Southern Journal of Engineering & Technology Vol. 02, Issue 01, 2024

Air Entrainment of Concrete Against Freeze And Thaw In Cold Areas of Pakistan

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Abstract: The study aims to investigate the influence of air entrainment in concrete against freeze-thaw. Standard cylinders with 150 mm diameter and 300mm length of two different mixes were cast and tested after 28 days against freeze-thaw cycles. The controlled specimens and the air-entrained mixes were exposed to 28 freeze and thaw cycles. Besides the freeze and thaw cycles, loss of mass and surface scaling were also measured. It is found that air-entrained specimens offer higher resilience to surface scaling than the control specimen. Similarly, weight loss is dominant in control condition specimens. A nondestructive test, the Schmidt hammer test was conducted for both the mixes before and following freeze and thaw cycles. The results reveal a low reduction in compressive strength of air-entrained mixes in comparison to the control specimen. The results further show that freeze-thaw is dangerous only when the sample is saturated to about 80%; below this freeze-thaw is almost ineffective. The experimental data recommend that air-entraining agents should be used in cold weathering areas like Astore and Skardu, where the average temperature in peak winter is about -13 ºC and the structures are exposed to daily freeze-thaw due to large differences in temperature during day and night.

Keywords: Concrete, Air-entrainment, Freeze and Thaw, Schmidt Hammer, Strength, Weight loss.

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1. Introduction

No one can deny that concrete and all technologies surrounding us have gone a long way since their discoveries. Middle Eastern architects discovered that a thin, moist coating of charred limestone applied to the outsides of their pounded-clay fortifications and dwelling walls reacted chemically with gases in the air to produce a hardened, protected surface around approximately 1300 BC. Concrete has become a more efficient material as time has gone on. The concrete's performance qualities might vary depending on the forces it must withstand. These pressures can occur from above (gravity), below (soil heaving), on the sides (lateral loads), or in the form of erosion, abrasion, or chemical assault, and they can be slow or strong. The design mix is a combination of concrete materials and proportions. Before the invention of cement in the 19th century, many natural materials like lime were being used as binding material. The use of cement in concrete made it possible to attain more strength within a short duration of time. During the 20th and 21st centuries, the most advanced forms of concrete were presented by researchers the world over Anwar Khitab & Anwar, (2016). These new smart materials can withstand harsh environments more effectively than conventional concrete. As technology advanced, so did the techniques of manufacturing concrete and cement. Today, concrete is the most extensively demanding and nonhomogeneous engineering material. It is even considered to be the first construction material on the surface of the moon A. Khitab et al., (2016). The durability of concrete is defined as the tendency to resist damaging effects on the environment without deterioration for a specific period. The durability of concrete involves resistance to freeze-thaw action, chemical attack, and so on H. Shang & Yi, (2013). Durability can be also defined as serviceability, as durable structure, stability, and strength should meet the requirements throughout the life span H. S. Shang et al., (2014). Internal cracking and surface scaling are the main damages that result from freeze and thaw action in concrete. Scaling may occur in any direction of the surface but mainly on the surface, which remains wet for longer periods. The scaling process increases significantly in case of the presence of any deicing agent on the surface of the concrete. Paul and Kelly studied the Freeze-thaw Resistance of Concrete and found that the air-entrained mixtures were predicted to have much higher freeze-thaw resistance than normal air-entrained mixes Kelly & Murphy, (2010). Cui et al. investigated the mechanical and failure criteria of air-entrained concrete under triaxle compression load after rapid freeze-thaw cycles and reported that after the same fast freeze-thaw cycles, the strength loss of air-entrained concrete is less than that of plain concrete under triaxial compression stress. Cui et al., (2017). They also anticipated that the failure mode of air-entrained concrete under triaxial compression strain would be unaffected by fast freeze-thaw cycles. Shang et al. studied the strength and ultrasonic velocity of air-entrained concrete and plain concrete in cold environments and reported that as the freeze-thaw cycles increased, the mechanical behavior of air-entrained concrete and plain concrete degraded. However, the loss of strength of air-entrained concrete specimens is lesser than that of the plain concrete specimens after the same freeze-thaw cycles H. S. Shang et al., (2014). Li, Yujing has reported that air entrainment is required even in dense concrete with a low water/cement ratio Li, (2007). He has also further elaborated that the combination of the air-entraining agent and the water-reducing agent, has a significant impact on frost resistance. Many admixtures and admixture combinations generate concrete with unreliable and unsuitable air pore systems. Korhonen studied the effect of high doses of chemical admixtures on the freeze-thaw durability of Portland cement concrete and found that the freeze-thaw process is merely slowed by air entrainment but it is not 100% prevented. The advent of high-performance concrete with its low w/c ratio favors that any water contained in its tiny microstructure should not freeze, however, air entrainment will continue to be necessary for concrete requirements until additional research indicates that high-strength concrete can be produced reliably in the field Korhonen, (2002). Shang et al. studied the freeze-thaw durability of air-entrained concrete and their investigation's findings state that as more freeze-thaw cycles were completed, the relative dynamic modulus of elasticity dropped. The relative dynamic moduli of elasticity of C25 and C30 air-entrained concrete were 94.36 and 98.77 percent after 100 freeze-thaw cycles, respectively while it was 64 percent for C30 plain concrete. As a result, air-entrained concrete has significantly better freeze-thaw resistance than plain concrete H. Shang & Yi, (2013). Shang et al. have suggested that the freeze-thaw endurance of plain concrete is low and may be improved by mixing with an air-entraining agent. It proves that standard-strength concrete can withstand freezing and thawing H. Shang & Yi, (2013). Prabir K. Kolay et al. investigated the freeze-thaw durability of air-entrained concrete incorporating natural and recycled concrete aggregates and found that before 150 cycles of freezing and thawing, samples lacking air-entraining admixture degraded significantly. As a result, adding an air-entraining ingredient to Portland cement concrete reduces weight loss and relative modulus of elasticity loss when the concrete is subjected to more freezing and thawing cycles Kolay et al., (2018). Smith et al. studied the service life of concrete in freeze-thaw environments and have reported that developing service life forecasts for freeze-thaw deterioration is still a developing subject of research and study. The forecast largely depends on parameters such as water-to-cement ratio, total air volume, air void spacing, and additional cementitious material capability gaps Smith et al., (2019).

In cold regions, concrete structures are often damaged gradually and their life span ends before the designed age and requires repairing. Air-entrained concrete is more resistant to heave and frost damage, making it ideal for use in the building of dams, multi-span bridges, and offshore structures in colder regions. This research work is intended to evaluate the effect of air-entraining agents on the freeze-thaw durability of local concrete. The important parameters examined, include weight loss, surface deterioration, and strength loss. The research is aimed at promoting the use of air entrainment in extremely cold areas of the country, where there is no prior history of using such techniques, and the buildings and bridges deteriorated by this devastating phenomenon causing huge loss to the national economy.

2. Materials and Methodology

2.1. Materials

Ordinary Portland cement (ASTM Type 1) was acquired from a local industry. The physical and chemical properties are mentioned in Table 1 and

Table *2* respectively.

Table 1. Physical characteristics of the cement

Parameter	Value
Color	Grey
Relative density	3.01
Consistency (%)	26.4
Fineness (%)	1
Initial setting time (min:)	51
Final setting time (min:)	610

Table 2. Chemical characteristics of the cement

Compounds	**Content (%)**
Silica	25
Lime	61
Iron Oxide	2
Alumina	5
ZnO	-
MgO	2
SO_3	2.4
K_2O	-
TiO_2	-
SrO	-
ZrO_2	-
V_2O_3	-
LOI	2.25

In this work Mangla coarse and fine of the city of Mirpur was used for making the Table *3* and *Table 4* respectively. Potable water available in the water supply network mixture. aggregates were used, whose properties are given in

Table 3. Physical characteristics of coarse aggregates

Property	**Value**
Water absorption (%)	1.49
Relative density	2.51
Bulk density (kg/m^3)	1601

Voids (%)	34.11
Impact Value (%)	13.2
Crushing Value (%)	28.2

Table 4. Physical properties of fine aggregates

Property	**Value**
Relative density	2.7
Fineness Modulus	2.71
Apparent Density (kg/m^3)	1502
Dry Bulk Density (kg/m^3)	1848
Water Absorption (%)	3.9
Moisture Content	2.1

The Air air-entraining admixture PAGEL X3 was used for air-entrainment purposes. This material is ready to use liquid admixture. The air-entraining admixtures are surfactants, which reduce the surface tension between the water and solid portion of the mix. As such more water gets detached from the mix, which ultimately creates air bubbles of the desired size. Or for more convenience, they can also be regarded as detergents, which create air bubbles in concrete mixing water. The modern air-entraining agents include but are not limited to fatty acids, resins, and sulfonated organic compounds. The used admixture is recommended for producing high-slump air-entrained concrete Vertex Pakistan, (2021). The admixture was added to plain concrete at a rate of 2.5 ml/kg of cement (0.26% by mass of cement). The concrete composition is summarized in Table 5.

Table 5. Concrete composition

	Cement (kg)	Sand (kg)	Coarse aggregates (kg)	Water to Cement ratio
Weight	300	660	1400	0.45

2.2. Methodology

Concrete was prepared by using a tilted drum mixer, as shown in Fig. 1. According to the requirement and capacity of the mixer concrete is prepared in four batches, two for controlled condition and two for modified condition. Here, batching by weight is carried out for the M15 (1: 2: 4). Similarly mixing by weight is preferred as it is an easier method, and it is the most preferred method for the mixing.

According to the experimental plan, 12 cylindrical specimens under control conditions and 12 cylinders under modified conditions were needed for different tests to be performed. After the introduction of one-half of the coarse aggregate sand and cement into the mixing drum, dry mixing was performed for 2 minutes. Then the remaining half was added with some water and the mixer was rotated for another 2 minutes at a 15º tilted angle. Finally, all required water (w/c=0.45) was added and the mixer was rotated until a uniform texture was acquired, as shown in Fig. 1. After casting 12 cylinders for control conditions same procedure is repeated for modified i.e., air-entrained specimens by adding the estimated amount of air-entraining agent. The admixture is first added in water and then water is mixed with other ingredients of concrete.

Fig. 1 Mixing of concrete ingredients in a tilted drum mixer

For the casting of test specimens i.e., cylinders, the molds have been thoroughly cleaned and moistened. The fresh density of the specimens was measured after the slump test. The cylinders of the standard size (150mm x 300mm) were cast by filling concrete in three to 4 layers and compacting each layer with 25 blows of temping rod. Surface finishing was done and de-molded after 24 hours, as shown in Fig. 2. Coding such as “C” for control samples and “M” for modified samples was marked to identify easily while used for tests.


(a) (b)

Fig. 2 Cylinder casting;(a) Cylinders just after casting (b) Surface finishing while casting

The workability of the concrete is determined after it has been prepared and before the samples are molded. Two workability tests are performed i.e. slump and compacting factor. The slump test was carried out by using ASTM standard method C143/C143M (ASTM C143/C143M, 2015), and the compacting factor test was performed using standard method IS 1199-1959 (IS 1199:1959, 2013). The slump test is shown in **Error! Reference source not found.**, whereas the compacting factor method is shown in Fig. 4.

Fig. 3. Slump test

Fig. 4 Compaction factor test

For curing, specimens are placed in a curing tank soon after demolding for 28 days. The compressive strength of the cylinders at 3 and 28 days as per standard method ASTM C 39 (ASTM C39, 2015). The prepared concrete cylinders are shown in Fig. 5. Before the test, samples were dried and surface-cleaned.

(a)

(b)

Fig. 5 (a) Controlled Specimen (b) Air Entrained Specimen

Schmidt hammer test is a nondestructive test and may be used to find the in-plane uniformity of concrete. The test is an indicator of the compressive strength based on a rebound number. The test was performed by the standard (ASTM C805/C805M-18, 2018).

Porosity is an important parameter affecting the durability, freeze-thaw, and corrosion resistance of concrete. Concrete is a porous material, and its performance is closely related to porosity. In this study, porosity is used as a durability predictor. The resistance of concrete specimens to rapid repetitive freezing and thawing cycles in the laboratory was determined using the standard method ASTM C 666 (Astm C666/C666M, 2003). The apparatus and testing are shown in Fig. 6.

(a) (b) (c)

Fig. 6 Freeze-thaw test

(a) (b)

Fig. 7 (a) Failure mode of C.C.S after 28 days (b)Failure mode of A.E.S after 28 days

The failed concrete cylinders after the compression test are presented in Fig. 7.

According to the ASTM standard code the specimen is made by cutting a core of 3 inches in diameter and 12 inches long, as shown in Fig. 8.

(a) (b)

Fig. 8. Core cutting for Freeze-thaw test

2.3. Results and Discussion

Workability

Slump test

The slump test of the two types of concrete under investigation is shown in Fig. 9, whereas the results are given in Table 6

Table 6. Effect of air entrainment on slump

(a) (b)

Fig. 9 Slump test (a) Control specimen and (b) Air-entrained concrete

Specimen	Slump (mm)
Control	86
Air-entrained	152

The results show that workability improves with the entrainment. The induced air bubbles act like spherical balls, which reduce the friction among the cement particles. As such the mobility of the paste is enhanced, which increases the workability “Concrete,” (2011).

2.4.. Compacting factor test

The outcome of the compacting factor method is summarized in Table 7.

Table 7. Effect of air entrainment on compacting factor

Specimen	Compacting Factor
Control	0.79
Air-entrained	0.92

The results show that the compacting factor improves with the entrainment. This method is considered to be more precise than the slump test for concretes, which are compacted by vibration. The relationship between workability, slump, and compacting factor is presented in Table 8 A. Khitab, (2012). The air-entrainment increases the workability as confirmed by both tests.

Table 8. Correlation among workability, compacting factor, and slump (A. Khitab, 2012)

Workability	Compacting Factor	Slump (mm)	Applications
Very low	0.8	0 to 25	Rigid pavements
Low	0.85	25 to 50	Mass concrete
Moderate	0.9	50 to 100	Normal
High	0.95	100 to 175	Congested reinforcement

3. Compressive strength

The compressive strength test outcomes are presented in Fig. 10. The results pertain to an average of five specimens. The results show that air entrainment slightly reduces the compressive strength, but the reduction is only 5% at 3 days and 3% at 28 days. According to Richardson, the air entrainment reduces the compressive strength of the concrete (Richardson, 2007). The strength reduces by almost 5% per unit percentage of the air-entraining agent. Thus the experimental results are in coordination with the past studies.

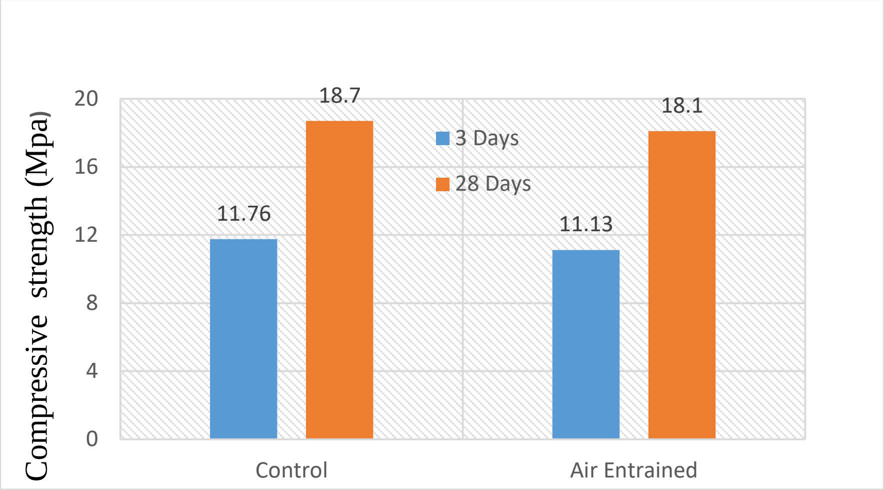


Fig. 10 Variation of compressive strength with air entrainment.

4. Rebound Number (Schmidt hammer test)

The rebound numbers as obtained by the Schmidt hammer test are summarized in Table 9. The results present an average of 6 values.

Table 9. Rebound number and compressive strength

Specimen	Rebound number	Actual Compressive strength (MPa)
Control	21	18.7
Air-entrained	19	18.1

The results show that the rebound number slightly decreases with air entrainment. The accuracy of the compressive strength by this test varies from 15-20% (Majeed et al., 2021). As such the values are a fair indicator of the compressive strength.

5. Fresh and Hardened Densities

The fresh and hardened densities are shown in Table 10. The hardened density was determined at the age of 28 days. The results show that both densities decrease with air-entrainment. The fresh density decreases by approximately 6% and the hardened density reduces by 5%. The decrease is attributed to the stabilization of air voids to surface tension provided by the surfactant (air-entraining agent). Many researchers have indicated that the compressive strength and the density are inversely related. A higher density leads to higher compressive strength and vice versa (Othman et al., 2021).

Table 10. Fresh and hardened densities

Specimen	Fresh density (kg/m^3)	Hardened density (kg/m^3)
Control	2548	2476
Air-entrained	2397	2351

5.1. Porosity

The evolution of water porosity with time is shown in Fig. 11. The results show that porosity increases with time and attains a constant value after 32 hours. There is a slight increase in the porosity of air-entrained concrete (approximately 3%). The porosity results are closely linked to the density and compressive strength as mentioned earlier.

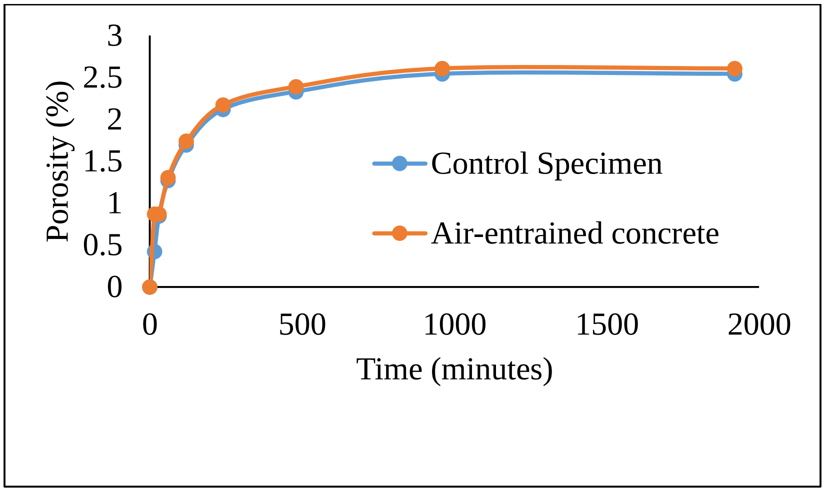
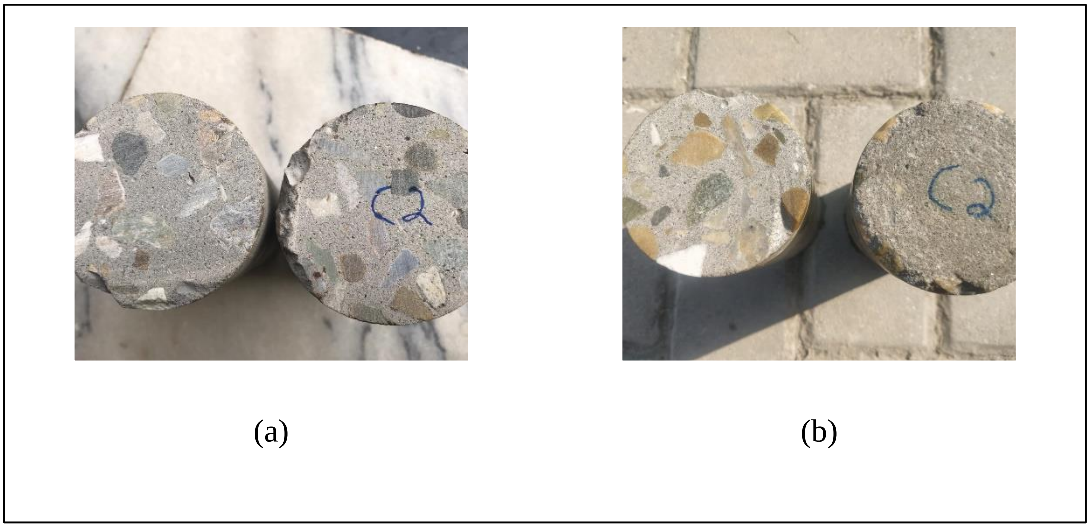


Fig. 11 Evolution of water porosity with time

5.2. Freeze-thaw

Surface deterioration

The two specimens (control and air-entrained) are shown in Fig. 12. Fig. 12(a) shows the specimens before freeze-thaw cycles and Fig. 12(b) shows those after freeze-thaw cycles.



(a) (b)

Fig. 12 (a) Before freeze-thaw (b) After freeze-thaw

It can be seen that after freeze-thaw surface scaling has occurred in the controlled sample while the air-entrained sample is unaffected. However, the dimensions of both specimens remained intact even after 20 freeze-thaw cycles.

5.3. Compressive strength

The loss of compressive strength after 20 freeze-thaw cycles is shown in

Table 11 Comparison between compressive strength before and after freeze-thaw

Specimen	Compressive strength before freeze-thaw (MPa)	Compressive strength After freeze-thaw (MPa)	% difference
Control	18.7	13.00	3.1
Air-entrained	18.1	14.10	2.2

The results show that the air-entrained concrete can withstand the freeze-thaw cycles better than the plain concrete. This is due to the presence of stable void spaces within the air-entrained concrete. The results are in coordination with the porosity and strength values as mentioned above as well as with the past studies. According to Shang et al., the loss of compressive strength is lesser for air-entrained concrete as compared to the relevant plain concrete without any air-entrainment (H. Shang et al., 2014).

5.4. Weight loss

After 20 freeze-thaw cycles, the weight loss in the control specimen and the air-entrained concrete was determined and is summarized in Table 12.

Table 12. Weight loss comparison between plain and air-entrained concretes

Specimen	Initial mass (gm)	Final mass (gm)	% loss in mass
Control	1580	1575	0.32
Air-entrained	1475	1475	0

The results show that the air-entrained concrete remains stable and does not show any weight loss after 20 freeze-thaw cycles.

6. Conclusions and Recommendations

Conclusions

The effects of AIR-ENTRAINMENT on local concrete are studied. The parameters examined include fresh and hardened densities, water porosity, compressive strength, and freeze-thaw (20 cycles). The air-entrainment agent was added to plain concrete (1:2:4 with 0.45 w/c ratio) at the rate of 2.5 ml/kg of cement. The findings are summarized as follows.

- The air entrainment enhances slump by 77% and compacting factor by 16.5%.
- The initial compressive strength (3 days) of air-entrained concrete reduces by 5% and the final compressive strength (28 days) reduces by only 3% as compared to that of plain concrete, which is not significant.
- The rebound number as determined by the Schmidt hammer is a fair indication of the actual compressive strength of both plain and air-entrained concretes.
- Air entrainment reduces the fresh density by 6% and the hardened density (28 days) by 5% and hence the resulting structures will be light in weight.
- The porosity of the air-entrained concrete is 2.6% less than that of the plain concrete.
- Air entrainment results in zero surface deterioration after 20 freeze-thaw cycles.

- The loss of compressive strength after 20 freeze-thaw cycles is 30% less than that of the plain concrete.
- Air entrainment results in zero weight loss after 20 freeze-thaw cycles.
- Based on the conclusions, the entrainment of bridges, roads, and buildings in northern areas, which are subjected to extreme cold is highly recommended for the socio-economic development of the country.

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