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Effect of Temperature on the Rate of Gain of Strength of Concrete

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Abstract*: This paper presents the effect of temperature on the rate of gain of strength of concrete. Different samples of concrete were cast at different temperatures and various properties of concrete in fresh and hardened state were determined. It was observed that the three strength parameters viz. the compressive strength, the split tensile strength and the flexural strength of concrete are adversely affected when the temperature during first 24 hours is less than or equal to zero degree Celsius. The compressive strength of concrete was determined using 100mm and 150 mm cubes and a comparison was made between the two. It was observed that the strength of 100 mm cubes was greater than that of 150 mm cubes. Later a relationship was developed between 7 days,14 days and 28 days strength.

Index Terms*: Age of concrete, cold weather, maturity of concrete, strength, temperature.

I. INTRODUCTION

Concrete is widely used because of its compressive strength. The compressive strength of concrete gives an overview about the quality of concrete as it is related to the structure of hydrated cement paste (Neville, 1997).This strength can be achieved by concrete only when hydration reaction takes place. For this hydration reaction temperature acts as a catalyst. So higher the temperature faster is the hydration reaction and vice versa.

The temperature of concrete effects its different properties and this topic has remained a subject of research for many researchers. The hydration of Portland cement gets affected by many variables e.g., specific surface area, fineness, chemical composition of cement, grade, temperature and relative humidity of mixing and curing conditions (Garcia and Sharp, 1998). Different researchers worked in different ways and investigated the effect of temperature on the properties of concrete. From the literature it is clear that the variation in temperature has positive as well as negative impact on the properties of concrete.

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According to Neville an increase in curing temperature increases the rate of hydration reaction and the hydration products are formed early. Although a higher casting temperature increases the initial strength of concrete,it may adversely affect its long term strength (Neville, 1997).

This is because at high initial temperature the hydration reaction will be fast, resulting in non uniform distribution of the hydration products with a poorer physical structure, consisting of more unfilled pores. Since the voids do not contribute to the strength of concrete, a low temperature with cause hydration at a slow rate, thus resulting in a uniform distribution of hydration products within the interstitial space and high strengths at latter ages.

Price (1951) and Klieger (1958)separately investigated that concrete cast at 4°C had 28-day compressive strength 22% lower than concrete cast at 21°C.

At extremely low temperature the strength of concrete is again affected, as the water which was added for hydration of cement is frozen. At low temperature the water gets converted into ice lenses which in turn apply some pressure inside the concrete resulting in the formation of cracks. Later melting of these ice lenses results in the formation of pores inside the concrete which further reduces its strength. So in order to avoid the negative impact of very high temperature or extremely low temperature concrete should be cast at an ambient temperature.

II. EXPERIMENTAL PROGRAM

In this experimental investigation nine casting were done at different temperatures with an interval of almost one week. In each casting four different types of moulds viz 100 mm cubes, 150mm cubes, 150mm X 300 mm cylinders and 100 mm X 100mm X 500mm prisms were used. For all the casting the mix proportion of various ingredients was kept constant.. Slump tests and compaction factor tests were performed to examine the effect of casting temperature on the properties of fresh concrete. The various concrete samples were cured in the curing tank. Compressive strength tests, split tensile strength test and flexural strength tests were performed at different ages on hardened concrete to investigate the effect of temperature on the rate of gain of strength of concrete. Further a comparison was made between the compressive strength of 150 mm cubes and 100 mm cubes and a relationship was established between the 7 days, 14 days and 28 days strengths (Compressive strength, split tensile strength and flexural strength) of concrete.

A. *Material*

The materials used in the study were OPC 43 Grade (JK cement),local river sand, confirming IS grading zone II, Crushed stone in sizes of 10 mm and 20 mm, and tap water. Various test results of cement are given in Table 1.

Table 1:Test results of Ordinary Portland Cement

S.No	Test	Average Value	Recommended value
1.	Fineness test	2.3%	<10%
2.	Standard consistency Test	285%	27% - 33%
3.	Initial setting time	1 hour 53 minutes	>30minutes
4.	Final setting time	5 hours 9 minutes	<10 hours
5.	Soundness test	1.67 mm	<10mm
6.	7 days compressive strength test	32.38 N/mm^2	>30.1 N/mm^2
7.	28 days compressive strength test	45.47 N/mm^2	>43 N/mm^2

B. *Mixture Proportioning*

Nominal mix M20 grade of concrete was used .The concrete mixes were prepared by hand mixing on a non – absorbing platform.

C. Tests Conducted:

In each casting Compaction factor test and slump test were conducted to measure the workability of fresh concrete. In each casting the concrete was casted in different moulds. After 24 hours the concrete samples were removed from the moulds and were kept in curing tank till the date of testing. The concrete samples were taken out of the curing tank at the age of 7 , 14 and 28 days and various tests were conducted on hardened concrete to determine various mechanical properties of concrete. On the other hand the temperature was recorded on daily basis during the entire period.

III. Results and Discussions

The results of workability in terms of slump and compaction factor are shown in Table 2 whereas the results of various Strength tests are shown in the form of compressive strength, Flexural Strength and split tensile strength in Table 3 and Table 4.

Table 2: Slump and compaction factor values of concrete cast at different temperatures

Casting No.	Min . Temperature during first 24 hours of casting(ºC)	Slump (mm)	Compaction Factor
1.	1.4	26	0.89
2.	-1.2	27.5	0.95
3.	2	25	0.80
4.	-2.5	25	0.86
5.	0.8	25.1	0.86
6.	1.6	25	0.86
7.	5	25.5	0.86
8.	4.5	26	0.89
9.	11	25	0.80

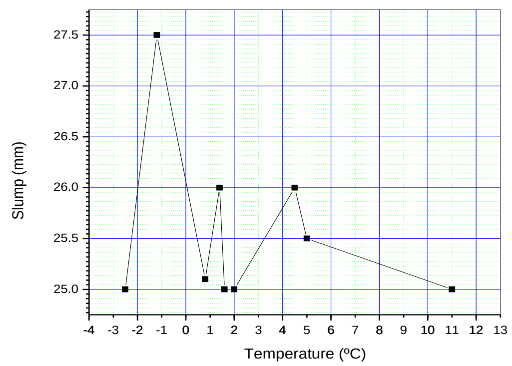
Table 3: Results of Compressive Strength of 150mm cubes & 100 mm cubes

Casting No.	Min . Temperature during first 24 hours of casting(ºC)	Compressive Strength (N/mm^2)					
		150 mm cubes			100 mm cubes		
		7 days	14 days	28 days	7 days	14 days	28 days
1.	1.4	14.80	21.28	24.31	14.4	21.5	25.8
2.	-1.2	13.27	18.44	20.84	13.1	19.3	22.0
3.	2	15.64	22.66	24.66	17.9	24.5	26.9
4.	-2.5	13.00	18.18	20.14	12.0	14.6	21.8
5.	0.8	13.97	19.64	23.51	14.1	21.0	24.0
6.	1.6	15.55	21.51	24.57	16.7	23.5	25.7
7.	5	17.77	23.16	25.15	19.5	25.4	26.7
8.	4.5	16.35	23.26	25.06	18.8	24.7	26.5
9.	11	18.33	24.00	25.77	19.7	26.4	27.1

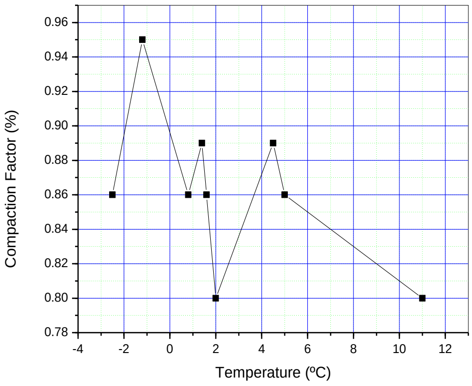
Table 4: Results of Flexural Strength and Split Tensile Strength

Casting No.	Min . Temperature during first 24 hours of casting(ºC)	Strength (N/mm2)					
		Flexural Strength			Split Tensile Strength		
		7 days	14 days	28 days	7 days	14 days	28 days
1	1.4	2.94	3.14	5.98	1.51	1.80	2.20
2	-1.2	1.16	2.20	3.92	1.02	1.48	1.81
3	2	4.51	4.60	6.96	1.68	2.08	2.86
4	-2.5	0.90	2.02	3.75	1.04	1.16	1.46
5	0.8	1.96	2.45	4.90	1.47	1.77	2.04
6	1.6	3.45	3.675	6.47	1.65	1.97	2.25
7	5	5.68	6.37	7.35	1.99	2.47	3.36
8	4.5	5.30	6.28	7.15	1.70	2.23	3.22
9	11	5.50	6.57	7.85	2.76	3.28	3.52

In order to study the effect of temperature on the properties of fresh and hardened concrete, a comparative study of the results achieved at different minimum temperature(during first 24hours of casting) was performed and various graphs were plotted.

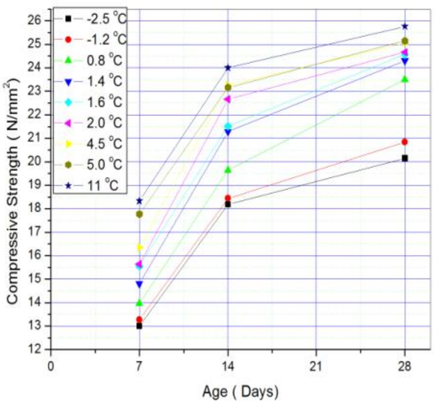


Graph 1. Slump v/s minimum temperature during first 24 hours after casting

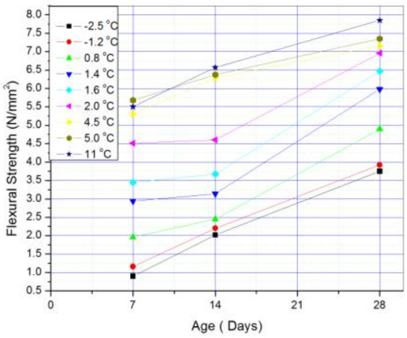


Graph 2. Compaction Factor v/s minimum temperature during first 24 hours after casting

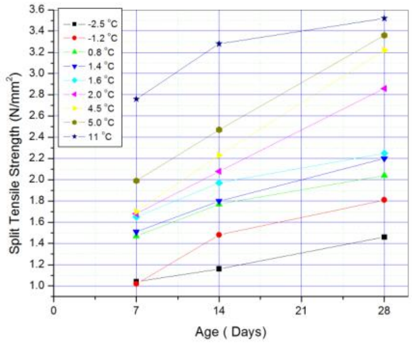
From the above graphs it is clear that there is fluctuation in the workability of concrete. The effect of temperature on the workability of concrete is clearly indicated by the changes in slump .From Graph 1 it is clear that as the temperature has increased from - 2.5 °C to 1.4 °C there is 1mm increase in the slump of concrete, This can be due to the availability of more free water due to the increase in temperature from negative to positive. Further, as the temperature increased from 5°C to 11 °C there is 0.5 mm decrease in slump of concrete, this can be due to the increase in the rate of hydration which in turn has resulted in an increase in the water demand thus decreasing the slump of concrete. From Graph 2 it is clear that the compaction factor is also showing same fluctuation with respect to change in temperature.



Graph 3. Compressive Strength of 150 mm cubes v/s age of concrete



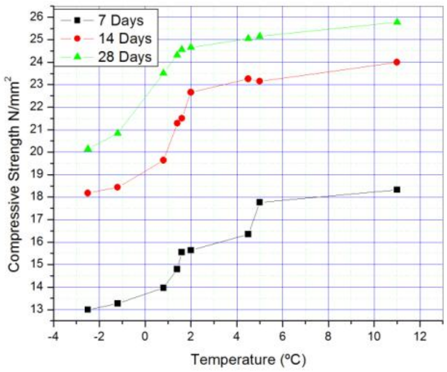
Graph 4 Flexural Strength v/s age of concrete



Graph5 Split Tensile Strength v/s age of concrete

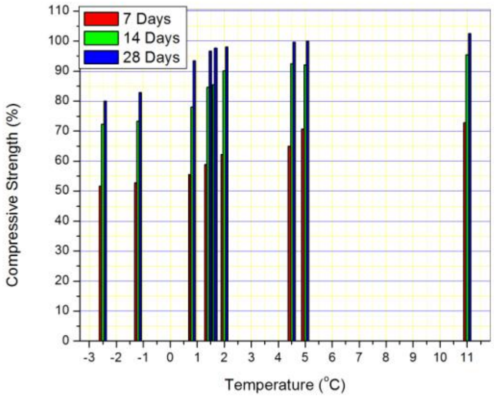
Compressive strength of hardened concrete was determined by testing 150 mm and 100 mm cube specimens under CTM, while as flexural strength and split tensile strength were determined by testing beam specimen & cylindrical specimen respectively. All the strength parameters were determined at the age of 7, 14 and 28 days for all the nine castings. From the above graphs (Graph 3,4&5) it is clear that all the strengths viz compressive strength, flexural strength & split tensile strength increases with the increase in the temperature(during first 24 hours) of concrete.

Graph 3 to 5 shows the effect of temperature on the strength development with reference to the age of concrete. The lower curve represents concrete cast at -2.5 °C while as the upper most curve represents the concrete cast at 11 °C.

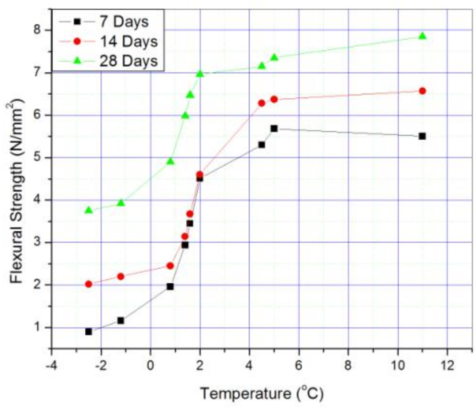


Graph 6 Compressive Strength (150 mm cubes) v/s minimum temperature during first 24 hours after casting

From Graph 6 it is clear that compressive strength at all the ages is affected by the variation in the casting temperature. The strength increases with the increase in the temperature of concrete during first 24 hours of casting.



Graph 7 Percentage of Compressive Strength attained v/s minimum temperature during first 24 hours after casting

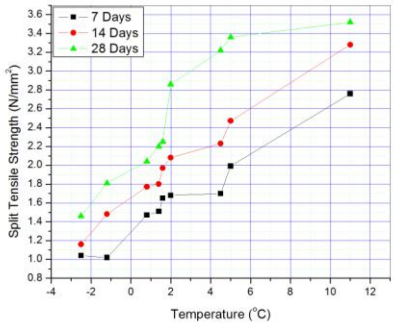


Graph 8 Flexural Strength v/s minimum temperature during first 24 hours after casting

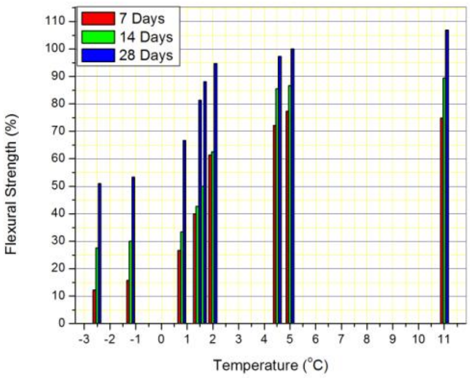
From the graph of compressive strength (Graph 7) it is clear that when the casting temperature of concrete is 5 °C 70% of the maximum strength (at 28 days) is attained at an age of 7 days. But when the casting temperature is -2.5°C (sub zero) only 51% of the maximum strength is attained at the age of 7days while as for the casting temperature of 11 °C about 72% of the maximum strength is attained at the age of 7 days. From the above it can be inferred that when the casting temperature is sub zero the initial gain of strength is low as the rate of hydration of cement is low. At sub zero temperature the water added to the concrete can freeze and less water will be available for the hydration of cement. Also low temperature retards the setting time and strength gain of concrete.

Further the 28 days strength attained by the concrete cast at the temperature of -2.5 °C is 20% less than the strength attained by the concrete cast at the temperature of 5^{oC} while as 28 days strength of the concrete cast at temperature of 11 °C is 2 % greater than the strength of the concrete cast at a temperature of 5 °C.

For all the samples which were cast at sub zero temperature the 28 days strength was 20% less than the strength of samples which were cast above zero degree Celsius. Although there was an increase in the curing temperature of casting no 2 and 4(having casting temperature of -1.2 and -2.5°C) at later stages(after 24 hours) but their 28 days strength never increased to the levels achieved by the concrete cast above zero degree Celsius. Below zero degree Celsius the water added for hydration could have frozen and would have resulted in the formation of ice lenses inside the plastic concrete. At later stage the frozen water could have evaporated leaving empty pores inside the hardened concrete thus reducing the strength & density of concrete.



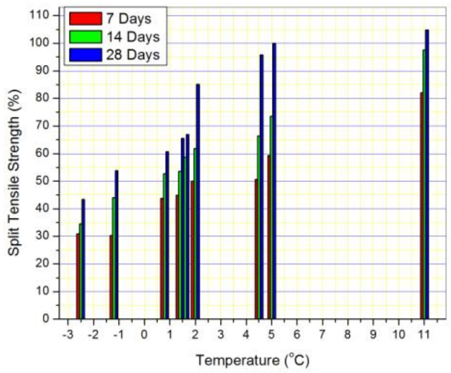
Graph 9 Split Tensile Strength v/s minimum temperature during first 24 hours after casting



Graph 10 Percentage of Flexural Strength attained v/s minimum temperature during first 24 hours after casting

Similar type of behavior can be seen in flexural strength and split tensile strength. From Graph 8 & Graph 9 it is clear that both flexural strength and split tensile strength are affected by the variation in the casting temperature. Both the strengths increase with the increase in the temperature. The effect of temperature variation on both the strength parameters is more prominent than that on the compressive strength parameter as is clearly shown by the steepness of graph.

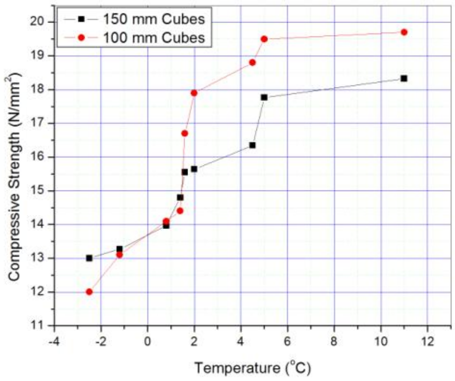
From the graph of flexural strength (Graph 10) it is clear that when the casting temperature of concrete is 5 ^{o}C 77% of the maximum flexural strength (at 28 days) is attained at an age of 7 days. But when the casting temperature is -2.5^{o}C (sub zero) only 12% of the maximum strength is attained at the age of 7days while as for the casting temperature of 11 ^{o}C about 74% of the maximum strength is attained at the age of 7 days. Further the 28 days Flexural strength attained by the concrete cast at the temperature of -2.5 ^{o}C is 49% less than the strength attained by the concrete cast at the temperature of 5^{o}C while as 28 days strength of the concrete cast at temperature of 11 ^{o}C is 6 % greater than the strength of the concrete cast at a temperature of 5 ^{o}C.



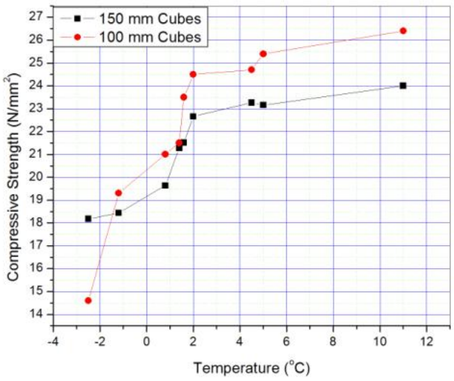
Graph 11 Percentage of Split Tensile Strength attained v/s minimum temperature during first 24 hours after casting

From the graph of split tensile strength (Graph 11)it is clear that when the casting temperature of concrete is 5 ^{o}C 60% of the maximum split tensile strength (at 28 days) is attained at an age of 7 days . But when the casting temperature is -2.5^{o}C (sub zero) only 30% of the maximum strength is attained at the age of 7days while as for the casting temperature of 11 ^{o}C about 82% of the maximum strength is attained at the age of 7 days. Further the 28 days split tensile strength attained by the concrete cast at the temperature of -2.5 ^{o}C is 57% less than the strength attained by the concrete cast at the temperature of 5^{o}C while as 28 days strength of the concrete cast at temperature of 11 ^{o}C is 5 % greater than the strength of the concrete cast at a temperature of 5 ^{o}C.

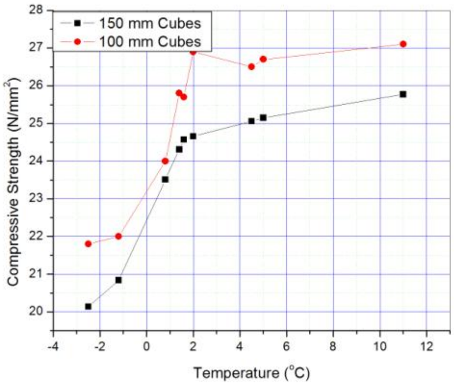
It means the effect on flexural strength and split tensile strength is more significant than that on the compressive strength of concrete. By studying all the above graphs, a remarkable adverse effect on the strength is observed when the temperature during first 24 hours dips below 0ºC. A minimum temperature of not below 5ºC (during first 24 hours) has a positive effect. There is a considerable increase in strength and rate of gain of strength is enhanced significantly by maintaining temperature above 5 ºC. As the compressive strength of hardened concrete was determined by testing two different sizes of cubes viz 150 mm and 100 mm a comparison has been made between the two in Graph 12, 13 & 14. Graph 12, 13& 14 show the variation of 7, 14 & 28 days compressive strength of 150 mm cubes & 100 mm cubes respectively. From all these graphs it is clear that the strength of 100 mm cubes is greater than that of 150 mm cubes at all the ages of curing. There is almost 6% greater strength in 100 mm cubes than 150 mm cubes. So for calculation of characteristic strength of concrete using 100 mm cubes, the values of compressive strength should be reduced by about 6%.



Graph 12 Comparison of 7 Days compressive Strength of 150 mm cubes & 100 mm Cubes



Graph 13 Comparison of 14 Days compressive Strength of 150 mm cubes & 100 mm Cubes



Graph 14 Comparison of 28 Days compressive Strength of 150 mm cubes & 100 mm Cubes

The increase in the compressive strength of concrete using 100 mm cubes is because of the smaller size of the specimen. As concrete is a heterogeneous mixture containing weaker as well as stronger elements, so smaller the size of the specimen lesser are the chances of presence of weaker elements in the specimen. So in case of 100 mm cubes there is lesser percentage of weaker elements than in case of 150 mm cubes.

IV. Conclusion

After analyzing the test results the following important conclusions were drawn

The three strength parameters viz: the compressive strength, the split tensile strength and the flexural strength of concrete are adversely affected under the conditions when temperatures (during first 24 hours) dip to around 0ºC and especially when temperatures reach below 0ºC. The effect on flexural strength and split tensile strength is more significant than that on the compressive strength. It is observed that under conditions of temperature above 0ºC(during first 24 hours), there is healthy growth of strength.

The variation in values of compressive strengths of concrete when testing is done on two different sizes of cubes (100 mm and 150 mm) ranges between 5 to 6 % the strength obtained on smaller size cubes being higher.

The relation between 7 days, 14 days and 28 days strength is as follows:

The 7 days and 14 days compressive strength is of the order of 64.4 % and 89.4% of 28 days strength respectively.

The 7 days and 14 days flexural strength is of the order of 53.4 % and 66% of 28 days strength respectively

The 7 days and 14 days split tensile strength is of the order of 65.5 % and 80.5% of 28 days strength respectively

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