Influence of Plastic Aggregate and Curing Condition on the Mechanical Properties of Concrete Containing Silica Fume in Marine Environments

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Abstract
In this study, Influence of plastic aggregate and curing condition on the mechanical properties of concrete containing silica fume has been investigated. Concretes included silica fume (SF) as a cement replacement levels of 10% and 15% and contain plastic waste aggregate (PWA) as a natural aggregate (NA) replacement. In this study plastic fine aggregate (PF) and plastic coarse aggregate (PC) are replaced at NA. The w/b ratio and total cementitious materials content were kept constant for all mixes at 0.50 and 350 kg/m^3 respectively. Concrete mixes were evaluated for compressive and tensile strengths at 7, 28 and 90 days in two different environment: a) laboratory environment (LE) and b) out (Marine) environment (ME/OE). The results show that Concretes containing silica fume compressive strength decreases with increasing of PWA as a replacement and outdoor condition is more important for surveying curing position.

Keywords: Plastic Waste, Concrete, Silica Fume, Compressive, Tensile, Curing.

1. Introduction

Surely nowadays Portland cement is the primary cementitious material used in structures and sometimes the production of vast amounts of PC results in environmental problems in part of energy utilization as well as pollution where the international Cement Associations reported that cement production was responsible for 2.83 billion tones of CO_2 emissions (approximately 2.3% of the total emissions) worldwide in 2008 (Alaa (2013)). Also, concrete made from Portland cement is subjected to certain durability problems that are difficult to solve. Indeed, it is clear that main effects were made throughout the 20th century to improve PC concrete technology. On the other hand, however, very limited researches were conducted on new binders able to provide technical alternatives to conventional cement that could be produced at a fraction of the energy cost and environmental impact. The use of active mineral admixtures (supplementary cementing materials, SCM) such as condensed silica fume, coal fly ash, natural pozzolan, or ground granulated blast furnace slag in concrete mix formulations is an effective way of reducing the Portland cement clinker consumption and then reducing the related CO_2 emissions. It also represents an effective way of improving the durability of concrete structures (Taylor (1990), Neville (1996)).

Silica fume (SF) is a byproduct of the smelting process in the silicon and ferrosilicon industry. It is also known as a micro silica, condensed silica fume, volatilized silica or silica dust. Silica fume color is either premium white or grey. Silica Fume consists of very fine vitreous particles with a surface area between 13,000 and 30,000m^2/kg. Its particles are approximately 100 times smaller than the average cement particle. Because of its extreme fineness and high silica content, silica fume is a highly effective pozzolanic material. Silica fume is used in concrete to improve its properties. It has been found that silica fume improves compressive strength, bond strength, and abrasion resistance; reduces permeability; and therefore helps in protecting reinforcing steel from corrosion. Their particles are extremely small, with more than 95% of the particles finer than 1μm. Silica fume is composed primarily of pure silica in non-crystalline form. Silica fume has a very high content of amorphous silicon dioxide and consists of very fine spherical particles. Because of its extreme fineness and very high amorphous silicon dioxide content, it is a very reactive pozzolanic material (Mohammad Iqbal Khane (2011)). Silica fume is well known for its improvement in both durability and mechanical properties of concrete (Alexander (1999), Poon (2006)).

On the other hand, Plastic, one of the most significant innovations of 20th century, is a ubiquitous material. A substantial growth in the consumption of plastic is observed all over the world in recent years, which also increases the production of plastic-related waste. The plastic waste is now a serious environmental threat to modern civilization. Plastic is composed of several toxic chemicals, and therefore plastic pollutes soil, air and water. Since plastic is a non-biodegradable material, land-filling using plastic would mean preserving the harmful material forever. The hazards that plastics pose are numerous. They may block the drainage system of a city. The blocked drains provide excellent breeding grounds for disease-causing mosquitoes and water borne diseases besides causing flooding. Plastic garbage can reduce the rate of rain water percolating and deteriorate the soil fertility if it is mixed with soil. The waste mass may hinder the ground water flow and can also block the movement of roots. Plastic waste also contains various toxic elements especially cadmium and lead, which can mix with rain water and pollute soil and water. Recycling plastics is a possible option. As plastic is an organic hydrocarbon-based material, its high calorific value can be used for incineration or in other high temperature processes. But, burning of plastics releases a variety of poisonous chemicals into the air, including dioxins, one of the most toxic substances. Plastic waste can also be used to produce new plastic based products after processing. However it is not an economical process as the recycled plastic degrades in quality and necessitates new plastic to make the original product. Although these alternatives are feasible except for land-filling, recycling of plastic waste to produce new materials, such as cement composites, appears as one of the best solution for disposing of plastic waste, due to its economic and ecological advantages. A vast work has already been done on the use of plastic waste such as polyethylene terephthalate (PET) bottle (Akcaozoglu (2010), Yesilata (2009)). In this paper use of PET as a fine or coarse aggregate in concrete containing silica fume is studied.

2. Experimental programs

2.1 Materials and mixture proportions

Total cementitious materials content and water to binder ratio were kept constant for all mixes at 350 kg/m^3 and 0.50 respectively. Materials utilized included type 2 Portland cement and silica fume. Chemical analysis and physical and mechanical characteristics of these materials are given in Tables 1 and 2 respectively. The results show conformance of the cement and SF with requirements of ASTM C150 (2006) and ASTM C1240 (2006) respectively. Drinking water was used in carrying out tests and making specimens. The workability of concretes mixes were kept constant in the slump ranges 100 ± 20 mm. The differences in water demand of various mixes were accounted for by use of required amount of a naphthalene formaldehyde sulphonate based superplasticizer (SP). The aggregates used for production of mixes were crushed coarse aggregate (CA) with nominal maximum size of 19 mm and specific gravity of 2.65 g/cm^3 and natural sand (FA) with specific gravity of 2.56 g/cm^3 and satisfied requirements of ASTM C33 (2006). Mixture proportions for the control and ternary mixes considered in this study and results are given in Table 3 and 4 respectively.

2.2 Tests carried out

The aim of the tests performed was to evaluate the compressive and tensile strength of the control and various ternary mixes. Compressive strength test was conducted at the ages of 7, 28, 90 on 100 mm cubic concrete specimens and tensile strength was done at the age of 28 days on 150mm×300mm cylindrical specimens in accordance with BS EN 12390 part 1 (2000). After casting, all concrete specimens (cubes and cylinders) were kept at 20 ±3 °C and relative humidity (RH) 65 ±5% for the first 24 h. The specimens were then demoulded and stored in water curing room at 20 ± 3 °C until the time of testing.

Table 1: Chemical analysis of cement and silica fume (%).

Oxide	Portland Cement	Silica fume
SiO_2	21.57	94.30
Al_2O_3	4.72	1.22
Fe_2O_3	3.61	0.75
CaO	63.22	0.49
MgO	2.20	0.89
SO_3	1.50	0.10
Na_2o	0.18	0.35
K_2O	0.54	1.25

Table 2: Physical and mechanical properties of cement and silica fume.

Property	Portland Cement	Silica fume
Fineness (m^2/kg)	296.2	19200
Density (kg/m^3)	3140	2210

For each test, three specimens were tested and the average value was reported. Concrete of different compositions was produced with varying replacement ratios of NA by PF and PC and also replacement ratios of cement with silica fume. Eight different mixtures with two various conditions were carried out. These sixteen mixes were named: S10PF0 (concrete with 10% SF only), S10PF5 and S10PF15 (concrete with 10% SF and 10, 15% PF respectively), S10PC5 (concrete with10% SF and 5% PC), S15PF0 (concrete with 15% SF only), S15PF5 and S15PF15 (concrete with 15% SF and 10, 15% PF respectively), S15PC5 (concrete with 15% SF and 5% PC).

The relative influence of the curing conditions on the mechanical properties of the concrete mixes produced was another aim of the research. Two curing conditions were created (LE and ME).

Table 3: Mixture proportions for concrete mixture studied.

s	w/b	SF(%)	PF(%)	PC(%)	Cement	SF	SP	Water	fine aggregate (kg/m^3)		Coarse aggregate (kg/m^3)	
					(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	FA	PF	CA	PC
S10PF0	0.5	10	0	0	315	35	5.6	175	861	0	1037	0
S10PF5	0.5	10	5	0	315	35	4.6	175	817.9	43.1	1037	0
S10PF15	0.5	10	15	0	315	35	2.8	175	731.8	129.1	1037	0
S10PC5	0.5	10	0	5	315	35	4.1	175	861	0	985	52
S15PF0	0.5	15	0	0	297.5	52.5	6.1	175	861	0	1037	0
S15PF5	0.5	15	5	0	297.5	52.5	5.5	175	817.9	43.1	1037	0
S15PF15	0.5	15	15	0	297.5	52.5	4.1	175	731.8	129.1	1037	0
S15PC5	0.5	15	0	5	297.5	52.5	5.3	175	861	0	985	52

SP: super plasticizer FA: fine aggregate CA: Coarse aggregate

3. Test results and discussion

3.1 Compressive strength

Figs. 1-6 show the compressive strength at 7, 28 and 90 days respectively for all mixes with 10 % and 20 % silica fume and different percents of plastic waste aggregate (PWA). These results indicate that concretes compressive strength decreases as soon as PWA is added, regardless of the type and period of curing and the type of plastic aggregate. These figures show that minimum amount of compressive strength is a result of maximum amount of PWA as an aggregate replacement. Figures.1-6 represent the maximum reduction (53.5%) among of 7, 28 and 90 days is occurred in S10PF15 specimen in ME position at 7 days and minimum reduction (42.5%) between 7, 28 and 90 days is occurred in S10PF15 specimen in ME position at 28 days. Comparison S10PF5 and S10PC5 specimens at various ages in all of figures indicates the compressive strength in S10PF5 is higher than S10PC5. The reason for lower compressive strength of S10PC5 specimen may be was different roles of FA and CA in hardened concrete. All in all, the factors that may be responsible for low compressive strength of concrete containing plastic aggregate are: (1) the very low bond strength between the surface of the plastic waste and the cement paste; (2) the hydrophobic nature of plastic waste, which can inhibit cement hydration reaction by restricting water movement (Nabajyoti (2012)). Since PWA are rough and have little affinity with water they repel it, thus limiting the cement hydration in the PWA/cementitious matrix interface and conditioning this bond (Ismail (2008), Saikia (2014)).

Table 4: Results

C (kg/m^3)	w/c	MD	Environment	SF (%)	PF (%)	PC (%)	$F^*_{c(7)}$ (MPa)	$F_{c(28)}$ (MPa)	$F_{c(90)}$ (MPa)	$F_{t(28)}$ (MPa)
350	0.50	S10PF0	LE	10	0	0	24.1	38.3	45.1	3.1
		S10PF0	ME	10	0	0	22.8	36.5	40.5	2.8
		S10PF5	LE	10	5	0	17.5	28.4	32.3	2.3
		S10PF5	ME	10	5	0	15.2	26.8	28.3	2.1
		S10PF15	LE	10	15	0	11.5	21.3	22.3	1.7
		S10PF15	ME	10	15	0	10.6	21.0	21.7	1.5
		S10PC5	LE	10	0	5	14.5	24.3	28.8	2.2
		S10PC5	ME	10	0	5	13.4	21.8	22.5	1.9
		S15PF0	LE	15	0	0	27.3	43.1	51.1	3.5
		S15PF0	ME	15	0	0	25.9	41.1	45.9	3.1
		S15PF5	LE	15	5	0	19.6	31.7	36.2	2.6
		S15PF5	ME	15	5	0	17.2	30.2	33.1	2.3
		S15PF15	LE	15	15	0	13.1	23.9	25.3	1.9
		S15PF15	ME	15	15	0	12.1	23.6	24.2	1.7
		S15PC5	LE	15	0	5	15.2	26.9	28.1	2.4
		S15PC5	ME	15	0	5	13.1	24.5	25.5	2.1

MD: Mix designation

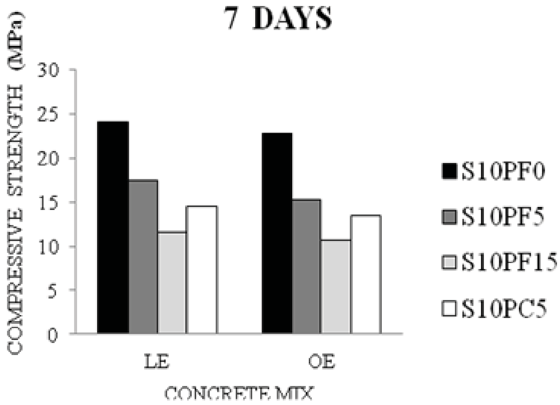

Fig 1. The results of compressive strength of specimens

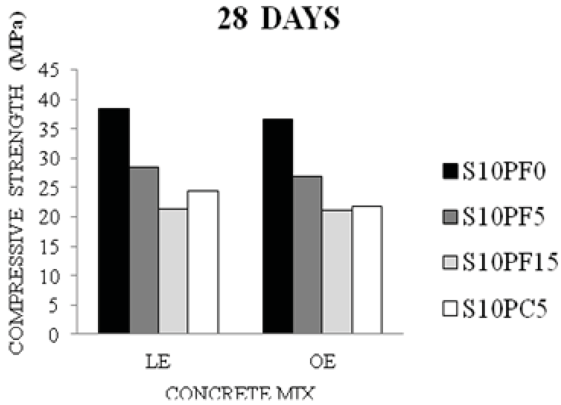

Fig 2. The results of compressive strength of specimens

Also addition of dosage of silica fume to the mix improves its compressive strength. When silica fume is added to concrete, it results in a significant change in the compressive strength of the mix. This is mainly due to the aggregate-paste bond improvement and enhanced microstructure. In cement concrete, the aggregate functions as inert filler but due to the presence of weak interfacial zone, composite concrete is weaker than cement paste. But, in silica fume concrete, the presence of silica fume eliminates this weak link by strengthening the cement paste aggregate bond and forming a less porous and more homogenous microstructure in the interfacial region (Rafat (2011)).

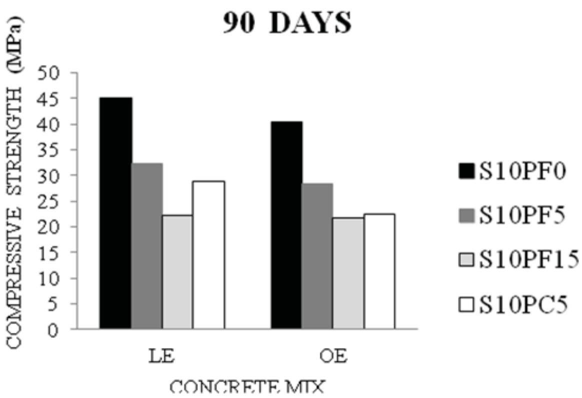

Fig 3. The results of compressive strength of specimens

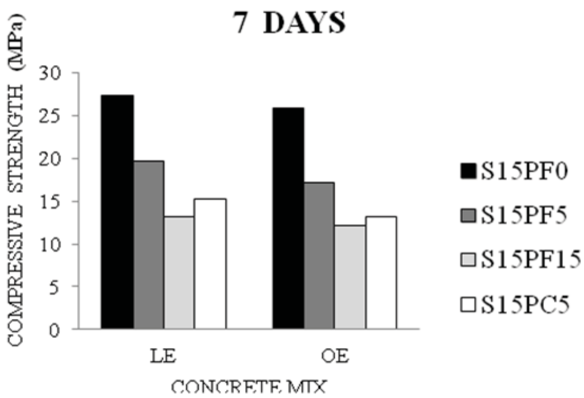

Fig 4. The results of compressive strength of specimens

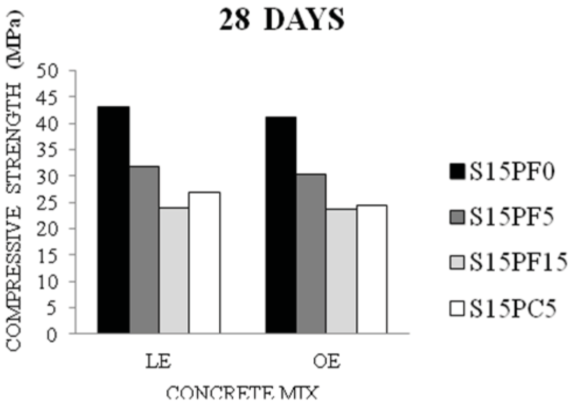

Fig 5. The results of compressive strength of specimens

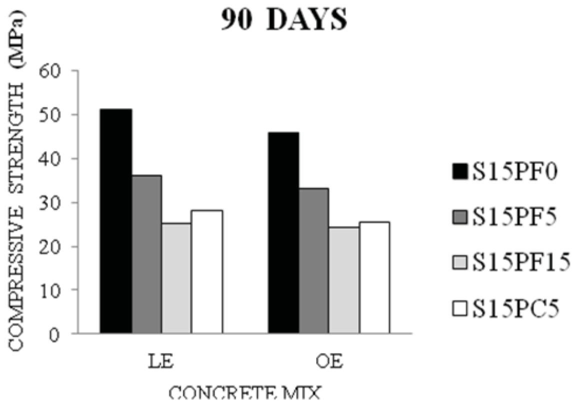

Fig 6. The results of compressive strength of specimens

3.2 Tensile strength

Figs. 7-8 show the tensile strength at 28 day respectively for all mixes with 10 % and 20 % silica fume and different percent of plastic waste aggregate (PWA). As expected, the splitting tensile strength decreases as the PWA incorporation ratio increases. These results indicate that concretes tensile strength decreases as soon as PWA is added. These figures show that minimum amount of tensile strength is a result of maximum amount of PWA as an aggregate replacement. Figures.7-8 represent the maximum reduction (46.4%) at 28 days is occurred in S10PF15 specimen in ME position and minimum reduction (45.1%) at 28 days is occurred in S10PF15 specimen in ME position. Comparison S10PF5 and S10PC5 specimens at 28 age in figures indicates the tensile strength in S10PF5 is higher than S10PC5. This happens for the same reasons that explain the influence of WPA on the mixes compressive strength. Maybe the splitting tensile strength of concrete is influenced by the properties of the interfacial transition zone (ITZ) and therefore the surface of the PWA particles and the free water accumulated at the surface of PWA granules could cause a weaker bonding between the PWA particles and the cement paste. Also Addition of dosage of silica fume to the mix improves its tensile strength.

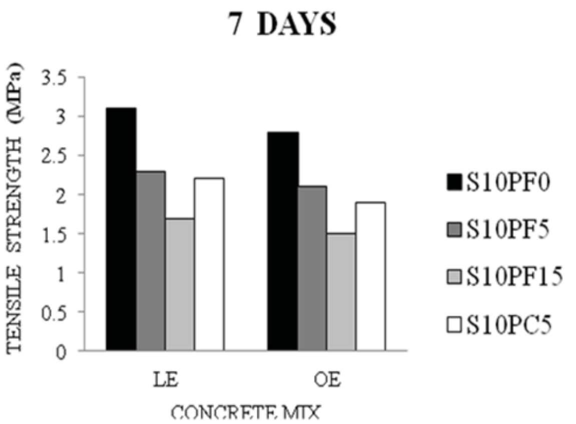

Fig 7. The results of tensile strength of specimens

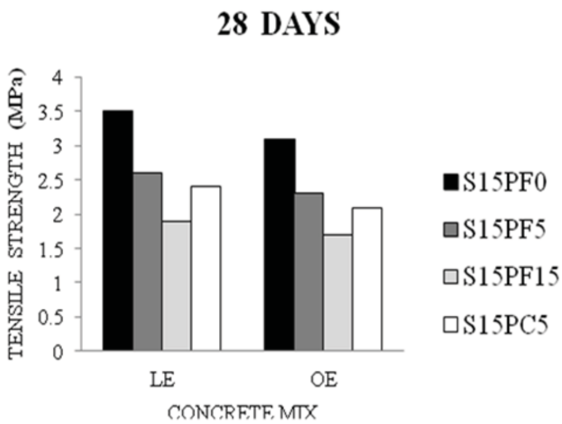

Fig 8. The results of tensile strength of specimens

All in all, the best and worst amount of limestone as a cement replacement is approximately 10% and 40% respectively. Totally, the reduction in the compressive strength of concrete is probably due to the large amount of calcium hydroxide resulting from the hydration process of the cement and limestone. Moreover, the loss of the compressive strength at a replacement level 20% and 40% can be related to the increasing of relative of powder for limestone as a replacement from sand.

3-3 Curing conditions in compressive strength

Figs. 9-14 show the effect of curing conditions on compressive strength at 7, 28 and 90 days respectively for all mixes with 10 % and 20 % silica fume and different percents of PWA. Due to humid weather conditions in the Chabahar city, compressive strength of specimens that they are in Marine environment is lower than another curing condition (LE). Mixtures subjected to laboratory environment initial temperatures reach greater initial strength. But compressive strength seems to be most sensitive to the incorporation of PWA under the LE regime and the least sensitive under the ME regime.

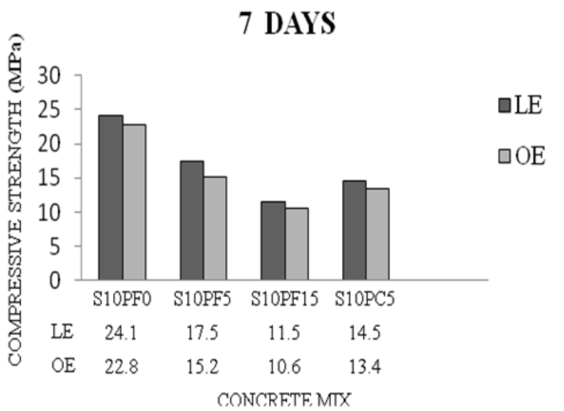

Fig 9. The results of curing conditions on compressive strength

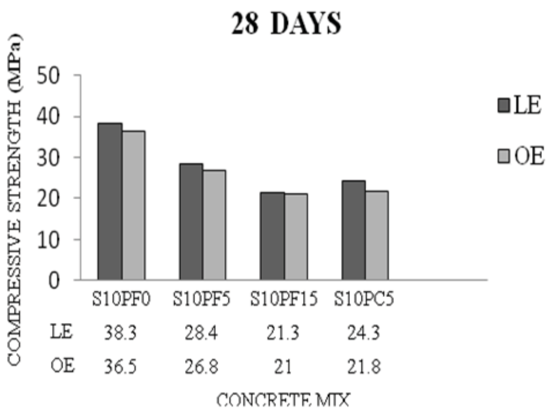

Fig 10. The results of curing conditions on compressive strength

The figures 9-14 show that compressive strength of S10PF15 or S15 PF15 specimens are approximately equal in both environments. Difference between compressive strength of mixtures in both environments is reduced with increasing amount of PF. But this process is not true for PC mixtures. On the other hand, maximum difference between compressive strength of mixtures in both environments is in S10PF0 or S15PF0 specimens. However, as the ME regime is more humid it should generate a greater difference between NA and the PWA mixes. When the size of PWA increases (S10PF5 to S10PC5) the mixes porosity also increases and magnifies this effect, which is why the compressive strength of the PC mixes is more sensitive to the incorporation of plastics than that of PF mixes.

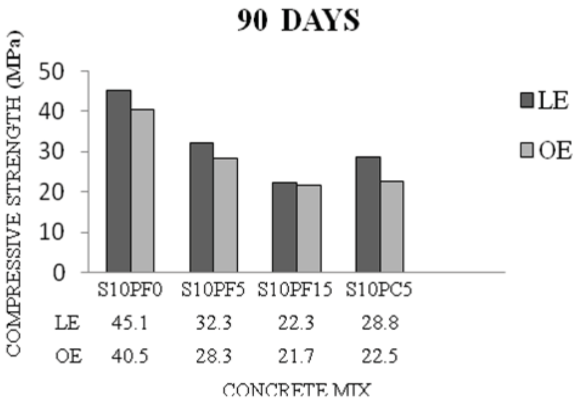

Fig 11. The results of curing conditions on compressive strength

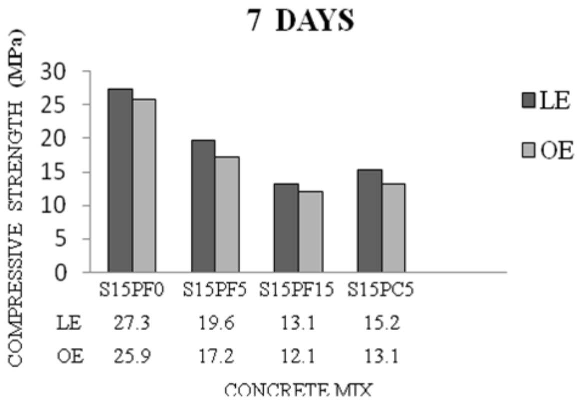

Fig 12. The results of curing conditions on compressive strength

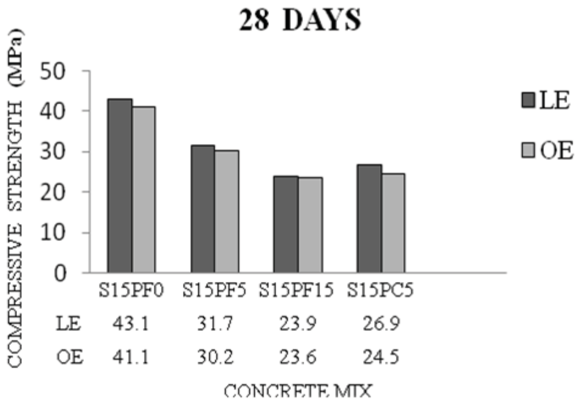

Fig 13. The results of curing conditions on compressive strength

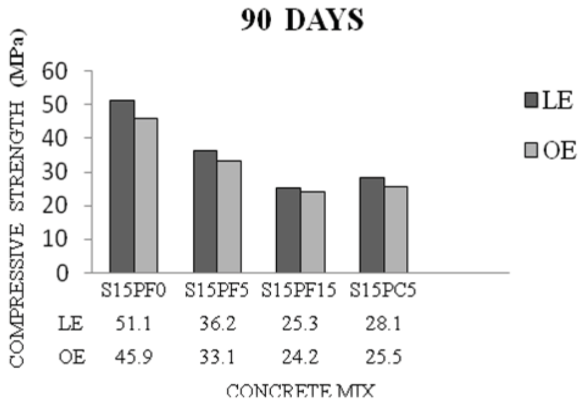

Fig 14. The results of curing conditions on compressive strength

3-4 Curing conditions in tensile strength

Figs.15-16 show the effect of curing conditions on tensile strength at 28 days respectively for all mixes with 10% and 20% silica fume and different percents of PWA. The same as compressive strength, Due to humid weather conditions in the Chabahar city, tensile strength of specimens that they are in Marine environment is lower than another curing condition (LE). The figures 15-16 show. Difference between tensile strength of mixtures in both environments is approximately constant with increasing amount of PF. But this process is not true for PC mixtures.

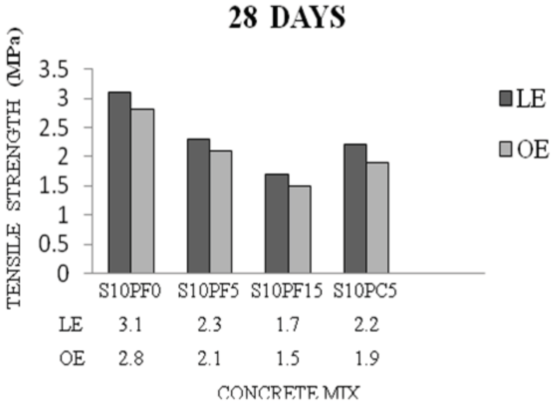

Fig 15. The results of curing conditions on tensile strength

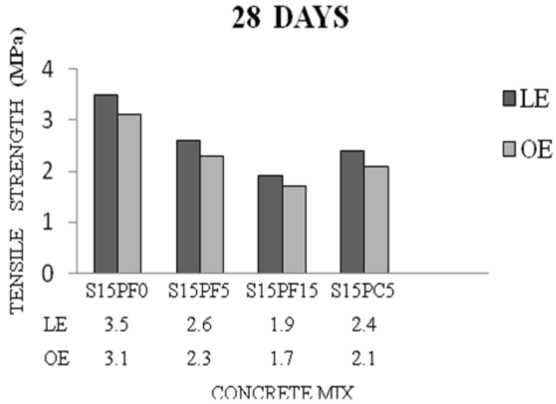

Fig 16. The results of curing conditions on tensile strength

4. Conclusions

Based on the findings of the experimental program presented above, the following conclusions can be drawn:

– Concretes containing silica fume compressive strength decreases with increasing of PWA as a replacement if natural aggregate.

– Maximum and minimum reduction of 7, 28 and 90 days in compressive strength is occurred in S10PF15 specimen in ME position.

– The same as compressive strength, the splitting tensile strength decreases as the PWA incorporation ratio increases.

– Due to humid weather conditions in the Chabahar city, compressive strength of specimens that they are in Marine environment is lower than another curing condition (LE).

– Difference between compressive strength of mixtures in both environments is reduced with increasing amount of PF. But this process is not true for PC mixtures.

– Maximum difference between compressive strength of mixtures in both environments is in S10PF0 or S15PF0 specimens.

– Mixtures subjected to laboratory environment initial temperatures reach greater initial strength. But compressive strength seems to be most sensitive to the incorporation of PWA under the LE regime and the least sensitive under the ME regime.

– Tensile strength of specimens that they are in Marine environment is lower than another curing condition (LE).

– Difference between tensile strength of mixtures in both environments is approximately constant with increasing amount of PF.

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