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Technical Note

Effect of Antifreeze Admixtures on Cold Weather Concrete

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ABSTRACT

Kashmir is located in a region where winter temperatures are very low. During the winter months, the temperature in Kashmir is often below 0^0 C. Generally concrete placed in colder regions with the help of insulated forms as well as heaters to protect freshly mixed concrete against freezing. These practices try to incorporate unnecessary carbon and leads to an disagreeable carbon footprint. The aim of this study was to evaluate the placing of concrete in colder temperatures with the help of antifreeze admixtures rather than insulated forms or heaters. The objective of this study was to optimize the proportions of two admixtures (Sodium nitrite, Potassium carbonate) to be used in cold weather concreting. Concrete specimens were tested to evaluate the properties such as Strength and elastic properties. The samples were cast in two phases i.e. in exterior winter conditions and under controlled conditions of -5°C with varying proportions of the admixtures. When compared to mixes without antifreeze admixtures the results showed increase in the strength of the concrete samples with addition of 3% Potassium carbonate as well as 3.5% Sodium nitrite by weight of cement was found to be optimum for the temperature range in consideration.

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1. INTRODUCTION

Concrete is widely utilized building materials, which are continuously exposed to temperature and moisture. The mechanical and physical properties of the concrete vary according to environmental conditions [1]. Some regions experience sub-zero winter temperatures in India. In these regions, concrete elements undergo freezing and thawing cycles and durability is also affected by frost action. Fresh concrete contains significant amount of water that is converted into ice at low temperatures. In fresh concrete, the formation of ice results in an increases in volume about 9% and it causes damage to concrete as well as structural integrity [2].

Part II of IS 7861 defines the cold weather concreting as any concreting operation at below or 5 °C atmospheric temperatures. Cold weather concreting of ACI 306 defines it is a period in which the following conditions exist for more than 3 consecutive days [3]:

- Daily average air temperature is below 5 °C
- The air temperature does not exceed 10 °C for more than half of the 24 hours.

The required concrete temperatures can be maintained in several ways during cold weather. Among the most commonly used methods are [4].

- Use of hot water in the concrete mixtures
- Use of steam heated aggregates
- Heating and tenting the concrete placing area
- Type III Portland cement
- Addition of 20% cement of Type I and II cement to obtained Type III response
- Use of accelerating admixtures

Among the above options addition of accelerating admixtures has the advantage that it can be used even where all above options fail in high early strength development. Because the main mechanism of an accelerating admixtures are to increase the hydration rate of tricalcium aluminate (C_3A) and tricalcium silicate (C_3S) phases of cement thereby of accelerating gain of strength [5]. Generally, the high early strength of concrete comprises more quantities of calcium and sulphates which accelerate the formation of calcium hydroxide, calcium silicate hydrate glue, calcium aluminate hydrates and imparts strength in less period of time.

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2. PROBLEM DEFINATION

Placing of concrete in colder regions is difficult to protect freshly mixed concrete against freezing. We have different methods to accelerate hardening of concrete in cold weather condition. However, one of the most effective methods is antifreeze admixtures.

3. MECHANISUM OF ANTIFREEZE ADMIXTURES

Due to water freezing under extremely cold condtions the hydration process in concrete is inhibited. Concreting in cold weather is not only economically exhorbitant but also slow with the final product of a poor quality which has:

- Lower strength and decreased durability due to cement paste matrix disruption
- Less resistance under pressure leading to damage in the form of chips flaking due to micro cracks and gaps developing consequent to ice crystals

Antifreeze admixture is a remedy to the freezing problem in concrete which prevents water from freezing before or during the process of hydration by:

- Decreasing the freezing point of water due to increased salt concentration
- Enhancing the concrete temperatures

4. OBJECTIVES

The Objectives of the present study are:

- To study the effect of antifreeze admixtures (sodium nitrite and potassium carbonate) on the strength (Compressive strength, Split tensile strength and Flexural strength) and elastic properties (Modulus of elasticity and Poisson's ratio) of concrete produced in exterior winter conditions in Jammu & Kashmir (India).
- To study the effect of antifreeze admixtures (sodium nitrite and potassium carbonate) on the properties of concrete under controlled conditions.
- To suggest antifreeze admixture as well as optimize its dosage for use during winter conditions.

5. EXPERIMENTAL CONDITIONS

5. 1. Experimental Plan The experiment was conducted in two phases; first in external winter conditions and secondly under controlled conditions of −5 °C. The external temperatures during the casting and curing period are summarized in Table 1. The casting of specimen was prepared during the latter part of the day or preferably during the nighttime, to utilize fully the sub-zero temperature conditions. Samples were cast under controlled conditions were stored in a freezer at −5 °C, within 30 minutes of mixing. The samples were stored at −5 °C for the first 2 days and after that exposed to normal weather conditions.

5. 2. Material Concrete mixtures were prepared using commercially available OPC [6], coarse aggregate of less than 20 mm and fine aggregate of Zone II were used with specific gravity of 2.78 and 2.68, respectively [7]. Distilled water was used for all sample preparation [8]. Table 2 shows the physical properties of materials.

In the present research, Sodium nitrite and Potassium carbonate of Thomas baker (chemicals) Pvt. Ltd used as antifreeze admixtures. The properties of Sodium nitrite and potassium carbonate are listed in Tables 3 and 4 respectively.

5. 3. Methods

5. 3. 1. Mechanical Properties Concrete cube specimens of dimension 150 X 150 X 150 mm were casted with and without antifreeze admixtures for compressive strength of concrete [9]. Cube specimens

TABLE 1. Exterior winter conditions

Date	maximum daily temperatures (°C)	Minimum daily temperatures (°C)
15-01-2016 (Casting 1)	6	-4
16-01-2016	8	-3
17-01-2016	10	-4
18-01-2016	11	-3
19-01-2016	10	-3
20-01-2016	8	-2
21-01-2016	5	-4
22-01-2016	6	-5
23-01-2016	6	-4
24-01-2016	8	-2
25-01-2016	5	-4
26-01-2016	5	-5
27-01-2016	7	-2
28-01-2016	9	-1
29-01-2016 (Casting 2)	7	-2
30-01-2016	10	2
31-01-2016	10	2
01-02-2016	7	-2
02-02-2016	8	-2
03-02-2016	8	-3
04-02-2016	9	-2
05-02-2016	5	-3
09-02-2016	11	-2
10-02-2016 (Casting 4)	5	-2
11-02-2016	7	-3
12-02-2016	9	-1
13-02-2016	8	-2
20-02-2016	13	-2
21-02-2016	12	-1
22-02-2016	14	2
23-02-2016	13	1
24-02-2016	11	2
25-02-2016	15	4

TABLE 2. Various material properties

S. No	Property	Obtained Value
1	Initial setting time of cement	3h 40 min
2	Final setting time of cement	5hr 20 min
3	Specific gravity of sand	2.68
4	Specific gravity of coarse aggregate	2.78
5	Standard consistency of cement	30%
6	Specific gravity of cement	3.12
7	Fineness modulus of sand	2.58 (Fine Sand)
8	Design mix	1:1.35:2.87

TABLE 3. Various properties of Sodium Nitrite

S. No	Various Chemicals in Sodium Nitrite	Percentage of Composition of Sodium Nitrite
1	Assay (ex NO_2)	98.0-100.5
2	Chloride (Cl)	0.02
3	Sulphate (SO_4)	0.005
4	Heavy Metals (as Pb)	0.001
5	Iron (Fe)	0.002
6	Sodium (Na)	0.4

TABLE 4. Various properties of Potassium carbonate

S. No	Various Chemicals in Potassium carbonate	Percentage of Composition of Potassium carbonate
1	Assay (ex NO_2)	99.5-100.5
2	Chloride (Cl)	0.005
3	Sulphate (SO_4)	0.004
4	Heavy Metals (as Pb)	0.005
5	Iron (Fe)	0.002
6	Calcium (Ca)	0.005

cast under exterior winter conditions as well as under controlled condition (-5 °C) and tested as per IS 516-1959 [10]. Cylindrical specimens of size 150 mm diameter and 300 mm length were used to evaluate the split tensile strength according to IS 5816-1999 [11]. Beam samples of standard dimensions 500 X 100 X 100 mm were casted and tested under two point loading to obtained flexural strength as per IS 516-1959 [10].

5. 3. 2. Modulus of Elasticity Static modulus of elasticity (E) was calculated on 150 mm X 300 mm cylindrical concrete according to ASTM C469 principles [12] as shown in Figure 1. Calculate the modulus of elasticity, to the nearest 50 000 psi (344.74 MPa) as follows:

$$E = \frac{S_2 - S_1}{\varepsilon_2 - 0.000050} \quad (1)$$

where E is Chord modulus of elasticity in psi, S_2 is stress corresponding to 40% of load, S_1 is stress corresponding to a longitudinal strain, ε_1, of 50 millionths, psi and ε_2 is longitudinal strain produced by stress S_2.

5. 3. 3. Poisson's Ratio Poisson's ratio (μ) was calculated on 150 mm X 300 mm cylindrical concrete samples according to ASTM C469 principles. Calculate Poisson"s ratio, to the nearest 0.01, as follows:

$$\mu = \frac{\varepsilon_{t2} - \varepsilon_{t1}}{\varepsilon_2 - 0.000050} \quad (2)$$

where μ is Poisson's ratio, ε_{t2} is transverse strain at mid height of the specimen produced by stress S_2. ε_{t1} is transverse strain at mid height of the specimen produced by stress S_1 and ε_2 is longitudinal strain produced by stress S_2.

6. RESULTS AND DISCUSSION

6. 1. Compressive Strength The cube compressive strength results at the various ages 7 and 28 days with and without antifreeze admixtures percentages as shown in Figures 2, 3, 4 and 5. The compressive strength values decreases with decrease in temperature when the concrete is exposed. The maximum decrease of the compressive strength observed under controlled concrete (-5 ºC). It was found that admixtures are increasing the rate of hydration of tricalcium aluminate and tricalcium silicate phases of cement, consequently giving not only heat evolution but also strength enhancement at all ages.

6. 2. Split Tensile Strength The cylinder splitting tensile strength of results at the various ages 7 and 28 days with and without different percentages of antifreeze admixtures are shown in Figures 6, 7, 8 and 9. The splitting tensile strength values decreases with decrease in temperature for the exposed concrete. The maximum decrease of the split tensile strength observed at reduced temperature of -5 ºC.

Figure 1. Cylindrical specimen fitted with a compressometer extensometer arrangement

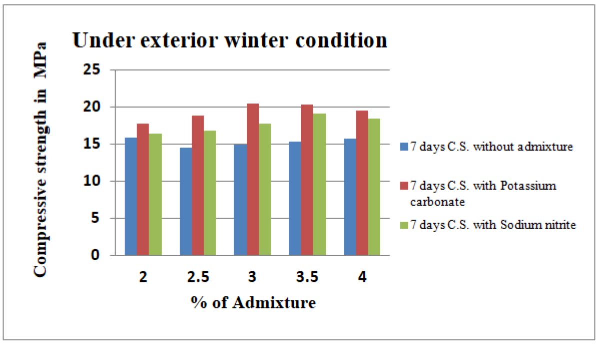

Figure 2. Compressive strength at 7 days under exterior winter condition

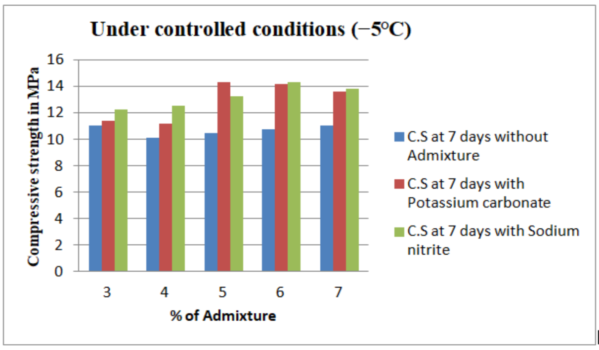

Figure 3. Compressive strength at 7 days under controlled condition

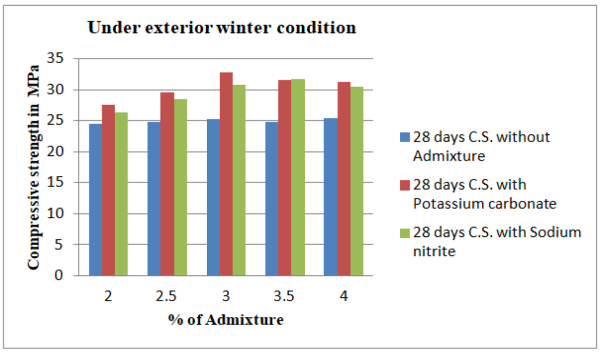

Figure 4. Compressive strength at 28 days under exterior winter condition

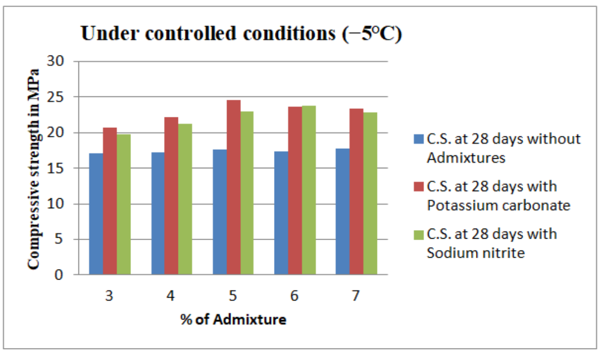

Figure 5. Compressive strength at 28 days under controlled condition

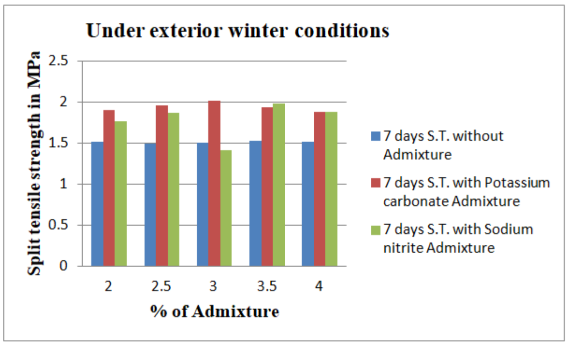

Figure 6. Splitting tensile strength at 7 days under exterior winter condition

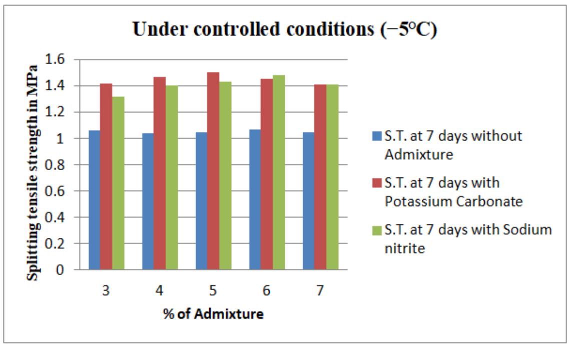

Figure 7. Splitting tensile strength at 7 days under controlled condition

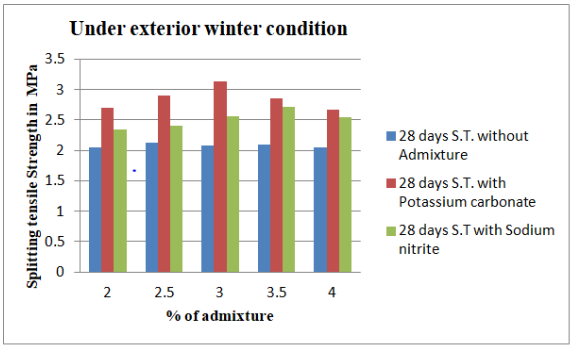

Figure 8. Splitting tensile strength at 28 days under exterior winter condition

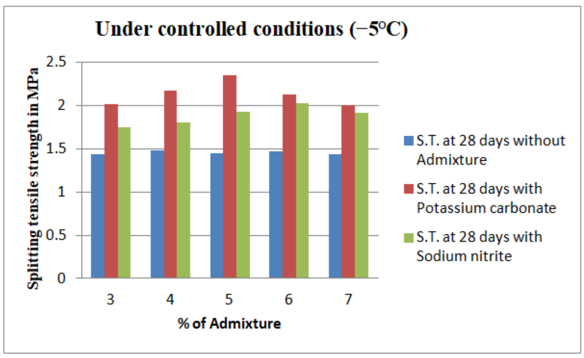

Figure 9. Split tensile strength at 28 days under controlled condition

6. 3. Flexural Strength The flexural strength of concrete results at the various ages 7 and 28 days with and without varying percentages of antifreeze admixtures are shown in Figures 10, 11, 12 and 13. The flexural strength values decreases with decrease in temperature when the concrete is exposed. The maximum decrease in the flexural strength observed at decrease temperature of -5 °C.

6. 4. Modulus of Elasticity The static modulus of elasticity results at 28 days with and without different dosage of antifreeze admixtures are shown in Figures 14 and 15. The static modulus of elasticity values decreases with decrease in temperature for the exposed concrete. The maximum decrease of the modulus of elasticity observed at decrease temperature of -5 °C.

6. 5. Poisson's Ratio The Poisson's ratio of concrete results at 28 days with and without proportions of antifreeze admixtures are shown in Figures 16 and 17. The Poisson's ratio values decreases with decrease in temperature when the concrete is exposed. The maximum decrease of the Poisson's observed at decrease temperature of -5ºC.

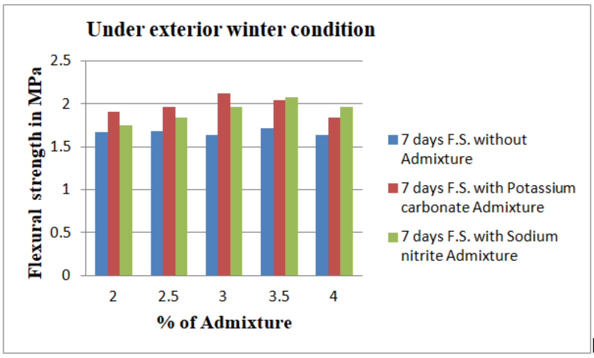

Figure 10. Flexural strength at 7 days under exterior winter condition

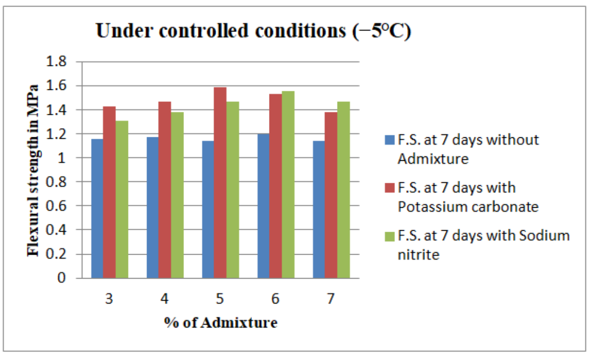

Figure 11. Flexural strength at 7 days under controlled condition

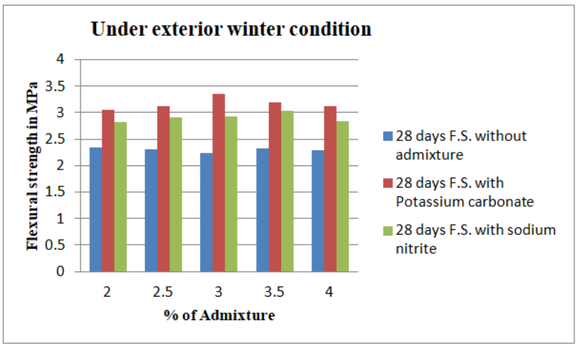

Figure 12. Flexural strength at 28 days under exterior winter condition

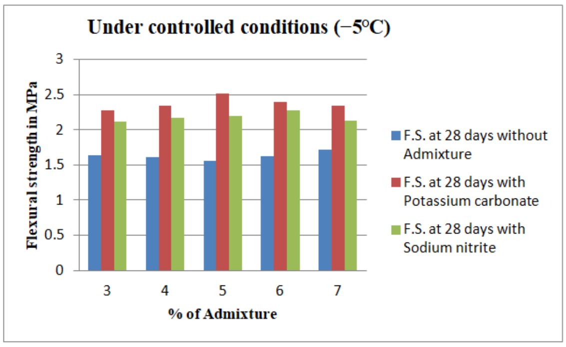

Figure 13. Flexural strength at 28 days under controlled condition

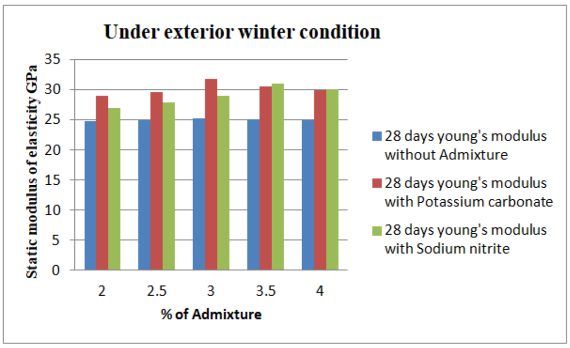

Figure 14. Static modulus of elasticity at 28 days under exterior winter condition

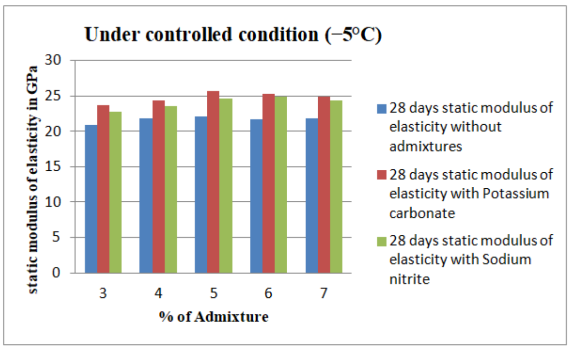

Figure 15. Static modulus of elasticity at 28 days under controlled condition

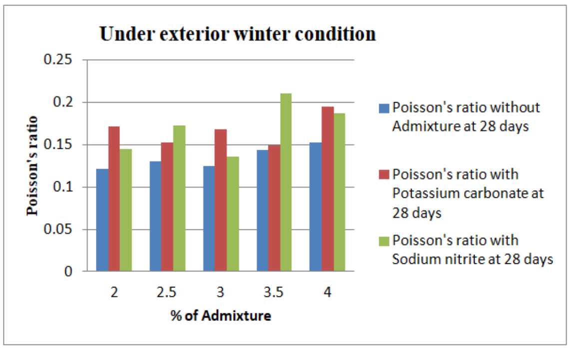

Figure 16. Poisson's ratio at 28 days under exterior winter condition

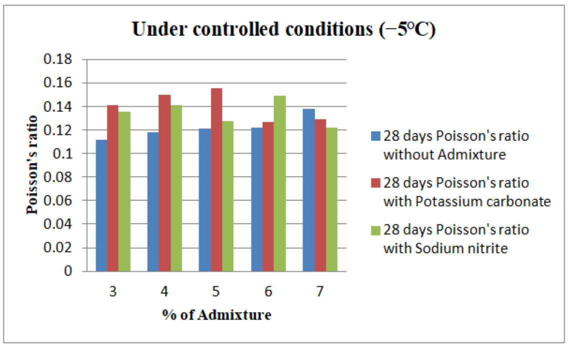

Figure 17. Poisson's ratio at 28 days under controlled condition

7. CONCLUSION

The following conclusions can be drawn from the results of this study:

- For exterior weather conditions, maximum values of concrete strength viz. compressive strength, flexural strength and split tensile strengths were observed for 3% K_2CO_3 and 3.5% $NaNO_2$. For 3% K_2CO_3 the 28-day compressive strength showed a 30% increase while the split tensile strength and flexural strength showed an increase of 51 and 50%, respectively. For 3.5% $NaNO_2$ the 28-day compressive strength showed a 28% increase while the split tensile strength and flexural strength showed an increase of 29 and 31%, respectively [13].
- An increase in 7-day compressive strength is higher than the increase in 28-day compressive strength. Thus, increase in early strength is more significant than increase in strength later on. An increase in early strength showed that the freezing of fresh concrete did not take place [14].
- For controlled conditions (wherein the concrete samples were exposed to a temperature of −5 ° C for first two days), maximum values of concrete strength viz. compressive strength, flexural strength and split tensile strength were observed for 5% K_2CO_3 and 6% $NaNO_2$. For 5% K_2CO_3 the 28-day compressive strength showed a 40% increase while the split tensile strength and flexural strength showed an increase of 62 and 62%, respectively. For 6% $NaNO_2$ the 28-day compressive strength showed a 37% increase while the Split tensile strength and Flexural strength showed an increase of 38 and 41%, respectively [15].
- The moduli of elasticity (E) values are in good agreement with the compressive strength values, with the maximum value of E corresponding to the maximum compressive strength. For K_2CO_3 the value of E showed an increase of 25.86%, while for $NaNO_2$ the value of E showed an increase of 22.14% at 3% and 3.5%, respectively.
- The Poisson's ratio however did not seem to follow any specific trends. This shall attribute to the fact that the determination of Poisson's ratio may be more sensitive to the loading rate of the arrangement than modulus of elasticity.
- One of the key observations is that in exterior weather conditions the design strength at optimum dosages was achieved which is not the case with controlled conditions.

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چکیده

کشمیر در منطقه‌ای است که دمای زمستان بسیار کم است. در طول ماه‌های زمستان، دما در کشمیر اغلب کمتر از ۰ درجه سانتی‌گراد است. بتن عموماً در مناطق سرد با اشکال‌های عایق و همچنین بخاری‌ها برای محافظت از بتن تازه مخلوط در برابر انجماد قرار می‌گیرد. این شیوه‌ها کربن غیر ضروری را به کار می‌اندازند و منجر به پدیده کربن ناخوشایند می‌شود. هدف از این مطالعه ارزیابی قرار دادن بتن در دماهای سرد با استفاده از افزودنی‌های ضد یخ به جای اشکال یا بخاری‌های عایق است. هدف از این مطالعه، به منظور بهینه‌سازی نسبت دو افزودنی (نیتریت سدیم، کربنات پتاسیم) برای استفاده در بتن‌سازی آب و هوای سرد است. نمونه‌های بتنی برای ارزیابی خواص مانند مقاومت و خواص کششی مورد آزمایش قرار گرفتند. نمونه‌ها در دو مرحله به عنوان مثال در شرایط زمستانی بیرونی و تحت شرایط کنترل -۵ درجه سانتی‌گراد با درصد متنوعی از افزودنی‌ها مورد بررسی قرار گرفتند. در مقایسه با مخلوط بدون افزودنی ضد یخ، نتایج افزایش مقاومت مصالح بتن با افزودن ۳٪ کربنات پتاسیم و همچنین ۳/۵٪ نیتریت سدیم به ازای وزن سیمان به دست می‌آید که برای محدوده دما مطلوب است.

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