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Research Article

Standardization the effect of shape of aggregates with respect to compressive strength of concrete

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ABSTRACT

It is proved that aggregate's types have the severe effect on physicommechanical properties of concrete as aggregate covered almost 70 to 80 percent of the total volume of concrete. The effect of Flaky and Elongated aggregates on strength, durability, and workability of concrete has often been qualitatively expressed. The aim of this work is establishing the same quantitatively. M25 grade concrete for different ratios of weights of Elongated to normal aggregate, Flaky to normal aggregate and combined Flaky & Elongated aggregate to normal aggregate was tested for compressive strength at 28 days concrete. Three different types of aggregates were employed in the investigation, namely; normal aggregate, Elongated aggregate, and Flaky aggregate. Density and water absorption also kept constant to identify the effects on properties of concrete only for differences in shape. Thirty-six concrete cylinder was cast at 28 days. Varying dosages of Normal aggregate (60%, 65%, 70%, 75%, 80%, 85%), flaky aggregate (40%, 35%, 30%, 25%, 20%, 15%), elongated aggregate (40%, 35%, 30%, 25%, 20%, 15%), by mixture volume and length of 12inch (304.8 mm) & diameter of 6inch (152.4 mm) cylinder were used to test. Compaction was done by temping rod. Concrete cylinder was tested at the age of 28 days of curing. This study proposed of mixing three different types of aggregate in concrete. Compressive strength of concrete was measured by the effect of three different shapes of aggregates of varying dosages.

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1. Introduction

Concrete is a composite material of sand, gravel, crushed rock, or other aggregate held together by a hardened paste of hydraulic cement and water. The thoroughly mixed ingredients, when properly proportioned, make a plastic mass which can be cast or molded into a predetermined size and shape. The shape and the surface texture of aggregates influence the properties of concrete. Generally, irregular textured, normal, and Elongated particles require more cement paste than smooth and rounded particles to produce workable concrete mixture because of higher void contents. In addition, mixtures with rough textured or crushed aggregates have higher strength, especially tensile strength, at early ages than a corresponding concrete with a smooth

or naturally weathered aggregate of similar mineralogy. As aggregates constitute 60% to 80% of the volume of concrete, the study of the influence of their properties on the performance of concrete is important. The relative effect of these variations in the nature of coarse aggregates on the compressive strength achieved by the concretes has been investigated and presented in this study. The shape of aggregate have a remarkable bearing capacity on compressive strength and permeability of pervious concrete. The magnitude of this effect is determined by conducting laboratory experiments on mixes of pervious concrete prepared using aggregates of different shape with varying water cement ratio. The shape of the aggregate is measured in terms of its normality number which is a laboratory method intended for comparing the properties of different aggregates for mix design

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purposes. strength vary as a function of shape of the aggregate along with size of aggregate and water cement ratio in the mix which leads to the conclusion that shape of aggregate shall be considered as an important parameter in deciding the suitability of coarse aggregate to prepare mix. Shape of coarse aggregates is one of the most important characteristic that affects the properties of concrete. However, its influence on mix design has not been considered in ACI codes of practice for design of concrete mix (ACI 211.1-91). Shape is related to sphericity, form and roundness (Galloway, 1994).

Sphericity is a measure of how nearly equal are the three principal axes or dimensions of a particle. The form is the measure of the relation between the three dimensions of a particle based on ratios between the proportions of the long, medium, and short axes of the particle. Form, also called 'shape factor', is used to distinguish between particles that have the same numerical sphericity (Hudson, 1999).

Concrete is a composite material produced by the homogenous mixing of selected proportions of water, cement, and aggregates. Strength is the most desired quality of a good concrete. It should be strong enough, at hardened state, to resist the various stresses to which it would be subjected. Compressive strength of concrete, therefore, is the value of test strength below which not more than a prescribed percentage of the test results should fall (Kong and Evans, 1987).

Ponnada (2014) studied the effects of various types of aggregate quantitatively. M25 grade of concrete for various ratios of weights of Elongated aggregate to Flaky aggregate and normal aggregate to overall aggregate were checked for compressive strength, density and workability. The results expose that the effect of Elongated aggregates is more than Flaky aggregates, on the characteristic compressive strength of concrete.

Abdullahi (2012) reported the effect of aggregate category on compressive strength of concrete. Three types of coarse aggregates used i.e., quartzite, granite, and river gravel, were used. Maximum compressive strength at total ages was noted with concrete made from quartzite aggregate tracked by river gravel and then granite aggregate.

Jain and Chouhan (2011) reported on the influence of shape of aggregate on compressive strength and permeability properties of permeable concrete. The shape of aggregate is measured in terms of normality number. Result indicate that strength and permeability of concrete vary as function of shape of aggregate alongside with aggregate size and water cement ratio in the mix.

Yong (2008) stated that smooth rounded aggregates was more workable but yielded a lesser compressive strength in the matrix than irregular aggregates with rough surface texture.

They were also of the opinion that a fine coating of impurities such as silt on the aggregate surface could hinder the development of a good bond and thus affects the strength of concrete. Chen and Liu (2004) as well as Rao and Prasad (2002) viewed aggregates as the skeleton of concrete and consequently persuaded that all forms of coatings should be avoided in order to achieve a good concrete.

Mansur and Islam (2002) reported an experimental study on the effects of different concrete specimen types on the compressive strength and established the inter-relationships between their strengths.

The test carried out by Soroka (1993) revealed the variations between the compressive strengths of concrete made with crushed stone and uncrushed stone. He achieved a better compressive strength with the crushed stone than the uncrushed stone. This strength performance was as a result several factors like water/cement ratio, grading, surface texture, shape, strength, and stiffness of aggregates used.

The objective of this work is to study the separately and combined effect of Elongated and Flaky of coarse aggregate on the compressive strength concrete and to establish a relation between strength of concrete with standard shape & proportion and irregular shape & proportion. The properties of the ingredients were determined as per ACI procedures and M25 grade concrete was designed. The coarse aggregate passing 40 mm and retained on 10 mm was considered for sorting into three parts - Elongated, Flaky and normal aggregates. Cylinders are casted for different ratios of weights of Elongated to normal, Flaky to normal & combined Elongated, Flaky aggregate and normal aggregate. Compressive strengths at 28 days were considered for study.

2. Mixture Proportions

A normal mix ratio of 1:2:4 (Cement: Fine Aggregate: Coarse Aggregate) was adopted for the purpose of this work and a water-cement ratio of 0.45 was used. The mix composition was computed using the absolute volume method from Eq. (1).

$$\left(\frac{W_w}{1000}\right) + \left(\frac{W_c}{1000SG_c}\right) + \left(\frac{W_{FA}}{1000SG_{FA}}\right) + \left(\frac{W_{CA}}{1000SG_{CA}}\right) = 1 \text{ (m}^3\text{)}. \quad (1)$$

where; W_w is weight of water (kg), W_c is weight of cement (kg), W_s is weight of sand (kg), SG_{FA} is specific gravity of sand, and SG_c is specific gravity of cement. Following cases were considered for this investigation work given in Table 1.

3. Experimental Investigation

The materials required for performing the project were procured. About 300 kg of coarse aggregate (20 mm passing and 4.75 mm retained), 150 kg of fine aggregates (passing 4.75 mm) and about 100 kg of 53 grade cement were procured. Preliminary tests on properties of these ingredients were done as per ACI procedures and the results are as follows:

Cement:

- Cement grade : 53 grade OPC [ACI 318:21.10.3.4]
- Fineness : 7.33% [ACI 211.1-91]
- Specific gravity : 3.04 [ACI 318:1904.2.2]
- Standard consistency : 28% [ACI 318:1903.3]
- Initial setting time : 87 minutes [ASTM C494]
- Final setting time : 515 minutes [ASTM C4 94]
- Soundness : 3 mm [ACI 211.1-91]

Table 1. Designation of different molds.

Designation	Description
M25-10	M-25 concrete mix with normal composition of concrete.
M25-40-10 ¹	M-20 concrete mix with 60% normal coarse aggregate mix + 40% of Flaky aggregate retained on 10 mm aperture size.
M25-35-10 ¹	M-25 concrete mix with 65% normal coarse aggregate mix +35% of Flaky aggregate passing from 10 mm aperture size.
M25-30-10 ¹	M-20 concrete mix with 70% normal coarse aggregate mix + 30% of Flaky aggregate passing from 10 mm aperture size.
M25-25-10 ¹	M-25 concrete mix with 75% normal coarse aggregate mix + 25% of Flaky aggregate retained on 10 mm aperture size.
M25-20-10 ¹	M-20 concrete mix with 80% normal coarse aggregate mix + 20% of Flaky aggregate passing from 10 mm aperture size.
M25-15-10 ¹	M-25 concrete mix with 85% normal coarse aggregate mix +15% of Flaky aggregate retained on 10 mm aperture size.
M25-40-10 ²	M-20 concrete mix with 60% normal coarse aggregate mix + 40% of Elongated aggregate retained on 10 mm aperture size
M25-35-10 ²	M-25 concrete mix with 65% normal coarse aggregate mix +35% of Elongated aggregate passing from 10 mm aperture size.
M25-30-10 ²	M-20 concrete mix with 70% normal coarse aggregate mix + 30% of Elongated aggregate passing from 10 mm aperture size.
M25-25-10 ²	M-25 concrete mix with 75% normal coarse aggregate mix + 25% of Elongated aggregate retained on 10 mm aperture size.
M25-20-10 ²	M-20 concrete mix with 80% normal coarse aggregate mix + 20% of Elongated aggregate passing from 10 mm aperture size.
M25-15-10 ²	M-25 concrete mix with 85% normal coarse aggregate mix +15% of Elongated aggregate retained on 10 mm aperture size.
M25-60-10 ¹	M-25 concrete mix with 40% normal coarse aggregate mix +30% of Elongated +30% flacky aggregate retained on 10 mm aperture size.
M25-60-10 ²	M-25 concrete mix with 40% normal coarse aggregate mix +25% of Elongated +35% flacky aggregate retained on 10 mm aperture size.
M25-60-10 ³	M-25 concrete mix with 40% normal coarse aggregate mix +20% of Elongated +40% flacky aggregate retained on 10 mm aperture size.
M25-60-10 ⁴	M-25 concrete mix with 40% normal coarse aggregate mix +15% of Elongated +45% flacky aggregate retained on 10 mm aperture size.
M25-60-10 ⁵	M-25 concrete mix with 40% normal coarse aggregate mix +35% of Elongated +25% flacky aggregate retained on 10 mm aperture size.
M25-60-10 ⁶	M-25 concrete mix with 40% normal coarse aggregate mix +40% of Elongated +20% flacky aggregate retained on 10 mm aperture size.

Coarse aggregates:

- Fineness modulus : 8.73 [ACI 211.1-91]
- Specific gravity : 2.79 (20 mm) [ACI 211.1-91]
- Water absorption value : 0.5% [ASTM C 128]
- Free surface moisture : NIL
- Flakiness index : 10% [ACI 211.1-91]
- Elongation index : 10.5% [ACI 211.1-91]
- Aggregate crushing value : [ASTM C 128]
- Aggregate impact value : [ACI 211.1-91]

Fine aggregates:

- Fineness modulus : 2.585 [ACI 211.1-91]
- Specific gravity : 2.71 [ACI 211.1-91]
- Water absorption : NIL [ASTM C 128]
- Free surface moisture : NIL 5 Zone of sand : II

Mix design procedure M25 grade concrete mix design was performed for the following design data.

- Grade designation: M25
- Type of cement: OPC 53 grade

- Maximum normal size of aggregate: 40 mm
- Minimum cement content: 300 kg/m³
- Maximum water cement ratio: 0.45
- Workability: 80 mm slump
- Exposure condition: mild
- Method of concrete placing: manual
- Degree of supervision: good
- Type of aggregate: normal aggregate, flacky aggregate, Elongated aggregate.

Table 2 shows the total ingredient of all mix proportions.

4. Results and Discussion

Thirty six batches of concrete cylinders were cast and compressive strength at 28 days curing were determined. The compressive strength test was performed as per ACI 318-02: 5.6.2.4. The results obtained in Table 3.

Table 2. Total ingredient of all mix proportions.

Water	Cement	Sand	Normal aggregate	Elongated aggregate	Flacky aggregate
28.5 lit.	63.5kg	142 kg	185kg	32kg	32kg

Table 3. Final results.

Designation Description	Ratio	Compressive strength (N/mm ²)
M25-10	-	27.42
M25-40-10 ¹	40 : 30 : 30	24.18
M25-35-10 ¹	40 : 25 : 35	25.41
M25-30-10 ¹	40 : 20 : 40	27.44
M25-25-10 ¹	40 : 15 : 45	27.86
M25-20-10 ¹	40 : 35 : 25	26.92
M25-15-10 ¹	40 : 40 : 20	26.64
M25-40-10 ²	60 : 40 : 00	25.41
M25-35-10 ²	65 : 35 : 00	26.94
M25-30-10 ²	70 : 30 : 00	28.13
M25-25-10 ²	75 : 25 : 00	28.32
M25-20-10 ²	80 : 20 : 00	28.05
M25-15-10 ²	85 : 15 : 00	27.56
M25-60-10 ¹	60 : 00 : 40	26.84
M25-60-10 ²	65 : 00 : 35	27.32
M25-60-10 ³	70 : 00 : 30	26.68
M25-60-10 ⁴	75 : 00 : 25	27.54
M25-60-10 ⁵	80 : 00 : 20	28.28
M25-60-10 ⁶	85 : 00 : 15	29.24

Fig. 1 shows that, compressive strength becomes high for the dosage of 25% flaky aggregate mixed with Normal aggregate and it becomes close to standard at 33% dosage. Fig. 2 shows that compressive strength becomes high for the dosage of 25% Elongated aggregate mixed with Normal aggregate and it becomes close to standard at 33% dosage. Fig. 3 shows that Angularity Number becomes high for the dosage of 15% elongated aggregate mixed with Normal aggregate and it becomes close to standard at 15% to 20% dosage. Fig. 4 shows that Compressive Strength rises with the increase in Angularity Number and decreases with the increase in Angularity Number after the value of 6. Fig. 5 shows that compressive strength becomes high for the dosage of 25% flaky aggregate mixed with Normal aggregate and it becomes close to standard at 22.5% & 30% dosages. Fig. 6 shows that compressive strength becomes high for the dosage of 25% flaky aggregate mixed with Normal aggregate and it becomes close to standard at 30% dosage. Fig. 7 shows that, Angularity Number becomes high for the dosage of 40% flaky aggregate mixed with Normal aggregate and it becomes close to standard at 15% to 30% dosage. Fig. 8 shows that Compressive Strength rises with the increase in Angularity Number and decreases with the decrease in Angularity Number. Fig. 9 shows that compressive strength becomes high for the dosage of 0.5 ratio of Elongated & Flaky Aggregate in the mix and it becomes close to standard at the ratio 0.8 & 2.8 dosages. Fig. 10 shows that compressive strength becomes close to standard at the ratio 0.8 & 2.8 dosages of Elongated & Flaky Aggregate in the mix. Fig. 11 shows that Angularity Number rises with the increase in dosages of

Elongated & Flaky Aggregate in the mix. Fig. 12 shows that Compressive Strength rises with the decrease in Angularity Number and increases with the increase in Angularity Number after the value of 10.

5. Conclusions

After completion of the tests and analysis of the results regarding compressive strength of concrete using three different shapes of aggregates it is evident that shape of aggregate plays an important role in property of strength of concrete. With the variation of percentage of aggregate following conclusions can be deduced-

- Strength increased with the decrease of percentage of flaky aggregate from 40% to 25%, after the strength decreased.
- Strength increased with the decrease of percentage of elongated aggregate from 40% to 25%, after the strength decreased.
- The effect of elongated aggregates is more on the strength of concrete when compared to that of flaky aggregates.
- The strength of concrete when 100% perfectly Normal aggregate was used is found to be maximum and the maximum 28days characteristic compressive strength was observed to be 27.42 MPa.
- For a constant EA: FA ratio, density increases but characteristic compressive strength decreases with decrease in NA: TA ratio. For a constant NA: EA: FA ratio, characteristic compressive strength is maximum.

- From the results, it can be concluded that the effect of flaky and elongated aggregates on strength is considerable. Even though, the work is done on one particular grade of concrete, it can be considered that the nature of variation may not change with grade of concrete.
- Results indicate that strength concrete varies as a function of shape of the aggregate along with size of aggregate and water cement ratio in the mix which leads to the conclusion that shape of aggregate shall be considered as an important parameter in deciding the suitability of coarse aggregate to prepare pervious concrete.

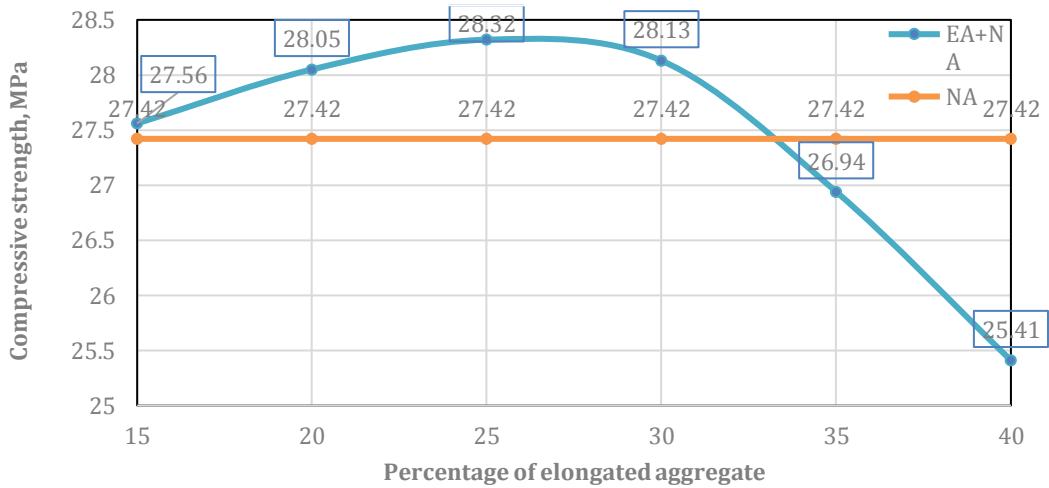


Fig. 1. Percentage of Elongated Aggregate in the mix Vs Compressive Strength, MPa.

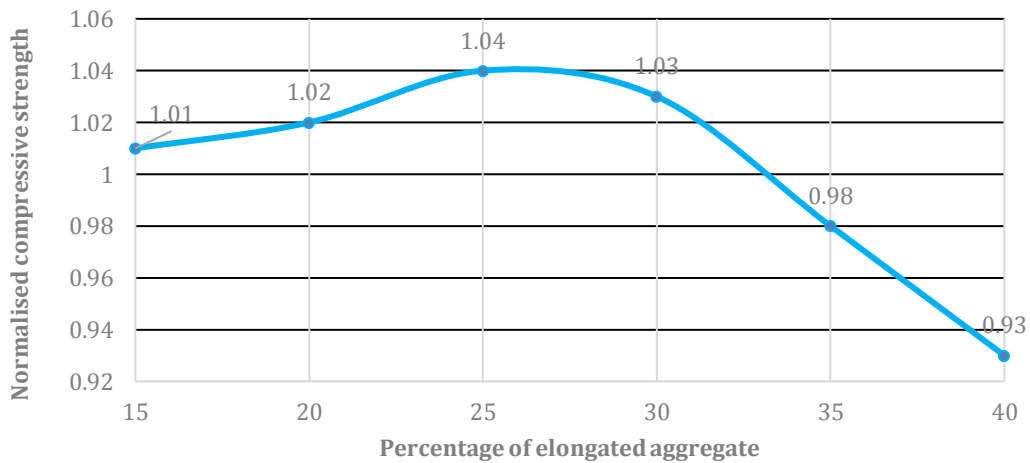


Fig. 2. Percentage of Elongated aggregate in the mix Vs Normalized Compressive Strength.

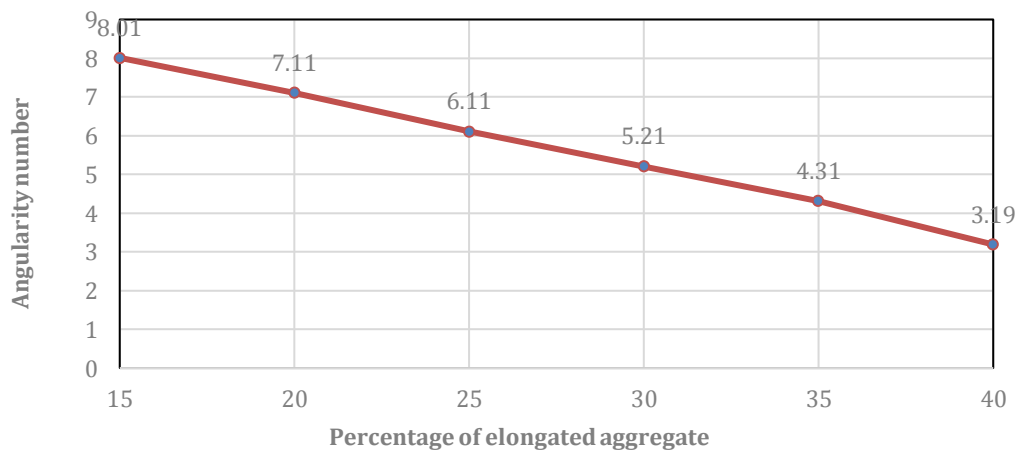


Fig. 3. Percentage of elongated aggregate in the mix Vs Angularity Number of coarse aggregate.

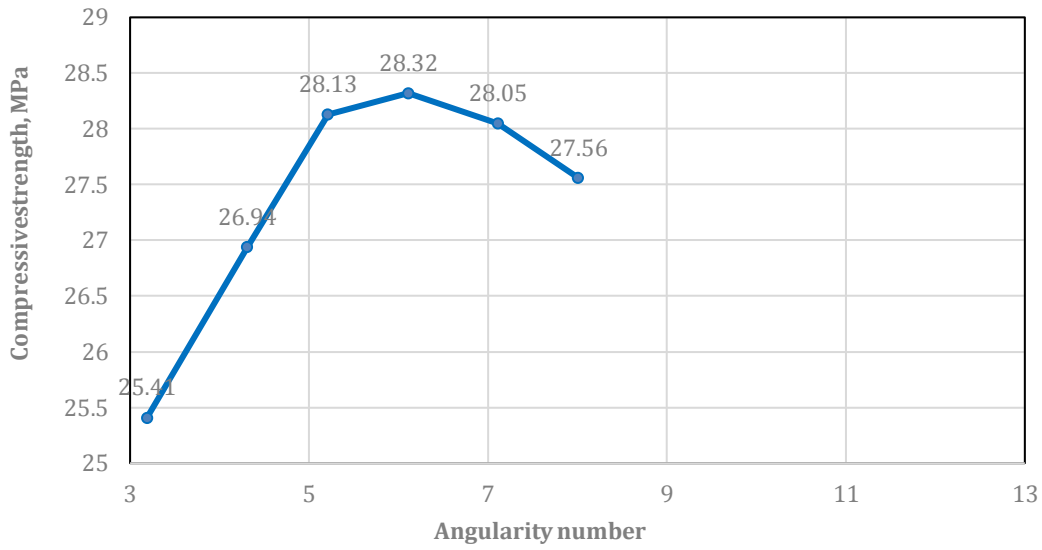


Fig. 4. Angularity Number of coarse aggregate in the mix Vs Compressive Strength, MPa.

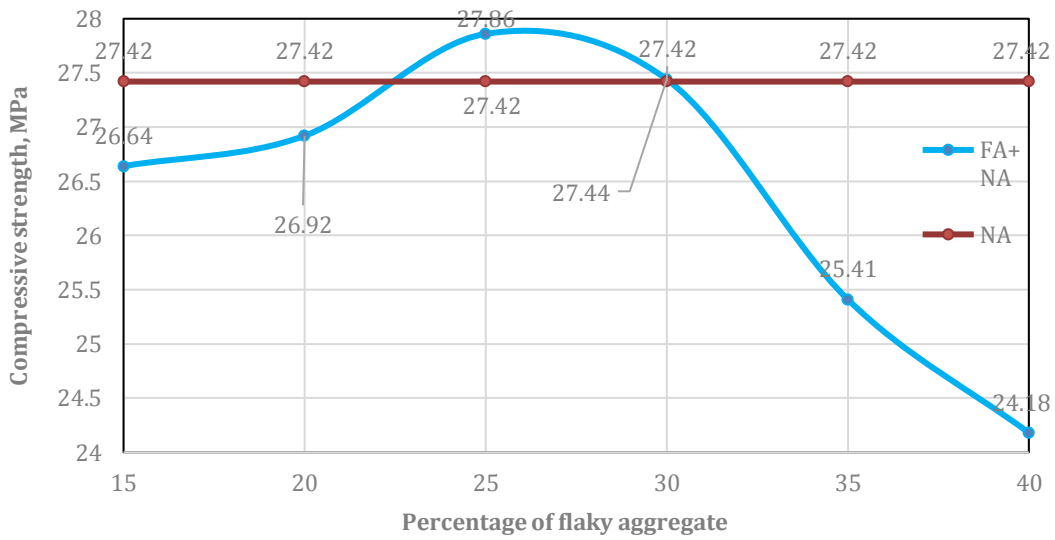


Fig. 5. Percentage of flaky aggregate Vs Compressive Strength.

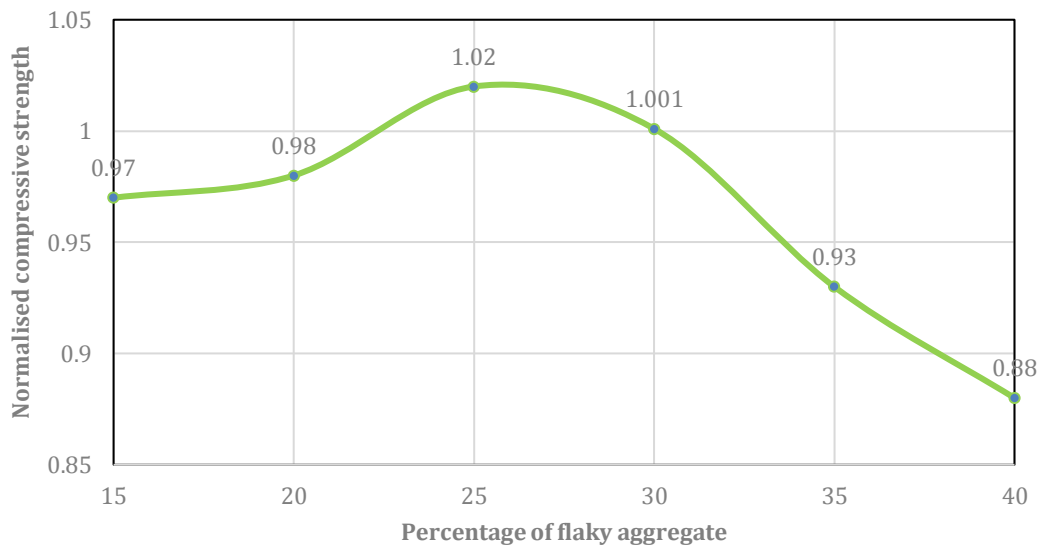


Fig. 6. Percentage of flaky aggregate Vs Normalized Compressive Strength, MPa.

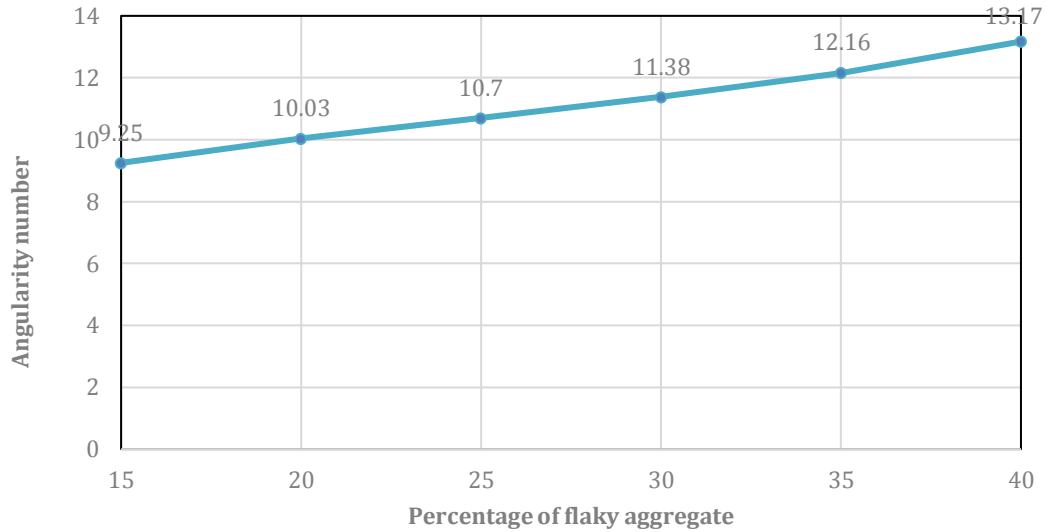


Fig. 7. Percentage of flaky aggregate Vs Angularity Number coarse aggregate in the mix.

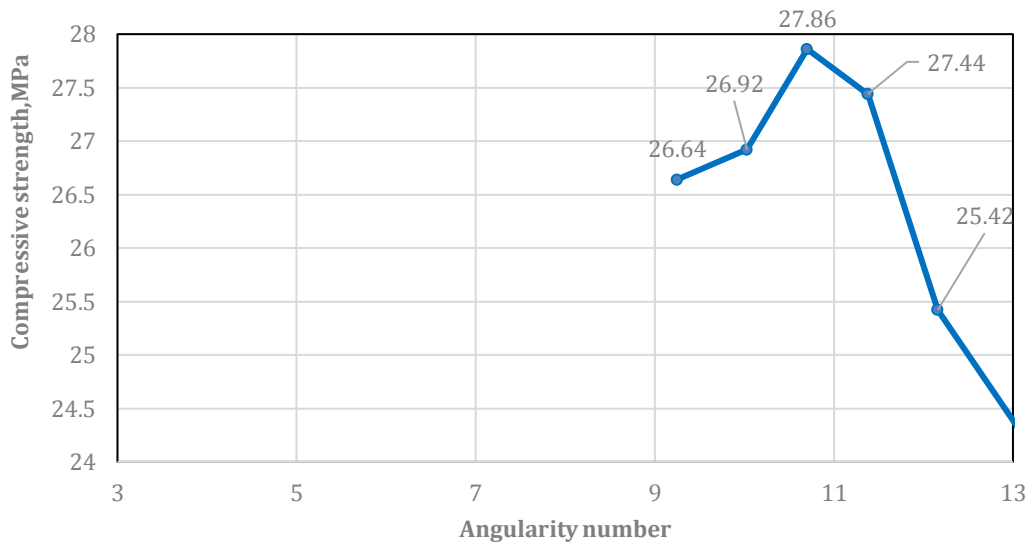


Fig. 8. Angularity Number of coarse aggregate in the mix Vs Compressive Strength, MPa.

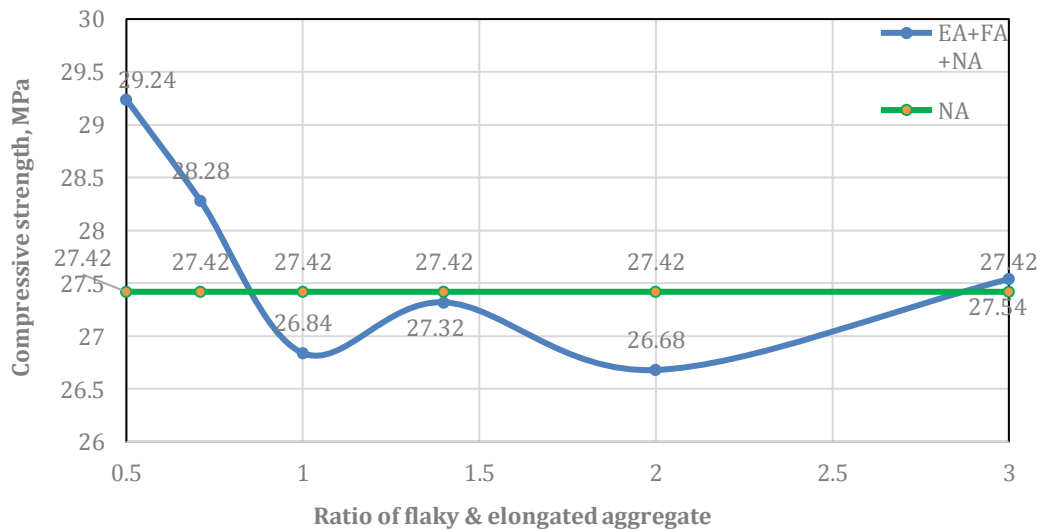


Fig. 9. Ratio of Elongated & Flaky Aggregate in the mix Vs Compressive Strength, MPa.

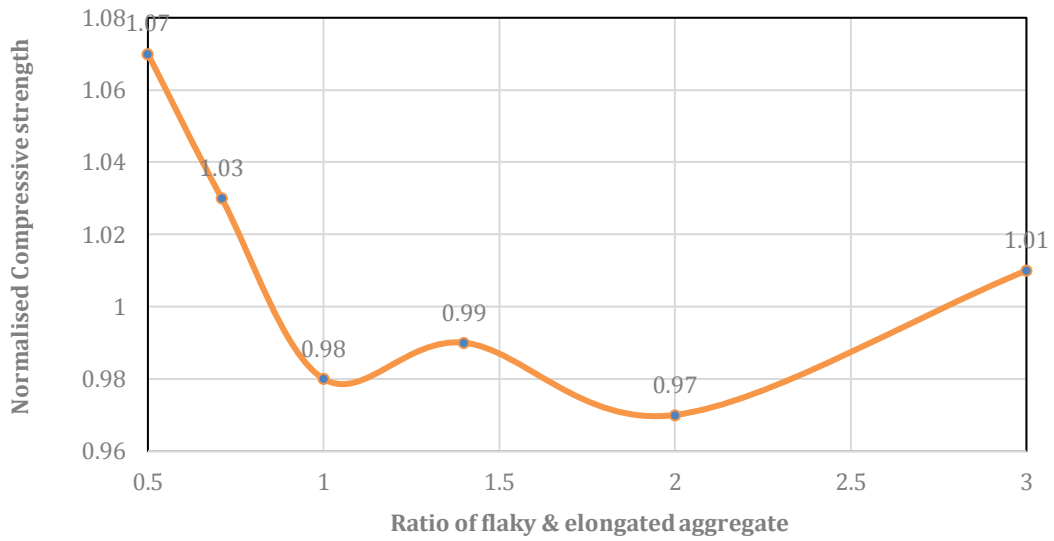


Fig. 10. Ratio of Elongated & Flaky Aggregate in the mix Vs Normalized Compressive Strength.

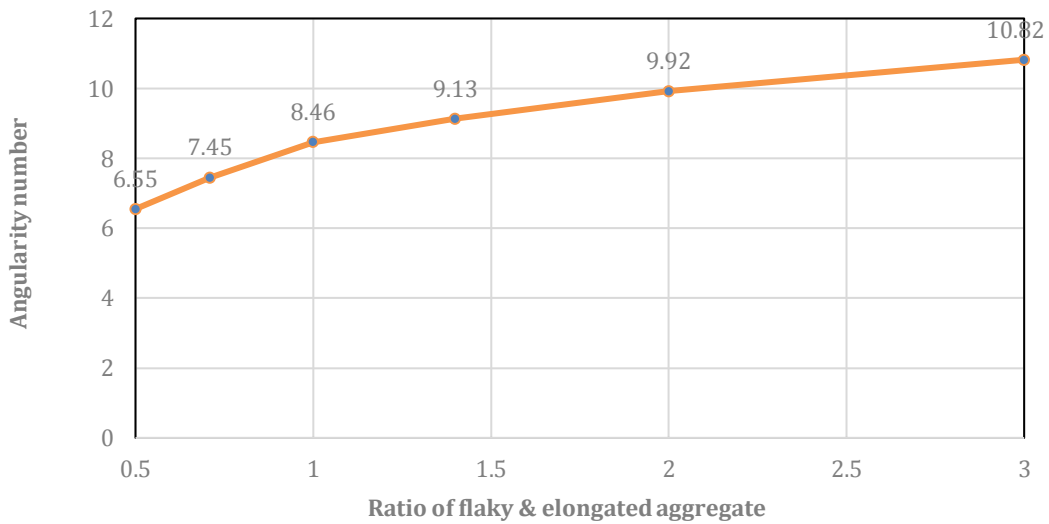


Fig. 11. Ratio of Elongated & Flaky Aggregate Vs Angularity Number of coarse aggregates.

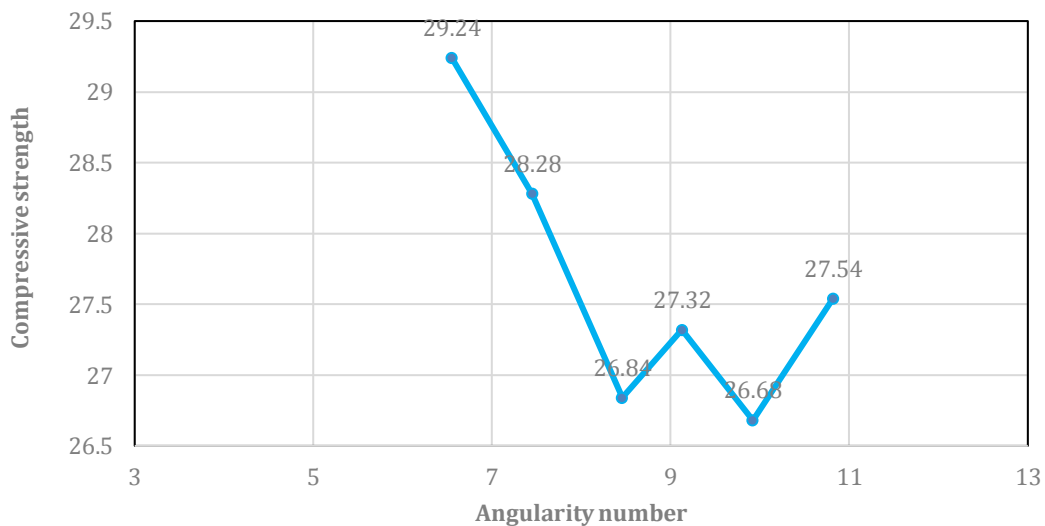


Fig. 12. Angularity Number of coarse aggregate in the mix Vs Compressive Strength, MPa.

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Research Article

Production of durable high strength flowable mortar reinforced with hybrid fibers

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ABSTRACT

This study deals with the production of durable high strength flowable mortar (HSFM). Firstly, the optimum percentage of silica fume was determined due to Pozzolanic Activity Index (P.A.I) test. Secondly, the selected mortar reinforced by different percentages of steel fibers or hybrid fibers of steel fibers, palm fibers and synthetic fibers (Barchip) to prepare HSFM mixes. Such mixes were tested in compressive strength, splitting tensile strength, static modulus of elasticity, flexural strength, toughness indices determination, and impact load for all the mixes. Lastly, the effects of seawater exposure on the properties of HSFM have been observed. The results show that the use of 10% silica fume as a partial replacement of cement indicate the best P.A.I. On the other hand, the hybridizations of such fibers enhance the performance of HSFM mixes. In addition, the hybrid fibers reduce the permeability of HSFM leading to significance improvement against seawater exposure.

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1. Introduction

High strength concrete or mortar subjected to axial compression is known to be a brittle material with almost no strain-softening behavior. Adding fibers to plain matrix has little or no effect on its pre-cracking behavior but enhances its post-cracking response, which leads to a greatly improved toughness and impact behavior (Burak et al., 2007). Fibers are known to affect the workability of concrete or mortar, the question arises as to whether or not the fibers are detrimental to the workability or flowability of these materials. The degree to which workability decreases depends on the type and content of the fibers used, the matrix in which they are embedded and the properties of the constituents of the matrix. A high fiber content is difficult to distribute uniformly; however, a good distribution, required to achieve optimum benefits of the fibers (Gang et al., 2008) The development of superplasticizer has proven to offer significant improvement in application of fibers like in slabs and floors, shell domes, rock slope stabilization, refractory linings, composite metal decks, seismic retrofitting,

repair and rehabilitation of structure, fire protection coatings, concrete pipes, among others (Burak et al., 2007). Over the last three decades, fiber reinforced concrete (FRC) has been the subject of many investigations. Researches have been performed on the behavior of fiber reinforced concrete subjected to various types of loading and incorporating different fibers ranging from steel, glass, plastic and natural fibers in various sizes and shapes (Burak et al., 2007; Okamura and Ouchi, 2003).

Steel fiber has a considerably larger length and higher Young's modulus, than the other fibers. This leads to an improved potential for crack control, although the volumetric density is high. As the result, the steel fiber content has to be reduced to a certain level. Optimizations of mechanical and conductivity properties can be achieved by combining different types and sizes of fibers, such as in the case of natural and synthetic fibers (Hayat and Morin, 2002; Bentur and Mindess, 2003).

The research concentrates on highlighting some properties of the produced high strength flowable mortar (HSFM) reinforced with hybrid fibers as well as the behavior of such mortar due to seawater exposure.

2. Materials and Mix Proportions

2.1. Materials

The cement used in concrete mixtures was ordinary Portland cement type I from Tasek Corporation Berhad. Silica fume was obtained from Scancem Materials Sdn. Bhd. and was used as partial replacement of cement. The chemical compositions of ordinary Portland cement and silica fume are given in Table 1.

The superplasticizer (SP.) is Conplast SP1000 obtained from Fosroc Sdn. Bhd. and was used to establish the desired workability of mixes. The fine aggregate was natural sand, with fineness modulus of 2.86 and maximum size of less than 5 mm. The palm fiber was supplied by Fiber-X (M) Sdn. Bhd, and their characteristics as are shown in Table 2. The synthetic fiber (Barchip) was obtained from elasto-plastic concrete and its characteristics are presented in Table 3. The steel fiber is supplied by Hunan Sunshine Steel Fiber Co. Ltd, and their mechanical properties are shown in Table 4.

Table 1. Chemical composition of ordinary Portland cement and silica fume.

Constituent	Ordinary Portland Cement % by weight	Silica fume % by weight
Lime (CaO)	64.64	1.0% (max)
Silica (SiO ₂)	21.28	90% (max)
Alumina (Al ₂ O ₃)	5.60	1.2% (max)
Iron Oxide (Fe ₂ O ₃)	3.36	2.0% (max)
Magnesia (MgO)	2.06	0.6%(max)
Sulphur Trioxide (SO ₃)	2.14	0.5%(max)
N ₂ O	0.05	0.8%(max)
Loss of Ignition	0.64	6% (max)
Lime saturation factor	0.92	-----
C ₃ S	52.82	-----
C ₂ S	21.45	-----
C ₃ A	9.16	-----
C ₄ AF	10.2	-----

Table 2. Physical and mechanical properties of palm fibers.

Fiber Properties	Quantity
Average fiber length (mm)	30
Average fiber width (micron)	21.13
Tensile strength (MPa)	21.2
Elongation at break (%)	0.04
Specific gravity	1.24
Water absorption (% , 24/48 hrs)	0.6

Table 3. Physical and mechanical properties of synthetic fiber (Barchip) fibers.

Fiber Properties	Quantity
Average fiber length (mm)	30
Average fiber width (micron)	0.52
Tensile strength (MPa)	550
Elongation at break (%)	8.2
Specific gravity	0.92
Melting point (C°)	150-165

Table 4. Physical and mechanical properties of steel fibers.

Fiber Properties	Quantity
Average fiber length (mm)	30
Average fiber diameter (mm)	0.56
Aspect ratio	56
Tensile strength (MPa)	>1100
Ultimate elongation (%)	<2
Specific gravity	7.85

2.2. Mix proportions

For the selection of optimum percentage of silica fume as a partial replacement of cement the Pozzolanic Activity Index (P.A.I) test was adopted by ASTM C311. Thus different silica fume percentages (0, 8, 10, 12, 14 and 16%) were used to check the best performance of such substitution. The design of mortar mix is shown in Table 5. The mix design of the reference mortar mix (M0) was carried out according to the absolute volume method given by the American Concrete Institute (ACI 211.1) for the production of high strength flowable mortar (HSFM). A reference mortar mix (M0) was prepared using water-binder (Cement+ Silica fume) ratio of 0.43 and silica fume replacement which was selected depending on P.A.I results. The amount of superplasticizer was varied from 1.8% to 2.2% by weight of binder materials to maintain the flowability as 100-110% for all mixes. The different HSFM mixes reinforced with steel fibers or hybrid fibers are also shown in Table 5.

3. Test Methods

Each test result is represented by three cube samples 50 mm and tested to determine the pozzolanic activity index and compressive strength for mortar mixes at after undergoing water curing. The Flow test for the mixes was performed according to ASTM C1437. The compressive strength test was done immediately according to ASTM C109 at 90 days age. The flexural strength of the specimens were conducted on 40 × 40 × 160 mm samples

at same age according to ASTM C348. The impact resistance test was conducted using $100 \times 100 \times 500$ mm specimens for all mixes. The impact test was determined using a steel rod blow of weight 4.5 Kg and dropping at a vertical height of 450 mm. The load was transferred

from the hammer to the surface of specimen through a 50 mm steel half-ball. The test of oxygen permeability was achieved according to the recommendation stated by Cembureau. However, some adjustments were prepared for the test according to Dawood and Ramli (2012).

Table 5. Mortar mix proportions.

Index	Cement (kg/m ³)	Silica fume (kg/m ³)	Water (kg/m ³)	SP (%)	Sand (kg/m ³)	W+SP/B	Steel fiber (SF) (%)	Palm fiber (PF) (%)	Barchip fiber (BF) (%)
M0	550	55	260	1.8	1410	0.43	0	--	--
M1	550	55	260	1.8	1410	0.43	0.25	--	--
M2	550	55	260	1.8	1410	0.43	0.50	--	--
M3	550	55	260	1.8	1410	0.43	0.75	--	--
M4	550	55	260	2.0	1410	0.43	1.0	--	--
M5	550	55	260	1.8	1410	0.43	1.25	--	--
M6	550	55	260	1.8	1410	0.43	1.50	--	--
M7	550	55	260	1.8	1410	0.43	1.75	--	--
M8	550	55	260	2.0	1410	0.43	2.0	--	--
M9	550	55	260	2.0	1410	0.43	1.75	0.25	--
M10	550	55	260	2.0	1410	0.43	1.5	0.5	--
M11	550	55	260	2.0	1410	0.43	1.25	0.75	--
M12	550	55	260	2.0	1410	0.43	1.0	1.0	--
M13	550	55	260	2.2	1410	0.43	1.0	0.50	0.50
M14	550	55	260	2.2	1410	0.43	1.250	0.50	0.25
M15	550	55	260	2.2	1410	0.43	1.25	0.25	0.50
M16	550	55	260	2.2	1410	0.43	1.5	0.25	0.25

4. Results and Discussion

4.1. Pozzolanic activity index (P.A.I.)

The results are shown in Table 6. It can be concluded that the Pozzolanic Activity Index (P.A.I.) of cement mortar increases at a higher silica fume content and the highest P.A.I was obtained using 10% of total cementitious materials. It has been seen that this percentage of the silica fume as a partial replacement of cement improves the compressive strength of the cement-mortar due to the pozzolanic reaction between the amorphous silica in silica fume and calcium hydroxide produced by the hydration of Portland cement and silica fume (Neville, 1995; Roy, 2002).

However, the use of more than 10% of silica fume lessens the enhancement in compressive strength due to the fact that C-S-H produced by silica fume has a lower C: S ratio than the C-S-H resulting from the hydration of Portland cement alone.

The C: S ratio is lower at a high content of silica fume in the cementitious material. At the same time the dense

microstructure of hydrated cement paste makes it difficult for water from outside to penetrate toward the unhydrated remnants of Portland cement or silica fume particle (Hotton, 1993). Fig. 1 shows the relation between the silica fume percentage and P.A.I for cement mortar mixes.

Table 6. Pozzolanic activity index.

Mix Type	Cement (kg/m ³)	Silica fume (kg/m ³)	SP (%)	Sand (kg/m ³)	W+SP/B	P.A.I. (MPa)
P0	540	---	1.5	1485	0.48	28
P1	508	32	1.7	1485	0.48	33
P2	497	43	1.9	1485	0.48	37.1
P3	486	54	2.0	1485	0.48	39.8
P4	475	65	2.1	1485	0.48	39.3
P5	464	76	2.2	1485	0.48	38.1
P6	453	87	2.4	1485	0.48	37.7

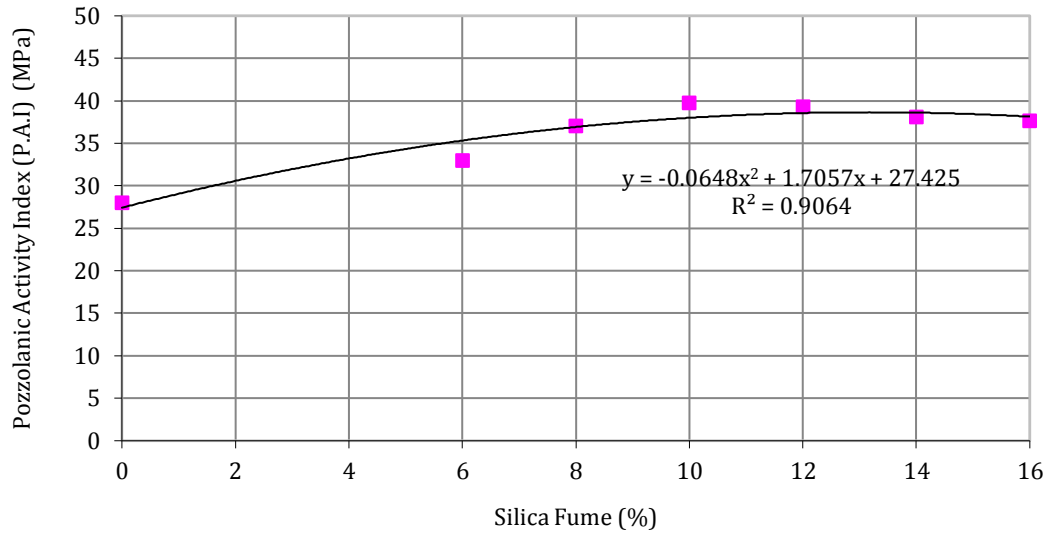


Fig. 1. Relationship between silica fume and pozzolanic activity index (P.A.I.).

4.2. Compressive strength

The results of the compressive strength of HSFM mixes shown in Table 7, indicate that the inclusion of steel fibers improves the compressive strength due to the enhancement in the mechanical bond strength between the steel fibers and mortar. The fibers play a major role to delay of micro-crack formation and arrest

their propagation afterwards up to a certain extent of fiber volume fraction (Felekoğlu et al, 2009; Sahmaran and Yaman, 2007).

The relationship between the compressive strength and the percentage of steel fibers in HSFM mixes is given in Fig. 2. It can be noticed from this figure that the maximum value of the compressive strength obtained using 1.25% of steel fiber in the HSFM.

Table 7. Mechanical Properties of HSFM.

Index	Steel fiber (%)	Palm fiber (%)	Barchip fiber (%)	Compressive strength (MPa) at 90 days	Flexural strength (MPa) at 90 days	Modulus of elasticity (GPa) at 90 days
M0	0	--	--	59.6	9.12	36.3
M1	0.25	--	--	66.5	9.88	36.8
M2	0.50	--	--	68.1	11.24	38.1
M3	0.75	--	--	69.1	12.68	38.9
M4	1.0	--	--	70.4	14.43	40.1
M5	1.25	--	--	71.8	14.85	41.1
M6	1.50	--	--	68.4	15.33	43.7
M7	1.75	--	--	66.1	18.42	45.2
M8	2.0	--	--	61.4	17.36	46.3
M9	1.75	0.25	--	65.6	17.64	48.3
M10	1.5	0.5	--	67.7	19.22	45.8
M11	1.25	0.75	--	61.1	14.95	43
M12	1.0	1.0	--	60.9	13.26	42.2
M13	1.0	0.50	0.50	59.8	14.15	41.5
M14	1.250	0.50	0.25	61.9	15.11	48.4
M15	1.25	0.25	0.50	63.8	15.24	49.7
M16	1.5	0.25	0.25	68.2	19.67	51.7

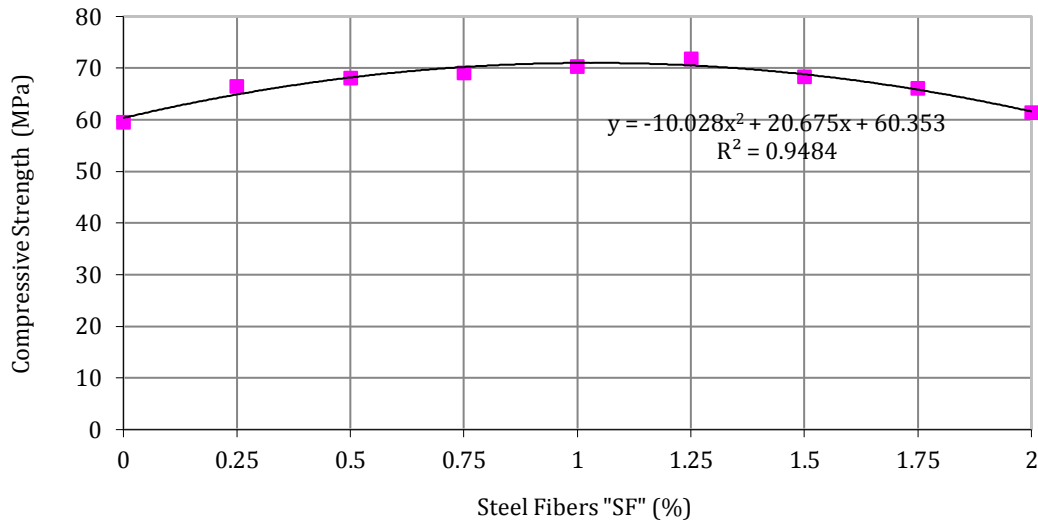


Fig. 2. Relationship between steel fibers and compressive strength of HSFM.

The comparison between control mortar mix (M0) and the mix of the highest volume fraction of steel fiber (2%) used in this study (M8) shows that there is no enhancement of compressive strength of HSFM.

This behavior maybe caused by a non-homogeneous distribution of the fibers within the mortar mix leading to a drop in the compressive strength of such mortar (Markovic et al., 2003).

The results of hybrid fiber (M9-M16) in the HSFM also illustrate that the use of low volume fraction of palm fiber or palm and Barchip fibers (0.25% to 0.5%) enhances the compressive strength as observed from mixes. This is can be attributed to the fact that hybrid fibers with different sizes and types offer different restrain (Chen and Liu, 2005).

Figs. 3 and 4 show the relative compressive strength of hybrid fibers HSFM by using steel fibers with palm fibers and also the using of steel, palm and Barchip fibers, respectively.

4.3. Static modulus of elasticity

Table 7 presents the results of modulus of elasticity for the different mortar mixes. The moduli of elasticity results reveal that there is a significant improvement in static modulus of elasticity for HSFM mixes by the inclusion of the steel fibers. The comparison between (M0) with (M8) shows that the use of 2.0% steel fibers leads to an increase in static modulus of elasticity. The relationship between steel fibers inclusion and static modulus of elasticity for HSFM is shown in Fig. 5.

The static modulus of elasticity increased by about 27% with the inclusion of steel fibers. This could be due to the fact that steel fibers have high stiffness resulting in a higher modulus of elasticity for HSM (Kayali et al., 2003). However, the effect of using hybrid fibers on the static modulus of elasticity is depicted in Figs. 6 and 7.

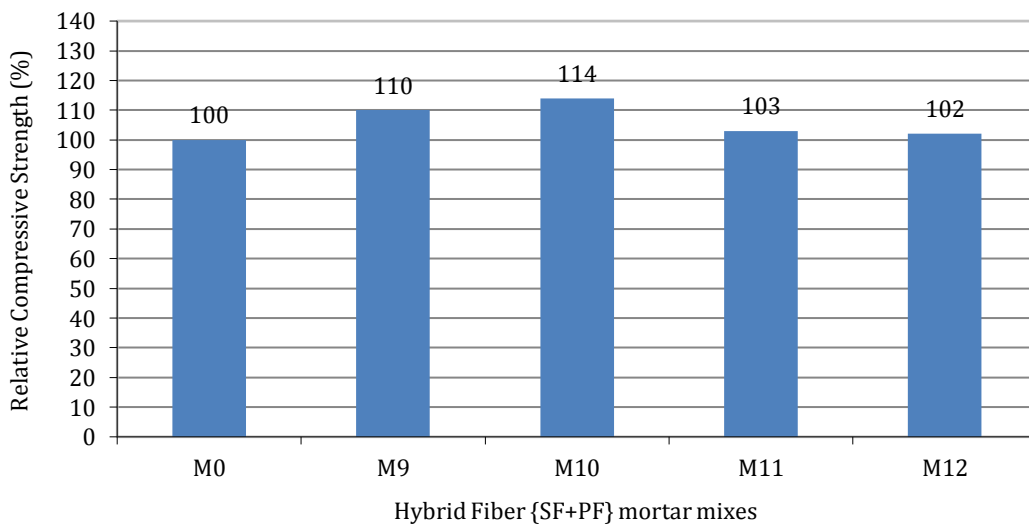


Fig. 3. Relationship between hybrid fibers {SF+PF} mortar mixes and relative compressive strength of HSFM.

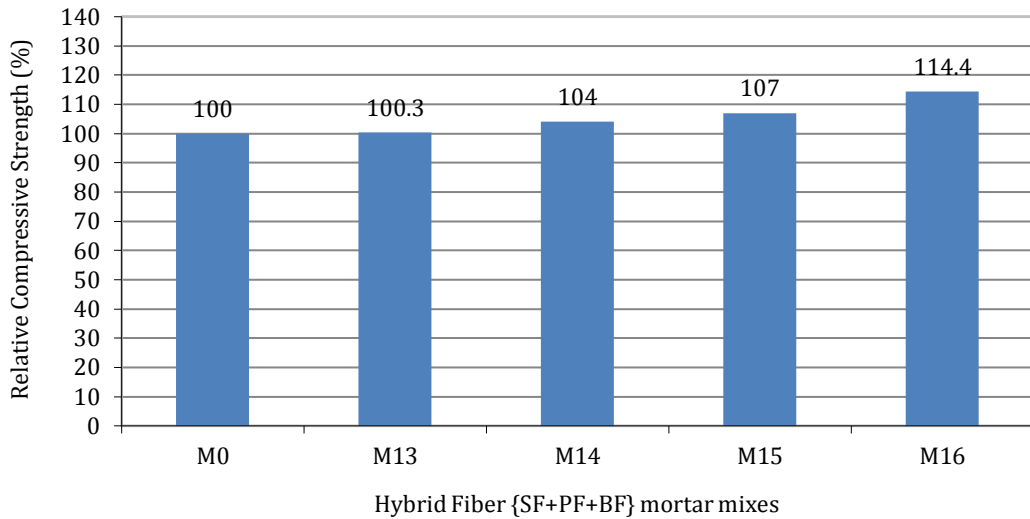


Fig. 4. Relationship between hybrid fibers {SF+PF+BF} mortar mixes and relative compressive strength of HSFM.

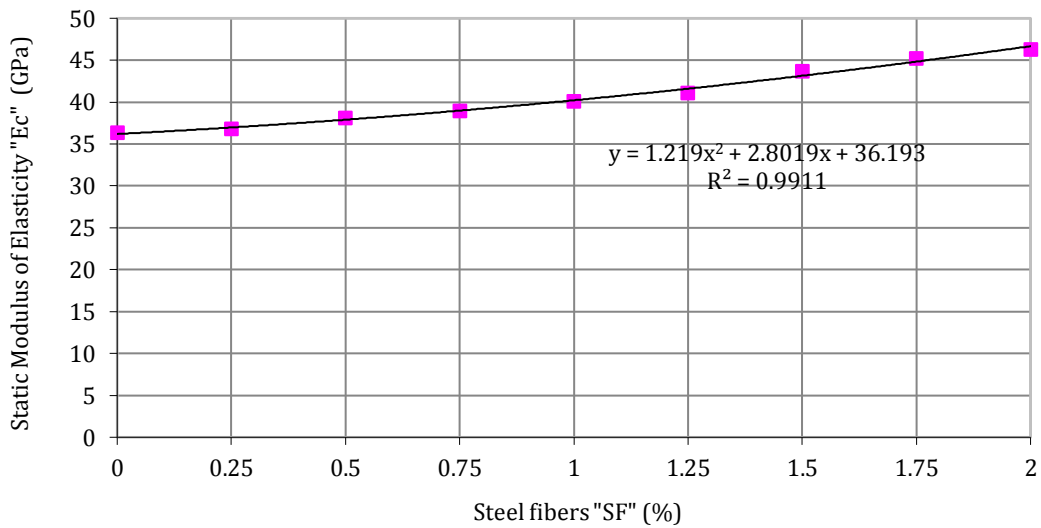


Fig. 5. Relationship between steel fibers and static modulus of elasticity for HSFM.

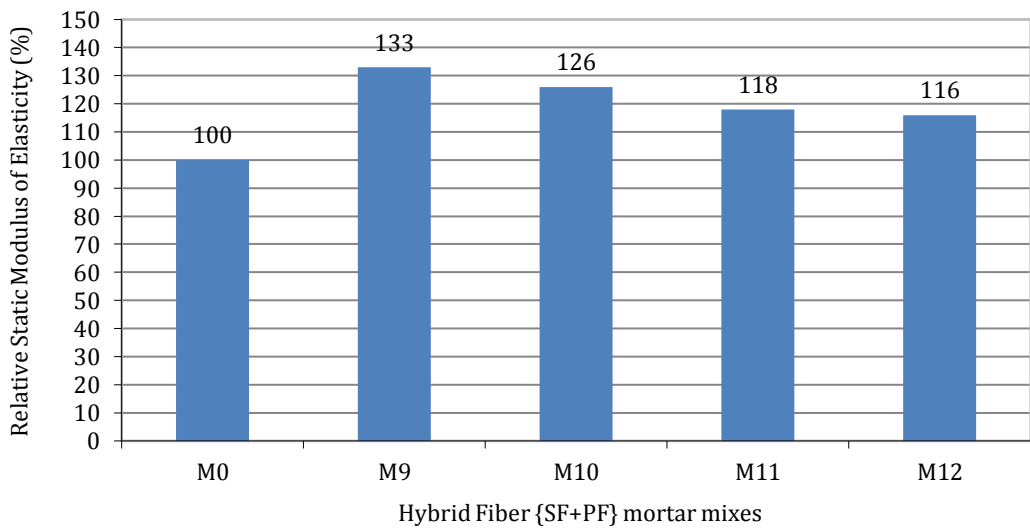


Fig. 6. Relationship between hybrid fibers {SF+ PF} mortar mixes and relative static modulus of elasticity for HSFM.

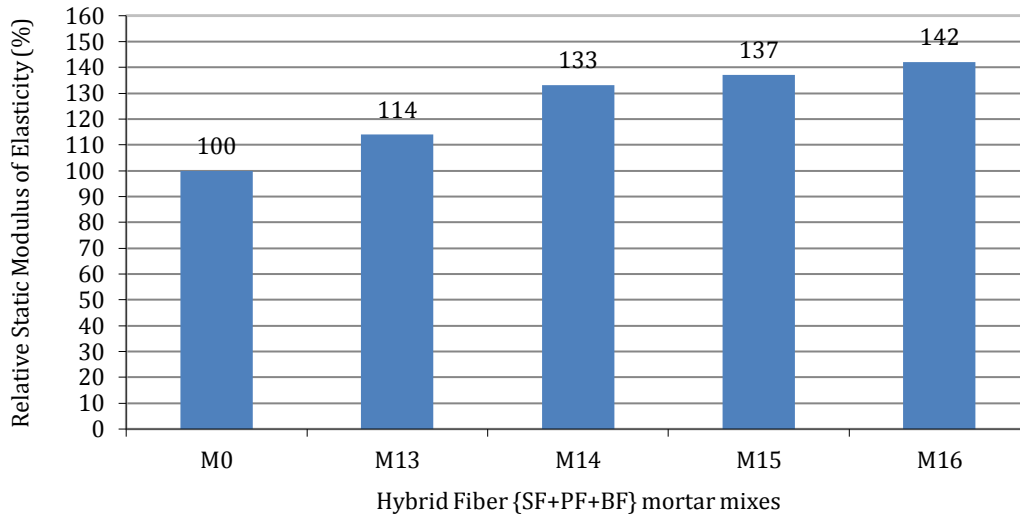


Fig. 7. Relationship between hybrid fibers {SF+ PF+BF} mortar mixes and relative static modulus of elasticity for HSFM.

These figures illustrate that the use of 0.25% of palm fibers or 0.5% of palm fibers and Barchip fibers in hybrid combination was found to be much affective. The increase percentages in static modulus of elasticity for these uses were found to be 25% and 34% respectively. This is probably due to the optimization of these percentages of fibers to operate the higher bond strength behavior and thus a higher modulus of elasticity (Chen and Liu, 2005). The increase in E_c for the HSFM mixes reinforced with hybrid fibers (steel fiber + palm fiber) is shown in this figure. The HSFM mix with 1.75% Steel Fiber + 0.25% Palm Fiber (M9) recorded a significant increase in the static modulus of elasticity with age. The E_c increased for the latter mix was 47.8 GPa at age of 28 days. Finally, the development of the static modulus of elasticity for HSFM reinforced by hybrid fibers (Steel fiber + Palm fiber + Barchip fibers) is given in Table 7. It can be seen from this figure that the inclusion of mixes with the hybrid fibers exhibited significant increases. Therefore, the HSFM reinforced with 1.5% Steel Fibers + 0.25% Palm Fibers + 0.25% Barchip Fibers (M16) shows an increase in static modulus of elasticity to 50.4 GPa at the age of 28 days.

4.4. Flexural strength

The results of flexural strength of mortar mixes are given in Table 7. The Flexural strength results of HSFM mortar mixes show that the increase of the flexural strength is compatible with the increase of steel fiber volume fractions. Fig. 8 illustrates the relationship between the steel fiber percentages in HSFM with the flexural strength. The increase of the flexural strength of the mix containing 1.75% volumetric fraction of steel fiber (M7) is about 94% higher than the control mix (M0), and this possibly due to the better compaction and homogeneity of fiber distribution in HSFM (Kayali et al., 2003; Nataraja et al., 1999; Sahmaran et al., 2003).

However, the results of hybrids fibers reveal that the increases in flexural strength are much effective. Fig. 9 shows the relative flexural strength of hybrid fibers HSFM by using steel fibers with palm fibers.

It can be seen that the increase in flexural strength by hybrid fibers containing 1.5% steel fiber + 0.5% palm fiber was found to be about 101% higher than that of the control mortar. The relative flexural strengths of hybrid fibers HSFM by using steel fibers, palm fibers and Barchip fibers, are shown in Fig. 10. It can be observed that the highest increase in flexural strength is 107% which was derived from the mix containing hybrid fibers of 1.5% steel fibers + 0.25% palm fibers + 0.25% Barchip fibers. This effective increase in flexural strength maybe resulted from better compaction and homogeneity of fibers distribution in mortar mixes and the ability of different types of fibers to restrain and bridge the cracks (Sahmaran et al., 2003).

4.5. Impact load test

The results of the impact resistance performances for all HSFM mixes are shown in Table 8 and Fig.11. The numbers of blows at the first crack appearance, the number of blows for failure, and the percentage increase in the number of blows at first crack with respect to number of blows at failure were determined. The results showed that the incorporating of 2% steel fibers into the HSFM, the number of blows to first crack increased by about 8 times. The other thing that can be observed clearly that the number of first crack appearance and the number of blows to failure are the same in case of control HSFM mix (M0). That's why; the percentage of post crack resistance increase was zero.

However, the use of 2% by volume of steel fibers increased this percentage from zero to 57.89%.

On the other hand, the results of impact load for hybrid fibers showed that the addition of different types of fiber may change the crack pattern from a single large crack to tiny multiple cracks, demonstrating the beneficial effects of fiber-reinforcement subjected to impact loading [26]. For the hybridization of fibers with 1.75% steel fibers plus 0.25% palm fibers, the post crack resistance increase was 61.11%. Whereas, the hybridization of fibers using 1.5% steel fiber + 0.25% palm fiber + 0.25% Barchip fiber increased the post crack resistance by about 58.82%.

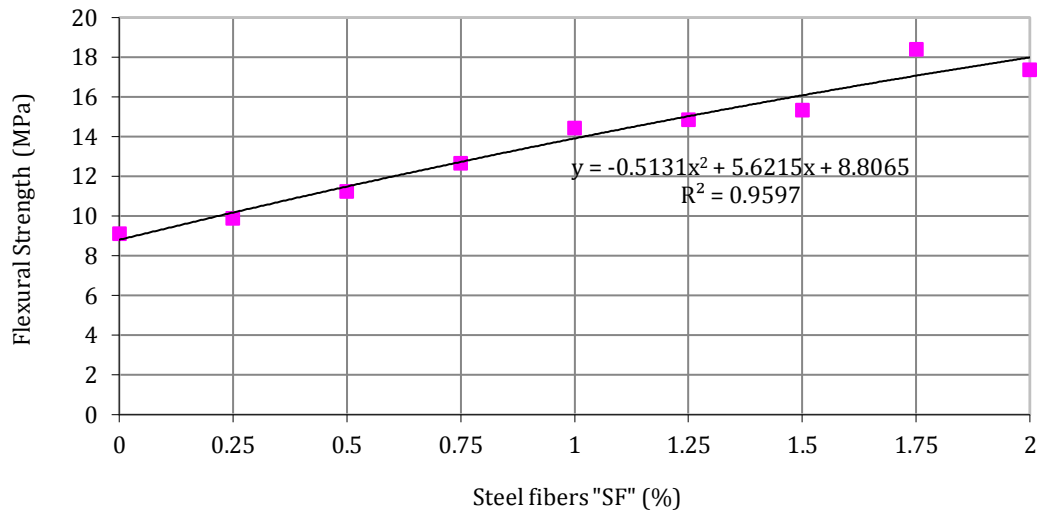


Fig. 8. Relationship between steel fibers and flexural strength of HSFM.

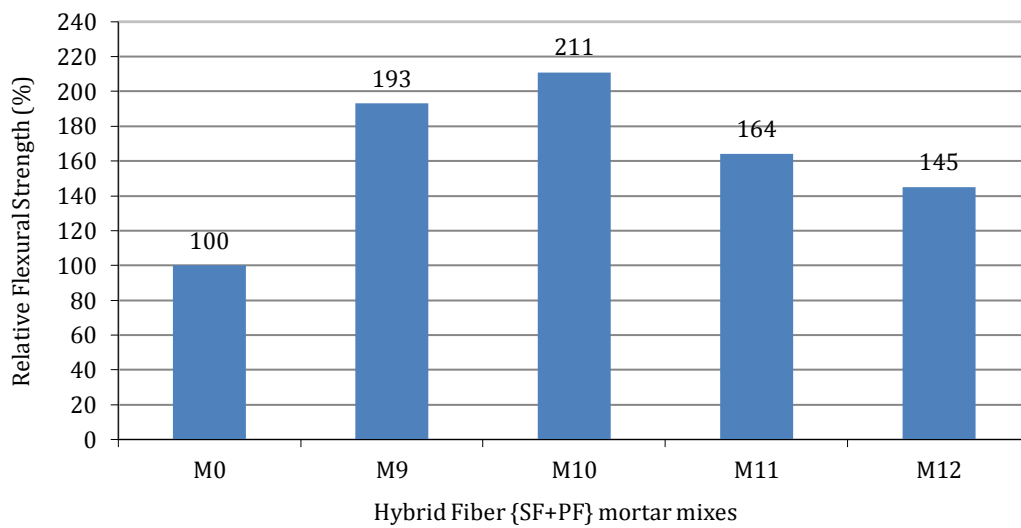


Fig. 9. Relationship between hybrid fibers {SF + PF} mortar mixes and relative static flexural strength of HSFM.

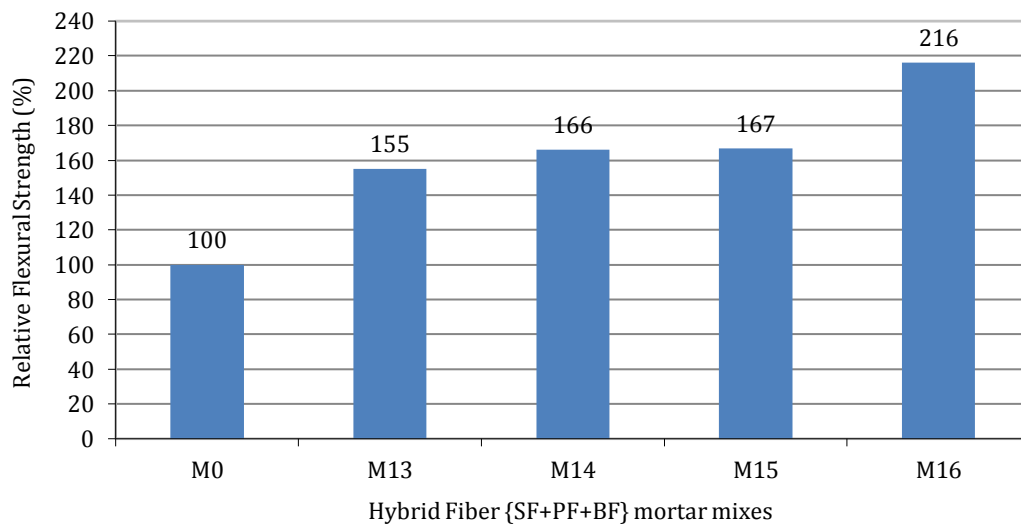
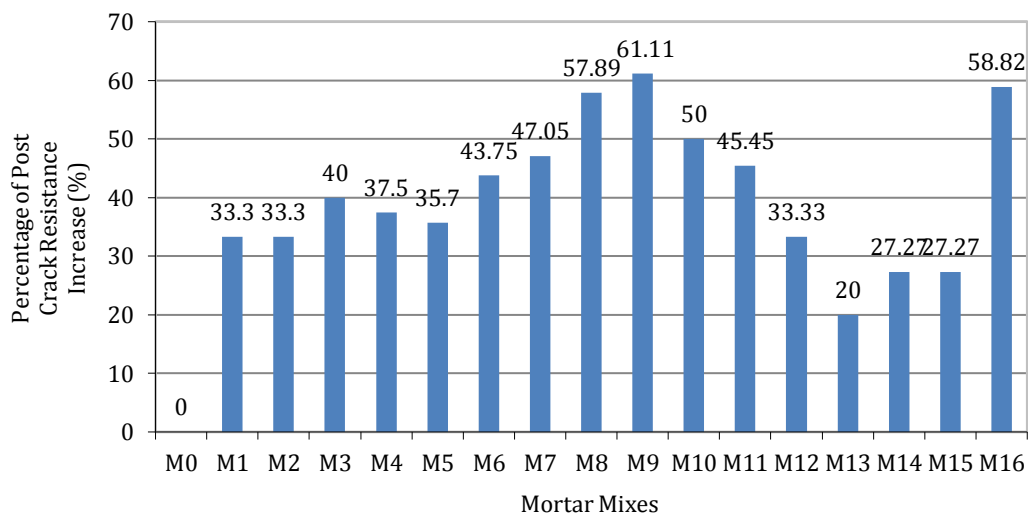


Fig. 10. Relationship between hybrid fibers {SF+ PF+BF} mortar mixes and relative static flexural strength of HSFM.

Table 8. Impact load of HSFM mixes.

Index	Steel fiber (%)	Palm fiber (%)	Barchip fiber (%)	First crack resistance (blows) (B1)	Ultimate crack resistance (blows) (B2)	Percentage of post crack resistance increase (%) $\{(B2-B1)/B1\} \times 100$
M0	0	--	--	2	2	0
M1	0.25	--	--	3	4	33.3
M2	0.50	--	--	3	4	33.3
M3	0.75	--	--	5	7	40
M4	1.0	--	--	8	11	37.5
M5	1.25	--	--	14	19	35.7
M6	1.50	--	--	16	23	43.75
M7	1.75	--	--	17	25	47.05
M8	2.0	--	--	19	30	57.89
M9	1.75	0.25	--	18	29	61.11
M10	1.5	0.5	--	14	21	50
M11	1.25	0.75	--	11	16	45.45
M12	1.0	1.0	--	9	12	33.33
M13	1.0	0.50	0.50	10	12	20
M14	1.250	0.50	0.25	11	14	27.27
M15	1.25	0.25	0.50	11	14	27.27
M16	1.5	0.25	0.25	17	27	58.82

**Fig. 11.** Relationship between mortar mixes and percentage of post crack resistance increase.

4.6. Seawater exposure effects

The results of the HSFM mixes exposed to sea-water are represented from Table 9. The reduction in compressive strength for the HSFM mixes was between 5-10% after 180 days of exposure to sea-water. The use of hybrid fibers recorded the minimum reduction in compressive strength which were obtained from the mixes of hybrid fibers in both cases of using steel fibers with palm

fibers and also the use steel, palm and Barchip fibers. This is possibly due to ability of different types of fibers reinforcement to make the mortar more impermeable (Hoseini et al., 2004; Atis and Karahan, 2009).

For the flexural strength results of HSFM mixes, it can be seen that the maximum reduction in flexural strength of HSFM obtained also when the mono-steel fibers used as 2% in mortar mixes. The reduction of flexural strength was about 8% after 180 days of sea-water exposure. This is also

was found by other researchers (Atis and Karahan, 2009), where the surface deterioration of steel fibers is worse under sustained flexural stress due to the increased cracking and vulnerability of steel fibers. Therefore, the hybridization

of different types of fibers improve the resistance of the HSFM as it can be noted for the results of the mortar mixes with hybrid fibers of steel and palm fibers and also for the use of steel fiber + palm fiber + Barchip fiber.

Table 9. Properties of HSFM exposed to seawater.

Index	Steel fiber (%)	Palm fiber (%)	Barchip fiber (%)	Compressive strength (MPa)	Flexural strength (MPa)	Modulus of elasticity (GPa)	Permeability	Permeability
				180 days (90 days normal water curing + 90 days seawater curing)	180 days (90 days normal water curing + 90 days seawater curing)	180 days (90 days normal water curing + 90 days seawater curing)	90 days normal water curing ($m^2 \times 10^{-18}$)	180 days (90 days normal water curing + 90 days seawater curing) ($m^2 \times 10^{-18}$)
M0	0	--	--	58.1	8.96	35.8	9.11	9.49
M1	0.25	--	--	64.3	9.64	35.9	8.45	8.82
M2	0.50	--	--	64.7	11.02	36.9	7.59	7.96
M3	0.75	--	--	65.1	12.32	37.7	6.58	6.97
M4	1.0	--	--	66.1	13.95	39	6.01	6.38
M5	1.25	--	--	66	14.28	39.9	5.45	5.78
M6	1.50	--	--	64.5	14.72	42.1	4.94	5.21
M7	1.75	--	--	63.6	17.72	44	4.76	4.94
M8	2.0	--	--	58.6	16.56	44.7	4.45	4.68
M9	1.75	0.25	--	62.9	17.10	46.8	4.36	4.58
M10	1.5	0.5	--	65.5	18.70	44.9	4.48	4.73
M11	1.25	0.75	--	59.5	14.58	42	5.12	5.39
M12	1.0	1.0	--	58.7	12.85	41.3	5.67	5.89
M13	1.0	0.50	0.50	58.2	13.90	40.4	5.49	5.73
M14	1.250	0.50	0.25	60.4	14.70	47.2	5.11	5.28
M15	1.25	0.25	0.50	61.7	14.81	48.6	4.88	5.11
M16	1.5	0.25	0.25	65.9	19.15	50.6	4.29	4.52

The results of static modulus of elasticity show that there is a reduction between 4-7% in elastic modulus of elasticity of mortar after 180 days of exposure to seawater. The minimum reduction of static modulus of elasticity was also obtained for the mixes of hybrid fibers of 1% steel, palm with 1% of either palm fiber or a combination of palm and Barchip fibers. This is also can be attributed to the same causes listed above where the palm and Barchip fibers have better durability performance against the sea-water (Hoseini et al., 2004; Atis and Karahan, 2009; Dawood and Ramli, 2012).

The most important test for the mortar specimens is the permeability test. It is well known that the permeability of the mortar is the key for improving the durability of the mortar against the aggressive solutions. From the results in Table 9, it can be seen that the presence of fibers can significantly reduce the permeability values.

The results of normal curing specimen shows that the comparison of mix (M0) with mix (M8) provided a significant reduction in permeability value from $9.11 \times 10^{-18} m^2$ to $4.45 \times 10^{-18} m^2$ by using 2% of steel fibers in the HSFM mixes. The results of hybrid fibers also revealed that a significant reduction of permeability was obtained by using 1.75% steel fibers + 0.25% palm fibers (M9) and the use of 1.5% steel fiber + 0.25% palm fiber + 0.25% Barchip fiber (M16). The values of permeability were changed from $4.29 \times 10^{-18} m^2$ to $5.67 \times 10^{-18} m^2$. The lowest value was obtained from M16.

The results indicated that the hybrid fibers mixes give the least value of permeability. The comparison between mix (M8) with mix (M16) shows that the use of 1.5% steel fibers+ 0.25% palm fibers + 0.25% Barchip fibers instead of using mono-steel fibers as 2% reduces the permeability values from $4.9 \times 10^{-18} m^2$ to $4.71 \times 10^{-18} m^2$.

This can be attributed to the densification of the matrix adjacent to the filaments and enhancement of the fibers–matrix bond with continued hydration and precipitation of hydration products in the interface between filaments and matrix as well as in empty spaces between the filaments of multi-filament yarn which can be named as bundle filling (Chin and Liu, 2004; Hannat, 1987).

5. Conclusions

Some conclusions are revealed for this study which deals with the production of flowable high strength mortar as follows:

- The incorporation of 10% silica fume in concrete and mortar mixes as a partial replacement for cement increases the compressive strength which is due to the Pozzolanic Activity Index of the silica fume.
- Hybridization of fibers was found to be effective in enhancing the modulus of elasticity of HSFM. Combining the volume fractions of 1.75% steel fiber and 0.25 % palm fibers or 1.5% steel fibers, 0.25% palm fibers and 0.25% Barchip fibers, increase the static modulus of elasticity by about 25% and 34%, respectively.
- The hybridization of fibers by 1.75% steel fibers + 0.25% palm fibers increases the number of blows to first crack appearance by about 25 times compared to that of a normal HSFM mix. Consequently, the percentage increase in the post crack is 78.6% which also implied that the effects of these fibers on the initial crack zone and post crack zone are significant
- In term of durability, after sea-water exposure, the minimum reduction in compressive strength was obtained for the HSFM of hybrid fibers in the cases of using steel fibers with palm fibers and also for the use of steel, palm and Barchip fibers.
- The use of 2% of steel fibers in HSFM mixes reduces the permeability value from $7.36 \times 10^{-18} \text{ m}^2$ to $4.21 \times 10^{-18} \text{ m}^2$. The results of hybrid fibers as 1.5% steel fibers + 0.25% palm fibers + 0.25% Barchip fibers shows a significant reduction in permeability up to $4.29 \times 10^{-18} \text{ m}^2$.

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Research Article

Effect of freezing-thawing on concrete behavior

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ABSTRACT

This study aims to determine the effect of change of temperature (freezing-thawing cycles) on the behavior of the mortar and the concrete. Also, the evaluation of the effect of air entering for improving the durability of the mortar and concrete was discussed. 23 mixes were cast to evaluate the purpose of this study. Cement types (Portland cement and limestone cement), aggregate types (dolomite and gravel), dosages of air entering 0.01, 0.1, 0.15 and 0.2% of cement weight and freezing thawing cycles (50, 100, 150, 200, 300 and 400 cycles) were considered. Relative dynamic modules of elasticity which is illustrated the internal cracks growth, durability factor and losses of weight were evaluated. Empirical correlations were formulated. The results showed that; 0.15% air entrained of cement weight improve the durability in term of freezing-thawing; where the durability factor for the mixes was $\geq 85\%$ that exposed to freezing-thawing cycles in range 0-200. Up to 200 cycles of freezing-thawing cycles did not effect on the compressive strength of the mixes and the durability of the mortar and the concrete. It is recommended that more than 300 freezing-thawing cycles must be avoided.

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1. Introduction

Durability of concrete is defined as its ability to withstand the deterioration such as aggressive media, freezing thawing cycles, fire and abrasion. The durable concrete can be kept in its quality and serviceability due to the surroundings. In cold weather, concrete structures located losses its quality and property due to freeze-thaw (F-T) cycles during their life cycle (ACI 216.1-17). Most civil engineering durability problems cover water inside porous media like stones and cementitious materials. In case of freezing and thawing, the in-pore ice/water phase change behavior plays a key role through the coupling of the unfrozen water content, the pore pressure, the liquid water in the porous network, and the therm mechanical behavior of each porous material constituent (Coussy and Fen-Chong, 2005; Coussy, 2005; Fen-Chong and Azouni, 2005). ACI 2016 reported the most important factors causes deterioration in concrete and how to prevent the damage in it. The methods to enhance the concrete durability are illustrated, also [ACI 224-08; ACI 201.2R-01; ACI 216.1-17]. When the moist

concrete exposed to F-T cycles are a dangers test for concrete to stay without deterioration. Using air entrained concrete in addition to the stages of manufactures of good concrete and design the mix resisted the freezing-thawing cycles for many years (Portland cement association V. 19-98). Some researchers investigated the important role of the air entrainment on the durability of concrete, (Powers and Helmuth, 1953; Setzer, 2001). In North America, the concrete structures exposed to dangerous environment; so the repeated cycles of F-T cycles causes the deterioration of concrete in form of cracking and scaling (Portland cement association V. 19-98; Kejin et al. 2009). Fen-Chong and Aza (2005) investigated a method to study the effect of cycles of freezing and thawing on the cohesive porous materials. The variation in the temperature was supercooling, freezing, and melting. Zeng et al. (2011) investigated the freezing behavior of cementitious materials through poromechanical approached after the Biot-Coussy theory. The results show that the poromechanical model can reasonably capture the freezing behaviors from pores pressure accumulation, pore pressure relaxation as well as the thermal

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shrinkage associated with the freezing process (Wang et al., 2008). Wang et al. (2009) presented investigation on the effect of low-permeability concrete. The effect of using air entrainment on the freezing-thawing durability was evaluated. The results indicate that all concrete mixes with proper air entrainment showed good F-T resistance (durability factor $\geq 85\%$) (Wang et al., 2009). Wang et al. (2008) presented a research project aimed to reduce variability and improve precision of air-void analyzer (AVA) and to develop rational specification limits for controlling concrete freezing and thawing (F-T) damage using the AVA test parameters. The results indicate that AVA is a time- and cost-effective tool for concrete quality control (Wang et al., 2008). Canbaz and Armagan (2016) studied the effect of different type of cements was used in SIFCON production with steel fibers due to the freezing-thawing cycles. Huda (2014) utilized demolished concrete as coarse aggregate as recycled coarse aggregate (RCA) for producing industry quality concrete. Durability performance of 25 MPa RAC was evaluated in terms of sulphate attack and cyclic wetting and drying along with chloride exposure. The durability performance of the different generations of repeated recycled coarse aggregate concrete was negatively affected by using different generations of such aggregates but still these findings will add a new achievement towards sustainable world (Huda, 2014). Richardson et al. (2011) studied the durability of recycled aggregate due to freeze/thaw. Recycled aggregate concrete was found to be of at least equal durability to concrete manufactured with virgin aggregates. This was due to careful selection of the replacement aggregate and treatment prior to batch. Penttala (2006) derived material freezing deformation by effective freezing stress arising from crystallization pressure based on the thermodynamic equilibrium of phase change. Fabbri et al. (2009) evaluated the effect of the ice content of porous materials using two methods (dialectic and ultrasonic apparatus). Results show that the effect of the ice content during a freezing-thawing depends on the material microstructure.

2. Research Significance

This research describes how air interment influences in the behavior of mortar and concrete due to freezing-thawing cycles in term of variation in the compressive strength, relative dynamic modules of elasticity which is illustrated the internal cracks growth, durability factor and losses of weight. The empirical correlations for different variables were formulated. Also the effect of types of cement and aggregates on the behavior of concrete due to freezing and thawing was evaluated. A relation between the durability factor and the compressive strength of the mixes was formulated.

3. Experimental Program

To carry out the aim of the experimental program, 23 mixes were prepared from mortar and concrete. Portland cement and limestone cement as different types of

cement were used. Two types of aggregates (dolomite and gravel) were used. Different dosages of air entering 0.0, 0.01, 0.1, 0.15 and 0.2% by weight of cement were used. The effect of freezing-thawing cycles (50, 100, 150, 200, 300 and 400 cycles), variation in the compressive strength, relative dynamic modules of elasticity and loss of weight were investigated. To evaluate the compressive strength, 120 cubes 100×100×100 mm were cast and tested. 60 prisms with 100×100×400 mm were cast to evaluate the freezing-thawing durability.

3.1. Materials

Portland cement (CEM I 42.5 N) and limestone cement (CEM II/B-L 32.5 N) was used and complied the requirements of E.S.S. 4765-1/2009. The specific gravity and Blain fineness of ordinary Portland cement were 3.16 and 3990 cm²/gm., respectively. 3.15 and 4850 cm²/gm. of specific gravity and Blain fineness of limestone cement were recorded. Well graded siliceous sand was used. Crushed dolomite and gravel as a coarse aggregate were used. The used aggregate comply the requirements of E.S.S. 1109/1971. Table 1 shows the physical properties of aggregate. Tap water was used for mixing the concrete. Air entering was used as super plasticizer meeting the requirements of ASTM C494/C494M-01. The admixture is a brown liquid having a density of 1.032 kg/liter at room temperature. The dosages of air entering were 0.0, 0.01, 0.1, 0.15 and 0.2% of the cement weight.

Table 1. Physical properties of aggregates.

	Sand	Crushed dolomite	Gravel
Specific gravity	2.6	2.72	2.63
Absorption (%)	0.78	3.2	1.9
Fineness modulus	2.55	7.1	6.8
Maximum nominal size	-	10	10

3.2. Casting and testing procedures

To prepare mortar mixes, cement and fine aggregate were mixed for one minute. For concrete mixes, the coarse aggregate were added to mixes. The slurry of water and admixture was added and mixing continued for four minutes to ensure full mixing. Initial and final sitting time was evaluated by Vicat apparatus. After 24 hours of casting, the specimens were removed from the molds and submerged in water at 20°C until testing. A 2000 KN capacity compressive strength testing machine was used to determine of the compressive strength considering the average value of three specimens as the representative value. The compressive strength test was performance in according with ASTM C579-01 test method B. Freezing-thawing test was performance according to ASTM C666-03. Freeze-thaw machine was used to perform the procedures of the test. Each freeze-thaw cycle continued 3.5 hours. The variation in the compressive strength, relative dynamic modules of elasticity and loss of weight were recorded at 0, 50, 150, 100, 200, 300 and 400 cycles. Mixes features are reported in Table 2.

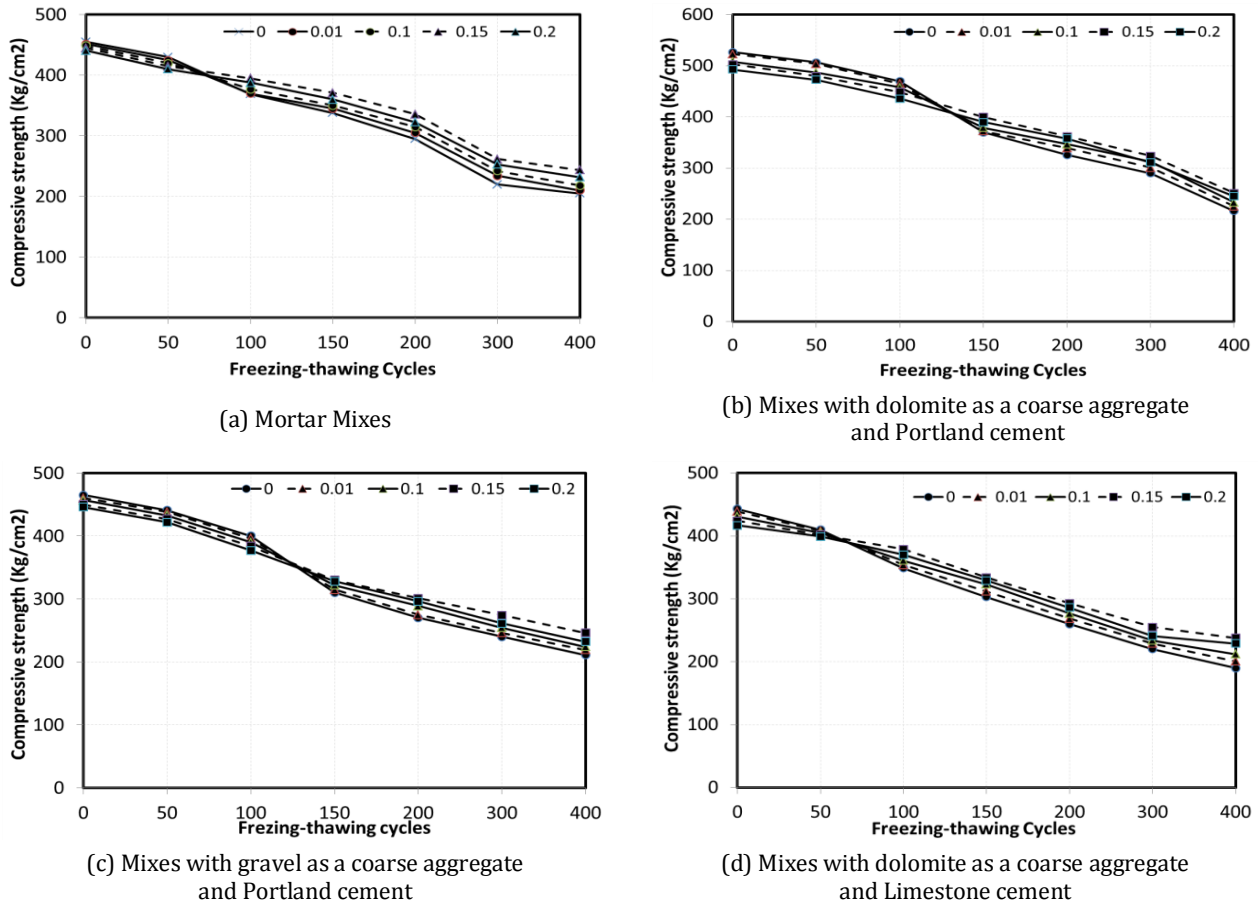


Fig. 2. Relationship between the compressive strength and freezing–thawing cycles at different dosage of air interned admixture.

At 100 F-T cycles, a slight effect was noticed on the compressive strength of the mixes. At 150, 200, 300 and 400 F-T cycles the percentage of increasing in compressive strength were 3, 4, 6 and 3% compared with the control mix. At 0.1% of air entrained.

The compressive strength was 420,377,350,315,242 and 218 kg/cm² at 50, 100, 150,200,300and 400 cycles. At100, 150, 200, 300 and 400 F-T cycles the percentage of increasing in the compressive strength were 2.3, 3.5, 6.4, 10 and 6% compared with the control mix. At 0.15% air entrained the compressive strength was 415, 395, 371, 336, 262 and 244 kg/cm² at 50, 100, 150, 200,300 and 400 cycles. At100, 150, 200, 300 and 400 F-T cycles the percentage of increasing in the compressive strength was 5.6, 5.7, 6.25, 7.7 and 10.7% compared with the control mix. At 0.2% air entrained the compressive strength was 410, 388, 360, 323, 253 and 232 kg/cm² at 50, 100, 150 and 200 cycles. At 100, 150, 200, 300 and 400 F-T cycles the percentage of increasing in the compressive strength was 5, 6.2, 8.3, 13 and 12% compared with the control mix. It is recommended that more than 200 F-T cycles must be avoided because the compressive strength decreased by an average 50% compared with the mix with zero cycles. Also at using dosage of 0.15% of air entrained get the best improvement in the compressive strength due to F-T cycles. The same trends were observation for the different concrete mixes as illustrated in Figs. (2-b) to (2-d). Fig. (2-b) illustrates the relation between the F-T cycles and the compressive strength for the mixes with dolomite and

Portland cement. The compressive strength for these mixes decreased as increased the percentage of air-entrained where the compressive strength was 527, 523, 508, 503 and 493 kg/cm² at 0, 0.01, 0.1, 0.15 and 0.2%. the illustrates that the compressive strength increased for the mixes with air-entrained as exposed to freezing-thawing cycles up to 100 F-T cycles compared with the mixes without air-entrained which exposed to the same cycles of freezing-thawing. The figure clears that, For the mixes with 0.01% of air entrained which is exposed to freezing-thawing cycles, the compressive strength was 504, 465, 372, 339, 301 and 225 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles For control mix without air-entrained. The compressive strength was 507, 470, 370, 326, 290 and 216 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles. It is noticed that the compressive strength for the mixes without air-entrained and exposed to 50 and 100 F-T cycles was more than that the mixes without air-entrained but doesn't exposed to F-T cycles. In addition to when exposed to 150, 200, 300 and 400 F-T cycles the percentage of increasing in the compressive strength for the mixes with 0.01% air-entrained compared with that without air-entrained by 0.5, 4, 3.7 and 4%. At 0.1% of air entrained the compressive strength was 487, 458, 379, 347, 313 and 233 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles. For the mixes which exposed to 100 F-T cycles the compressive strength still more than the compressive strength for the mixes without air-entrained. In addition to, by exposing the 150, 200, 300 and 400 F-T cycles, the effect of air-

entrained on the enhancement of the compressive strength was noticed. Where the percentage of increasing in the compressive strength for the mixes with air-entrained was 2.4, 6.1, 7.4 and 7.3 compared the mixes without air-entrained. At 0.15% of air entrained, the compressive strength was 480, 449, 400, 362, 324 and 251 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles. For the mixes which exposed to 100 F-T cycles its compressive strength still more than the compressive strength of the mixes without air-entrained. In addition to, by exposing the 150, 200, 300 and 400 F-T cycles, the effect of air-entrained on the enhancement of the compressive strength was noticed. Where the percentage of increasing in the compressive strength for the mixes with air-entrained was 7.5, 10, 10.5 and 14% compared the mixes without air-entrained. At 0.2% of air entrained. The compressive strength was 473, 436, 390, 358, 311 and 245 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles. For the mixes which exposed to 100 F-T cycles its compressive strength still more than the compressive strength for the mixes without air-entrained. In addition to, by exposing the 150, 200, 300 and 400 F-T cycles, the effect of air-entrained on the enhancement of the compressive strength was noticed. Where the percentage of increasing in the compressive strength for the mixes with air-entrained was 5.2, 9, 6.8 and 11.9% compared the mixes without air-entrained. Fig. (2-c) illustrates the relation between the F-T cycles and the compressive strength for the mixes with gravel and Portland cement. The compressive strength for these mixed decreased as increased the percentage of air-entrained where the compressive strength was 465, 460, 457, 450 and 446 kg/cm² at 0, 0.01, 0.1, 0.15 and 0.2%. The figure illustrates that the compressive strength increased for the mixes with air-entrained as exposed to freezing-thawing cycles up to 100 F-T cycles compared with the mixes without air-entrained which exposed to the same cycles of freezing-thawing. The figure clears that, For the mixes with 0.01% of air entrained which is exposed to freezing-thawing cycles, the compressive strength was 438, 396, 315, 275, 246 and 219 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles for control mix which have nothing air-entrained. The compressive strength was 441, 400, 310, 270, 240 and 211 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles. It is noticed that the compressive strength for the mixes without air-entrained and exposed to 50 and 100 F-T cycles was more than that the mixes without air-entrained but doesn't exposed to F-T cycles. In addition to when exposed to 150, 200, 300 and 400 F-T cycles the percentage of increasing in the compressive strength for the mixes with 0.01% air-entrained compared with that without air-entrained by 1.6, 2, 2.5 and 3.7%. At 0.1% of air entrained, the compressive strength was 433, 390, 322, 289, 254 and 224 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles. For the mixes which exposed to 100 F-T cycles the compressive strength still more than the compressive strength of the mixes without air-entrained. In addition to, by exposing the 150, 200, 300 and 400 F-T cycles, the effect of air-entrained on the enhancement of the compressive strength was noticed. Where the percentage of increasing in the compressive strength for the mixes with 0.2% air-entrained was 3.8, 6.6, 5.6 and 5.9% compared the mixes without air-entrained. At 0.15% of

air entrained, the compressive strength was 427, 384, 330, 301, 274 and 246 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles. For the mixes which exposed to 100 F-T cycles the compressive strength still more than the compressive strength for the mixes without air-entrained. In addition to, by exposing the 150, 200, 300 and 400 F-T cycles, the effect of air-entrained on the enhancement of the compressive strength was noticed. Where the percentage of increasing in the compressive strength for the mixes with 0.2% air-entrained was 6.1, 10.3, 12.5 and 14.3% compared the mixes without air-entrained. At 0.2% of air entrained, the compressive strength was 422, 377, 328, 296 and 261 kg/cm². For the mixes which exposed to 100 F-T cycles the compressive strength still more than the compressive strength for the mixes without air-entrained. In addition to, by exposing the 150, 200, 300 and 400 F-T cycles, the effect of air-entrained on the enhancement of the compressive strength was noticed. Where the percentage of increasing in the compressive strength for the mixes with 0.2 air-entrained was 5.5, 2.4, 8.1 and 9.1% compared the mixes without air-entrained. Fig. (2-d) illustrates the relation between the F-T cycles and the compressive strength for the mixes with dolomite and limestone cement. Although the compressive strength decreased by the increasing the percentage of air-entrained where the compressive strength was 443, 439, 431, 424 and 417 kg/cm² at 0, 0.01, 0.1, 0.15 and 0.2%. After exposed to F-T cycles the compressive strength for the mixes with different dosage of air-entrained increased compared the mixes without air-entrained at the same F-T cycles. The figure clears that, for the mixes with 0.01% of air entrained which is exposed to freezing-thawing cycles, the compressive strength was 408, 354, 312, 269, 229 and 201 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles.

For the mixes without air-entrained, its compressive strength was 410, 349, 303, 260, 220 and 190 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles. For the mixes which exposed to 50 F-T cycles the compressive strength still more than the compressive strength for the mixes without air-entrained. In addition to, by exposing the 100, 150, 200, 300 and 400 F-T cycles, the effect of air-entrained on the enhancement of the compressive strength was noticed. Where the percentage of increasing in the compressive strength for the mixes with 0.01 air-entrained was 1.5, 2.9, 3.4, 4 and 5.5% compared the mixes without air-entrained. At 0.1% of air entrained. The compressive strength was 405, 361, 323, 277, 234 and 212 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles. For the mixes which exposed to 50 F-T cycles the compressive strength still more than the compressive strength for the mixes without air-entrained. In addition to, by exposing the 100, 150, 200, 300 and 400 F-T cycles, the effect of air-entrained on the enhancement of the compressive strength was noticed. Where the percentage of increasing in the compressive strength for the mixes with 0.1 air-entrained was 3.4, 6.2, 6.1, 6 and 10.4% compared the mixes without air-entrained. At 0.15% air entrained the compressive strength was 402, 379, 334, 293, 255 and 238 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles. For the mixes which exposed to 50 F-T cycles the compressive strength still more than the compressive strength for the mixes without

air-entrained. In addition to, by exposing the 100, 150, 200, 300 and 400 F-T cycles, the effect of air-entrained on the enhancement of the compressive strength was noticed. Where the percentage of increasing in the compressive strength for the mixes with 0.15 air-entrained was 8, 9.3, 11.3, 13.8 and 20.2% compared the mixes without air-entrained. At 0.2% air entrained the compressive strength was 399, 370, 329, 286, 241 and 229 kg/cm² at 50, 100, 150, 200, 300 and 400 cycles. For the mixes which exposed to 50 F-T cycles the compressive strength still more than the compressive strength for the

mixes without air-entrained. In addition to, by exposing the 100, 150, 200, 300 and 400 F-T cycles, the effect of air-entrained on the enhancement of the compressive strength was noticed. Where the percentage of increasing in the compressive strength for the mixes with 0.2 air-entrained was 5.7, 8, 9.1, 8.2 and 17.1% compared the mixes without air-entrained.

The empirical formulation for the compressive strength of the mortar and concrete mixes as a function of freezing thawing cycles were formulated as illustrated in Figs. 3 to 6. Nearly 0.98 is the root square for these equations.

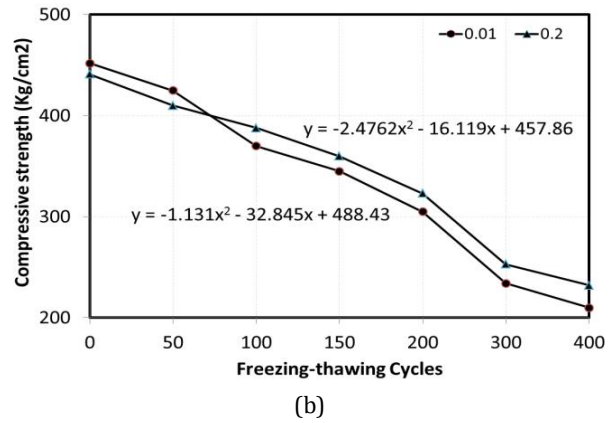
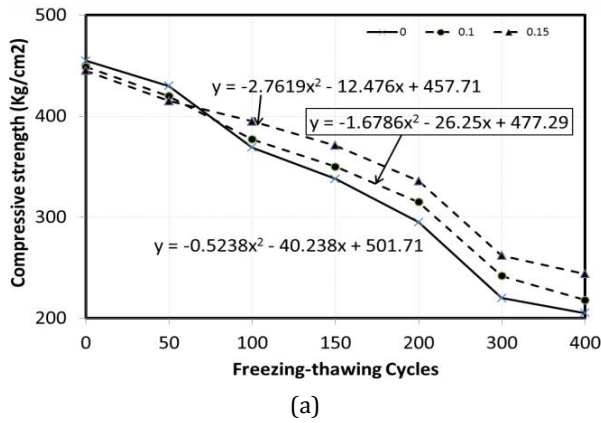


Fig. 3. Empirical correlations for freezing-thawing cycles and compressive strength for the Mortar mixes.

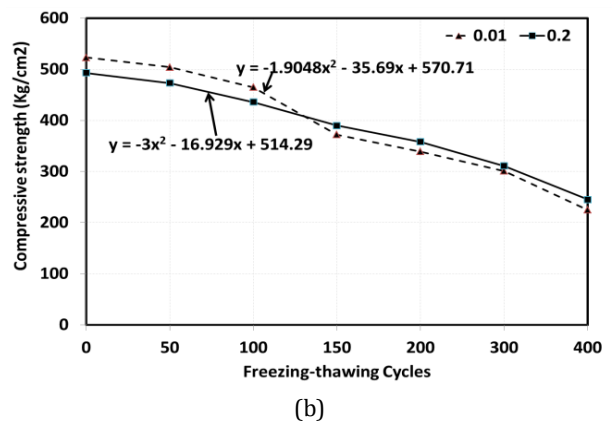
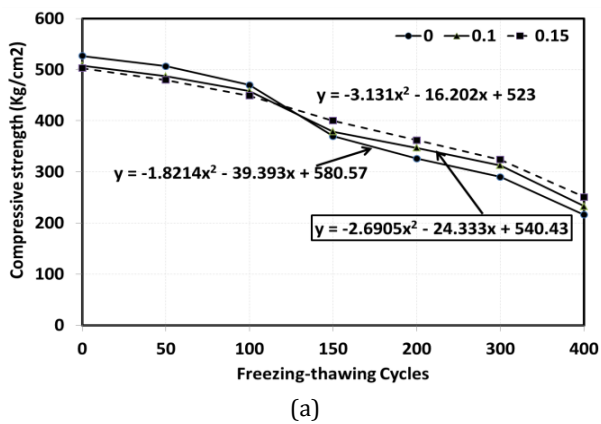


Fig. 4. Empirical correlations for freezing-thawing cycles and compressive strength for the mixes with Portland cement and dolomite as a coarse aggregates.

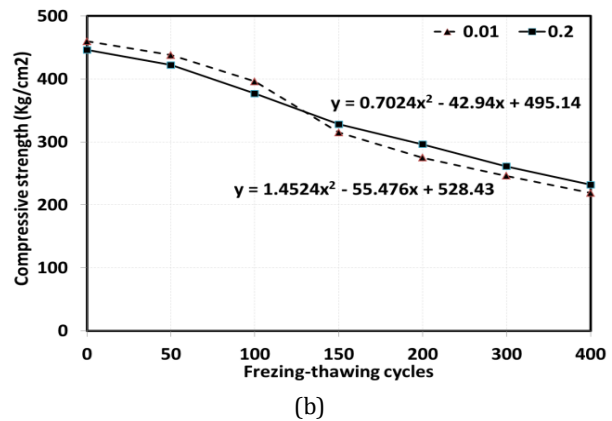
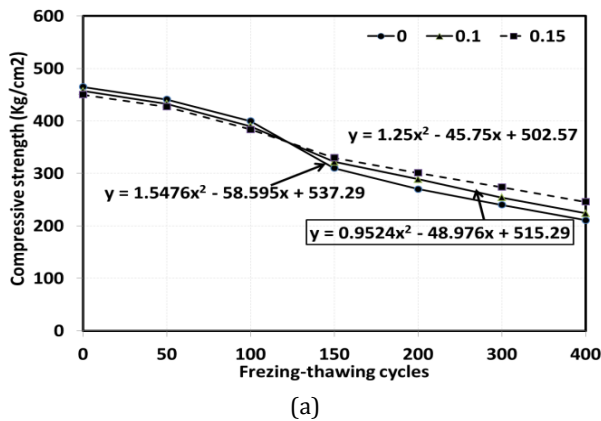


Fig. 5. Empirical correlations for freezing-thawing cycles and compressive strength for the mixes with Portland cement and gravel as a coarse aggregates.

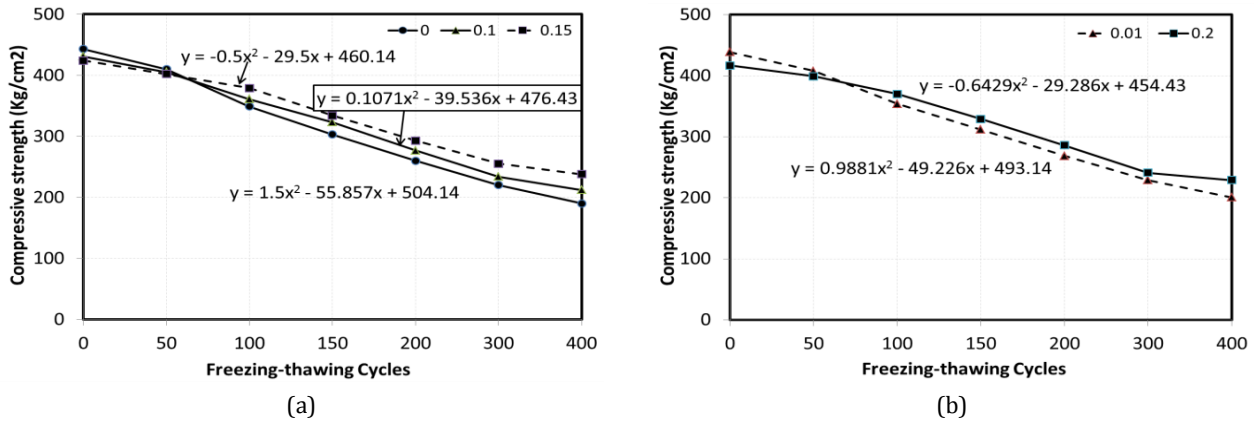


Fig. 6. Empirical correlations for freezing-thawing cycles and compressive strength for the mixes with limestone cement and dolomite as a coarse aggregate.

4.3. Effect of freezing-thawing cycles on the weight loss

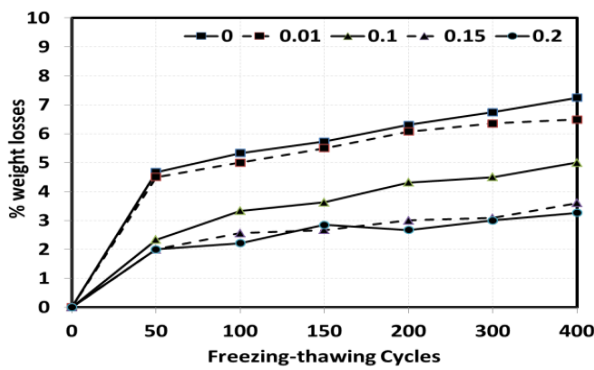
Due to freezing-thawing cycles a change in dimensions and weight as a type of deterioration will be observed. The reaction of alkali-silica in the mortar with that in aggregates causes the deteriorations, so the weight losses. This leads too reduction in the strength of the mortar or concrete. The movement of water in the specimens gives rise the change of the weight loss due to the freezing-thawing cycles where the deteriorated zone filled with water due to the cracking occurs in the specimens so the change in the weight of the specimens recorded (Zeng et al., 2011; Ranz et al., 2014). Fig. 7 illustrates the effect of F-T cycles on the weight loss percent for the mortar and concrete mixes. It can be seen generally, as increasing the F-T cycles as increasing the weight losses percent. Also as increasing the dosage of air entrained the decreasing in the weight losses. Fig. (7-a) shows the relationship between the F-T cycles and weight losses percent for the mortar mixes At 50 F-T cycles, the weight losses percent was 4.5, 2.33, 2 and 1.9% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained compared with the control mix without air entrained. At 100 F-T cycles, the weight losses percent was 5, 3.33, 2.56 and 2.21% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 150 F-T cycles, the weight losses percent was 5.5, 3.65, 2.67 and 2.58% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 200 F-T cycles, the weight losses percent was 6.07, 4.31, 3 and 2.07 % for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 300 F-T cycles, the weight losses percent was 6.35, 4.5, 3.09 and 3% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 400 F-T cycles, the weight losses percent was 6.49, 5, 3.6 and 3.26 % for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. From the previous results, it can be concluded that as increasing the dosage of air entrained the weight losses decreases by an average 5.6% for the different F-T cycles. On the other hand, it can be noticed that the rate of reduction in the percent of weight losses decreased by increasing the air-entrained as 2.66 , 3.2 ,

3.6 , 4, 4.32 , and 4.6% for 0.01, 0.1, 0.15 and 0.2 at 0, 50, 100, 150, 200, 300 and 400 F T cycles compared with the control mixes without air-entrained .

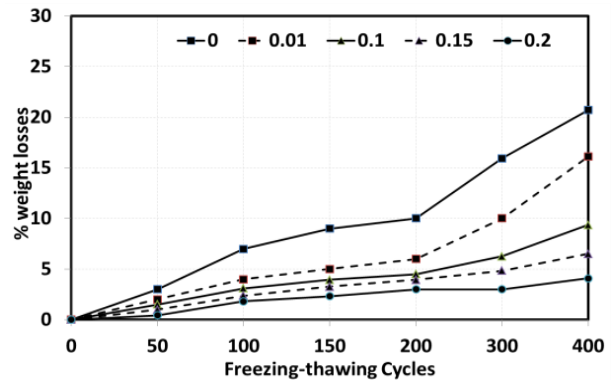
From the figure we can observed also, at 0.01% air entrained, the weight losses percent was 4.5, 5, 5.5, 6.07, 6.35 and 6.49% at 50, 100, 150, 200, 300 and 400 F-T cycles. The weight losses percent was 2.33, 3.33, 3.65, 4.31, 4.5 and 5% at 50, 100, 150, 200, 300 and 400 F-T cycles for the mixes with 0.1% of air entrained. At 0.15% of air entrained. The weight losses percent was 2, 2.56, 2.67, 3, 3.09 and 3.6% at 50, 100, 150, 200, 300 and 400 F-T cycles. At 0.2% the weight losses percent was 1.9, 2.21, 2.58, 2.67, 3 and 3.26% at 50, 100, 150, 200, 300 and 400 F-T cycles. The results illustrates that as increasing the F-T cycles, the weight losses increasing by an average 9% for 50, 100, 150, 200, 300 and 400 F-T cycles for all dosage of air entrained F-T cycles. The same trends were found for the concrete mixes as illustrated in Fig. (7-b) to Fig. (7-d). Fig. (7-b) illustrates the relation between the F-T cycles and weight losses percent for the mixes with dolomite and Portland cement. At 50 F-T cycles, the weight losses percent was 3, 2, 1.5, 0.98 and 0.43% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained compared with the control mix without air entrained. At 100 F-T cycles, the weight losses percent was 4, 3.1, 2.36 and 1.81% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 150 F-T cycles, the weight losses percent was 5, 3.93, 3.26 and 2.32% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 200 F-T cycles, the weight losses percent was 6, 4.5, 3.93 and 3% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 300 F-T cycles, the weight losses percent was 10, 6.27, 4.84 and 3% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 400 F-T cycles, the weight losses percent was 16.1, 9.37, 6.5 and 4.08% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained- From the previous results, it can be concluded that as increasing the dosage of air entrained the weight losses decreases by an average 15% for the different F-T cycles. On the other hand, it can be noticed that the rate of reduction in the percent of weight losses decreased by increasing the air-entrained as 3 , 7 , 9 , 10

, 15.95 and 20.71% for 0.01, 0.1, 0.15 and 0.2 at 50, 100, 150, 200, 300 and 400 F-T cycles compared with the control mixes without air-entrained. From the figure we can observed also, at 0.01% air entrained, the weight losses percent was 2, 4, 5, 6, 10 and 16.1 at 50, 100, 150, 200, 300 and 400 F-T cycles. The weight losses percent was 1.5, 3.1, 3.93, 4.5, 6.27 and 9.37% at 50, 100, 150, 200, 300 and 400 F-T cycles for the mixes with 0.1% of air entrained. At 0.15% of air entrained. The weight losses percent was 0.98, 2.36, 3.26, 3.93, 4.84 and 6.5 at 50, 100, 150, 200, 300 and 400 F-T cycles. At 0.2% the weight losses percent was 0.43, 1.8, 2.32, 3, 3 and 4.08% at 50, 100, 150, 200, 300 and 400 F-T cycles. The results illustrates that as increasing the F-T cycles, the weight losses

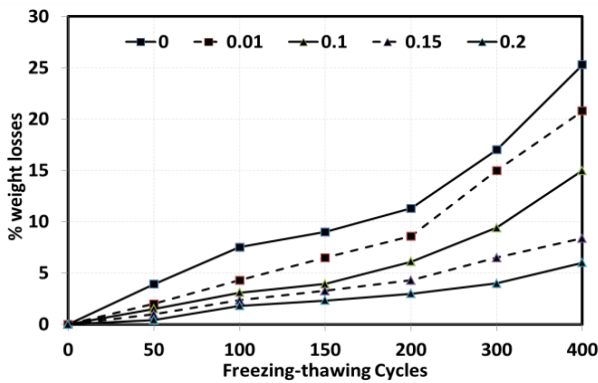
increasing by an average 25% for 50, 100, 150, 200, 300 and 400 F-T cycles for all dosage of air entrained. Fig. (7-c) illustrates the relation between the F-T cycles and weight losses percent for the mixes with gravel and Portland cement. At 50 F-T cycles, the weight losses percent was 2, 1.5, 1 and 0.45% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained compared with the control mix without air entrained. At 100 F-T cycles, the weight losses percent was 4.3, 3.15, 2.4 and 1.83% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 150 F-T cycles, the weight losses percent was 6.5, 3.95, 3.31 and 2.35% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained.



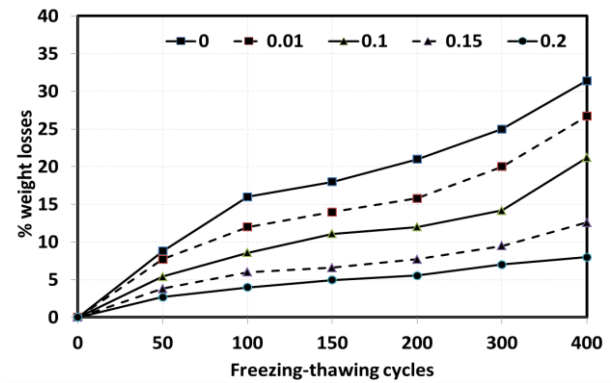
(a) Mortar Mixes



(b) Mixes with dolomite as a coarse aggregate and Portland cement



(c) Mixes with gravel as a coarse aggregate and Portland cement



(d) Mixes with dolomite as a coarse aggregate and Limestone cement

Fig. 7. Relationship between the percent of weight losses and freezing-thawing cycles at different dosage of air interned admixture.

At 200 F-T cycles, the weight losses percent was 8.6, 6.1, 4.3 and 3% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 300 F-T cycles, the weight losses percent was 15, 9.4, 6.5 and 4% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 400 F-T cycles, the weight losses percent was 20.8, 15, 8.4 and 6% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. From the previous results, it can be concluded that as increasing the dosage of air entrained the weight losses decreases by an average 25% for the different F-T cycles. On the other hand, it can be noticed that the rate of reduction in the percent of weight

losses decreased by increasing the air-entrained as 1.23, 2.91, 4.02, 5.5, 8.72 and 12.55 for 0.01, 0.1, 0.15 and 0.2 at 0, 50, 100, 150, 200, 300 and 400 F-T cycles compared with the control mixes without air-entrained. From the figure we can observed also, at 0.01% air entrained, the weight losses percent was 2, 4.3, 6.5, 8.6, 15 and 20.8% at 50, 100, 150, 200, 300 and 400 F-T cycles. The weight losses percent was 1.5, 3.1, 3.93, 6.1, 9.4 and 15% at 50, 100, 150, 200, 300 and 400 F-T cycles for the mixes with 0.1% of air entrained. At 0.15% of air entrained. The weight losses percent was 1, 2.4, 3.3, 4.3, 6.5 and 8.4% at 50, 100, 150, 200, 300 and 400 F-T cycles. At 0.2% the weight losses percent was 0.45, 1.85, 2.35, 3, 4 and 6%

at 50, 100, 150, 200, 300 and 400 F-T cycles. The results illustrates that as increasing the F-T cycles, the weight losses increasing by an average 22% for 50, 100, 150, 200, 300 and 400 F-T cycles for all dosage of air entrained. Fig. (7-d) illustrates the relation between the F-T cycles and weight losses percent for the mixes with dolomite and limestone cement. At 50 F-T cycles, the weight losses percent was 7.7, 5.4, 3.8 and 2.7% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained compared with the control mix without air entrained. At 100 F-T cycles, the weight losses percent was 12, 8.6, 6 and 4% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 150 F-T cycles, the weight losses percent was 14, 11.1, 6.6 and 4.96% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 200 F-T cycles, the weight losses percent was 15.8, 12, 7.7 and 5.57% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 300 F-T cycles, the weight losses percent was 20, 14.2, 9.5 and 7% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. At 400 F-T cycles, the weight losses percent was 26.7, 21.2, 12.6 and 8% for 0.01, 0.1, 0.15 and 0.2% dosage of air entrained control mix without air entrained. From the previous results, it can be concluded that as increasing the dosage of air entrained the weight losses

decreases by an average 4.9, 7.65, 9.16, 10.27, 12.67 and 17.12% for the different F-T cycles. On the other hand, it can be noticed that the rate of reduction in the percent of weight losses decreased by increasing the air-entrained as 8.8, 16, 18, 21, 25 and 31.4 for 0.01, 0.1, 0.15 and 0.2 at 0, 50, 100, 150, 200, 300 and 400 F-T cycles compared with the control mixes without air-entrained. From the figure we can observed also, at 0.01% air entrained, the weight losses percent was 7.7, 12, 14, 15.8, 20 and 26.7% at 50, 100, 150, 200, 300 and 400 F-T cycles. The weight losses percent was 5.4, 8.6, 11.1, 12, 14.2 and 21.2% at 50, 100, 150, 200, 300 and 400 F-T cycles for the mixes with 0.1% of air entrained. At 0.15% of air entrained. The weight losses percent was 3.8, 6, 6.6, 7.7, 9.5 and 12.6% at 50, 100, 150, 200, 300 and 400 F-T cycles. At 0.2% the weight losses percent was 2.7, 4, 4.96, 5.57, 7 and 8% at 50, 100, 150, 200, 300 and 400 F-T cycles. The results illustrates that as increasing the F-T cycles, the weight losses increasing by an average 15% for 50, 100, 150, 200, 300 and 400 F-T cycles for all dosage of air entrained.

The empirical formulation for the weight losses of the mortar and concrete mixes as a function of freezing thawing cycles were formulated as illustrated in Figs. 8-11. Nearly 0.95 is the root square for these equations.

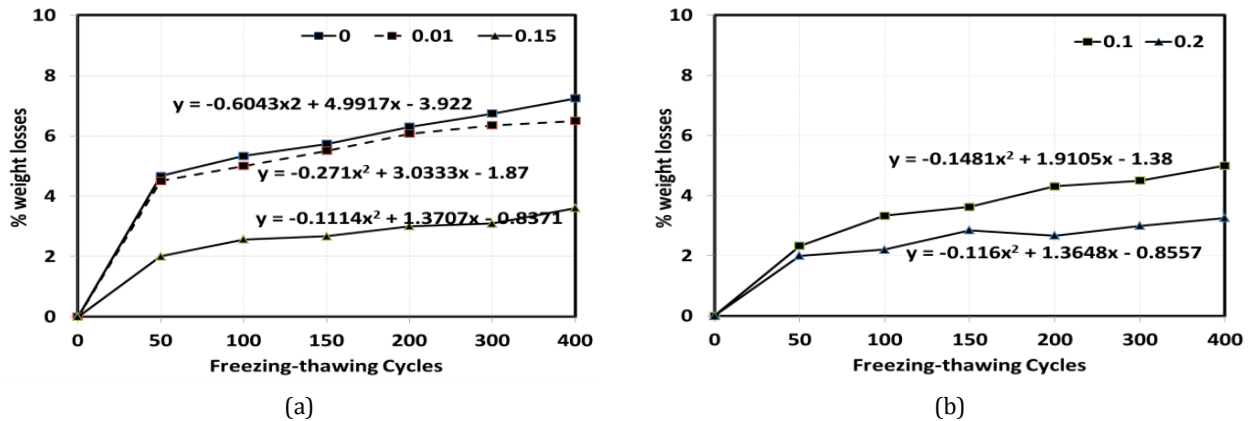


Fig. 8. Empirical correlations for freezing-thawing cycles and percent of weight losses for the mortar mixes.

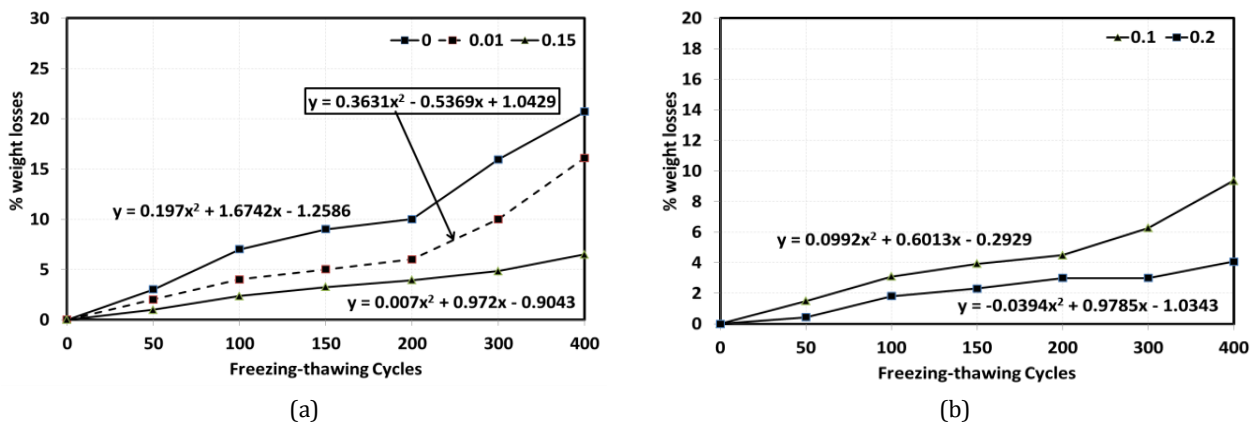


Fig. 9. Empirical correlations for freezing-thawing cycles and percent of weight losses for the mixes with Portland cement and dolomite as a coarse aggregate.

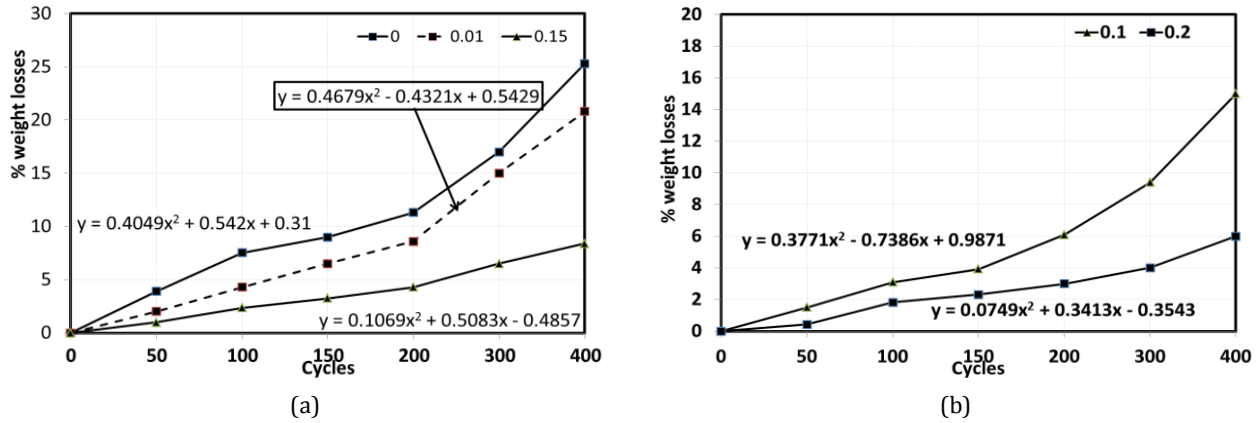


Fig. 10. Empirical correlations for freezing-thawing cycles and percent of weight losses for the mixes with Portland cement and gravel as a coarse aggregate.

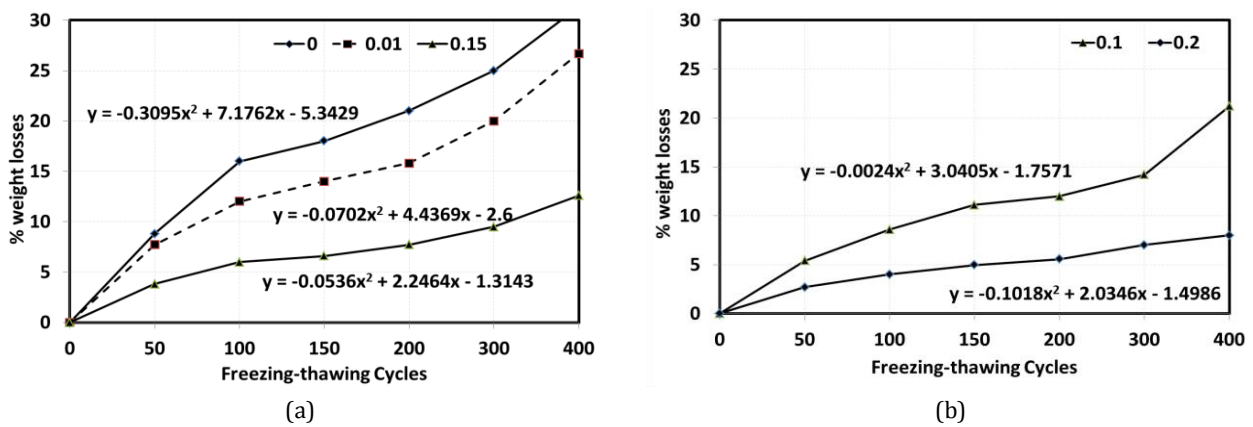


Fig. 11. Empirical correlations for freezing-thawing cycles and percent of weight losses for the mixes with limestone cement and dolomite as coarse aggregates.

4.4. Variation of ultrasonic velocity

Ultrasonic method is proposed as nondestructive tests to evaluate the damage of concrete during the life cycle. The deterioration can occur due to the thermal stress, so that the internal cracks and micro cracks can develop. Table 3 shows the variation in the ultra-sonic velocity for the different mixes. The results illustrate that as increasing the freeze-thaw cycles as decreasing loses of ultrasonic velocity.

4.5. Variation in the relative dynamic modulus of elasticity due to the freezing thawing cycles

Internal cracks in the specimens of the mortar or concrete can be inferred by calculating the dynamic modulus of elasticity (RDME) during freezing-thawing cycles. ASTM C666-03 defines the equation for calculation the RDME. Fig. 12 shows the effect of cycles of freezing thawing on RDME at different percentage of air- entrained. The RDME decreased for the mixes with air-entrained compared with the control mix without air-entrained. The results indicate that the RDME increased as freeze-thaw cycle increase for the control specimen. Also as increasing the dosage of air-entrained the RDME decreased. The mix with 0.2% air-entrained gives the best results for resisting the effect of freezing-thawing cycles.

Figs. 13-16 present the empirical correlation for percentage of RDME as a function of freezing-thawing cycles at the different dosage of air-entrained. The root square for these equations were nearly 0.96.

4.6. Durability factor

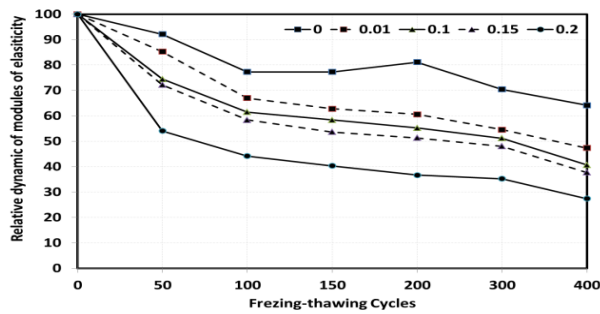
Fig. 17 illustrates the effect of cycles and dosage of air-entrained on the durability factor of mortar. ASTM C666 defines that when the durability factors $\geq 85\%$, the mortar and concrete become more resistance due to the F-T cycles. On the other hands where the durability factor $\leq 40\%$ the mixes become poor resistance for F-T cycles. Fig. (17-a) illustrates the effect of F-T cycles on the durability factors of the mortar. it is noticed that the durability factor $\geq 85\%$ for the mixes with 0, 0.01, 0.1, 0.15 and 0.2% air entrained up to 100 F-T cycles. Also for the control mix with air entrained; durability factor $\leq 40\%$ when exposed to 400 F-T cycles. In addition to at 0.2% air entrained the mortar become more resistance to F-T cycles where the durability factor was $\geq 85\%$ up to 150 F-T cycles and from 200 to 400 F-T cycles the durability factor ranged from (83% to 73%). The slight decreasing for the durability factors by an average 1%. The same trend was noticed for the different concrete mixes as in figures (17-b), (17-c) and (17-d). Where, the durability factor $\geq 85\%$ for the mixes with 0, 0.01, 0.1, 0.15 and

0.2% air entrained up to 100 F-T cycles. Also for the control mix with air entrained; durability factor $\leq 40\%$ when exposed to 400 F-T cycles. In addition to at 0.2% air entrained the mortar become more resistance to F-T cycles where the durability factor was $\geq 85\%$ up to 150 F-T cycles and from 200 to 400 F-T cycles the durability factor ranged from (83% to 73). The slight decreasing for the durability factors by an average 1% as in Fig. (17-b) for the mixes with dolomite as coarse aggregate and Portland cement. Fig. (17-c) the durability factor $\geq 85\%$ for the mixes contains gravel as a coarse aggregate and Portland cement and with 0, 0.01, 0.1, 0.15 and 0.2% air entrained up to 100 F-T cycles. Also for the control mix with air entrained; durability factor $\leq 40\%$ when exposed to 400 F-T cycles. In addition to at 0.2%

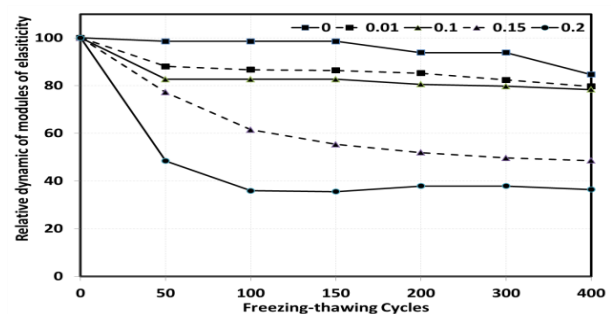
air entrained the mortar become more resistance to F-T cycles where the durability factor was $\geq 85\%$ up to 150 F-T cycles and from 200 to 400 F-T cycles the durability factor ranged from (83% to 73). The slight decreasing for the durability factors by an average 1%. Fig. (17-d) the durability factor $\geq 85\%$ for the mixes contains dolomite as a coarse aggregate and limestone cement and with 0, 0.01, 0.1, 0.15 and 0.2% air entrained up to 100 F-T cycles. Also for the control mix with air entrained; durability factor $\leq 40\%$ when exposed to 400 F-T cycles. In addition to at 0.2% air entrained the mortar become more resistance to F-T cycles where the durability factor was $\geq 85\%$ up to 150 F-T cycles and from 200 to 400 F-T cycles the durability factor ranged from (83% to 73). The slight decreasing for the durability factors by an average 1%.

Table 3. Variation in the ultra-sonic velocity for the mixes.

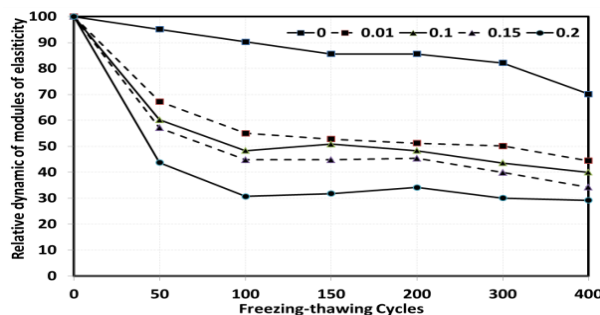
Code	0.01	0.1	0.15	0.2	Code	0.01	0.1	0.15	0.2		
Mortar	1	7.69	13.7	15.01	26.4	Portland cement +gravel	13	17.97	22.4	24.4	33.8
	2	18.15	21.6	23.6	33.51		14	25.8	30.4	33.05	44.5
	3	20.76	23.57	26.7	36.5		15	27.3	28.7	33.05	43.6
	4	22.15	25.7	28.35	39.4		16	28.4	30.4	32.63	41.5
	5	26.15	28.4	30.69	40.6		17	29.2	34	36.8	45.2
	6	31.25	36.2	38.6	47.6		18	33.3	36.7	41.4	45.98
Portland cement + dolomite	7	6.15	9.09	12.13	30.4	Limestone cement + dolomite	19	3.84	4.6	8.9	28.4
	8	6.92	9.09	21.6	40.04		20	5.44	8.7	12.45	33.7
	9	7.07	9.1	25.6	40.39		21	5.9	8.7	18.77	36.8
	10	7.69	10.24	27.95	38.47		22	7.05	8.7	22.1	36.85
	11	9.2	10.7	29.5	38.47		23	7.88	9.9	24.1	35.6
	12	10.76	11.5	30.3	39.64		24	10.25	12.5	22.1	35.6



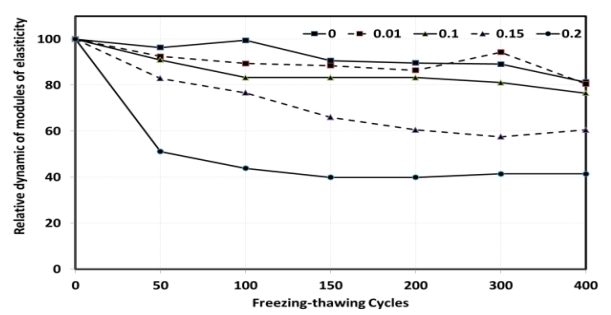
(a) Mortar Mixes



(b) Mixes with dolomite as a coarse aggregate and Portland cement

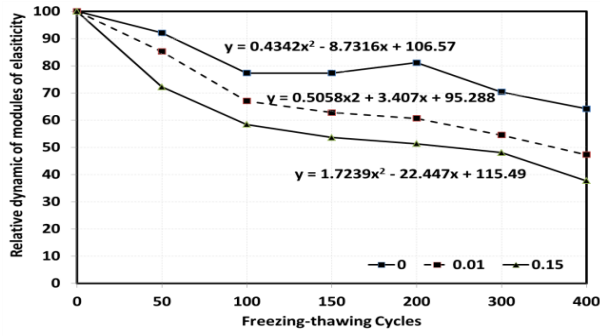


(c) Mixes with gravel as a coarse aggregate and Portland cement

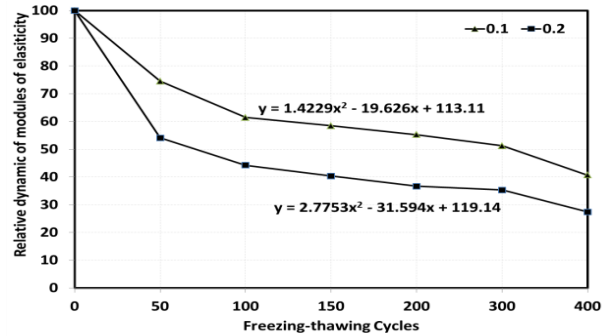


(d) Mixes with dolomite as a coarse aggregate and Limestone cement

Fig. 12. Relationship between the relative dynamic of modules of elasticity and freezing–thawing cycles at different dosage of air interned admixture.

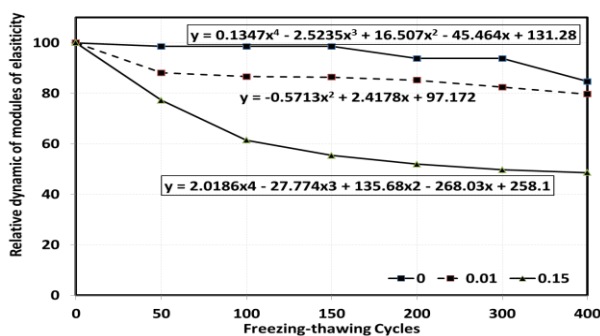


(a)

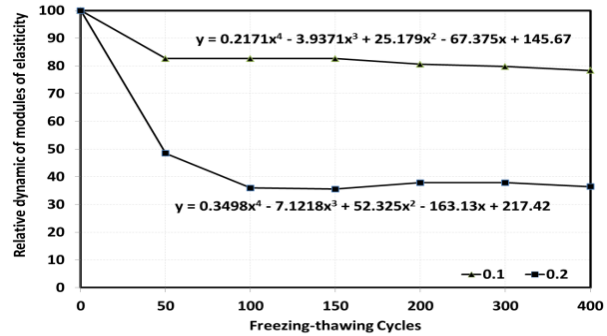


(b)

Fig. 13. Empirical correlations for freezing-thawing cycles and percent of relative dynamic of modulus of elasticity for the mortar mixes.

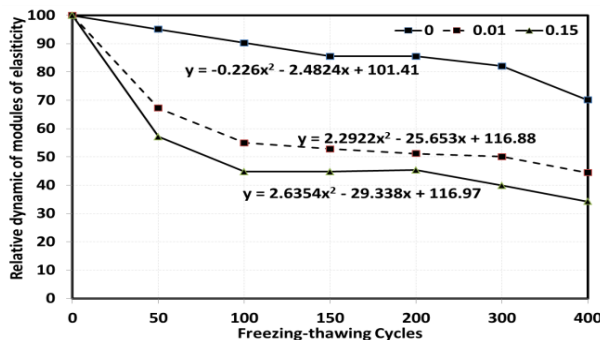


(a) Air-entrained to cement=0.01

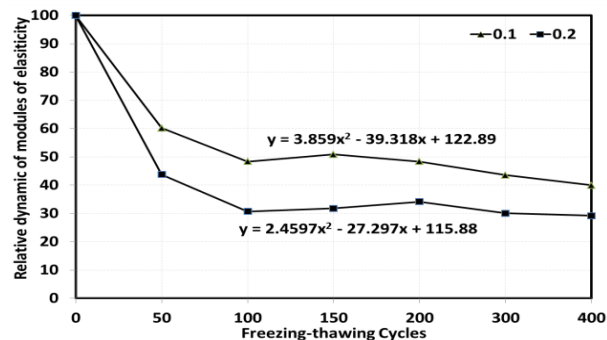


(b) Air-entrained to cement=0.1

Fig. 14. Empirical correlations for freezing-thawing cycles and percent of relative dynamic of modulus of elasticity for the mixes with Portland cement and dolomite as a coarse aggregate.

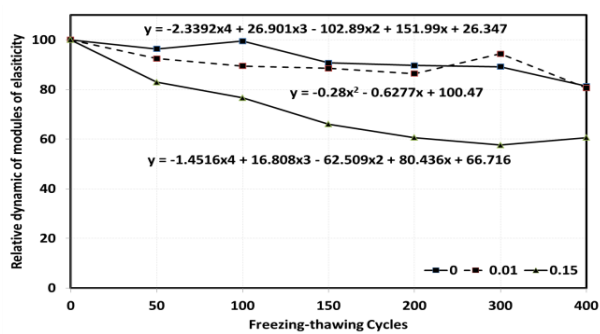


(a) Air-entrained to cement=0.01

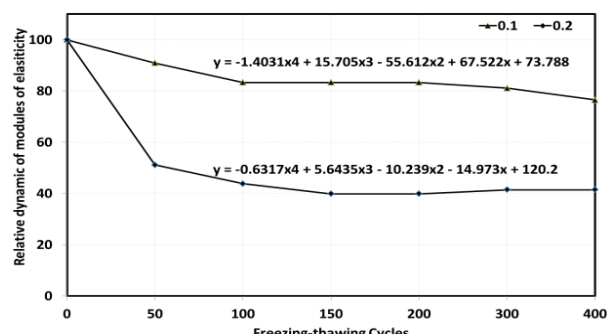


(b) Air-entrained to cement=0.1

Fig. 15. Empirical correlations for freezing-thawing cycles and percent of relative dynamic of modulus of elasticity for the mixes with Portland cement and gravel as a coarse aggregate..

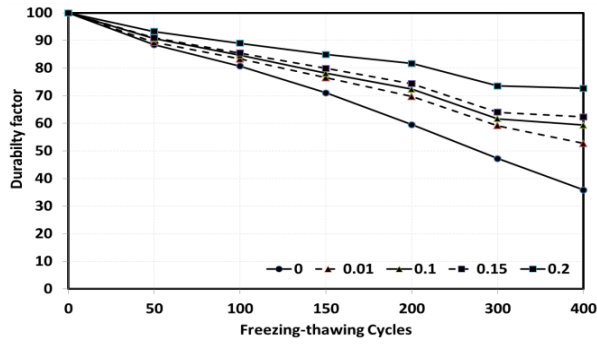


(a)

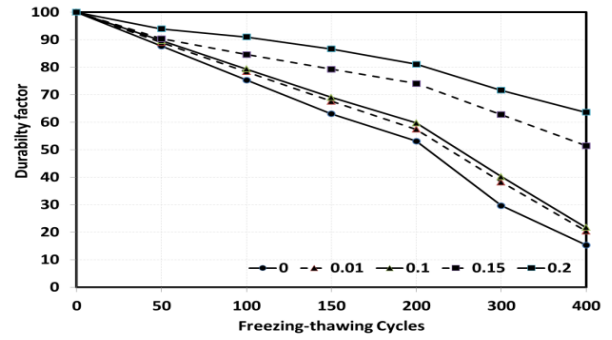


(b)

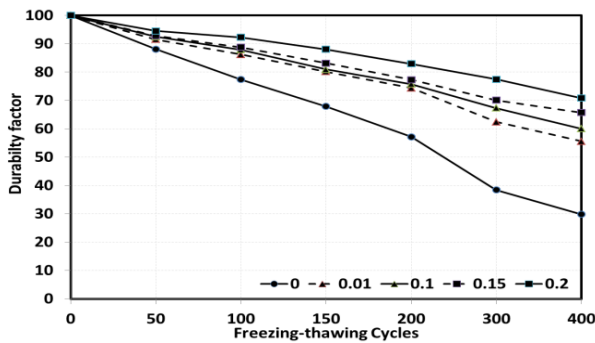
Fig. 16. Empirical correlations for freezing-thawing cycles and percent of relative dynamic of modulus of elasticity for the mixes with limestone cement and dolomite as a coarse aggregate.



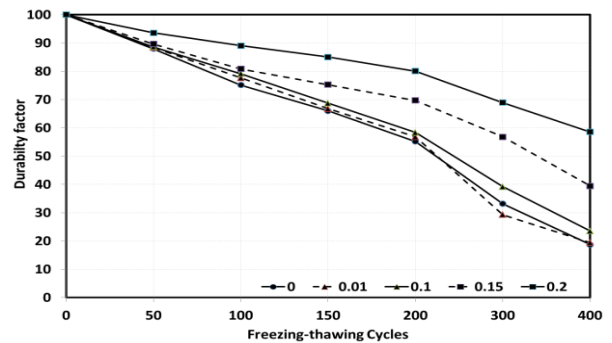
(a) Mortar Mixes



(b) Mixes with dolomite as a coarse aggregate and Portland cement



(c) Mixes with gravel as a coarse aggregate and Portland cement

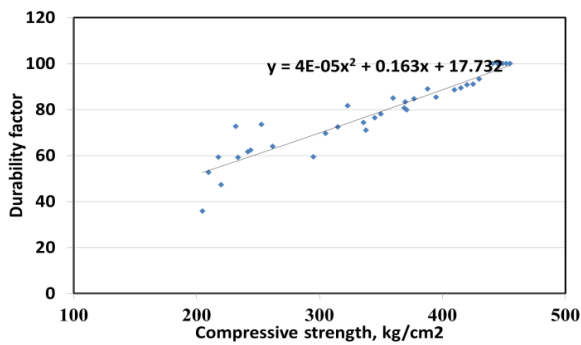


(d) Mixes with dolomite as a coarse aggregate and Limestone cement

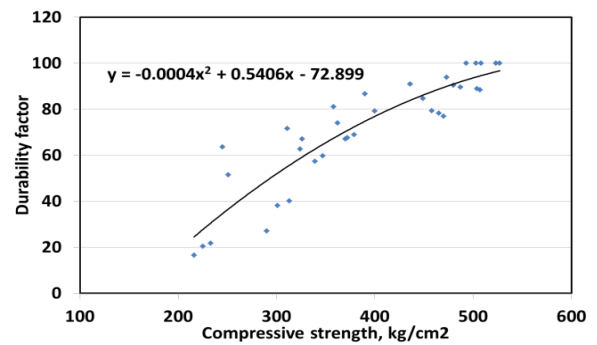
Fig. 17. Relationship between the freezing-thawing cycles on the durability factor at different dosage of air interned admixture.

Fig. 18 presents the effect of durability factor on the compressive strength of the mixes whereas the durability factor increases as the compressive strength increase.

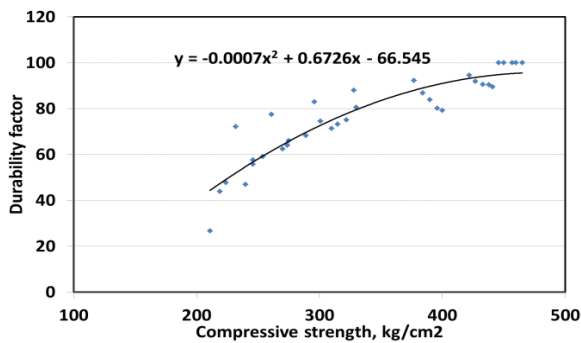
The empirical equations for the durability factor as a function in the compressive strength were formulated as in the figure.



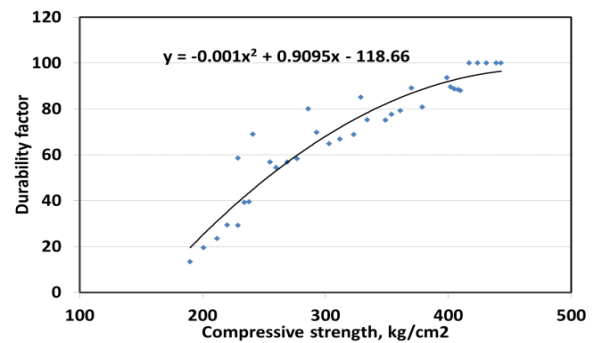
(a) Mortar Mixes



(b) Mixes with dolomite as a coarse aggregate and Portland cement



(c) Mixes with gravel as a coarse aggregate and Portland cement



(d) Mixes with dolomite as a coarse aggregate and Limestone cement

Fig. 18. Relationship between the compressive strength and the durability factor.

4.7. Effect of cement types on the behavior of concrete due to freezing and thawing

Fig. 19 shows the effect of cement types on the compressive strength during freezing-thawing (F-T) cycles for the mixes with dolomite as a coarse aggregate and without air entrained. It can be seen that, the mixes with Portland cement have a compressive strength more than that with limestone cement during F-T cycles. The removal of the large cement particles allows lime stone cement mixtures to have pore size distributions. Also the percentage of C3S in the Portland cement is more than that of lime stone cement and this yield to more strength and hardened. The compressive strength was 453, 395, 340, 300, 290, 250 and 200 kg/cm² for the mixes with portland cement at 50, 100, 150, 200, 300 and 400 F-T cycles,

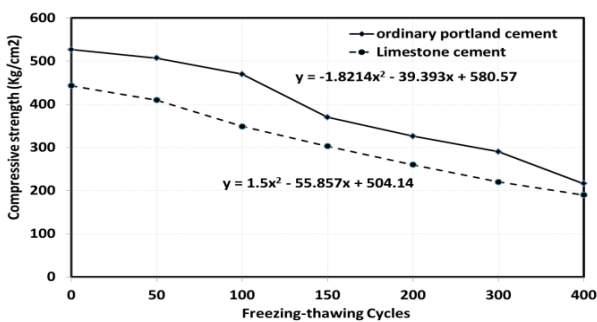


Fig. 19. Effect of cement type on the compressive strength at different freezing thawing cycles, dolomite.

Fig. 21 illustrates the effect of cement type of the durability factor. Also, Fig. 22 illustrates the relationship between the compressive strength and durability factor for the mixes with different cement types. It is clear that, as the compressive strength increases as the durability factor increases. The results show that, the mixes with strength more than 350 kg/cm² showed good F-T resistance where the durability factor more than or equal

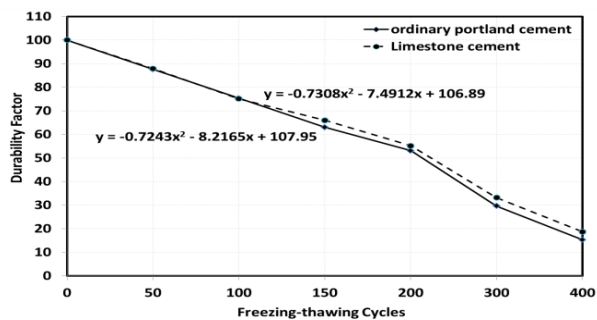


Fig. 21. Effect of cement type on the durability factor at different freezing thawing cycles, dolomite.

4.8. Effect of aggregate types on the behavior of concrete due to freezing and thawing

Fig. 23 shows the effect of aggregate types on the compressive strength during freezing-thawing cycles for the mixes with Portland cement and without air entrained. It can be seen that, the mixes with dolomite

respectively. In addition to the compressive strength for the mixes with limestone cement were 410, 385, 335, 290, 270, 222 and 175 kg/cm² at 50, 100, 150, 200, 300 and 400 F-T cycles, respectively. From the results the percent of increasing in the compressive strength for the mix with Portland cement was 10.5, 2.6, 1.5, 7.4, 12.6 and 14.3% at 50, 100, 150, 200, 300 and 400 F-T cycles, respectively compared with the mixes with lime stone cement. The effect of cement types on the percent of weight losses during F-T cycles was illustrated in Fig. 20. The loss for the mix with limestone cement is more than that for the mixes with Portland cement. The percent of increasing in the weight losses for the mix with limestone cement were 133, 144, 100, 90, 35 and 15% at 50, 100, 150, 200, 300 and 400 F-T cycles, respectively compared with the mixes with Portland cement.

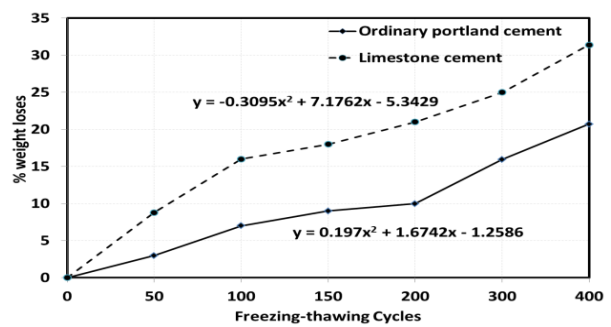


Fig. 20. Effect of cement types of the % weight losses at different freezing thawing cycles, dolomite.

85%. This reported by Wang et al. (2008). These results nearly observed for the mixes exposed to 50 F-T cycles. By increasing the F-T cycles as 100, 150, 200, 300, and 400 cycles the durability factors decreases as the compressive strength decreases. The durability factors reduces from 74.33% to 9.55% for the mixes with Portland cement and reduces from 71.89% to 2.36% for the mixes with limestone cement.

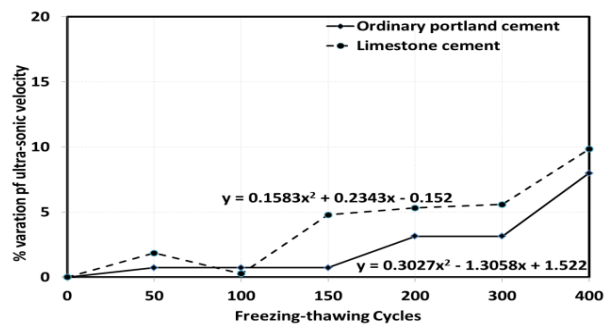


Fig. 22. Relationship between the % ultra-sonic velocity and freezing-thawing cycles for different types of cement.

have a compressive strength more than that with gravel during F-T cycles. The compressive strength was 453, 395, 340, 300, 290, 250 and 200 kg/cm² for the mixes with dolomite at 50, 100, 150, 200, 300 and 400 F-T cycles, respectively. In addition to the compressive strength for the mixes with gravel were 410, 385, 335, 290, 270, 220 and 183 kg/cm² at 50, 100, 150, 200,

300 and 400 F-T cycles, respectively. From the results the percent of increasing in the compressive strength for the mix with dolomite was 10.5, 2.6, 1.5, 7.4, 13.6 and 9.3% at 50, 100, 150, 200, 300 and 400 F-T cycles, respectively compared with the mixes with gravel. The effect of aggregate types on the percent of weight losses during F-T cycles was illustrated in Fig. 24. The weight loss for the mix with gravel is more than that for the mixes with dolomite. The percent of increasing in the weight losses for the mix with dolomite were 2.3, 7, 10, 11.5, 6.2 and 18% at 50, 100, 150, 200, 300 and 400 F-T cycles, respectively compared with the mixes with gravel.

Fig. 25 shows the effect of type of aggregate on the durability factor of the mixes during F-T cycles. The relationship between the compressive strength and durability factor for the mixes with different aggregate types was illustrated in Fig. 26. It is clear that the mixes with dolomite as a coarse aggregate give a durability factor best of the mixes with gravel. Also, the mixes with strength more than 350 kg/cm² showed good F-T resistance where the durability factor more than or equal 85%. These results nearly observed for the mixes exposed to 50 F-T cycles. By increasing the F-T cycles as 100, 150, 200, 300, and 400 cycles the durability factors decreases as the compressive strength decreases. The durability factors reduces from 74.33% to 9.55% for the mixes with dolomite and reduces from 64.7 to 8.7% for the mixes with gravel.

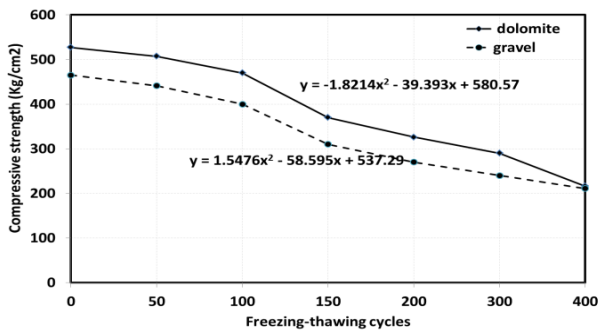


Fig. 23. Effect of aggregate type on the compressive strength at different freezing-thawing cycles.

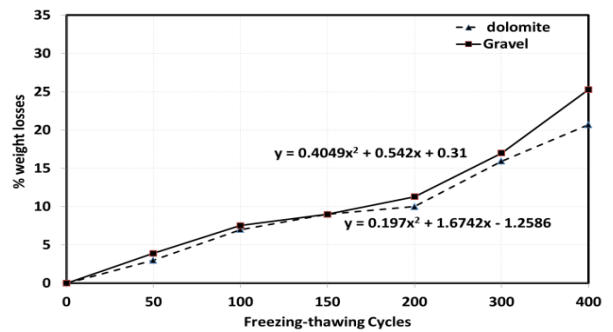


Fig. 24. Effect of aggregate types of the % weight losses at different freezing-thawing cycles.

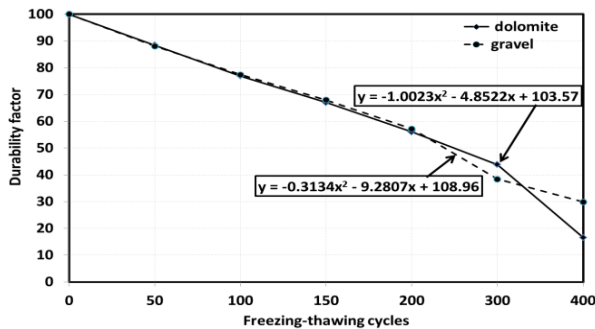


Fig. 25. Effect of aggregate type on the durability factor at different freezing-thawing cycles.

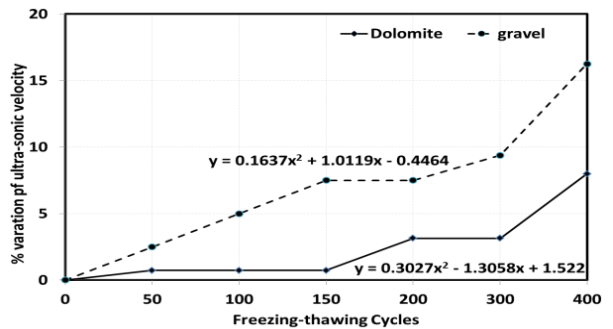


Fig. 26. Relationship between % ultra-sonic velocity and the freezing-thawing cycles for different types of aggregate.

5. Conclusions

- Using air-entrained agent improve the durability of concrete.
- The mixes with compressive strength more than 350 kg/cm² showed good F-T resistance where the durability factor more than or equal to 85%.
- The durability factors reduces from 74.33% to 9.55% for the mixes with Portland cement and dolomite as a coarse aggregate, reduces from 71.89 to 2.36% for the mixes with limestone cement and reduces from 64.7 to 8.7% for the mixes with gravel.
- The weight loss for the mix with gravel is more than that for the mixes with dolomite. The percent of increasing in the weight losses were 2.3, 7, 10, 11.5,

- 6.2 and 18% at 50, 100, 150, 200, 300 and 400 F-T cycles, respectively compared with the mixes with gravel.
- 0.15% air entrained of cement weight improve the durability in term of freezing-thawing; where the durability factor for the mixes was $\geq 85\%$ for the exposed to freezing-thawing cycles in range (0-200).
- Up to 200 cycles of freezing-thawing didn't effect on the compressive strength of the mixes and the durability of the mortar and the concrete
- The percent of increasing in the compressive strength for the mix with Portland cement was 10.5, 2.6, 1.5, 7.4, 12.6 and 14.3% at 50, 100, 150, 200, 300 and 400 F-T cycles, respectively compared with the mixes with lime stone cement.

- The mixes with dolomite have a compressive strength more than that with gravel during F-T cycles. The percent of increasing in the compressive strength for the mix with dolomite was 10.5, 2.6, 1.5, 7.4, 13.6 and 9.3% at 50, 100, 150, and 200, 300 and 400 F-T cycles, respectively compared with the mixes with gravel.
- The percent of increasing in the compressive strength for the mix with Portland cement was 10.5, 2.6, 1.5, 7.4, 12.6 and 14.3% at 50, 100, 150, 200, 300 and 400 F-T cycles, respectively compared with the mixes with lime stone cement.
- The mixes with dolomite have a compressive strength more than that with gravel during F-T cycles. The percent of increasing in the compressive strength for the mix with dolomite was 10.5, 2.6, 1.5, 7.4, 13.6 and 9.3% at 50, 100, 150, and 200, 300 and 400 F-T cycles, respectively compared with the mixes with gravel.
- An empirical correlation were formulated for the compressive strength, weight loss and durability factor as a function of freezing-thawing cycles. Also, the empirical equations for the durability factor as a function in the compressive strength were formulated.

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