Analysis of Influence Factor for Carbonated Concrete

Effects of Carbon dioxide in Concrete

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Abstract: This paper exhibits the experimentation of adding liquid Carbon-dioxide [CO_2 (l)] in the concrete and analysis of the obtained results to interpret a generalized statement describing the nature of its influence. The concept explains that using liquid Carbon Dioxide as an admixture helps to gain more strength, reducing the cement content required for achieving the desired strength and decrease the production demand. The binding properties of carbon-dioxide and the reduction in the atmospheric emission are studied. The proposed technology not only saves cement as a resource but also saves money spent on it. The study of the effect is directed on the strength gain and the consumption of CO_2 and influence curve is obtained from the determinant values of the results. This curve shows the nature of Carbonated Concrete.

***IndexTerms*– Carbon dioxide, Concrete, Influence Factor**

I. Introduction

This report deals with an approach to employ the beneficial reaction between carbon dioxide and freshly hydrating cement as an industrial process which could successfully use carbon dioxide as a feedstock in the production of concrete building products and effectively 'close the loop' of the carbon dioxide emitted during the cement production.

The Carbon dioxide can bind as solid and make stable carbonate reaction product in the cement matrix and provide a positive impact on the concrete properties. It not only increases the strength of the concrete but also stays bound within it.

II. Concept

When liquid carbon dioxide reacts with the hydrating cement-concrete, it reacts with the Calcium Silicate and Water to form a denser crystalline of C-S-H Gel with Calcium Carbonate. This reaction was developed from a more common reaction of Carbon Dioxide with Calcium Hydroxide.

Chemically, Calcium Hydroxide is a common byproduct in cement concrete which does not contribute to gain strength and only fills the physical voids within the product. It is due to the disintegration of the silicate compound in the crystalline structure. The Calcium Carbonate allows forming the Calcium Silicate Gel which increases the bond strength. The gel occupies the space and contributes to increase of the strength as well. This allows the formation of Calcium Carbonate which improves the performance of concrete.

The less dense compound of the calcium silicate which is less prone to hydrate and form the desired calcium silicate gel forms the product when it reacts with the Carbonic Acid. It is formed with the process of carbonation where carbon dioxide reacts with water. It is obtained as the byproduct of the reaction between carbon dioxide with calcium hydroxide. Calcium Hydroxide is the dissolution of Calcite in cement with water. Thus, the series of reactions interdependent on each other all present in the hydrating cement concrete paste lead to the formation of the desired product from the less reactive ingredient.

Physically, the carbon dioxide stays trapped as it again regenerates from the reaction after it dissolves with the reactant. The strength achieved is more and so implementation of this technology with less cement content would give the required strength. Decrease in cement content makes the product more economic.

- This technology is developed to achieve increased compressive strengths or reduced carbon footprints though incorporation of carbon dioxide (CO_2) into the concrete production cycle.
- The strength improvement can then be leveraged in the optimization of the mix design for a specific end goal, such as early age strength, 28 day strength or binder efficiency.
- This technology is compatible with almost all concrete types and applications. Dosages of CO_2 supplied will vary based on individual combinations of ingredients.
- It is an extension of the reaction between Calcium Hydroxide and Carbon Dioxide.

Thus, implementation of this reaction would be feasible. It also potentially contributes to environment, industry and stays competitive in the market.

III. Chemistry Involved

To understand the chemistry of cement and concrete involved with the carbon dioxide, it is essential to understand the chemistry involved with the Cement-Concrete.

➢ ***Reaction of Cement and Water to form the Concrete is as follows***

- $C_3S + (1.3 + x)\ H \rightarrow C_{1.3}SH$
- $C_2S + (0.3 + x)\ H \rightarrow C_{1.3}SH + 0.3\ CH$
- $2C_3A + 21\ H \rightarrow C_4AH_{19} + C_2AH_8 \rightarrow 2\ C_3AH_6 + 9\ H$
- $C_3A + 3\ CSH_2 + 26\ H \rightarrow C_6AS_3H_{32}$
- $2C_3A + C_6AS_3H_{32} + 4\ H \rightarrow 3C_4ASH_{12}$

C_3S, C_2S, C_3A are the compounds which are bounded in adhesion within the crystalline structure. These compounds in expanded form are written as $3CaO.SiO_2$, $2CaO \cdot SiO_2$, $3CaO \cdot Al_2O_3$ respectively. Aluminates ($Al2O_3$ component) in the above compounds are more reactive and play the first role in formation of the C-S-H Gel. Silicate (SiO_2 component) in the above compounds is steadier and plays crucial role in formation of the bond. Lime (CaO component) is reacts exothermically to get in the more thermodynamically stable state. When in presence of water, it forms Calcium Hydroxide (Ca $(OH)_2$). Calcium Carbonate ($CaCO_3$) is the byproduct which forms due to breaking for the compound and reach a more stable state.

- ***Reaction of Cement and Water with Carbon dioxide to form the Concrete is as follows***
  - $3CaO \cdot SiO_2 + (3-x)\ CO_2 + y\ H2O \rightarrow x\ CaO \cdot SiO_3 \cdot y\ H2O + (3-x)\ CaCO_3$
  - $2CaO \cdot SiO_2 + (2-x)\ CO_2 + y\ H2O \rightarrow x\ CaO \cdot SiO_3 \cdot y\ H2O + (2-x)\ CaCO_3$
  - $Ca\ (OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

When the compounds of calcium silicates (C_3S, C_2S) undergo carbonation with water, it also gives C-S-H gel and calcium carbonate ($CaCO_3$) as the byproducts. The calcium hydroxide (Ca $(OH)_2$) also forms calcium carbonate when reacted with carbon dioxide. Thus, it gives the more stable state of byproducts and forms C-S-H gel which contributes to the strength.

IV. Scope of Study

The concept shows that the carbon dioxide helps to form the C-S-H Gel and thus helps in forming a stronger bond which results in more strength. The extent of this increase in strength and the nature of increase of the strength must be studied. This nature of increase in strength gives the information which can be used to study the relation of the carbon dioxide quantity in concrete and the rate of change in the strength. It also gives the nature of rate at which the change occurs.

It involves the experimentation for testing of the compressive strength for various grades of mix design strength with the different proportions of the carbon dioxide. The experimentation will give the results which can be interpreted to verify the concept. The difference in the result of the samples with the various specifications will also give the extent of the effects on various parameters. The concept is verified and its extent is tested which gives the working range of carbon dioxide as an admixture.

The results obtained from the experimentation can be used to compute the following

1. The relation of the strength gain of concrete and the proportion of carbon dioxide.
2. The nature of the increase in strength of concrete for change in parameters.
3. The rate of increase of the strength in the concrete for the change in proportion of carbon dioxide.
4. The rate of increase of the strength in the concrete for the change in grade of concrete

V. Experimentation

The following experiments must be performed in order to obtain the results which are taken as the desired data to analyze and iterate the influence factor.

i. Experiment I

- In the first experiment, concrete with a selected grade is tested for increase in strength for different proportions of carbon dioxide. M20 grade of concrete is chosen to test the strength increase with varying proportion of carbon dioxide in 0 base points, 40 base points, 50 base points and 60 base points by weight of concrete. (Yash Lohana, 2018)
- Chosen criteria of the experiment:
  - Grade of Concrete: M20 (Conducted), M30 (Iterated with Exoeriment II), M40 (Iterated with Experiment II)
  - Proportion of CO_2: 0%, 0.43%, 0.53%, 0.63% by weight of cement.

ii. Experiment II

- In the second experiment, strength test is carried out for M20, M30 and M40 grade of concrete mix design for carbon dioxide of 0 base points and 60 base points for weight of concrete. (Sourabh Patil, 2018)
- Chosen criteria of the experiment:
  - Grade of Concrete: M20, M30, M40
  - Proportion of CO_2: 0% (Conducted), 0.43% (Conducted), 0.53% (Iterated with Experiment I), 0.63% (Iterated with Experiment I) by weight of cement.

iii. Experiment III

- In the third experiment, the concrete with no inclusion of the carbon dioxide is taken. Then the cement content is reduced proportionally which results in less strength. Finally, the carbon dioxide is included in this concrete with less cement content resulting increase in strength to achieve the desired strength. (Sean Monkman, 2014)
- The proportion of carbon dioxide to be introduced must be known or must be figured out with trial and error. This experimentation is carried out and the results are analyzed and interpreted. The values can also be optimized from the interpretation of results which are to be obtained from the second and third proposed experiment
- Chosen criteria of the experiment:
  - Grade of Concrete: M20 (Conducted), M30 (Iterated), M40 (Iterated)
  - Proportion of CO_2: 0% (Conducted) , 0.43% (Conducted), 0.53%, 0.63% (by weight of cement)

VI. Results Obtained:

- **Experiment I**
  - The result for M20 Grade of Concrete

Days	Compressive strength of M20 at various proportions of CO_2			
	0% of CO_2	0.43% of CO_2	0.53% of CO_2	0.63% of CO_2
7	19.6	28.25	24	24.67
14	26.5	29.18	25.3	28.5
28	29.5	31.08	26.83	30.94

Table 1. Various proportions of CO_2 for M20 grade concrete

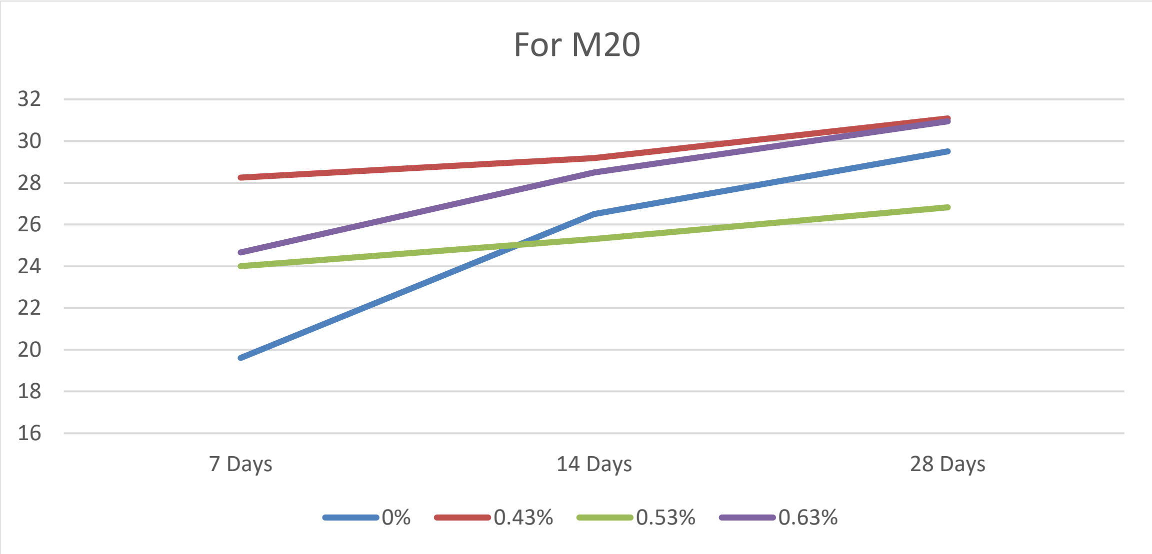


Fig 1. Various proportions of CO_2 for M20 grade concrete

  - The result for M30 Grade Concrete

Days	Compressive strength of M30 at various proportions of CO_2			
	0% of CO_2	0.43% of CO_2	0.53% of CO_2	0.63% of CO_2
7	21.24	38.25	32.513	33.4
14	31.13	39.512	34.2	38.59
28	34.5	42.08	36.34	41.8

Table 1. Various proportions of CO_2 for M20 grade concrete

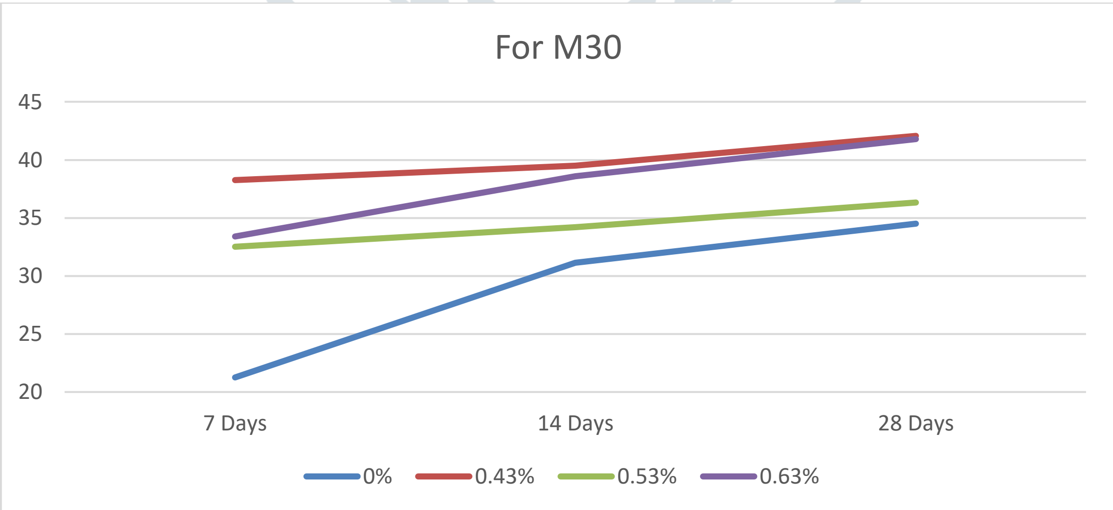


Fig 2. Various proportions of CO_2 for M30 grade concrete

  - The result for M40 Grade Concrete

Days	Compressive strength of M40 at various proportions of CO_2			
	0% of CO_2	0.43% of CO_2	0.53% of CO_2	0.63% of CO_2
7	31.98	48.25	41	42.13
14	44.28	49.84	43.13	48.6
28	49.2	53.08	45.83	52.7

Table 3. Various proportions of CO_2 for M20 grade concrete

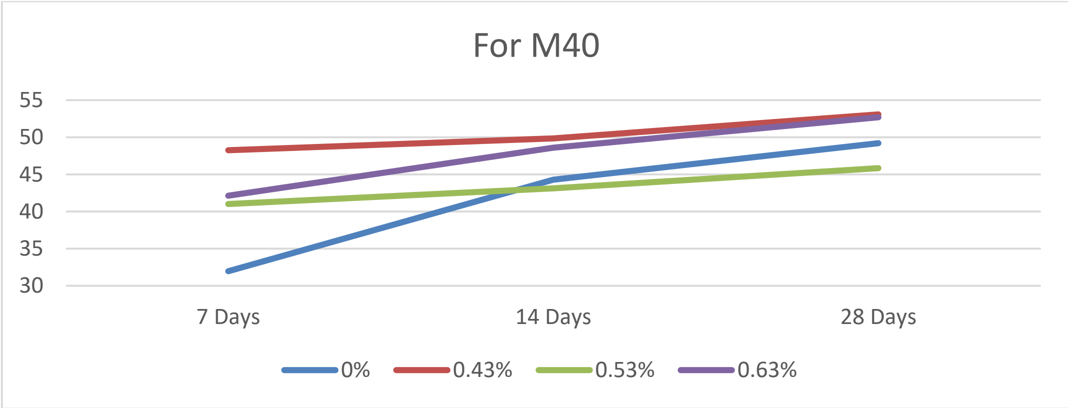


Fig 3. Various proportions of CO_2 for M40 grade concrete

- **Experiment II**

  Following are the matrices (C_{ij}) which give the strength of various grades of concrete (C_i) at various stages of time (C_j) of its strength gain for the specified presence of CO_2 in-terms of percentage by the weight of cement in the designed concrete. The values are obtained from the results in experiment These values are used to form a determinant which when solved gives the influence factor represented by (IF_x).

  This influence factor indicates the influence of the given proportion of CO_2 for various grades of concrete. The relative difference between the influence factors gives the intensity of the influence between the different proportions of CO_2.

$$(IF_{n+1}) - (IF_n) > 0 \qquad \text{(i)}$$

  If $(IF_{n+1}) - (IF_n) > 0$ then, (IF_{n+1}) is more influencing else (IF_n) is more influencing and vice versa. The values of influence factors are very sensitive.

  - Compressive strength of various grades of concrete at 0% CO_2

$$D1 = \begin{bmatrix} 19.6 & 21.24 & 31.98 \\ 26.5 & 31.13 & 44.28 \\ 29.5 & 34.5 & 49.2 \end{bmatrix} = -1.2423$$

  - Compressive strength of various grades of concrete at 0.43% CO_2

$$D2 = \begin{bmatrix} 28.25 & 38.25 & 48.25 \\ 29.18 & 39.51 & 49.84 \\ 31.08 & 42.08 & 53.08 \end{bmatrix} = -0.076$$

  - Compressive strength of various grades of concrete at 0.53% CO_2

$$D3 = \begin{bmatrix} 24 & 32.513 & 41 \\ 25.3 & 34.2 & 43.13 \\ 26.84 & 36.34 & 45.83 \end{bmatrix} = -0.0058674$$

  - Compressive strength of various grades of concrete at 0.63% CO_2

$$D4 = \begin{bmatrix} 24.67 & 33.4 & 42.13 \\ 28.5 & 38.59 & 48.6 \\ 30.94 & 41.8 & 52.7 \end{bmatrix} = -\,0.170588$$

- **Experiment III**

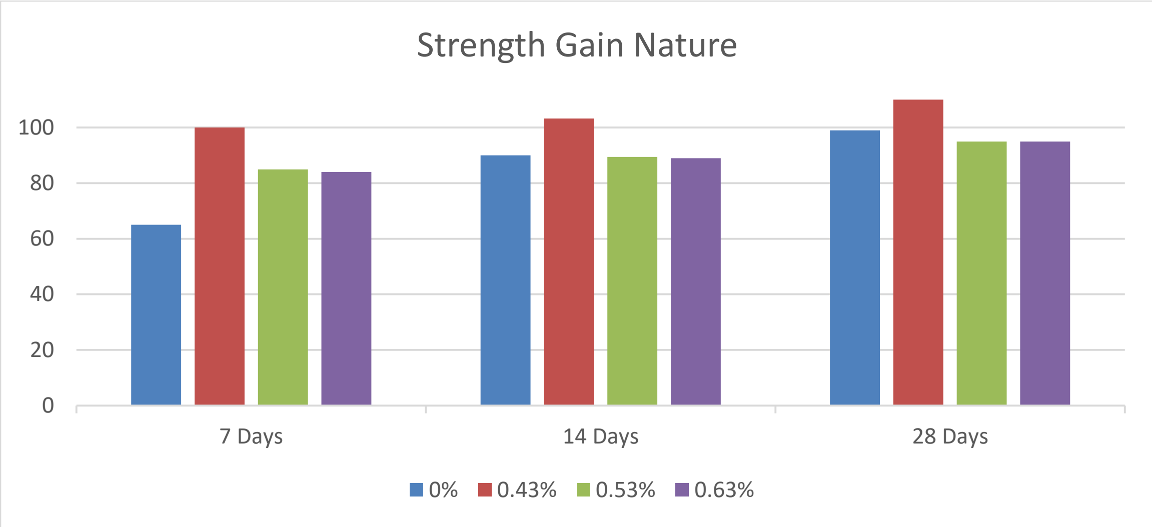
  The data in the experiment conducted by Sean Monkman is shown:

Air Entrained	Reduced Binder	6	4.2	144.4	84
	Reduced Binder with CO_2	5	3.4	147.2	81
	Standard Mix	6	3.5	146.0	84

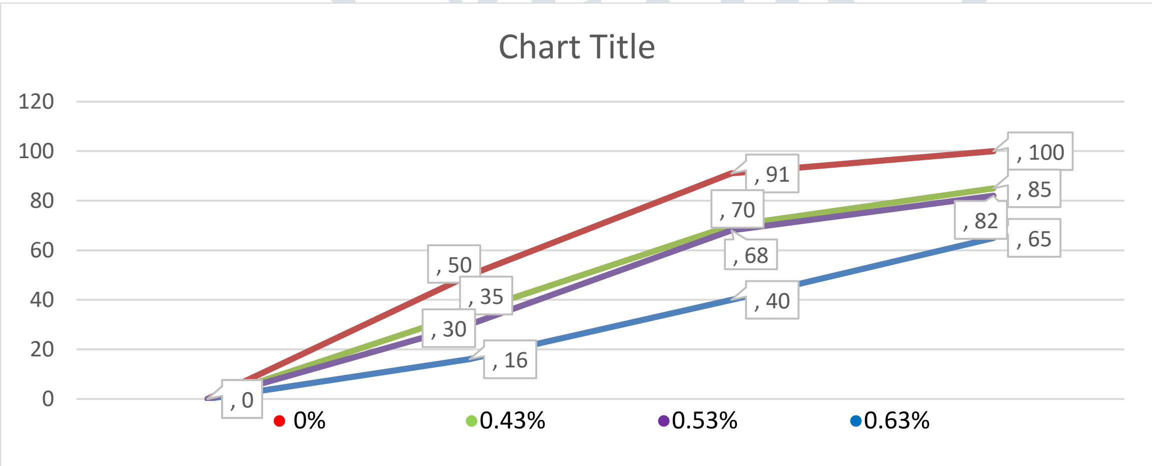
VII. Analysis Of Results:

Results from the above experimentation are analyzed

Experiment 1



It is depicted that the nature of the strength gain is observed irrespective of the Grade of Concrete in which the specified proportion of CO_2 is considered. Thus, the strength growth curve for the different proportions of CO_2 is represented in the percentage gain of the strength as a generalized reference. This curve is shown below.



Experiment 2

The obtained values of determinant can give the relationship of influence between the respective proportions of CO_2 present in the concrete. This relationship can be obtained by either taking the difference between the factors or by taking the determinants of factors. To find the relationship of influence by the method of solving determinants there are 6 combinations possible. These combinations can be solved by both the methods.

Here, we have taken the difference between the influences to determine this relationship. We have considered the linear increase in proportion of CO_2 presence for this calculation.

i. $D2 - D1 = 1.1663$

ii. $D3 - D1 = 1.2364$

iii. $D4 - D1 = 1.0717$

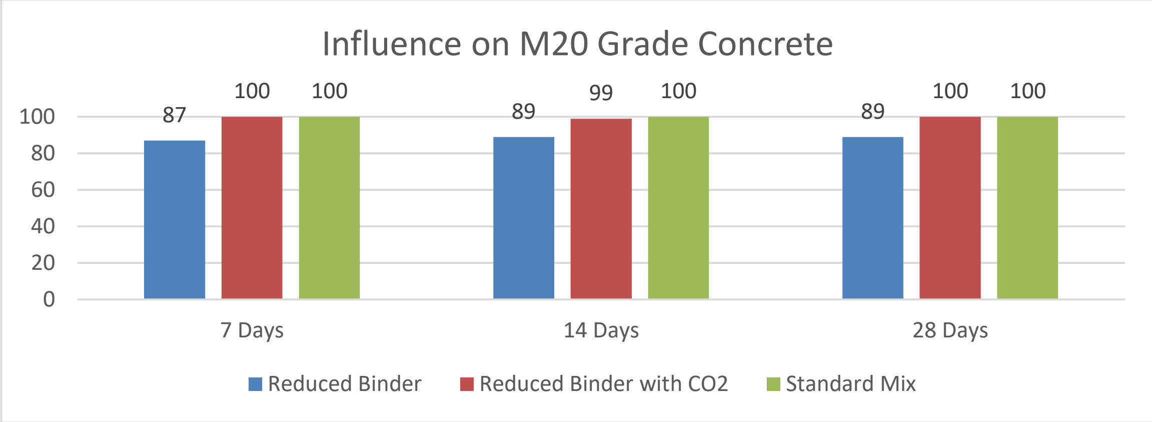
iv. $D3 - D2 = 0.0701$

v. $D4 - D2 = -0.0945$

vi. $D4 - D3 = -0.1647$

Experiment 3

Each mix was compared in 3 cases: A standard mix shown in green color, the standard mix with a reduction in binder loading shown in blue color, and the standard mix with a reduction in binder which was further incorporated with addition of optimized dose of CO_2 shown in red color. The reduction in amount of binder was about 7%.



However, in case of addition of CO_2 to reduced binder batch there is increase in strength which is equivalent to the strength of the standard mix. The experiment was conducted using M20 grade concrete with addition 0.43% CO_2 by the weight of cement in the reduced binder with CO_2 mix.

VIII. Interpretation of Results:

The interpretation of the results can be realized by graphical and analytical methods. Both the methods are supposed to give the same interpretation. These interpretations can be expressed in the form of the relationships which would be derived from the obtained results within the extremities.

The result will determine whether the rate of increase in strength is linear or non-linear with respect to proportion of the carbon dioxide. This will allow iterating the value of the strength gain for different grades of concrete for the specified proportion of the strength gain. A check is possible by testing the results of the strength for other variations as well.

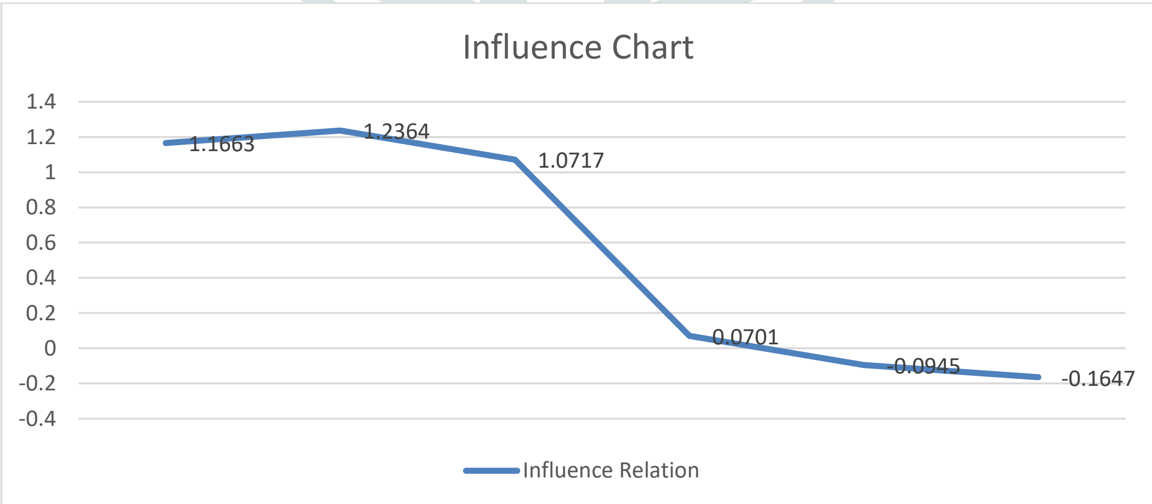
If the relationship is linear then it is concluded that the relationship is established and the rate of variation observed is the final result. The rate of variation can be tested for different grades of concrete and the result is concluded.

If the relationship is not linear then it is concluded that the relation between the rate of increase in strength and the proportions of carbon dioxide is not established. In this case the non-linear relationship which is obtained is considered and applied for all the grades. The test for determining this non-linear relationship is carried out by further experimentation. This reverse approach is tested to check whether the rate of increase in strength is depended on the proportion of the carbon dioxide. After the verification of the obtained values with experimentation this non-linear obtained relation is verified and considered to be standard for all the grades of concrete.

With both the approaches mentioned, the graph is plotted and the common points are taken to find the proportion in terms of area which gives the percentage of carbon dioxide needed for effective strength gain. Various optimization techniques can also be used to find the range of most probable occurrence and refinement in the obtained result.

The determinant formed from the rows representing proportions of carbon dioxide and columns representing the grade of concrete will give the factor of influence of carbon dioxide in the concrete. This factor can give the universal limit of implementation to describe

1. The increase in strength of concrete for proportion of carbon dioxide irrespective of the grade.
2. The proportion ratio to iterate the decrease in cement content for a reduction in cement due to addition of carbon dioxide.



Influence Chart

In the family of curves of the strength gain of concrete with respect to time for different grade of concrete, the gradient of influence in the z-axis is given in the above influence chart.

IX. CONCLUSIONS AND SIGNIFICANCE

Various conclusions are obtained from the above mentioned research.

1. The amount of the carbon consumed by concrete is possible to state with certainty and thus the Influence Factor can be obtained. This approach is accepted and recommended if the Influence Factor is greater than unity.
2. The range for various grade of concrete is obtained for the Influence Factor. Thus, the window of feasibility is obtained.
3. Verification of the thesis is carried out and it is found that the influence factor is dependent on the amount of the Carbon Dioxide present in the concrete.
4. Relationship between the rate of increase in the strength and the proportion of carbon dioxide is verified and interpreted.
5. Value of the factor of influence of carbon dioxide in concrete is obtained.

X. FUTURE SCOPE:

The future scope for this is given below

1. Industrial scale experiments assessed the feasibility of adding gaseous carbon dioxide to a ready mix production cycle in order to achieve beneficial sequestration of carbon dioxide in the concrete is also allowed.
2. The fresh properties were impacted such that additional mix water may be required to reach the target slump but at the expense of slightly decreasing the compressive strength. Alternatively, the mix water can be unchanged and lower slump can be addressed through admixture addition prior to placement.

XI. ACKNOWLEDGMENT

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