# PERFORMANCE OF DIFFERENT TYPES OF CEMENTS IN MARINE ENVIRONMENT

**Asad-ur-Rehman Khan[1] and Tatheer Zahra[2]**

[1]Department of Civil Engineering, NED University of Engineering and Technology, Karachi, Pakistan
e-mail: asadkhan@neduet.edu.pk ; web page: http://www.neduet.edu.pk

[2]Department of Civil Engineering, NED University of Engineering and Technology, Karachi, Pakistan
e-mail: tatheer@neduet.edu.pk ; web page: http://www.neduet.edu.pk

**Keywords:** Performance, Marine Environment, Blended Cements, Strength Reduction, Permeability

## ABSTRACT

This study presents the performance of different kinds of cements in extreme marine environment. An experimental study was conducted for this purpose in which mortar cubes of different cements including OPC, Slag cement and Blended cements (varying percentages of 10%, 20%, 30% Fly ash and 10%, 20%, 30% Silica fume) were cast. Compressive strength of each was measured at 7 days and 28 days initially. Samples were then immersed in sea water for 180 days to observe the impact of marine environment. OPC samples showed the highest compressive strength initially but after 180 days of marine exposure, strength degradation was observed and reduction was more as compared to all blended cement samples except for Fly ash 30% samples. Increased percentages of Fly ash and Silica fume resulted in reduction in strength as well as reduced resistance to aggressive chemical attack. Results were found to be in close agreement with the data available in literature.

## 1 INTRODUCTION

Concrete generally performs well under loads and have shown robustness as far as the strength is concerned; however, durability is the factor which has to be considered if the structures are to serve for their design life span. Concrete structures exposed to the severe conditions of marine environments can be affected by three types of deterioration mechanisms: 1) physical, such as freezing and thawing, wetting and drying, and abrasion, 2) chemical attack and 3) chloride induced corrosion [1]. Corrosion, one of the main causes of deterioration in concrete structures, initiates due to its exposure to harmful chemicals that may be found in nature such as in some ground waters, industrial effluents and sea waters. The most aggressive chemicals that affect the long term durability of concrete structures are the chlorides and sulfates [2]. The dissolved chloride in waters reacts with chemical constituents of concrete and results in leaching and thus increases the porosity of concrete, and leads to loss of stiffness and strength [2]. Calcium, sodium, magnesium, and ammonium sulfates are, in increasing order of hazard, harmful to concrete as they react with hydrated cement paste leading to expansion, cracking, spalling and loss of strength [3].

Different Codes (ACI 357R-84 [4], BS 6349-1:2000 [5], RILEM Technical Committee [6]) recommend certain guidelines for obtaining more durable concrete in marine environments. Specifications include least compressive strength of concrete, limiting water-cement ratio, minimum $C_3A$ content and choice of cements and admixtures. ACI 318 requires Type II cement or Type I plus a pozzolan to resist the moderate sulfate attack from seawater. ACI 357 permits Type I, II, and III cement but recommends that the tricalcium aluminate ($C_3A$) content is between 4% and 10% [7]. Fly ash, blast furnace slag, and silica fume are the most common pozzolans used in concrete mixtures for marine environments. Pozzolans combine with the calcium hydroxide and water in the mix to form hardened cementitious products. These hydrated products increase the strength and reduce the permeability of the concrete. Pozzolans also chemically combine with the lime to form less soluble products, thus reducing the effects of lime leaching [8]. Use of suitable coatings on concrete to decrease permeability and for better performance in aggressive marine environment has also been reported in literature [9].

This research is aimed to compare the performance of different types of blended cements in marine environment. A testing programme was conducted for this purpose. Mortar samples for OPC, Slag cement, OPC with 10%, 20%, 30% fly ash and silica fume were cast. Compressive strengths of mortar samples were determined at seven (07) and twenty eight (28) days to be used as reference for comparison with compressive strengths after exposure to marine environment. Remaining samples were then immersed in sea water collected from local Karachi region for about 6 months (180 days). Compressive strengths were determined at 90 and 180 days for each sample. Sea water characteristics were also tested in lab which was found high in magnesium and chloride content.

## 2 EXPERIMENTAL PROGRAM

For comparing the performance of different cements, mortar cubes and concrete cylinders were cast and tested. Cement types that were used for study includes OPC, Slag cement, Blended cements with 10%, 20%, 30% Silica fume and 10%, 20%, 30% Fly ash (class C). A total of 8 cement types were studied for comparison of their performance when exposed to marine environment. Compressive strength of mortar cubes were tested at 28 days for comparison with the strength after 180 days exposure to sea water. Sea water used for immersing the mortar samples was collected from local Karachi beach.

### 2.1 Casting and Testing of 2″× 2″ Mortar Cubes

Mortar cubes of size 2″× 2″ were cast and tested according to ASTM C 109 standard. Cement and fine aggregates were mixed in a ratio of 1:5 and water cement ratio was kept at 0.5 for all types of cements mentioned above. After demolding, mortar cubes were cured in tap water for 28 days and were tested in uniaxial compression to determine compressive strength at 7 and 28 days. After 28 days remaining samples were then immersed in sea water collected from a Karachi beach for 180 days. They were tested after 90 and 180 days of sea water exposure for making comparisons with the control specimens. Summary of the number of mortar samples cast and tested is given in Table 1.

**Table 1.** Mortar Specimen tested for Compressive Strength Comparison

| Cement Type | Specimen age (days) | Number of Specimen | Cement Type | Specimen age (days) | Number of Specimen |
|---|---|---|---|---|---|
| OPC | 7 | 3 | Silica Fume (10%, 20%, 30%) | 7 | 9 (3 for each % blend) |
| | 28 | 3 | | 28 | 9 (3 for each % blend) |
| | 90 | 3 | | 90 | 9 (3 for each % blend) |
| | 180 | 3 | | 180 | 9 (3 for each % blend) |
| Slag Cement | 7 | 3 | Fly Ash (10%, 20%, 30%) | 7 | 9 (3 for each % blend) |
| | 28 | 3 | | 28 | 9 (3 for each % blend) |
| | 90 | 3 | | 90 | 9 (3 for each % blend) |
| | 180 | 3 | | 180 | 9 (3 for each % blend) |
| Total Mortar Samples | | | | | 96 |

## 3 RESULTS AND DISCUSSION

Results were obtained in terms of compressive strength of mortar and concrete samples. Compressive strengths of each type of mortar samples were compared with OPC at 28 days as well as after exposure of mortar samples to sea water for 90 days and 180 days. All the samples were visually inspected to qualitatively assess the damage after 90 and 180 days of sea water exposure before testing to determine the compressive strength. Properties of sea water used to immerse mortar samples are presented in Table 2.

It can be seen from Table 3 that sea water has high turbidity and TDS level along with high chloride and magnesium contents. High turbidity and TDS level can lead to severe deterioration in concrete structures on continuous exposure whereas high chloride content can cause carbonation and corrosion of steel and Magnesium in the form of Sulphates may invite sulphate attack and spalling of concrete.

**Table 2.** Properties of Sea Water

| Parameter | Result |
|---|---|
| pH | 6.6 |
| Turbidity | 5.63 NTU |
| TDS | 38500 mg/L |
| Hardness | 7500 mg/L |
| Calcium | 800 mg/L |
| Magnesium | 1576 mg/L |
| Chloride | 2299 mg/L |

### 3.1 Comparison of Strength of Mortar Samples

Compressive strengths determined for mortar samples of each cement type at 7 and 28 days normal curing period as well as after 90 and 180 days exposure of sea water are presented in the form of bar charts in Figures 1 to 3. Results presented here are average of three samples for each cement type.

Figure 1 shows the comparison between OPC and Slag cement mortar samples. It can be seen that at 7 and 28 days strengths of OPC and Slag cement samples are comparable, but after dipping in sea water, both type of cements gained strength up to 90 days exposure and after that there is a reduction in strength for both types of cements with Slag cement showing a better response as compared to OPC. This behaviour is in agreement with the findings of Wegian [13]. In fact, OPC samples have a lesser strength as compared to that of 28 days strength while Slag cement samples have strength higher than 28 days strength. Better response of Slag cement samples is in agreement with the results reported by Ferreira *et al.* [10].

Comparison of OPC mortar samples with mortar samples of different percentages of Silica fume is shown in Figure 2. A similar response can be seen as was observed in the case of Slag cement i.e. gain in strength up to 28 days and 90 days of exposure to sea water and reduction in strength after 180 days of exposure. 10% Silica fume samples performed much better than other two and results are quite comparable strength with that of OPC. But increasing percentages of Silica fume has caused reduction in strength at every level of study period. Response of samples with higher percentages of Silica fume is in agreement with conclusions of Duxson *et al.* [11] who have reported that increasing percentages of silica fume decrease the volume of cement paste resulting in reduction in strength due to its less specific gravity as compared to other cementitious materials [11].

Figure 3 shows the comparison between mortar samples of OPC and with blended cements with different proportions of Fly ash. Once again a similar trend as in the case of Slag cement and Silica fume cements was observed. Strength of Fly ash samples for all the replacements of Fly ash was on the lower side in comparison to OPC mortar samples which is typical of Fly ash as reported in available literature. Samples with 10% Fly ash were found to have the maximum strength gain followed by the samples with 20% and 30% replacements. Strength variation in Fly ash blended cement mortar samples was found to be smaller as compared to OPC mortar samples between 90 and 180 days of exposure to sea water. The better resistance of Fly ash mortar samples against chemical penetration when immersed in sea water is in close agreement to the findings of Cao and Liana [12].

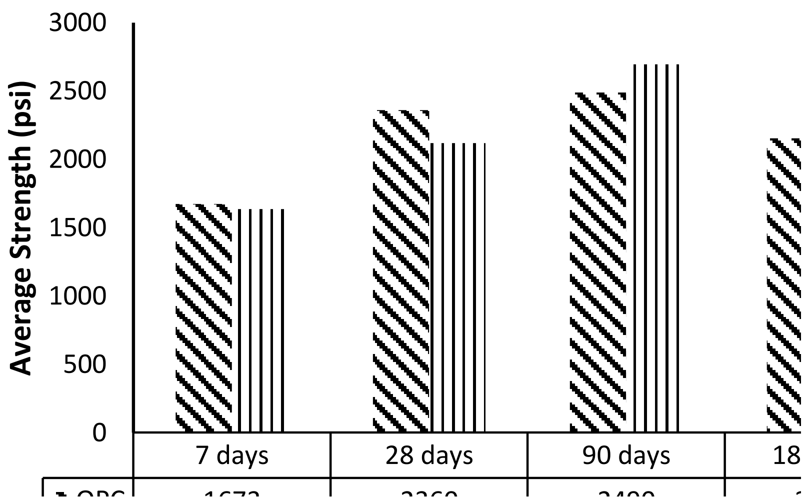


**Figure 1.** Comparison of Compressive Strength between OPC and Slag Cement Mortar

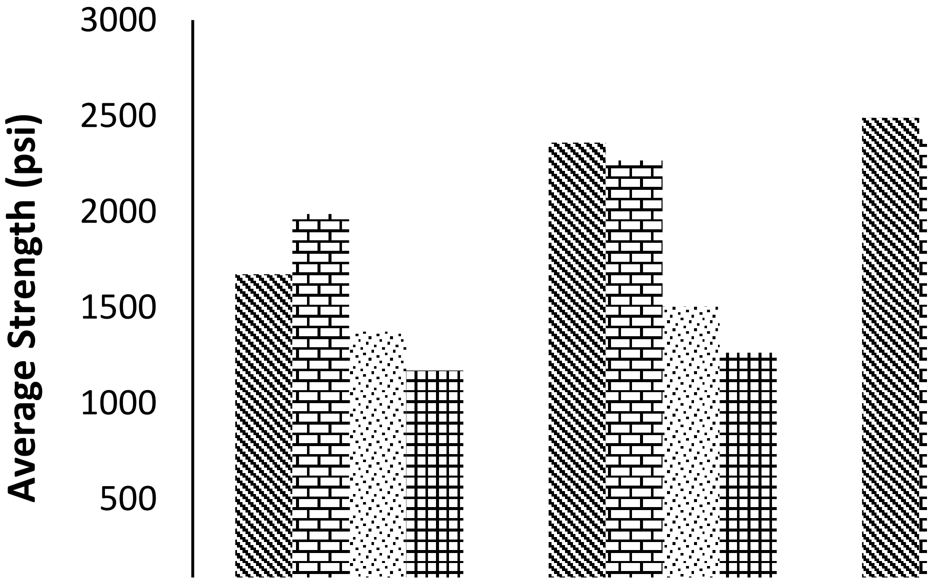


**Figure 2.** Comparison of Compressive Strength between OPC and Different Percentages of Silica Fume

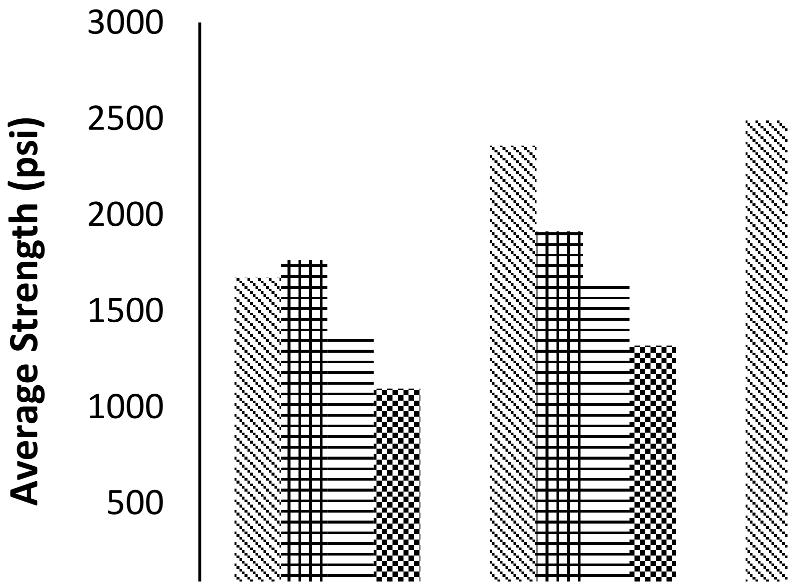


**Figure 3.** Comparison of Compressive Strength between OPC and Different Percentages of Fly Ash

Overall comparison of the strength of all types of cement mortar cubes is given in Figure 4. Observed trend of strength gain up to 28 days and 90 days of exposure to sea water can be seen very clearly in Figure 4. It can also be noticed from the figure that after 90 days of exposure, strengths of OPC, Slag, Silica fume (10%) and Fly ash (10%) samples are comparable. Overall comparison shows that Slag cement has a better performance after 90 days and 180 days exposure to sea water in terms of strength. Performance in terms of better resistance against aggressive chemical attack is discussed in the following section.

### 3.2 Reduction in Compressive Strength of Mortar Samples

The degree of deterioration was also evaluated by measuring the reduction in compressive strength. The reduction in compressive strength was calculated as follows:

$$\text{Reduction in compressive strength (\%)} = \frac{B-A}{A} \times 100$$

where *A* is the average compressive strength of three specimens after 90 days of exposure to sea water in psi; and *B* is the average compressive strength of three specimens exposed to the sea water after 180 days in psi. Normally, strength reduction is calculated based on 28 days compressive strength but the trend seen in all the types of cements show that strength gain is up to 90 days of sea water exposure it seems appropriate that reduction in strength is calculated with reference to 90 days sea water exposure strength.

Strength reduction for all types of cements used in the study is shown in Figure 5. Maximum reduction (26.6%) was found to be in Fly ash (30%) samples while least reduction (4.3%) was observed in Silica fume (10%) samples. It can be seen from the figure that as the percentage of Silica fume and Fly ash is increasing resistance to chemical attack is decreasing and is more pronounced in Fly ash samples. Performance of Silica fume (10%) and (20%) samples is better than Fly ash (10%) samples as well as Slag samples. It can be noticed that almost all the blended cements have performed better or close to OPC except for Fly ash (30%) samples where maximum deterioration is observed indicating that blended cements are a better option in marine environment.

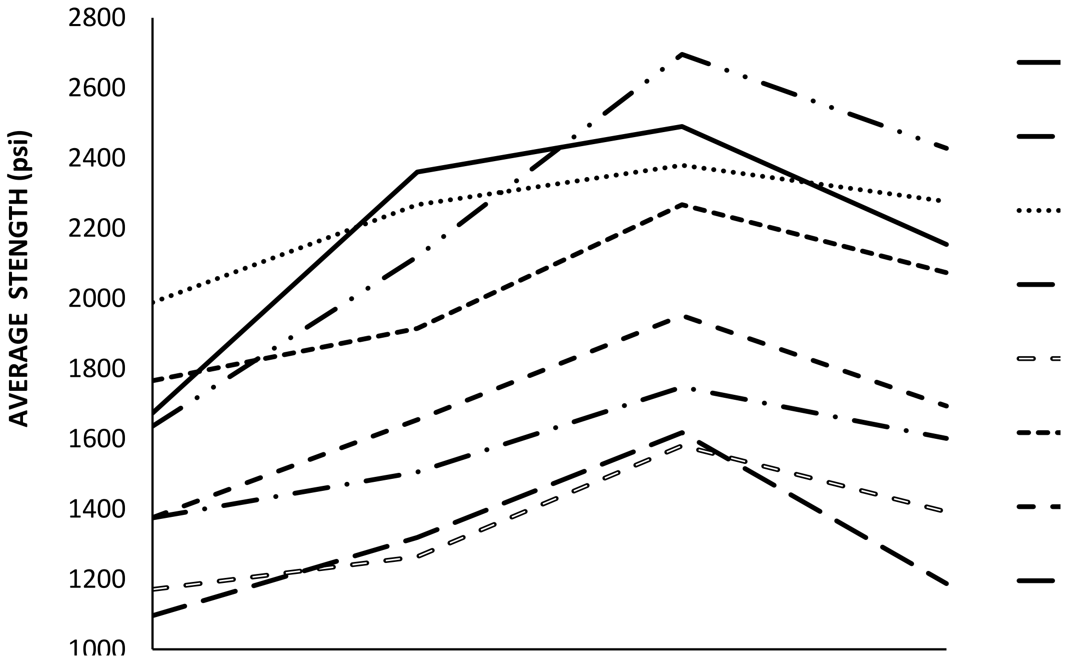


**Figure 4.** Overall Comparison of Compressive Strength of Mortar Samples

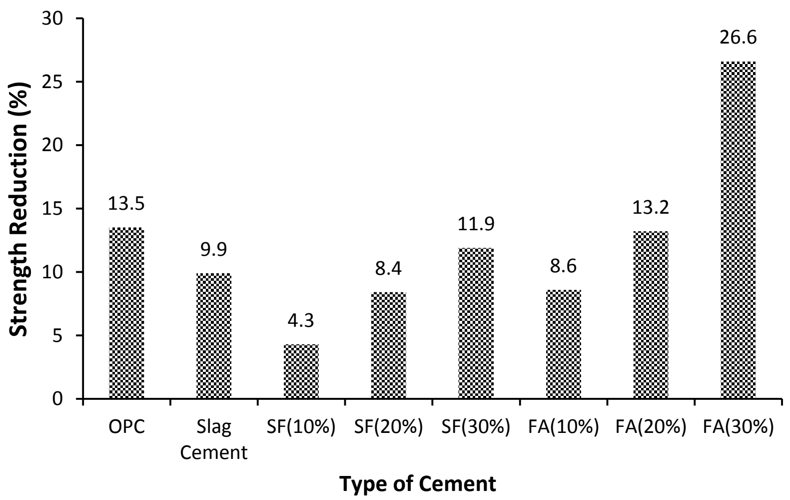


**Figure 5.** Percentage change in compressive strength of mortar samples

## 4 CONCLUSIONS

Conclusions drawn from the study are as follows:

1. 90 days of exposure to sea water resulted in strength gain in all the cement types used in the study.
2. In terms of strength, performance of slag cement was found to be better than other cement types followed by OPC, Silica fume (10%) and Fly ash (10%). Performance of Fly ash (30%) samples was found to be worst among all the cement types used.
3. In terms of resistance to aggressive chemical attack, performance of Silica fume (10%) was found to be better than other types of cement used in the study followed by Silica fume (20%), Fly ash (10%) and Slag cement. Performance of Fly ash (30%) samples was again found to be the worst among all the cement types used.
4. It is further recommended that study be extended for longer exposure to marine environment to have a better idea of performance of blended cements.

## ACKNOWLEDGEMENT

The authors are indebted to the Department of Civil Engineering at NED University of Engineering & Technology, Karachi, Pakistan and the University itself, in the pursuit of this work.

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