Efficacy of Superabsorbent Polymers on High Strength Concrete in Cold Weather Conditions

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Abstract: One of the key considerations in concrete technology is gaining control over water. Water is needed to hydrate the cement, mixing, transporting, placing and compacting. With the little increase of free water content the danger of segregation, bleeding of fresh concrete increases, and consequence to this reduction of durability. The effects of cold weather concreting are delayed setting, freezing and cracking. Super Absorbent Polymer (SAP) is a new type of Internal curing material. They contribute to the control of the rheological properties of fresh concrete, mitigation of autogenous and plastic shrinkage through internal curing. It will not affect the durability of concrete. This article gives an overview of performance of superabsorbent polymers (SAPs) on Durability aspects of High Strength Concrete (HSC) in Extreme Cold Climatic Conditions.

Keywords : Superabsorbent Polymers (SAPs), High Strength Concrete (HSC).

I. INTRODUCTION

Leh, along with Kargil, forms the region of Ladakh in East Kashmir. Ladakh, a high-altitude plateau, is a cold desert lying in the Western Himalayan mountains very often called “moonland” due to its peculiar terrain. The Himalayas shadow Ladakh and form a very effective barrier to rain. Few clouds creep across their awesome heights and as a result Ladakh is barren without relief. Being a cold desert, the weather conditions in Ladakh are extreme. The soil is underdeveloped and precipitation is hardly 100mm and vegetation is very sparse. A major source of water for drinking and irrigation is glacial melt water. Located in the leeward side of the trans-Himalayan range, the region receives no precipitation from the south-west monsoon. For permanent infrastructures concrete is the material, but concrete needs curing for attaining its strength. To address this problem SAP is used in concrete which cures concrete internally to achieve the strength.

For development of strength, cement content in concrete needs to be completely hydrated. The water present in SAP will continue to hydrate the cementitious material even after 14 days. This will create evenly distributed pores inside concrete and this will help to sustain the freeze thaw effect. To study the effect of SAP in high strength concrete an experiment program was conducted and results are discussed in the present article.

II. PROPERTIES OF SAPs

Super absorbent polymers (SAP) are made up of cross-linked networks of hydrophilic polymers which have the capacity to retain and absorb large amount of aqueous solutions or water. When SAPs are exposed to water, they swell, and when subsequently subjected to drying, they reversibly shrink. SAPs are polymeric materials that have the ability to absorb a large amount of liquid from the surroundings and retain it within their structure. They are mainly developed for absorption of aqueous solutions and, in extreme cases, they may have a water uptake of 5000 times their own weight [4]. Standard, industrial-quality SAPs typically have a water absorption of 100 to 400 g/g dry and they can be produced in almost any size and shape. SAPs have extreme water absorption characteristics; this makes them particularly interesting in relation to concrete. Due to the water absorption, SAPs may also be considered a means to control porosity, which is another important property for concrete. The principle of using SAPs as a concrete admixture has received considerable interest—both from the concrete research society and from the industry.

III. INFLUENCE ON STRENGTH

Addition of SAPs to concrete has two opposite effects[5]: while the SAP generates voids in the concrete and thus reduces strength, the internal water curing provided by the SAP enhances the degree of hydration and thereby increases the strength. Which of these two effects is dominant depends on the water-cement ratio (*w/c*), the maturity of the concrete, and the amount of SAP addition. In particular, at a high *w/c* (>0.45), SAP addition has very little effect on hydration and therefore generally reduces compressive strength. At a low *w/c* (<0.45), SAP addition may increase the compressive strength. This type of water binder ratio is very commonly used in HSC.

IV. FROST PROTECTION

SAPs may also be used as a means to engineer the pore structure of cementitious materials. During cement hydration, the SAP particles shrink and leave air voids. This can potentially be used for controlled air entrainment to improve the frost resistance of concrete. The use of SAPs

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offers the possibility of actively controlling the entrained air in the hardened concrete, including the total air content, the spacing of the air bubbles, and the size (and even the shape) of the individual cavities. With the addition of SAPs to concrete, the amount of scaled material is reduced by a factor of 60, thereby significantly improving the freezing- and-thawing resistance[4]. Based on an air-void analysis of the hardened concrete, the porosity generated by the SAP addition (entrained air content) is about 2.8% of the concrete volume.

V. EXPERIMENTAL SETUP (APPLICATION OF SAP IN HSC)

5.1 Design Mix. The w/c ratio was 0.3 and the target strength chosen was M50. Table 1 gives the quantity per cubic meter of concrete of various constituents. The mix design used is based on the standards recommended by the Bureau of Indian Standards wherein the design procedures are considered from the IS 10262-2009 (Cement and Concrete Sectional Committee).. Mix design with SAP was carried out as per the above mentioned IS code to give a design strength of M50. The cement proportion is initially chosen as 450 KG/ Cum and fly ash as 25% of replacement of cement by volume. Water binder ratio is chosen as 0.3. Superplasticizer is 2% by mass and SAP is 0.3% by mass.

Table 1. Concrete Mix Design

Constituents	Quantity/Cum of Concrete
Cement	450 Kg
Sand	635.68 Kg
Water	152 Liters
20mm Aggregate	452.6 Kg
10mm Aggregate	679 Kg
Fly ash	112.5 Kg
Superplastizer	10.465 Liters
SAP	0.3 % by mass

5.2 Test Procedure. Tests were carried out to check compressive strength and permeability test results as per IS 516 – 2018 and DIN Code 1048.

5.2.1 Compressive Strength Test

Compressive strength is an important property of concrete mix which is required to be tested to determine some of its important characteristics such as shrinkage and maintenance of high strength criteria (M50+) (Neville, 2012). The design and material proportioning for concrete (be it normal, high strength or high performance) is mostly governed by this unique property. This unique property of concrete mix is tested as per IS:516-1959 on 7th ,14th and 28th day of curing. However, for ascertaining the performance of SAP in extreme cold climatic conditions, the cubes were cured under different temperature conditions varying between 20 ºC to – 20 ºC.

5.2.2 Permeability Test

The test was carried out according to German Standard DIN 1048 on concrete specimens of size 150x150x150 mm, at an age of 28 days. Permeability of cement mortar or concrete is of particular significance in structures which are intended to retain water or which come into contact with water. Besides functional considerations, permeability is also intimately related to the durability of concrete, especially its resistance, against progressive deterioration under exposure to severe climate, and leaching due to prolonged seepage of water, particularly when it contains aggressive gases or minerals in solution.

5.3 Different temperature cycles undergone by the cubes before testing their compressive and permeability are as mentioned below:

(a) Freeze Thaw Cycle (Between – 10^{O}C and – 20^{O}C).

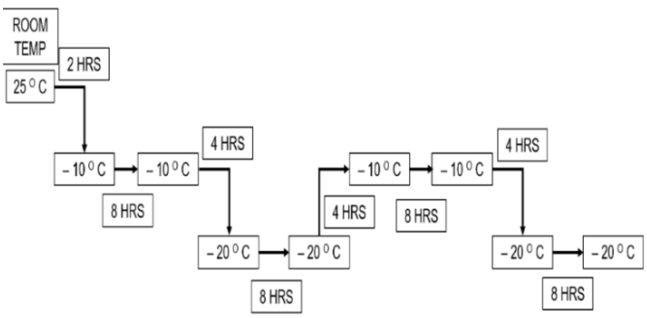
(b) Freeze Thaw Cycle (Between 20^{O}C and – 10^{O}C).

(c) Freeze Thaw Cycle (Between 20^{O}C and – 20^{O}C).

(d) Cubes cured in normal room temperature for 28 days.

5.3.1 Freeze Thaw Cycle

Leh, at 3,500 meters altitude, the average temperature reaches **25°C during the day in summer** while it dips to **-15°C at night in winter**. It can be significantly colder at higher altitude where night-time temperatures can drop below zero even in summer. Cold weather concrete construction under sub-zero temperatures presents challenging problems for the professionals involved in construction industry and are the main reason for poor development of such regions. Freezing of concrete before it gains required minimum strength at early age together with considerable retardation in setting time due to freezing temperatures are the two major problems with cold weather concreting. To address this problem SAP is used in concrete which cures concrete internally to achieve the strength and to check the performance of SAP in concrete, the test cubes were cured for 28 days in three different temperature conditions in different cycles



(a) (Between – 10^{O}C and – 20^{O}C)

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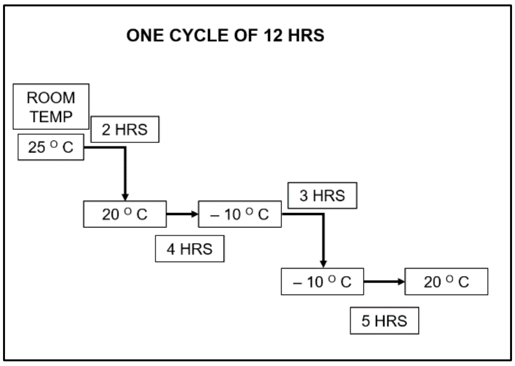
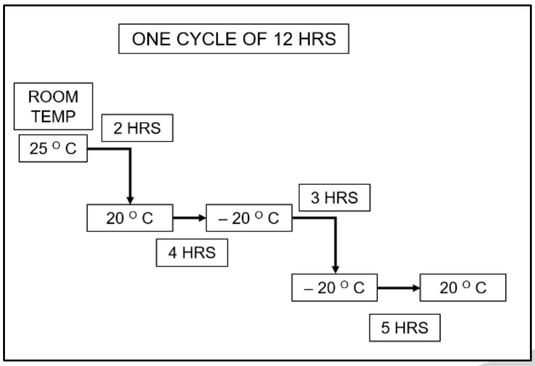


(b) (Between 20^{O}C and – 10^{O}C)



(c) (Between 20^{O}C and – 20^{O}C)

Fig 1 – Freeze Thaw Cycles

Fig 1 (a) shows that the sample after demoulding was placed in freeze thaw chamber which was set for temperature variation between – 10ºC and – 20ºC. The cycle followed was drop in temperature from room temperature to – 10ºC in 2 hours and then the chamber was maintained at – 10ºC for 8 hours and after that the chamber was set such that in next 4 hours the temperature falls to – 20ºC and the chamber remains at this temperature for 8 hours. The chamber was set to rise from – 20ºC to – 10ºC in 4 hours and remain the same state for 8 hours and then gradually in 4 hours dip down to – 20ºC and stay in this condition for 8 hours. This cycle of variation in temperature between – 10ºC and – 20ºC was followed for 28 days.

Fig 1(b) illustrates the freeze thaw cycle followed for the temperature variation between – 10ºC and 20ºC. After the initial drop from room temperature the chamber was maintained to undergo temperature variation between 20ºC to – 10ºC in period of 4 hours and remain at – 10ºC for 3 hours and then gradually increase to 20ºC form – 10ºC in a time period of 5 hours.

Fig 1(c) illustrates the freeze thaw cycle followed for the temperature variation between 20ºC and – 20ºC. After the initial drop from room temperature the chamber was maintained to undergo temperature variation between 20ºC to – 20ºC in period of 4 hours and remain at – 20ºC for 3 hours and then gradually increase to 20ºC form – 20ºC in a time period of 5 hours.[9]

9 cubes were used to ascertain the strength of cubes after 7,14 and 28 days as per IS 456 (2000) and IS 516 (2018). 3 cubes were taken out from the Freeze Thaw equipment and left for one day in room temperature and then tested for compressive strength and 3 cubes were tested immediately after taking out of the Freeze Thaw chamber as this would be the realistic ground conditions same as at Leh and Ladakh where the temperature during winters is very low. The compressive strength results found are as mentioned below:

5.4 Compressive Strength Results

Cubes were cured for 28 days in the freeze thaw chamber between – 10^{O}C and – 20^{O}C. The extreme conditions that the temperature is always below the freezing point. After 28 days the test cubes were taken out and kept outside for one day curing in room temperature. The compressive strength results for 7,14 and 28 days are shown in Fig 2.:

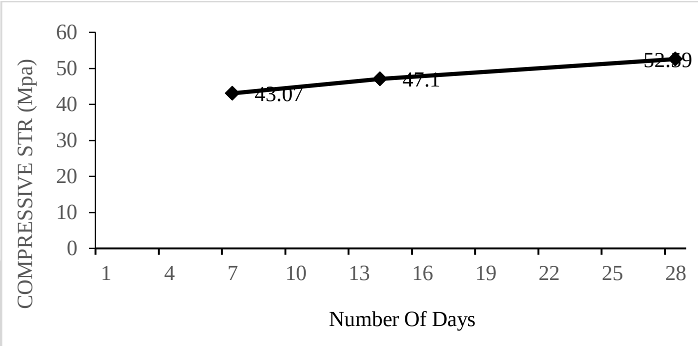


Fig 2 – Compressive Strength Results of cubes cured – 10^{O}C and – 20^{O}C

Mix design with SAP was carried out as per IS code 10262-2009 to give a design strength of M50.The results shows that after 28 days the test cubes had attained the desired compressive strength after undergoing the extreme condition of curing between – 10^{O}C and – 20^{O}C.

5.4.1 Simulation to show the real effects of temperature conditions on the concrete was carried out. Hence, One sample was tested immediately after taking out from the Freeze Thaw chamber. The comparative results between cubes undergoing curing for 28 days in freeze thaw chamber and one day curing at room temperature vs cubes tested immediately after taking out from the freeze thaw chamber is as shown below:

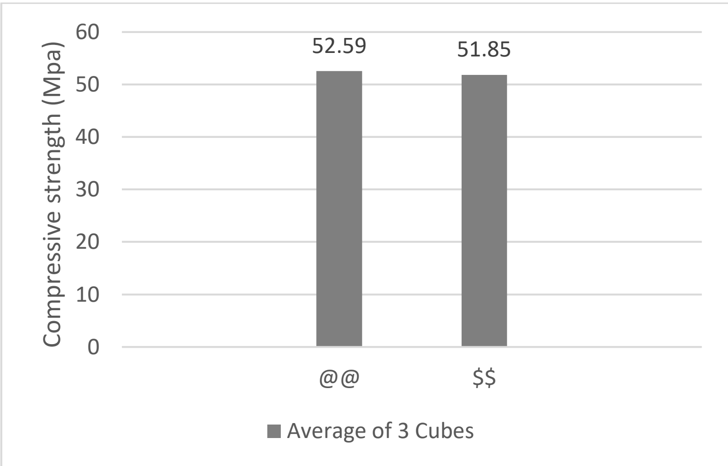


Fig 3 – Compressive Strength Results of samples cured at different temperature conditions.

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@@ 28 Days curing in freeze thaw chamber + 1 Day curing at room temperature

$$ Immediately after 28 Days curing from freeze thaw chamber

Fig 3 shows the Compressive Strength Results of samples cured at different temperature conditions. Two sample was made to undergo curing between – 10^{O}C and – 20^{O}C in the freeze thaw chamber for 28 days and after 28 days one sample was tested immediately after taking out from the freeze thaw chamber and the other was taken out from the freeze thaw chamber and kept at room temperature for 24 hours. The test cubes which were cured for 28 days in freeze thaw chamber and one day curing at room temperature had achieved greater compressive strength as compared to the test cube which had under gone curing for 28 days and was tested immediately after taking out from the freeze thaw chamber.

5.4.2 Comparative Results of compressive strength of samples cured at different temperature in freeze thaw chamber and room temperature are:

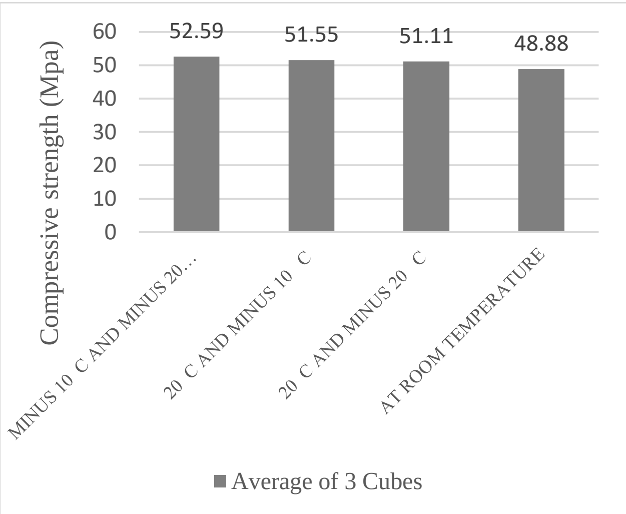

Fig 4 – Compressive Strength Results of samples cured at different temperature conditions

Fig 4 shows the Compressive Strength Results of samples cured at different temperature conditions. To check the performance of SAP in HSC under different temperatures conditions the samples were cured in the freeze thaw chamber under various temperature conditions. The sample which was cured at room temperature had attained less compressive strength as compared to the samples which had undergone freeze thaw cycles.

5.5 Permeability Test Results. To study the permeability of Super Absorbent Polymer, modified concrete specimens were tested under water pressure. Concrete is a porous and heterogeneous matrix. The permeability depends on how porous and connectivity of internal pores.

5.5.1 Permeability test was carried out as per DIN 1048 and the results of samples cured under different conditions and temperatures is as shown:

(i) Sample 1 – 3 cubes cured for 28 days in freeze thaw cycle (Between – 10^{O}C and – 20^{O}C).

(ii) Sample 2 – 3 cubes cured for 21 days at room temperature and then placed in NaCl solution for 7 days and then placed in freeze thaw machine for 24 hrs (temperature of freeze thaw chamber was maintained between 20 ^{o}C and minus 10 ^{o}C).

(iii) Sample 3 – 3 cubes cured for 28 days at room temperature and then placed in freeze thaw machine for 24 hrs (temperature of freeze thaw chamber was maintained between 20 ^{o}C and minus 10 ^{o}C).

(iv) Sample 4 – 3 cubes were casted and cured for 28 days in freeze thaw machine (temperature of freeze thaw chamber was maintained between 20 ^{o}C and minus 10 ^{o}C).

(v) Sample 5 – 3 cubes were casted and cured for 28 days in freeze thaw machine (temperature of freeze thaw chamber was maintained between 20 ^{o}C and minus 20 ^{o}C).

(vi) Sample 6 – 3 cubes were casted and cured for 28 days at room temperature.

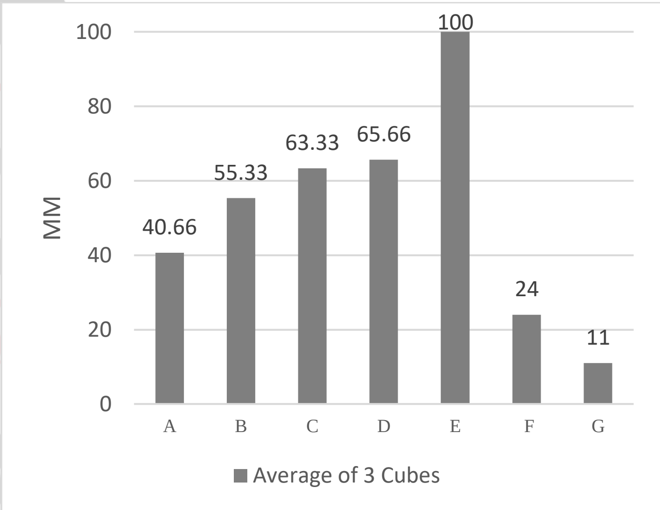

Fig 5 – Permeability Test Results

A - 28 DAYS CURING (FREEZE THAW CYCLE – 10^{0}C TO – 20^{0}C)

B - 28 DAYS CURING (FREEZE THAW CYCLE 20^{0}C TO – 10^{0}C)

C - 21 DAYS NORMAL CURING ROOM TEMPERATURE + 7 DAYS IN NaCl SOLUTION + 24 HRS FREEZE THAW CYCLE 20^{0}C TO – 10^{0}C

D - 28 DAYS NORMAL CURING ROOM TEMPERATURE + 24 HRS FREEZE THAW CYCLE 20^{0}C TO – 10^{0}C

E - 28 DAYS CURING (FREEZE THAW CYCLE 20^{0}C TO – 20^{0}C)

F - 28 DAYS CURING AT ROOM TEMPERATURE

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G – Reference concrete M50

Fig 5 shows the results of permeability test of samples which were made to undergo curing under different conditions and temperature variations and the results were compared with reference concrete. Freeze thaw cycles had an effect on the permeation of water in the concrete.

5.5.2 To check the performance of SAP in concrete and see the Permeability results of the samples undergoing curing under different temperature conditions and the medium such as curing under NaCl solution, room temperature and water curing. The test cubes were cured in NaCl solution as NaCl lowers the freezing point of water, attracts moisture, and increases pressure of frozen water. Also, NaCl can increase the freeze-thaw cycles if the temperature fluctuates between 15°F and 25°F.

Test results of water permeability samples cured under different temperatures conditions shows that:

(i) Samples cured in freeze thaw chamber for 28 days (between 20^0C and – 20^0C) had recorded 100 mm penetration which is 160% higher than the reference concrete and the samples which were cured at room temperature for 28 days had recorded 24 mm penetration which is 74.28% higher than reference concrete.

(ii) When the freeze thaw cycle is below sub-zero temperature (between – 10^0C and – 20^0C) the penetration recorded was 48 mm.

VI. CONCLUSION

Compressive strength of concrete is the most important characteristic and it is generally assumed that an improvement in concrete compressive strength will improve its mechanical properties; however, in case of concrete in which cement is partially replaced by mineral admixtures, all mechanical properties are not directly associated with compressive strength and the effects of the same amount of different mineral admixtures on the mechanical properties of hardened concrete are not same. Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposure environment and properties desired. Based on limited experimental study following conclusion is warranted:

(a) Design compressive strength was achieved for all test samples.

(b) The samples cured at room temperature recorded 2.24% less compressive strength in comparison to the reference concert.

(c) The samples which had undergone one cycle of freeze thaw recorded 7% less compressive strength as compared to reference concrete.

(d) Freeze Thaw cycles effect the permeation of water in the concrete

(e) Curing temperature effects permeation of concrete, it decreased with increase in temperature.

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