A study on mechanical properties of concrete with incorporation of CO2

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Abstract - Concrete is one of the most used construction materials in the world. In addition, concrete is the second most consumed substance in the world after water. Approximately ten billion tons of concrete is produced every year. Annual production represents one ton for every individual on the planet. There are some negative impacts of more production of concrete like continuous extensive extraction of aggregate from natural resources will lead to its depletion and ecological imbalance. Apart from this production of cement release approximately 8% of Carbon-dioxide into the environment. A step for finding a elucidation for the above mention mess, Carbon Capture utilization storage technique is fast growing solution in this modern world. For enhancing this concept a dry-ice which is the solid form of CO_2 is added into the concrete at various percentage (5%, 10%, 20%) in an open chamber. Mechanical properties of concrete with CO_2 such as compressive strength, split tensile strength and flexural strength were tested and the results were discussed.

INTRODUCTION

The second most popular man-made material is concrete. Cement, fine aggregate, and coarse aggregate are the components of concrete. Although cement, a binding agent, only makes up about 10 to 15 percent of its mass, the energy-intensive manufacturing process causes chemical reactions that increase the amount of carbon dioxide released into the atmosphere. Around 8% of all carbon emissions worldwide are caused by cement, making it a major source of emissions. However, unlike other necessary, high-emissions industries like heating, electricity, and transportation, which can be reduced with heat pumps, renewable energy sources, nuclear power, and batteries, there isn't a clear low-emissions substitute for the most widely used building material.

A promising opportunity for this industry to go green is the incorporation of carbon capture, utilization, and storage (CCUS) technologies into the manufacturing process. Despite the limited commercial presence of CCUS, a recent report from the international energy forum identifies the technology as the crucial component needed to achieve the goals of energy security, affordability, and decarbonization, and it also outlines deployment strategies that will allow for rapid advancement. Utilizing CO2 that has been captured in concrete can enhance green building practices. A practical substitute for underground storage is provided by converting emissions to value through construction that combines engineered and naturally occurring solutions.

The need for the sequestration of carbon dioxide is increasing now, and the following experimental investigation gives an eye-opening solution for the sequestration of carbon dioxide into concrete.

Mineralization of Carbon-Dioxide in Concrete

CO2 can be transformed into solid carbonates in a number of ways to increase or replace other ingredients in concrete. It can react with calcium or magnesium oxide to form a solid carbonate, replacing or enhancing aggregates and other concrete components. It can also be used as an input for a CO2-based, non-cementitious concrete. It can be injected to cure the cement mix (replacing energy-intensive steam curing) and mineralizing to strengthen the concrete.

All of these methods entail the concrete permanently storing the carbon, barring burning. This is a particularly appealing CCUS application because other uses of the carbon may eventually release the carbon back into the atmosphere. Concrete with CO2 in it has the potential to eventually act as a carbon sink if scaled up enough. "New and emerging technologies enable CCUS across nearly every major concrete component," says a report from carbon 180. By scaling up these solutions, concrete that captures and stores more emissions than it emits during production and usewill eventually become carbon-negative.

Although actively removing carbon dioxide from the atmosphere is not the same asinjecting it into concrete, it does offer a way for a high-emissions sector to offset emissions and encourage the development of a market for captured CO_2.

Literature review

Vivian WY. Tam, Anthony Butera, Khoa N.Le (2021) "Mechanical properties of CO_2 concrete utilising practical carbonation variables". Sequestration of carbon dioxide into recycled as well as cement paste of concrete has established an outstanding potential by improving qualities of cementitious material and imprisoning undesirable gas as a mineral. This literature aimed to strength the mechanical property of recycled aggregate concrete. To ensure the successful increase in mechanical properties the use of compressive, flexural, tensile strength and modulus of elasticity examinations were utilised.

Rui Guo, Jiaoyue wang, Longfei Bing, Dan Tong, et al.(2021) "Global carbon dioxide uptake by cement from 1930 to 2019". A study show that, a life cycle assessment is necessary to determine the actual net carbon impacts of the industry. A comprehensive analytical model to estimate the amount of CO_2 that had been absorbed from 1930 to 2019 in four types of cement materials, including concrete, mortar, construction waste and cement kiln dust (CKD). In addition, the process CO_2 emission during the same period based on same datasets was also estimated.

Zarina Itam, Mohd Hafiz Zawawi, Yuovendra Sivaganese , et al.(2020) " Carbon Dioxide Sequestration in concrete and its effects on concrete compressive strength". In this literature the carbondioxide is incorporated in the concrete in the form of gas and the mechanical property such as compressive strength is studied and tested. Sequestered CO_2 in concrete can provide an impact on reducing the carbon footprint and also to improve the compressive strength of concrete. On a bigger scale, this would entirely change the construction industry. Also, it was found that the concrete mixture exposed to carbon dioxide requires more water compared to concrete mixture without exposure to the carbon dioxide gas injection because of the reduction of water during the chemical reaction.

John Kline and Charles Kline (2020) "Carbon dioxide capture from cement manufacture and reuse in concrete". In this article, cement manufacturing industries emit carbon dioxide into the atmosphere which pollute the environment badly by developing various techniques, the emitted carbondioxide is recaptured and reused in the concrete. Closing the loop with cement producers provide the triple benefits of reducing the cement plant's specific carbon dioxide emissions, reducing the amount of cement used in concrete and improving the bottom lines for all parties involved.

Duo Zhang, Victor C.Li , and Brian R.Ellis(2018) "Optimal pre-hydration age for CO_2 sequestration through Portland cement carbonation". This literature has overlooked a fact that different Portland cement hydration ages prior to carbonation could lead to distinct carbonation efficiencies and subsequent hydration behaviors. The pre hydration path was traced with isothermal calorimetry. It was found that a pre-hydration beyond the late deceleration period of pc hydration led to a higher hydrate content of cement paste, hence forming a higher compressive strength of mortar compared to the non-carbonated benchmarks at 28 days.

Vivian WY. Tam, Anthony Butera, Khoa N.Le (2016) "Carbon-conditioned recycled aggregate in concrete production". This paper examined that the process of carbon-conditioning recycled aggregate provides an improvement to the physical and mechanical properties of the recycled concrete.

Y.Shao , S.Monkman, and A.J.Boyd(2015) "Recycling carbondioxide into concrete: a feasibility study" . Here CO_2 concrete is investigated in their curing processes. The CO_2 uptake capacities of four commonly used concrete building products: masonry block , paving stone, cement board and fibreboard were evaluated during this study. Commonly these four building blocks are ideal candidates for CO_2 sequestration. In the united states and Canada, the cement consumed in their production is about 14 million tonnes if all these products were carbonation cured then the net annual sequestration of CO_2 would reach 0.98 million tonnes using flue gas or 1.8 million tones of CO_2 using recovered CO_2. With a low energy consumption and high gain in performances, the carbonation curing technology offers a promising tool for greenhouses gas mitigation.

Shu-yuan Pan, E.E.chang, Pen-Chi Chiang (2015) "CO_2 capture by accelerated carbonation of alkaline wastes: A review on its principles and applications" CO_2 capture , utilization and storage (CCUS) is a recently growing technology wherein CO_2 is captured and stored in stored in solid form further utilization instead of being released into the atmosphere in high concentrations. Here natural silicates-minerals and industrial residues mainly alkaline wastes such as steelmaking slags and metalworking waste water are carbonated using carbonation technologies. Results show that alkaline waste has a effective way to capture CO_2. The process also enabled on-site recycle and reuse of wasted materials.

Carla Furcas, Ginevra Balletto, Stefano Naitza, et al.(2014) "Evaluation of CO_2 Uptake under mild accelerated carbonation conditions in Cement – Based and Lime-Based motars" . This study is based on concept of CO_2 sequestration capacity of a cement-based motar and lime-based mortar over the first 28 days of curing. The results are verified by means of using X-ray diffraction along with calcimetry analysis, confirmed that carbon sequestration by common mortars during their curing time is not negligible, especially CM has higher CO_2 sequestration capacity during the first 28 days of curing.

Ronny Andersson, Katja Fridh, Hakan Stripple,et al.(2013) "Calculating CO_2 uptake for existing concrete structures during and after service life",In this article they present a model that can calculate the uptake of CO_2 from all the building ,including its uptake after service life. The CO_2 uptake can be estimated by 2 models, one is theoretical and another one is based on field measurements. The difference between the two results is small. Uncertainties and reliability of themethod and the model are important aspects of future applications. The reliability is dependent on both the quality of the input data, which also consists of historical data, and the model(method)

SUMMARY OF LITERATURE

- Cement production is responsible for about 8% of annual CO_2 emissions, which are mainly created by burning fuels and calcination reaction in the production of clinker.
- The emitted carbon-dioxide is captured and injected into the concrete mix, it will increase the strength of the concrete because CO_2 react with water produce CO^{2-} ions. Simultaneously cement react with water produce ca^{2+} ions.
- This CO^{2-} and ca^{2+} ions react with each other and produces CaCO particles.
- $CaCO_3$ fill the pores of the concrete which in turn increase the strength of the concrete.

Engaged materials and their uses

The following materials are used in the experimental investigation and their test results arealso given below.

Cement

Cement is used as binding material in concrete. It react with water and produce C-S-H gel.The formation of C-S-H gel is responsible for the strength of concrete. An ordinary Portland cement OPC53 is used here for binding purpose. The laboratory test results were given below.

S.NO	DESCRIPTION	OBTAIN VALUE	SPECIFICATION
1	Soundness test	2mm	Max-10mm
2	Consistency test	32%	-
3	Initial setting time	40mins	Mini 30mins
4	Final setting time	360mins	Max 600mins
5	Fineness	2%	10%
6	Specific gravity	3.14	3.16

Fine aggregate

Manufactured sand/M-sand is a fine aggregates, which is an eco-friendly and economical alternative to river sand. It is manufactured by crushing suitable stones and is finely grades to much the IS standard requirements. The crushed sand is of cubical shape with grounded edges, washed and graded to as a construction material.

S.NO	DESCRIPTION	OBTAINED VALUE
1	Specific gravity	2.65
2	Sieve analysis	Zone II

Coarse aggregate

It is a stone which are broken into small size and irregular in shape. Aggregate which has asize bigger than 4.75mm are which retained on 4.75mm IS sieve are know as coarse aggregate. The aggregate which used in building construction must possess and fulfilled the following requirement.

S.NO	DESCRIPTION	OBTAIN VALUE
1	Specific gravity	2.7
2	Water absorption	0.72%

Dry-ice

Carbon-dioxide is used as a refrigerant, in fire extinguishers, for inflating life rafts, and lifejackets, blasting coal, foaming rubber and plastics, promoting the growth of plants in greenhouses, immobilizing animals before slaughter, and in carbonated beverages. Carbon-dioxide is now available in solid, liquid and gas. The form of carbon-dioxide that was used to cast the concrete cubes was solid in form which is usually called as dry-ice. The dry-ice was collected at Sri Venkateswara Carbonic gases Pvt Ltd Coimbatore. It is a high-flying manufacture, Exporter and supplier of the wide assortment of industries supplies. Cylinders, Carbon-dioxide, dry-ice and gas mixture are product of this industry. 5kg of dry ice was collected. Price ranges from 320rupees including taxes.

Mix-design

Concrete mix design is the process of finding the proportions of concrete mix interms of ratios of cement, fine aggregates and coarse aggregate. The main aim of concrete mix design is to enable a person to design a concrete mix for a particular strength. Using IS 10262:2019 mix designfor M30 grade was done and the following proportions were figure it out.

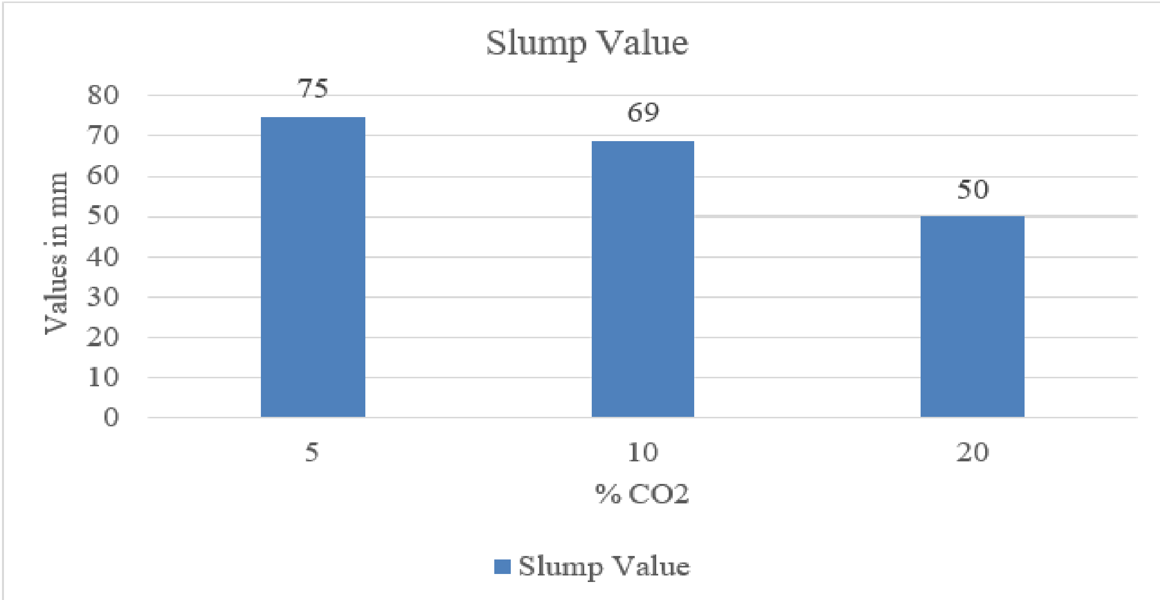
SNO	Cement	Fine aggregate	Coarse aggregate	Water cement ratio
1	413kg/m^3	670 kg/m^3	1179kg/m^3	0.43

Fresh properties

Using above calculation batching was done. Cement, fine aggregate and coarse aggregate were collected and poured into the pan mixture. After one revolution water was added to the mixture at a correct interval. Dry-ice was added to the mixture at various percentage. 5%, 10%, 20% are the respective percentages. 5kg dry-ice was broken into small pieces using iron rod available at the laboratory. The broken dry-ice picture was given above. As carbon-dioxide was in the form of solid it takes time to mix with the concrete.

Nearly after 7mins of mixing the concrete in the pan mixture, it was allowed to pour into the plate that was fixed under the mixture. It was noted that the temperature of the concrete is comparatively high to conventional concrete. Concrete can't be able to handle with a bare hand. It was also noted that most of the dry-ice was evaporated when it was added to the concrete. The temperature was varry according to the percentage of dry-ice added to the concrete.

Once the mixing of concrete was done, fresh properties test such as workability test was conducted. The following bar chart shows the values of slump for 5%,10%,20% of CO_2 in concrete.



After the workability test was checked, the concrete are used to fill the moulds such as cubes of size 150mm x 150mm x150mm, cylinder of size 150mm x 300mm and prism of size 500mm x 10mm x 50mm.

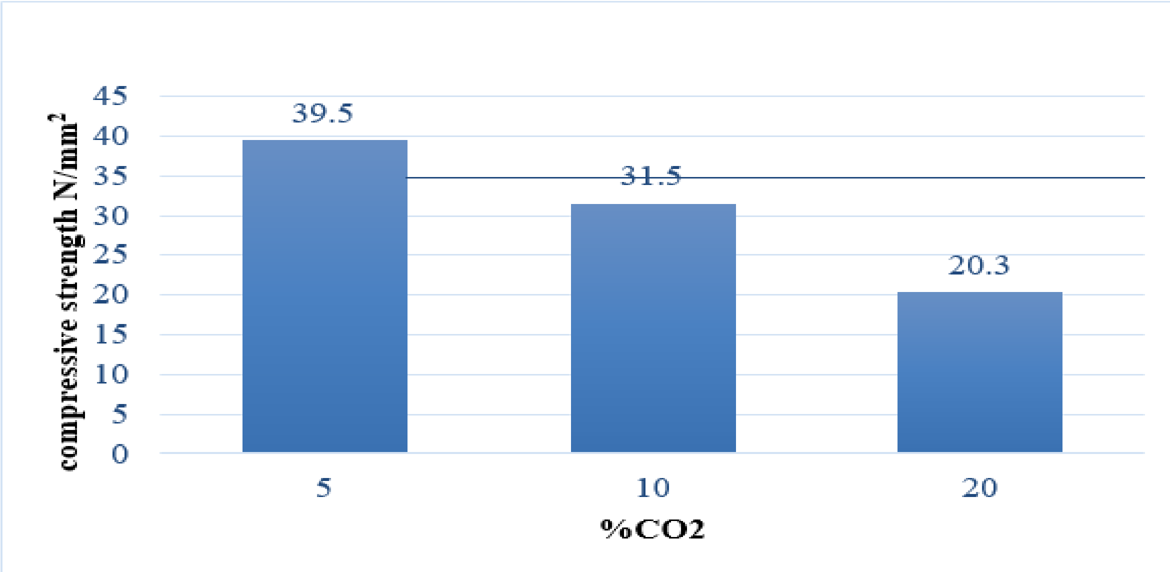


Result and discussion

Thenceforth of casting and curing of specimens, mechanical properties of the concrete were tested and given below.

Compressive strength

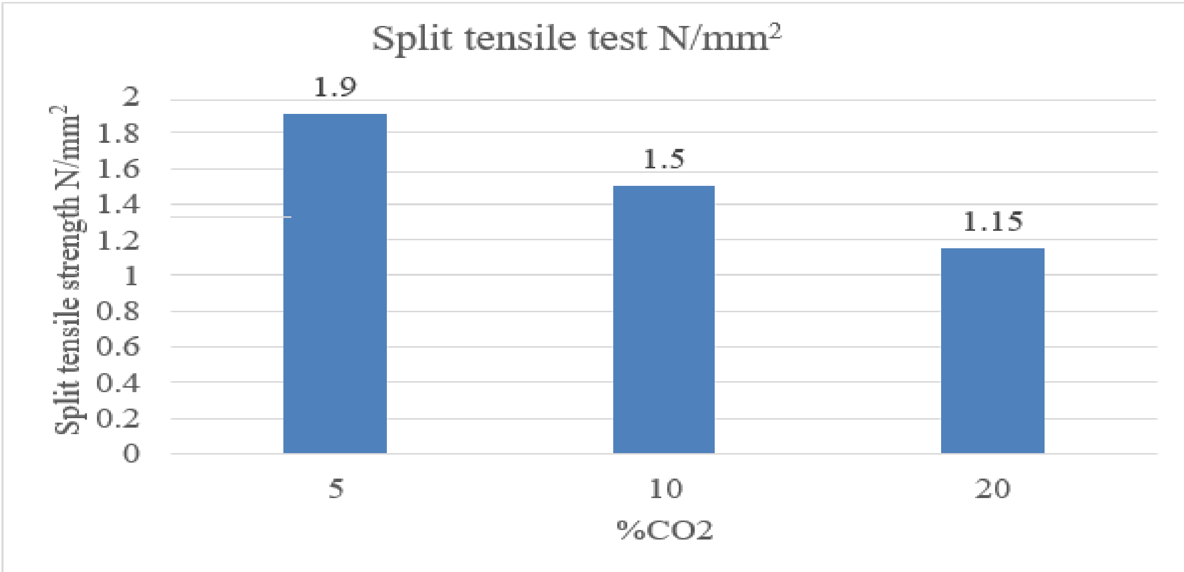
The most crucial aspect of concrete is its compressive strength. It is the maximum compressive stress that a specific solid material can withstand under a gradually applied load without breaking. A 150mm x 150mm x 150mm test specimen was used for the experiment. The curing times used were 3, 7, and 28 days. Compressive strength averages for various mixes are completed after 28 days of curing.



Compressive strength of 5%, 10%, 20% of CO_2 in concrete decrease gradually. For 5% of CO_2 in concrete increase the compressive strength compared to conventional concrete.

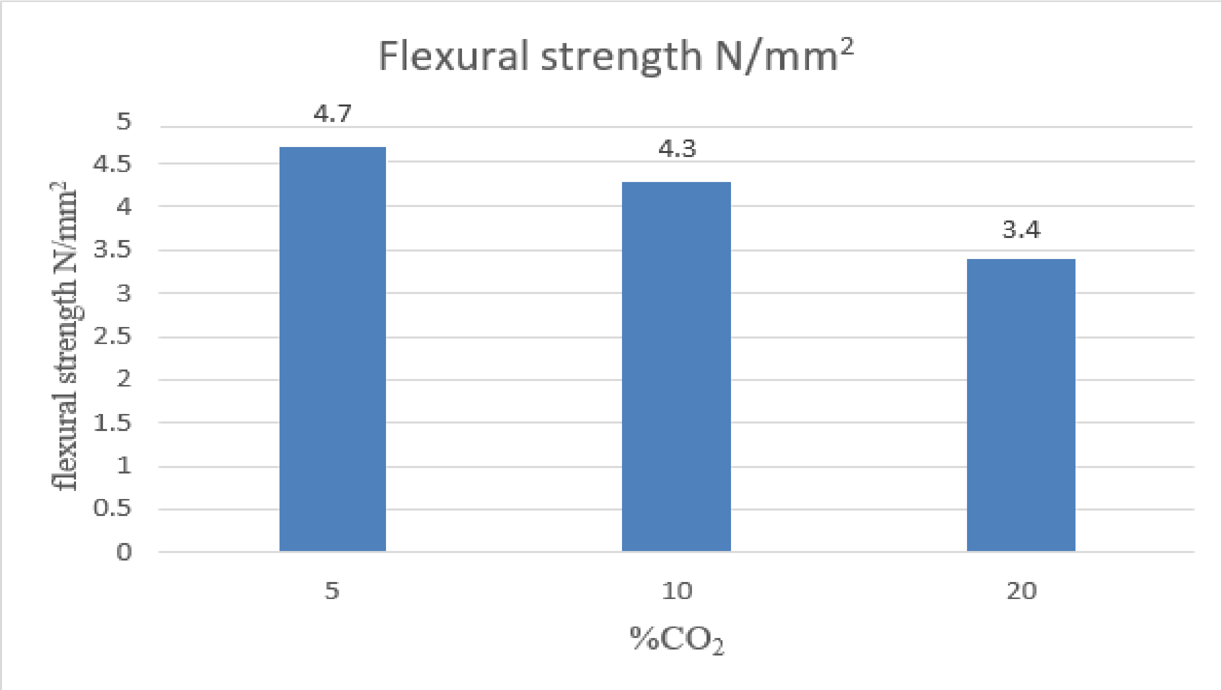
Split-tensile Strength

One of the fundamental and vital characteristics of concrete is its tensile strength. A cylindrical specimen with a 150mm diameter and 300mm height is used for the test. The adopted cure duration was 28 days. Various blends' split tensile strengths after 28 days of curing are displayed.



Flexural strength

It is also referred to as bend strength or rupture modulus. It is the ability of a concrete beam to withstand failure brought on by bending. For a 28-day curing period, a flexural strength test was performed on a test specimen with dimensions of 500 mm x 100 mm x 50 mm.



CONCLUSION

- Various literature were collected from different sources and their important points were noted down.
- According to the uses and literature, materials were collected and respective tests were conducted.
- Using the above mix ratio and concrete specimens were cast.
- CO_2 were added in the percentage of 5%,10% and 20%
- Cast specimens were tested such as compressive strength, split-tensile strength and flexural strength.
- 5% of CO_2 addition gives more compressive strength, split-tensile strength and flexural strength compared to 10% and 20%.

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