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A Study on the Mechanical Properties of Concrete by Partial Replacement of Cement with Calcium Chloride

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Abstract - *There are a lot of accelerators used in concrete and calcium chloride is one of those accelerators which increases the hardening rate of concrete particularly the finishing time as it reduced about more than one-third of the normal time taken. There are different forms of calcium chloride such as solution form, flake from, pellet from and powder form. Calcium chloride can be used in concrete in construction projects where there is a time constraint. This research is aimed to study the mechanical properties of concrete by partial replacement of cement with calcium chloride. The objective is to study the effects of $Cacl_2$ in the concrete mix and to determine the compressive strength and split tensile strength of concrete. In this research calcium chloride was used in powder form for the purpose of obtaining its effect in concrete. For the cube samples, cement was replaced partially with calcium chloride in various proportions (1%, 2%, 3% and 4%) by weight to obtain its compressive strength. A similar proportion was used for the cylinder samples to obtain the split tensile strength. Mix design was done as per ACI method for C30 grade concrete to obtain the mix proportion. A total number of 15 samples of cubes and 15 samples of cylinders were cast. Curing was done for 28 days for all the samples. The average compressive strength of concrete mix contains 3% of calcium chloride was 39N/mm² which is considered as the optimum replacement level of $Cacl_2$. The average compressive strength increased by 17% compared to the control mix. Similarly the average split tensile strength for 3% replacement is 2.9 N/mm² which is in the range. It is observed that there is an increase in compressive and tensile strength of concrete up to 3% replacement and for further increase in calcium chloride there is a proportionate decrease in strength of concrete.*

***Key Words*: Concrete, Admixture, Calcium Chloride, Cement, Compressive Strength**

1. INTRODUCTION

Concrete is one of the fundamental products which has been used a long time ago. It contains materials like aggregates, cement and being mixed with water in a fixed proportion. Admixtures are used to in improving specific properties of concrete like durability, strength and chemical resistance. Cacl2 is used in concrete in two ways. It can be used as admixture and as a replacement of cement in some specified percentages as it should not exceed 4% if it is considered as a replacement of cement. It is an inorganic compound and a combination of salts and chemicals. It is in a crystallized shape in white color. For a long period of time about the 1950s to 1960s, calcium chloride usage was being concentrated at that time. It is used depending on the weight of cement. is one of those accelerators which is increases the hardening rate of concrete particularly the finishing time of the construction as it reduced about more than one-third of the normal time taken. A lot of weeks and times to wait is being eliminated for the process of the construction by using calcium chloride as partial replacement of cement in the concrete. It is necessary to use this material in any urgent project work as it is significantly eliminates the time required to finish the construction. In agreement with the valuable properties of the calcium chloride has, the usage of these materials should be known to the engineers. The objective of this research is to study the effects of calcium chloride in the concrete mix and to determine the compressive and split tensile strength of concrete samples.

Seventy two samples were crushed, 36 cube containing zero percent of calcium chloride and the other cubes containing 4% of calcium chloride. At all different ages, the result was obtained for the three brands of cement with and without calcium chloride as an admixture. According to the tables given, the compressive strength in cubes with calcium chloride is more than the compressive strength of cubes without calcium chloride. The highest results were while using the Burham cement at 7, 14, 21, 28 is increasing 18.89, 21.78, 22.81, 25.29 respectively. On other hand, the lowest is while using Elephant cement type and without calcium chloride. In Conclusion, it was observed that the concrete cubes compressive strength made up from the three types Elephant, Burham and Danogate cement with the calcium chloride admixture, increases with the increase of the curing age [1].

Calcium chloride used for reinforced concrete, it will take the consideration and full understanding of the percentage of calcium chloride to be replaced by the weight of cement because of the steel reinforcement used. The amount of calcium chloride used are commonly 2% and it is mostly in flake form. There are some aggregates which are being collected from different coastal places which are called coastal aggregates. So, the percentages of chloride to be replaced or added it is depending on the chloride which

is in the coastal aggregates. They have figure out that the maximum percentage of the soluble chloride used in dry concrete is 1%. On other hand, the maximum percentage of the soluble used is 0.3% while the concrete is exposed to moisture [2].

In another journal, they experimentally determined the impact of using calcium chloride as a hydrator which can affect the characteristic of cement paste by using Ordinary Portland Cement. They used various percentages of calcium chloride which were dissolved in water during the mix which are 0.25%, 0.5% and 0.75%. The hydration characteristic is tested by taking various determination such as the determination of phase compositions, total porosity, combined water content, compressive strength, and X-ray diffraction analysis (XRD). Two types of admixtures are added at different ages which are an accelerator and retarder which are added to the cement paste. Calcium chloride increases the hardening of OPC. The materials used in this determination were OPC, GCB, CaCl2, water, NFS as a water-reducing agent (super- plasticizers). The water cement ratio was used for all mixes is 0.25. The mixes are molded in the cubes and then cured for about 7 days. After that, all the cubes are immersed in water for checking the hydration for about 180 days [3].

The objective of earlier study was to determine the impact and effect of calcium chloride as an accelerating admixture in concrete mix for three percentages (1%,2% and 4%). The effects of using calcium chloride on workability, tensile strength, compressive strength, cement setting time and rate of strength gained for the concrete were observed. Calcium chloride is highly recommended specially in increasing strength and hardening the concrete. The mix ratio used is 1:1.5:3. The results obtained from slump test are for control mix, 1percent, 2percent and 4 percent calcium chloride mix are 53, 48, 45 and 40. 24 samples are produced, 8 for 7 days curing and 8 for 14 days curing and other one is 28 days curing. For 7,14 and 28 days curing the average of compressive strength is 16.35 to 17.70MPa, 18.65-21.4MPa, 26.6-31.35MPa. According to the results of compressive strength, the concrete with calcium chloride admixture, increases with increase of the curing age. In tensile strength test, as the percentages of calcium chloride increased (0%,1%,2% and 4%) the average tensile strength also increased and the results obtained were 3.862, 4.548, 4.570 and 4.647 respectively [4].

Another study describes the tests to measure the properties of mortars exposed to calcium chloride solutions. The mortars were prepared using two types of cement. A substantial decrease in transport properties like absorption, oxygen diffusivity and oxygen permeability was observed in samples exposed to solutions of higher concentrations of $CaCl_2$.The results of this study show that at high concentrations of $CaCl_2$ the formation of chemical reaction may be a dominant factor in the determination of service life of concrete [5].

2. INGREDIENTS

The ingredients of concrete are cement, fine aggregate, coarse aggregate and water. Apart from this calcium chloride obtained in flake form has been used to replace cement by weight.

2.1 Cement

Concrete constitutes 25-40% cement and 60-75% aggregates 1-2% voids with cement as its main constituent [6]. Ordinary Portland cement (53 grade) was used to prepare the concrete mix and replaced partially by $CaCl_2$ powder (1%,2%,3% and 4%) by weight.

2.2 Fine and Coarse Aggregates

Natural river sand and crushed gravel are normally selected as fine and coarse aggregates respectively as concrete ingredients. The aggregates which are passing 4.75mm sieve and retained on 2.36mm sieve are taken as fine aggregates. Similarly aggregates passing 20mm sieve and retained on 14mm sieve size are separated and used as coarse aggregates in the concrete mix. The properties of fine and coarse aggregates are given in Table 1

Table -1: Properties of Aggregates

Aggregate Properties			
S. No.	Type of Test	Fine Aggregate	Coarse Aggregate
1.	Specific Gravity	2.55	2.7
2.	Fineness Modulus	4.2	5.5
3.	Water Absorption (%)	1.2	0.9

2.3 Calcium Chloride

Calcium chloride is available in many forms which can be used as an admixture. There is a substantial increase in the compressive strength of concrete with an increase in CaCl2 content in the concrete mix[7]. Calcium chloride which is obtained in flake form is powdered before replacing it for cement in the concrete mix. It was obtained from Oman Chlorine LLC. (Fig-1)

Fig -1: Calcium Chloride

3. METHODOLOGY

The procedure involved in fixing the mix proportion, mixing the ingredients of concrete and testing of hardened concrete is elaborated in this section.

3.1 Mix Design

The process of selecting suitable ingredients for concrete and determining their relative amounts with an objective of producing a concrete of required strength, durability and workability as economical as possible is termed as concrete mix design [8].

The mix proportion for cement, fine aggregate, coarse aggregate and water is fixed using the properties of aggregates by ACI method. From the mix design calculations a ratio of 1:1.77:2.34:0.5 was obtained. Based on this proportion the quantity of cement, fine aggregate, coarse aggregate and water required for each mix is derived separately for casting the cube and cylindrical specimens.

3.2 Casting Process

The cube and cylindrical moulds are cleaned, oiled and kept ready for filling it with concrete mix. The required quantity of ingredients for conventional mix is weighed using a digital weighing machine and each material is added consecutively in the concrete mixer machine. The mixer machine is switched on and water is added in the machine gradually to generate a homogenous mix. The cube and cylinder moulds are filled with concrete in 3 layers and each layer is compacted 25 times in order to remove the voids in concrete (Fig-2).

Fig -2: Compaction of Cube Samples

After this the top surface of the cube and cylinder moulds are leveled. It is labelled with details of the mix such as date of casting, $CaCl_2$ replacement percent etc. All the samples are kept in room temperature for a period of 3 to 6 hours to dry. Methods of concrete curing depend on the type of structure, type of cement and local climatic conditions [9].

The moulds are removed and the samples are immersed in water to cure for 28 days (Fig-3)

Fig -3: Curing of Samples

3.3 Testing of Samples

The cube samples are removed from water after the curing period and allowed to dry and they are placed in the compression testing machine. The load is applied gradually on each sample (Fig-4). The compressive strength of concrete is also influenced by friction between the test plates and samples. The friction prevents lateral spreading of sample which results in a higher compressive strength of concrete [10]. The load at which the fracture appears is recorded for all the samples and the compressive strength of cubes are calculated using relevant formula. The cylindrical samples are kept on the machine and same process is repeated until ultimate load is reached (Fig-5). The split tensile strength of the cylinders are determined using suitable formula.

Fig-4: Compression Test on Cubes

Fig -5: Split Tension Test on Cylinders

4. RESULTS AND DISCUSSION

The compression and split tensile test results are shown in this section. Suitable charts are drawn and both the results are discussed in detail. Table 2 below shows the ultimate load for each sample and the corresponding compressive strength is calculated using the following steps

$$\text{Compressive strength} = \frac{\text{Ultimate load applied}}{\text{Cross sectional area}}$$

$$= \frac{700.2 \times 10^3}{150 \times 150} = 31 \text{ N/mm}^2$$

Table –2 Compression Test Results of Concrete with Different proportions of CaCl2 Replacement

Calcium Chloride	Ultimate Load (KN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)
0%	700.2	31	32
	705.9	31.4	
	743.7	33	
1%	748.2	33.3	34
	786.1	35	
	755.4	33.6	
2%	796.2	35.3	37.1
	855.3	38	
	850.1	38	
3%	878.3	39	39
	886.5	39.4	
	857.1	38.1	
4%	674.2	30	30.4
	685.1	30.4	
	691.3	30.7	

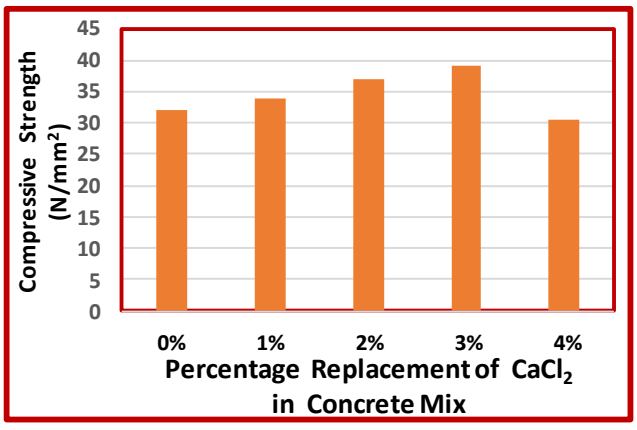


Chart –1: Compressive Strength of Cube Samples

Based on the test results a chart is drawn and the results are discussed below. From Chart-1 it is seen that a maximum strength of 39 N/mm² is achieved at 3percent replacement of cement with calcium chloride hence it is considered as optimum replacement level of calcium chloride in concrete mix. For every percentage increase in calcium chloride 5 to 10 percent increase in strength is observed in the concrete mix until it reaches the optimum level. A substantial increase in strength is observed while comparing the optimum replacement strength value with that of conventional mix value. A further increase in $CaCl_2$ content decreases the strength. A minimum strength of 35.3 N/mm² is obtained when 25% of cement in concrete is replaced with fly ash which is close to the control mix result.

The observations and results of sea water cured concrete samples are shown in Table 4.2 below.

Table 3 below shows the ultimate load for each sample and the corresponding split tensile strength is calculated using the following steps

$$\text{Split tensile strength} = \frac{2P}{\pi dL}$$

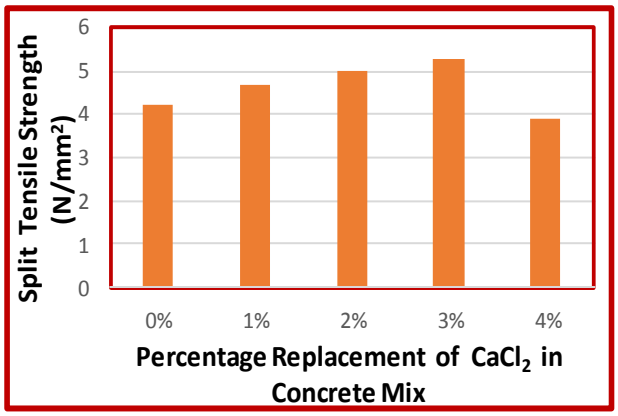
P - Maximum applied load (KN)
d - diameter of the cylinder (mm)
L - length of the cylinder (mm)

$$\text{Split tensile strength} = \frac{193 \times 1000}{\Pi \times 150 \times 300}$$

$$= 2.7 \text{ N/mm}^2$$

Table –3 Split Tension Test Results of Concrete with Different proportions of CaCl2 Replacement

Calcium Chloride	Ultimate Load (KN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)
0%	193	2.7	2.5
	157.3	2.2	
	180.3	2.5	
1%	180.6	2.55	2.65
	188.2	2.7	
	190.5	2.7	
2%	213	3	2.8
	188.4	2.7	
	197.7	2.8	
3%	219.1	3.1	2.9
	197.3	2.8	
	208.2	2.9	
4%	179	2.5	2.4
	164.8	2.3	
	171.9	2.4	



Chart–2: Split Tensile Strength of Cylinder Samples

A chart is drawn with the above data and the results are discussed below. From Chart-2 it is seen that a maximum split tensile strength of 2.9 N/mm² is achieved at 3percent replacement of cement with calcium chloride hence it is considered as optimum replacement level of calcium chloride in concrete mix. For every percentage increase in calcium chloride 3 to 6 percent increase in strength is observed in the concrete mix until it reaches the optimum level. Fourteen percent increase in strength is observed while comparing the optimum replacement strength value with that of conventional mix value. A further increase in $CaCl_2$ content decreases the tensile strength of concrete mix.

5. Conclusions

From the above research work the following conclusions are drawn:

- It is evident from the results that the maximum strength is achieved at 3% replacement of cement with calcium chloride while conducting compression and split tensile strength tests.
- A compressive strength of 39N/mm² is obtained at 3% replacement of $CaCl_2$ which is 17% higher than the control mix value.
- It is also found that compressive strength values of concrete mixed with $CaCl_2$ is higher than the strength of conventional mix values up to 3% replacement of cement with $CaCl_2$.
- The variation of strength between control mix and 4% $CaCl_2$ replaced mix is negligible since it produces minimum strength.
- Split tensile strength also follows a similar pattern as that of compressive strength while comparing the replaced concrete mix values at each increment.
- It can be concluded that calcium chloride replacement improves the compressive strength of concrete mix to some extent hence, it may be used as a replacement material in concrete.

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