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Air Entrained Self Compacting Concrete for Extreme Cold Region of Ladakh-A Report

Arghadeep Dasgupta
arghadeep.dasgupta24@gmail.com

Abstract: Concrete which has microscopic bubbles in it is called Air entrained self compacting concrete. The method of forming a small tiny bubble in the concrete is known as Air entrainment. During the concrete making process, some air entraining nano-particle along with inorganic salt enhancing self-compaction of concrete are added in the concrete which forms air bubbles in it with enhanced hardening property. Bubbles are created in the concrete when the concrete is in the plastic stage, most of the bubbles are surviving in the hardened stage of concrete. The main primary purpose of the air entrainment in the concrete is to increase the durability of the hardened concrete where the climates are subject to freeze and thaw. The main secondary purpose is to increase the workability of concrete at its plastic stage. Due to air stickier is produce so it gives good less result of segregation and good attractive surface of the concrete.

Keywords: *Self-compacting concrete, water mixing method, entrained air nano-capsule, freezing / thawing, workability of concrete, inorganic salt etc.*

Introduction:

Self-compactability of concrete mortar is illustrated with air entrainment and other laboratory test results. The desired level of compactability was achieved with air content of approximately 14% by controlled mixing method. An effective mixing method called water dividing and AE dividing mixing method were introduced in order to increase level of compactability of fresh concrete. This could be even achieved with lower air content which was approximately 10% by water dividing mixing method. This resulted in the development of new type of self-compacting concrete (SCC) called air-enhanced self-compacting concrete (airSCC). This concrete was developed by making use of ball bearing effect of entrained air. Effective air bubble for airSCC was entrained with water- dividing mixing method and excessive dosage of air-entraining agent. These resulted in air-enhanced self-compactability of fresh concrete. Accordingly, aggregate amount in concrete mix proportions could be increased, resulted in the reduction in cement content, requirement of fine sand in mix proportions. Air entrain concrete is a manmade mixture of concrete with controlled air pockets in it. In fresh concrete, the tiny air bubbles act as a lubricant in the mix which improves its workability and increases its slump. The Air bubbles provide the space for the Expansion of the concrete due to freezing and thawing and protect concrete from cracks and damage.

Also, in a sense, the bubbles function as a third aggregate. Because of their small size, the bubbles act as fines, thereby cutting down the amount of sand needed. In this study we observe controlled intrusion of nano air bubbles and inorganic salt mix which enhances self compactibility of concrete.

Figure 1: Site Location where Air Entrained SCC is used

Air-entrained self-compacting concrete is an concrete mix design for structures exposed to severe frost action and de-icers. This method is useful for constructing heavy engineering structures like hydrao-electric dam, via-ducts, lined tunnel etc. in areas exposed to heavy freezing and

thawing.

In these construction project, although the labor cost for concrete work could be reduced by employing SCC, total cost of concrete work is still high, comparing to that of concrete work using normal concrete.

Entrained air is well known as the factor that is added to concrete mix in order to improve freezing and thawing resistance of concrete in the cold environment. Furthermore the secondary benefit of entrained air has been observed in workability enhancement. Slump of fresh concrete increased approximately 10 to 50 mm by increasing entrained air approximately 5%. Therefore entrained air enhances flowability of concrete mix.

Figure 2: In-Situ Casted Cube for determining Compressive Strength

Literature Review:

Properties of Air Entrained Self Compacting Concrete:

Workability: - If the workability of air entrained scc is improved than reduce water and sand requirement particularly in lean mixes of concrete. If the air bubbles are disconnected then it reduces segregation and bleeding of plastic concrete.

Freeze-Thaw and Durability: - In the freezing process, the water is expanding and create enough pressure for rupture in the concrete. Air bubbles work in the concrete as reservoirs to protect the concrete from the expansion water and protect the damage in concrete.

De-icers Resistance: - Air entrained scc is mostly used where concrete is contact with de-icing chemicals because entrained air prevents scaling caused by de-icing chemical use for snow and ice removal.

Sulphate Resistance: - If concrete is made with low w/c ratio, entrained air and cement having low tri-calcium aluminate content is useful to resist the sulphate attack. Entrained air is very useful to resist the sulphate attack in concrete.

Figure 3: Group Pile Casted with Air Entrained SSC

Strength:-The strength of air entrained scc is basically determined from the voids to the cement ratio. In this ratio, voids define as the total volume of water plus air. If the air content in concrete remains constant the strength varies inversely with the w/c ratio. If the air content increases than we can generally maintain a given strength by the help of holding the voids to the cement ratio constant.

Abrasion Resistance: - The abrasion resistance in the air entrained scc is the same compressive strength of non-air entrained self compacting concrete. If abrasion resistance increases than the compressive strength also increase.

Water Tightness: - The water tightness of air entrained self compacting concrete is more than the non-air-entrained scc. Entrained air prevents the interconnection of capillary channels from forming. So, air entrained self-compacting concrete is very useful where water tightness is required.

Effect of Air Entrainment on Strength of Concrete:

The main thing which is affected by the air entrained self-compacting concrete is workability and the compressive strength of concrete. The air entrained self-compacting concrete has increased the workability of concrete without increase the water-cement ratio. If the workability of the concrete is increasing than compressive strength is automatically decrease because workability and the compressive strength are always inversely proportional to each other.

Figure 4: Concrete Testing at Site

Air entraining admixture commonly introduced to increase concrete workability without affecting the concrete strength very much. The air-entrained concrete having 7.5 cm slump is better than the slump of 12.5 cm of the non-air-entrained concrete. If we use air-entrained admixture in large or huge quantity than the compressive strength of concrete is reduced. The common factors which affect the reduction of the strength of concrete are mix proportions, type of concrete, and grading of concrete, type of cement, and entraining agent.

The strength of concrete reduces with the use of air entrained admixtures is varied from 3 to 7%. The variation of this 3 to 7% is considered in the concrete mix design so the desired compressive strength is achieved with the required amount of admixture and workability. Before design trial mix designs are done and find the exact variation of strength with the use of the admixtures and then suitable corrections are done in the mix design. Generally assumed that a loss of 5% of the compressive strength of concrete occurs due to each 1% by volume entrained air in the concrete mix.

For estimating of the water-cement ratio required for an air entrained self-compacting concrete which allows for strength reduction is incorporated in the mix design and assumes the high target mean strength. High target mean strength for an air-entrained mix is given by:-

Target mean strength = f_c + m/ (1-0.055a)

where, f = specified characteristic strength,
m = the margin
a = % by volume of entrained air

Figure 5: Pile Load testing at site with Air-SCC

Effect of Air Entrainment on Flexural Strength of Concrete: The reduction of flexural strength of the concrete due to air entrainment is generally not determined as in case of compressive strength. From the report, if the air content is 4% in concrete than achieved maximum flexural strength. From both the case it concludes that compressive and flexural strength of lean concrete mix design increase

with provided that, maximum water reduction considers and small maximum aggregate size is employed.

Air-entrained Self-compacting concrete (SCC) is used at construction site affected with freezing and thawing is to enhance durability of concrete structures. Cement or powder content of SCC is approximately two times higher than that of conventional concrete for achieving self-compactability of fresh concrete. This resulted in high unit cost of SCC because unit cost of concrete mainly depends on cement content in mix proportion. Furthermore to avoid flowing obstruction by coarse aggregate, coarse aggregate content is limited approximately as 30% of unit volume of concrete. In construction project, where in accessibility is a factor of concern leading to restriction of machine and equipment also higher labour cost at remote freezing terrain air –SCC is extensively used for greater workability and attainment of higher shear strength.

Workability:

The introduction of air into concrete mixes has some pronounced effects on the characteristics of both the plastic and the hardened concrete. In fresh concrete, the tiny airbubbles act as a lubricant in the mix which improves its workability and increases its slump. Also, in a sense, the bubbles function as a third aggregate. Because of their small size, the bubbles act as fines,thereby cutting down the amount of sand needed.

Figure 6: Air Entrained SCC Technical Properties

Because air entrainment affords increased slump, it is possible to decrease the amount of water to get higher strengths without affecting workability. Less water means less drying shrinkage always a desirable feature.

Bleeding in concrete is cut approximately in half by entrained air. This reduces considerably the adverse effects of a higher water/cement ratio at the surface of slabs and of laitance forming on concrete surfaces. Air also produces stickier, more cohesive concrete; as a result, less segregation is experienced and more attractive surfaces are achieved.

In hardened concrete, the outstanding attributes of air entrainment are the enhanced weather ability and resistance to scaling afforded. Damage to concrete by freezing and thawing is caused when enough ice forms in the capillaries to create a pressure greater than the tensile strength of the cement paste. This disrupts the capillary walls. Where enough air voids are present, however, hydraulic pressure created by freezing forces the remaining water into theair voids. These air voids in air entrained self-compacting concrete act thus as a safety valve by giving the water a reservoir into which to flow. When thawing occurs, compressed air in the voids forces the water back into the capillaries, thereby freeing the voids for use again during the next freeze.

Test sections of foundation at sub-zero temperature in Ladakh State built with air entrainment resulted in to better foundation durability. For working in logistically remote places like Ladakh and Arunachal Pradesh, the workability of mixes containing angular and poorly graded aggregates is improved greatly with entrained air. It is not a cure-all ofcourse: if concrete is made with un-sound or soft aggregates, pop outs may occur whether the mix is air- entrained or not. But such surface defects should not be confused with surface scaling, which is significantly reduced by entrained air.

Segregation and excessive bleeding, common characteristics of unsatisfactory concretemixes, can be reduced or eliminated by use of entrained air. Segregation refers to the separation of gravel or crushed stone from the mortar (cement, sand, and water) in fresh concrete. It results in a non-uniform concrete. Bleeding is the term used to describethe appearance of water on the sur face of freshly placed concrete. Excessive bleeding increases the water-cement ratioof the mix at the surface of the concrete and thus weakens thewearing sur face. Bleeding also carries silt, clay and other nondurable materials to the sur face. Many of the common defects in hardened concrete can be traced to excessive segregation and bleeding. Not only does air-entrained concrete minimize segregation but the billions of disconnected air bubbles also provide a barrier to the movement of water to the sur face, thereby reducing the formation of capillaries or channels. This in turn reduces the possible later passage of water through the hardened concrete, resulting in a more watertight concrete—which means longer life and less maintenance.

Figure 7: Concrete Cube Casted with Air Entrained SCC

Most concrete contains some moisture which expands during freezing temperatures. Without room for this expansion, large forces develop that can rupture the surface causing what is commonly called surface scaling. The small, entrained air bubbles serve as reservoirs or expansion chambers to relieve these pressures. Research has shown that the spacing and size of air bubbles are important in assuring their proper action. Tobe effective, bubbles must be spaced not more than .01 inchesapart throughout the cement paste. Using today's methods of entraining air, it is not difficult to obtain this bubble spacing.

Entrained air means more than just durable concrete to the contractor; it means more plastic concrete that can be hauled and placed easier, that flows into forms and around complex reinforcement easily and with less vibration. It means concrete that will discharge and flow down longer chutes with flatter slopes; concrete that can be finished sooner and with resultingsurface textures remarkably free of pits, honeycomb or other blemishes. It means concrete that can be placed with lower slumps due to the substantial increase in workability of air - entrained concrete.

Figure 8: Air Entrained SCC cube with controlled moisture content

Mixing Process:

As per the data received from the earlier performed experiments, the following amounts of air should be specified for air-entrained concrete. These air contents provide adequate safety against scaling due to ordinary deicers and deterioration due to freezing and thawing

Sl	Size of Coarse Aggregate	Air Content
1	4cm to 6cm	1% to 5%
2	2cm to 3cm	1% to 6%
3	1cm to 1.5cm	1% to 7.5%

Air contents are usually expressed in terms of percent air by volume of the concrete. Air is entrained only in the paste, cement and water portion of a mix. Since the amount of paste varies with the size aggregate used, it follows that the air content in the total mix will also varywith the size aggregate.
Forms should be ready when the ready mix trucks arrive with air entrained self compacting concrete. Lifts of concrete should be no deeper than 12 to 18 inches and each lift should be puddled or vibrated to remove the large entrapped air voids. These air voids are not entrained air and usually result in pitted surfaces. Entrapped air voids occur in all concrete, air-entrained or not, and a conscientious effort should be made to eliminate them during placing.

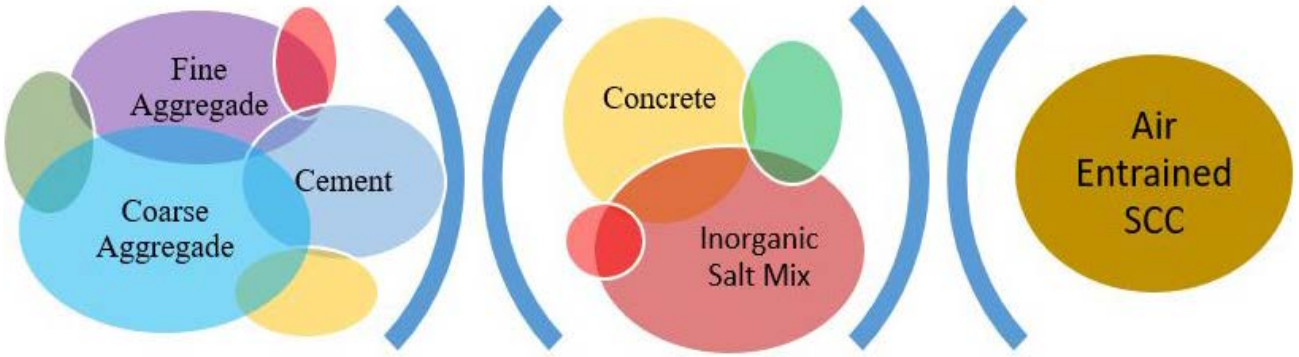

Figure 9: Chemical Process involved in Air Entrained SCC

All the materials are placed in the mixer & mixed well. The sample is taken out and poured in to the moulds. For this test, 2 types of Inorganic salt mix as plasticizer is used in order to reduce absorption of cement in SSC, along with air entraining agent were used. Ordinary Portland cement was used as cementitious material. Water cement ratio and Sand to mortar ratio were fixed as 45% by weight and 55% by volume respectively. Total coarse aggregate is 30% of volume of concrete.
Cement, sand and coarse aggregate were mixed for 30 seconds. Then liquid materials, water, inorganic salt, air entraining nano-particles were added and mixed for 2 minutes for mortar and 3 minutes for concrete. Slump-flow test, air contents test and box test were carried out for fresh concrete was tested by. Materials used in this study are given in table below:

Cement	Fine aggregate	Coarse aggregate	**Plasticizer**	**Air-Entraining Agent**
Ordinary Portland cement (3.15g/cm3)	Crushed Limestone sand	Size 5-15 mm 60% Size 15-20 mm 40% Total coarse aggregate is 30 % of volume of concrete	Inorganic Salt	Air-entraining Nano particle capsule

Firstly, cement and sand were mixed together for 30 seconds, and then 50% of water with inorganic salt mix were added and mixed for 60 seconds. At this step, mortar is made softer before adding air entraining nano-capsules. This might affect characteristic of air bubbles in mortar. Then another 50% of water with air entraining agent were added and mixed for 60 seconds. Once the proper mortar was achieved, air content was measured, then flowability test of mortar was measured, then glass beads was added to mortar and stirred for 20 times, finally flowability of mortar with model coarse aggregate were measured. The proper mortar mix was repeated 2 more times to confirm the stability of the results.
After the moulds are being casted they are placed in freezing cabinet having a constant temperature not warmer than -23°C for 24 hours and removed as per IRC: SP: 89 (Part II)-2018. The specimen is weighed and measured. Then the cubes are placed in a moist chamber at 25°C to 30°C and relative humidity of 100% for 24 hours and removed. After 12 cycles of these repeated process along with intermediate scaling and crapping of the surface area the specimen is dried at 110°C and determine the dry density of the sample.
After proper curing, the samples are placed under UTM to determine the desired compressive strength, result of whose are tabulated below:

Test Result:

Result of the sample are tabulated below:

Sl	Ingredient	Non Air Entrained	Air Entrained-SSC
1	Water	135 Litre	112 Litre
2	Cement	270 Kg	250 Kg
3	Coarse Aggregate	860 Kg	860 Kg
4	Fine Aggregate	560 Kg	510 Kg
5	Inorganic Salt	NA	4% of total volume
6	% Air Content	1	5
7	28 Days Compressive Strength	30 MPa	29.5 MPa
8	Unit Weight	2.4 gm/cc	2.3 gm/cc
9	Slump	8.9 cm	8.9 cm
10	Workability	Fair	Excellent

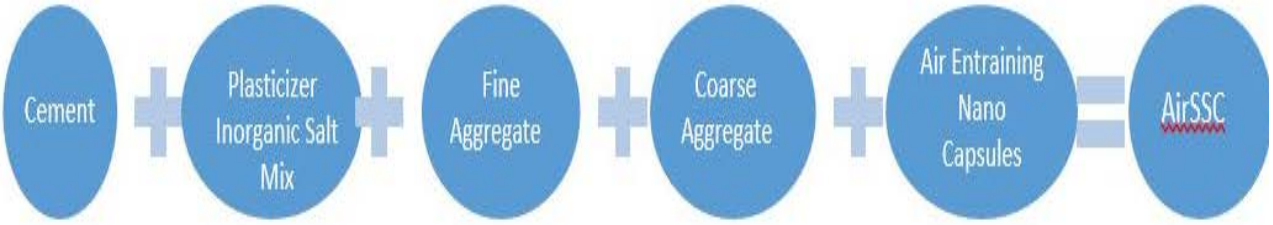

Figure 4: Flowchart of the Process

Conclusion:

Post laboratory test, the findings suggest that in enhancing self-compactability of fresh concrete by employment of entrained air along with inorganic salt mix enhances the self-compactibility of concrete in region affected by freezing and thawing.
High level of self-compactability could be achieved with air content of over 15% by simple mixing method, It is also observed that after a specific % of nano-capsule of air-entraining chemical by volume there is a decrease in compressive strength, which could be compensated with addition of required inorganic slat mix as per the desired proportion, also it is observed that the workability of the air-SCC mix is considerably better with no increase in slump.
It is further observed that, the strength of air-SCC concrete depends on the water/cement ratio and inorganic salt mix proportion,thus can be designed as per desired strength.

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