of concrete due to its chemical base. The severe reduction of water that will occur due to using carboxylate super-lubricant in concrete is a suitable option for temperate and tropical climate regions and precast concrete factories. Carboxylated polymer additives have a higher power in



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concrete softening than other similar polymer additives, and their usage ratio is much lower than that of other concrete softeners. As a result, the carboxylate polymer additive will be more economical than other conventional methods. In this section, the laboratory results of the discussed concretes are discussed. It should be mentioned that the details of the materials used, the mixing ratios, and the method of performing the above tests are given in the third chapter. As mentioned, carboxylate polymers were used in making the samples. Pozzolan was not used in the above samples to determine the optimal percentage of carboxylate. Finally, two types of pozzolan, fly ash and iron smelting slag, have been used in different percentages to prepare samples.

3.2.1 Slump samples

The slump of each mixture is given in Table 7. In addition, some of the concrete mixture slumps are given in Figure 2.



Figure 2. Slump types of concrete mixes



4. Results

4.1 Slump samples with a weight of 400 kg/m³

The results for samples with a grade of 400 kg/m³ are presented in Table 7. Furthermore, the results are analyzed in the form of Figures 3 and 4.

Table 7. Amount of slump for samples with a weight of 400 kg/m³

Concrete mix	Concrete mixes (grade 400)					
Sample	M1	M2	M3	M4	Sample	M6
Carboxylate percentage	0.3%	0.5%	0.7%	1%	1.3%	1.6%
Water to cement ratio	0.45	0.44	0.43	0.41	0.40	0.39
Slump (mm)	35	45	63	97	123	162

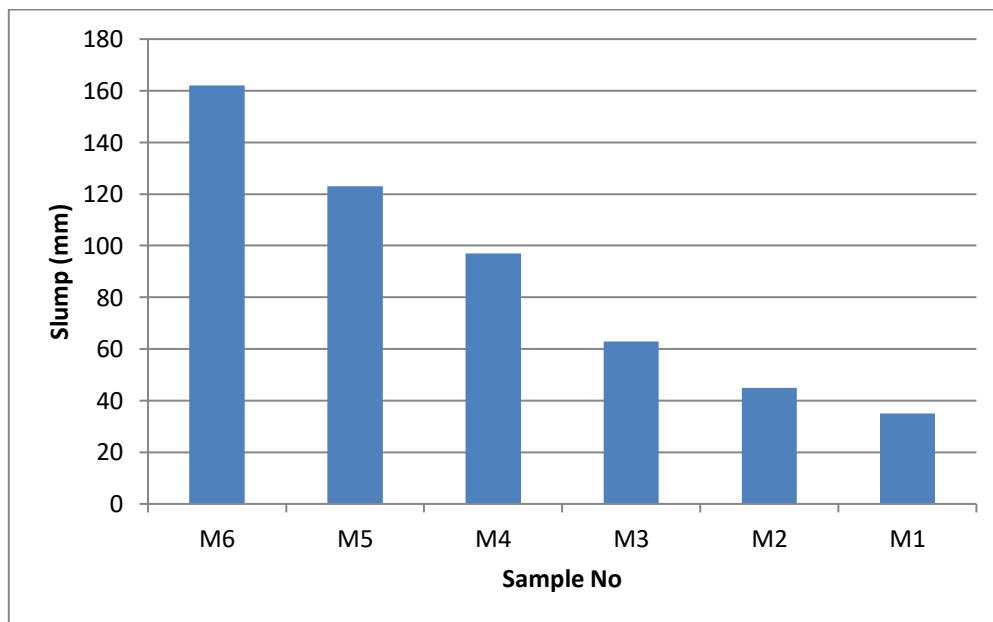


Figure 3. Slump comparison of concrete samples with a grade of 400 kg/m³

The slump changes for the changes in the ratio of water to cement for samples with a grade of 400 kg/m³ are shown in Figure 4.

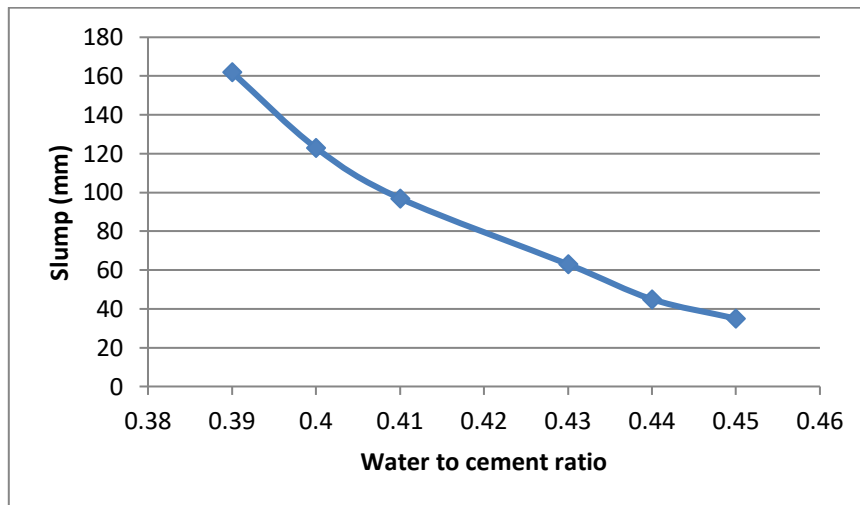


Figure 4. Slump changes against changes in water-cement ratio for concrete samples with a weight of 400 kg/m^3

Concrete samples with a weight of 400 kg/m^3 were examined for slump changes against changes in the water-cement ratio, and it was observed that the slump increased as the water-cement ratio decreased. The slump increased from 35 to 162 mm by decreasing the water-to-cement ratio from 0.45 to 0.39 (4.6 times). Finally, the slump changes for changes in the percentage of polycarboxylate lubricant in samples with a grade of 400 kg/m^3 are shown in Figure 5.

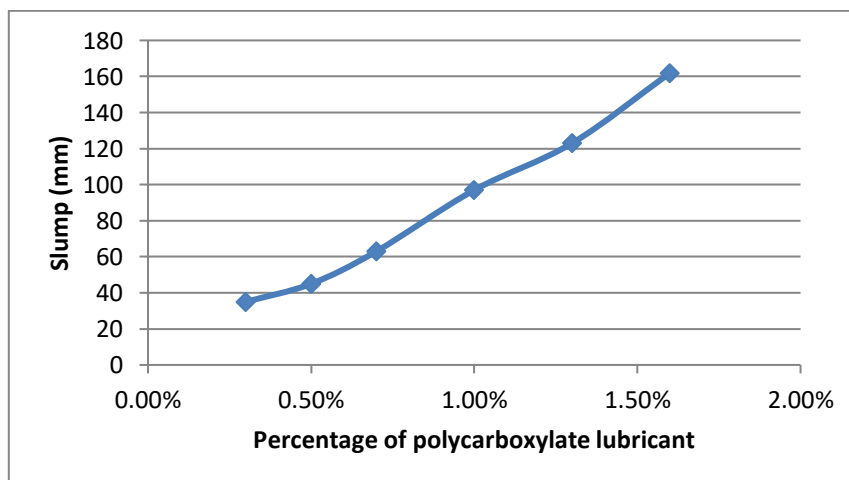


Figure 5. Slump changes against polycarboxylate lubricant percentage changes for concrete samples with a grade of 400 kg/m^3

According to the results, the amount of slump in the samples increased with the percentage of polycarboxylate lubricant. The slump increased from 35 to 162 mm with an increase in the



lubricant percentage from 0.3 to 1.6%, which means that the ratio of slump growth to growth in the lubricant percentage is equal to 0.86.

4.2 Slump samples with a weight of 450 kg/m³

Table 8 presents the results for slump samples with a grade of 450 kg/m³ and the results were analyzed in the form of Figures 6 and 7.

Table 8. Amount of slump for samples with a grade of 450 kg/m³

Concrete mix	Concrete mixes (grade 450)					
Sample	M7	M8	M9	M10	M11	M12
Carboxylate percentage	0.3%	0.5%	0.7%	1%	1.3%	1.6%
Water to cement ratio	0.39	0.38	0.37	0.36	0.35	0.34
Slump (mm)	31	55	76	91	121	147

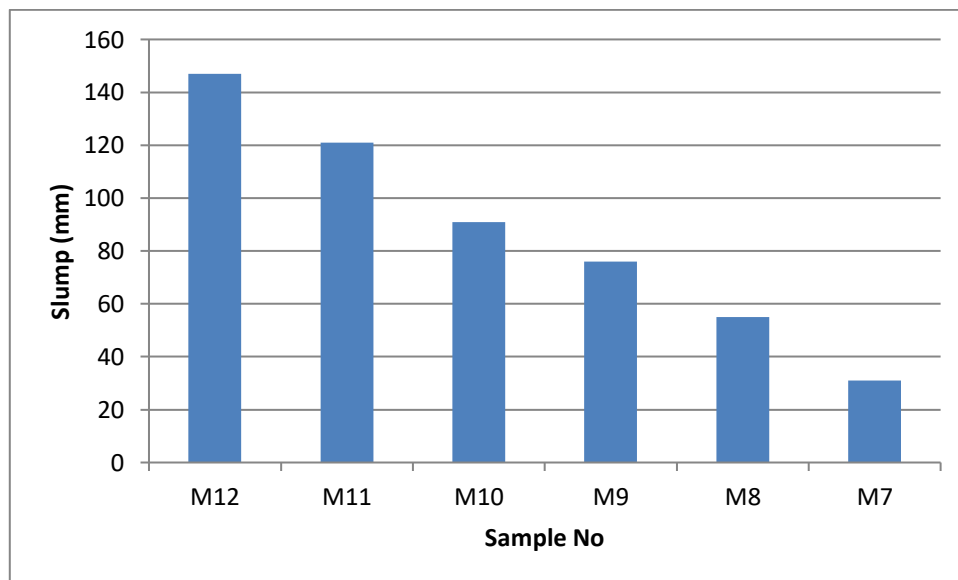


Figure 6. Slump comparison of concrete samples with a grade of 450 kg/m³

Changes in the slump for changes in the water-cement ratio in samples with a weight of 450 kg/m³ are shown in Figure 7.

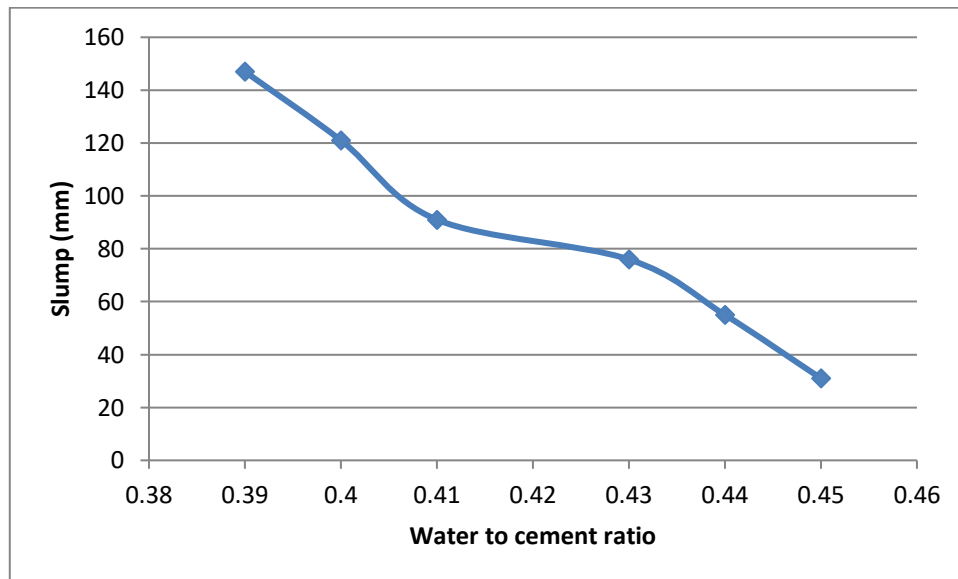


Figure 7. Slump changes against water-cement ratio changes for concrete samples with a weight of 450 kg/m^3

Based on the results of slump changes against changes in the water-cement ratio for concrete samples with a grade of 450 kg/m^3 , the slump has increased with the decrease in the water-cement ratio. Thus, the slump increased from 31 to 147 mm by decreasing the water-to-cement ratio from 0.39 to 0.34, an increase of 4.7 times. Finally, changes in the amount of slump for changes in the percentage of polycarboxylate lubricant for samples with a grade of 450 kg/m^3 are shown in Figure 8.

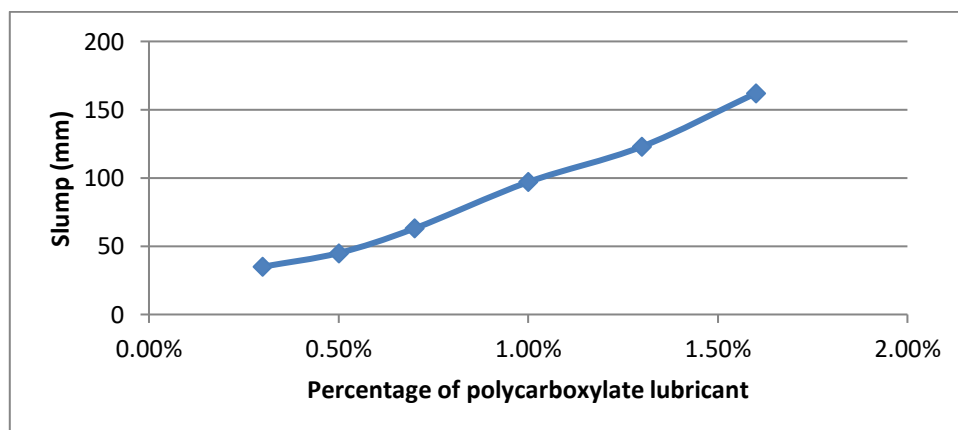


Figure 8. Slump changes against polycarboxylate lubricant percentage changes for concrete samples with a grade of 450 kg/m^3



According to the results, the amount of slump in the samples increased with the increased percentage of polycarboxylate lubricant. Because of the slump growth to lubricant growth percentage (0.88), the slump increased from 31 to 147 mm as the lubricant percentage increased from 0.3 to 1.6%.

5. Conclusion

The reliability of concrete structures in the southern coasts of the Persian Gulf has become a critical challenge due to rapid development in strategic areas. Premature deterioration and a significant reduction in useful life are major issues confronting the region. To address this problem, this study investigated the effectiveness of fly ash pozzolans, iron smelting slag, and water-cement-based polymers in enhancing the mechanical properties and durability of concrete under harsh environmental conditions. The results of the study indicate that incorporating these materials significantly improves the compressive strength, permeability, and resistance to chloride ion penetration, thereby contributing to the development of more sustainable and durable concrete structures in the region.

Moreover, the study also evaluated the effect of water-cement ratio and polycarboxylate lubricant percentage on the slump characteristics of concrete samples with grades of 400 kg/m³ and 450 kg/m³. The results indicate that adjusting the water-cement ratio and the percentage of polycarboxylate lubricant can significantly affect the slump characteristics of the concrete. This finding has important implications for the workability and performance of the concrete in practical applications.

The study provides valuable insights into optimizing the mix design and enhancing the properties of concrete, which could lead to the development of more efficient and sustainable construction materials. Future research could investigate other factors, such as the size and shape of aggregates and curing conditions, on the slump characteristics of the concrete. Additionally, further investigation of the effect of polycarboxylate lubricants on other properties of concrete, such as the compressive strength and durability, would be beneficial for a more comprehensive understanding of the factors influencing the properties and performance of concrete. This research ultimately contributes to the development of more sustainable and efficient construction materials.

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