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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 ≥ 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 supercoiling, 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 ≥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 $cm^2/gm.$, respectively. 3.15 and 4850 $cm^2/gm.$ 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.

Table 2. Mix proportions by weights (kg/m^3).

Code		O.P.C	L.S.C	Sand	Water	Dolomite	Gravel	A.E
Mortar	1	648	-	1944	259.2	-	-	0
	2	647.8		1943.4	259.12			0.055
	3	646		1938	258.4			0.55
	4	645		1935	258			0.825
	5	644		1932	257.6			1.1
Portland cement + dolomite	6	400	-	597.4	180	1194.8	-	0
	7			597.25		1194.5		0.04
	8			595.75		1191.5		0.4
	9			594.95		1189.9		0.6
	10			594.67		1189.34		0.8
Portland cement +gravel	11	400	-	597.4	180	-	1194.8	0
	12			597.25			1194.5	0.04
	13			595.75			1191.5	0.4
	14			594.95			1189.9	0.6
	15			594.67			1189.34	0.8
Limestone cement + dolomite	16	-	400	597.4	180	1194.8	-	0
	20			597.25		1194.5		0.04
	21			595.75		1191.5		0.4
	22			594.95		1189.9		0.6
	23			594.67		1189.34		0.8

OPC: Portland cement L.S.C: limestone cement A.E.: Air-entrained agent

4. Results and Discussion

4.1. Effect of air entrained on initial and final sitting time of cement

Fig. 1 shows the effect of% of air entering on the initial and final sitting time of cement. The initial and final sitting time ranged from 45 to 120 min and from 200 to 310 min, respectively. It is clear that; there is no negative effect on the sitting time of cement for all the dosage of air entering.

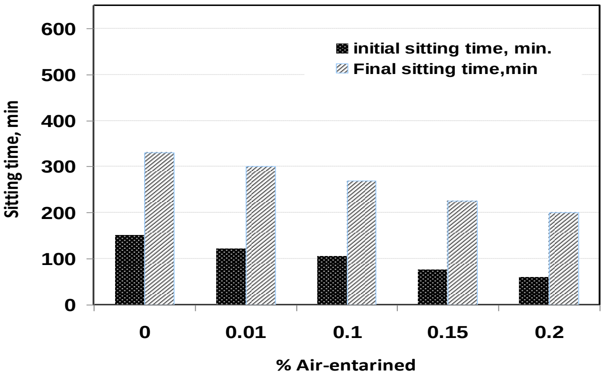
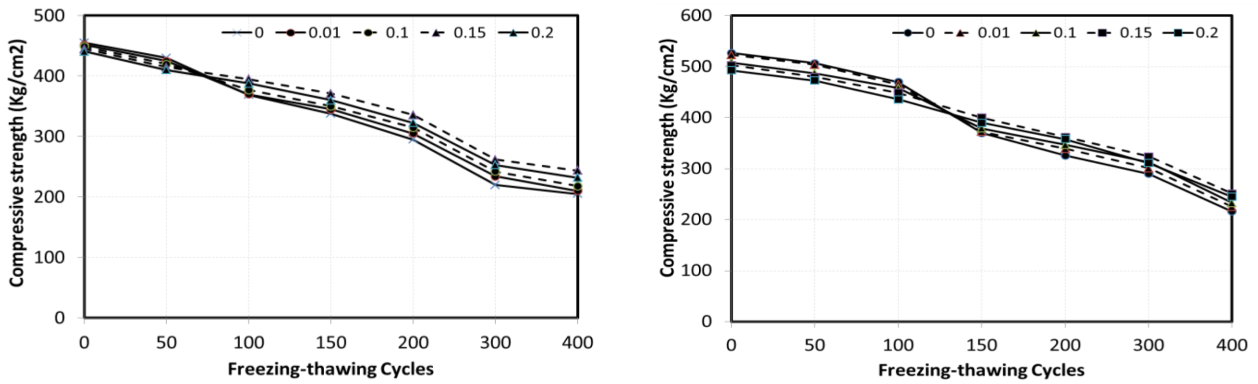


Fig. 1. Effect of dosage of air entrained on sitting time.

4.2. Effect of freezing and thawing cycles on the compressive strength

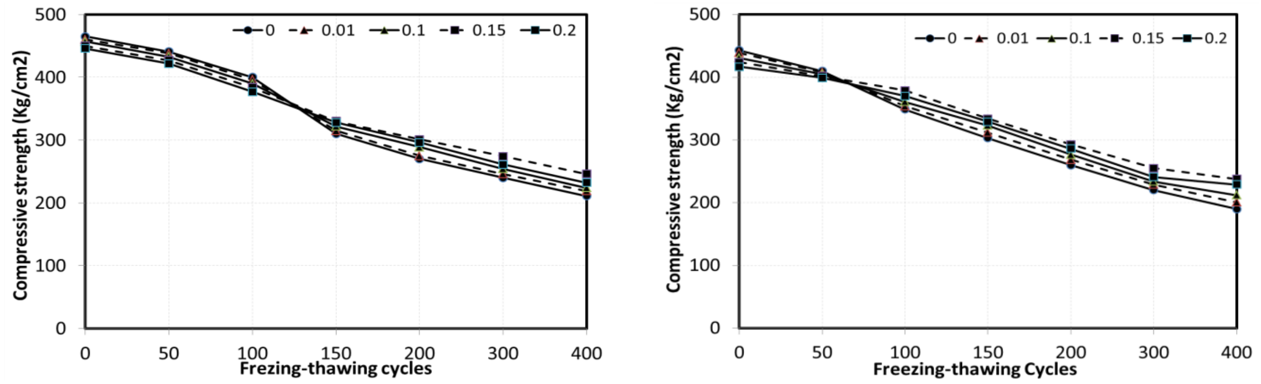
Fig. 2 illustrates the effect of freezing-thawing cycles on the compressive strength of the mixes. In general; as increasing the freezing-thawing (F-T) cycles as decreasing the compressive strength at the same dosage of air-entrained. We noticed that, during exposure to freezing-thawing cycles, the compressive strength have increased for the mixes with air-entrained compared with the control mix without air-entrained at the same freezing-thawing cycles. In addition to the 0.15% air entrained is the optimum value to improve the behavior of mixes when exposed to F-T cycles. The following examples illustrate the effective of F-T cycles on the compressive strength. Fig. (2-a) illustrates the relationship between the F-T cycles and the compressive strength for the mortar mixes at different dosage of air-entrained. The figure clears that, for the mixes with 0.01% of air entrained which is exposed to freezing-thawing cycles, the compressive strength was 425, 370, 345, 305, 234 and 210 kg/cm^2) at, 50, 100, 150, 200 , 300 and 400 cycles. For control mix without air-entrained.

The compressive strength was 430, 369, 338, 295, 220, 205 kg/cm^2 at 50,100, 150, 200, 300 and 400 cycles. We noticed that, at 50 Freezing-thawing cycles the compressive strength more than that 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

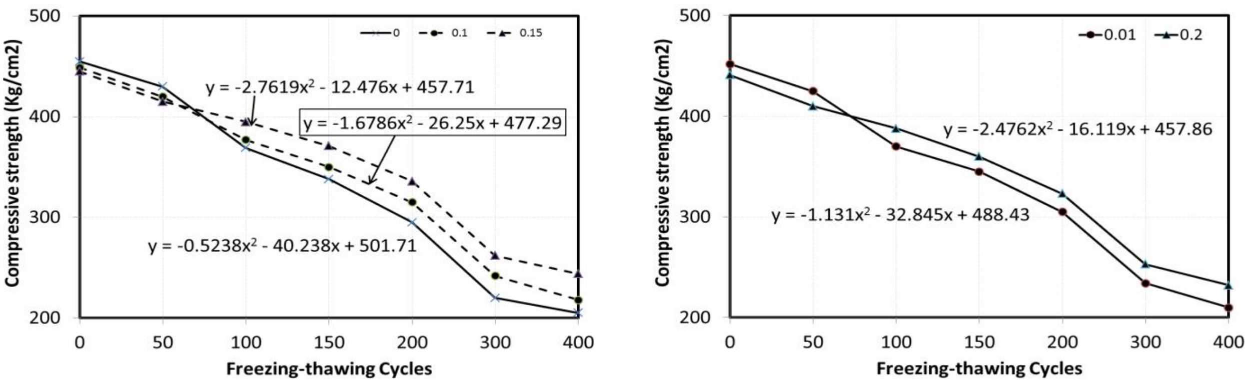
Fig. 2. Relationship between the compressive strength and freezing–thawing cycles at different dosage of air interned admixture.

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/cm^2) 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/cm^2 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/cm^2 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/cm^2 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/cm^2 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/cm^2 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/cm^2 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/cm^2 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/cm^2 at, 50, 100, 150, 200, 300and 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/cm^2 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/cm^2 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/cm^2 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/cm^2 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/cm^2 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/cm^2. 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/cm^2 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/cm^2 at, 50, 100, 150, 200, 300 and 400 cycles.

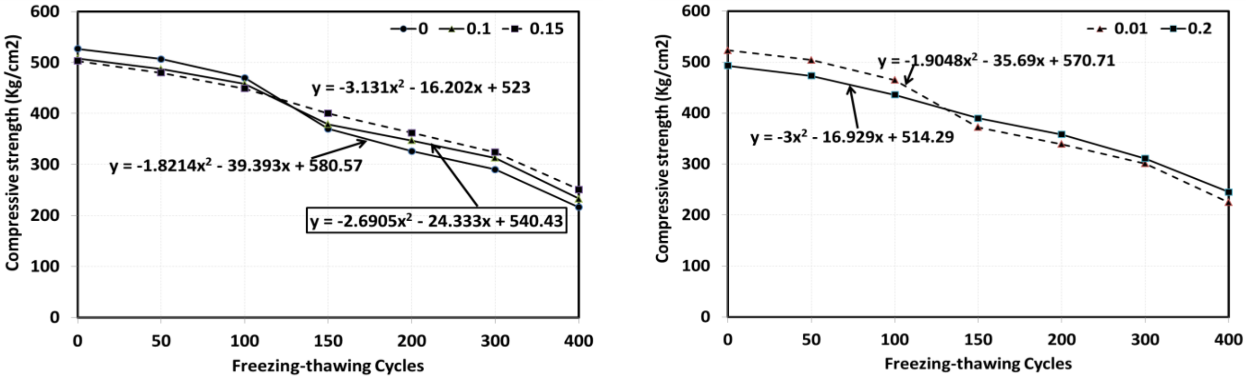
For the mixes without air-entrained, its compressive strength was 410, 349, 303, 260, 220 and 190 kg/cm^2 at 50,100, 150, 200, 300 and 400 cycles. For the mixes which exposed to 50 F-T cycles the compressive strength still more than the compressive strength for the mixes without air-entrained. In addition 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/cm^2 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/cm^2 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.



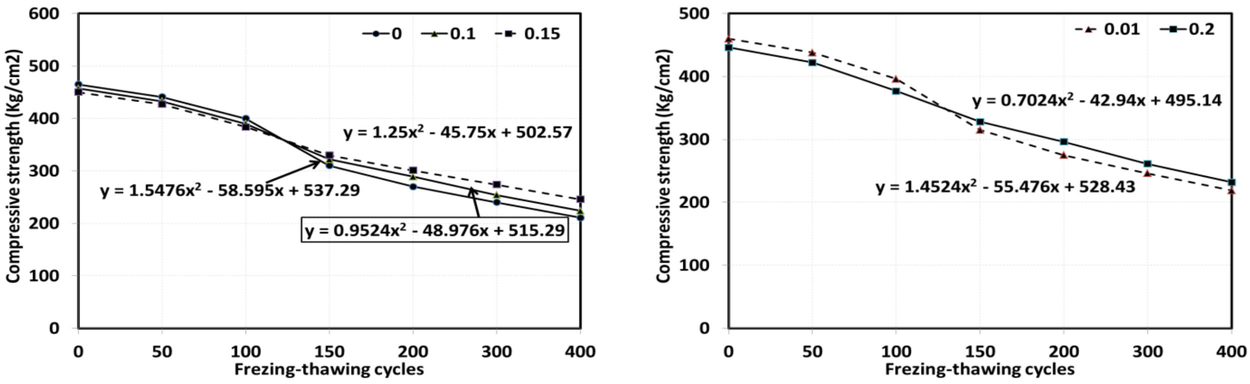
(a) (b)

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



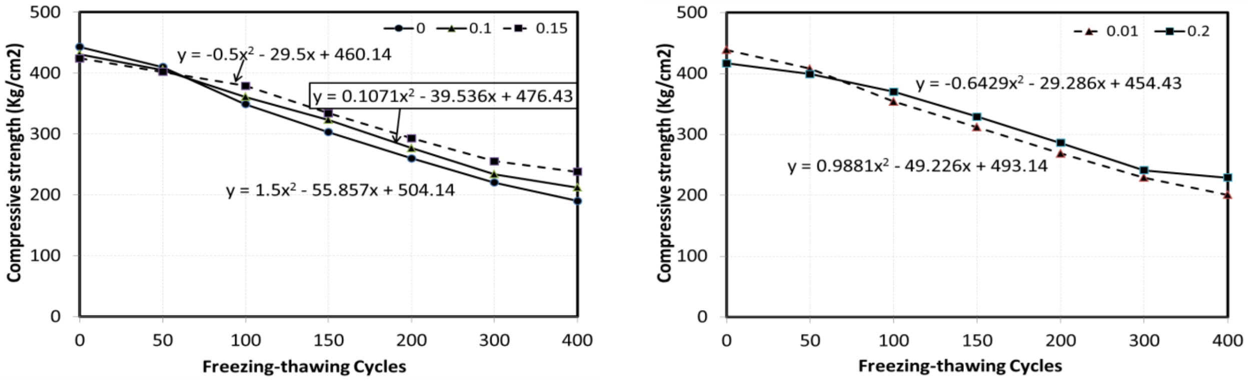
(a) (b)

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



(a) (b)

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



(a) (b)

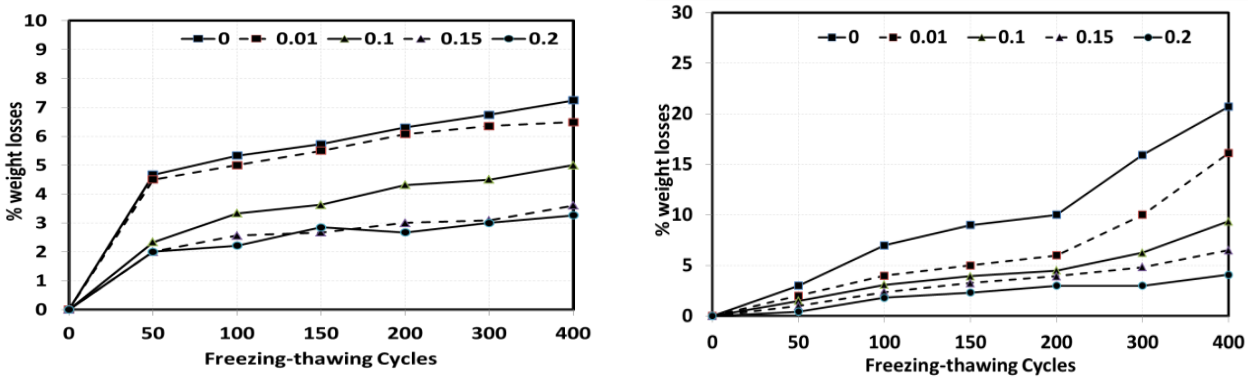
Fig. 6. Empirical correlations for freezing-thawing cycles and compressive strength for the mixes with limestone cement and dolomite as a coarse aggregate.

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 .

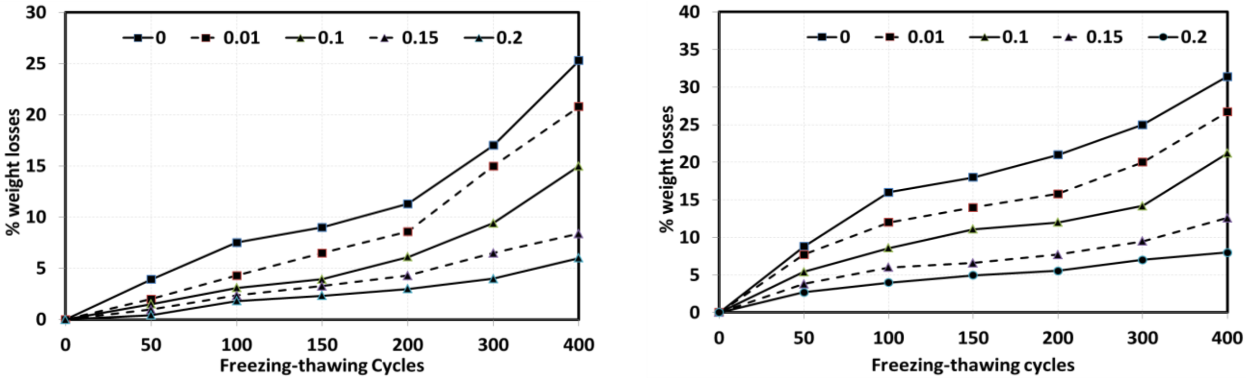
From the figure we can observed also, at 0.01% air entrained, the weight losses percent was 4.5, 5, 5.5, 6.07, 6.35 and 6.49% at 50, 100, 150, 200, 300 and 400 F-T cycles. The weight losses percent was 2.33, 3.33, 3.65, 4.31, 4.5 and 5% at 50, 100, 150, 200, 300 and 400 F-T cycles for the mixes with 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, 1and 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, 3.31and 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

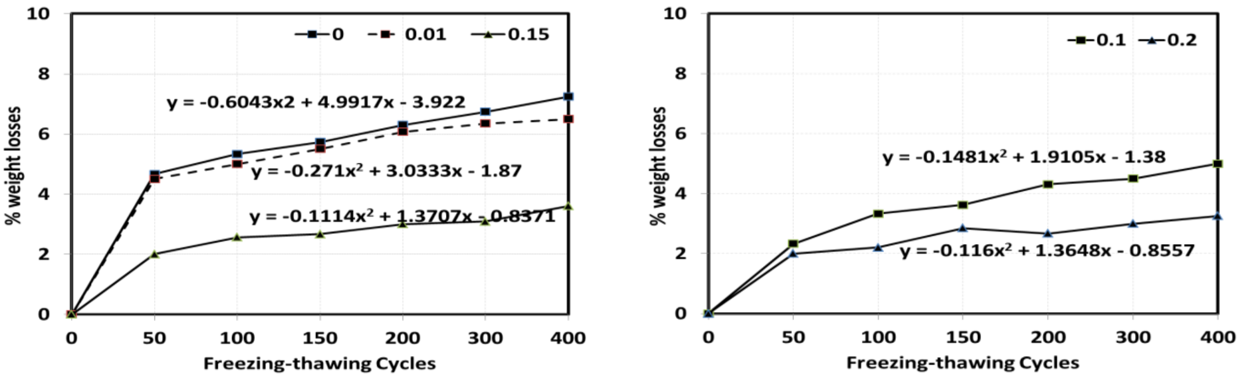
(d) Mixes with dolomite as a coarse aggregate and Limestone cement

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, 6.5and 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%

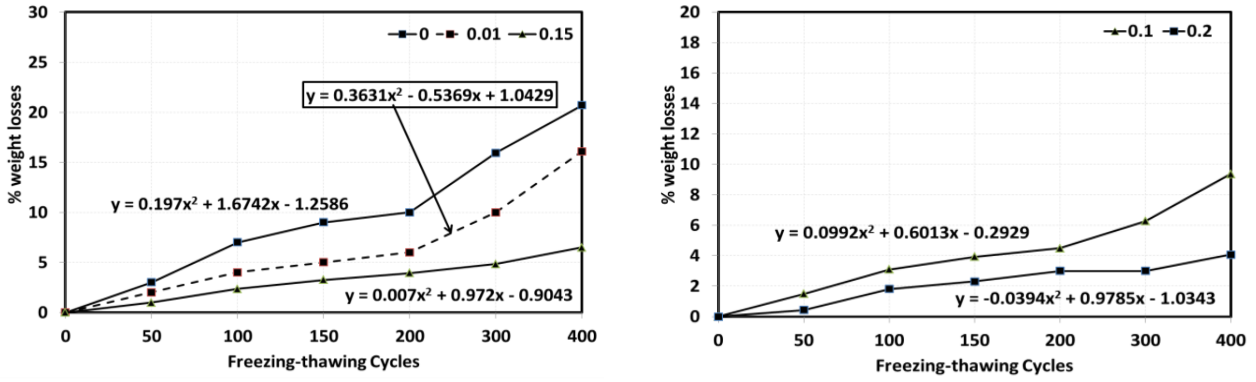
at 50, 100, 150, 200, 300 and 400 F-T cycles. The results illustrates that as increasing the F-T cycles, the weight losses increasing by an average 22% for 50, 100, 150, 200, 300 and 400 F-T cycles for all dosage of air entrained. Fig. (7-d) illustrates the relation between the F-T cycles and weight 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, 6and 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, 7.7and 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, 20and 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, 9.5and 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, 7and8% 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 theses equations.



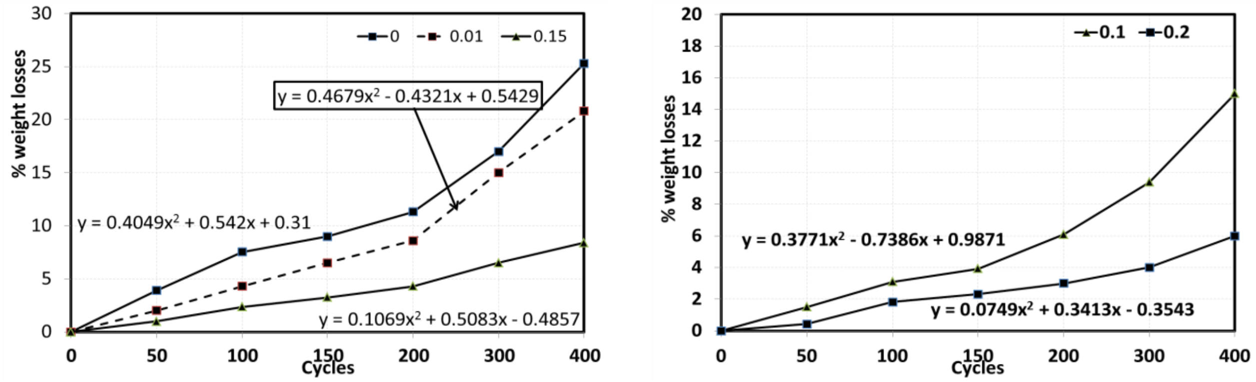
(a) (b)

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



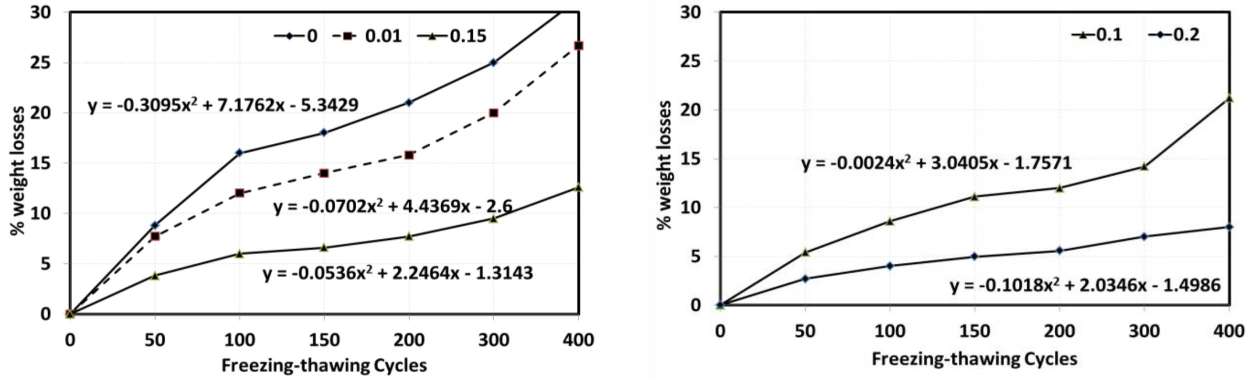
(a) (b)

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.



(a) (b)

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.



(a) (b)

Fig. 11. Empirical correlations for freezing-thawing cycles and percent of weight losses for the mixes with limestone cement and dolomite as a 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 modules 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 modules 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 RDEM as a function of freezing-thawing cycles at the different dosage of air-entrained. The root square for these equations were nearly 0.96.

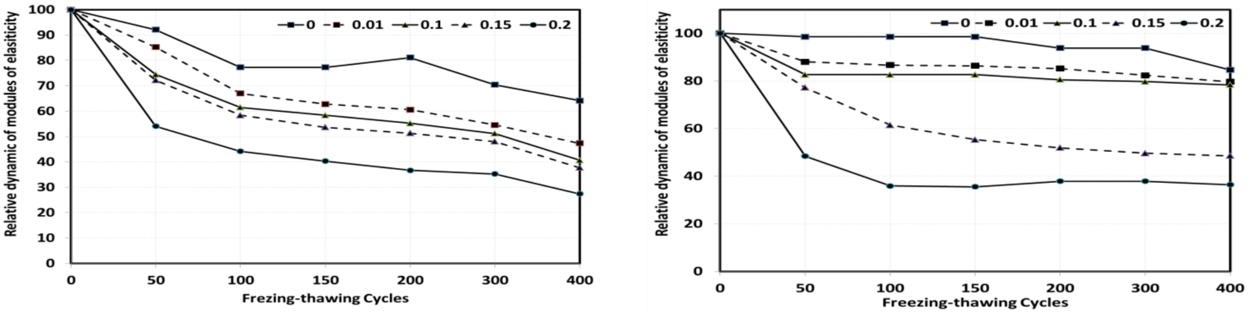
4.6. Durability factor

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 ≥ 85%, the mortar and concrete become more resistance due to the F-T cycles. On the other hands where the durability factor ≤ 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 ≥ 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 ≤ 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 ≥ 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 ≥ 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 ≤ 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 ≥ 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 ≥ 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 ≤ 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 ≥ 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 ≥ 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 ≤ 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 ≥ 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%.

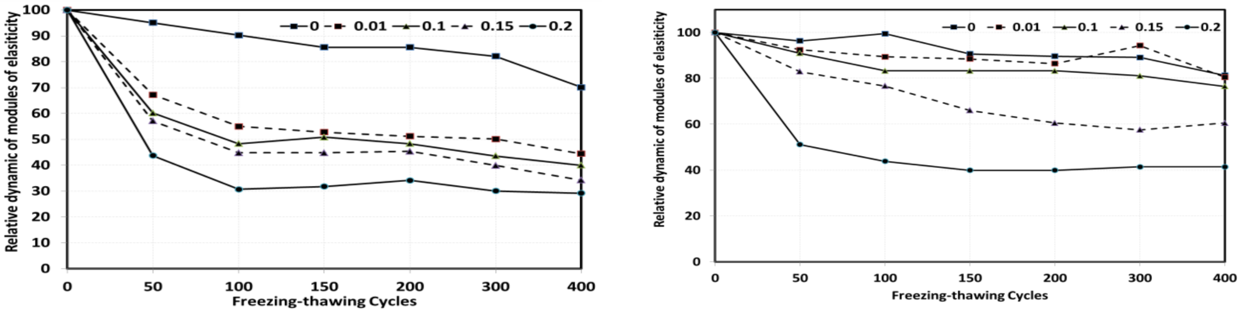
Table 3. Variation in the ultra-sonic velocity for the mixes.

	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

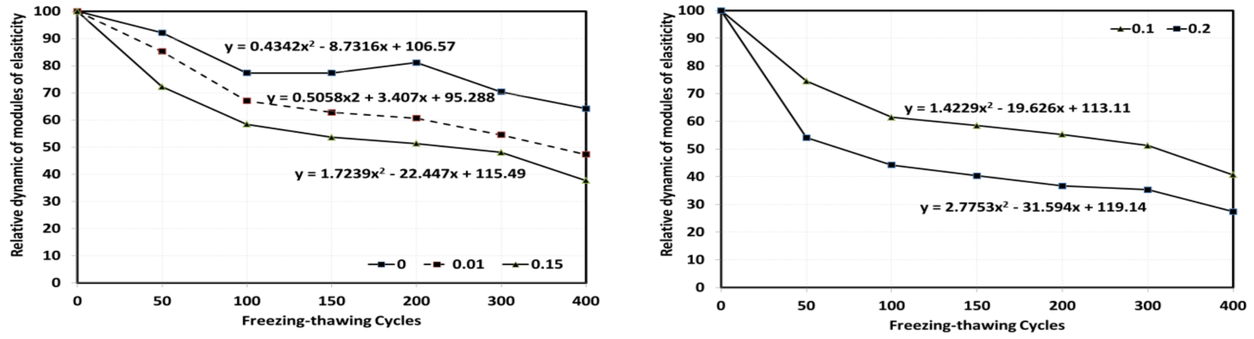
(b) Mixes with dolomite as a coarse aggregate and Portland cement



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

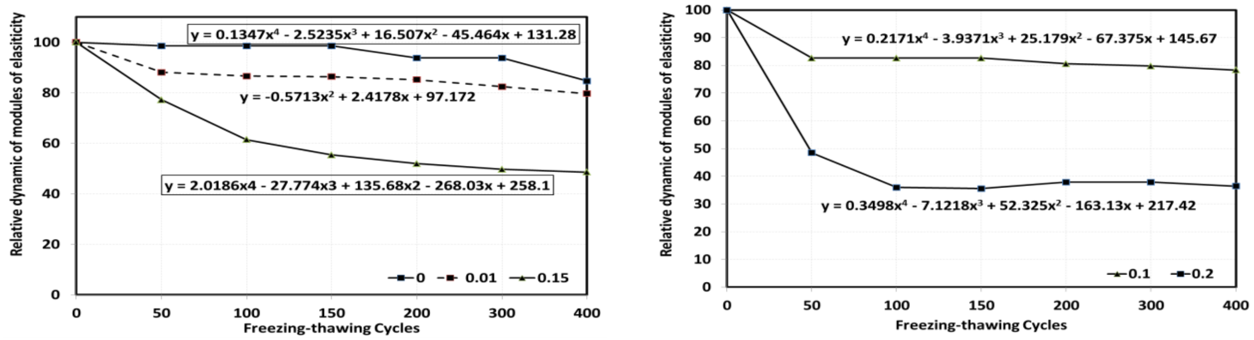
(d) Mixes with dolomite as a coarse aggregate and Limestone cement

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



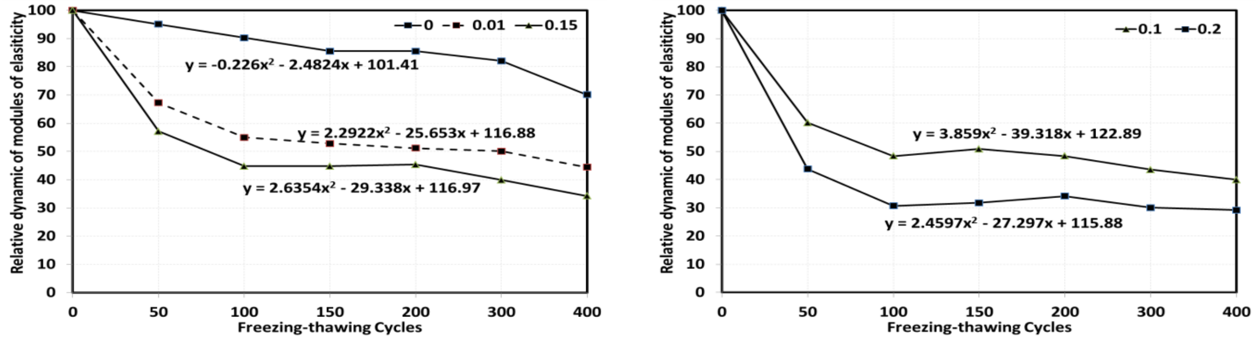
(a) (b)

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



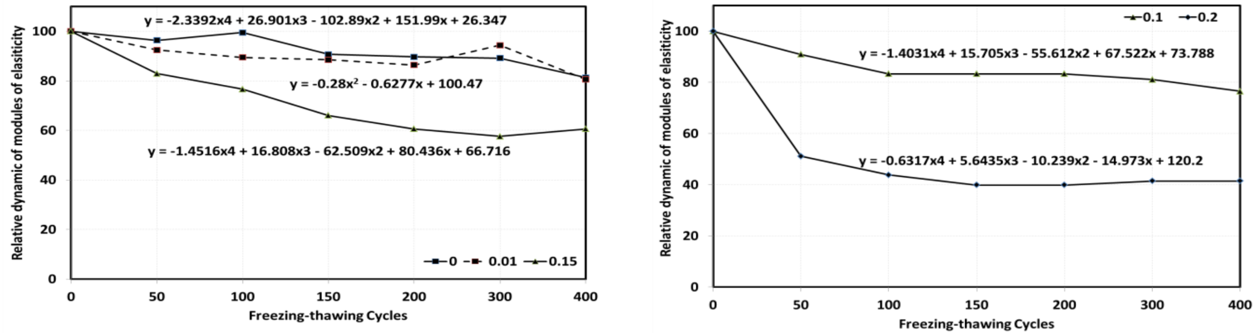
(a) Air-entrained to cement=0.01 (b) Air-entrained to cement=0.1

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.



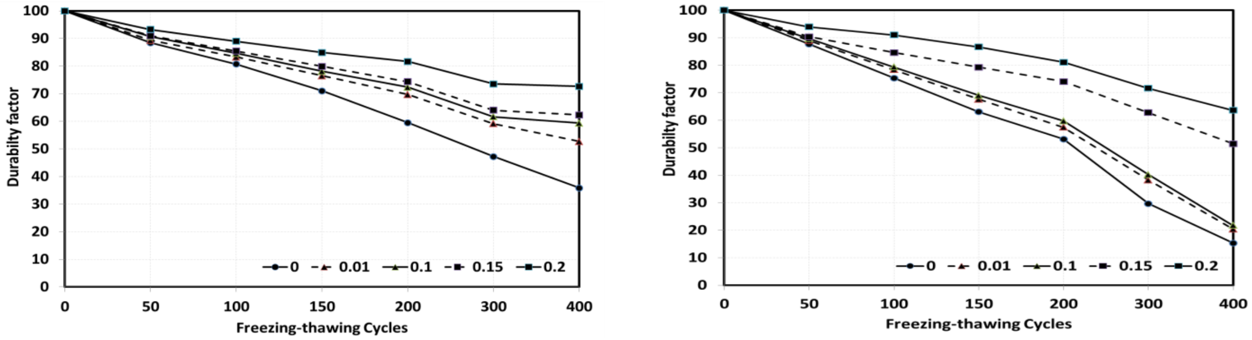
(a) Air-entrained to cement=0.01 (b) Air-entrained to cement=0.1

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..



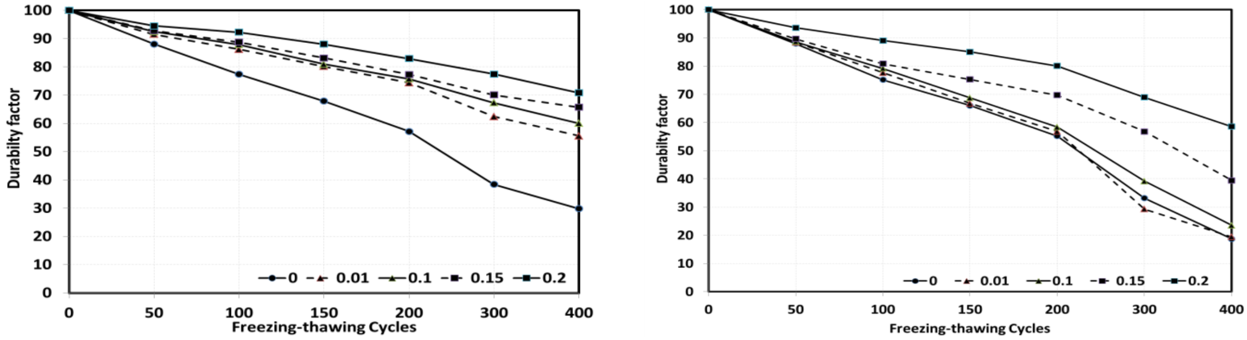
(a) (b)

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

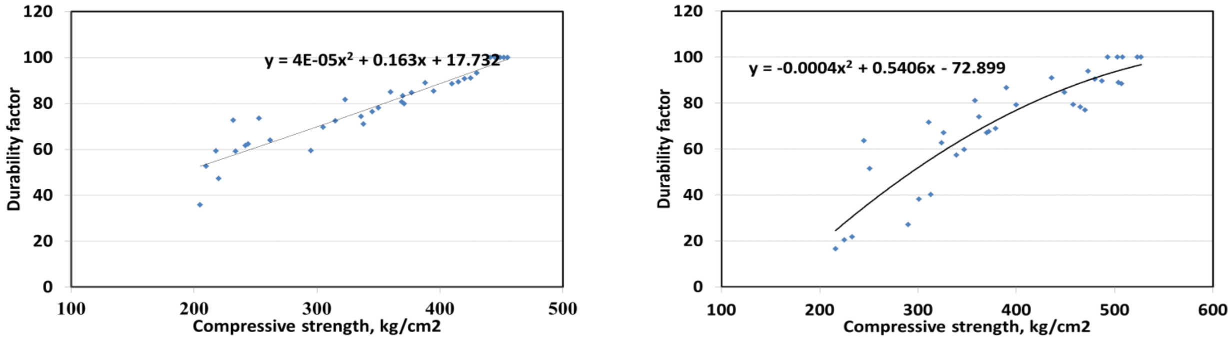


(c) Mixes with gravel as a coarse aggregate and Portland cement

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

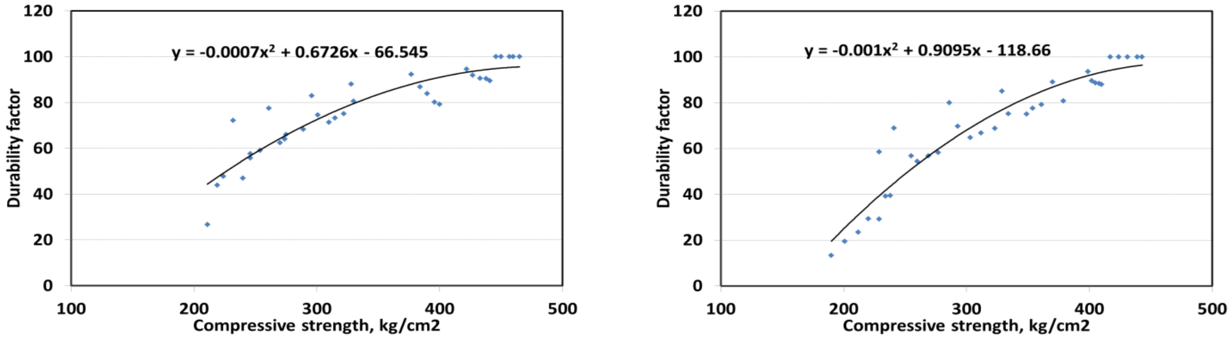
Fig. 17. Relationship between the freezing-thawing cycles on the durability factor at different dosage of air interned admixture.

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/cm^2 for the mixes with portal cement at 50, 100, 150, 200, 300 and 400 F-T cycles, respectively. In addition to the compressive strength for the mixes with limestone cement were 410, 385, 335,290, 270, 222 and 175 kg/cm^2 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.

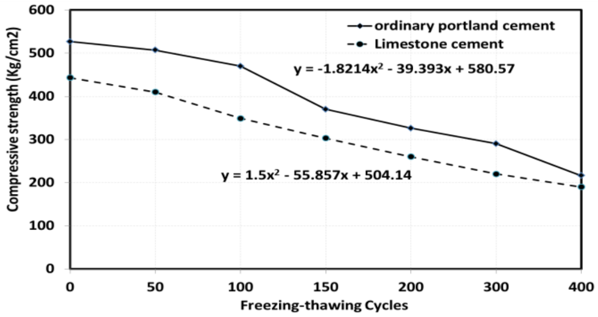


Fig. 19. Effect of cement type on the compressive strength at different freezing thawing cycles, dolomite.

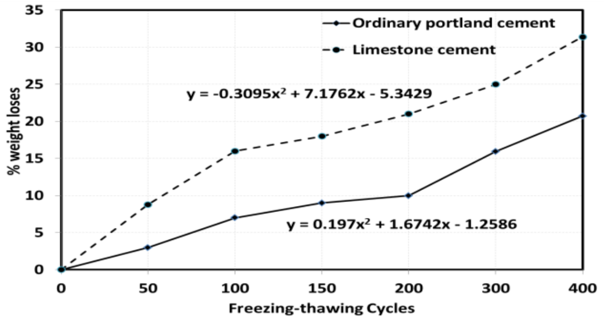


Fig. 20. Effect of cement types of the % weight losses at different freezing thawing cycles, dolomite.

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/cm^2 showed good F-T resistance where the durability factor more than or equal 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.

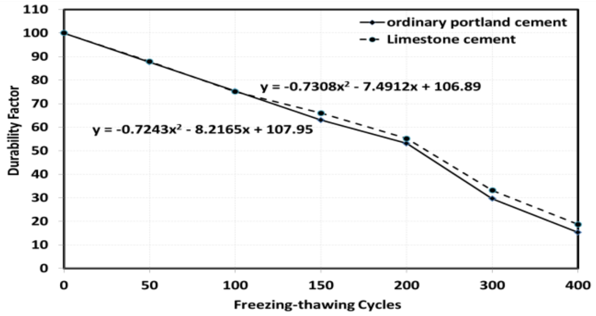


Fig. 21. Effect of cement type on the durability factor at different freezing thawing cycles, dolomite.

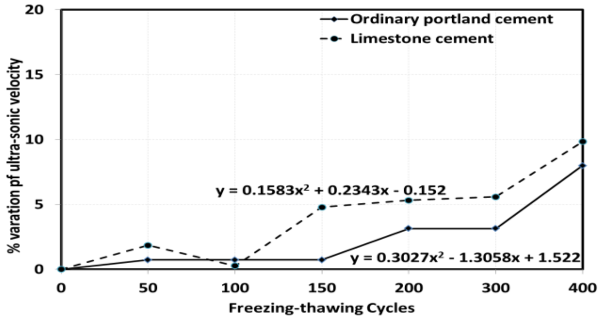


Fig. 22. Relationship between the % ultra-sonic velocity and freezing-thawing cycles for different types of cement.

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 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/cm^2 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/cm^2 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/cm^2 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.

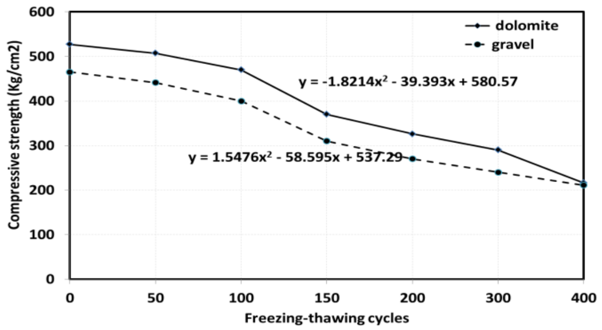


Fig. 23. Effect of aggregate type on the compressive strength at different freezing-thawing cycles.

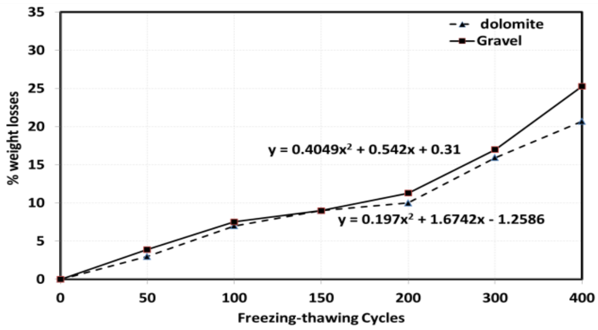


Fig. 24. Effect of aggregate types of the % weight losses at different freezing-thawing cycles.

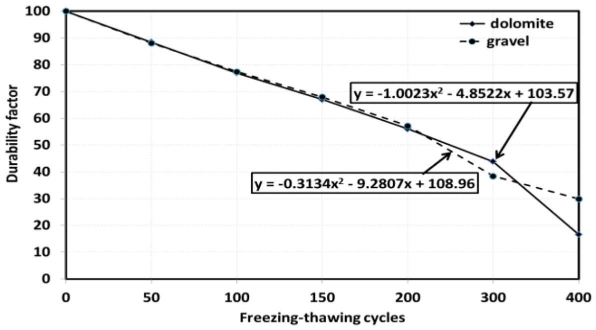


Fig. 25. Effect of aggregate type on the durability factor at different freezing-thawing cycles.

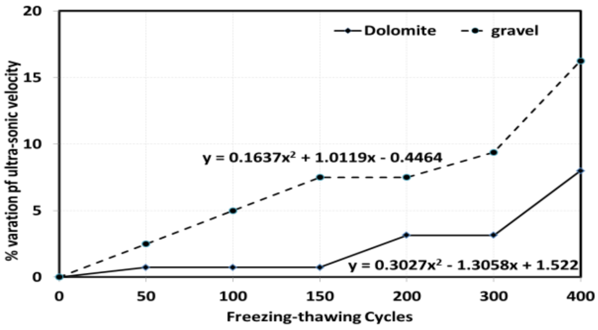


Fig. 26. Relationship between % ultra-sonic velocity and the freezing-thawing cycles for different types of aggregate.

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, 6.2and 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 ≥ 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 formulates 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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