Assessment of Lime Stone Dust as Replacement of Cement to Support Affordable Housing- A Step Towards Sustainability

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Abstract: The major environmental impact of using concrete as a prime building material is the amount of CO_2 emissions produced during the cement manufacturing process. In the recent decade fly ash was utilized as the substitute of cement in the manufacturing industry but due to closing down of thermal power plants the availability of fly ash is scarce. Thus limestone being in abundance can be considered as the replacement for cement. The main objective of this research study is to ascertain the use of limestone powder as a partial replacement of cement, to reduce the consumption of energy and CO_2 emissions. In this study limestone of various ratios are used to replace a portion of Portland cement and efficiency of this replacement is noted. Studies suggest the predictable reduction in the structural properties of the concrete mainly due to dilution effect caused by partially replacing cement with limestone will also be checked during the course of this paper.

Keywords: Limestone Powder; Sustainable Development; Affordable Housing; Drying Shrinkage; Carbon Foot Print; Cement Replacement

1. Introduction

As the country moves towards achieving the "Sustainable development goals2030", it will not be able to achieve that without curbing the CO_2 generated during the cement production. After mass production of cement and its transportation, cement industry contributes enormous amount of CO_2 in the environment making it one of the first few sectors that are largest source of carbon emissions. The World Business Council for Sustainable Development (WBCSD)'s Cement Sustainability Initiative (CSI) launched Low Carbon Roadmap for Indian Cement Industry which emphasis on partial replacement of ordinary Portland cement (OPC) with environment friendly filler materials that can reduce the carbon footprints.

AFFORTABLE HOUSING- ECONOMICAL ASPECT

It is estimated that two- third of India's population will make their way to the cities by 2050 due to better life quality and employment opportunities. It is also analyzed that few non metro cities will experience over flowing of immigrates as and when metro cities are unable to sustain any more flow of migration. It is to note that most metro cities like Delhi and Mumbai are facing space crunch and are issuing guidelines to curb further construction. In a situation like these cities are demanding more housing and commercial complexes which in turn surge the demand of cement production.

With the increase in urban growth, the cement manufacturing industry may exceed the production capacity and this would create an imbalance between the supply and demand. This situation may result in invariably high pricing of cement and will make it very difficult for people who fall in low income group to have a house and the vision of India to provide "Housing for all" would be defeated. Thus use of a suitable alternative material to replace portions of cement becomes crucial.

Over the decade *fly ash* produced by the thermal power plant during the burning of coal was used as the alternative to cement as an effort to reduce the impact of it to the environment. But due to various restrictions and shutting down of numerous power plants the availability of fly ash is scarce and a similar sustainable alternative is required to release the burden from the already over stressed cement producing industries. This will enable the reduce in the cost of housing and in turn will be able to provide the opportunity for the poor to have their own house. With *fly ash* supplies decreasing, *limestone powder* seems to be a supplement material to be used instead of batching concrete.

UTILIZATION OF LIME STONE DUST- ENVIRONMENTAL ASPECT

The quarrying of lime stone produces enormous amount of waste in terms of lime stone dust which goes unutilized. These are then dumped in open spaces which in turn pollute the environment around that region. This is a main health hazard being experience by the states which produces lime stone in large number like Rajasthan, Madhya Pradesh and Andhra Pradesh with Rajasthan being the largest producer.

The main reason that lime stone dust went unutilized is because very little known about the impact it has on the structural strength of the structure and the amount to which it alters the property and strength of the concrete mix.

Fly ash is one of the widely used waste material as a replacement to cement because of its cementitious and pozzolanic properties. From 2017 onwards there is notable declination of production of power from coal as a fuel and is being replacement by other renewable resources. With the gain in popularity of green renewable energy sources like solar, natural gas and nuclear, there is seen a reduction in the availability of fly ash due to the lesser consumption of coal in the power sector. Fly ash was considered the chief ingredient that was used in the replacement of cement and was known to size the gap which was there due to inefficiency in manufacturing of cement. Therefore, an environment friendly alternative is needed for the replacement of cement. The process of calcination of the limestone i.e. decomposition of limestone to lime and carbon dioxide in order to get cement is the prime cause for the release of carbon dioxide in the process of manufacturing of cement. Hence, there can be a considerable reduction in the emission of carbon dioxide by employing limestone powder as a replacement for cement. The limestone need to be milled before it is used as a replacement to cement which also produces some amount of CO_2. The amount of carbon dioxide released through the milling of limestone to powdered depends largely upon the particle size of the limestone powder to be used as fine limestone and it constitute around 3–15% of CO_2 emissions compared to emissions produced by one ton of cement. Thus, this makes the use of fine (powdered) limestone to be used as a substitute for concrete to a certain portion a greener and more sustainable alternative to cement.

UTILIZATION OF LIMESTONE DUST- STRUCTURAL ASPECT

The structural strength or stability of an infrastructure remains the primary focus during the selection of building material. The economy of the structure is the next important parameter to be considered for the selection of construction material. Thus this makes these two as the fundamentals for the selection of adapt material for the construction.

And for the structure sustainable, one of the approach is to select a building material which are the byproducts and are considered harmful to the environment because of the difficulty to discard them.

Limestone or calcium carbonate ($CaCO_3$), has been known to be used as a main component in the manufacturing of cement and contributes to a major portion of 75% of the manufacturing of cement. Limestone is known to reduce the amount of water needed to achieve the desired workability of concrete [3]. Also, as the particle size of the limestone ranges between 4 μm to 15 μm they act as the prefect filler between the voids and help reduce the porosity of the cement as it fills up the voids and doesn't allow the water to seeps into it. This in turn results in lesser water cement ratio and enhance durability of the structure [6].

AIMS AND OBJECTIVES

1. To establish the physical properties of Limestone dust found in Mohammadpur area of Rajasthan.
2. To establish the engineering properties of Limestone dust found in Mohammadpur area of Rajasthan.
3. Finally, to ascertain the suitability of Limestone dust as the building construction material.

EXPERIMENTAL STUDY

Materials

Ordinary Portland Cement-43 grade was used and partial replacement of limestone powder with different grade of cement was carried out. The replacement of the cement ranges from 10%, 20%, and 30% by mass of the limestone powder. The concrete mixture contains naturally available coarse aggregate and sand with a fineness modulus of 2.64. The water-to-cement ratio was kept at 0.45 and is calculated using total amount of cement and limestone powder used during preparation. During the testing the nominal size of limestone powder was kept constant at 4.5 μm.

Methodology

In the experiment, three specimen of dimension 150 mm x 150 mm x 150 mm and three beams of size 150 mm x 150 mm x 700 mm were casted using limestone as partial replacement for cement in the portion of 10%, 20%, and 30% by mass of the limestone powder. The concrete was mixed in accordance to IS 10262:2009, and limestone powder was added in fixed proportions to the drum mixer after the addition of cement. After the cement was mixed, the freshly prepared mixture was tested for workability. The freshly prepared concrete is then casted into molds of specified dimensions for testing. They are tested for compressive strength and flexural strength after 7 days and 28 days from the day of casting. For testing

Concrete Technology lab of School of Engineering & Technology of IFTM University, Moradabad was used.

Figure 1 Curing of concrete for 7 days and 28 days

Efficiency of Limestone Powder

Rene Féret in 1896 formulated an equation that relates the strength of concrete to the water and cement by determining the volumetric proportions of the cement, water, and air. In general water-cement ratio and degree of compaction are marked as a parameter for estimating the strength of concrete, the volume of air voids also marks as an important factor and should not be neglected, as higher volume of air voids contributes to the loss in strength. Equation (1) indicates that the strength of concrete (fc) with minimum water content decreases with increase in the a/c, where a, c, and w are absolute volumes of air, cement, and water in concrete, respectively. The relationship between the water/cement ratios and compressive strength specifies that a high strength concrete with minimum air voids can be achieved with lower water/cement ratios. However, a rapid loss in strength is evident if the water/cement ratios fall below the practical limit. [2]

Féret's Rule:

$$f_c = K\left(\frac{c}{c+w+a}\right)^2 \qquad (1)$$

The dilution effect caused by mixing a portion of limestone powder in place of cement causes lower hydraulic reactivity which in turn affects the compressive strength of the concrete. This also increases the bonds per unit of cement which in turn reduces the porosity [17]. Although limestone powder does not exhibit the cementitious properties however to determine the efficiency of limestone powder as a replacement to cement, it must be compared to properties of cement.

The main focus of this paper is to show that both the structural properties and environmental effects have to be considered in conjunction with each other to utilize limestone powder in concrete. Using the structural properties, the effectiveness of limestone powder as a cement replacement must be compared to properties of cement. Féret's equation can be modified to determine an efficiency factor (EF) of limestone powder and can be used as a concrete strength prediction model for concrete containing limestone powder which will be the part of further study.

RESULTS AND DISCUSSION

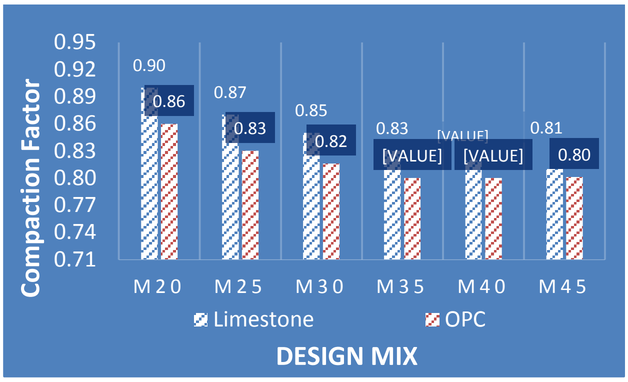
WORKABILITY

A compaction factor test was conducted on freshly prepared concrete to ascertain the workability in its fresh state as per IS 1199 (1999). The curve in Figure 1 to 3 shows change in workability by replacing limestone powder with cement in the proportion of 10%, 20% and 30% by mass of the limestone powder.

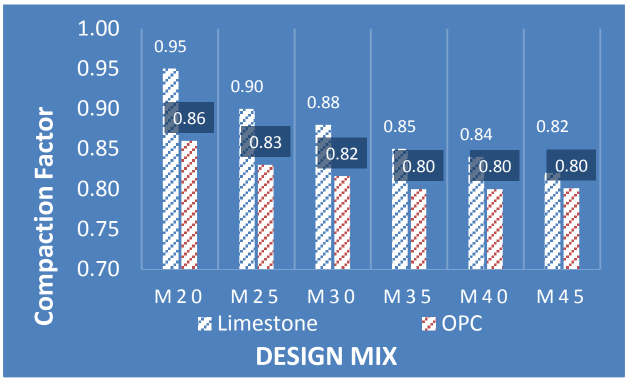
Table 1 Compaction Factor

a. For 10% Replacement

Batch Data	M20	M25	M30	M35	M40	M45
Compaction Factor	0.90	0.87	0.85	0.83	0.82	0.81



Workability test for 10% Replacement



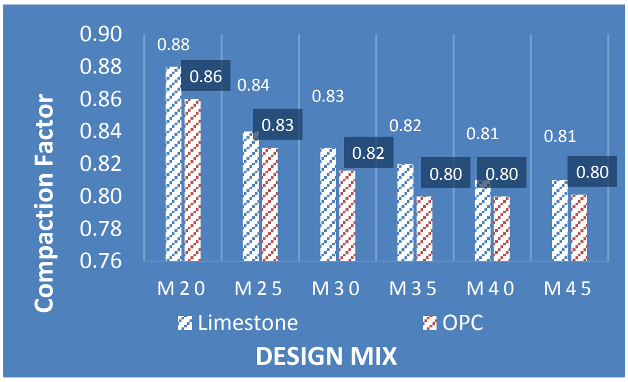
Workability test for 20% Replacement

b. For 20% Replacement

Batch Data	M20	M25	M30	M35	M40	M45
Compaction Factor	0.95	0.90	0.88	0.85	0.84	0.82

c. For 30% Replacement

Batch Data	M20	M25	M30	M35	M40	M45
Compaction Factor	0.88	0.84	0.83	0.82	0.81	0.81



Workability test for 30% Replacement

Figure 2 Result of Workability Test

The addition of limestone powder in the concrete slightly increases the slump value. The above graph shows workability of concrete first increases as the percentage of limestone powder is increased and then with further increase in limestone powder in cement the workability deceased drastically.

COMPRESSIVE STRENGTH

The concrete cube specimens were casted and tested as per IS 516 (1999). The result represents the compressive strength of the limestone powder replacement specimens at the ages of 1, 7, 14, 28, and 90 days.

Table 2 Concrete compressive strength.

a. 0% Replacement

Mix Design (MPa)	1 Day	3 Day	7 Day	28 Day	90 Day
M20	3.20	8.00	13.4	20	23.00
M25	4.00	10.00	16.75	25	28.75
M30	4.80	12.00	20.1	30	34.50
M35	5.60	14.00	23.45	35	40.25
M40	6.40	16.00	26.8	40	46.00
M45	7.20	18.00	30.15	45	51.75

b. 10% Replacement

Mix Design (MPa)	1 Day	3 Day	7 Day	28 Day	90 Day
M20	3.2	8.1	13.7	21.4	25.0
M25	4.0	10.2	17.4	26.8	31.4
M30	4.9	12.3	21.1	32.4	37.9
M35	5.8	14.3	24.7	37.8	44.4
M40	6.4	16.1	27.9	43.0	49.4
M45	7.2	18.1	31.2	48.1	55.3

c. 20% Replacement

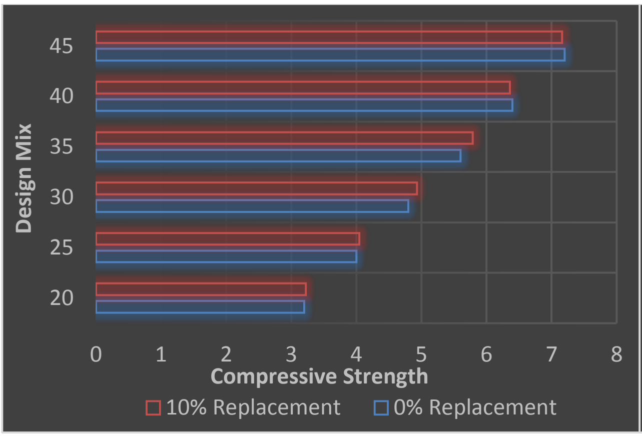
Mix Design (MPa)	1 Day	3 Day	7 Day	28 Day	90 Day
M20	3.1	8.2	14.1	21.7	25.2
M25	3.9	10.3	17.7	27.2	31.6
M30	4.8	12.4	21.3	32.8	38.1
M35	5.6	14.5	25.0	38.4	44.5

Mix Design (MPa)	1 Day	3 Day	7 Day	28 Day	90 Day
M40	6.4	16.4	27.6	42.2	48.9
M45	7.2	18.4	30.9	47.3	54.9

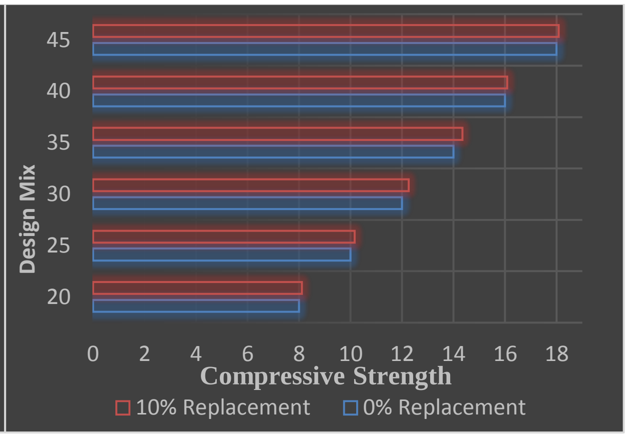
d. 30% Replacement

Mix Design (MPa)	1 Day	3 Day	7 Day	28 Day	90 Day
M20	19.2	6.9	11.4	19.2	22.0
M25	3.6	8.5	14.2	23.8	27.4
M30	4.3	10.3	17.1	28.5	32.7
M35	5.0	11.6	19.8	33.0	37.9
M40	5.4	13.1	22.5	37.9	43.6
M45	5.9	14.7	24.8	43.1	49.5

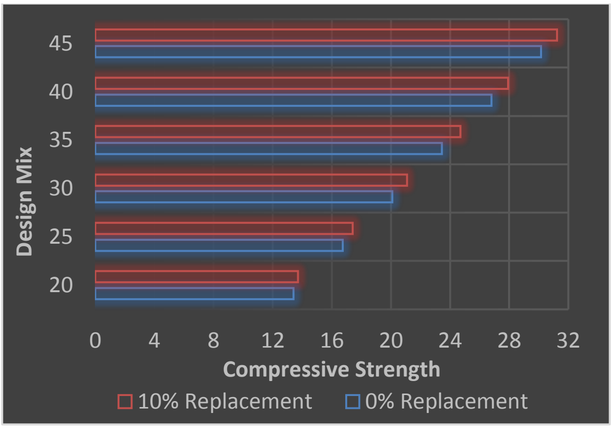
a. For 10% Replacement



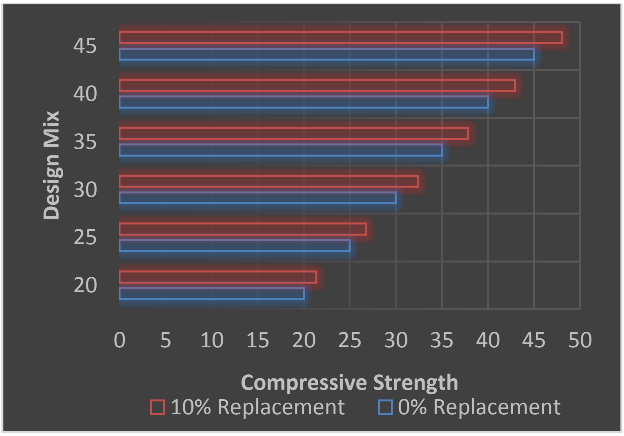
a. 1 Day



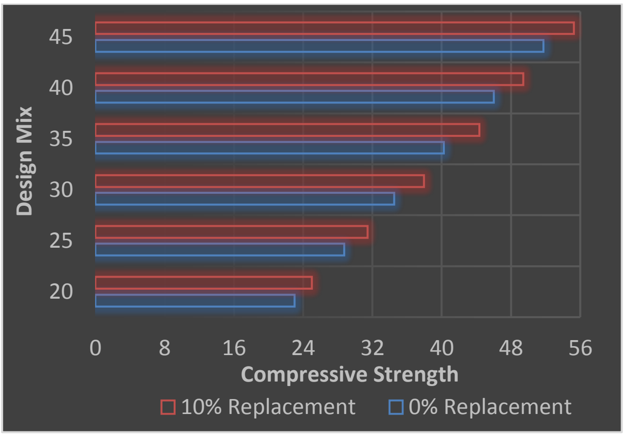
b. 3 Day



c. 7 Day



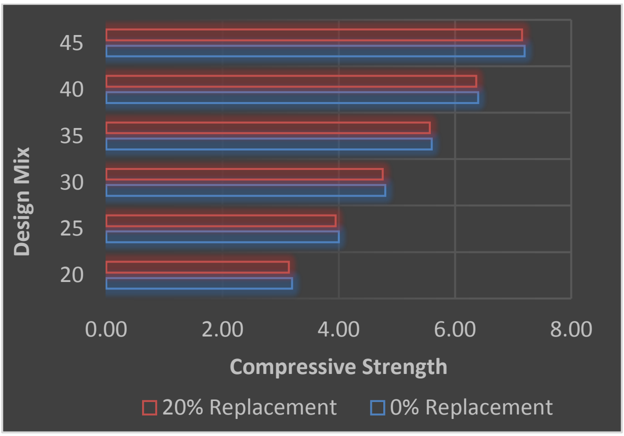
d. 28 Day



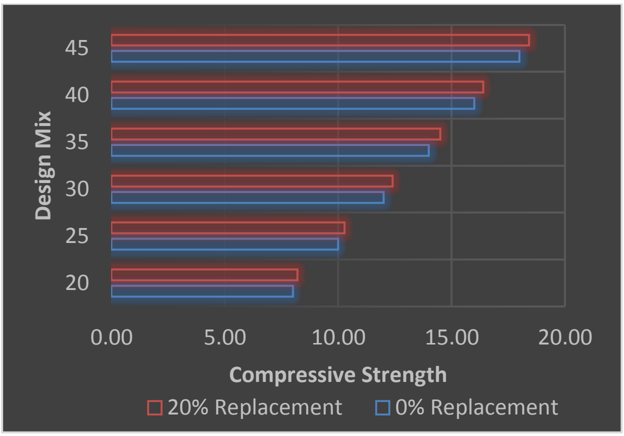
e. 90 Day

Figure 3 Effects of limestone powder on compressive strength at 10% replacement.

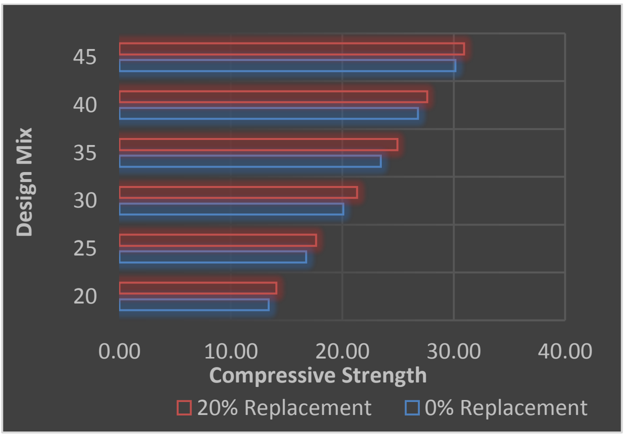
b. For 20% Replacement



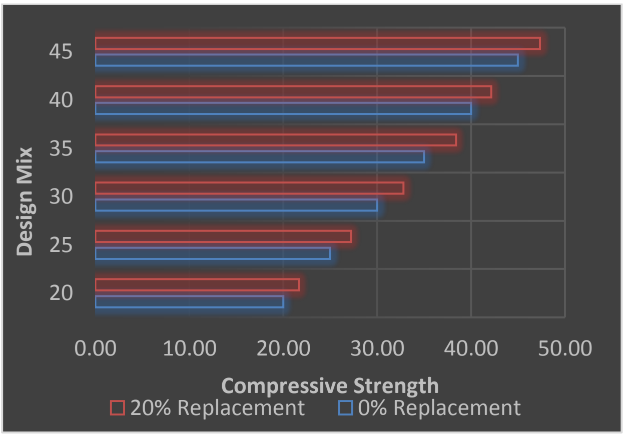
a. 1 Day



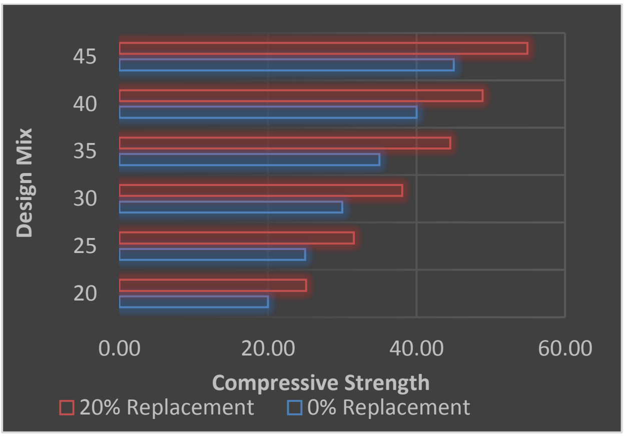
b. 3 Day



c. 7 Day



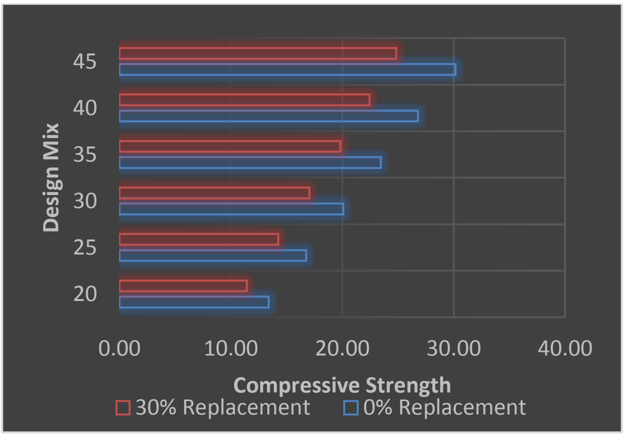
d. 28 Day



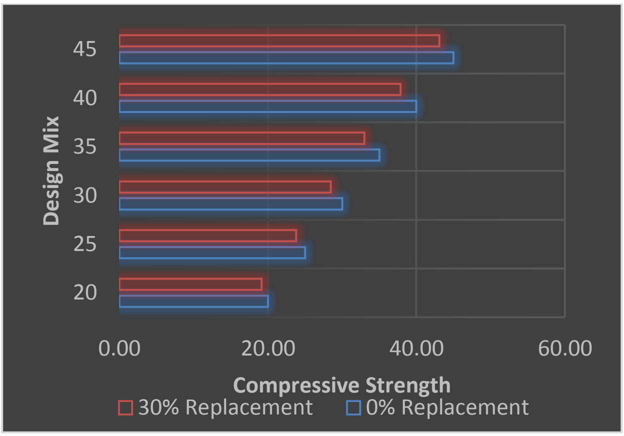
e. 90 Day

Figure 4 Effects of limestone powder on compressive strength at 20% replacement.

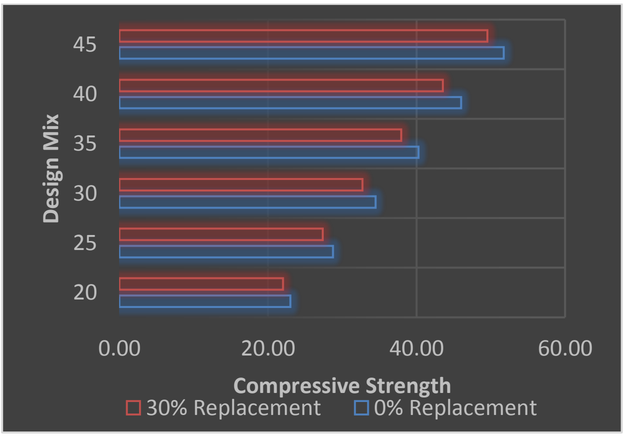
c. For 30% Replacement



a. 7 Day



b. 28 Day



c. 90 Day

Figure 5 Effects of limestone powder on compressive strength at 30% replacement.

The effect of the limestone powder on compressive strength with a 10% replacement is illustrated in Figure 4 to Figure 6. With 10% replacement with limestone powder, the compressive strength was seen to increase by around 1 to 2% in the initial days to around 8% till 28 days. The compressive strength kept increasing and showed 10% increase till 90 days.

A similar trend was observed with a 20% replacement of cement as shown in Figure 5, in which the compressive strength did not show significant increase in initial days but it increases to 9% on 28 day. The compressive strength increases upto 10% till 90 days.

However, the test results of a 30% replacement with limestone powder shown in Figure 6 illustrate the drastic decrease in compressive strength of the specimen. This data demonstrates that the addition of larger quantity of limestone by volume decreases the compressive strength rapidly. The compressive strength was seen to decrease by about 10% in the initial days and continue to show decreasing trend at 28 and 90 day with a reduction of about 4% in 28 and 90 day.

CONCRETE FLEXURAL STRENGTH

Flexural strength for concrete was calculated after an aging period of 7 days and 28 days. Table 3 illustrates the calculated average MPa from three specimens that were tested for the flexural strength till failure.

Table 3 Flexural strength of concrete at 7 day and 28 day

a. 0% Replacement

	Average Flexural Strength OPC	Average Flexural Strength OPC
Grade of Concrete	**7 Day**	**28 Day**
M 10	1.81	2.21
M 15	2.21	2.71
M 20	2.56	3.13
M 25	2.86	3.50
M 30	3.13	3.83
M 35	3.38	4.14
M 40	3.61	4.43
M 45	3.83	4.70

b. 10% Replacement

	Average Flexural Strength with 10% Replacement	Average Flexural Strength with 10% Replacement
Grade of Concrete	**7 Day**	**28 Day**
M 10	1.55	2.34
M 15	1.89	2.87
M 20	2.18	3.30
M 25	2.43	3.69
M 30	2.66	4.04
M 35	2.89	4.33
M 40	3.05	4.62
M 45	3.22	4.90

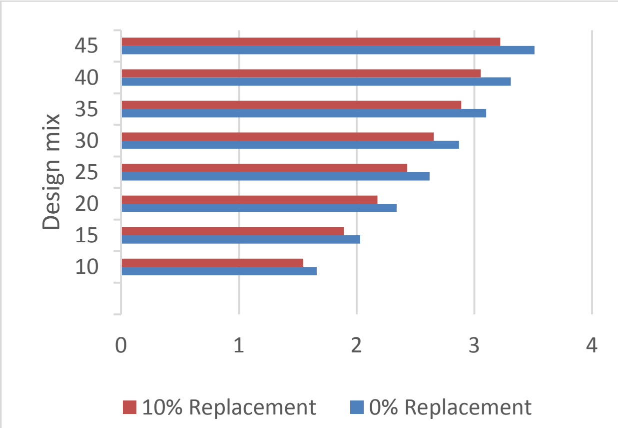
c. 20% Replacement

Grade of Concrete	Average Flexural Strength with 20% Replacement 7 Day	Average Flexural Strength with 20% Replacement 28 Day
M 10	1.48	2.19
M 15	1.81	2.70
M 20	2.08	3.10
M 25	2.33	3.46
M 30	2.55	3.79
M 35	2.75	4.08
M 40	2.94	4.34
M 45	3.12	4.59

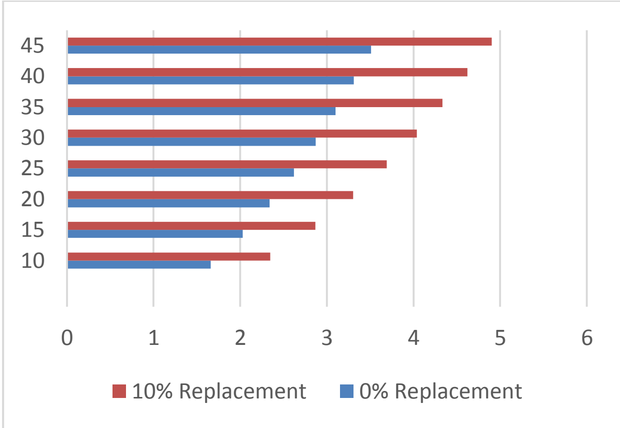
d. 30% Replacement

Grade of Concrete	Average Flexural Strength with 30% Replacement 7 Day	Average Flexural Strength with 30% Replacement 28 Day
M 10	1.48	2.15
M 15	1.81	2.63
M 20	2.08	3.03
M 25	2.33	3.37
M 30	2.55	3.69
M 35	2.75	3.97
M 40	2.94	4.24
M 45	3.12	4.49

The flexural strength results in Table 3 illustrates the decreasing values as the limestone powder increased. The adverse effects of the limestone powder are significant and can be clearly seen to reduce both compressive as well as flexural strength of concrete. As 10% replacement of cement reduced the flexural strength on average by 5%, a 20% replacement reduced the strength by 10%, and an average of 12% reduction was observed with a 30% replacement.

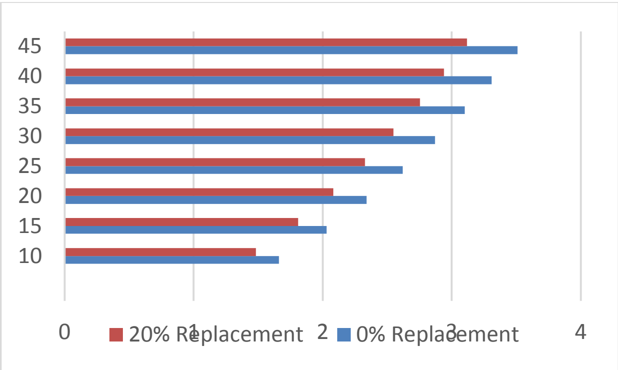


a. 7 Day

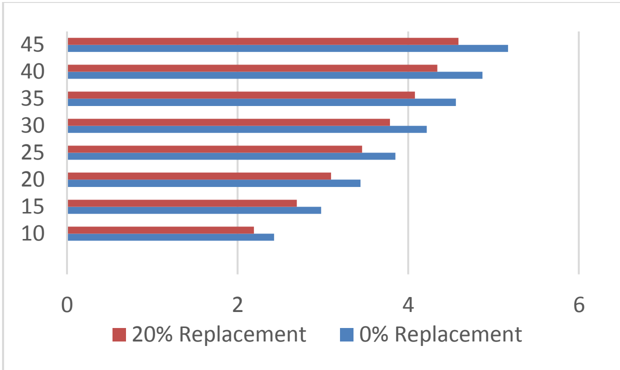


b. 28 Day

Figure 6. Effects of limestone powder on flexural strength at 10% replacement.

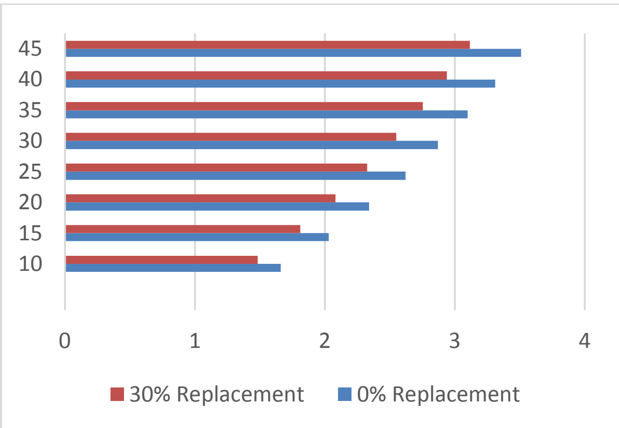


a. 7 day

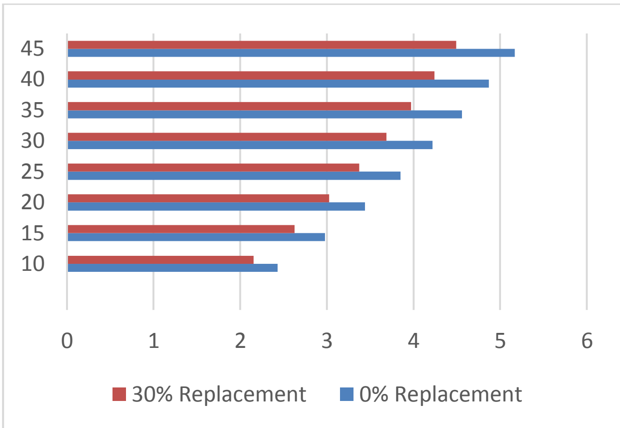


b. 28 day

Figure 7. Effects of limestone powder on flexural strength at 20% replacement



a. 7 day



b. 28 day

Figure 8. Effects of limestone powder on flexural strength at 30% Replacement

CONCLUSIONS

This study was carried out to evaluate the effect on the characteristics of concrete when cement was replaced with limestone powder of different proportion. It is well known fact that the replacement of limestone powder with cement results in comparatively lower CO_2 emissions. Limestone powder, however, has a negative effect on the compressive strength. And various other structural parameters.

A summary of all conclusions made in this study is included below:

a. The use of limestone powder as a cement replacement in concrete has very marginal to no effect on fresh properties.

b. As the percentage of limestone powder increases, the negative effect on the compressive strength of concrete was evident.

c. With increase in the percentage of limestone powder, the flexural strength was adversely affected.

RECOMMENDATIONS

It is recommended to replace the cement from limestone till a certain proportion. As seen from this study, till 20% replacement the engineering properties and mechanical properties were increasing but beyond 20% the values started to decline. As the limestone doesn't exhibit cementitious properties, this led to the decline of engineering and mechanical characteristics of the mix.

Although, further study is needed to ascertain the exact percentage replacement required to achieve the desired mix.

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